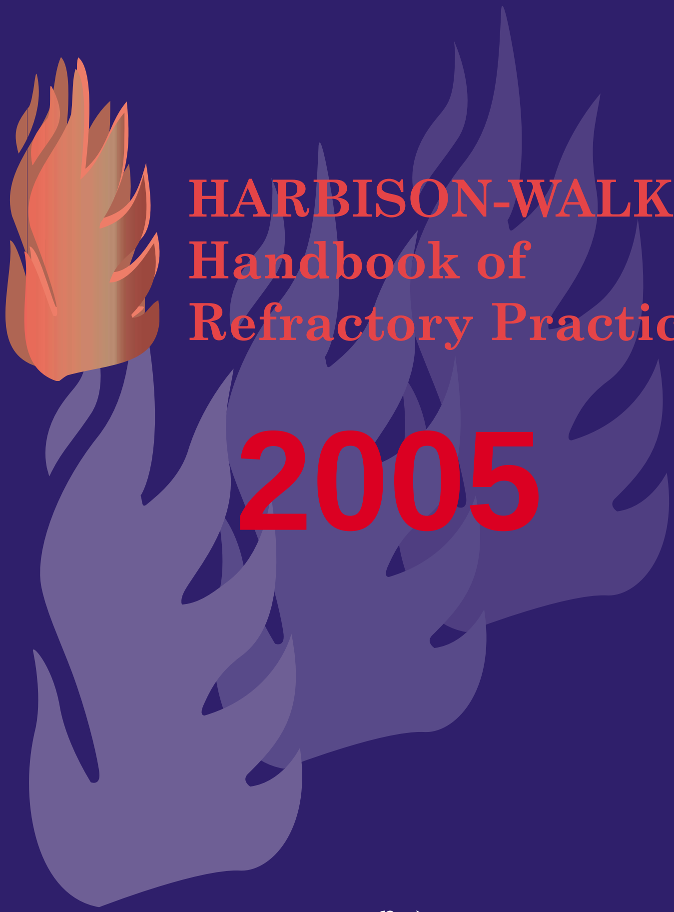

HARBISON-WALKER
Handbook of Refractory Practice

2005

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WARNING: Some materials which are present in refractory products are harmful. One such group is classified as substances known to cause cancer to humans. Other substances may be classified as probably or possibly carcinogenic. These materials include minerals used in or formed during the manufacture of these products. The primary threat presented by many of these materials comes from inhaling respirable dust. The use of proper respiratory equipment, as well as other personal protective equipment is mandatory where required by applicable law. Please refer to the applicable Material Safety Data Sheet for such product.

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Handbook of Refractory Practice

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SECTION 1

Introduction

INTRODUCTION

Out of the Fire

The history of high heat manufacturing and refractory technology began with the discovery of fire. Nature provided the first refractories, crucibles of rock where metals were softened and shaped into primitive tools. Modern refractories are customized, high-temperature ceramics designed to withstand the destructive and extreme service conditions needed to manufacture metals, glass, cement, chemicals, petroleum and other essentials of contemporary life.

The History of Harbison-Walker

The refractories company known as Harbison-Walker opened on March 7, 1865, as the Star Fire Brick Company. The firm was founded by J.K. Lemon, a Pittsburgh entrepreneur who hoped to build a fortune on America's growing demand for refractory brick following the Civil War.

In 1866, Lemon hired Samuel Pollock Harbison as a part-time bookkeeper. Within four years, the ambitious accountant had acquired enough stock and refractory expertise to be named General Manager of Star Fire Brick. In 1875, Harbison teamed with another stockholder, Hay Walker, to purchase the under-achieving company, and renamed it Harbison-Walker.

Almost immediately, Harbison and Walker realized a major opportunity to grow their business and its reputation. Through an on-going relationship with Thomas Carnegie, the fledging company landed a contract from Kloman, Carnegie, and Company to build the Lucy Furnace, the largest blast furnace ever designed.

The company garnered accolades for the superior performance of the Lucy Furnace and began to expand rapidly, pushed in large measure by the explosive growth of the steel industry. In 1910, a 10-company merger created Harbison-Walker Refractories Company, a 33-plant operation that was the largest of its kind in the world. Harbison-Walker also thrived on its vertical structure, exerting control over every stage of its production process, through mining and raw materials management to manufacturing, transportation and distribution.

In the decades that followed, Harbison-Walker established and fortified its position of industry leadership by building new facilities and acquiring related organizations.

- In 1916, Harbison-Walker organized the Northwest Magnesite Company near Chewelah, WA. This gave the company a secure domestic source of magnesite, a material of choice for industrial furnaces in short supply during World War I.

- In 1927, Harbison-Walker acquired majority ownership of Northwest Magnesite, and following World War II, commissioned the company to build and operate a sea-water magnesite facility at Cape May, NJ.

- In 1945, the company purchased Canadian Refractories Limited, makers of MAGNECON, an outstanding refractory for rotary cement kilns.

- In the 1950's, Harbison-Walker built a high-quality magnesite facility at Ludington, Michigan. This keyed the development of several industry standard products, including direct-bonded magnesite-chrome brick, pitch-bonded and pitch-impregnated magnesite products, and magnesite-carbon refractories.

- In 1954, Harbison-Walker became the first U.S. company to produce refractories for the basic oxygen furnace.

- In 1962, the company discovered massive deposits of high purity bauxitic kaolins at Eufaula, AL. This permitted the company's Bessemer and Fairfield, Alabama, plants to manufacture significantly improved high-alumina brick that became a refractory of choice for much of the refractory consuming industries.

- In 1967, Harbison-Walker was purchased by Dresser Industries, prompting an accelerated diversification into non-steel related industries.

- In 1994, the company became a part of Global Industrial Technologies, a major manufacturer of technologically advanced industrial products. This development enabled Harbison-Walker to strengthen its presence in several key markets through alliances with other Global Industrial Technologies companies. They included Refractories Mexicanos (REFMEX) and Refractorios Chileanos (RESCA), two of Latin America's leading refractory producers; and Magnesitwerk Aken, a German refractory maker.

- In 1998, Harbison-Walker acquired A.P. Green Industries, Inc. With 22 plants in six countries, A.P. Green, a major refractory producer in its own right, expanded considerably the global resources at Harbison-Walker's disposal.

- In 2000, RHI AG, an Austrian company with many holdings in the global refractories industry, completed its acquisition of Global Industrial Technologies, Inc., the parent company of Harbison-Walker. RHI AG subsequently combined North American Refractories Company (NARCO) and Harbison-Walker, at the time naming the resulting organization RHI Refractories America.

Today, the U.S. and export operations have been reorganized and operate independently under the name ANH Refractories. Because of the strong reputations that Harbison-Walker and NARCO established over their long histories, the companies have retained their names and are continuing to be the refractory suppliers of choice in their respective market places. Harbison-Walker continues to provide outstanding refractory materials to meet the needs of the industrial markets, while NARCO serves the needs of the steel industry.

Harbison-Walker Today

Following World War II and the subsequent proliferation of technological advances, Harbison-Walker recognized the need for additional research capacity. In 1958, the company opened Garber Research Center, now known as the Technical Center West Mifflin. The new facility vastly enhanced Harbison-Walker's ability to test products under simulated service conditions and to conduct "post-mortem" analyses of used refractory samples.

Today, the Technical Center West Mifflin, ranks among the world's largest and most well-equipped refractory research facilities. A staff of outstanding physicists, chemists, metallurgists and engineers work closely with Harbison-Walker customers to develop new products and to solve process or production problems.

In the mid-1990s, Harbison-Walker completed a multi-million-dollar investment in the Technical Center West Mifflin aimed at providing the company's engineers and scientists with the very latest testing and analytical equipment. This commitment, made at a time when many refractory companies were diminishing their internal research capability, aggressively positioned Harbison-Walker for the new century of refractory industry leadership.

The capabilities and equipment at the Technical Center West Mifflin have been further enhanced by its additional staff and equipment acquired through its acquisition of A.P. Green and merger with NARCO.

Application Focused Technical Marketing and Sales Support

Harbison-Walker has adopted a marketing structure that enables it to function more like a network of smaller, industry-focused companies. Throughout each of its markets, Harbison-Walker employs application focused technical marketing support, each with specific training in a particular industry or series of related industries. Individual market segments include glass, industrial metals, minerals processing and environmental, energy and chemicals markets.

Over the long term, this structure is specifically designed to promote innovation through a continuous dialogue between Harbison-Walker and the individual industries the company serves. On a daily basis, this structure allows Harbison-Walker to respond more quickly to customer requests and to serve as a reliable and ever present problem-solving partner.

Over the years, this studied, individualized approach to customer service has yielded an unending stream of innovative refractory products and application strategies for the entire range of heat-processing industries.

Broad Based Expertise

Harbison-Walker's sales and technical support staff consists of chemical, ceramic, metallurgical, industrial and mechanical engineers. With strong technical educations and practical knowledge of the industries they serve, these individuals are highly skilled at working with customers to identify and select refractories that can extend service life and improve process efficiencies.

Typical consultations explore specific operating conditions in a customer's furnace and why those conditions suggest the implementation of one refractory type over another in a particular furnace zone. This process can be further aided through interactive CAD systems that allows customers to select and preview refractory linings and configurations.

Another valuable service Harbison-Walker offers is performance assessments. This process is usually aimed at identifying causes for deteriorating refractory performance resulting from changing operating conditions within a customer's plant. Most often, diagnoses are based on post-mortem analyses of used refractories to determine the modes of refractory wear.

Test results may point to the adaptation of existing refractories, applying refractories in new combinations, the selection of different refractory brands or the custom design of new refractories to better meet the altered service conditions.

Helping customers understand and implement a proper refractory management strategy is the first step in an on-going relationship between Harbison-Walker and the refractory user. Sales and technical representatives are often on-site for refractory installation and furnace start-up. Follow-up technical support can include orientation and training programs, troubleshooting, and service and performance assessments.

Quality Control

Harbison-Walker's quality control programs encompass every facet of the organization, from the acquisition of raw materials to the packaging and shipment of the finished material.

The company operates an aggressive program of mineral land acquisition, permitting it to control a significant percentage of the raw materials it consumes. This program also helps ensure the uniform quality of raw materials while insulating the company from fluctuating supplies of key refractory minerals. Imported minerals, such as chrome ore, also are examined and tested for quality by Harbison-Walker engineers.

At the processing stage, manufacturing sites are dedicated to a single product or single class of products. This enables Harbison-Walker to maintain a high degree of chemical purity, resulting in uniform products, free of contaminants and capable of tight dimensional tolerances.

In addition, each plant maintains a laboratory and a staff of quality control engineers to measure product characteristics against stated specifications.

The company also operates a centralized Quality Control Department in West Mifflin, PA., which is responsible for monitoring quality standards for all Harbison-Walker brands.

Industry Dialogue

Harbison-Walker encourages a continuous dialogue among its industry “partners” by communicating continuously with contractor/installers and soliciting regular customer input and feedback about all aspects of refractory performance.

Every year, the company brings together its engineers and select installers to disseminate technical information in an educational forum. This presents opportunities for installers to discuss their goals and expectations of refractory performance, as well as plant safety requirements.

In turn, Harbison-Walker engineers offer refractory product updates, and a comprehensive review of installation and construction techniques. This mutual information exchange leaves participants more prepared to work cooperatively throughout the year

As the refractory industry continues to evolve and expand, Harbison-Walker pledges to maintain this dialogue, seeking ways to better ways to contain the heat of industrial progress.

SECTION 2

Classes of Refractories

CLASSES OF REFRACTORIES

The broad variety of pyroprocessing applications across industry demands great diversity in the supply of refractory materials. In fact, many of these materials have been developed specifically to meet the service conditions of a particular process. The characteristic properties of each refractory class are a function of both their raw materials base and the methods used to manufacture the refractory products.

Primarily, refractories are classified as basic, high-alumina, silica, fireclay and insulating. There are also classes of “special refractories” which include silicon carbide, graphite, zircon, zirconia, fused cast and several others. Most refractory materials are supplied as preformed shapes. However, they also are manufactured in the form of special purpose clays, bonding mortars, and monolithics, such as hydraulic setting castables, plastic refractories, ramming mixes and gunning mixes. A variety of processed refractory grains and powders are also available for certain applications.

This section reviews primary refractory classifications, their typical properties and most common applications, as well as several specially designed refractories.

BASIC REFRACTORIES

Overview

Basic refractories were so named because they exhibit resistance to corrosive reactions with chemically basic slags, dusts and fumes at elevated temperatures. While this is still a useful definition, some classes of basic refractories have been developed that exhibit excellent resistance to rather acidic slags. Some types of direct bonded chrome-magnesite brick, such as those used in primary copper applications, fall into this latter category.

Broadly speaking, basic refractories generally fall into one of five compositional areas:

1. Products based on deadburned magnesite or magnesia.
2. Products based on deadburned magnesite or magnesia in combination with chrome-containing materials such as chrome ore.
3. Deadburned magnesite or magnesia in combination with spinel.
4. Deadburned magnesite or magnesia in combination with carbon.
5. Dolomitic products.

One of the more important types of magnesite brick are those that have low boron oxide contents and dicalcium silicate bonds. These chemical features give the brick excellent refractoriness, hot strength and resistance to load at elevated temperatures. Another category of magnesite brick contains a higher boron oxide content to improve hydration resistance.

Basic refractories containing chrome continue to be an important group of materials due to their excellent slag resistance, superior spalling resistance, good hot strengths and other features. Historically, silicates in the groundmass or matrix formed the bond between the chrome ore and periclase in the brick. However, the advent of high purity raw materials in combination with high firing temperatures made it possible to produce “direct bonded” brick, where a ceramic bond between the chrome ore and periclase particles exists. These direct bonded brick exhibit superior slag resistance and strengths at elevated temperatures.

Magnesite-spinel brick have increased in importance due to a desire to replace chrome-containing refractories because of environmental concerns. Brick made with spinel and magnesite have better spalling resistance and lower coefficients of thermal expansion than brick made solely with deadburned magnesite. These features minimize the chance of the brick cracking during service.

Basic brick containing carbon include pitch impregnated burned magnesite brick with carbon contents up to 2.5%, pitch bonded magnesite brick containing about 5% carbon and magnesite-carbon brick which contain up to 30% carbon. Development of the more corrosion resistant magnesite-carbon brick has resulted in decreased consumption of pitch impregnated and pitch bonded magnesite brick. In addition, in many instances the magnesite-carbon brick have replaced magnesite-chrome brick in applications such as electric arc furnaces. It is anticipated that magnesite-carbon brick will continue to grow in importance as new products are developed and additional uses for these products are found.

Dolomitic products are an important class of refractories that are used for example in rotary cement kilns and AOD’s. Dolomite brick offer a good balance between low cost and good refractoriness for certain uses. They also offer good metallurgical characteristics for certain “clean steel” applications.

RAW MATERIALS

The principal raw materials used in the production of basic refractories are dead-burned and fused magnesites, dead-burned dolomite, chrome ore, spinel and carbon. In recent years, the trend has shifted to developing highly engineered basic refractories. This has resulted from attempts to address the rapidly evolving needs of the metallurgical and mineral processing industries that use basic refractories. One result of this effort has been the development of technology to address specific wear mechanisms by employing special additives in the refractory composition. These additives generally constitute less than 6% of the total mix, although levels at 3% and below are probably the most common.

Examples of these special additives include zirconia, which is sometimes used to improve the spalling resistance of burned basic refractories. As carbon has become an important constituent in the formulation of composite magnesite-carbon refractories, metallic additives, such as powdered aluminum, magnesium or silicon have been used to improve hot strength and oxidation resistance. Small boron carbide (B_4C) additions also can improve the oxidation resistance of certain magnesite-carbon compositions. These compositions are used in special applications such as bottom blowing elements of basic oxygen furnaces.

MAGNESITE BRICK

Brick made with dead-burned magnesite are an important category of basic refractories. Magnesite brick are characterized by good resistance to basic slags as well as low vulnerability to attack by iron oxide and alkalies. They are widely employed in applications such as glass tank checkers, subhearth brick for electric arc furnaces, and sometimes as backup linings in basic oxygen furnaces. They are often impregnated with pitch in the latter application. Magnesite compositions are also widely used to control the flow of liquid steel in continuous casting systems, either as the slide gate refractory or as a nozzle.

Various grades of dead-burned magnesite are available for the production of magnesite brick. They range from natural dead-burned materials, with MgO contents of 90% or less, to high purity synthetic magnesites containing 96% MgO or greater.

A large amount of work has been done to produce highly refractory magnesites. Since magnesia itself has an extremely high melting point, i.e., 5070°F (2800°C), the ultimate refractoriness of a magnesite brick is often determined by the amount and type of impurity within the grain. In practice, the refractoriness of a dead-burned magnesite is improved by lowering the amount of impurities, adjusting the chemistry of the impurities or both.

There are many types of magnesite refractories, both burned and chemically-bonded. For simplification, they can be divided into two categories on the basis of chemistry. The first category consists of brick made with low boron magnesites, generally less than 0.02% boron oxide, that have lime-to-silica ratios of two to one or greater. Often, the lime-to-silica ratio of these brick is intentionally adjusted to a molar ratio of two to one to create a dicalcium silicate bond that gives the brick high hot strength. Brick with lime-to-silica ratios greater than two to one are often of higher purity than the dicalcium silicate-bonded brick. This greater chemical purity makes them more desirable for certain applications.

The second category of magnesite brick generally has lime-to-silica ratios between zero and one, on a molar basis. These brick may contain relatively high boron oxide contents (greater than 0.1% B_2O_3) in order to impart good hydration resistance. Sometimes, for economic reasons, these brick are made with lower purity natural dead burned magnesites with magnesia contents of 95% or less. At other times, the brick are made with very pure magnesites with MgO contents greater than 98% for better refractoriness.

MAGNESITE-CHROME AND CHROME-MAGNESITE BRICK

A major advance in the technology of basic refractories occurred during the early 1930's, when important discoveries were made regarding combinations of chrome ore and dead-burned magnesite.

Chrome ores are often represented by the generic formula $RO\bullet R_2O_3$, where the RO constituent consists of MgO and FeO, and the R_2O_3 constituent consists of Al_2O_3, Fe_2O_3 and Cr_2O_3. It should be recognized that most of the iron content of raw chrome ores is present as part of the RO constituent. Chrome ores also contain siliceous impurities as interstitial gangue minerals. These are generally olivine, orthopyroxene, calcic plagioclase, chlorites, serpentine and talc.

If raw chrome ore were fired in the absence of dead-burned magnesite, the FeO that is present would oxidize readily to Fe_2O_3. This would result in an imbalance between the RO and R_2O_3, as the RO decreases and the R_2O_3 increases. Two solid phases would appear: (1) a spinel consisting mainly of $MgO\bullet R_2O_3$ and (2) a solid solution of the excess R_2O_3 constituents (Fe_2O_3,Cr_2O_3 and Al_2O_3). Frequently, the solid solution is easily visible under the microscope as needle-like inclusions.

When a chrome ore is heated with added magnesia, as in a chrome-magnesite or magnesite-chrome brick, MgO enters the chrome spinel to replace the FeO as it oxidizes to Fe_2O_3. The MgO also combines with the newly formed Fe_2O_3 to maintain the spinel structure. The new spinel will have essentially the formula $MgO\bullet R_2O_3$.

The reaction of chrome ore with dead burned magnesite increases the refractoriness of the spinel minerals, since spinels formed by MgO with Cr_2O_3, Al_2O_3 and Fe_2O_3 have higher melting points than the corresponding spinels formed by FeO. In addition, the added magnesia also reacts with the accessory silicate minerals of low melting points present in the groundmass of the ore, and converts them to the highly refractory mineral forsterite, $2MgO\bullet SiO_3$. These reactions explain why magnesite-chrome and chrome-magnesite refractories have better hot strength and high temperature load resistance than refractories made from 100% chrome ore.

Direct-Bonded Magnesite-Chrome Brick

While the reactions between chrome ore and magnesite outline the fundamental chemistry of magnesite-chrome brick, a significant advance in the quality of these products occurred in the late 1950's and early 1960's with the introduction of "direct-bonded" brick. Prior to that time, most magnesite-chrome brick were silicate-bonded. Silicate-bonded brick have a thin film of silicate minerals that surrounds and bonds together the magnesite and chrome ore particles. The term direct-bonded describes the direct attachment of the magnesia to the chrome ore without intervening films of silicate. Direct-bonding was made possible by combining high purity chrome ores and magnesites, and firing them at extremely high temperatures. High strength at elevated temperatures is one of the single most important properties of direct-bonded brick. They also have better slag resistance and better resistance to "peel spalling" than silicate-bonded brick.

Direct-bonded magnesite-chrome brick are available with various ratios of magnesite-to-chrome ore. The balance of properties of the brick is a function of the magnesite-to-chrome ore ratio. For example, a direct bonded brick containing 60% magnesia would generally be regarded as having better spalling resistance than one containing 80% magnesia, although the latter might be considered a better choice in a high-alkali environment. This changing balance of properties as a function of the ratio of magnesite-to-chrome ore makes it possible to choose products best suited for an individual application.

Chrome-Magnesite Brick

Burned chrome-magnesite brick may be of either the direct-bonded or silicate-bonded variety. The direct-bonded brands are used under more severe service conditions.

Chemically-Bonded Magnesite-Chrome and Chrome-Magnesite Brick

Some magnesite-chrome brick are chemically-bonded rather than burned. These chemically-bonded brick do not have the high temperature strength, load resistance or slag resistance of burned compositions. They are widely used, usually as lower cost compositions to balance out wear profiles in various applications.

Chemically bonded magnesite-chrome brick are sometimes used with steel casing. In service, the steel oxidizes and forms a tight bond between the brick. The technique of steel casing has accounted for improved service life in many applications.

FUSED MAGNESITE-CHROME GRAIN BRICK

Products have been developed that contain fused magnesite-chrome grain to offer improved slag resistance. Fused grain is made by melting deadburned magnesite and chrome ore in an electric arc furnace. The melted material is then poured from the furnace into ingots and allowed to cool. The resulting ingots are crushed and graded into grain for brickmaking. Brick made from this grain, are called "rebonded fused magnesite-chrome brick".

Fused magnesite-chrome grain has extremely low porosity and is chemically inert. In addition, brick made from this grain have a tendency to shrink on burning rather than expand, as is characteristic of many direct-bonded magnesite-chrome brick. As a result of these features, the rebonded fused magnesite-chrome brick have lower porosity and superior slag resistance as compared to direct-bonded magnesite-chrome brick.

This type of brick is used in AOD's, degassers and sometimes in the more severe areas of nonferrous applications.

The fused grain brick used in North America typically contain 60% magnesia. Some compositions contain a combination of fused and unfused materials for better spalling resistance, to lower cost, or to achieve a balance of properties that is appropriate to the particular application in which they will be used.

COBURNED MAGNESITE-CHROME GRAIN BRICK

Some magnesite-chrome brick are made from coburned magnesite-chrome grain, often referred to merely as coburned grain. Coburned grain is made by combining fine magnesia and chrome ore and dead-burning in, for example, a rotary cement kiln. The resulting grain is dense and exhibits a direct-bonded character. Like brick made with fused magnesite-chrome grain, brick made with coburned grain shrink in burning and thus can have lower porosity than certain classes of direct-bonded magnesite-chrome brick. Brick made with coburned grain find wide variety of uses, such as in vacuum degassers in steelmaking and in certain nonferrous industries, such as primary copper and nickel production.

MAGNESITE-SPINEL BRICK

Magnesite-spinel brick have been more broadly used in recent years. The term "spinel" as used in describing this type of brick refers to the mineral $MgO•AI_2O_3$. In discussing magnesite-chrome brick and chrome ores, the term "spinel" is often used to refer to the family of minerals that crystallize in the cubic system and have the general formula $RO•R_2O_3$, where RO may be MgO, and FeO and R_2O_3 may be Fe_2O_3, Al_2O_3 and Cr_2O_3. While usage of the term "spinel" in this broader sense is accepted practice, the mineral spinel has the chemical formula $MgO•Al_2O_3$. It has become accepted usage to use the term magnesite-spinel brick to refer to the products containing $MgO•Al_2O_3$.

A family of magnesite-spinel brick has been developed by combining the constituent raw materials in various ways. Some magnesite-spinel brick are made by adding fine alumina to compositions composed mainly of magnesia. On firing, the fine alumina reacts with the fine magnesia in the matrix of the brick to form an in situ spinel bond. An alternative is to add spinel grain to a composition containing magnesia.

One of the principal benefits of combining spinel and magnesia is that the resulting compositions have better spalling resistance than brick made solely with dead burned magnesite. This feature results in the avoidance or inhibition of peel spalling caused by temperature cycling and infiltration of constituents from the service environment. Spinel additions also lower the thermal expansion coefficients of magnesite compositions. This can reduce thermal stresses that could contribute to cracking in certain environments.

A desire to use chrome-free basic brick for environmental reasons has increased the importance of magnesite-spinel brick. Trivalent chromium (Cr^{+3}) present in magnesite-chrome brick can be converted to the hexavalent state (Cr^{+6}) by reaction with alkalies, alkaline earth constituents and other compounds that are present in some service environments. These factors have led to broad use of magnesite-spinel brick in rotary cement kilns. They have excellent spalling resistance, good thermal expansion characteristics and have been shown to provide excellent service results in many rotary kilns.

CARBON-CONTAINING BASIC BRICK

The idea of adding carbon to a magnesite refractory originally stemmed from the observation that carbon is not easily wetted by slag. Thus, one of the principal functions of carbon is to prevent liquid slag from entering the brick and causing disruption. Until the mid 1970's brick based on carbon in combination with magnesite were mainly used in basic oxygen steelmaking furnaces; but since that time they have been more broadly utilized in electric arc furnaces and steel ladle applications.

Carbon-containing basic brick can be categorized as follows:

1. Pitch-impregnated, burned magnesite brick containing about 2.5% carbon;
2. Pitch-bonded magnesite brick containing about 5% carbon;
3. Magnesite-carbon brick containing 8% to 30% carbon (in this class, carbon contents ranging from 10% to 20% are most common).

While all brick in these categories contain both magnesite and carbon, the term "magnesite-carbon brick" as typically used in the United States refers to brick with carbon contents greater than 8%.

Pitch-impregnated and pitch-bonded magnesite brick can be thought of as products containing just enough carbon to fill their pore structures. In magnesite-carbon brick, however, the carbon addition is too large to be considered merely a pore filler. These brick are considered composite refractories in which the carbon phase has a major influence on brick properties.

Burned Pitch-Impregnated Magnesite Brick

One category of burned pitch-impregnated magnesite brick is made with a dicalcium silicate bond. Dicalcium silicate has an extremely high melting point of about 3870°F (2130°C). Use of this bond in combination with tight chemical control of other oxides gives these brick excellent hot strength and an absence of fluxes at temperatures commonly found in metallurgical processes.

The carbon derived from the impregnating pitch when the brick is heated in service prevents slag constituents from chemically altering the dicalcium silicate bond, preserving the hot strength and high refractoriness. The carbon also prevents the phenomenon of peel spalling, where the hot face of a brick cracks and falls away due to slag penetration in combination with temperature cycling.

Dicalcium silicate bonded burned magnesite brick that have been impregnated with pitch are used in a number of applications. In basic oxygen furnaces, this type of brick is sometimes used in charge pads, where its high strength enables it to resist cracking and disruption caused by the impact of steel scrap and liquid metal being added to the furnace. These brick are also widely used as a tank lining material, i.e. as a backup lining behind the main working lining of a basic oxygen furnace. They are also used in subhearths of electric arc furnaces.

Not all pitch impregnated burned magnesite brick are dicalcium silicate bonded, however. One important class of brick that deserves mention has a low lime to silica ratio and a high boron oxide content. These chemical features cause the brick to have relatively low hot strength, but at the same time, result in very good hydration resistance. Thus, brick such as this are the products of choice where it is judged that there is potential for hydration to occur.

Pitch-Bonded Magnesite Brick

Pitch-bonded magnesite brick are used in various applications, but mainly in basic oxygen furnaces and steel ladles. These products have excellent thermal shock resistance and high temperature strength, and good slag resistance.

Pitch-bonded magnesite brick were the principal working lining materials for basic oxygen furnaces for many years. Although in severe service environments they have been replaced to a large extent by more erosion resistant graphite-containing magnesite-carbon brick, they continue to play an important role in, for example, lower wear areas of basic oxygen furnaces.

Magnesite-Carbon Brick

The high carbon contents of magnesite-carbon brick are generally achieved by adding flake graphite. The high oxidation resistance of flake graphite contributes to the reduced erosion rates of these brick. In addition, the flake graphite results in very high thermal conductivities compared to most refractories. These high thermal conductivities are a factor in the excellent spalling resistance of magnesite-carbon brick. By reducing the temperature gradient through a brick, the high thermal conductivities reduces the thermal stresses within the brick. High thermal conductivity also results in faster cooling of a magnesite-carbon brick between heats and thus reduces potential for oxidation.

In recent years, product development efforts have been directed towards producing magnesite-carbon brick with good slag resistance and high temperature stability. High temperature stability refers to the ability of the brick to resist internal oxidation-reduction reactions that can reduce hot strength and adversely affect the physical integrity of the brick at elevated temperatures (i.e. the oxides in the brick are reduced by the carbon). A high degree of slag resistance and good high temperature stability have been found to be advantageous in the hotter and more corrosive service environments.

The high temperature stability of magnesite-carbon brick has been achieved by utilization of high purity graphites and magnesites. Since flake graphite is a natural, mined material, there are impurities associated with it. These may be minerals such as quartz, muscovites, pyrite, iron oxides and feldspars. Although much purification is accomplished through flotation processes, most flake graphites contain a limited amount of these impurities. These mineral impurities are often referred to as graphite "ash". Some of the ash constituents, especially the silica and iron oxide, are easily reduced by carbon and thus will result in a loss of carbon from the brick and a reduction in hot strength at elevated temperatures.

Magnesia can also be reduced by carbon at high temperatures. For best high temperature stability, high purity magnesites are used. Magnesites with very low boron oxide contents are especially desirable.

The service environments in which these carbon-containing basic brick are used are very diverse due to process changes in the steelmaking industry and due to broader use of the products. A great deal of work has been done to develop special additives to improve the performance of carbon-containing brick in these applications. These additives include powdered metals such as aluminum, magnesium and silicon. One reason for adding these metals is to improve oxidation resistance. The metals consume oxygen that would otherwise oxidize carbon. The aluminum and silicon also cause the pore structure of a magnesite-carbon brick to become finer after the brick is heated. It is believed that the pores become finer due to formation of aluminum carbide (AI_4C_3) and silicon carbide (SiC) by reaction between the metals and the carbon in the brick. The finer pores result in decreased permeability of the brick and inhibit oxidation by making it more difficult for oxygen to enter the brick structure.

Another reason for adding metals is to improve the hot strength of magnesite-carbon brick. It has been suggested that the improvement in hot strength is due to the formation of carbide "bridges" within the matrix of the magnesite-carbon brick.(1) Another way that metals may improve hot strength is simply by protecting the carbon bond in these brick from oxidation.

Silicon has been employed as an additive to inhibit the hydration of aluminum carbide that is formed in aluminum-containing magnesite-carbon brick. Aluminum carbide can react with atmospheric humidity or any other source of water to form an expansive reaction product that can disrupt the brick. This is illustrated by the following equation:

$$Al_4C_3 + 12H_2O \bullet CH_4 + 4Al(OH)_3$$

This reaction represents a potential problem for applications with intermittent operations such as some steel ladles or electric arc furnaces. Adding silicon to an aluminum-containing brick greatly extends the time before which hydration will occur.

Boron-containing compounds such as boron carbide (B_4C) are used to improve oxidation resistance in certain critical applications such as tuyere elements in bottom blown basic oxygen furnaces. In addition, magnesite-carbon brick are sometimes impregnated with pitch in order to improve oxidation resistance as well as to promote brick to brick bonding in service.

DOLOMITE BRICK

Dolomite brick are available in burned and carbon-bonded compositions. The carbon-bonded varieties include both pitch and resin-bonded versions. Some of the carbon-bonded products contain flake graphite and are somewhat analogous to magnesite-carbon brick. Dolomite brick are widely applied in applications as diverse as argon-oxygen decarburization vessels (AOD's), rotary cement kilns and steel ladles.

(1) A. Watanabe et.al., "Effects of Metallic Elements Addition on the Properties of Magnesia-Carbon Bricks", Preprint of The First International Conference on Refractories, Tokyo, Japan, Nov. 1984, pp 125-134.

HIGH ALUMINA REFRACTORIES

Overview

The term high-alumina brick refers to refractory brick having an alumina (AI_2O_3) content of 47.5% or higher. This descriptive title distinguishes them from brick made predominantly of clay or other aluminosilicates which have an alumina content below 47.5%.

High-alumina brick are classified by their alumina content according to the following ASTM convention. The 50%, 60%, 70% and 80% alumina classes contain their respective alumina contents with an allowable range of plus or minus 2.5% from the respective nominal values. The 85% and 90% alumina classes differ in that their allowable range is plus or minus 2% from nominal. The final class, 99% alumina, has a minimum alumina content rather than a range, and this value is 97%.

There are several other special classes of high-alumina products worth noting:

- Mullite brick - predominantly contains the mineral phase mullite ($3Al_2O_3 \bullet 2SiO_2$) which, on a weight basis, is 71.8% Al_2O_3 and 28.2% SiO_2.
- Chemically-bonded brick - usually phosphate-bonded brick in the 75% to 85% Al_2O_3 range. An aluminum orthophosphate ($AlPO_4$) bond can be formed at relatively low temperatures.
- Alumina-chrome brick - typically formed from very high purity, high-alumina materials and chromic oxide (Cr_2O_3). At high temperatures, alumina and chromia form a solid solution which is highly refractory.
- Alumina-carbon brick - high-alumina brick (usually bonded by a resin) containing a carbonaceous ingredient such as graphite.

CHEMISTRY AND PHASE MINERALOGY

For alumina-silica brick, refractoriness is generally a function of alumina content. The refractoriness of 50% alumina brick is greater than fireclay brick and progressively improves as alumina content increases up to 99+%. This relationship is best described by the Al_2O_3-SiO_2 phase diagram. The primary mineral phases present in fired high-alumina brick are mullite and corundum which have melting points of 3362°F (1850°C) and 3722°F (2050°), respectively. However, since phase equilibrium is seldom reached, particularly in the fired refractory, the Al_2O_3-SiO_2 diagram cannot be strictly applied. For example, a 70% alumina product might contain a combination of a bauxite aggregate of about 90% alumina, with various clay minerals containing less than 45% Al_2O_3. When fired, the brick could contain a range of phases which includes corundum (alumina), mullite, free-silica and glass.

In addition to Al_2O_3-SiO_2 content, the presence of certain impurities is critical in determining refractoriness. Most naturally occurring minerals contain amounts of alkalies (Na_2O, K_2O and Li_2O), iron oxide (Fe_2O_3) and titania (TiO_2). Alkalies can be particularly harmful since they ultimately react with silica to form a low melting glass when the brick are fired or reach high temperature in service. Both Fe_2O_3 and TiO_2 will react with Al_2O_3 and SiO_2, to form lower melting phases. Therefore, within any class of high-alumina brick, the raw materials and their associated impurities impact on the quality of the product and performance in service.

In addition to the melting behavior of brick, several other properties are affected by composition.

Slag Resistance

High-alumina brick are resistant to acid slags, that is, those high in silica. Basic components in slag, such as MgO, CaO, FeO, Fe_2O_3 and MnO_2 react with high-alumina brick, particularly brick high in silica. As Al_2O_3 content increases, slag resistance generally improves.

Creep or Load Resistance

This property is most affected by melting point and, therefore, is likely to be directly related to Al_2O_3 content. Impurities, such as alkalies, lime, etc., have a significant effect on creep resistance. Mullite crystal development is also particularly effective in providing load resistance.

Density

Alumina has a specific gravity of 3.96 and silica, in its various forms, ranges in specific gravity from 2.26 to 2.65. In refractories formulated from both alumina and silica, bulk density increases with alumina content.

Other physical, chemical and thermal properties will be discussed within the following sections concerning high-alumina brick.

TYPES OF HIGH-ALUMINA BRICK

50% Alumina Class

As previously mentioned, a brick classified as a 50% alumina product has an alumina content of 47.5% to 52.5%. Chemically, such brick are not greatly different from superduty fireclay brick which can contain up to 44% alumina. Brick within the 50% alumina class are often upgraded versions of fireclay brick with the addition of a high-alumina aggregate. Compositions of this class are designed primarily for ladles. These 50% alumina class brick have low porosity and expand upon reheating to 2910°F (1600°C) - desirable features for ladle applications since they minimize joints between brick, giving a near monolithic lining at service temperature. These brick are also characterized by low thermal expansion and good resistance to spalling. Many high-temperature industries use them as backup brick.

50% alumina products based on high purity bauxitic kaolin, and other ingredients in the matrix, provide exceptional load-bearing ability, alkali resistance and low porosity. These qualities make such brick an excellent choice for preheater towers and calcining zones of rotary kilns.

60% Alumina Class

The 60% alumina class is a large, popular class of products. These brick are used in the steel industry, as well as rotary kilns. Brick in this class are made from a variety of raw materials.

Some are produced from calcined bauxitic kaolin and high purity clay to provide low levels of impurities. As a result of firing to high temperature, these brick have low porosity, excellent hot strength and creep resistance, and good volume stability at high temperatures.

70% Alumina Class

This is the most frequently used high-alumina product class because of its excellent and cost-effective performance in multiple environments. Applications include the steel-industry and cement and lime rotary kilns.

Most brick in this class are based on calcined bauxite and fireclay. Brick are usually fired to fairly low temperatures to prevent excessive expansion in burning which causes problems in final brick sizing. Expansion is caused by reaction of the siliceous ingredients with bauxite to form mullite. The brick typically undergo large amounts of secondary expansion when heated. This is advantageous in reducing the size of joints between brick and providing a tight vessel structure, e.g., a rotary kiln.

A higher cost and higher quality alternative to producing a 70% alumina brick is represented by brands based on high purity calcined bauxitic kaolin. These brick have superior high temperature strength and refractoriness and significantly lower porosity than typical products based on calcined bauxite. Due to their more homogeneous structure, they show somewhat less expansion on reheating than bauxite-based products.

80% Alumina Class

These products are based primarily on calcined bauxite with additions of various amounts of other fine aluminas and clay materials. They are usually fired at relatively low temperatures to maintain consistent brick sizing. Most brick in this class have about 20% porosity, good strength and thermal shock resistance. Because they are relatively inexpensive, perform well and are resistant to most slag conditions present in steel ladles, they are used extensively in steel ladle applications.

90% and 99% Alumina Classes

These brick contain tabular alumina as the base grain and may include various fine materials such as calcined alumina, clay and fine silica. As these brick generally have low impurity levels, alumina and silica typically make up 99% of the chemical composition. Usually, the only mineral phases present are corundum and mullite. Properties such as high hot strength, creep and slag resistance benefit from this purity level.

ALUMINA-CHROME BRICK

Alumina-chrome brick consist of combinations of the two oxides fired to develop a solid-solution bond. A wide range of products are available depending upon Cr_2O_3 content. These include a 90% Al_2O_3-10% Cr_2O_3 product based on high purity sintered alumina and pure chromic oxide. The solid-solution developed in firing results in brick with exceptional cold strength, hot strength and load-bearing ability. In addition, the solid-solution bond between alumina and chromic oxide is inert to a wide variety of slags.

Brick with higher Cr_2O_3 content are also available. Based on a special fused grain high in chromic oxide, these products are selected for the most extreme cases of high temperature and corrosiveness.

MULLITE BRICK

In brick of this special category, the mineral phase mullite predominates. The alumina content varies from about 70% to 78% and the brick can contain a major portion of either sintered grain or fused mullite grain. These brick are typically fired to high temperature to maximize mullite crystal development.

PHOSPHATE-BONDED BRICK

Phosphate-bonded brick can be produced from a variety of high-alumina calcines, but typically they are made from bauxite. A P_2O_5 addition, such as phosphoric acid or various forms of soluble phosphates, reacts with available alumina in the mix. After the pressing operation, brick are cured at temperatures between 600°F and 1000°F (320°C and 540°C) which sets a chemical bond of aluminum phosphate. They may even be fired at higher temperatures to develop a combination chemical and ceramic bond. Phosphate-bonded brick are characterized by low porosity and permeability and very high strength at intermediate temperatures between 1500°F (815°C) and 2000°F (1090°C).

Phosphate-bonded brick are widely used in the mineral processing industries, particularly in applications such as nose rings and discharge ends of rotary kilns where excellent abrasion resistance is required.

ALUMINA-CARBON BRICK

In this class, brick are bonded by special thermosetting resins that yield a carbonaceous bond upon pyrolysis. A wide variety of compositions are possible based on the various high-alumina aggregates now available. Graphite is the most common carbonaceous material, although silicon carbide is used, as well.

FIRECLAY REFRACTORIES

OVERVIEW

Refractory fireclay consists essentially of hydrated aluminum silicates with minor proportions of other minerals. As defined by the American Society for Testing Materials (ASTM), there are five standard classes of fireclay brick: superduty, high-duty, medium-duty, low-duty and semi-silica. These classes cover the range from approximately 18% to 44% alumina, and from about 50% to 80% silica.

A blend of clays is commonly used in the manufacture of high-duty and superduty fireclay brick. Flint clays and high-grade kaolin impart high refractoriness; calcined clays control the drying and firing shrinkages; plastic clays facilitate forming and impart bonding strength. The character and quality of the brick to be made determines the relative proportions of clays used in a blend.

Superduty fireclay brick have good strength and volume stability at high temperatures and an alumina content of 40% to 44%. Some superduty brick have superior resistance to cracking or spalling when subjected to rapid changes of temperature. There are several possible modifications in the superduty fireclay class, including brick fired at temperatures several hundred degrees higher than the usual product. High firing enhances the high temperature strength of the brick, stabilizes their volume and mineral composition, increases their resistance to fluxing, and renders them practically inert to disintegration by carbon deposition in atmospheres containing carbon monoxide gas.

High-duty fireclay brick are used in large quantities and for a wide range of applications. Because of their greater resistance to thermal shock, high-duty fireclay brick can often be used with better economy than medium-duty brick for the linings of furnaces operated at moderate temperatures over long periods of time but subject to frequent shutdowns.

Medium-duty brick are appropriate in applications where they are exposed to conditions of moderate severity. Medium-duty brick, within their serviceable temperature ranges, can withstand abrasion better than many brick of the high-duty class.

Low-duty fireclay brick find application as backing for brick with higher refractoriness, and for other service where relatively moderate temperatures prevail.

Semi-silica fireclay brick contain 18% to 25% alumina and 72% to 80% silica, with a low content of alkalies and other impurities. With notable resistance to shrinkage, they also have excellent load-bearing strength and volume stability at relatively high temperatures.

FIRECLAY MATERIALS

Refractory fire clays consist essentially of hydrated aluminum silicates with minor proportions of other minerals. The general formula for these aluminum silicates is $Al_2O_3 \bullet 2SiO_2 \bullet 2H_2O$, corresponding to 39.5% alumina (AI_2O_3), 46.5% silica (SiO_2) and 14% water (H_2O). Kaolinite is the most common member of this group. At high temperatures, the combined water is driven off, and the residue theoretically consists of 45.9% alumina and 54.1% silica. However, even the purest clays contain small amounts of other constituents, such as compounds of iron, calcium, magnesium, titanium, sodium, potassium, lithium and usually some free silica.

Of greatest importance as refractories are flint and semi-flint clays, plastic and semi-plastic clays, and kaolins.

Flint clay, also known as “hard clay”, derives its name from its extreme hardness. It is the principal component of most superduty and high-duty fireclay brick made in the United States. Most flint clays break with a conchoidal, or shell-like, fracture. Their plasticities and drying shrinkages, after they have been ground and mixed with water, are very low; their firing shrinkages are moderate. The best clays of this type are low in impurities and have a Pyrometric Cone Equivalent (PCE) of Cone 33 to 34-35. Deposits of flint and semi-flint clays occur in rather limited areas of Pennsylvania, Maryland, Kentucky, Ohio, Missouri, Colorado and several other states.

Plastic and semi-plastic refractory clays, often called “soft clays” or “bond clays”, vary considerably in refractoriness, plasticity and bonding strength. Drying and firing shrinkages are usually fairly high. The PCE of clays of this type ranges from Cone 29 to Cone 33, for the most refractory varieties, and from Cone 26 to Cone 29 for many clays of high plasticity and excellent bonding power. Substantial deposits of plastic and semi-plastic refractory clays are found in Pennsylvania, Ohio, Kentucky, Missouri, Mississippi, Alabama and various other states.

Kaolins consist essentially of the mineral kaolinite. They usually are moderately plastic and have extremely high drying and firing shrinkages. Siliceous kaolins shrink less and bauxitic kaolins shrink more than kaolins which consist almost wholly of kaolinite. Refractory kaolins generally have a PCE of Cone 33 to 35; less pure varieties with a PCE of Cone 29 to 32 are common. Among the largest deposits of refractory kaolin are those which occur in Georgia and Alabama.

Most commercial deposits of flint and plastic refractory clay occur in sedimentary strata in association with coal beds. Usually, individual occurrences are relatively small and of irregular form. In the north-central Ozark region of Missouri, bodies of refractory clay occur in the form of isolated sink-hole deposits. The kaolin deposits of Georgia and Alabama occur in the form of lenslike bodies.

BRICK CLASSIFICATIONS

Superduty

The outstanding properties of superduty fireclay brick are refractoriness, alumina content of 40% to 44%, strength, and volume stability at high temperatures. Many superduty brick have good resistance to cracking or spalling when subjected to rapid changes of temperature. Their refractoriness, in terms of their PCE values, may not be less than 33. In the class of superduty fireclay refractories are several modifications, including brick which are fired at temperatures several hundred degrees higher than the usual product. The high firing temperature enhances the high-temperature strength of the brick, stabilizes their volume and mineral composition, increases their resistance to fluxing and renders them practically inert to disintegration by carbon deposition in atmospheres containing carbon monoxide gas.

High-Duty

The PCE value of high-duty fireclay brick may not be less than 31$^1/_2$, and ordinarily varies from 31$^1/_2$ to 32$^1/_2$ -33.

Medium-Duty and Low-Duty

Fireclay brick of the medium-duty class have PCE values of 29 to 31. The PCE values of low-duty fireclay brick cover the range from 15 to 27-29.

FIRECLAY BRICK MANUFACTURE

Most fireclay brick are made from blends of two or more clays. Some brick, especially those of the low-duty class, are made of a single clay. The mixes for superduty and high-duty brick commonly contain raw flint and bond clays, with or without calcined clay. In making brick of kaolin and various other clays, a large proportion of the mix is precalcined to control firing shrinkage and stabilize the volume and mineral composition of the product.

In making fireclay brick, the particles of ground clay must include a range of graded sizes, each in proper proportion. The clays are typically ground in a “dry pan,” which is a rotating, pan-shaped grinding mill having slotted openings in the bottom. The batches are screened to the desired sizes and thoroughly mixed with a small but closely controlled amount of water. The moistened batch is then fed to a mechanically or hydraulically operated press in which the brick are formed under pressure.

In a modification of the power-press process, certain physical properties are enhanced by the application of a high vacuum during the forming of the brick. Brick made in this way typically have a more homogeneous texture and are harder, stronger, less porous and more dense than those made without vacuum. As a consequence, they are more resistant to impregnation and corrosion by slags and to penetration by gases.

The extrusion process is sometimes used for making special shapes. In making extruded brick, clays are ground in a dry pan, mixed wet or dry in a mixer, brought to the proper consistency in a pug mill, and extruded through the die of an auger machine in the form of a stiff column. The air is removed from the clay before extrusion by a deairing system within the auger machine chamber. The column is cut into brick by means of wires. The brick are then typically repressed to give them sharp corners and edges and smooth surfaces. Many intricate special shapes are formed in vertical piercing-and-forming presses, in which blanks from the extrusion machine are completely reshaped.

Brick formed by any of the processes described above are dried in tunnel or humidity driers. The temperature of firing depends upon the maturing temperatures of the clays, and often upon the service for which the brick are intended. In firing the brick, several necessary ends are accomplished: free and combined water are driven off; iron and sulfur compounds and organic matter are oxidized, and the gases formed are eliminated; mineral transformations and changes in volume are affected; and finally, the particles of clay are ceramically-bonded together into mechanically strong brick.

Overview

Silica refractories are well adapted to high temperature service because of their high refractoriness, high mechanical strength and rigidity at temperatures almost up to their melting points, as well as their ability to resist the action of dusts, fumes and acid slags.

The American Society for Testing Materials (ASTM) divides silica brick into Type A and Type B based on the brick's flux factor. Flux factor is determined by adding the alumina content and twice the total alkali content. The Type A class includes silica brick with a flux factor of .50 or below; Type B includes all silica brick with a flux factor above .50.

Both classes require that brick meet the following criteria: Al_2O_3 less than 1.5%; TiO_2 less than 0.2%; Fe_2O_3, less than 2.5%; CaO less than 4%; and average modulus of rupture strengths not less than 500 psi.

This system for classifying silica brick was preceded by a less exact system which still is referenced today. Under the earlier system, non-insulating silica brick were either of conventional or superduty quality. Insulating silica brick were classified only as superduty. Brick classified as superduty silica brick could not contain more than a total of 0.5% alumina, titania and alkalies.

MANUFACTURE OF SILICA REFRACTORIES

The raw material used in the manufacture of silica refractories consists essentially of quartz in finely crystalline form having the proper characteristics for conversion to the high temperature crystal modifications of silica. To assure the highest commercial quality in the refractory product, the mineral must be washed to remove natural impurities.

After being formed, the brick must be fired at a temperature high enough to convert the quartz into forms of silica that are stable at high temperatures. In the firing and cooling process, refractories must pass through several critical temperature ranges; consequently, it is necessary to maintain a carefully planned time-temperature schedule during the firing process. A proper schedule assures the production of strong, well-bonded brick which attain their normal permanent expansion of 12% to 15% by volume.

EFFECTS OF ALUMINAS AND ALKALIES

After firing, silica brick contain a small proportion of silicates in the body that is otherwise crystalline silica. Upon being reheated to high temperatures, these silicates melt and form a small amount of liquid. As the temperature rises, the liquid increases because the silica also melts, at first slowly and then more rapidly, especially above 2900°F (1600°C). When relatively small amounts of silicate liquid are present, the solid crystalline portion of the brick forms a rigid skeleton, with liquid merely present between the solid particles, and the brick as a whole retains its rigidity even under load. When larger amounts of liquid develop at higher temperatures, the bond weakens and the brick may lose its rigidity.

When silica brick contain the usual 2% to 3.5% of lime, the percentage of liquid formed at high temperatures increases almost in direct proportion to the total amount of alumina, titania and alkalies present. The temperature of failure under load decreases correspondingly. Individually, these oxides and alkalies vary appreciably in their effects on temperature of failure, but their total concentration is the significant factor. When the sum of alumina, titania and alkalies is less than 0.5%, the temperature of failure under a load of 25 pounds per square inch is 50°F (28°C) to 90°F (50°C) higher, than for brick containing a total of 1% of these oxides. For this reason, brick classified as superduty must contain no more than a total of 0.5% alumina, titania and alkalies.

CHARACTERISTIC PROPERTIES

Among the important properties of silica brick are their relatively high melting temperatures, i.e., approximately 3080°F (1695°C) to 3110°F (1710°C); their ability to withstand pressure of 25 to 50 pounds per square inch at temperatures within 50°F (28°C) to 100°F (56°C) of their ultimate melting points; high resistance to acid slags; constancy of volume at temperatures above 1200°F (650°C); and virtual freedom from thermal spalling above 1200°F (650°C). At high temperatures, the thermal conductivity of most silica brick is somewhat higher than that of fireclay brick.

At temperatures below 1200°F (650°C), silica brick have less resistance to thermal shock. They are readily attacked by basic slags and iron oxide at high temperatures in a reducing atmosphere.

SILICA BRICK PRODUCTS

Certain superduty silica brick have been developed to meet the demand for a silica refractory that would permit higher furnace temperatures, give longer life and reduce maintenance costs. These brick contain no more than 35% alumina plus alkalies and titania. Superduty silica brick are used with excellent results in the superstructures of glass-tank furnaces.

For many years, conventional quality silica brick have been regarded as the standard. The properties responsible for the excellent service record of this brick are rigidity under load at high temperatures, high resistance to spalling above 1200°F (650°C), high mechanical strength, resistance to abrasion, resistance to corrosion by acid slags and uniformity of size. Improved versions of conventional quality silica brick are available having better resistance to high temperature thermal shock.

A lightweight silica brick with a bulk density of 65 to 70 pounds per cubic foot (1,041 to 1,121 kg/m^3) is suitable for use up to 3000°F (1650°C). At a mean temperature of 1200°F (650°C), its insulating value is excellent. Lightweight silica brick are used largely for the insulation of silica brick constructions, especially the crowns of glass-tanks. They are also ideal for the construction of tunnel kiln crowns, and their properties are conducive to arches having a wide span.

Overview

Materials that surpass commonly used refractories in one or more of their essential properties are often required for industrial purposes. Carbon and graphite, silicon carbide, zircon, zirconia, fused cast, fused silica and insulating brick are some of the refractories with extraordinary properties for special applications.

CARBON AND GRAPHITE

This type of refractory is essentially composed of the element carbon. Its use is limited to applications which are either strongly reducing or where the oxygen content of the atmosphere at a given operating temperature is low enough to prevent appreciable combustion of carbon. Starting materials for the production of carbon refractories are typically the amorphous carbons, e.g., metallurgical coke, petroleum coke, heat treated coal tar pitches and the like.

Naturally occurring flake graphite or artificial graphites are sometimes blended with amorphous carbons to achieve a desired thermal conductivity. These materials are combined with high carbon yielding resins or pitch and formed into blocks and slabs. Such shapes are well suited to places where high heat transfer is required, such as areas using watercooled panels. Historically, carbon blocks have been used to line the hearth and bosh of blast furnaces. Carbon blocks have also been used to line the hearth and sidewalls of aluminum reduction pots. Electrodes and anodes used in numerous industrial applications also are typically made from carbon.

Carbon is a desirable element for refractory use because it is not wetted by most molten metals and slags; it has excellent thermal shock resistance; and its strength increases when it becomes heated. Because of its susceptibility to oxidation, however, this refractory should be used under reducing conditions; or efforts should be made to minimize reaction with gaseous oxygen by adding oxidation inhibitors to the shape, such as boron carbide, fine metals (Al, Si, Mg), or by coating the shape with a protective glaze. Metal melting crucibles made of clay-graphite have been used for a considerable number of years as have clay-graphite shapes, such as stopper rods and sleeves. Clay-graphite shapes have been replaced, for the most part, by alumina-graphite shapes which provide longer service life.

SILICON CARBIDE

Silicon carbide, a major component in this special refractory class, is produced by reacting silica sand and coke at temperatures above 3600°F (2000°C). The center of the reacted mass is the area having the highest purity, with the purity level decreasing towards the outer zones of the mass. By selectively cropping a silicon carbide ingot, a producer can sell various grades of silicon carbide grains ranging from 90% SiC content to 98% SiC. Silicon carbide by itself is extremely inert. Under normal atmospheric conditions, it will not selfbond, even at highly elevated temperatures. Various schemes have been developed to bond silicon carbide using clay, silica, metallic powders and molten silicon.

Clay bonded SiC refractories are made by adding crude clay to silicon carbide grain and firing the shape to sufficient temperature to vitrify the clay and produce a glassy bond. These shapes are used with success in hot, abrasion-prone applications with temperatures under 2600°F (1427°C). Their usefulness is limited by the refractoriness of the clay bond.

Higher strength bonds can be achieved by bonding silicon carbide with a nitride phase or by self-bonding silicon carbide grains with secondary in situ formed silicon carbide. Nitride bonds are typically formed by adding fine silicon powder to SiC, forming a shape and heating the shape in a nitrogen atmosphere to above 2200°F (1205°C). Gaseous nitrogen reacts with the dispersed silicon phase and forms silicon nitride crystals which readily bond to the surface of the silicon carbide aggregate. To produce a silicon oxynitride bond, an oxygen source (typically silica) is added to the starting materials. To form a sialon bond, alumina is typically added to the starting mixture. The various nitride phases all possess non-wetting properties, relatively low thermal expansion and high strength. The selection of an appropriate nitride bond is dependent upon the degree of oxidation in the service environment. Generally, the sialon bond possesses the highest degree of oxidation resistance. Nitride-bonded SiC-shapes are typically used in aluminum melting and refining applications, as well as in the bosh and lower in wall of blast furnaces.

Self-bonded SiC refractories are made by first forming a shape using conventional ceramic binders and then firing the shape at very high temperatures 3622°F to 4082°F (2000°C to 2250°C) in an atmosphere of silicon vapors. Fine carbon placed in the starting materials reacts with the silicon vapors to form a silicon carbide secondary phase. Such shapes have a “recrystallized” appearance and are readily distinguishable. Self-bonded SiC is typically used in heating elements and structural supports.

ZIRCON

Zircon is a silicate of zirconium having a composition of about 67% zirconia and 33% silica. Zircon refractories are made by blending beneficiated zircon sands, milled zircon sands and a plasticizer or temporary binder, forming a desired shape, and firing to an elevated temperature. The firing temperature of zircon is limited to temperatures beneath 2732°F to 3000°F (1500° to 1650°C), because within this temperature range zircon dis-sociates. The actual temperature at which zircon dissociates into zirconia and silica is influenced by mineralizers, such as alkalies and fluorides. Brick consisting essentially of zircon are typically made by a forming process called impact pressing, originally developed by Harbison-Walker. This process uses a rapid series of air hammer impacts to compress the mix into simple shapes, such as rectangles. Other, more intricate shapes are made by air ramming or vibration casting. The main advantages of zircon refractories are their relative chemical inertness against acidic slags and their good thermal shock resistance.

ZIRCONIA

Zirconia (ZrO_2) is usually obtained through a chemical process involving zircon or by fusing zircon with coke in an electric furnace. Zirconia has held promise as an ideal refractory material for many decades. It has long been known to have excellent chemical inertness. It has an extremely high melting point of 4856°F (2680°C). Widespread use of zirconia has been limited, however, because of two major drawbacks, its high cost and its tendency to change crystal form upon heating.

Zirconia can occur in three polymorphs; monoclinic, tetragonal, and cubic. The typical room temperature phase is monoclinic which is stable to about 2120°F to 2174°F (1160°C to 1190°C) upon heating. Heating through the monoclinic-tetragonal transition causes a volume contraction; cooling through the transition causes a volume expansion. The phase change transition through cooling is instantaneous and results in spontaneous failure of the zirconia crystal. This failure is expressed in the cracking and/or disintegration of the refractory shape.

The fundamental cracking problem can be overcome using either of two contrasting approaches. One is to mill monoclinic zirconia to a fine size (less than one micron) and disperse it within a refractory body so that destructive micro-cracking is avoided. In fact, the dispersed phase works as a stress absorber as energy is absorbed by zirconia to convert from one phase to another. In this way, the dispersed phase is said to produce a "toughening" effect.

The other approach is to stabilize the cubic structure with lime, magnesia or yttria by heating zirconia with one of these oxides within the temperature range 2750°F to 3100°F (1500°C to 1700°C). The cubic form of zirconia has a uniform thermal expansion, whereas thermal expansion of the other polymorphs reflect volume changes which occur upon heating. A disadvantage of stabilized zirconia is its tendency to thermally age. That is, the stabilizer tends to migrate out of the structure when the material is exposed to long term temperatures within the 1472°F to 2552°F (800°C to 1400°C) range.

Due to its high cost, zirconia refractories are only used in critical applications, such as metering nozzles used in continuous casting and inserts in the bore area of slide gates. In these applications, control of the bore diameter during casting is vital. Some zirconia is used to make crucibles for refining special alloys where purity of the molten metal is of concern. The main use of zirconia in the refractories industry, however, is as an additive to increase the thermal shock or slag resistance of the refractory.

FUSED SILICA REFRACTORIES

Fused silica is produced by electrically heating quartzite (SiO_2) with a purity of at least 98% silica in a fusion furnace. In this process, the crystalline nature of the silica is transformed into an amorphous structure by rapid quenching from a molten condition. Because of the extremely low thermal expansion of fused (amorphous) silica, this material has excellent thermal shock resistance. Fused silica also has excellent corrosion resistance in acidic media, such as strong acids. Fused silica powders are used in the electronics industry as resin extenders due to their excellent electrical insulating property. Fused silica filled resins are used to encapsulate electronic components to protect them from the environment.

Fused silica grains are classified into various sizes and formulated into a slip mix for casting into plaster molds. Using this technique, many intricate, complex shapes can be made. These shapes are used as coke oven doors, shroud tubes, glass-tank refractories, nonferrous troughs and spouts, and as linings for chemical reactors. Fused silica shapes can be used in constant temperatures up to 3000°F (1650°C) and cyclical temperatures up to 2000°F (1094°C). Beyond about 2000°F (1094°C) amorphous silica devitrifies into cristobalite which undergoes a volume expansion when heated, displaying a significantly higher thermal expansion than fused silica. Because of these properties, devitrified fused silica is not considered volume or thermally stable when heated to elevated temperatures.

FUSED CAST REFRACTORIES

As the name implies, this classification of refractories is formed by melting refractory compounds in a fusion furnace and casting the liquid melt into a simple shape, such as a block. Special attention must be paid to the cooling rate of the melt to prevent cracking of the shape and localized defects, such as shrinkage cavities.

The advantage of using fused cast refractories to contain molten metal or slag is their lack of interconnected porosity, a feature inherent to sintered refractories. The absence of open porosity enables this type of refractory to resist corrosion and infiltration of corrosive agents. The main disadvantage of fused cast refractories is their great sensitivity to thermal fluctuations. The sudden temperature changes which occur in many applications are simply too rapid to prevent cracking or shattering of fused cast refractories.

Fused cast refractories are typically sold in the following compositions: alumina, alumina-zirconia-silica, alumina-silica, magnesite-chrome, zircon and spinel.

Fused cast alumina is primarily used is in refining and superstructure areas of glass tanks. The predominant type of fused cast is alumina-zirconia-silica. It is used in melting and superstructure areas. Fused cast magnesite -chrome refractories are generally composed of 50% to 60% dead-burned magnesite and 40% to 50% chrome ore. They offer excellent resistance to fluid corrosive basic slags; however, their relatively high cost and the development of suitable alternative refractories at lower cost has limited their wide-spread usage.

INSULATING BRICK

Insulating brick are made from a variety of oxides, most commonly fireclay or silica. The desirable features of these brick are their light weight and low thermal conductivity, which usually results from a high degree of porosity. The high porosity of the brick is created during manufacturing by adding a fine organic material to the mix, such as sawdust. During firing, the organic addition burns out, creating internal porosity. Another way to accomplish high porosity involves the addition of a foaming agent to slip. Using this approach, insulating brick can be cast instead of dry pressed. Additions of lightweight aggregates like diatomite, haydite, etc., is another approach. Because of their high porosity, insulating brick inherently have lower thermal conductivity and lower heat capacity than other refractory materials.

ASTM classifies fireclay and high-alumina insulating refractories in the following sequence: 16, 20, 23, 26, 28, 30 and 33. These numbers multiplied by 100 represent the nominal service temperature in degrees Fahrenheit to which the refractory can be exposed in service. Products numbered from 16 to 26 are made from a fireclay base and products numbered from 28 to 33 are made from a high-alumina base. Typically, insulating refractories are used as backup materials, but they can also be used as working linings of furnaces where abrasion and wear by aggressive slag and molten metal are not a concern. Where they can be used, insulating materials offer several distinct advantages:

- Savings in fuel cost due to decreased heat losses through the furnace lining and less heat loss to the refractory.
- Faster heat-up of the lining due to the insulating effect and lower heat capacity of the insulating refractory.
- Thinner furnace wall construction to obtain a desired thermal profile.
- Less furnace weight due to the lower weight of the insulating refractory.

A variety of insulating brick provide a range of thermal efficiencies and strengths. By composition and property characteristics, lightweight insulating silica brick are similar to conventional silica brick with the exception of density and porosity. They have a maximum service limit of 3000°F (1650°C) and are used in the crowns of glass furnaces and tunnel kilns. Insulating brick based on fireclay aggregate are also available with a combination of high strength and low thermal conductivity. These brick offer a maximum service limit in the range of 2100°F to 2300°F (1150°C to 1261°C). They are primarily used in rotary cement kilns and glass tanks.

For even higher temperature and corrosive applications, lightweight, insulating 90% and 99% alumina brick and alumina-chrome bricks are also made.

MORTAR MATERIALS

Overview

Masonry built of refractory brick consists of many relatively small units laid together to conform to a prescribed plan or design. The strength of the masonry depends upon the strength of the individual brick, the manner in which they are laid together and the nature of the mortar material used in the joints. The purpose of the mortar is to fill the joints and bond the individual brick together. It should protect the joints from attack by slag and other fluxes and provide resistance to infiltration by cold air and to the outward flow of gases.

Mortar material should be selected as carefully as the brick with which it is to be used. Users of refractories recognize that poorly made joints, or joints filled with improper material, may greatly shorten the life of a refractory structure.

MORTAR CLASSES

Refractory mortar materials are divided into two classes: heat-setting mortars and air-setting mortars.

Most heat-setting mortars require relatively high temperatures to develop a ceramic set, in contrast with air-setting mortars which take a rigid set merely upon drying. Phosphate-bonded mortars develop a chemical bond at lower temperatures. Temperatures in excess of 700°F (370°C) are necessary to permit formation of more stable phosphate bonds which are less susceptible to rehydration in high moisture conditions. Included in each of these groups are materials of various compositions for use in specific applications.

Mortar materials and their methods of preparation have been developed for particular combinations of properties each bonding mortar should possess. Among the factors included are workability, plasticity, water retention, fineness of grind, drying and firing shrinkages, chemical composition, refractoriness, cold and hot bonding strengths, vitrification temperature and resistance to chemical attack.

The conditions which a bonding mortar must meet in service are often extremely exacting and require a carefully adjusted balance of properties. For economy and convenience in laying, a mortar should have good working properties when mixed to either dipping or trowelling consistency. With excellent workability and water retention over a range of consistencies, a mortar can be used for dipped or trowelled joints, as a surface coating for walls, or for patching. The mortar should not shrink excessively upon drying or heating, nor should it overfire and become vesicular at the maximum service temperature. The thermal expansion of the mortar should be approximately the same as that of the brick with which it is used; otherwise, temperature changes will affect the bond between brick and mortar and cause surface coatings to crack or peel. If strong joints are needed, the mortar material must be affected sufficiently by the heat to develop a strong ceramic bond. However, the refractoriness of the mortar must be high enough to resist melting or flowing from joints at high temperatures.

In some cases, there must be adequate chemical reaction between brick and mortar to develop a strong bond between them, but in no case should the chemical reaction be sufficient to damage the brick. In many types of service, it is essential that joint material be highly resistant to chemical attack by the furnace charge, slag, dust, volatized fluxes or gases; and for certain uses it is important that the mortar material should not discolor nor otherwise contaminate the material being processed in the furnace. Mortars which do not develop a strong bond are often desirable for use in laying brick walls which are alternately subjected to soaking heat and cooling cycles.

TYPES OF MORTARS

Fireclay Mortars

Air-setting mortars containing a mixture of high fired, fireclay and high-alumina calcines and smooth working plastic clays are recommended for use in laying high-alumina brick in the 50% to 70% range, as well as insulating brick. Mortars of this kind meet ASTM specification C 178-47 superduty class mortar and are available in a wet or dry form.

Other air-setting mortars are available with high refractoriness, excellent intermediate temperature strength and smooth working properties.

High-Alumina Mortars

Heat-setting mortars with very high refractoriness, volume stability, and resistance to attack by molten metal or slag are used in laying high-alumina and superduty fireclay brick in various applications, especially those where resistance to ferrous slags is required. These mortars can be dipped or trowelled.

High-alumina air-setting mortars are used in applications up to 3200°F (1760°C). They have high refractoriness and excellent resistance to attack by corrosive slags.

Phosphate-bonded mortars with high refractoriness and exceptionally smooth working properties are used for laying high-alumina brick in a variety of applications.

Heat-setting mortars based on high purity tabular alumina calcines are available for use up to 3400°F (1871°C). These mortars have exceptional stability and load-bearing ability at high temperatures and are highly resistant to corrosion by volatile alkalies and slags in all types of furnaces. They are typically used for laying brick in the 90% alumina class.

Phosphate-bonded alumina-chrome mortars generate high bond strengths and show excellent resistance to corrosion by ferrous and nonferrous metals. Mortars of this kind are recommended for use when laying alumina-chrome brick, brush coating over refractory walls, or other applications where strong bonded joints and resistance to slag or metal penetration are desired.

Basic Mortars

Dry, air-setting mortars with a chrome ore base have excellent resistance to a wide range of corrosive slags and fumes in chemical applications. They are used for laying basic brick of all types, but can be used as a neutral layer between basic and acid brick.

Mortar brands are also available which contain high quantities of penetration and corrosion inhibitors. These materials have exceptionally high resistance to corrosive slags and are used for laying all types of basic brick, as well as some high-alumina compositions where slag attack and corrosion are especially damaging.

Mortars based on high purity magnesite are also available and often used for refractories with high MgO content. These are usually dry and may be used with other types of basic brick.

Overview

Monolithic or monolith-forming refractories are special mixes or blends of dry granular or cohesive plastic materials used to form virtually joint-free linings. They represent a wide range of mineral compositions and vary greatly in their physical and chemical properties. Some are relatively low in refractoriness, while others approach high purity brick compositions in their ability to withstand severe environments.

ADVANTAGES OF MONOLITHIC REFRACTORIES

Monolithic refractories are used to advantage over brick construction in various types of furnaces. Their use promotes quick installation, avoiding delays for the manufacture of special brick shapes. Using monolithics frequently eliminates difficult bricklaying tasks, which may be accompanied by weakness in construction. They are of major importance in the maintenance of furnaces because substantial repairs can be made with a minimum loss of time and, in some cases, even during operations. Under certain conditions, monolithic linings of the same chemical composition as firebrick provide better insulation, lower permeability and improved resistance to the spalling effects of thermal shock.

Monolithic refractories are packaged in suitable containers for convenience in handling and shipping. With little or no preparation, they can be applied to form monolithic or joint-free furnace linings in new construction, or to repair existing refractory masonry.

TYPES OF MONOLITHIC REFRACTORIES

Common usage divides monolithic refractories into the following groups:

- Plastic Refractories
- Ramming Mixes
- Gunning Mixes
- Castables

Plastic refractories are mixtures of refractory aggregates and cohesive clays, prepared in stiff plastic condition at the proper consistency for use without further preparation. They are generally rammed into place with pneumatic hammers, but may also be pounded into place with a mallet.

Ramming mixes consist essentially of ground refractory aggregates, with a semi-plastic bonding matrix which can be purchased ready-to-use or prepared by adding water in the mixer at the construction site. Ramming mixes are placed with pneumatic hammers in 1-1½ inch layers. They supply a denser, stronger refractory body than plastics, but need some sort of form to restrain them when rammed.

Gunning mixes consist of graded refractory aggregate and a bonding compound, and may contain plasticizing agents to increase their stickiness when pneumatically placed onto a furnace wall. Typically, gunning mixes are supplied dry. To use, they are predamped in a batch mixer, then continuously fed into a gun. Water is added to the mix at the nozzle to reach the proper consistency.

Castables consist of graded dry refractory aggregates combined with a suitable hydraulic-activated bonding agent. Castables are furnished dry and form a strong cold set upon mixing with water. They are usually poured or cast in much the same manner as ordinary concrete, but are sometimes vibrated, trowelled, rammed or tamped into place, or applied with air placement guns. They form strong monolithic linings, possessing combinations of properties that make them ideal for many applications.

In more recent years, new installation technologies have been developed for refractories that parallel that of Portland cement. New equipment and improved refractory materials have led to new installation techniques like self leveling castables and pumping and wet spraying of refractory mixes. Pumping low cement and ultra-low cement castables in a variety of applications is now an accepted installation practice. Wet spraying is different than gunning since this is a wet castable pneumatically applied with a set activator added at the nozzle. In gunning, dry material is conveyed to the nozzle and water added at the nozzle creating the wet mixture as it is applied to the wall. The great upsurge in the use of these installation techniques is sufficient evidence of its utility and effectiveness and its acceptance by all segments of the pyro-processing industries as an important methods for the placement of refractory concretes.

The discussion above suggests the manner in which each class of monolithic refractory is most commonly installed. However, not infrequently, material of one group may be installed by a technique more common to another group. Specially designed plastics are sometimes gunned, as are many castables and ramming mixes. Gunning mixes are often cast or trowelled. Typically, however, the best properties are achieved when monolithic materials are installed in their intended manner.

When air-setting or hydraulic activated monolithic refractories are used, the entire thickness of a lining becomes hard and strong at atmospheric temperatures. The strength can be somewhat lower through the intermediate temperature range, but increases at higher temperatures with the development of a ceramic bond.

Heat-setting monolithic refractories have very low cold strength and depend on relatively high temperatures to develop a ceramic bond. In the case of a furnace wall having the usual temperature drop across its thickness, the temperature in the cooler part is usually not enough to develop a ceramic bond. However, with the use of a suitable insulating material as backup, the temperature of the lining can be high enough to develop a ceramic bond throughout its entire thickness.

When monolithic linings are used as the primary furnace lining, they are usually held in place with either ceramic or high temperature steel anchors. Each method of anchoring has advantages, depending upon furnace conditions and installation technique.

Plastic Refractories

Plastic refractories are used to form refractory monolithic linings in various kinds of furnaces, and are especially adaptable for making quick, economical emergency repairs. They are easily rammed to any shape or contour.

The high refractoriness, the range of compositions, and the ease with which they can be rammed into place make plastics suitable for many important applications. Plastic refractories are often highly resistant to destructive spalling.

Plastics can include all the fireclay, clay-graphite, high-alumina, high-alumina graphite and chrome types adapted for many different operating conditions. They are typically packaged in strong, easy to handle, moisture proof cartons. Special gunning versions are also available and are shipped in granulated form in moisture resistant pallet packages. These are prepared at the proper consistency, ready to use.

Types of Plastic Refractories

Heat-setting superduty fireclay plastics form a solid monolithic surface highly resistant to thermal shock and many acid slags. They have excellent workability and very low shrinkage, making them the ideal choice for rotary kiln hoods, incinerators and other general superduty plastic requirements. Cold setting versions of superduty fireclay plastics are available with many of the same features.

Superduty heat-setting plastics with graphite exhibit excellent resistance to wetting and corrosion by molten metal and slags. This type of composition is typically used in metal applications.

Plastics in the 50% alumina class typically serve as upgrades to superduty plastics. They are resistant to spalling due to thermal shock and many types of acid slags.

Heat-setting 60% alumina class plastics offer higher refractoriness over superduty plastics, with increased strength and volume stability throughout their temperature range. Application areas include cement kiln coolers and bull noses.

Air-setting high-alumina plastics in the 80% alumina class are primarily used where improved refractoriness over 60% alumina plastics is desired. They offer good resistance to fluxing oxides and slags up to their maximum service temperature.

Phosphate-bonded high-alumina plastics ranging in alumina contents from 70% to 90% are widely used in many applications as primary lining materials and for patching existing refractory linings. These products typically have high density and strengths, combined with excellent volume stability throughout their temperature range. Plastics ranging from 70% to 85% alumina content are often used in applications where resistance to slags and metal wash are required. The excellent abrasion resistance of 85% alumina plastics make them suitable for use in high abrasion conditions in petrochemical applications. Additional uses include both ferrous and nonferrous metal applications, where slag and metal penetration are wear mechanisms. Plastics in the 90% alumina class are based on high purity aluminas. These products typically have high strengths at high temperatures and are often used in the foundry and steelmaking process.

Phosphate-bonded alumina-chrome plastics have very high strength at high temperatures. These compositions, based on high purity alumina aggregates and chromic oxide, form an alumina-chrome solid solution bond at high temperatures which has extremely good resistance to high iron oxide slags of an acid to neutral nature and to attack by coal slag.

Other phosphate-bonded alumina-chrome plastics with lower alumina contents have been developed for specific service conditions. These include mullite based alumina-chrome plastics which have outstanding slag resistance to acid to neutral slags. The presence of mullite grain allows for earlier reaction, making this type of plastic refractory ideal for slagging applications between 2500°F (1370°C) and 2900°F (1593°C).

Silicon-carbide based phosphate-bonded plastics with an aluminum phosphate bond are also available. These have high conductivity and high abrasion resistance as well as non-wetting properties to many acid slags and nonferrous metals.

Castable Refractories

Castables are generally referred to as refractory concretes. They are available in a wide variety of base materials and typically consist of a refractory aggregate, special purpose additives and a cement binder. The bonding systems used are often used to classify the types of castables into four categories: conventional, low cement, ultra-low cement and lime-free castables.

Conventional castables have a cement-bonded matrix where, typically, a calcium-aluminate type of cement fills in the spaces between aggregates. This kind of castable is the most versatile for placement purposes in that normally it can be poured, vibrated, rammed or gunned into place while maintaining its designed properties.

Low cement castables are materials with lime contents of roughly between 1% to 3%. High densities and strength are achieved by careful particle packing and the use of additives to reduce the water needed to cast.

Ultra-low cement castables contain from 0.2% to 0.8% lime. Like low cement castables, they consist of sized particles to achieve maximum particle packing. Because of the low cement content, these mixes are not usually as strong in the low to intermediate temperature range as other types of castables; but they tend to have higher hot strength and refractoriness compared to chemically similar mixes with conventional or low cement bonds.

Lime-free castables have been developed with bonding systems containing no cement. These castables have desirable properties for use in certain chemical applications and where the highest possible hot strength and high temperature load resistance is required, such as metallurgical operations and other high temperature furnace applications. Some of these materials can approach the properties of pressed and fired brick.

Fireclay Castables

Mixtures of high fired fireclay with a refractory cement binder are designed to impart high initial strength and maintain good intermediate temperature strength. At high temperatures, a strong ceramic bond forms, providing good strength throughout their working temperature range. These castables are used in many applications, including boiler furnace ash pits, piers, hoppers, annealing furnace tops, tunnel kiln car bottoms, flues, stacks, linings for chain sections in rotary kilns and subbottoms of various types of furnaces.

Use of higher purity aggregates and higher purity cements can create castables with additional refractoriness. Primary uses for these castables include rotary cement and lime kilns in sections other than the burning zone.

Other types of fireclay castables include high purity conventional types developed for high strength and abrasion resistance. These are excellent all-purpose castables for applications up to 2800°F (1538°C). In the petrochemical and mineral processing industries, fireclay castables designed for extreme abrasion applications in the intermediate temperature range, have been developed. They have outstanding intermediate strength and abrasion resistance.

Low cement fireclay castables are used where high strength and refractoriness are needed. The lower lime content and porosity compared to conventional fireclay castables make them ideal for many applications.

High-Alumina Castables

High-alumina castables typically consist of accurately sized high-alumina aggregates with low iron refractory cements. This mixture provides good all-purpose castables with service temperature limits of 3000°F (1650°C).

Upgraded high-alumina conventional castables based on low alkali, high purity alumina-silica aggregate and super purity cements offer better high temperature strengths and more total refractoriness than castables made from lower purity cements. These products have a wide range of uses up to 3100°F (1705°C).

High purity alumina-bonded conventional castables with super high purity cement typically have extremely high refractoriness and chemical resistance up to 3300°F (1816°C). These types are extremely low in silica content, making them quite effective where silica could react with furnace constituents. This form of castable is used in many severe abrasion and chemically corrosive applications.

Low cement high-alumina castables with excellent intermediate to high temperature properties are another alternative in this category. When properly vibrated into place, they provide high density, strength and excellent abrasion resistance. The lower lime content provides good chemical resistance to furnace atmospheres that can attack lime. Alumina contents of 60% to 70% are typical of many low cement castables and are used for applications up to 3100°F (1705°C), such as kiln floors, doors, cartops, cement kiln coolers, and precast shapes.

High-alumina castables also include 85% alumina low cement castables for use up to 3200°F (1760°C). They are chemically similar to 85% phos-bonded plastics, but can develop greater intermediate strengths. Their uses include rotary kiln lifters and cooler curbs.

Low cement castables based on high purity aluminas with alumina contents from 90% to 98% are also used. Because of their high purity and very low silica content, they have outstanding hot strength at elevated temperatures and are excellent for metal contact areas.

Ultra-low cement castables in the 70% alumina category exhibit excellent high temperature strength and thermal shock resistance.

Bauxite-based, 85% alumina ultra-low cement castables offer excellent hot strength and thermal shock resistance.

Silica Castables

Silica-based castables include those made with vitreous silica as the raw material with extremely low thermal expansion, giving them excellent resistance to cracking under repeated thermal cycling to 2000°F (1093°C). Their maximum service temperature is 2400°F (1316°C) under continuous service conditions. Primary applications are coke oven doors, zinc induction furnaces, glass forming dies and aluminum transfer ladles.

Other silica-based castables include high strength castables containing a fortified matrix and silica aggregate. This type of composition has substantially lower density and thermal conductivity than fireclay extra strength castables with comparable strengths and abrasion resistance. This combination of properties allows it to be used as a single component lining where a dense castable with a lightweight castable backup would otherwise be used.

Ultra-low cement silica based castables with chemistry, refractoriness, density and porosity equivalent to high quality fired silica brick are also produced.

Basic Refractory Castables

This class of castables includes chrome ore base products with hydraulic cement binders. These compositions have outstanding strength and abrasion resistance and resist chemical attack and thermal spalling. Typical uses include patching for rotary kiln linings.

Basic castables also come in the form of chrome-magnesite mixes with chemical air-setting bonds. They can be cast, rammed or gunned and have many uses. Other high strength, air-setting magnesite castables have bonding systems which can give them extremely high hot strength.

Refractory Gunning Mixes

In some industrial furnaces, turnaround time and installation costs are the major factors when choosing a refractory lining. In other cases, repairs need to be made with little or no downtime. In both circumstances, pneumatic convey-ing of material, or gunning, is often the method of choice. Dense, homogeneous monolithic linings can be gunned without the use of forms and with a marked savings in time.

Gun mixes include siliceous, fireclay, high-alumina, dead-burned magnesite and chrome types. Many castables, ramming mixes and specially designed plastics can also be applied successfully with pneumatic guns. Acid gun mixes are normally predamped and fed through a continuous dual chamber or rotary gun. Magnesite and hot gun mixes are not predamped and are placed in a batch pressure gun. Gun mixes should wet up well, have as wide a water range as possible, and provide excellent coverage in a variety of applications.

Fireclay Gunning Mixes

Fireclay gunning mixes include multi-purpose hard-fired fireclay and standard calcium-aluminate cement compositions especially formulated for easy installation and low rebounds. These mixes are used in boilers, incinerators, process heaters, stacks, breechings and a variety of other medium service areas.

There are also fireclay gunning mixes with high purity calcium-aluminate bonding systems, designed for more severe service conditions experienced in incinerators. Other versions are designed for high alkali applications such as in cement kiln preheaters; or to provide excellent CO and load deformation resistance, for use in steel making.

High-Alumina Gunning Mixes

These are high purity alumina mixes which provide exceptional refractoriness, volume stability and a service temperature up to 3000°F (1650°C). Gun mixes which combine high fired alumina aggregate with a high strength, high purity calcium-aluminate binder have excellent strength and chemical purity which allow them to withstand severe environments with a maximum service temperature of 3300°F (1820°C). Primary application areas are primarily chemical.

There are also gunning mixes developed specifically for hot gunning maintenance. These are based on high-alumina content aggregates, providing a 3000°F (1650°C) service temperature limit. They typically have good slag and corrosion resistance.

Silica and Silicon Carbide Gunning Mixes

A gun mix based on vitreous silica and a special combination of calcined fireclay and high purity calcium-aluminate cement binder gives excellent strength and abrasion resistance coupled with outstanding thermal shock resistance and low thermal conductivity.

Silicon carbide-based gunning mixes are designed for preheater buildups and cooler bull noses. They are available in a variety of silicon carbide levels and have a high purity calcium-aluminate cement bond. The cement bond has the advantage of forming a room temperature set and a water insoluble bond at low temperatures.

Basic Refractory Gunning Mixes

A series of gun mixes are available for hot electric furnace maintenance. These range in magnesia content from 60% to 95% and are available with or without a phosphate bond. Gunning mixes of this kind are designed to provide an even feed in a batch gun, wet up well and stick to a hot furnace wall.

Refractory Ramming Mixes

Refractory ramming mixes consist of refractory aggregates and a semi-plastic bonding phase. When properly installed, ramming mixes offer a way of placing a cementless monolithic lining at high density and relatively low porosity.

A well balanced selection of ramming materials includes compositions with base materials of silica, high-alumina, corundum, mullite, dead-burned magnesite, chrome ore, zircon and others. These materials are particularly suited for forming dense monolithic, lining construction and numerous other monolithic constructions. Ramming mixes are typically supplied in both wet and dry forms, depending on the binder system.

High-Alumina Ramming Mixes

Alumina-silicon carbide ramming mixes are designed for non-ferrous industries.

High purity ramming mixes based on mullite grain are also used in steelmaking, burner blocks, ports and similar applications.

Ramming mixtures of 80% plus alumina content have excellent resistance to shrinkage and thermal spalling at high temperatures.

Other air-setting high-alumina mixes employ stabilized, chemically refined high purity aluminas. These have excellent resistance to thermal spalling at high temperatures and remarkable volume stability up to their temperature limit.

Phosphate-bonded, alumina-chrome ramming mixes can offer exceptionally high purity. They typically feature very high strength at high temperatures and extremely good resistance to acid to neutral slags, including coal ash slags.

Alumina-graphite ramming mixes are designed for the steelmaking industry. Their combination of high-alumina aggregate and slag inhibitors gives them excellent slag resistance to acid to slightly basic slags.

Basic Refractory Ramming Mixes

Dry ramming mixes based on high purity magnesite and a sintering aid have been designed for steelmaking. Magnesite ramming mixtures of exceptional purity and stability are used primarily as lining materials for coreless-type induction furnaces melting ferrous alloys. Magnesite-chrome fused grain ramming mixes exist which provide exceptional density and strength. The bond of this composition provides adequate strength at low temperatures until direct-bonding occurs at higher temperatures.

SECTION 3

Properties of Refractories

PROPERTIES OF REFRACTORIES

An understanding of the important properties of refractories is fundamental to the development, improvement, quality control and selection of refractory linings for high temperature processes.

While properties of refractories alone cannot be used to predict lining performance, comparisons among properties of refractories are often used as screening tools by refractory engineers and users to select and upgrade refractory linings. The systematic selection process starts with a careful evaluation of furnace operating conditions and performance demands, i.e., the degree to which refractories must contain corrosive process atmospheres, metals and slags and provide thermal protection and mechanical stability to safeguard the furnace. Matching refractory lining requirements to service demands typically proceeds with a review of the hot physical and chemical properties of the lining materials under consideration.

Evaluation of refractory properties is also vital to the manufacture of superior refractory products. Quality control and manufacturing engineers use property determinations throughout the manufacturing process to assure that products meet defined standards for the brand.

Post-mortem analyses of the properties of refractories taken from service are useful in improving both refractory and furnace operating performance. Comparison of properties of used refractories against original properties often helps to identify wear mechanisms and actual operating conditions, including operational upsets.

Refractory properties are equally important to the work of refractory research engineers who use them as product design criteria in the development of new and improved refractories.

This section discusses important room temperature and hot properties of refractories, the methods used in their determination and their relationship to service conditions.

PROPERTIES OF REFRACTORIES

Important properties of refractories which can be determined most readily are chemical composition, bulk density, apparent porosity, apparent specific gravity and strength at ambient temperatures. These properties are often among those which are used as controls in the manufacturing and quality control process. The chemical composition serves as a basis for classification of refractories. The density, porosity and strengths of fired products are influenced by many factors. Among these are type and quality of the raw materials, the size and "fit" of the particles, moisture content at the time of pressing, pressure of pressing, temperature and duration of firing, kiln atmosphere and the rate of cooling.

The mechanical strength of refractory brick is governed largely by the groundmass material between the larger grains. At ambient temperatures, the compressive strength is typically much higher than the tensile strength. For example, a fireclay or 50% alumina product may contain glassy material in the bonding phase. This glassy material is difficult to compress but may be broken quite readily in tension. A product's room temperature strength is an important indicator of its ability to withstand abrasion and impact in low temperature applications and to withstand handling and shipping. Other important properties determined at ambient temperatures are porosity, permeability and pore size distribution.

The strength of brick at ambient temperatures may provide little or no indication of their strength at furnace operating temperatures. For example, a fireclay or 50% alumina material that has good strength at ambient temperatures will typically exhibit significantly reduced strength at elevated temperatures where the glassy phase may become quite soft or even fluid.

Important properties determined at elevated temperatures are hot modulus of rupture, hot crushing strength, creep behavior, refractoriness under load, spalling resistance, dimensional changes and thermal conductivity.

PHYSICAL PROPERTIES — ROOM TEMPERATURE

Chemical Composition

Chemical composition serves as a basis for classification of refractories and as a guide to their chemical properties and refractories. Another important application of chemical analysis, as related to refractories, is in the control of quality of both raw materials and finished products. Minor components once thought to be unimportant are now recognized as controlling factors in the performance of many refractories. Among the applications of chemical analysis to control of quality are: the determination of iron oxide and alkali contents of some clays; the alumina content of bauxites; the alumina and alkali content of silica refractories; the chromic oxide content and accessory oxide levels in chrome ores; the carbon content of graphite; and the boron oxide level in magnesites.

The chemical composition of a refractory material may not be the most important selection criterion, as brick of almost identical chemical composition may differ widely in their behavior under the same furnace conditions. Chemical analysis of a refractory alone does not permit evaluation of such properties as volume stability at high temperatures or ability to withstand stresses, slagging or spalling.

In any given class of refractory brick, the various brands commercially available differ considerably in chemical composition. Table 3.1 shows typical chemical analyses for common industrial refractories. Relatively few consist of more than 90% of any single component and some, particularly in the basic category, are rather complex chemically.

Of the three types shown in Table 3.1a (fireclay, high-alumina, silica), alkalies constitute the most serious impurity or accessory and, generally, the less the better. However, other oxides, such as TiO_2, Fe_2O_3, CaO, and MgO, should also be low to obtain best performance characteristics. The lime (CaO) content of silica brick is an exception. It is deliberately added during manufacture and actually improves service performance.

For the basic refractories listed in Table 3.1b, MgO, Cr_2O_3, and Al_2O_3 are considered the primary refractory components, with SiO_2, Fe_2O_3 and CaO the accessory oxides. However, basic refractories often have a spinel mineral structure which is tolerant of considerable iron content, thus explaining many of the high totals in the "others" column.

The special refractory brick listed in Table 3.1c are essentially single-component systems. Zircon is naturally-occurring zirconium silicate and is refractory in that form. Silicon carbide will contain a small amount of SiO_2 as a result of oxidation during manufacture.

Alumina-carbon and magnesia-carbon brick are special refractories not shown in Table 3.1c.

Bulk Density (ASTM C134)

The bulk density is a measure of the ratio of the weight of a refractory to the volume it occupies. Bulk density is usually expressed in pounds per cubic foot (pcf) or kilograms per cubic meter (kg/m^3). The density of refractories is an indirect measurement of their heat capacity or ability to store heat. This is particularly important in applications such as regenerator installations.

Apparent Porosity (ASTM C830)

The apparent porosity, sometimes referred to as open porosity, is a measure of the open or interconnected pores in a refractory. The porosity of a refractory has an effect upon its ability to resist penetration by metals, slags and fluxes and, in general, the higher the porosity, the greater the insulating effect of the refractory. In contrast to apparent porosity, true porosity represents a sample's total porosity, both open and closed pores. Closed porosity refers to porosity within the coarser grains, which cannot be readily determined. Hence, true porosity may be difficult to measure.

Abrasion Resistance (ASTM C704)

In many types of service, refractories are subjected to impact by heavy pieces of material charged into the furnace; abrasion by metallic or nonmetallic solids; or direct impingement by abrasive dusts and high velocity gases. For greatest resistance to these actions, brick should be mechanically strong and well-bonded. The strongest brick generally show the highest resistance to abrasion. As compared with other properties, the modulus of rupture or crushing test offers the best indication of resistance to abrasion.

The abrasion test determines the resistance of a material to erosion when impacted by fine silicon carbide at room temperature. This test is particularly appropriate to applications in which particulate laden gas streams impinge on refractories, or where charge material contacts refractory surfaces at lower temperatures.

Cold Crushing Strength and Modulus of Rupture of Refractory Brick and Shapes (ASTM C133)

Strength is one of the most widely used parameters for evaluating refractories. Strength can be measured at room temperature or at any temperature for which suitable test equipment exists. Room temperature (cold) strength measurements cannot be used directly to predict service performance, but do provide a good tool for evaluating the degree of bond formation during production. Room temperature testing also indicates the ability of brick to withstand handling and shipping without damage and to withstand abrasion and impact in relatively low-temperature applications.

Strength testing at elevated temperatures is valuable in assessing the ability of a material to survive stresses caused by restrained thermal expansion, thermal shock and mechanical loading. Impact and abrasion resistance depend on material strength, as well. It is also common to use high temperature strength numbers to predict resistance to erosion and corrosion by metals and slags, although other properties, such as mineral composition and porosity, may be of equal or greater importance.

Two types of strength tests are common. The modulus of rupture (MOR) test measures the flexural (transverse) breaking strength and the crushing strength test measures the compressive strength. Both tests have a version for cold (ambient) temperatures and high (service) temperatures. The cold crushing strength (CCS) and cold modulus of rupture tests are described by ASTM Method C133. In the cold crushing strength test, a sample 4½” x 4½” x 2½” or 3” is loaded at a standard rate using a suitable mechanical testing machine (see Figure 3.1). The load is applied vertically to the 4½” x 4½” face of the sample until failure. The crushing strength is calculated by dividing the maximum load supported by the sample over the surface area of the face which receives the load.

The equation for calculating is:

$$S = W/A$$

where:

S = cold crushing strength, psi (N/mm^2)
W = maximum load, lbf (N)
A = cross-sectional area, in^2 (mm^2)

Table 3.1 Chemical Analysis of Common Industrial Refractories

3.1a Refractory Brick of the Alumina-Silica Types

Types of brick	Alumina (Al_2O_3)	Silica (SiO_2)	Alkalies (Na_2O, K_2O, Li_2O)	Others (TiO_2, Fe_2O_3, CaO, MgO)
Fireclay				
Superduty	41.9%	53.2%	1.2%	3.7%
High-duty	41.0	51.6	2.0	5.3
Low-duty	30.0	62.0	3.7	4.3
High-Alumina				
60% class	58.0	38.0	0.1	3.9
70% class	69.2	26.2	0.2	4.4
85% class	86.5	8.9	0.1	4.5
90% class	88.5	11.0	0.2	0.3
Corundum class	99.2	0.4	0.2	0.2
Silica				
Conventional	0.5	95.9	0.1	3.4
Superduty	0.2	96.5	0.04	3.4

3.1b Basic Brick

Types of brick	Magnesia (MgO)	Chromia (Cr_2O_3)	Alumina (Al_2O_3)	Others (SiO_2, Fe_2O_3)
Magnesite, fired	98.2%	–	0.2%	1.6%
Magnesite-chrome, fired	55.7	4.1%	3.3	36.9
Magnesite-chrome, unfired	72.1	8.8	9.7	9.5
Chrome, fired	18.4	30.4	32.1	19.1
Chrome-magnesite, fired	36.1	24.8	22.3	16.8
Chrome-magnesite, unburned	31.5	26.6	23.4	18.5

3.1c Special Refractory Brick

Types of brick	Silica (SiO_2)	Zirconia (ZrO_2)	Carbide (SiC)	Others (Al_2O_3, TiO_2, Fe_2O_3)
Zircon	32.3%	66.0%	–	1.7%
Silicon carbide	5.6	–	90.8%	3.6

The setup for the cold modulus of rupture test is shown in Figure 3.2. The test specimen, again a standard nine-inch straight, is placed on two bearing cylinders with the top and bottom (9” x $4^1/_2$”) faces oriented horizontally. The specimen is broken at mid-span in flexure at a standard loading rate. The modulus of rupture is calculated using the following equation:

MOR = 3PL/2bd²

$$MOR = 3PL/2bd^2$$

where:

MOR = modulus of rupture, psi (N/mm^2)

P = load at rupture, lbf (N)

L = span between supports, in (mm)

b = breadth or width of sample, in (mm)

d = depth or thickness of sample, in (mm)

Strength values vary widely among classes of refractories and even among refractories of the same classification. Typical values for a number of refractories are given in Table 3.2. Variables which significantly affect cold strength of refractories are bond chemistry, firing temperature, porosity, and the strength and sizing of the aggregate.

Figure 3.1 Cold Crushing Strength Test

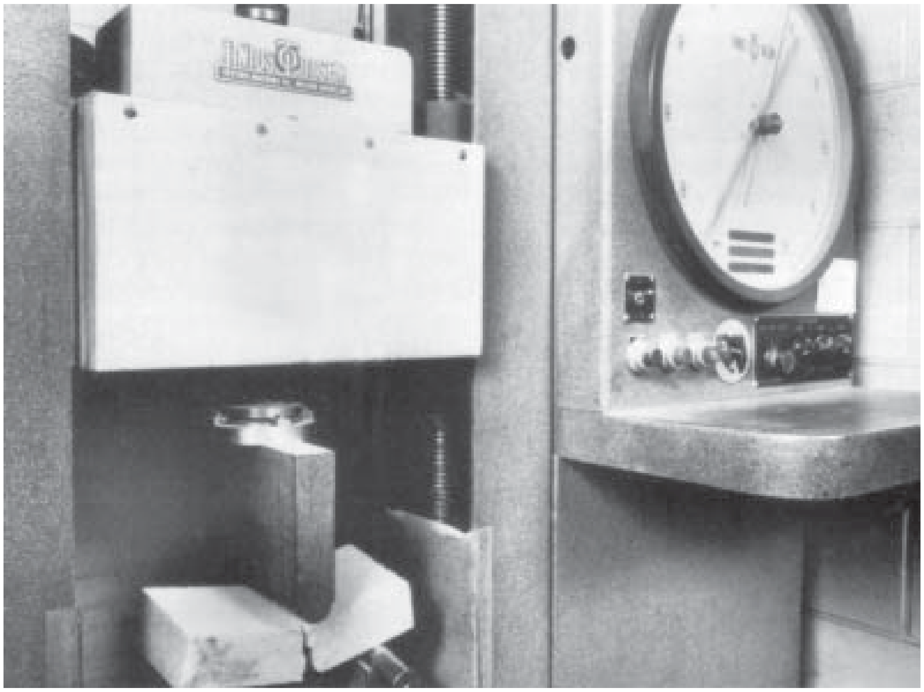


Figure 3.2 Modulus of Rupture Test

PHYSICAL PROPERTIES — ELEVATED TEMPERATURE

The most significant properties of refractories are those which enable them to withstand the conditions to which they are exposed in service at elevated temperatures. These conditions may be classified broadly as thermal, mechanical, chemical and various combinations of the three.

Refractories must be sufficiently refractory to withstand the maximum temperatures to which they will be exposed in service. Frequently, they must be resistant to the stress effects of rapid temperature change within critical temperature intervals. They may be required to withstand varying loads, abrasive action and penetration and corrosion by solids, liquids and gases.

High temperature properties of refractories which are relevant to service conditions include the following:

- *Refractoriness*
- *Melting behavior*
- *Mechanical strength and load bearing capacity*
- *Changes in dimensions when heated*
- *Resistance to abrasion, mechanical erosion and impact of solids*
- *Resistance to corrosion and erosion at high temperatures by solids, liquids, fumes and gases*
- *Resistance to spalling*
- *Thermal conductivity*

Thermal Effects

The one condition obviously common to all furnace operations is high temperature. A closely related combination of other thermal effects results from high temperatures and from the rate of temperature change. Heat energy flows into the refractory structure when the furnace is heated and a temperature differential develops between the inside and outside surfaces. Part of the heat energy is stored in the refractory structure and part flows through the walls and other parts of the furnace structure and is lost to the outside air through radiation and convection.

When refractories are hot their linear dimensions and volumes are greater than when they are cold due to “reversible thermal expansion.” With some refractories, additional volume change, usually not reversible, results from mineral inversions and transformations and sometimes from other causes.

Within a single brick in a furnace wall or arch, there is commonly a temperature drop of many hundreds of degrees between the hot face and the cold end. Consequently, differences in the amount of thermal expansion in various sections of the brick will cause internal stresses to develop within the brick. In a refractory structure, pressure inherent in the furnace construction, such as arch stresses, generally will be increased by thermal expansion of the brickwork. Unequal volume changes resulting from rapid fluctuations in temperature may cause the development of higher stresses within the refractories than they are capable of withstanding.

Table 3.2 Physical Properties of Refractory Brick

Types of brick	Density, lb/ft^3	Apparent porosity	Cold crushing strength, lb/in^2	Modulus of rupture, lb/in^2
Fireclay				
Superduty	144-148	11-14%	1,800-3,000	700-1,000
High-duty	132-136	15-19	4,000-6,000	1,500-2,200
Low-duty	130-136	10-25	2,000-6,000	1,800-2,500
High-Alumina				
60% class	156-160	12-16	7,000-10,000	2,300-3,300
70% class	157-161	15-19	6,000-9,000	1,700-2,400
85% class	176-181	18-22	8,000-13,000	1,600-2,400
90% class	181-185	14-18	9,000-14,000	2,500-3,000
Corundum class	185-190	18-22	7,000-10,000	2,500-3,500
Silica (superduty)	111-115	20-24	4,000-6,000	600-1,000
Basic				
Magnesite, fired	177-181	15.5-19	5,000-8,000	2,600-3,400
Magnesite-chrome, fired	175-179	17-22	4,000-7,000	600-800
Magnesite-chrome, unburned	185-191	–	3,000-5,000	800-1,500
Chrome, fired	195-200	15-19	5,000-8,000	2,500-3,400
Chrome-magnesite, fired	189-194	19-22	3,500-4,500	1,900-2,300
Chrome-magnesite, unburned	200-205	–	4,000-6,000	800-1,500
Magnesite-carbon	170-192	9-13	–	1,000-2,500
Dolomite	165-192	5-20	1,500-3,500	500-2,500
Fused cast magnesite-chrome	205-245	1-15	900-1,400	6,000-8,000
Silicon carbide	160-166	13-17	9,000-12,000	3,000-5,000
Zircon	225-232	19.5-23.5	7,000-11,000	2,300-3,300

Reactions Between Refractories

When no single kind of refractory material is adequate to meet the various conditions prevailing in different parts of a furnace, two or more different kinds of refractories may be employed in the construction. However, refractories of dissimilar chemical compositions may react chemically with each other if in contact at high temperatures. Furnace fumes, dust, and slags can accelerate these reactions.

In the high temperature portions of a furnace, it is good practice to separate reactive refractories by an intermediate course of refractory brick which will not react with either at the temperature of operation, or by a joint of non-reactive bonding mortar.

Pyrometric Cone Equivalent (ASTM C24)

A standard method of evaluating the high temperature softening behavior of alumina-silica and fireclay compositions is the determination of their Pyrometric Cone Equivalent, abbreviated PCE (ASTM C24).

A ground sample of the material to be tested is molded into the form of test cones and mounted in a ceramic plaque with a series of standard pyrometric cones having known high temperature softening values. The plaque is heated at a fixed rate until the test cones soften and bend. The number of the standard cone whose tip touches the plaque at the same time as the tip of the test cone is reported as the PCE value of the test cone.

The PCE does not indicate a definite melting point or fusion point because the test is not a measurement, but merely a comparison of the thermal behavior of the sample to that of standard cones. The test is used in evaluating the refractory quality of clays and the softening temperature of slags, as well as in the manufacture and quality control of fireclay products. PCE values of alumina-silica refractories are given in Table 3.3.

CHANGES IN DIMENSION

Permanent Reheat Change (ASTM C113)

This is also referred to asPermanent Linear Change or PLC. In the firing of refractory brick, permanent changes in dimensions generally occur, altering the individual brick from the mold size to the fired size. It is desirable that the changes be completed in the firing step to prevent expansion or shrinkage later in service. However, changes in dimensions and volume require time as well as temperature for completion. As firing proceeds, the rate of dimensional change gradually diminishes. Yet, it is rarely feasible to attain complete expansion or contraction during the firing process. Therefore, in service, if the furnace temperature is high enough and maintained for a sufficient period of time, there can be an additional change in dimensions, generally slight, but permanent. Excessive dimensional changes in service are objectionable due to their potentially harmful effect on the stability of the furnace. A reheat test

Table 3.3 Typical Pyrometric Cone Equivalents of Refractory Brick

Types of brick	Minimum PCE ASTM C24	Typical PCE
Fireclay		
Superduty	33	33 to 34
High-Duty	31.5	31.5 to 33
Medium-Duty	29	29 to 31
Low-Duty	15	15 to 27
Semi-Silica	–	27 to 31
High-Alumina		
50% Alumina Class	34	35
60% Alumina Class	35	36 to 37
70% Alumina Class	36	37 to 38
80% Alumina Class	37	39
90% Alumina Class	–	40-41
Mullite Class*	–	38
Corundum Class*	–	42 Minus

* Estimated and shown for convenience. It is generally impractical to obtain the PCE values of high-alumina brick above the 50% or 60% alumina class.

In reporting PCE values, the word “to” is used between two standard cone numbers to indicate that different lots of the given material have a range of softening from the lower to the higher value. A dash (-) between two standard cone numbers does not indicate a range, but shows that the material has a position as to softening approximately midway between the two pyrometric cone values.

determines the amount of permanent change in dimensions of refractory brick which may occur at high temperatures. This permanent reheat or linear change is in addition to the reversible linear thermal expansion that all refractories exhibit when they are heated or cooled.

High temperature reheat tests may be used to reveal (1) whether a refractory composition of a given quality has been fired long enough; or (2) at a high enough temperature; or (3) if not fired, whether it is made of volume stable materials; and (4) whether a composition has adequate refractoriness and volume stability. The tests may be used in these ways to estimate refractoriness. The results should be interpreted with caution, however, as the amount of shrinkage or expansion depends not only on the refractory’s characteristics, but also on the temperature and time of heating during the test. The results of a short term reheat test may not be a sufficient basis for predicting the long term volume changes which a refractory may undergo in service.

In the standard ASTM reheat test, Method C113, brick are placed in a furnace, gradually heated to a predetermined temperature and maintained at that temperature for five hours. After cooling, measurements are made to determine changes in linear dimensions and volume.

Reheat Change of Fired Refractories

In the reheat test at 2550°F (1400°C), high-duty fireclay brick generally show a slight (up to 1.5%) linear contraction. At 2910°F (1600°C), superduty fireclay brick usually shrink 0.0% to 1.0% in length. Some fireclay brick expand slightly in the reheat test, however, the expansion does not occur if the brick are in compression.

For high-alumina brick of the 50% to 80% alumina classes, the temperature of the reheat is usually 2910°F (1600°C). Some brick show a linear shrinkage of as much as 2.0% to 2.5%; others, an expansion up to 3.5% or more. For brick of the 90% alumina class, corundum brick, and mullite brick, the temperature of the test may be 3140°F (1725°C) and the linear change is usually within the range of minus 0.5% to plus 1.5%.

The reheat test is not usually applied to silica brick, as the apparent specific gravity provides an adequate measure of the amount of permanent or residual expansion.

In the reheat test at 2910°F (1600°C), most basic brick will show a slight linear shrinkage, varying from a few tenths of a percent or less for some types of brick, up to 2.5% for others. High fired chrome-magnesite brick usually have little or no shrinkage in the reheat test at 2910°F (1600°C) and a shrinkage of only some tenths of a percent at 3000°F (1650°C).

Linear Thermal Expansion

In common with essentially all other structural materials, refractories will expand when heated and contract when cooled. Knowledge of the thermal expansion behavior of refractory materials is often crucial in designing furnace linings. If the lining is constrained by the furnace structure, destructive forces may result as the lining expands during furnace heat-up. In such cases, the lining must be designed to allow some free expansion. The amount of expansion allowance, however, must not be so much as to cause lining instability. An understanding of thermal expansion characteristics is also important in assessing the thermal shock resistance of a material. Thermal shock occurs when severe temperature gradients in a material cause internal stresses due to differential thermal expansion.

The measurement of the linear thermal expansion of a refractory is usually made by determining the change in length of a bar-shaped specimen heated uniformly at a constant rate. The movement of the sample may be detected by connecting an electrical transducer, located above the furnace, with the top of the specimen by means of a sapphire rod. A device of this type is known as a dilatometer.

Thermal Expansion of Fired Refractories

If no changes of a permanent nature occur during heating, fired refractories return to their original dimensions when cooled. This characteristic is known as “reversible thermal expansion.” Typically,

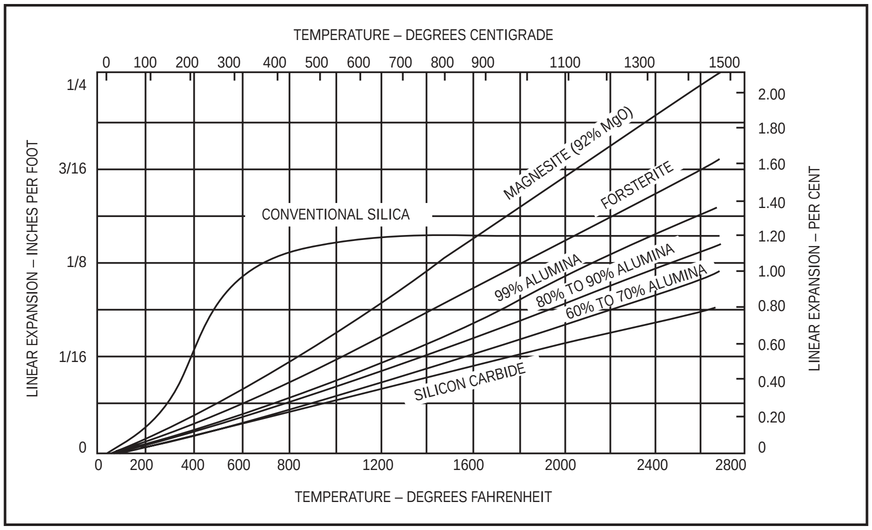


FIGURE 3.3 Approximate Reversible Thermal Expansion of Brick

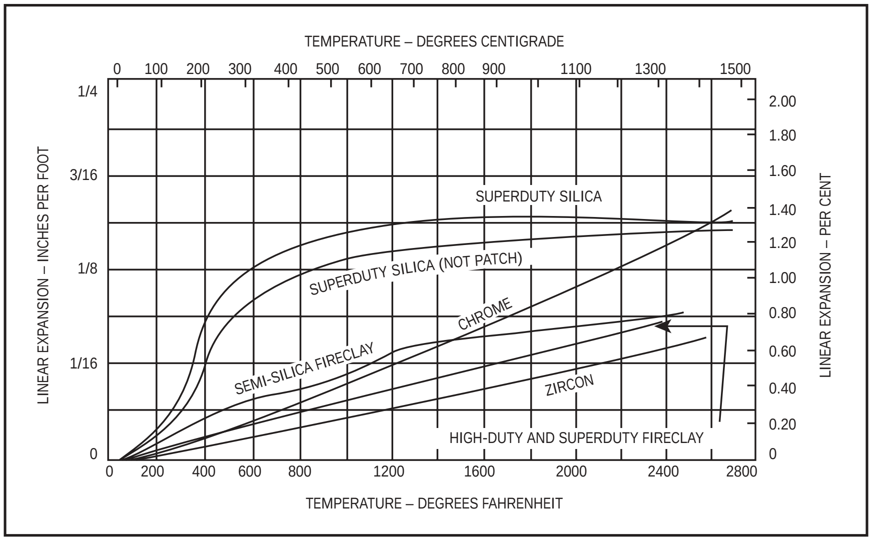


FIGURE 3.4 Approximate Reversible Thermal Expansion of Brick

refractories that are heated to temperatures below their firing temperature show this behavior. The linear thermal expansion characteristics of a number of fired refractories are given in Figures 3.3 and 3.4. The expansions of different brands in each class of refractory differ somewhat among themselves, and the data therefore represent mean values. Magnesite and forsterite brick have relatively high rates of thermal expansion; fireclay, silicon-carbide, zircon brick, and most insulating firebrick have relatively low rates. The thermal expansions of other refractories have intermediate values. For most fired refractories, thermal expansion increases at a fairly uniform rate over the working range of temperature. Notable exceptions are silica brick which undergo the greater part of their expansion below 800°F (about 425°C).

Thermal Expansion of Unfired Refractories

In general, the thermal expansion behaviors of unfired refractories are more complex than those of their fired counterparts. During initial heating, dramatic expansions or contractions may occur in an unfired material as a result of changes in bonding structure, changes in minerology, and sintering effects.

The thermal expansion characteristics of a number of cement-bonded refractories during initial heat-up are shown in Figure 3.5. These materials show shrinkage over the temperature range 400°F to 600°F (205°C to 315°C) which is associated with thermal decomposition of the cement. The amount of shrinkage is determined by the quality and amount of cement. At temperatures above 1800°F to 2000°F (980°C to 1090°C), additional shrinkage occurs as a result of sintering. The underlying thermal expansion is determined by the characteristics of the aggregate. The shrinkages which take place during initial heat-up to 2600°F (1430°C) are permanent in nature and commonly are on the order of 0.2% to 1.5%.

The thermal expansion curves for initial heat-up of several phosphate-bonded plastics and clay-bonded plastics are shown in Figure 3.6. Typically, these materials show linear behavior below about 1900°F (1040°C). At about 1900°F (1040°C), however, mineralogical changes among the clay constituents result in densification and the materials contract. Permanent shrinkages of 0.2% to 0.6% are common after initial heating to 2600°F (1430°C).

CREEP AND THERMAL EXPANSION UNDER LOAD

Changes in Dimensions Under Load

In service, refractory materials must support a load which, at its minimum, is equal to the weight of the lining above the reference point. The pressure which is exerted depends on the height of the lining and the density of the material. Therefore, for applications in which the entire lining component is at high temperatures, it is important to understand the load-bearing capabilities of candidate materials. Examples of such applications include blast furnace stoves and carbon bake furnaces in which the refractories are heated relatively uniformly to high temperatures.

The standard laboratory tests for refractories include one for the determination of the behavior of brick under load at high temperatures. In this test, two 9-inch straight brick are set on end in a furnace of specified design and a vertical load of 25 lb/in^2 is applied. In the standard procedure, (ASTM C16), the temperature is gradually raised in

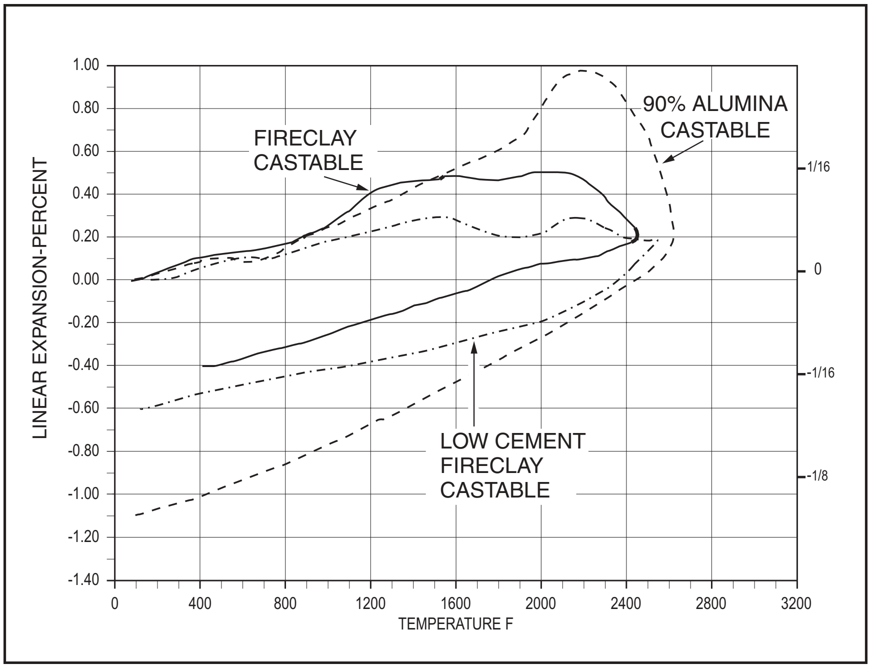


FIGURE 3.5 Thermal Expansion of Various Refractory Castables

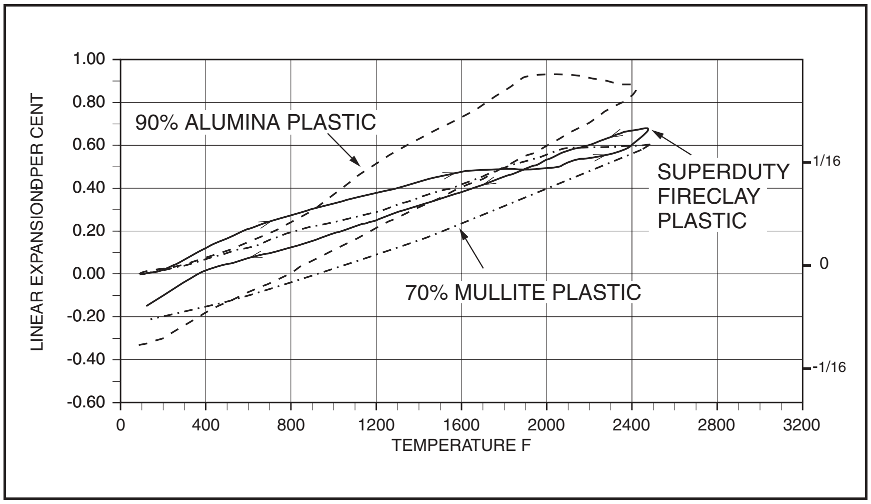


FIGURE 3.6 Thermal Expansion of Various Refractory Plastics

accordance with a definitely prescribed schedule. For fireclay and high-alumina brick, the maximum temperature is held for 1½ hours, after which the furnace is allowed to cool by radiation to 1830°F (1000°C) or lower before the load is removed.

The amount of subsidence is reported as percentage of the original length. The normal temperature of the hold for high-duty fireclay brick is 2460°F (1350°C); for superduty fireclay brick, 2640°F (1450°C). However, recent improvements in the high-temperature strength of certain types of high-duty fireclay brick, especially checker brick, have led to their being tested at 2,640°F. For most classes of high-alumina brick the top temperature of testing is 2640°F (1450°C); for those of the 90% alumina class and mullite and corundum brick it is 2900°F (1595°C) and 3200°F (1760°C).

Results of such testing on fireclay and high-alumina brick are shown in the upper portion of Table 3.4.

The lower portion of Table 3.4 show results for silica, basic, and silicon-carbide brick. It will be seen that test results are reported as “withstands load to” rather “subsidence after heating to.” This reflects a marked difference in the way the latter types behave under the combined forces of heat and mechanical stress. They typically maintain their integrity until a particular temperature is reached, after which failure occurs abruptly rather then showing gradual subsidence over time as with fireclay and high-alumina brick. Test procedures are different for those brick which are simply heated on a rising curve until failure occurs.

Load testing provides very significant data relative to maximum service temperatures in the field. More recently, the preferred test is the ASTM method for measuring the thermal expansion and creep of refractories under load (ASTM C832). Commonly referred to as a “creep test,” the test is more sophisticated than the conventional ASTM load test. Rather than measuring the subsidence of a sample after testing, it provides a continuous monitoring of this sample’s dimensional changes during the test.

The properties measured during this test are known as thermal expansion under load (TEUL) for the heating portion of the test, and “creep” during the hold portion. In the standard procedure, ASTM method C832, a constant vertical load, usually 25 psi, is applied to the 1½” x 1½” faces of a specimen measuring 1½” x 1½” x 4½”. After heating to the prescribed temperature at a constant rate, the sample reaches a point of peak expansion, called the maximum dilation point; the temperature and expansion at this point characterize the thermal expansion under load. The temperature of the sample is then held for 50 hours or longer, and the creep behavior is characterized by the amount of subsidence which occurs between the 20th and 50th hours.

Like most structural materials, refractories show creep behavior when exposed to high temperatures. Most refractories show two characteristic stages of creep. In the first stage, called primary creep, the rate of subsidence declines gradually with time. In the secondary stage, called steady state, the rate of subsidence is constant. At very high temperatures, steady state creep is sometimes followed by a tertiary creep

TABLE 3.4 Typical Results of Load Test as Indicated by 25 lb/in^2 Load Testing

Type of brick	Results of load testing
Fireclay	
Superduty	1.0-3.0% subsidence after heating at 2640°F
High-duty	Withstands load to <2640°F
Low-duty	Withstands load to <2640°F
High-Alumina	
60% Class	0.1-0.5% subsidence after heating at 2640°F
70% Class	0.4-1.0% subsidence after heating at 2640°F
85% Class	0.2-0.8% subsidence after heating at 2640°F
90% Class	0.0-0.4% subsidence after heating at 3200°F
Corundum Class	0.1-1.0% subsidence after heating at 2900°F
Silica (superduty)	Withstands load to 3060°F
Basic	
Magnesite, fired	Withstands load to 3200°F
Magnesite-Chrome, fired	Withstands load to 2700°F
Magnesite-Chrome, unburned	Withstands load to 2950°F
Chrome, fired	Withstands load to 2800°F
Chrome-Magnesite, fired	Withstands load to 3020°F
Chrome-Magnesite, unburned	Withstands load to 3020°F
Silicon Carbide	Withstands load to 2800°F
Zircon	0.1-0.8% subsidence after heating at 2900°F
Conversion Factor: °C = (°F - 32)/1.8	

region where the rate of subsidence accelerates and leads to catastrophic failure or creep rupture. Primary creep is generally short in duration, while secondary creep can occur over a long term. Therefore, secondary creep usually provides a more meaningful comparison of refractories. Secondary creep is the parameter determined by the method described above. The creep behavior at 2600°F (1430°C) of a series of fired high-alumina refractories is illustrated by Figure 3.7. It is obvious that the creep behaviors of brick cannot be predicted based only on their chemistry. Important variables which affect creep behavior are chemistry of the bonding phase and firing temperature. Formation of low viscosity glassy phases results in poor creep behavior, whereas well-formed crystalline bond phases give good creep behavior. Aggregate sizing and porosity also affect creep behavior with larger aggregate and lower porosity giving better creep resistance.

HEAT TRANSMISSION

Thermal Conductivity

When a furnace is heated, thermal energy flows into the refractory structure, causing a temperature difference to develop between inside and outside surfaces of walls and roofs. Part of this thermal energy is stored in the refractory structure and its foundation, and part flows through the walls, roofs, and hearths, and is lost to the outside air by radiation and convection. The amount of heat which escapes in this manner is often of considerable importance in the economy of the process. In estimating the quantities of heat flowing through the parts of a furnace, use is made of a coefficent known as the thermal conductivity, or K-value, of each material involved in the construction. The thermal conductivity value differs not only for different materials, but usually also for the same material at different temperatures. The thermal conductivity is reported at the mean temperature of the test brick. Measured thermal conductivites of various refractories are given in Table 3.5.

Major factors which affect the thermal conductivity of a refractory material are the mineral composition, the amount of amorphous material (glass or liquid) which it contains, its porosity and its temperature. For materials which have similar mineralogical compositions, the proportion of pore space is questionably the most important factor affecting the amount of heat which will flow through it at a given temperature. Within the temperature range seen in most applications, thermal conductivity decreases with increasing porosity.

At ambient temperatures, the thermal conductivity of glass is considerably lower than that of crystalline material of the same composition. With rising temperatures, the conductivity of glasses tends to increase, while that of crystalline material tends to decrease. However, in refractory bodies consisting of crystal aggregates with limited amount of glass, the temperature effects are difficult to predict. The conductivity of a refractory in service at high temperature is often changed somewhat, either by an increase in the amount of glass or liquid it contains, or by devitrification of any glass it may contain.

High thermal conductivity is desirable for refractories used in constructions requiring efficent transfer of heat through brickwork, as in retorts, muffles, byproduct coke oven walls and recuperators. In most types of vessels, however, low thermal conductivity is desirable for heat conservation, but is usually less important than other properties of the refractories.

Heat Flow

The rate of heat flow in refractory constructions can be calculated only approximately for several reasons:

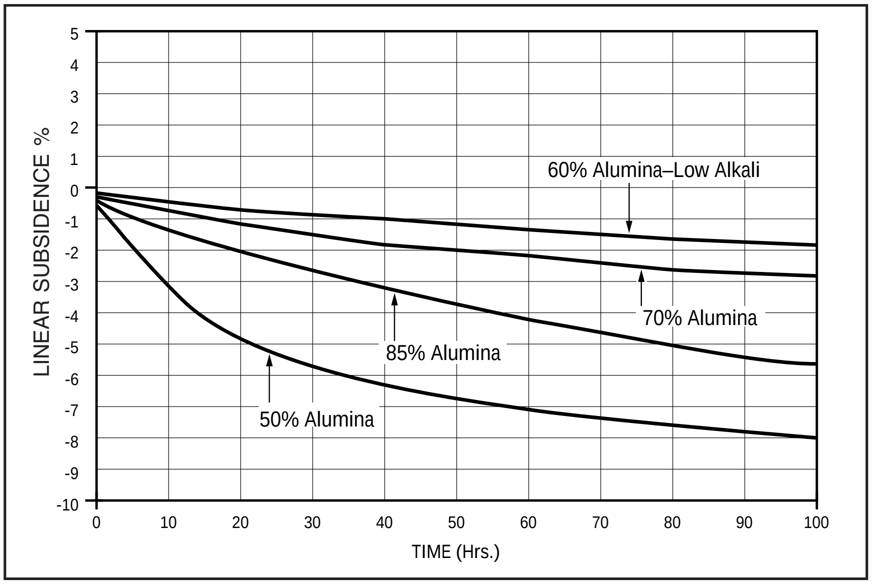


FIGURE 3.7 Creep measurement of various high-alumina refractories under 25 psi load at 2600°F for 0-100 hrs. Note the excellent creep resistance of 60% alumina low alkali brick.

Table 3.5 K-Values for Refractory Brick at Various Mean Temperatures, Btu • in/ft^3 • hr • °F

	Mean Temperature, °F					
Types of brick	**600**	**1200**	**1500**	**1800**	**2200**	**2600**
Fireclay						
Superduty	9.8	9.9	10.2	10.5	11.4	12.8
High-duty	8.1	8.3	8.5	8.7	9.2	10.0
High-Alumina						
60% Class	13.0	12.9	13.1	13.3	14.1	15.7
70% Class	15.6	14.4	14.4	14.3	14.6	14.9
85% Cclass	18.4	16.2	16.9	17.5	19.6	22.9
90% Class	21.9	18.5	17.6	17.6	17.9	18.8
Corundum Class	34.6	22.6	20.7	18.7	17.9	18.3
Silica (superduty)	9.0	10.1	11.0	11.8	13.5	16.1
Basic						
Magnesite, fired	73.2	43.9	36.1	31.7	30.5	32.3
Magnesite-Chrome, fired	17.9	15.2	14.7	14.2	14.7	16.2
Magnesite-Chrome, unburned	18.4	17.2	15.7	14.5	14.7	16.0
Chrome, fired	15.2	15.0	15.1	14.5	13.3	12.9
Chrome-Magnesite, fired	11.8	12.3	12.4	12.5	12.5	13.6
Magnesite-Carbon	150.0	115.0	106.0	100.0	95.0	90.0
Silicon Carbide	121.2	112.0	107.5	103.0	97.0	94.6
Zircon	22.4	16.5	16.6	16.6	16.8	17.9

- *The accuracy of the methods used to measure thermal conductivity is unconfirmed.*
- *The temperatures of the hotter and cooler faces of the refractory wall or roof are rarely known with exactness.*
- *The conductivity of a refratory may be altered in service by mineral changes in the refractory, by vitrification of the refractory, or by absorption of slags, metals or other materials.*
- *The thickness of a furnace lining may not remain constant during operation. The lining may become thinner because of wear and transmit more heat; or it may become thicker and transmit less heat because of the formation of a solid coating (as in rotary cement kilns).*
- *The rate of heat flow is influenced by the pressure of the furnace gases and by the permeability of the refractory. A positive pressure tends to force hot gases out through the walls, while a negative pressure tends to draw cold air from the surroundings into the furnace.*
- *The rate of heat flow may be influenced by the thickness of the joints and gaps between lining components and by the character of the bonding mortar, if used.*

Other important factors which affect the amount of heat flowing through refractory linings include the emissivity of the refractory or metal shell; the kind of gases within the furnace; and the external convection currents.

Effects of Gases

In refractory structures built of insulating firebrick or other very porous refractories, the type of furnace atmosphere can have a very appreciable effect on heat loss through the refractory walls. This is especially true of atmospheres with a high content of hydrogen.

Most protective atmospheres, including dissociated ammonia, exothermic gases, and endothermic gases, contain appreciable percentages of hydrogen. The conductivity of the hydrogen must be taken into consideration in calculating the heat losses through the refractory walls of controlled atmosphere, heat-treating furnaces.

The thermal conductivity of hydrogen is approximately seven times as great as that of air. Consequently, the presence of hydrogen gas in the pores of a porous refractory product increases the rate of heat flow through the refractory. With an atmosphere of 100 percent hydrogen, the heat flow through an insulating firebrick or other refractory with similar porosity would be two to two and one-half times as great as in an atmosphere of air. At lower concentrations of hydrogen, the increase will be less and the relationship is almost directly proportional to the percentage of hydrogen present.

As compared with the conductivity of air, that of nitrogen is 100 percent, carbon dioxide about 59 percent, and carbon monoxide about 97 percent.

SPALLING

Spalling is the loss of fragments or spalls from the face of a refractory brick or structure through cracking and rupture. In various types of furnace operation, service conditions necessarily expose the brickwork to spalling influences. The resistance of refractory brick to spalling is enhanced by the addition of spall inhibitors, proper design of the brick shapes, optimum sizing of grains, proper choice of grains and close manufacturing control. For a given refractory, spalling can also be minimized by proper design, construction, and operation of the furnace.

Spalling of refractory bodies can be divided into three general types: thermal, mechanical and structural.

Thermal Spalling

This type of spalling is caused by stresses resulting from unequal rates of expansion or contraction between different parts of the brick and is usually associated with rapid changes in temperature. Brick with the greatest resistance to thermal spalling are those having the lowest average rate of thermal expansion, high tensile strength and a texture conducive to flexibility and relief of stress. These compositions also do not show a high rate of thermal expansion through narrow temperature ranges. Other factors being equal, temperature gradients and stresses which cause spalling are least destructive in brick having the highest thermal conductivities. A refractory of a given mineral composition will usually have maximum resistance to spalling when the ratio of strength to the modulus of elasticity is a maximum.

The spalling characteristics of fireclay brick are generally dependent upon the amount of free silica present in the clays, the composition of the glassy bond and the size and “fit” of the particles. The amount and character of the glass are fixed by the quantity and kind of accessory minerals in the clays and by the time and temperature of firing. Within the temperature range at which the glass is rigid, a high glass content is conducive to spalling. However, at temperatures high enough to cause the glassy bond to become somewhat viscous, fireclay brick can be highly resistant to spalling.

Relatively porous, light-duty fireclay brick are usually more resistant to spalling than denser, hard-burned brick. Superduty fireclay brick of the spall resistant variety, while dense and hard burned, have high resistance to spalling and retain this resistance upon exposure to high temperatures.

Some high-alumina brick also have excellent resistance to spalling. In many cases, brick are designed to generate a system of stress-relieving microcracks to enhance their spalling resistance. With other conditions being equal, higher density, lower porosity compositions tend to have poorer spall resistance than average density, average porosity compositions.

Most silica brick are sensitive to rapid temperature changes at low temperatures due to the abrupt volume changes associated with the crystalline inversion of the mineral cristobalite. However, silica brick may be heated or cooled quite rapidly as long as they remain above the inversion temperature of about 1200°F (650°C).

Burned basic brick, in general, do not have as high a resistance to thermal spalling as fireclay and high-alumina brick. However, with proper choice of raw materials, basic brick with improved thermal shock resistance can be manufactured.

Mechanical Spalling

The spalling of refractory brick caused by stresses resulting from impact or pressure is known as mechanical spalling. Shattering or spalling of brickwork may result from such influences as the rapid drying of wet brickwork, inadequate provision for thermal expansion, or pinching of hot ends of brick, especially in furnace arches. Brick which are strongest and toughest at operating temperatures have the greatest resistance to mechanical spalling.

“Pinch spalling” is often observed in sprung brick arches because the hot ends of the brick expand more than the cold ends. This condition is aggravated by rapid heating because the furnace structure cannot rapidly adjust to the expansion forces. The differential expansion may cause a concentration of arch stresses upon relatively small bearing surfaces at the inner ends of the brick. Insulation decreases the temperature gradient through a roof arch and tends to somewhat reduce pinch spalling.

Structural Spalling

Structural spalling of a refractory unit is caused by stresses resulting from differential changes in the structure of the unit. The word “structural”, as used in this context, does not refer to the furnace or the furnace lining assembly, but to the texture or structure of the individual brick units in the lining.

Contributing to structural spalling are changes which occur in service to the texture and composition of the hotter portions of the brick through the action of heat, the absorption of slags or fluxes and their reactions with the refractory. These alterations may result in zones in the brick which differ in mineral content and chemical and physical properties from the unaltered portions of the brick. Following the development of a zoned structure, hot ends of the brick may spall or fall off for various reasons, including differences in thermal expansion or contraction between adjacent zones, increased sensitivity to rapid temperature changes or the presence of shrinkage or expansion cracks.

Monolithic refractories, not having been fired prior to installation, are more resistant to thermal spalling than are their fired-brick counterparts, at least until they have become vitrified or slagged in service.

Being lower in strength than fired brick, however, monolithic refractories may be more subject to mechanical spalling.

Spalling Tests

Several tests are commonly used to determine the relative resistance of refractory compositions to spalling. The most common are the panel spalling test, the prism spalling test and the loss of strength test.

SLAG REACTIONS

Slag attack refers to chemical reactions and solutions which corrode the surface of a refractory lining in service and reactions which can take place between the molten slag, refractory and fluxing agents which have been absorbed. Erosion of the refractory often follows corrosion. An example is the washing away of refractory grains after the bond between grains has been dissolved by fluxing agents in the slag.

The composition of industrial slags, of the refractories which they contact in service, and of the reaction products derived from them are exceedingly complex. The most advantageous selection of refractories frequently is governed by the chemical nature of fluxing agents present in the furnace. Alkaline materials are highly basic; most metallurgical slags and metallic oxides are basic; and fluxes high in silica are acidic. To determine whether a particular slag is acidic or basic, the ratio of lime-to-silica in the slag is commonly examined. As a general rule, if the CaO/SiO_2 ratio (or $CaO + MgO/SiO_2 + Al_2O_3$ ratio) is greater than 1, the slag is usually considered to be basic. If the ratio is less than 1, the slag is considered to be acidic.

Fireclay, high-alumina or silica brick are generally used where the corrosive agent is acidic. High-alumina refractories may be preferred if the flux is only slightly basic. For highly basic slags, magnesia, chrome or a blend of these two materials typically give the best service. Exceptions to these general principles are based on operating and reaction temperatures, reaction rates and formation of protective glazes and coatings on the refractory surfaces.

Slag Tests

In many industrial applications, the refractory is in contact with a slag or metal during service. A chemical reaction often results between the refractory and the slag or metal. Some reaction products can be extremely detrimental to brick service life while other reactions result in little or no change in service life. In order to determine the relative resistance of a refractory to the slag or metal present in an industrial application, various slag tests have been developed. Among the most common are the cup slag test, drip slag test, gradient slag test, rotary slag test, dip and spin tests and aluminum boat test. The slag used in the tests may be the actual material provided by the customer or a synthetic material prepared to be chemically similar to the slag or metal chemistry typical of the customer's operation.

MINERAL COMPOSITION

Minerals and Glasses

At room temperature, all refractory products which have been molded into brick and later given a ceramic bond by firing, consist of crystalline mineral particles bonded by glass or by smaller crystalline mineral particles. They contain a significant volume of small pores. When such a brick is again heated to high temperatures, as in service, a liquid phase develops, largely from the groundmass materials, in proportions which depend upon the composition of the refractory and upon the temperature. The physical properties of a refractory at any given temperature are fixed by the amount and character of the minerals, glass, and liquid of which it is composed.

A mineral may be defined as a natural inorganic substance which is either definite in chemical composition and physical properties, or which varies in these respects within fixed limits. A mineral usually has a definite crystalline structure, although a few comparatively common minerals are amorphous in nature. Opal is an example of such a mineral.

A mineral having a true or congruent melting point when heated will pass completely from the crystalline condition to the liquid state at a definite temperature. When cooled slowly, the liquid formed will solidify or freeze at the same definite temperature, and will again assume the crystalline form. With rapid cooling, the liquid may solidify with an amorphous forming glass.

A mineral is said to have an incongruent melting point when it does not change from a completely solid to a completely liquid condition at a definite temperature, but dissociates, forming a different solid crystalline phase and a liquid phase. When the temperature rises above the temperature of dissociation, the solid material dissolves gradually in the liquid. As an example, the mineral clino-enstatite ($MgO•SiO_2$) melts incongruently at 2835°F (1557°C) to form a mixture of forsterite ($2MgO•SiO_2$) and liquid.

A glass differs from a crystalline material in several respects. Its chemical composition may vary continuously over rather wide limits, it lacks crystalline structure, and it has no specific melting point. When a glass is progressively heated, the change from the apparently solid state to the fluid state is gradual and continuous. When a molten glass is cooled, the change from the fluid state to the apparently solid state is likewise gradual and continuous. Theoretically, at least, a glass is not a solid at all, but is an under cooled liquid which has stiffened as it cooled, until the viscosity has become so great that the body conforms to the generally accepted concept of a “solid.”

A glass will change into the crystalline condition or “devitrify” if kept for a sufficient time within a critical temperature range. Some melts crystallize even with very rapid cooling. Others must be maintained at a critical temperature for a considerable length of time before any crystals are formed. Alkali-silicate melts high in silica are extremely viscous and do not crystallize readily upon cooling. This immunity to devitrification is an essential attribute to commercial glass compositions.

The Ceramic Bond of Brick

One of the most important purposes for which brick are fired is to give them permanent mechanical strength, by causing adjacent particles to adhere. The bond developed by the heat treatment is known as a “ceramic bond.”

Unfired or “green” brick consist of mixtures of particles of refractory material which usually vary from coarse through intermediate to very fine sizes. The coarser particles in some cases have a diameter of ¼ inch or more. The fines, which may be regarded as the particles which will pass a 200-mesh screen, often amount to as much as 30 percent of the total. After having been fired, the borders of the larger particles are usually distinct; the fines generally form a more or less vitrified groundmass, which bonds together the particles of larger size. The character and continuity of this groundmass, and its degree of adherence to the particles, have very important effects upon the physical properties of the fired refractory brick.

The strength of the ceramic bond is dependent upon the character of the brick mix as well as upon the time and temperature of firing. In many cases, the constituents of a refractory which occur in only small amounts (the so called impurities) play an important role in the development of the bond. With some types of refractories small amounts of reactive materials are intentially added; the bond is formed by chemical reaction of the material added with a portion of the refractory. In the manufacture of silica brick for example, about 1.8 to 3.5 percent of lime is added for bonding.

During the firing of refractory brick, mineral dissociation or transformation occurs; such minerals as kaolinite or diaspore dissociate, and quartz is transformed wholly or in part into other forms of silica. Crystal growth and chemical reactions may occur also in the solid state, resulting in the formation of a strong ceramic bond between particles in contact. This type of bonding is common in basic brick compositions. However, solid-state reactions are believed to have less influence upon the bonding of silica-alumina brick than does the formation of a liquid phase. In the case of brick molded wholly or in part from calcined or dead-burned materials, some of the changes described above in this paragraph may have already occurred in the original heat treatment.

In the firing of refractory brick, a small amount of liquid can be expected to form in the groundmass at a temperature some hundreds of degrees below that at which complete fusion would occur. With rise in temperature, this liquid takes other materials present into solution and thereby increases in amount. The liquid becomes a medium suitable for the transport of material which it dissolves, and for the formation and growth of crystals, especially at interfaces between liquid and solid particles.

Upon cooling, the liquid formed at high temperatures may become a rigid glass, or it may become partly or wholly crystalline. The relative proportions of glass and crystalline material in the bonding groundmass will depend upon its composition, and upon the rate of cooling. Rapid cooling favors the formation of glass; slow cooling, the formation of crystals.

The brick mass is bonded together and given strength by the adhesive power of the glass, by adherence of particles, and by interlacing of crystals. Elongated crystals, like those of mullite, may tend to interlace; crystals having a nearly equidimensional habit, like periclase(MgO), obviously cannot interlace.

A brick containing a large amount of glass will usually have high strength in the cold condition; but if the glass is of low viscosity at furnace operating temperatures, the brick may deform readily under pressure. For a brick to withstand pressure at high temperatures without deformation, its content of glass must be low, or the viscosity of the glass must be high, or both; in general, the brick should have been fired under conditions which are favorable to the growth of crystals.

Certain types of refractories have their load carrying capabilities at high temperatures materially increased by incorporation in the brick mixes of finely ground materials which affect changes in the body. The added material may function in one of several ways; it may react chemically with the glass and transform it into highly refractory crystalline material; it may make the glass more viscous at furnace operating temperatures; it may cause or accelerate solid-state reactions; or it may cause improvement merely by reducing the proportion of the glass. A change which reduces the amount of glass or liquid in the refractory would usually be more beneficial in service than a change which makes the glass more viscous.

Equilibrium Diagrams

Melting of mixtures of two or more minerals or oxides takes place over a range of temperatures. The temperatures at which melting is complete depend upon both the relative amounts of the materials present and their compositions. The melting behavior of such mixtures and the nature of the equilibria between the solids and the liquids formed by melting have engaged the attention of many investigators. Since the early years of the twentieth century, many papers on the subject have appeared in scientific literature. Those published by the staff of the Geophysical Laboratory of the Carnegie Institution and by the College of Mineral Industries of The Pennsylvania State University, have contributed much fundamental information to the ceramic industries.

The data are presented mainly in the form of drawings known as phase equilibrium diagrams. A compilation of these diagrams, called “Phase Diagrams for Ceramists,” was published in 1956 under the auspices of the American Ceramic Society, Incorporated (ASC); a supplement, “Phase Diagrams for Ceramists, Part II,” was published in 1959. The first volume contains a section of general material on phase diagrams, including an explanation of the phase rule, an interpretation of diagrams, experimental methods, a glossary of terms, and a selected bibliography. In 1960, the American Ceramic Society published ten large-scale equilibrium diagrams of important ternary systems. Expanded volumes were published by the ACS in 1964, 1969, 1975, 1981, 1983, and 1987.

Alumina-Silica System

The equilibrium diagram for mixtures of alumina and silica, published by Bowen and Greig in 1924, for the first time gave a clear picture of the equilibrium conditions in alumina-silica compositions.

Aramaki and Roy revised the alumina-silica diagram on the basis of standard quenching experiments, in which the specimens were heated in sealed platinum-rhodium containers to prevent losses due to exposure to the furnace atmosphere. Their results are shown in Fig 1. The new diagram is in close agreement with the older one up to 55 percent alumina, and thus conclusions based upon the earlier diagram for silica and fireclay compositions are not materially altered by this later work. However, revisions of a major nature have been made in the high-alumina side of the diagram.

Significant features of the new diagram are the following:

(1) The earlier conclusion is confirmed that mullite of the composition $3Al_2O_3 \cdot 2SiO_2$ (71.8 percent Al_2O_3, 28.2 percent SiO_2) is in equilibrium with silica up to about 2903°F (1595°C). The mullite which occurs in fireclay refractories therefore has the molecular alumina: silica ratio of 3:2.

(2) The composition of mullite in equilibrium with siliceous alumina-silica liquids was found to change a little with rising temperatures above 2903°F (1595°C), becoming slightly more aluminous. The alumina content of the mullite at 3345°F (1840°C) is apparently about 72.1 percent.

(3) Mullite does not melt incongruently as formerly believed, but has a true melting point of about 3362°F (1850°C). At this temperature, however, it contains approximately 73.0 percent alumina, instead of the theoretical 71.8 percent.

(4) There is a eutectic between corundum and mullite at 3344°F (1840°C) with 77.4 percent alumina.

(5) In compositions containing more than 71.8 percent alumina, mullite forms solid solutions with corundum. Accordingly, solid solution mullites containing as much as 78 percent alumina can be prepared. Those containing more than about 74.2 percent alumina are believed to be “metastable,” that is, they have limited stability.

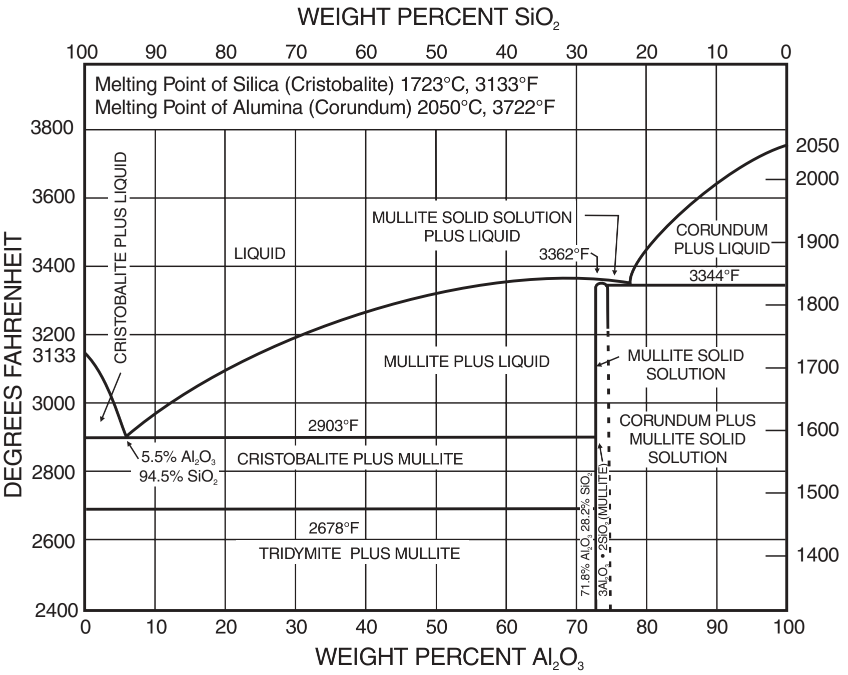


Figure 1 Equilibrium Diagram of the System Alumina-Silica ($Al_2O_3 \cdot SiO_2$)

The new alumina-silica diagram is used in the following paragraphs to illustrate the application of phase diagrams in determining the behavior of refractories at high temperatures. When conditions are favorable for the volatization of silica, such as the presence of a reducing atmosphere, or a temperature of about 3270°F(1800°C) or above, caution must be exercised in the precise application of the phase rule data to predict or interpret reactions in compositions containing more than about 55 percent alumina.

It cannot be emphasized too strongly that all phase diagrams apply strictly only (1) to completely pure materials, and (2) to conditions of complete equilibrium. Practically the first condition is never met by commercially fired refractory materials, and the second condition is seldom if ever attained in furnace practice. Moreover, phase diagrams give no information concerning rates of reaction, or the viscosity of the liquid phases, both of which have considerable effect on the properties of refractories at high temperatures. Consequently, the theoretical considerations outlined here need to be amplified by other data, for a complete understanding of the melting behavior of refractory clays and other alumina-silica materials.

Detailed Description: The temperatures of complete melting of all possible mixtures of pure silica and pure alumina, under conditions of complete equilibrium, are represented in Figure 1 by the heavy curved line (the "liquidus" line), which extends across the width of the diagram. The melting point of the pure silica is 3133°F (1723°C). With increasing amounts of alumina, up to 5.5 percent, complete melting occurs at successively lower temperatures, reaching a minimum of about 2903°F (1595°C), at a composition of 5.5 percent alumina and 94.5 percent silica, and then the melting temperature rises as the alumina content exceeds 5.5 percent. Such a composition of lowest melting point is known as a "eutectic composition," and the temperature at which it melts is known as a "eutectic temperature."

Consider any homogenous composition of alumina and silica with less than 5.5 percent alumina (Al_2O_3). To achieve homogeneity in a reasonable time, it is necessary to start with finely divided and uniformly mixed particles, and to heat them until the mullite-forming reaction is complete, preferably at a temperature just below that at which a liquid could begin to form (2903°F or 1595°C). As the temperature of the material is further increased, the entire mass will remain solid until the temperature of 2903°F (1595°C) is reached. At this temperature a portion of the batch will melt, forming an exceedingly viscous liquid of the eutectic composition (5.5 percent Al_2O_3, 94.5 percent SiO_2). All of the alumina will enter into the formation of this liquid, and if equilibrium conditions have been obtained, any excess silica above the eutectic ratio will remain in the solid form as cristobalite. With further temperature rise above 2903°F (1595°C) the amount of solid silica will decrease. The amount of liquid will increase through solution of the solid, until the entire mass has melted. The temperature at which complete melting occurs for any specific mixture is indicated by the heavy curved liquidus line.

Any composition of alumina and silica which contains more than 5.5 percent and less than 71.8 percent alumina, will melt in part at the eutectic temperature 2903°F (1595°C). The initial liquid phase will have the same composition as the eutectic (5.5 percent alumina, 94.5 percent silica), and the unmelted solid will consist of crystals of the mineral mullite. Mullite formed under these conditions has the chemical formula $3Al_2O_3 \cdot 2SiO_2$, corresponding to 71.8 percent alumina, 28.2 percent silica. When the temperature rises above 2903°F (1595°C) the liquid takes mullite into solution. The amount of liquid thereby increases and its composition changes, becoming richer in alumina, until the temperature reaches the heavy curved line for the particular composition being heated, when complete melting occurs. The temperature of complete melting is almost constant from 60 to about 77 percent alumina.

The mullite composition in equilibrium with siliceous liquid changes with the temperature, becoming somewhat more aluminous at the higher temperatures. However, the difference is so slight that the line at the right-hand side of the field of "mullite plus liquid" in Figure 1 appears to be vertical, up to about 3345°F (1840°C), and therefore appears to represent a constant alumina-silica ratio.

Mullite has a true or congruent melting point of 3362°F (1850°C). However the mullite which melts at this temperature has an alumina content of about 73.0 percent, instead of the theoretical 71.8 percent.

As shown in Figure 1, there is a eutectic between mullite and corundum, similar to that between silica and mullite previously described. The eutectic temperature for the mullite-corundum range is 3344°F (1840°C), and the eutectic contains 77.4 percent alumina by weight. Thus any alumina-silica composition containing more than 71.8 percent alumina will show the first liquid development at 3344°F (1840°C). If the composition contains more than 71.8 percent alumina, but less than 77.4 percent, the solid phase in equilibrium with the liquid will be mullite; if the composition contains more that 77.4 per cent alumina, the solid phase is corundum. Again, as the temperature rises above 3344°F (1840°C), the solid phase (mullite or corundum) will dissolve in the liquid until complete melting occurs.

Under equilibrium conditions, mullite can take excess alumina into solid solution in the crystal, up to 74.2 percent total alumina. In fact, mullites containing up to 78 percent alumina are easily prepared and commonly found in fusion-cast mullite; however it is believed that the mullites richest in alumina are metastable. X-ray diffraction spacings of various solid-solution mullites vary with heat treatment almost as much as they vary with chemical composition; hence they are not reliable indices of composition. Index of refraction measurements on true glasses containing up to 77 percent alumina were also used to locate the liquidus line in Figure 1.

The diagram (Figure 1) shows that there is no solid solution of silica in mullite under equilibrium conditions. This has been confirmed by the authors in another report.

Relative Amounts of Components: By a simple calculation, based upon the so-called "lever principle," the amount of each component present at equilibrium can be determined for any composition and any temperature. Consider, for example, a composition of 40 percent alumina, 60 percent silica. At all temperatures included in Figure 1 below 2678°F (1470°C), tridymite and mullite coexist in equilibrium and are the only minerals present. Equilibrium percentages are determined thus:

$$\%\ \text{Tridymite} = \left(\frac{71.8\text{-}40.0}{71.8\text{-}0.0}\right) 100 = 44.3\%$$

$$\%\ \text{Mullite} = \left(\frac{40.0\text{-}\ 0.0}{71.8\text{-}0.0}\right) 100 = 55.7\%$$

At 2678°F (1470°C) the tridymite changes to cristobalite. With further heating, no other changes occur until the eutectic temperature of 2903°F (1595°C) is reached. At that point all the cristobalite melts, with some of the mullite, forming a liquid with the composition 5.5 percent alumina, 94.5 percent silica. At the eutectic temperature, the relative amounts of the components as calculated are 48.0 percent liquid, 52.0 percent mullite.

With further rise in temperature above 2903°F (1595°C) progressive solution of the mullite in the liquid occurs. The composition of the melt changes, as indicated by the curved liquidus line shown in Figure 1. All of the mullite is dissolved at about 3265°F (1796°C) and the material is then completely melted.

Upon cooling, the mass would undergo the same changes as described above, in reverse order. Between 3265°F (1796°C) and 2903°F (1595°C) mullite would crystallize from the liquid, and at the eutectic temperature, 2903°F (1595°C), the entire mass would solidify abruptly, becoming a mixture of crystals of cristobalite and mullite.

The Sillimanite Minerals: The minerals sillimanite, kyanite, and andalusite all have the theoretical composition $Al_2O_3 \cdot SiO_2$, corresponding to 62.9 percent alumina, 37.1 percent silica. Dissociation of these minerals can be affected by a heat treatment at a sufficiently high temperature and for a long enough time to provide the necessary energy to alter their crystal structure. By such heat treatment, any of the sillimanite minerals can be converted into a mixture consisting of about 88 percent mullite and 12 percent free silica.

Sillimanite begins to dissociate into mullite and free silica at about 2785°F (1530°C), kyanite at 2415°F (1325°C), and andalusite at 2460°F (1350°C).

Mineral Changes During the Heating of Fireclay

In the commercial burning of fireclay brick, the mineral changes which occur do not follow as simple a pattern as that described on the preceding page. The main reasons are that the ground clay mixtures are not homogeneous either as to mineral composition or as to particle size, and firing temperatures are not held long enough to attain equilibrium. The mineral compositions may vary over a wide range and the grains may vary all the way from pieces ¼ inch or more in diameter to particles much smaller than one-thousandth of an inch in diameter.

Clays are composed essentially of one or more of a group of minerals classified as "clay minerals." Typically, these are hydrous aluminum silicates. Refractory clays consist mainly of the clay mineral kaolinite, which has the approximate composition $Al_2O_3 \cdot 2SiO_2 \cdot 2H_2O$, corresponding to 39.5 percent alumina (Al_2O_3), 46.5 percent silica (SiO_2), and 14 percent water (H_2O). Pure kaolinite has a P.C.E. value of Cone 35, corresponding to a softening temperature of about 3245°F (1785°C).

The clays of greatest importance in the refractories industry are refractory flint and semi flint clays, refractory plastic and semi-plastic clays, and refractory kaolin.

Even clays of highest quality contain significant amounts of constituents other than the alumina-silica mineral kaolinite. Many clays contain substantial amounts of illite, a form of mica which has more combined water and less potash than is found in muscovite ($3Al_2O_3•6SiO_2•K_2O•2H_2O$). The hydrous mica in clays is somewhat variable in composition, but apparently averages about 6 percent in potash (K_2O). In many refractory clays the accessory mineral present in largest amount is quartz (SiO_2); in others it is diaspore ($Al_2O_3•H_2O$). Nearly all refractory clays contain minor amounts of titania-bearing minerals. Other common accessory minerals are chlorite, montmorillonite, pyrite (FeS_2), feldspars, and micaceous minerals other than illite. Siderite ($FeCO_3$) occurs in some deepmine clays, limonite (hydrated iron oxide) in clays which occur near the surface.

The changes which take place in heating a fireclay have been the subject of extensive investigation for a great many years. Some of the changes now believed to take place on heating a fireclay composed mainly of kaolinite are outlined in the following paragraphs.

Upon being heated, kaolinite loses most of its combined water (dehydrates) at about 750^o to 980^oF (400^o to 525^oC) depending on the particle size, with the formation of a semi-crystalline compound metakaolin, $2Al_2O_3•4SiO_2$. This reaction is endothermic.

When metakaolin is heated to about 1700^oF (925^oC) an exothermic reaction takes place, in which some of the silica migrates out of the metakaolin, leaving behind a cubic spinel type phase approximately $2Al_2O_3•3SiO_2$ in composition. The silica set free may be amorphous; at least, it is so poorly crystallized that it cannot be identified as crystalline material by X-ray diffraction.

At about 1920^o to 2010^oF (1050^o to 1100^oC) the spinel-type phase begins to break down and to discard more silica. A phase resembling mullite and of uncertain composition forms, probably containing more silica than the composition $3Al_2O_3•2SiO_2$. The discarded silica appears as cristobalite, giving a well-defined X-ray diffraction pattern. Heat is evolved in this temperature range.

Above 2190^oF (1200^oC) cristobalite and mullite continue to develop. The mullite formed at 2550^oF (1400^oC) or above is believed to have the composition $3Al_2O_3•2SiO_2$ with no excess silica. Thus the alumina –silica ratio varies from 1:2 in the original kaolinite and in metakaolin, through 2:3 in the spinel type phase, to 3:2 in the final mullite.

Up to this point little has been said regarding the effects of the accessory minerals at high temperatures. Quartz which is present as an accessory mineral begins to change to cristobalite at about 2280^oF (1250^oC). If the quartz crystals are large the central portions may remain as residual quartz in bodies which have been heated to a temperature as high as 2700^oF (1480^oC). Some of the oxides present in the accessory minerals lower the temperature at which liquid begins to form and increase the amount of liquid at any given temperature. The alkalies soda and potash are especially potent in this respect, reacting to form a highly viscous liquid at temperatures several hundred degrees below the temperature at which liquid would begin to form if the body consisted wholly of alumina and silica.

In clays which are otherwise pure, a very small amount of potash is sufficient to lower the temperature of initial liquid formation to 1805^oF (985^oC). In the alkali-alumina-silica liquid, accessory minerals containing lime, magnesia, and iron oxide dissolve wholly or in part, as do both amorphous and crystalline silica and at very high temperatures even mullite. Over a wide range of temperatures above 1805^oF, the liquid is so viscous that it behaves essentially as if it were a solid. However, the viscosity gradually decreases as the temperature becomes higher. The temperature of complete melting depends upon the alumina-silica ratio, and upon the compositions and amounts of the accessory minerals.

In a single ground clay, most of the larger particles have nearly the same composition as the finer sizes, which form the groundmass of fired products made from the clay. However, there is probably some concentration of accessory minerals in the groundmass. For this reason, and because of its greater fineness, the groundmass develops more liquid than the larger particles during firing of fireclay brick.

When fireclay brick are at the firing temperature, they consist of mullite and cristobalite crystals and a viscous liquid. On cooling, some additional cristobalite and mullite may separate from the liquid. However, much of the liquid cools to a rigid glass, which bonds the mass together and gives it strength. Additional strength is imparted by the interlacing and adherence of crystals. Mullite is especially effective as a ceramic bond, as it forms interlacing needle-like crystals.

Mineral Composition of Fireclay and High-Alumina Brick

Burned fireclay refractories are composed largely of mullite and free silica (cristobalite, quartz, and rarely tridymite). The crystals are mainly submicroscopic in size, but are identifiable by means of their X-ray diffraction patterns. Glass also is present in amounts depending upon the composition of the material, the time and temperature of firing, and the rate of cooling. Super duty fireclay brick usually contain less glass than do brick of the high-duty class. In any fireclay brick, the impurities tend to be concentrated in the glass.

In fireclay brick exposed to high temperatures, the mullite crystals increase in size. In photomicrographs of super duty fireclay brick reheated to 2910^oF (1600^oC), the presence of mullite crystals is clearly indicated.

High-alumina brick contain mullite and usually corundum, some free silica (generally cristobalite with occasional quartz), and glass in amounts varying with the alumina content of the brick. The mineral constitution is also influenced by the raw materials from which the brick were made, the mineral placement with respect to grains and the matrix, the proportion of accessory oxides, and the firing treatment.

If complete equilibrium could be attained during the firing process, any pure alumina-silica refractory with less than 71.8 percent alumina would contain no crystalline material other than mullite and free silica. One with more than 71.8 percent alumina would contain only mullite, with a small amount of alumina dissolved in it, or the mullite solid solution and corundum. However, in brick made wholly or in part from bauxite or diaspore clay, corundum may be present even in compositions with less than 71.8 percent alumina, and free silica may be present even in compositions with more than 71.8 percent alumina. Under favorable conditions the development of mullite during firing proceeds to an advanced degree, yet it does not proceed to completion. The mullite formed at the surfaces of the grains of bauxite or diaspore appears to act as a protective film, retarding or preventing further reaction between the corundum on the interior of the grains and the free silica formed from the fireclay between the grains.

A similar condition exists when fused alumina (artificial corundum) is added to or is bonded by fire clay in the manufacture of high alumina brick. When the refractory is fired, a protective film of mullite forms at the surfaces of the grains of corundum by combining with free silica released by recrystallization of the fire clay. The interior of the corundum grains is unaltered by the firing treatment.

The Minerals in Silica Refractories

Stability relations of the silica minerals: The three common crystal modifications of silica are quartz, tridymite, and cristobalite. The form generally found in nature is quartz. This mineral may be converted to tridymite or cristobalite by appropriate heat treatment. The formation of tridymite appears always to require the presence of a liquid, which may be formed by reaction of silica with a suitable fluxing agent. Cristobalite is formed in the absence of liquid. Quartz is the stable form of silica below 1598°F (870°C); tridymite is the stable form from 1598°F (870°C) to 2678°F (1470°C); and cristobalite is the stable form above 2678°F (1470°C). However, at ambient temperature and pressure, there is no perceptible tendency for cristobalite or tridymite to change to quartz.

In the absence of a liquid phase, quartz does not change to trydimite, even within the temperature range at which tridymite is the stable form. At about 2280°F (1250°C) quartz begins to change slowly to cristobalite; the rate of transformation increases rapidly as the temperature rises. At 2900°F (1593°C) transformation is complete in approximately one hour.

In the presence of an appropriate liquid, cristobalite changes to tridymite at temperatures between 2280°F (1250°C) and 2678°F (1470°C). The change is very slow at 2280°F (1250°C) and is not rapid even at 2630°F (about 1445°C).

The specific gravity at room temperature of quartz is 2.65; that of cristobalite, 2.32; that of tridymite 2.26. Hence the transformation of quartz to cristobalite causes a volume increase of 14.3 percent; of quartz to tridymite, a volume increase of 17.2 percent.

Each of the three crystal forms of silica has high-temperature and low-temperature modifications. These are known as high-quartz and low-quartz; high cristobalite and low-cristobalite; and upper high-tridymite, lower high-tridymite, and low-tridymite. A change takes place rapidly from a low temperature to a high temperature form on heating, and from a high to low form on cooling.

The change from low-quartz to high-quartz or the reverse, which occurs at about 1063°F (573°C), is accompanied by an abrupt volume increase of approximately 0.9 percent on heating, and a corresponding shrinkage on cooling. However, the total reversible expansion which occurs between 600°F (316°C) and 1100°F (593°C) is about 3.2 percent. When heated or cooled rapidly through the inversion point quartz has a strong tendency to crack.

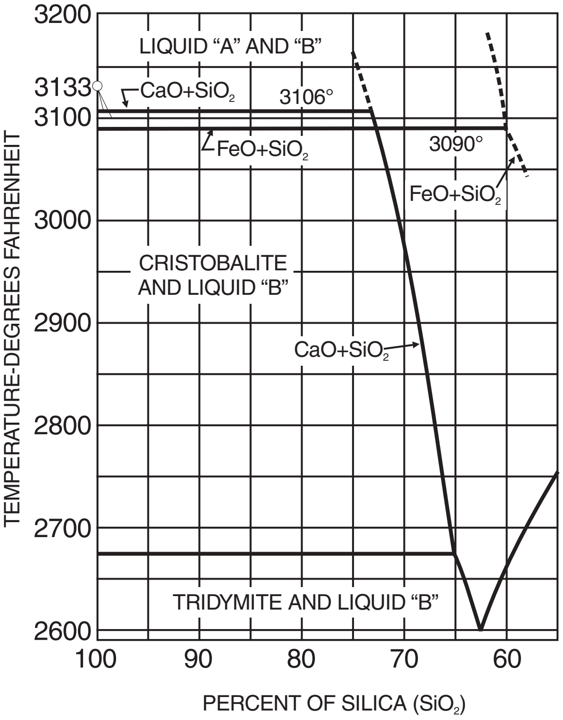


Figure 2 Partial Equilibrium Diagram of the Binary Systems Lime-Silica and Ferrous Oxide-Silica (CaO•SiO$_2$ and FeO•SiO$_2$)

The low-high inversion of cristobalite occurs at about 428°-513°F (220°-267°C) on heating; the reverse change on cooling takes place at about 480°-392°F (249°-200°C). However, the temperature is somewhat variable, and depends both on the material from which the cristobalite was formed and the temperature of formation. Cristobalite, when heated or cooled through the inversion range, has a volume change of about 2.8 percent. Refractory brick or other bodies consisting largely of this mineral tend to crack or spall if heated or cooled rapidly through the inversion range.

Two well-crystallized tridymites occur at ambient temperature, designated as tridymite-M (for metastable) and tridymite-S (for stable). Tridymite-M passes through reversible inversion points at 235^{o} and 306^{o}F; (113^{o}, and 152^{o}C) tridymite-S at 147^{o}, 235^{o}, and 280^{o}F (64^{o},113^{o}, and 138^{o}C). The total volume changes through the inversion points are small, probably not exceeding 0.35 percent. So far as is known, no cracking occurs when tridymite is heated or cooled rapidly through the inversion points.

Equilibrium Diagrams and Silica Refractories: Highly siliceous mixtures of silica with certain other oxides have a constant temperature of complete melting over a wide range of composition. Within this range the mixtures form two immiscible liquids upon melting, instead of the usual single liquid. The two liquids do not blend, but preserve their separate identitites, like mixtures of oil and water. Highly siliceous mixtures of silica with lime or with ferrous oxide exhibit this type of melting behavior, as shown in Figure 2.

The addition of up to 1 percent lime to silica results in a progressive lowering of the temperature of complete melting from 3133^{o}F (1723^{o}C) to 3106^{o}F (1708^{o}C). Further additions of lime, however, do not result in additional lowering of the melting temperature, but the formation of a second liquid containing 27.5 percent lime and having the same melting point 3106^{o}F (1708^{o}C). Thus the addition of 2.5 percent lime to silica would result in the formation of only (2.5/27.5) x 100, or about 9 percent liquid at temperatures just below 3106^{o}F (1708^{o}C). Similarly, all mixtures of silica and ferrous oxide, containing from 1 percent to 40 percent ferrous oxide, under equilibrium conditions melt completely at 3090^{o}F (1699^{o}C).

The equilibrium diagrams of silica with alumina, with titania, and with the alkalies do not show the "Immiscibility Plateau" effect. Instead, a single liquid results from melting, and the temperature of complete melting drops rapidly with even small additions of any one of these oxides. Moreover, in lime-silica or ferrous oxide-silica mixtures, a small percentage of alumina or alkalies destroy the immiscibility.

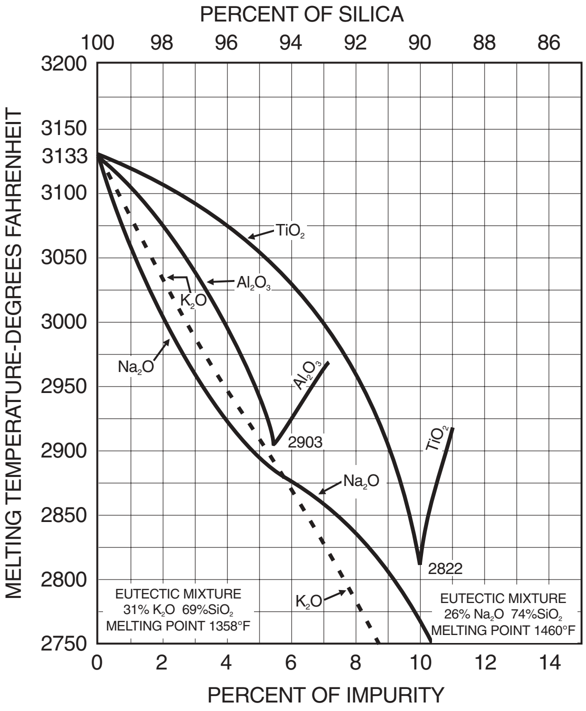


Figure 3 Effect of Certain Impurities Upon Melting Behavior of Silica

The effect of the "Immiscibility Plateau" upon the melting temperature can be seen by comparison of Figures 2 & 3. At 2920^{o}F (1605^{o}C), a mixture of 5.5 percent lime with 94.5 percent silica under equilibrium conditions will consist of 82 percent solid material with 18 percent liquid, while at the same temperature a mixture of 5.5 percent alumina, soda, or potash with silica will be completely melted.

The Mineral Changes Which Occur Upon Firing Silica Brick

The raw material used in the manufacture of silica refractories is a rock consisting almost wholly of quartz. In that used for making brick of conventional quality the sum of the alumina, titania, and alkalies is usually about 0.5 to 1.2 percent and the ferric oxide content about 0.3 to 1.0 percent. The raw material used in the manufacture of superduty silica refractories contains about 99.0 percent silica, with a total of 0.15 to 0.4 percent alumina, titiania, and alkalies. In the manufacturing process, 1.8 to 3.5 percent of lime is added for bonding.

During the firing, most of the quartz changes with accompanying expansion into other forms of silica. The lime combines with silica and the impurities of the rock to form a liquid which solidifies largely to a glass on cooling. Under some conditions, the mineral pseudowollastonite ($CaO•SiO_2$) is formed also.

The coarse grains in a silica brick usually contain 99+ percent silica, often being well in excess of 99.5 percent SiO_2. Hence the fine grained groundmass, about 25 percent of the total weight of the brick, contains almost all the lime and iron oxide, as well as much of the alumina, titania, and alkalies. Thus the lime content of the groundmass is of the order of 8 to 10 percent, a significant factor in the development of the liquid phase during firing. In the system $CaO-Al_2O_3-FeO-SiO_2$, liquid can form at a temperature as low as about 2048^{o}F (1120^{o}C). Small amounts of alkalies may depress this temperature

Table I
MINERAL COMPOSITION OF SILICA BRICK

	Percent				
Type	Tridymite	Cristobalite	Quartz	Pseudo-wollastonite	Apparently Noncrystalline Material *
Superduty	33-61	27-49	<1.3+	<2.5+	9-17
Superduty-Spall Resistant	35-38	33-35	2.3+	1.3+	20-30
Conventional	40-54	28-41	<1	<1.5+	5-24

* By difference; believed to consist of "disordered" silica and 5 to 15 percent glass   < = less than

still further. Besides its effect on bonding strength, the liquid has a marked influence on the rate at which the mineral transformations occur.

In the firing of silica brick, conversion of quartz to cristobalite begins at about 2280°F (1250°C). The rate of transformation is slow at this temperature, but increases as the temperature rises. Small grains in the groundmass are converted first, together with the surfaces of the larger grains. The transformation progresses into the interiors of the larger grains gradually, and ultimately the only quartz remaining, if any, is that in the interior of the largest grains.

During the firing, the liquids formed in the groundmass begin to affect the cristobalite, converting it to tridymite, the stable form of silica at the firing temperature of about 2625°F (1440°C). In a silica brick after firing, the larger grains are likely to consist predominately of cristobalite, with thin rims of tridymite at their surfaces, and with any remaining unconverted quartz in the centers of the largest grains. Most of the tridymite is in the groundmass, with the glass from which it crystallized.

The permanent linear expansion of silica brick during firing, due to the transformation of quartz to cristobalite and tridymite, is about 4.2 percent.

Silica brick, as now manufactured, consist mainly of tridymite and cristobalite, with some glass, residual quartz, and often small quantities of a finely crystalline mineral, which has been identified as pseudowollastonite ($CaO \bullet SiO_2$). The amounts of these phases which occur in silica brick are shown in Table I.

Silica brick ordinarily are light in color with a yellowish cast, but often are mottled or splotched in irregular brownish patterns. Such coloration is due to subtle changes in the groundmass, accompanying devitrification. These odd colorings, which are of no practical significance, are most likely to appear in brick of the highest purity, or in those containing more than about three times as much lime as alumina. As the alumina content increases, the color generally becomes less pronounced.

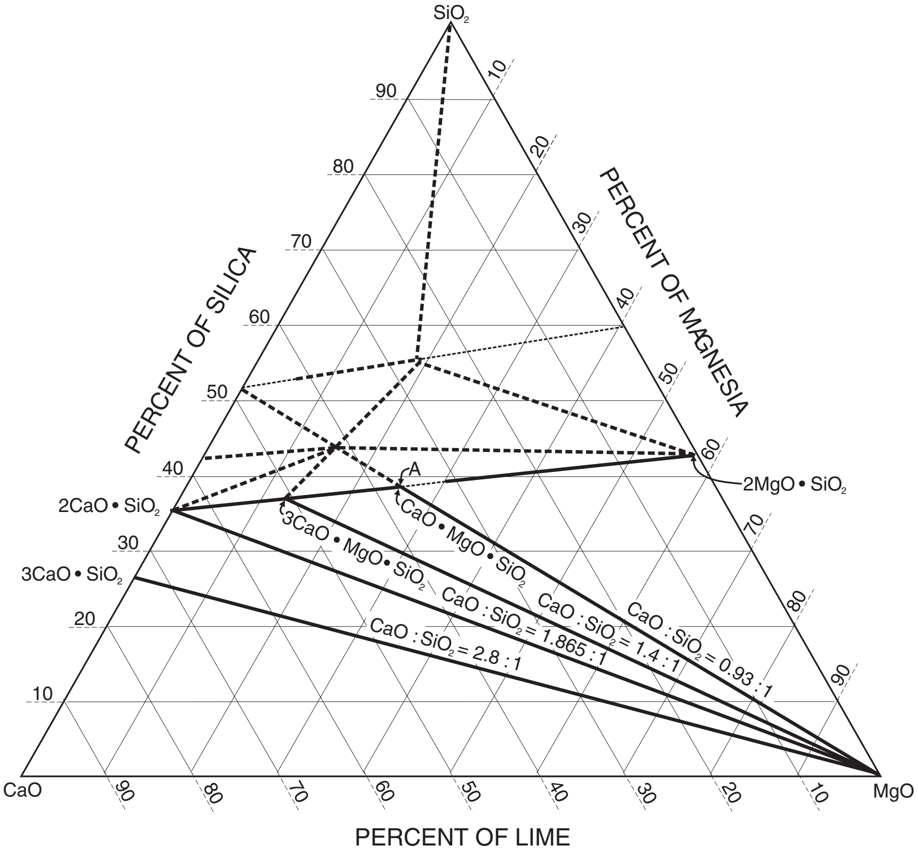


Figure 4 Composition Triangles in the Lime-Magnesia-Silica ($CaO \bullet MgO \bullet SiO_2$) System

The Mineral Composition of Magnesite Refractories

Magnesite Materials: The raw materials used in the manufacture of refractories consisting essentially of the basic oxide magnesia (MgO) are (1) chemically precipitated magnesium hydroxide, (2) the mineral magnesite, which is naturally occurring magnesium carbonate, and to a minor extent (3) the mineral brucite, naturally occurring magnesium hydroxide. Chemically precipitated magnesium hydroxide, prepared by causing slaked lime or slaked calcined dolomite to react with magnesium-bearing brine, contains small amounts of accessory minerals derived from the limestone or dolomite, and from the brine. The natural mineral magnesite contains small amounts of accessory minerals, such as dolomite, serpentine, talc, chalcedony, and quartz. Iron carbonate, in solid solution with the magnesium carbonate, is present in many magnesites.

Raw magnesia-containing materials are “dead-burned” in rotary or shaft kilns to prepare them for use. The dead-burning consists of a high-temperature heat treatment which drives off chemically combined water and/or carbon dioxide, and converts the remaining product into dense grains or lumps resistant to atmospheric moisture and carbon dioxide. In dead-burning, additions such as iron oxide, alumina, silica, or lime may be made to obtain desired compositions.

The temperature of dead-burning varies from about 2800°F to 3350°F (1540°C to 1845°C), depending upon the type and purity of the product. In the process of dead-burning, magnesia hydroxide dissociates to form magnesia and water vapor; magnesium carbonate dissociates to form magnesia and carbon dioxide gas. The water vapor and the carbon dioxide escape with the kiln gases. The dead-burned product,

Table II
TYPICAL COMPOSITIONS OF DEAD-BURNED MAGNESITE

		For Furnace Bottoms	For Making Brick
Magnesia	(MgO)	83-98%	88-98%
Lime	(CaO)	1.0-6.0	1.0-3.5
Silica	(SiO_2)	0.5-8.0	0.5-6.0
Alumina	(Al_2O_3)	0.3-1.5	0.3-1.5
Ferric Oxide	(Fe_2O_3)	0.3-3.0	0.3-6.5

which is known commercially as "dead-burned magnesia" consists mainly of aggregates of periclase crystals, with a fine-grained crystalline groundmass usually composed of silicates of magnesium and to a minor extent of calcium.

The color of dead-burned magnesia low in iron oxide varies from white to buff or tan. Dead-burned magnesia which contains several percent of iron oxide is generally chocolate-brown in color, and microscopic examination shows that the periclase crystals usually contain dark moss-like inclusions. These have been identified as magnesioferrite ($MgO \bullet Fe_2O_3$).

The most desirable amounts of the accessory constituents, and their relative proportions, depend upon the purposes for which the product is to be used. Dead-burned magnesia used in furnace hearths in general has a higher content of accessory constituents than that used for making brick. The compositions of most of the commercial dead-burned magnesias used in the United States lie within the ranges shown in Table II. In recent years, ultra high purity dead-burned magnesia containing 99 percent MgO have gained wide spread use.

The exact mineral composition of magnesia grains cannot be calculated accurately from the chemical composition, because adequate data regarding the six component system MgO-CaO-Al_2O_3-FeO-Fe_2O_3-SiO_2 are not available, and because equilibrium conditions are not entirely reached in the brief period of exposure to high temperatures during dead-burning. However, the major components can be identified by painstaking research with X-ray diffraction.

The CaO-MgO-SiO_2 System: Consideration of the three component system CaO-MgO-SiO_2 serves as an excellent starting point in studying the mineral composition of magnesia refractories. The composition triangles in this system are shown in Figure 4, which is explained as follows: Any point within the large equilateral triangle of Figure 4 represents a definite composition, consisting solely of CaO, MgO, and SiO_2. For example, the point "A" represents a composition of 35.9 percent CaO, 25.6 percent MgO, and 38.5 percent SiO_2, which corresponds to the composition of the mineral monticellite.

The large equilateral triangle is divided by heavy lines into triangles of unequal size. These are known as "composition triangles." Each of the three apexes of any composition triangle represents the chemical composition of a specific mineral. A line connecting any two apexes represents all compositions in which the two minerals indicated may coexist in equilibrium. The area within a triangle represents all compositions in which the three minerals indicated by the apexes may coexist in equilibrium.

The particular minerals to be found in any stable blend of lime, magnesia, and silica may be predicted from the triangle within which the composition lies. Under equilibrium conditions, the body would consist of the three minerals represented by the apexes of the triangle, in relative amounts fixed by the distances from the point representing the composition, to the individual apexes.

That part of the CaO-MgO-SiO_2 system in which the magnesia is present in great excess, and in which therefore periclase (MgO) is invariabley a component, is of particular interest in connection with magnesia refractories. In Figure 4 the composition triangles of this part of the system appear as full lines. The calcium and magnesium silicates which may coexist in equilibrium with periclase are indicated. For any given composition, the particular silicates which may be present, and their relative proportions, are fixed by the lime-silica ratio.

In that part of the three component system CaO-MgO-SiO_2 in which magnesia (MgO) is present in great excess, and in which the lime-silica ratio is less that 1.86 to 1 by weight (less than 2 to 1 on a molecular basis), either one or two magnesium-bearing silicate minerals will invariable be present at room temperatures, as shown

Table III
MINERALS IN THE CaO-MgO-SiO_2 SYSTEM WHICH COEXIST IN EQUILIBRIUM WITH PERICALSE

Case	Molecules of CaO to 1 Molecule of SiO_2	Parts By Weight of CaO to 1 part of SiO_2	Compatible Components	
			Minerals	Compositions
1	Under 1 (Less CaO than SiO2)	Less than 0.93 parts	Forsterite Monticellite	$2MgO \bullet SiO_2$ $CaO \bullet MgO \bullet SiO_2$
2	1	0.93 parts	Monticellite	$CaO \bullet MgO \bullet SiO_2$
3	1-1 ½ (More CaO than SiO2)	0.93 – 1.40 parts	Monticellite Merwinite	$CaO \bullet MgO \bullet SiO_2$ $3CaO \bullet MgO \bullet 2SiO_2$
4	1 ½	1.40 parts	Merwinite	$3CaO \bullet MgO \bullet 2SiO_2$
5	1 ½-2	1.40 – 1.86 parts	Merwinite Dicalcium Silicate	$3CaO \bullet MgO \bullet 2SiO_2$ $2CaO \bullet SiO_2$
6	2	1.86 parts	Dicalcium Silicate	$2CaO \bullet SiO_2$
7	2-3	1.86 – 2.80 parts	Dicalcium Silicate Tricalcium Silicate	$2CaO \bullet SiO_2$ $3CaO \bullet SiO_2$
8	3	2.80 parts	Tricalcium Silicate	$3CaO \bullet SiO_2$
9	Over 3	Over 2.80 parts	Tricalcium Silicate Lime	$3CaO \bullet SiO_2$ CaO

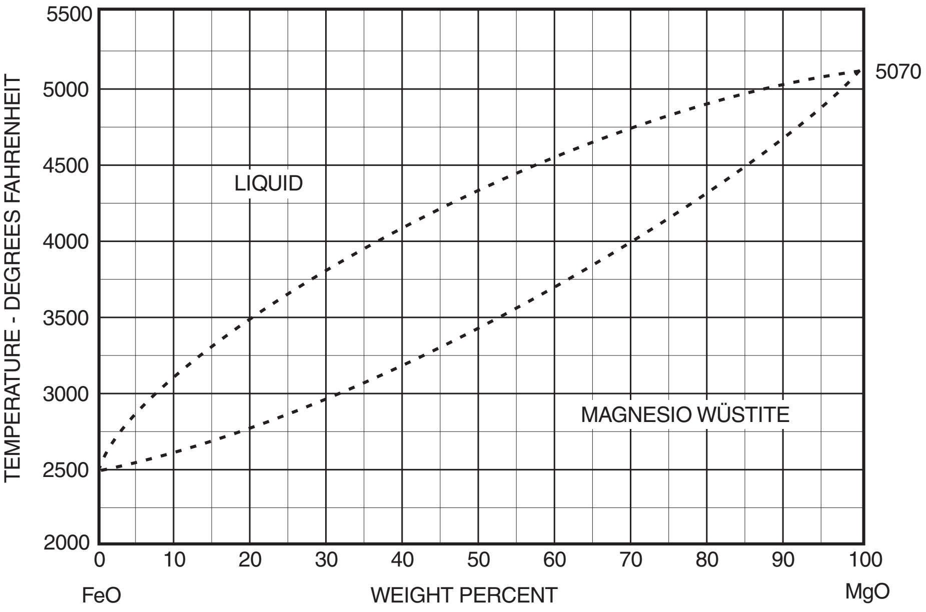


Figure 5 Equilibrium Diagram of the system FeO•MgO

in Table III. If the lime-silica ratio of the high magnesia compositions is 1.86 or higher, no magnesium-bearing silicates will be present.

The lime-silica ratio has an important bearing upon the melting behavior of lime-magnesia-silica compositions. Any combination of lime, magnesia, and silica alone, in which periclase is a component, and in which the amount of lime by weight is less than 1.86 times the amount of silica, will develop a liquid phase at 2867°F (1575°C), and may develop liquid at a temperature as low as 2714°F (1490°C). If completely homogenous mixtures could be obtained, no combination of these oxides, in which the amount of lime is equal to or more than 1.86 times the amount of silica, would form liquid below 3254°F (1790°C). However, lower lime-silica ratios, in areas of even microscopic size, would permit small quantities of liquid to form at temperatures lower than 3254°F (1790°C), and would cause some coalescing together of particles, even though diffusion at higher temperatures should cause the liquid to disappear.

The Accessory Minerals in Magnesia Refractories: Incomplete data are available concerning the complex six-component system $CaO\text{-}MgO\text{-}SiO_2\text{-}Al_2O_3\text{-}FeO\text{-}Fe_2O_3$, the system applicable to refractories which consist essentially of magnesia. However, the more important relationships are fairly well understood. In such mineral compositions, consisting mainly of periclase, if the amount of lime is less than 0.93 times the amount of silica, the minerals forsterite and monticellite will form at high temperatures in the groundmass. If the amount of lime is between 0.93 and 1.40 times the amount of silica, monticellite and merwinite will form; and if it is between 1.40 and 1.86 times the amount of silica, merwinite and dicalcium silicate will form. In all these compositions, any ferrous oxide present dissolves in the magnesia; alumina and ferric oxide combine with the magnesia, forming the spinel minerals $MgO\bullet Al_2O_3$ and $MgO\bullet Fe_2O_3$.

If the amount of lime equals or exceeds 1.86 times the amount of silica, in the six-component system, the mineral relationships are much more complex, and the lime-silica ratio does not suffice to determine what minerals are present. The lime reacts with silica to form dicalcium or tricalcium silicate, and with alumina and ferric oxide to form calcium aluminates and calcium ferrites. Many attempts have been made to formulate rules whereby the mineral compositions at room temperatures can be calculated from the chemical analyses, but often the calculated compositions are not in satisfactory agreement with the results of microscopic and X-ray determinations.

Forsterite is a common bonding constituent of magnesia refractories of low lime content. It is highly refractory and has no undesirable mineral inversions; it is little affected by the pres-

Table IV
MELTING POINTS OF COMPOUNDS WHICH MAY BE PRESENT
IN MAGNESITE REFRACTORIES

		°F	°C
Lime	CaO	~4660	~2570
Pericalse	MgO	~5070	~2800
Spinel	$MgO\bullet Al_2O_3$	~3875	~2135
Dicalcium Silicate	$2CaO\bullet SiO_2$	~3865	~2130
Forsterite	$2MgO\bullet SiO_2$	~3450	~1900
Tricalcium Silicate	$3CaO\bullet SiO_2$	Stable only from 3452°F (1900°C) to 2880°F (1250°C). At and above 3452°F (1900°C) it dissociates into $2CaO\bullet SiO_2$ and CaO; below 2280°F (1250°C) it tends to dissociate into $2CaO\bullet SiO_2$ and CaO.	
Dicalcium Ferrite	$2CaO\bullet Fe_2O_3$	Melts incongruently at 2617°F(1436°C) forming CaO and liquid.	
Magnesioferrite	$MgO\bullet Fe_2O_3$	Dissociates slightly; begins to melt at 3115°F (1713°C).	
Monticellite	$CaO\bullet MgO\bullet SiO_2$	Melts incongruently at 2709°F (1487°C) to form MgO and liquid; melting complete at approximately 3000°F (1650°C).	
Merwinite	$3CaO\bullet MgO_2\bullet SiO_2$	Melts incongruently at 2871°F (1577°C) to form $2CaO\bullet SiO_2$, MgO and liquid	

~ = Approximately

ence of moderate amounts of ferric oxide, but reacts with lime to form the minerals monticellite and merwinite.

Monticellite and merwinite melt at relatively low temperatures, and in minor amounts may have some value in the development of the ceramic bond of magnesia brick. Dead-burned magnesia compositions having a lime:silica ratio favorable to the development of an undesirable amount of monticellite or merwinite can be corrected by the addition of sufficient lime so that there will be 1.86 times as much lime as silica, by weight. When this is done, magnesia is displaced from the silicates, and the lime and silica combine to form the compound dicalcium silicate ($2CaO•SiO_2$).

Dicalcium silicate ($2CaO•SiO_2$) is highly refractory. It does not react with magnesia (MgO), and it is stable in the presence of moderate amounts of ferric oxide (Fe_2O_3). At one time, it was regarded as an undesirable component of basic refractories, because of its tendency to turn completely into dust on cooling; this affect results from a mineral inversion at about 1340°F (725°C) which is accompanied by an abrupt volume increase of 10 percent. However, means have been found to prevent the dusting of dicalcium silicate by adding small amounts of stabilizing minerals to the raw magnesia or magnesium hydroxide, before dead burning. These added materials inhibit the inversion of the silicate on cooling.

The lime compounds tricalcium silicate ($3CaO•SiO_2$) and dicalcium ferrite ($2CaO•Fe_2O_3$), which may occur in magnesia refractories having high lime-silica ratio, are compatible with dicalcium silicate but do not coexist in equilibrium with monticellite, merwinite, or forsterite. Tricalcium silicate is unstable below about 2280°F (1249°C) and tends to dissociate into dicalcium silicate and free lime. Dicalcium ferrite is unstable above 2617°F (1436°C), and decomposes into free lime and a liquid high in iron oxide. It has been suggested that when this occurs the iron oxide may leave the liquid and combine with magnesia to form the mineral magnesioferrite ($MgO•Fe_2O_3$); and that, if the material is cooled rapidly, the dicalcium ferrite might not re-form. Under these conditions, free lime would be present in the dead-burned magnesite after cooling.

In basic refractories, the state of oxidation of the iron changes with the temperature, and with changes in the oxygen pressure of the furnace atmosphere. When heated in air, free ferric oxide loses oxygen at 2530°F (1368°C) and changes to the spinel mineral magnetite ($FeO•Fe_2O_3$). If the furnace atmosphere is strongly reducing, iron oxide will be in the form of FeO; if strongly oxidizing, it will be ferric oxide (Fe_2O_3).

An important property of magnesium oxide is its ability to absorb great amounts of iron oxide-either ferrous or ferric-without undue decrease in refractoriness. This property of magnesia, together with its very high melting temperature, is responsible, in large measure, for its value as a refractory. It accounts for the fact that refractories high in magnesia can be used advantageously in the presence of iron oxides, in either an oxidizing or a reducing atmosphere, and also, for some of the particular advantages of steel-encased basic brick.

Table V

MELTING POINTS OF SOME CaO-MgO-SiO_2 EUTECTICS

	Melting Points of Eutectics	
Eutectics Between These Compounds	°F	°C
MgO and CaO	~ 4172	~2300
MgO, CaO and $3CaO•SiO_2$	~3360	~1850
MgO, $3CaO•SiO_2$ and $2CaO•SiO_2$	~3255	~1790
MgO and $2CaO•SiO_2$	~3270	~1800
MgO, $2CaO•SiO_2$ and $3CaO•MgO•2SiO_2$	2867	1575
MgO, $3CaO•MgO•2SiO_2$ and $CaO•MgO•SiO_2$	2714	1490
MgO, $CaO•MgO•SiO_2$ and $2MgO•SiO_2$	2736	1502
MgO and $2MgO•SiO_2$	~3380	~1860

~ = Approximately

The equilibrium diagram for the MgO•FeO system is shown in Figure 5, if the incongruent melting of FeO is neglected. Magnesium oxide (MgO) and ferrous oxide (FeO) form a continuous series of solid solutions which decrease in refractoriness with increasing proportions of ferrous oxide. However, even with more than 50 percent FeO, the refractoriness is still high.

Magnesium oxide reacts with ferric oxide (Fe_2O_3) to form magnesioferrite, which begins to melt only at 3115°F (1713°C), notwithstanding the fact that it contains 80 percent Fe_2O_3. With less than 70 percent Fe_2O_3, the temperature of incipient melting is even higher than 3115°F (1713°C).

At ordinary temperatures, iron oxide in dead burned magnesia or in magnesia brick may be present within the periclase grains as MgO•FeO solid solution, or as inclusions of magnesioferrite ($MgO•Fe_2O_3$) particles. If the lime-silica ratio by weight exceeds 1.86, iron oxide may be present also in the groundmass in combination with lime and alumina as brownmillerite ($4CaO•Al_2O_3•Fe_2O_3$), in combination with lime as dicalcium ferrite ($CaO•Fe_2O_3$), or in solid solution with silicates.

While magnesioferrite is completely soluble in periclase at high temperatures, it separates out upon cooling, unless cooled very rapidly. This accounts for the presence of the dark colored inclusions in periclase crystals frequently observed in microscopic examination.

Very dense grains of magnesia often are greenish in their interiors, which were cooled out of contact with air, and chocolate-brown at their surfaces, which were exposed to air during cooling. In the greenish centers the periclase crystals probably contain ferrous oxide in solid solution; in the brown surface portions the periclase crystals contain inclusions of magnesioferrite particles. Porous grains are less likely to have green centers than dense grains.

Dead-burned magnesia sometimes contain somewhat more free lime than would be anticipated from their $CaO:SiO_2$ ratio. The free lime has no disadvantage from the standpoint of melting, but it is very active chemically and slakes upon exposure to the air.

Chrome Refractories

Ores: Chrome ores in general consist of massive or granular aggregates of chromite crystals, with minor amounts of silicates in the matrix. Refractory chrome ores may be regarded as naturally occurring mixtures of two components: (1) the essential component, a highly refractory chrome-containing spinel; (2) accessory components, consisting mainly of magnesium silicates in the form of interstitial material and veinlets. These silicates are often of complex and widely varying compositions.

Chrome Spinel: The spinel minerals all have the general formula $RO \bullet R_2O_3$ and all crystallize in the cubic system. In the spinels of chrome ores, the RO consists of FeO and MgO (ferrous oxide and magnesia), and the R_2O_3 of Cr_2O_3, Al_2O_3, and Fe_2O_3 (the sesquioxides of chromium, aluminum, and iron). The proportion of Fe_2O_3 is relatively small.

An important property of the spinel minerals is their habit of forming solid solutions, or isomorphous mixtures, with each other. The various spinel minerals are soluble in each other over a very wide range of compositions. Their tendency to form mixed crystals is so great that some of the spinel minerals are not known to occur pure in nature. For example, chromite of the formula $FeO \bullet Cr_2O_3$ is known only in meteorites; all other natural chromites are believed to be isomorphous mixtures.

The composition of a chrome spinel (excluding all accessory minerals) may be stated in terms of molecular ratios of RO and R_2O_3. For example, the average molecular composition of the spinel in chromite of one of the larger deposits in the Camaguey district of Cuba is approximately the following:

RO		R_2O_3	
MgO	75%	Cr_2O_3	40%
FeO	25%	Al_2O_3	55%
		Fe_2O_3	5%
	100%		100%

This composition may be expressed more simply by the formula $m_{75}f_{25} \bullet (c_{40}a_{55}f_5)$, in which m=MgO, c= Cr_2O_3, a= Al_2O_3, f outside the parenthesis =FeO, f within the parenthesis = Fe_2O_3. The subscripts represent molecular percentages.

Typical molecular compositions of certain other chrome spinels, as reported by J. R. Rait and others, may be represented by the following formulas:

Cuban (Moa Bay)	$m_{72}f_{28}\ (c_{47}a_{50}f_3)$
Rhodesian	$m_{66}f_{34}\ (c_{73}a_{21}f_6)$
Philippine	$m_{73}f_{27}\ (c_{42}a_{55}f_3)$
Transvaal, brown	$m_{47}f_{53}\ (c_{62}a_{28}f_{10})$
Turkish	
Refractory Grade	$m_{71}f_{29}\ (c_{42}a_{55}f_3)$
Metallurgical Grade	$m_{74}f_{26}\ (c_{77}a_{19}f_4)$

There is evidence which indicates that the crystals of balanced spinel in a given specimen of chrome ore may not all be of identical composition. Therefore, the molecular formula of a chrome spinel, calculated from its chemical composition, is merely an average value, and does not necessarily apply strictly to each individual spinel crystal.

Frequently, the compositions of chrome ore are reported in terms of individual spinels, as if the ore contained a series of spinels existing side by side. However, the preponderance of evidence is that the individual spinel minerals have no identity as such in the spinel solid solution of chromite.

Accessory Minerals: The accessory minerals which occur most abundantly in chrome ores are serpentine ($3MgO \bullet 2SiO_2 \bullet 2H_2O$) and chlorite, a complex hydrated silicate of magnesium, iron, and aluminum. The composition of clinochlore, one of the members of this group is $5(Mg,Fe)O \bullet Al_2O_3 \bullet 4H_2O$. Other accessory minerals include the following:

Olivine	$2(Mg,Fe)O \bullet SiO_2$
Talc	$3MgO \bullet 4SiO_2 \bullet 2H_2O$
Pyroxene	
Diopside	$CaO \bullet MgO \bullet 2SiO_2$
Enstatite	$MgO \bullet SiO_2$
Bronzite	$(Mg,Fe)O \bullet SiO_2$
Hypersthene	$(Fe,Mg)O \bullet SiO_2$
Feldspar	
Anorthite	$CaO \bullet Al_2O_3 \bullet 2SiO_2$

The amount of accessory minerals in commercial chrome ores varies from 5 percent to 25 percent. Most of the accessory minerals have relatively low melting points, well below 3000°F or 1650°C. The heat-resisting qualities of chrome ore depend largely upon the character and the amount of the silicates which the ore contains.

Analyses and Melting Points: Typical analyses of chrome ores are given in Table VI. The ores used for refractories

Table VI
TYPICAL ANALYSIS OF CHROME ORES

Source of Ore	Cr_2O_3	Al_2O_3	FeO	MgO	CaO	SiO_2
Pakistani Chrome Ore	54.4	10.4	15.4	6.6	0.2	2.8
Phillipine Chrome Ore						
Gov't Stockpile	33.7	26.5	14.9	17.4	0.6	5.3
+ 10 mesh	32.4		16.6		0.4	5.2
Fine Lump Ore	32.0	27.5	14.4	19.4	0.5	6.0
Transvaal Chrome Ore						
Gov't Stockpile	44.7	12.8	26.6	10.2	0.3	4.3
ERS Grade	44.3	15.9	26.1	11.6	0.2	0.8
MN46	44.2	15.9	28.2	9.8	0.3	0.9
-48 mesh	45.0	15.4	28.5	9.2	0.4	1.3
Tiegaghi Chrome Ore	55.3	10.2	15.3	15.7	0.2	3.2
Marico Chrome Ore	48.4	16.3	22.3	11.6	0.2	0.8

usually fall within the ranges of 30 to 50 percent chromic oxide (Cr_2O_3), 14 to 20 percent ferrous oxide (FeO), 14 to 20 percent magnesia (MgO), 12 to 25 percent alumina (Al_2O_3), 3 to 6 percent silica (SiO_2) and less than 1 percent lime(CaO). The Philippine chrome ores are noted for their high content of alumina. To an increasing extent, ores are being used which contain as much as 26 percent ferrous oxide and as little as 8 percent magnesia and 10 percent alumina.

As might be expected from its constitution, a chrome ore does not have a true melting point, but rather a melting range. The melting behavior of a particular chrome ore depends not only on the composition and refractoriness of its major component chrome spinel, but also on the amount, composition, and melting points of the silicates present, and on the furnace atmosphere, whether oxidizing or reducing.

From Table IV, showing the melting points of the individual spinel minerals, it may be inferred that the most refractory chromites are those highest in magnesia and chromic oxide.

In most chrome ores of refractory grade, melting of the silicate impurities begins at temperatures as low as 2300^{o}F (1260^{o}C). As the temperature rises, some solution of the spinels in the liquid occurs, but melting of these spinels is not complete until a much higher temperature is reached-possibly as high as 3900^{o}F (2150^{o}C).

Mineral Changes During Firing of Chrome Ore

The thorough investigations of Rigby, Lovell, and Green and others, concerning the behavior of various chrome ores and synthetic spinels on firing, appear to have established the following facts:

(1) Chrome spinels in general are balanced, containing equal molecular percentages of RO and R_2O_3 constituents.

(2) Most of the iron content of chrome ores is present as part of the RO constituent.

(3) The FeO in the spinel of most chrome ores is readily oxidized into $Fe_2O_3$when the ores, or brick containing them, are fired in an oxidizing atmosphere. This results in an unbalance between RO and R_2O_3, as the RO decreases and the R_2O_3 increases. Two solid phases appear: (a) a spinel consisting mainly of MgO•R_2O_3 and (b) a solid solution of the excess R_2O_3 constituents (Fe_2O_3, Cr_2O_3, and Al_2O_3). Frequently the solid solution is easily visible under the microscope as needle like inclusions.

(4) Chrome spinels of relatively high alumina content appear to have a lesser tendency to oxidize in air at temperatures up to 2640^{o}F (1449^{o}C) than those in chromic oxide.

(5) Raw chrome ores, in which most of the iron is present as FeO, are apparently affected relatively little by heating in a reducing atmosphere. However, in a chrome ore which has been fired, the iron is present largely as Fe_2O_3 in an R_2O_3 solid solution, and is readily reduced by heating in a reducing atmosphere. In extreme cases, it may be reduced to metallic iron.

(6) In a chrome ore which has become oxidized on firing, reduction of the Fe_2O_3 in the R_2O_3 solid solution is usually accompanied by expansion and an increase in porosity, and sometimes by cracking. The expansion and cracking are observed only when the oxidized ore is exposed to reducing gases. Repeated oxidation and reduction may cause an ore to become friable. Chrome ores high in alumina show much less tendency to become friable.

(7) When a chrome ore is heated with added magnesia, as in a chrome-magnesite or magnesite-chrome brick, MgO enters the chrome spinel to replace the FeO, as it oxidizes to Fe_2O_3, and also combines with the newly formed Fe_2O_3 to maintain the spinel structures. The new spinel will have essentially the formula MgO•R_2O_3.

(8) During oxidation, in the presence of excess magnesia, part of the Fe_2O_3 may leave the spinel crystal as MgO enters, react with MgO, and form a border of MgO•Fe_2O_3 surrounding the chrome spinel crystal.

(9) While Fe_2O_3 in the simple spinel MgO•Fe_2O_3 is easily reduced, it is much more stable in the spinel MgO•R_2O_3, when the R_2O_3 consists of Al_2O_3 and Cr_2O_3, as well as Fe_2O_3. Thus, an oxidizing heat treatment of a chrome ore in the presence of excess MgO to stabilize the spinel renders it less likely to become friable when exposed to alternating oxidizing and reducing conditions.

(10) The stabilization of the chrome spinel by oxidation of FeO and absorption of MgO may be accompanied by a volume expansion of about 5 to 10 percent, depending on the amount of FeO oxidized. This effect may be partially offset by shrinkage of the silicates present as accessory minerals.

(11) The stabilization of the chrome spinel by MgO increases the refractoriness of the spinel grains, since spinels formed by MgO with Cr_2O_3, Al_2O_3, and Fe_2O_3 have higher melting points than the corresponding spinels formed by FeO.

(12) The added magnesia also reacts with the accessory magnesium silicate minerals of low melting point present in the groundmass of the ore, and converts them to the highly refractory mineral forsterite, 2MgO•SiO_2. However, the amount of magnesia absorbed by the spinel is probably much greater than that which enters into the formation

of forsterite in the matrix.

(13) The volume expansion of stabilization with MgO may cause the edges of the spinel grains to shatter, and may also weaken the natural bond between grains. In addition the increase in refractoriness of the silicate groundmass, resulting from the addition of MgO, may decrease the bonding strength. Therefore a fired chrome magnesite brick will normally not be as strong at room temperature as a brick consisting only of chrome ore, but is usually stronger at high temperature.

Composite Chrome-Magnesia Refractories

In the early 1930's, important discoveries were made concerning combinations of chrome ore and dead-burned magnesia. Most of the silicates in chrome ores have relatively low melting points. It was learned that if finely ground dead-burned magnesia were added to chrome refractories, the silicates would be largely converted, during firing, to the refractory mineral forsterite ($2MgO•SiO_2$), which has a melting point of 3450^{o}F (1900^{o}C). Later, it was discovered that the addition of the magnesia resulted also in stabilization of the chrome spinel. These discoveries provided great impetus to the use of chrome-containing refractories, since the improvements led to the production of brick of greater utility.

Today, a large proportion of all the basic refractories used commercially consist essentially of blends of dead-burned magnesia and chrome ore in various proportions and in numerous modifications. There are two main groups: (1) chrome-magnesia brick, in which chrome ore predominates, and usually constitutes all the larger grains, while the dead-burned magnesia is confined to the fine-grained groundmass; and (2) magnesia-chrome brick, in which dead-burned magnesia, the main component, consists of a complete range of sizes, while the chrome ore is coarsely ground. However, there are various other modifications of the sizing of the particles.

In the manufacture of chrome-magnesia refractories, considerably more magnesia is customarily added than is required for reaction with the silicates. Part of the excess magnesia enters the chrome-spinel grains to maintain the RO: R_2O_3 balance when the FeO of the spinel is oxidized at high temperatures to Fe_2O_3; and part of the magnesia remains in the brick as free periclase.

The mineral relationships in the six-component system $CaO•MgO•SiO_2•Al_2O_3•FeO•Fe_2O_3$ have been described on preceding pages. The relationships in the broader system containing Cr_2O_3 also are similar. With the ratio of lime to silica of 1.86 or less, the phases containing lime and magnesia are the same as those shown in Table III, and the sesquioxides Cr_2O_3, Al_2O_3, and Fe_2O_3 are combined with FeO and MgO to form spinel solids solutions. Chrome-magnesia brick usually have a lime-silica ratio less than 0.93 by weight, and consist of spinel solid solutions, periclase, forsterite, and monticellite. At high temperatures, periclase absorbs iron oxides from the spinel grains to form solid solutions of MgO with FeO and $MgO•Fe_2O_3$.

With $CaO:SiO_2$ ratios greater than 1.86 by weight, compounds of CaO with sesquioxides will occur. This condition rarely if ever exists in commercial chrome-magnesia compositions as manufactured, but may occur in service as the result of exposure to basic slags.

While the addition of magnesia to chrome refractories increases their refractoriness, and has an important effect on their high-temperature mineralogy, the addition of chrome ore to refractories consisting mainly of dead-burned magnesia serves a different purpose. The addition of coarse chrome ore imparts improved spalling resistance to brick consisting mainly of dead-burned magnesia, apparently by providing stress relief in an otherwise relatively rigid structure. Usually, magnesia-chrome brick are chemically bonded and encased in steel sheets. They are also made with internal steel plates.

The mineral changes occurring in magnesia-chrome refractories in service are similar to those which occur in magnesia and chrome refractories. Any forsterite ($2MgO•SiO_2$) or monticellite ($CaO•MgO•SiO_2$) present in the refractory may react with basic slags to produce secondary periclase (MgO), merwinite ($3CaO•MgO•2SiO_2$), and occasionally dicalcium silicate ($2CaO•SiO_2$). The ferrous oxide (FeO) in the chrome ore oxides to ferric oxide (Fe_2O_3) and is replaced in the spinel structure by magnesia. The ferric oxide produced reacts with additional magnesia to form magnesioferrite ($MgO•Fe_2O_3$). The steel plates oxidize also, and the oxide formed diffuses into the magnesia adjacent to the plates to form additional magnesioferrite. Chrome grains adjacent to the oxidized steel plates frequently show growth of magnetite ($FeO•Fe_2O_3$) or magnesioferrite ($MgO•Fe_2O_3$) on the surface of the chrome spinel crystals.

Forsterite Refractories

Forsterite is a magnesium silicate with the theoretical formula $2MgO•SiO_2$, corresponding to 57.3 percent magnesia (MgO) and 42.7 percent silica (SiO_2). Its melting point is 3450^{o}F (1900^{o}C). Forsterite almost always occurs in homogenous combination with fayalite ($2FeO•SiO_2$). The series of mixed crystals consisting of forsterite and fayalite is called "olivine" or "chrysolite," while the rock consisting of Mg-Fe olivine, with minor amounts of accessory minerals, is known as "dunite." Commonly the iron content of magnesium olivines used for the production of refractories corresponds to about 15 percent of fayalite.

The accessory minerals occurring in the olivine used for making forsterite brick are largely serpentine and talc. Serpentine has the composition $3MgO•2SiO_2•2H_2O$, and contains equal amounts of magnesia and silica by weight. The composition of talc is

$3MgO•4SiO_2•2H_2O$, corresponding to only half as much magnesia as silica by weight. Upon heating, both these minerals develop large amounts of liquid at relatively low temperatures. At 2838°F (1559°C) pure serpentine would form 60.5 percent forsterite and 39.5 percent of a siliceous liquid; at 2811°F (1544°C) pure talc would become 4.4 percent cristobalite and 95.6 percent liquid. In either case, the presence of these natural impurities in olivine lowers the temperature at which liquid forms.

The development of a considerable amount of liquid in a refractory body is not of itself a serious matter. For example, Fireclay brick contains large proportions of liquid at temperatures within their working range. Yet the liquid is so very viscous that there can be no drainage from the pores. However, brick containing magnesium silicate melts behave quite differently. Birch and Harvey found that a brick made of Mg-Fe olivine relatively high in accessory minerals, when heated to 2640°F (1450°C) developed a melt of such high fluidity that liquid drained freely from the pores. They also found that this drainage could be prevented by the addition of sufficient magnesia to convert the magnesium silicates serpentine and talc into forsterite upon firing, and to combine with the iron oxide present to form magnesioferrite ($MgO•Fe_2O_3$).

Forsterite brick are fired products consisting essentially of olivine with added magnesia. During the firing under oxidizing conditions, important changes take place in the forsterite fayalite solid solution of the olivine. The forsterite is stable, and persists as such in the finished brick. The ferrous oxide (FeO) of the fayalite oxidizes to form ferric oxide (Fe_2O_3), and the silica of the fayalite is liberated. The ferric oxide then combines with a part of the added magnesia to form magnesioferrite ($MgO•Fe_2O_3$). The silica liberated by the decomposition of the fayalite unites with part of the added magnesia to form secondary forsterite.

A comparable transformation occurs in the accessory silicate minerals. Any serpentine present in fissures or in the groundmass decomposes upon firing to form secondary forsterite and silica. The latter forms additional amounts of secondary forsterite by reacting with a portion of the added magnesia.

An important modification of burned forsterite brick is made by the addition of alumina which during the firing reacts with free magnesia and iron oxide from the olivine to form a solid-solution spinel. This stabilized spinel is highly resistant to growth resulting from cyclic oxidation and reduction.

SECTION 4

Using Refractories

WARNING: Some materials which are present in refractory products are harmful. One such group is classified as substances known to cause cancer to humans. Other substances may be classified as probably or possibly carcinogenic. These materials include minerals used in or formed during the manufacture of these products. The primary threat presented by many of these materials comes from inhaling respirable dust. The use of proper respiratory equipment, as well as other personal protective equipment is mandatory where required by applicable law. Please refer to the applicable Material Safety Data Sheet for such product .

Using Refractories

Just as the design and construction of masonry and concrete structure must meet exacting load-bearing and curing demands, so must refractory materials stand up to the demands of high temperature and otherwise destructive environments. Slag, molten metal, abrasive raw materials, corrosive gases or any combination of these elements can contact and threaten the integrity of refractories. A substantial investment in products intended to handle these conditions can be lost through inadequate design and careless construction of refractory structures.

This section addresses problems inherent to refractory design and construction and describes workable solutions to many of them. Discussions involve thermal expansion of refractories, thermal conductivity, heat transfer and the installation of monolithic refractories including anchoring and the construction of refractory furnace linings and arches. Calculations are also provided for a variety of arch and ring combinations.

A comprehensive treatment of refractory design and construction issues is beyond the scope of this section. If your specific refractory lining problem is not addressed in the following pages, please contact your Harbison-Walker representative for assistance.

SELECTION OF REFRACTORIES

Optimum use of refractories is achieved by careful study of furnace design and evaluation of operating conditions prior to selection of refractory products which meet the design and operating requirements.

From the multiple factors listed below, it may appear that the choice of most suitable material would be exceedingly difficult. Sometimes this is true.

However, there are usually data on hand from previous experience under similar conditions. Moreover, the best refractory selection often depends on a few requirements so important that other factors play a minor role. In some cases, refractoriness, i.e., maximum service temperature, alone will be the deciding factor, and in others high refractoriness will have to be coupled with resistance to thermal shock. Under other circumstances, resistance to metals, slags, or disintegration by reducing gases may be the governing factors. Sometimes high insulating value is desirable, but in other situations high thermal conductivity may be needed. When selecting refractories, the following major factors must be identified.

OPERATING FACTORS

- Function of the furnace
- Nature of material being processed
- Rate and continuity of operation
- Range and rapidity of temperature changes
- Chemical attack by metals, slags, ash, etc.
- Fluidity of molten metal or slag
- Velocity of furnace gases
- Abrasion from contained solids or gases
- Impact from charging
- Erosion by molten furnace contents
- Impinging flames or hot spots

FURNACE DESIGN AND CONSTRUCTION

- Type of furnace
- Design and dimensions of walls and arches
- Loads imposed on the lining
- Conditions of heating (one or more sides)
- Amount of insulation
- Air- or water-cooling
- Type of refractory construction (brick or monoliths)
- Methods of bonding or support
- Provision for thermal expansion
- Mechanics of any moving furnace parts

REFRACTORY-RELATED FACTORS

- ***Properties at room temperature*** –
  - Workmanship and physical strength
  - Density, porosity, permeability
  - Chemical and mineral composition
  - Uniformity
  - Size and design
- ***Properties at high temperatures*** –
  - Refractoriness or maximum service temperature
  - Reversible thermal expansion
  - Resistance to thermal shock
  - Resistance to chemical attack
  - Resistance to mechanical impact or stress
  - Resistance to abrasion or erosion
  - Permeability to gases or liquids
  - Volume stability (bloating or shrinkage)
  - Resistance to gases and fumes
  - Thermal conductivity
  - Heat capacity
  - Electrical resistance
- ***Economic factors***
  - Delivered cost
  - Cost of installation (brick vs. monoliths)
  - Special shapes or forming required
  - Service life

ORDERING REFRACTORIES

Refractory technology is becoming increasingly specialized, year after year, so that it is often necessary to thoroughly understand an application area before making refractory selections. Harbison-Walker Marketing Representatives have been trained to do this work and are ready as an accommodation to discuss your application with you. H-W offices are listed in phone books in major cities throughout the United States.

In most cases, careful specification of your requirements and operation will help Harbison-Walker fill your order correctly and without delay. When you order various shapes and sizes, it is not necessary to send drawings, but provide a complete description and correct dimensions for the shapes that you need. If you order circle brick or other shapes designed to fit a circular lining, provide both the inside and outside diameter of the lining.

Orders for brick should include enough mortar material of the right kind to lay the brick. Information required to specify the number, shape and size of brick as well as the quantity of mortar appears in the following tables and in the Brick Sizes and Shapes Section of the Handbook.

Number of Refractory Straights Required Per Square Foot of Wall or Floor

Wall or Floor Thickness, Inches	9 X 4½ X 3 Inch Brick
3	3.6
41/2	5.3
6	7.2
71/2	8.9
9	10.7
131/2	21.4
18	21.4
27	32.1
Number of brick per cubic foot	14.2

Special Shapes

On initial orders for special shapes, send a drawing of the shape and the assembly into which it fits. The assembly drawing will help Harbison-Walker engineers evaluate the design and verify that the combination of refractories and design produces the best results. On subsequent orders the Harbison-Walker drawing number or your drawing and shape number will ensure that the order is properly filled. Refer to the previous order by number and date.

When filling orders for special shapes, Harbison-Walker makes a slightly larger number of shapes than specified to cover possible breakage in firing. In some cases, all of the extra pieces will come from the kilns in perfect condition.

Then, Harbison-Walker will ship a limited quantity of extra pieces in accordance with the following table, unless special instructions are entered on the order. This standard procedure also helps avoid shortages resulting from breakage during transit and handling.

Standard Packaging

Standard packaging for monolithic refractories are 55 lb. sacks, pails, cartons, 2,000 lb., 3,000 lb., and 4,000 lb. bulk bags. Non standard palletizing for brick or monoliths and non standard packaging options including export palletizing are available for additional charges.

Approximate Pounds of Mortar per 1000 9-Inch Brick (9 X 4½ X 2½ Inch)*

Mortar Materials	Brick Laid Dry and Grouted	Brick Laid with Dipped or Thinly Trowelled Joints
Heat-Setting Mortars		
SATANITE®	250 - 300	350 - 450
Air Setting Mortars		
HARWACO BOND®	250 - 300	350 - 450
‘SAIRSET®	250 - 300	350 - 450
H-W® PERIBOND™	300 - 400	500 - 600
‘SAIRBOND®	250 - 300	350 - 450

* This is for 9-inch straights. Normally, for larger sizes the quantities required are reduced in porportion to the decrease in surface area covered by the mortar per 1000 9-inch equivalent.

NOTE: Minimum figures are used ordinarily for estimating.

OVERAGE

Quantity Specified	Overage	Quantity Specified	Overage
1-100	10%	5,000 - 10,000	2%
100-1,000	7%	Over 10,000	1%
1,000-5,000	3%		

*Not less than one shape. If in sets, one complete set.

THERMAL EXPANSION

Overview

Like virtually every construction material, refractories expand or contract at high temperatures. Thus, thermal expansion must be considered in the design of most refractory structures. Walls must be allowed to expand freely upward, and joints must permit the horizontal expansion required by the refractories.

Further, expansion allowances must be determined with reasonable accuracy. Too little will cause pinch spalling; too much may weaken the wall or roof unnecessarily. How much expansion allowance to calculate depends largely on the refractory material; and how expansion will occur depends on several factors, including the type of refractory.

THERMAL EXPANSION TYPES

Refractory thermal expansion occurs in two forms. "Permanent" thermal expansion takes place as the result of mineralogical changes within the refractory brick when they remain at high temperatures for long periods of time. "Reversible" thermal expansion occurs as the brick expand and shrink when the temperature rises and falls during operation.

Results of reheat testing, shown with other properties of each brand, indicate the amount of permanent linear expansion to be expected.

The table below lists approximate expansion values for refractory brick in high temperature service. Reversible thermal expansion for certain refractory brick classes shown in thermal expansion graphs are available from your Harbison-Walker Marketing representative. Thermal expansion data can be found in the Harbison-Walker HEATransfer™ 2003 program found on our webpage at www.hwr.com.

The thermal expansion data represents average values. Brands even within a class, will differ somewhat among themselves. Generally, fireclay, silicon carbide, zircon brick and most insulating firebrick have relatively low rates of expansion. Basic brick show relatively high rates of thermal expansion while other refractories fall between the two.

Thermal Expansion of Refractory Brick in High Temperature Service

Type of Brick	Approximate Expansion Per foot, inches	Approximate Expansion Per meter, cm
Fireclay		
Super Duty	3/32	0.76
High-Duty		
Low-Duty		
High-Alumina		
60%Class	3/32	0.76
70%Class		
85%Class		
90% Class	1/8	1.04
Corundum Class	5/32	1.30
Silica	5/32	1.30
Basic		
Magnesite, fired	1/4	2.08
Magnesite-chrome, fired	1/4	2.08
Magnesite-chrome, unburned	3/16	1.55
Chrome, fired	1/8	1.04
Chrome-magnesite, fired	1/8	1.04
Chrome-magnesite, unburned	5/32	1.30
Silicon Carbide	3/32	0.76
Zircon	3/32	0.76

EXPANSION ALLOWANCES

Brick Refractories

Methods of making allowance for thermal expansion in refractory brick differ considerably, depending on wall dimensions, insulation, the mortar used and operating conditions, as well as the type of refractories involved.

Adequate provision for expansion becomes especially important in high or long walls where total thermal expansion may be substantial. The thickness and insulation of a wall determine the temperature drop between hot and cold face, and, thus, the amount of thermal expansion at both faces.

When construction calls for a heat-setting mortar, vertical expansion joints can be staggered to tighten construction. However, where brick are laid with an air-setting mortar, expansion joints must be lined up vertically from course to course. Brick required to move with respect to each other as the refractory expands should not be laid with air-setting mortar.

In fireclay boiler settings with walls 15 feet or more in length, furnace builders customarily stagger vertical expansion joints 4 to 6 feet apart. If the walls are low, expansion joints may fall somewhat farther apart than in other types of construction. For example, tunnel kiln construction usually calls for expansion joints 10 to 15 feet apart in the high temperature section and 15 to 20 feet apart in the low temperature section.

In silica brick walls, vertical expansion joints typically are placed to extend from bottom to top, spaced 10 to 16 feet apart.

Basic brick-magnesite and chrome-are laid in a number of ways to allow for expansion. Some furnace builders lay the brick dry with sufficient space at each vertical joint, or at about 18-inch or wider intervals. Basic brick also can be laid dry with a heavy paper or cardboard filler in each vertical joint.

Click here to go to Harbison-Walker HEATransfer™ 2003 program or go to www.hwr.com

THERMAL EXPANSION

Castable Refractories

In any consideration of thermal expansion, castable refractories differ considerably from brick. Castables are not fired before installation. Only after prolonged exposure to heat do they assume the reversible expansion and contraction characteristics found in fired ceramic bodies.

During initial heat-up, castables show the results of complex forces at work:

- The fired aggregate expands according to its chemical composition;
- The cement phase shrinks as it loses the water of hydration; and
- The body itself expands or contracts as it sinters and mineralogical reactions occur.

Most background material concerning thermal expansion of refractories is based on brick, and that knowledge is difficult to transfer to castables. But, in the field, there are two practical rules of thumb:

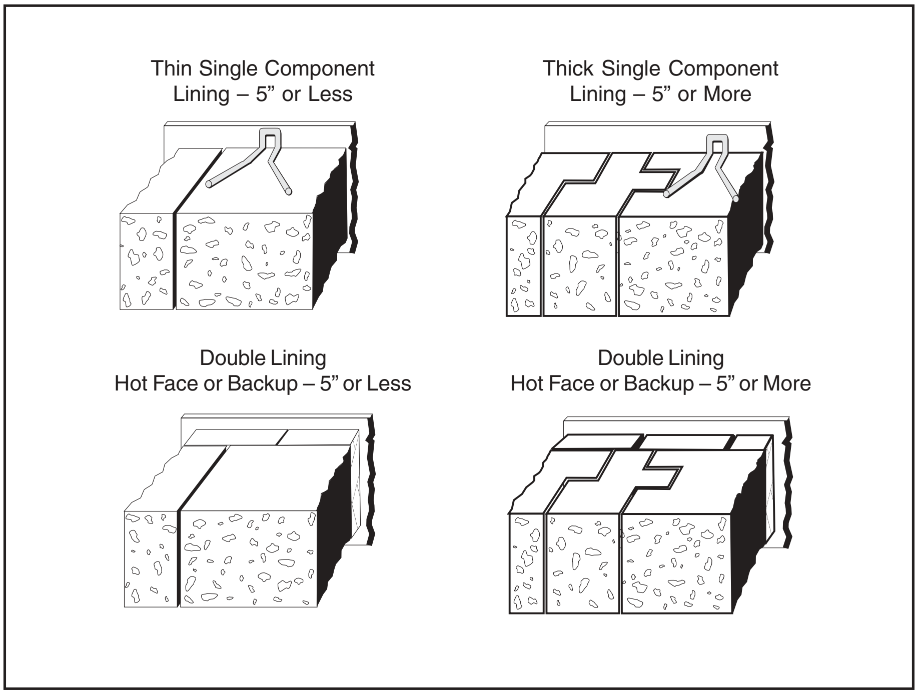
- Fireclay castables do not normally require an expansion allowance; and
- Certain dense, highly refractory castables have substantial reversible thermal expansion up to 2000°F (993°C) or more. Castables of this type may require an expansion allowance in massive installations.

Construction joints are suggested for most castable installations except for those which will be used in metal contact. Construction joints control shrinkage and cracks that can form on drying.

Expansion joints in refractory castables are typically designed in the same manner as construction joints required to control shrinkage. However, some types of compressible material should be incorporated in the expansion joint. The figure below illustrates typical configurations for joint construction.

If you have specific questions about thermal expansion in refractories, please call your Harbison-Walker Marketing Representative.

Typical Joint Construction



When construction joints are required, anchors should remain halfway between them. Anchor tines should be 2 to 3 inches from the joint. If joint position is not fixed in the drawing, always cut or form the joint midway between anchors. No anchors should be located at any joint. Expansion joint construction is the same, except that the joint is thicker to permit insertion of the required expansion material.

Overview

In selecting refractory lining configurations for high temperature vessels, it is often necessary to calculate the heat flow and temperature profile of the refractory lining. Heat flow rates are important in assessing the economics of furnace operation. Temperature profiles are important in choosing combinations of materials which prevent overheating of refractories and support structures, such as the shell and anchors, and in determining the solidification and condensation of furnace process components in the lining. Thermal conductivity data for many of our products are available on our HEATransfer™ 2003 program which can be access on our website at www.hwr.com. A user name and password is required to secure this data and perform on-line heat flow calculations. With certain limitations, steady-state heat flow rates and temperature profiles in walls and roofs can be calculated with sufficient accuracy for most engineering purposes.

ONE DIMENSIONAL STEADY STATE FLOW

For most furnace designs, it is usually acceptable to assume that all heat entering the hot face of the lining flows in one direction, perpendicular to its surface. In order for this assumption to be valid, the lining must be of uniform thickness and the lining materials must be uniform in all directions parallel with the hot face. Examples of areas of a vessel in which one-dimensional flow cannot be assumed are corners and regions of transition between material zones. In the case of a wall zoned vertically, some heat may flow between zones, upward or downward, depending on relative conductivity. In the case of a corner, heat flows along different paths having different lengths; these are commonly referred to as edge effects. In areas which are well removed from edge effects, one-dimensional flow may be assumed.

A widely used method for calculating one-dimensional steady state heat flow is presented in A.S.T.M. Proposal P142, “Proposed Procedure for Calculating Heat Losses Through Furnace Walls.” This method uses an interactive approach which, for practical reasons, typically requires use of a computer.

When a furnace lining is under steady state (or equilibrium) conditions, the rate of heat flow into the lining is equal to the rate of heat flow out of the lining. In conventional furnaces, heat enters the inside surface of the lining, passes through the lining via conduction, and escapes to the surroundings at the outside surface via radiation and convection. Therefore, the steady state condition for flow through a flat wall or roof may be expressed mathematically as:

$$Q_L = Q_S$$

where Q_L is the heat flux in the lining, and Q_S is the heat flux at the outside surface.

The heat flux in the lining may be determined using the following expression:

$$Q_L = (T_i - T_o)/ R_T$$

where

Q_L = heat flux in the wall, BTU/ft^2-hr(W/m^2)

T_i = temperature of inside surface, °F (°C)

T_o = temperature of outside surface, °F (°C)

R_T = total thermal resistance of wall, ft^2-hr-°F/BTU (m^2-K/W)

The total thermal resistance of the wall is calculated by summing the individual thermal resistances of all refractory components and the furnace shell:

$$\sum_{j=1}^{n} R_T = L_j/K_j$$

where

n = number of components

L_j = thickness of component j, in. (m)

K_j = thermal conductivity of component j, BTU-in/ft^2-hr-°F (W/m-K)

For example, a wall consisting of two refractory components and a shell would have a thermal resistance given by:

$$R_T = (L_1/K_1)+(L_2/K_2)+(L_3/K_3)$$

The inside and outside surfaces are commonly called the hot and cold faces of the furnace wall. The hot face temperature is usually assumed to be equal to the gas temperature within the furnace. Actually, the hot face temperature is somewhat cooler, but the difference is typically too small to warrant the complex calculation.

The heat flux at the cold face, Q_s, is determined by two mechanisms, radiation and convection. The portion which is lost by radiation may be quantified by using the following equation:

$$Q_r = \sigma\varepsilon(T_o^4 - T_a^4)$$

where

Q_r = heat loss by radiation, BTU/ft^2-hr (W/m^2)

σ = 1.74×10^{-9} BTU/ft^2-hr-°R^4 (5.67×10^{-8} W/m^2-K^4)

ε = total emissivity of outside surface, dimensionless

T_o = temperature of outside surface, °F (K)

T_a = temperature of surrounding air, °F (K)

The convection mechanism may be either natural or forced. Natural convection occurs when no forced air motion occurs. In this case, the motion of the air at the outside surface is caused by differences in density (hot air rises), and the proper equation is:

$$Q_{nc} = 0.53C(1/T_{avg})^{0.18}(T_o\text{-}T_a)^{1.27}$$

where

Q_{nc} = heat loss by natural convection, BTU/ft^2-hr

C = 1.39 for a vertical wall or 1.79 for a crown

T_{avg} = average of outside surface and surrounding air temperatures, °R

T_o = outside surface temperature, °R

T_a = surrounding air temperature, °R

Forced convection occurs when forced air moves across the outside surface, e.g., wind and fan-blown air. The appropriate equation here is:

$$Q_{fc} = (1 + 0.225V)(T_o\text{-}T_a)$$

where

Q_{fc} = heat loss by forced convection, BTU/ft^2-hr

V = air speed, ft/sec

T_o = outside surface temperature, ^{o}F

T_a = surrounding air temperature, ^{o}F

The convection equations were determined empirically and apply only for the units given; heat flux values in metric units can be obtained by multiplying Q_{nc} or Q_{fc} in BTU/ft^2-hr by 3.153 to convert to units of W/m^2. It must be realized that only one convection equation is applicable to a given condition.

To find the steady state solution, a set of conditions, including hot face temperature (T_i), surrounding air temperature (T_a), and total emissivity of the outside surface (ε), must be given. If forced convection is in effect, the air speed (V) must also be known. The approach is to determine the temperature of the outside surface which satisfies the heat balance criterion:

$$Q_L = Q_r + Q_{nc}$$

or

$$Q_L = Q_r + Q_{fc}$$

After the correct outside surface temperature is determined, the interface temperature between any two lining components may be calculated in accordance with the following relation:

$$T_n = T_i – Q_L \sum_{j=1}^{n} R_j$$

j=1

For the first interface (closest to the inside surface):

$$T_1 = T_i \text{-} Q_L R_1$$

For the second interface:

$$T_2 = T_i \text{-} Q_L\ (R_1 + R_2)$$

And so on.

Example 1: Estimate the steady state heat flux and interface temperatures in a furnace wall consisting of 6" of 60% alumina brick (UFALA®), 2 ½ " of 2300°F (1260°C) insulating firebrick, and a ¼" steel shell. The inside surface temperature is 2700°F (1482°C), and the surrounding air temperature is 70°F (21°C). There is no forced air motion. The total emissivity of the shell is 0.9.

The first table on the following page shows the sequence of computer calculations searching for heat balance (i.e., heat in equals heat out). For each iteration, the thermal resistance value of each component was re-evaluated based on the newly chosen value of the outside surface (cold face) temperature, since thermal conductivity changes with temperature. A cold face temperature of 402°F (206°C) resulted in heat balance with a heat flux of 1099 BTU/ hr-ft^2 (3465 W/m^2).

If the material used for a lining component has a thermal conductivity curve which does not approximate a straight line over the range of the gradient through it, the component should be subdivided. Each subcomponent is given its own thermal conductivity characteristic which should be more accurate, since its temperature gradient is smaller. Subdivision is usually not necessary, but with the use of a computer, it is a good practice since calculation time is typically of no concern.

Example 2: A 6-inch layer of tabular alumina castable has been chosen as a working lining of a furnace wall. The engineer must determine the maximum amount of 2200°F (1204°C) lightweight castable which can be safely used for the insulating layer. The design criteria are:

1. Hot face temperature: 2500^{o}F (1370°C)
2. Outside air temperature: 100°F (38°C)
3. No forced air at outside surface
4. Emissivity of shell: 0.85

The thickness of the insulating component was varied from 2 to 5 inches in ½ inches increments. The temperature at the first interface, the shell temperature, and the heat flux for each lining thickness are shown in the second table on the following page. The 4-inch thickness gave an interface temperature of 2196°F (1202°C); this was essentially equal to the maximum service temperature of the lightweight castable, but it is common practice to allow a 100°F (38°C) safety factor. Therefore, a 2½ to 3inch thickness would be chosen.

Example 3: The shell of the furnace wall described in Example 1 is coated with aluminum paint (emissivity = 0.30). The computer solution indicated that the heat flux would decrease from 1099 to 1055 BTU/ft^2-hr (3465 to 3326 W/m^2) and the shell temperature would increase from 402°F to 547°F (206°C to 286°C). By decreasing the emissivity of the shell, less heat would be radiated to the surroundings; and since more heat would be retained (stored), the shell temperature would increase.

Heat Balance Calculations

T_o(°F)	R_T(ft²-hr-°F/BTU)	Q_L(BTU/ft²-hr)	Q_R(BTU/ft²-hr)	Q_{NC}(BTU/ft²-hr)
70	2.062	1275	0	0
170	2.235	1132	123	81
270	2.173	1118	321	193
370	2.137	1090	620	319
470	2.100	1062	1048	453
460	2.064	1085	998	440
450	2.071	1087	950	426
440	2.074	1090	904	412
430	2.078	1093	859	399
420	2.081	1095	816	385
410	2.085	1098	774	372
400	2.089	1101	733	358
401	2.092	1099	737	660
402	2.091	1099	741	361

Determinants of Insulation Thickness

Insulation Thickness (in)	Interface Temperature (°F)	Shell Temperature (°F)	Heat Flux (BTU/ft²-hr)
2	1980	460	1310
2 ½	2050	428	1130
3	2110	403	992
3 ½	2160	382	886
4	2200	364	802
4 ½	2230	348	732
5	2250	334	674

Example 4: The shell of the furnace wall described in Example 1 is cooled using forced air; the air speed is constant at 10 ft/ sec (3.05m/sec). Here, the convection mechanism is forced. The solution predicts that the heat flux would increase from 1099 to 1128 BTU/ ft²-hr and the shell temperature would decrease from 402°F to 297°F. The forced air flow would draw heat away from the outside surface at a faster rate; and since less heat would be retained, the shell temperature would decrease.

In Examples 1 through 4, it is assumed that the walls are flat. Many vessels have a cylindrical geometry which may require special treatment because the inside surface area may be significantly less than the outside surface area. In the case of a cylindrical vessel which is heated at the inside surface, heat flows radially outward, and even under steady state conditions, the heat flux decreases as the distance from the inside surface increases.

For this case ($T_i > T_o$), the equation for steady state heat flux at the outside surface caused by conduction is:

$$Q_L = (T_i - T_o)/r_o \sum_{j=1}^{n} (L_j/K_j)(\ln(r_{jo}/r_{ji})$$

where

Q_L = heat flux at outside surface, BTU/ft²-hr (W/m²)

T_i = temperature of inside surface, °F (K)

T_o = temperature of outside surface, °F (K)

r_o = radius of outside surface, in (m)

r_{jo} = outside radius of jth component, in (m)

r_{ji} = inside radius of jth component, in (m)

K_j = thermal conductivity of jth component, BTU-in/ft²-hr-°F (W/m-K)

lj = thickness of jth component, in (m)

n = number of components

The effect of wall curvature is indicated in the following example:

Example 5: The table below gives the shell temperatures and heat fluxes of cylindrical walls having different inside diameters but identical linings. Each wall is heated at the inside surface to 2000°F (1093°C) and consists of 6 inches of fused silica castable and a ¼ inch steel shell. Notice that as the inside diameter grows, the values approach those for a flat wall of the same construction.

In the sample calculations, values having as many as four significant digits were used to precisely illustrate various effects. Realistically, however, no more than three significant digits are appropriate.

Effect of Wall Diameter on Heat Flow

Inside Diameter (ft)	Shell Temperature (°F)	Heat Flux (BTU/hr-°F)
0.5	435	1240
1.0	471	1450
2.0	500	1630
4.0	519	1760
8.0	531	1850
16.0	538	1900
∞*	545	1950

* flat wall

INSTALLING CASTABLES

Overview

Castables are defined as the large group of refractory concretes containing a hydraulic setting binder. They are shipped dry and develop strength when tempered with water. These instructions cover the basic principles of castable installations with specific reference to mixing, consistency, placement, forms and curing. Individual product data sheets and package instructions provide information relevant to each product.

MIXING

All castable refractories should be mechanically mixed in a paddle mixer of 4 to 12 cubic foot capacity. These mixers assure a rapid, thorough mix, discharge the full batch and virtually clean themselves from batch to batch.

The mixer *must* be clean. Some substances found in dirty mixers combine with the cement in castables and can cause flash setting or otherwise lower the ultimate strength of the castable. The water used in mixing castable refractories must be fit to drink. In cold weather, warm water can be used to raise the temperature of the mix to between 60°F and 80°F (16°C and 27°C); however, it should never exceed 100°F (38°C). In hot weather, the water or castable should be cooled so that the temperature does not exceed 80°F (27°C) at the mixer.

To begin a mix, pour one-half to three-quarters of the total amount of water required for a batch into the mixer with the paddles turning. Add the dry castable in units of full bags. Segregation of castable components may occasionally occur during transportation. If a partial bag is to be used, the contents should be carefully dry mixed beforehand. Add the balance of water required to bring the mix to casting consistency in small increments after the castable in the mixer comes to a uniform color. Do not use more than the recommended amount of water. Decreased castable strength results from excess moisture.

Specific mixing instructions follow for Harbison-Walker's wide range of castables.

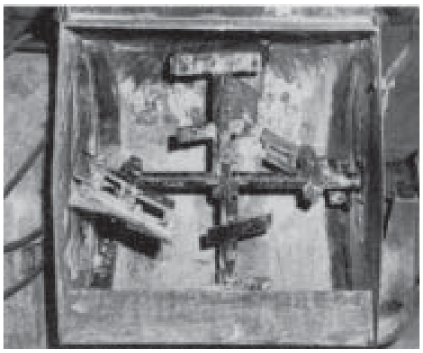
Conventional Castables

For mechanical mixing a clean paddle-type mixer is recommended. Add potable water to material and mix thoroughly to desired casting consistency. Water contents are listed on product data sheets. Dense castables should never be mixed for less than 2 to 3 minutes. Lightweight castables should be mixed for 2 to 3 minutes. To avoid breaking down the lightweight aggregate in the mix, do not over mix (i.e., past the point where proper casting consistency is reached). Excessive mixing will generate heat, speed up setting time, reduce strength and break down the aggregate.

Castable refractories tend to stiffen somewhat after leaving the mixer. Judgment on whether the mix has reached proper consistency should be made at the point of placement.

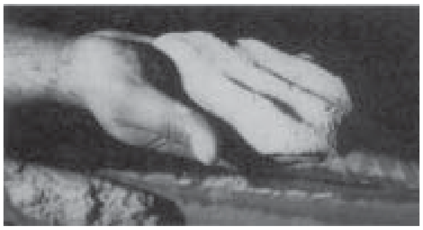
The "ball-in-hand" test for cast installations provides a useful guide to proper consistency. Tossed 6 to 12 inches, a ball of properly mixed castable should adapt to the shape of the hand when it is caught. The ball should not flow through the fingers or break apart. Breaking may indicate insufficient water in the mix.

Castables should be poured into forms immediately after they are mixed, particularly when being installed under high temperature and/or humidity conditions. In no case should the time between mixing and casting exceed 30 minutes. Castables containing high purity calcium-aluminate cements should be placed within 15 minutes.


A paddle mixer is used for castables.


This ball shows too much water in the mix.


This ball is too dry for casting.


A properly mixed ball shows the impression of fingers when tossed 6 to 12 inches in the air and caught.

EXPRESS® Free Flowing Castables

EXPRESS® castables are available in conventional and ultra-low cement formulations. They can be installed using a wide variety of pouring or pumping systems and require no vibration to fill the mold or surround anchors. EXPRESS® castables allow quick installation into the most intricate lining cavities and molds without forming air pockets.

VERSAFLOW® Castables and ULTRA-GREEN® Ultra-Low

Cement Castables

For mixing EXPRESS® and VERSAFLOW® castables, paddle or turbine mixers are recommended to obtain effective distribution of the low water additions for these products. Tempering water should be added conservatively and mixing continued for a minimum of five minutes. The longer mixing time will help distribute the low water additions. At one time, only mix an amount that can be cast within 30 minutes. Specific water contents are published on the castable bag and should be followed. At proper consistency, a handful of material should begin to level and consolidate when shaken vigorously back and forth. For pump cast installations with EXPRESS® and VERSAFLOW® castables, a wet "ball-in-hand" consistency is desired. Mixing often is done in large paddle mixers, continuous mixes and transit trucks.

Guidelines for placing ULTRA-GREEN® ultra-low cement castables are similar to those for VERSAFLOW®. Water contents for these products are critical in order to obtain maximum physical properties. These materials should be placed immediately after mixing, with extreme care in placement and vibration.

INSTALLATION

To prevent premature loss of moisture from the mix, forms or molds used for casting refractories must be thoroughly oiled or greased. The ultimate strength of the refractory will be reduced by premature loss of water required for hydration of the cement. Casting should be carried out quickly enough to assure that the exposed surface of the castable does not dry out.

All high strength castables should be vibrated into place, especially coarse aggregate mixes. An immersion vibrator should be drawn slowly up through the castable so it does not leave holes or channels behind. The mix is too stiff if the vibrator leaves holes (see accompanying photographs). Extended vibration will segregate components and weaken the castable.

For VERSAFLOW® castables and ULTRA-GREEN® ultra-low cement castables form vibration is the preferred installation method. This can be accomplished with a clamp-on or bolt-on style vibrator. Steel forms are preferable to wood forms, which tend to dampen vibration. When used, wood forming should be treated to prevent absorption of water from the mix and if the castable is placed against existing masonry, the masonry must also be waterproofed beforehand. Immersion vibration must be used with care to prevent holes being left when withdrawing the vibrator from the castable. Extended vibration will segregate the components and weaken the castable.

Generally speaking, construction joints will coincide with the expansion joints shown on the drawings of the installation. Whenever possible, an alternate bay system should be used in construction. This permits initial shrinkage to take place prior to installation of the adjacent section, and reduces total linear shrinkage within the lining.

Pumping Installations

Most conventional castables are not typically installed using pump casting methods due to segregation of mixes at high water contents.

EXPRESS® and VERSAFLOW® castables can be installed using pump casting methods.

For large installations where pumping the castable is the desired method of placement, tempering water contents in the upper end of the recommended range will be necessary. Large multiple paddle mixers or Redi-Mix trucks have been used for this type of installation.

IMPORTANT SAFETY NOTES

All persons performing castable installations should wear protective long-sleeved clothing, gloves and plastic safety helmets, as well as close-fitting safety goggles. A respirator mask should be worn over the mouth and nose to protect the respiratory tract from dust.

This mix is right for vibration casting.

This contains too much water for vibration.

There is not enough water in this batch.

CURING

Upon mixing with water, an exothermic hydration reaction takes place with the calcium aluminate cement. Mixing and casting should always take place in ambient temperatures between 60°F and 80°F (16°C and 27°C). This is because the heat released from the exothermic reaction tends to increase the material temperature into the temperature range for optimum development of strength.

The heat released during the hydration reaction may partially dry out the refractory surface. Loss of water from the surface before the cement is fully hydrated promotes dusting when the furnace is heated. The preferred and common method to prevent surface moisture loss is to spray a generous coating of resin-based concrete curing compound onto the surface. The curing compound will form an impermeable membrane or vapor barrier during curing, but will burn off at relatively low temperatures.

After the initial 24-hour air cure and under ideal conditions, the refractory may be air dried indefinitely before heat is applied.

Curing Temperatures Less Than 70°F (21°C)

As with all chemical reactions, the cement hydration reaction is time-temperature dependent. The lower the atmospheric temperatures, the slower the hydration reaction therefore, increased curing time is required.

In cold weather, i.e., less than 50°F (10°C), the cement-containing monolith should be mixed and installed within the temperature range of 50°F to 80°F (10°C to 27°C). The temperature in the area where the castable is being installed should also fall within this range. Space heaters can be used to accomplish this. Temporary exterior shell insulation can be used to retain heat on the steel shell generated by the heat of hydration.

If the unit is to be idle for long periods in very cold weather, the lining should be heated to at least 250°F to 300°F (121°C to 149°C). This temperature range is sufficient to drive off excess casting water and prevent ice crystal formation within the refractory. In long periods of cold weather, releasing steam into the unit is an ideal way to heat the lining.

Refractory damage will occur if the cement freezes before it has developed full strength. Seventy to eighty percent of the cement's strength should be developed after the 24-hour cure, but this takes longer in very cold weather. Curing at low temperatures also increases the risk of steam spalling during initial heat-up.

STORAGE

To obtain maximum storage life for castable and gun mix refractories, the material must be kept completely dry. Castables and gun mixes should be stored away from weather elements, preferably indoors. If stored outside, the bags must be protected from rain or dripping water. If bags are protected by plastic sheeting, be sure there is sufficient ventilation under the plastic sheet to prevent water from condensing on the bags. Do not set bags on damp ground or concrete, and avoid storing in areas of high humidity.

All Harbison-Walker castables and gun mixes have a finite shelf life. Any castable or gun mix will eventually become unsuitable for use, even under good storage conditions. Typically, storage life for conventional castables and gun mixes is one year from date of manufacture. Harbison-Walker castables are stamped with a code date when manufactured to aid in determining the age of the material. This also aids in rotating inventory to use the oldest code dated materials first. New products and low cement castables may have shorter shelf lives. Consult Harbison-Walker for the current shelf life of these materials.

HEAT-UP

See Heat-Up information on page UR-14

INSTALLING GUN MIXES

Overview

Harbison-Walker Gun Mixes are specifically designed to provide the highest quality gunned linings at the lowest possible installed cost. The installation procedures review the steps to control predampening, air pressure, material feed, nozzle water and flow technique. Following the installation steps as outlined is most important to assure the quality of Harbison-Walker's Gun Mixes.

Predampening

Proper predampening is required to control hose flow and limit rebounds and dust at the point of application. For dense gunning mixes, pre-dampening with 4% to 6% by weight of water in a paddle or similar mixer is typical. Lightweight and medium-weight gunning mixes could require 10% to 15% or more by weight of water. Material consistency should allow a handful of the gun mix to be squeezed into a column which, when tapped, breaks into pieces. For KAST-O-LITE® Gun Mixes pre-dampening to high moisture levels is the key to successful installation. Refer to specific product data sheets for recommended levels.

Air Pressures and Material Feed

Harbison-Walker gun mixes require high air pressures and high material feed rates for optimum installation. A 600 CFM, 100 psi air compressor is suggested for single gun operation. Larger compressors are recommended when several guns are used concurrently.

High air pressures and material feed rates speed the gun mix through the nozzle water ring. This tends to widen the water range because the more material that passes the water ring per given amount of time the less sensitive the material is to slight changes in the amount of water added. High pressures also help reduce laminations within the refractory mass.

Nozzle Water Control

The appearance of the gunned refractory surface is the best indicator of the correct water/mix ratio. The amount of water should be controlled so that a gunned surface has a wet, silky sheen and the coarse aggregate makes craters on the surface upon impact. A sandy, gritty surface indicates too little water is being used. Slumping, ripples or a washboard effect on the surface indicates too much water is being used.

Harbison-Walker's Gunning Mixes were designed to have a wider water range and therefore less sensitivity to the amount of water added. Gunning materials have optimum adhesion in the "sticky" material condition. In Figure 1, it is clear that the water adjustment range is much wider for optimum adhesive quality. Water control is not as critical and product slumping and dusting is minimized. With old style gun mixes (castables shot through a gun), the proper sticky consistency range is very narrow.

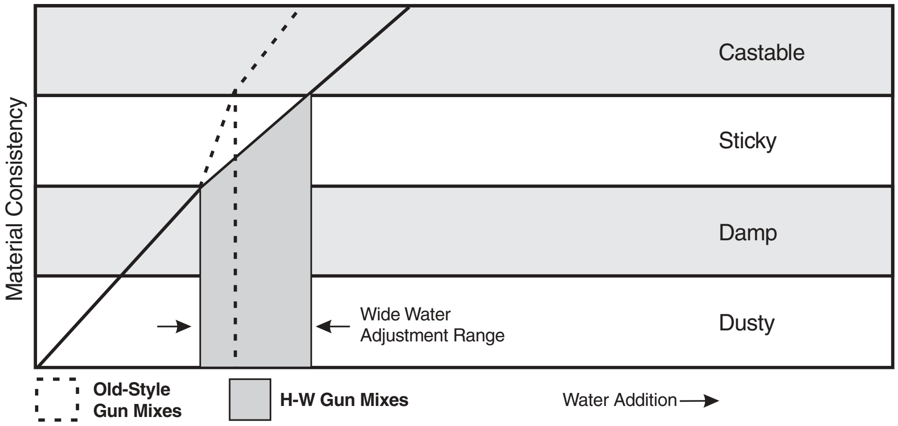
Equipment Preparations

Prior to start-up, check to insure that the hoses are laid with no loops to prevent plugging. The water ring and nozzle liner must be clean and in good condition. There should be plenty of air for sufficient material flow and at least 80 psi water via a $^{3}/_{4}$-inch diameter hose. If one of these variables is below par it can adversely affect the flow emerging from the gun and ruin the quality of the job. Water booster pumps can help achieve up to 150 psi water pressure and should be used with H-W gun mixes.

Controlling the Flow

When gunning starts, the nozzle operator and gun operator are teammates. Together, by means of hand signals or radio, they control air and water pressures and material feed rates so that proper flow occurs and the correct consistency of material emerges from the nozzle.

Figure 1



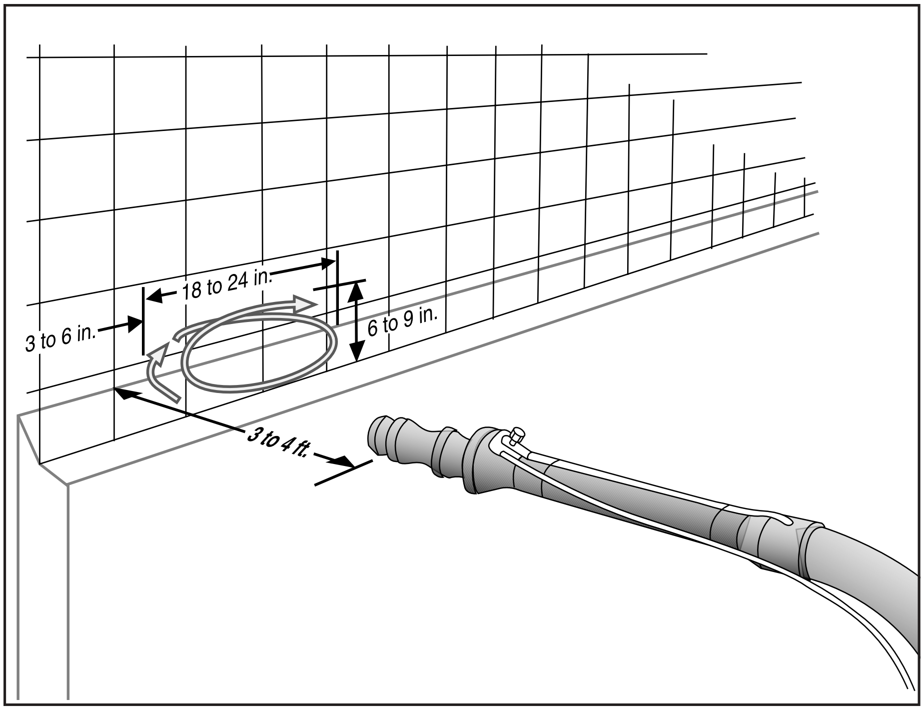


Illustration 1
Direct nozzle spray to form loops.

Aiming the Nozzle

Once proper flow is achieved, the nozzle operator should direct the stream of material at the base of the wall and proceed to build upward. The nozzle should be kept perpendicular to and about three to four feet from the surface of the work. Material is deposited as the nozzle is moved rhythmically in a series of oval loops six to nine inches high and 18 to 24 inches wide. See Illustration 1.

Be careful that rebounds fall or bounce clear of the target and are not entrapped. Entrapment of rebounds by the fresh stream from the nozzle can lead to laminations or spots of low density in the lining.

General Gunning Preparations

Most of the water is added at the nozzle during placement. Typically, most gun mixes should be predampened before gunning. This makes flow through the nozzle easier and traps cement that might dust off at the nozzle.

During actual gunning, the nozzle should be pointed at an angle 90 degrees to the surface, and work should begin at the lowest point of the installation. Corners should be shot first in order to prevent trapping rebounds. Limit the work to an area which can be kept moist.

Gunning to repair existing linings provides somewhat better adhesion than casting, especially for irregular patches. Anchors should be welded on the shell in the appropriate anchor pattern spacing. The edges should be square and the patch area clean. For better adhesion, the existing refractory should be wetted immediately before placement. Following standard procedures, the new material can be gunned into place.

Installing Medium-weight and Lightweight Gunning Mixes

A quality medium-weight or lightweight installation depends at least as much on the gunning technique as on the characteristics of the gun mix. With traditional techniques, higher than specified densities and relatively high rebounds are expected. High predamp and high gun pressure reverse the rules, reducing rebounds and significantly lowering the density of the installation. At the same time, these techniques can also increase production rates.

Harbison-Walker recommends the use of high predampening and high pressure material feed rates. Maintain the nozzle-to-surface distance of three to four feet. Following these procedures will significantly cut rebounds, lam-inations and density, as well as material, labor and installation costs, while increasing the insulating value of the lining.

HEAT-UP

See Heat-Up information on page UR-14

DRYING AND HEAT UP OF CASTABLES AND GUN MIXES

HEAT-UP

After curing for a minimum of 24 hours, castable and gun mix linings must normally undergo a controlled heat-up schedule to remove the moisture. This is especially true for those containing high strength, high purity binders.

Heat will remove the free water as steam at around 212°F (100°C), while the water of hydration will be driven off between 400°F (204°C) and 1200°F (649°C). With increasing temperature, sintering takes place between the cement and the refractory aggregate in the 1,600°F to 2500°F (871°C to 1371°C) range (depending on the aggregate and binder).

Initial firing rates typically raise the temperature at about 50°F (28°C) per hour. For high strength, high purity cement binders, the rate is 30°F (17°C) per hour. Normally, holds are incorporated at 250°F (121°C), 500°F (260°C) and 1000°F (538°C). The time period for the temperature hold is dependent on refractory thickness. Thicker linings contain a larger volume of material and thus, a larger volume of water. Steam dissipation should be slower for thicker linings to prevent steam spalling. As a rule of thumb to determine the time period, use one hour per inch of thickness for dense linings. The hold period helps dissipate steam and allows heat to penetrate the lining (this avoids a steep thermal gradient with increasing temperature). Steep thermal gradients can cause stresses within the lining and spalling. If, at any point during the heat-up, steaming is noticed, the temperature should be held until steaming subsides. Direct flame impingement on the refractory should be avoided.

Because each installation is unique, no one dry-out schedule can be advised to fit all uses. Consult your installation representative for specific guidance.

For the proper schedule for specific products, use this link to the Mixing and Use section of our web site. www.hwr.com

CAUTION:

IF PROPER PROCEDURES FOR PREPARATION, APPLICATION AND HEAT-UP OF CASTABLES ARE NOT OBSERVED SPALLING DURING HEAT-UP MAY OCCUR.
SEE INSTRUCTIONS ON PRODUCT PACKAGE.

THE TEMPERATURES REFERRED TO IN SCHEDULES ARE THE TEMPERATURES OF THE HOT GASES IN CONTACT WITH THE CASTABLE OR GUN MIX AND NOT THE LINING ITSELF. THERMOCOUPLES MAY BE PLACED ½” AWAY FROM THE LINING SURFACE FOR AN ACCURATE MEASURE OF TEMPERATURE DURING HEAT-UP.

IF AT ANY TIME DURING THE HEAT-UP OR HOLD TIME, STEAMING OF THE LINING IS OBSERVED, THE HOLD PERIOD SHOULD BE MAINTAINED UNTIL STEAMING SUBSIDES. INCREASED HEATING DURING STEAMING CAN RESULT IN SIGNIFICANT STEAM PRESSURE BUILD UP AND POSSIBLE STEAM SPALLING.

PROPER VENTILATION AND AIR CIRCULATION WITHIN THE FURNACE MUST BE PROVIDED FOR THE REMOVAL OF STEAM AND EXHAUST GASES. FLAME IMPINGEMENT ON THE REFRACTORY MUST BE AVOIDED. THIS WILL CAUSE LOCALIZED OVERHEATING AND POSSIBLE SPALLING.

Overview

H-W manufactures plastics for both rammed and gunned installations. Here are some basic guidelines for the proper installation of each.

RAMMED PLASTICS

Procedure

A pneumatic ramming tool with a minimum 2½ – 3-inch convex aluminum head is strongly recommended for positive knitting of plastic refractory slabs. When ramming plastics, the best knitting is accomplished by breaking the slabs into smaller pieces. The direction of the rammer should always be parallel to the hot face of the material and vessel walls, roof or floor. The entire mass should be rammed thoroughly two or three times to secure its integrity. The best anchor system to use with rammed plastics are ceramic anchors. When seating anchors into the plastic, tap them into the mass with a leather mallet to be certain that they set properly and that there are no voids around them. When ramming around burner ports or refractory anchors, slabs of plastic must be broken up to facilitate installation in these tight areas.

As installation progresses, the ramming force should be directed into the main refractory mass in a manner that forces the plastic to seal against the anchors or ports. A lining thickness overage of ⅛ – ¼-inch of plastic should be installed, so that when forms are stripped and the surface of the hot face is finished, the refractory mass will retain its full specified thickness. When ramming next to forms, ram the 3-inch area adjacent to the form one extra time to minimize laminations.

Peening. Plastic adjacent to anchors should be lightly rammed up and around the anchors to give a tighter seal.

Wall Finishing. After ramming is completed, the hot face of the plastic must be trimmed (or shaved) back to the face of the refractory anchors, using a trowel or trimming spade. Care should be taken not to peel the plastic away from the anchor. Shave toward the anchor to press the plastic tight against the anchor. If forms were needed, only strip as much as can be finished in a short time, e.g., two or three hours. This will save material and make a better installation.

During trimming, special care must be taken not to smooth the exposed surface of the refractory hot face; a coarse surface is necessary for uniform drying. To minimize and control cracking on all massive installations, it may be desirable to cut “construction joints” in the refractory hot face. These joints should be scored approximately 2 inches deep on 36-inch centers, horizontally and vertically between anchors. After scoring the joints with a trowel, they should be patted shut so that only a thin line remains on the surface of the hot face.

Roof Finishing. Overhead installation of plastics, particularly phosphate-bonded types, requires special attention. Generally, they require support forms to prevent slumping during installation. After ramming, these forms need to be progressively removed and replaced with expanded metal since the ignition of wood forms during heat-up can cause spalling of the refractory surface. As an intermediate step, the plastic adjacent to anchors should be lightly rammed up and around the anchors to give a tighter seal. This technique is called peening.

Venting

Immediately after finishing is complete, pierce the finished plastic with a $^1/_8$ or $^3/_{16}$-inch diameter rod to provide escape vents for steam which develops during heat-up. These steam vents should be installed on 8 or 12-inch centers and should penetrate to about two-thirds of the refractory lining thickness.

For special conditions such as very thick walls, please contact Harbison-Walker's Technical Support Group in Pittsburgh, Pennsylvania for installation guidelines.

Patching with Plastics

Refractory plastics provide a simple way to repair almost any worn brick, castable, or plastic refractory structure. Strong, phosphate-bonded plastics are especially suited for repairs. To make a lasting repair patch, chip back the worn refractory area until a sound, unpenetrated and unaltered surface is exposed. Loose particles must be removed and, for best results, the void should have steeply angled sides to provide a grip for the repair patch. In any but the smallest patches, it is advisable to cut away the worn refractory in a V-shape toward the cold face. This helps tie in the patch with the refractory mass. When using phosphate-bonded plastics, a thin coat of PHOXBOND® high-alumina phosphate-bonded mortar should be applied to the entire void after the surface is prepared. Trim off any excess plastic in the patch so that its surface is flush with the hot face. Roughen the surface of the patch to facilitate moisture removal. The patch will develop a phosphate bond at approximately 500°F (260°C) during heat-up and will become extremely strong and resistant to penetration and erosion.

GUNNED PLASTICS

Here you can see the BSM Gun, the “V” Shaped opening in the bulk carton, and the GREENGUN® plastic being raked into the hopper.

Gunning Advantages

GREENGUN® Plastic Gunning Technology was developed in 1986 in response to refractory contractors who were looking for a more efficient and faster method to install plastic refractory. The best anchor system to use with gunned plastics are ceramic anchors. The installation time of GREENGUN® can be as much as 50% less than the installation time of air rammed plastic. Today, H-W’s GREENGUN® Plastics are widely accepted throughout the refractory market place.

Installation

Equipment. The key to a successful installation is the GREENGUN® BSM Gun, Model GL 404-50, with a 15 pocket feed wheel.

Other required key hardware includes:

- 1⅜" ID, high pressure, BSM material hose, which is available in 33' lengths.
- a 440 volt, 3 phase, electric power source required to operate the BSM Gun.
- a 750 CFM air compressor needed to transport the gunned material through the hoses.

Common job tools needed for installation are a fork lift, two way radios, shovels, trimming tools, face shields and hard hats, plus extra wear pads and drive belts.

Harbison-Walker is the exclusive distributor for the BSM Gun in the United States and the gun is available to rent or purchase.

Procedure. The typical crew size on any GREENGUN® project is 4 to 6 people. The crew includes: one BSM Gun operator, one nozzle man, two material handlers, and for larger jobs, two trimmers and rebound reclaimers.

The installation process is very simple. The GREENGUN® bulk containers are placed above the BSM Gun. Next, the GREENGUN® carton is cut into a “V” shaped opening. Then the material is raked into the feed hopper of the BSM Gun. The GREENGUN® material falls into the feed wheel pockets. Air pressure transfers the material into the hose and is then applied to the refractory surface.

GREENGUN® Plastics gunning rebound can be recycled. For estimating purposes, typical rebound rates with GREENGUN® are 15-20%.

HEAT-UP

It is necessary to begin heat-up as soon as possible after completion of the structure. If this cannot be done, all refractory surfaces should be covered with a resin-based curing compound to slow drying and reduce shrinkage cracks. The use of a colored curing compound is helpful when performing a visual inspection of surface coverage. Shrinkage cracks should be resprayed with curing compound to keep them from getting larger, although they normally close during heat-up. If desired, cracks can be sealed with a slurry of PHOXBOND® mortar. (Do not use an air-setting mortar.) Remove forms; do not permit wood forms to burn out. If forms cannot be removed, then expanded metal forms are often a better choice because they allow the heat to penetrate the plastic better.

PLUS® DESIGNATION

Plastics that include the word PLUS® in the product name contain non-metallic fiber additions to facilitate moisture removal during the dry-out. These plastics have passed a very severe spalling test indicating that under specific conditions they can be heated more quickly. For specific heat-up requirements, contact your Harbison-Walker Sales Representative.

PACKAGING

Harbison-Walker packages rammed plastic refractories in 55-lb (25 kg) or 100-lb (44 kg) cartons. The refractory mass is divided into four to six slabs, or more, depending on product or customer preference. Plastics are made to specified workability and moisture levels. Harbison-Walker will manufacture to individual customer requirements as needed. This can be important when thick walls, overhead installation, or immediate installation is anticipated. Please discuss your special workability needs with your H-W representative. Plastic is sealed in polyethylene to minimize moisture loss and preserve the plastic's workability.

Gunned plastics are packaged in 1500, 2500, and 3000-lb. bulk containers.

Storage

STORAGE

Even though Harbison-Walker plastic refractories are carefully packaged to retain moisture, dry-out is possible if plastics are stored too long, especially in warm places. Unopened packages of plastic materials should be stored in cool, shaded areas under roof and away from sources of heat. The optimum temperature for storage of plastics is 55-60°F (13-16°C) . If plastics must be stored outdoors, the packages should be covered with a tarpaulin or similar covering. In hot outdoor areas, the tarp or covering should be raised to provide an 8–12 inch space for air circulation. In winter, plastics should be prevented from freezing. As a rule of thumb, use plastics as soon after receipt as possible, on a first-in, first-out basis. Check all plastic carefully before use. During installation, unwrap only as much plastic as is immediately needed. Pre-opened plastic may lose moisture and workability, resulting in improper knitting of slabs and a less than satisfactory installation.

WINTERIZING

For heat-set and air-set plastics, Harbison-Walker offers a winterized version. This lowers the freezing point to below 15°F (-9°C) and permits storage of the products at lower temperatures. The winterizing process has no effect on refractory properties. Phosphate-bonded plastics already have a similar freezing point and do not require winterizing. All plastic materials, even those winterized, should be kept above freezing before installation and, equally important, after installation until heat-up.

Schedule I:

Heat-Setting and Air-Setting Plastics

1. From ambient temperature, heat to 500°F (260°C) at the hot face of the lining at a rate not exceeding 50°F (10°C) per hour.
2. Hold at 500°F (260°C) for one hour per inch plastic thickness.
3. Heat to 1000°F (538°C) at a rate of 50°F–75°F (10°C–24°C) per hour.
4. Hold at 1000°F (538°C) for one hour per inch plastic thickness.
5. Heat to operating temperature at a rate not exceeding 100°F (38°C) per hour.
6. Hold for steaming (see note).

Schedule II:

Phosphate-Bonded Plastics

1. From ambient temperature, heat at a rate not exceeding 50°F (10°C) per hour to 250°F (121°C) at the hot face of the lining.
2. Hold at 250°F (121°C) for one hour per inch plastic thickness.
3. Heat to 500°F (260°C) at a rate of 50°F (10°C) per hour.
4. Hold at 500°F (260°C) for one hour per inch plastic thickness.
5. Heat to 1000°F (538°C) at a rate of 50°F–75°F (10°C–24°C) per hour.
6. Hold at 1000°F (538°C) for one hour per inch plastic thickness.
7. Heat to operating temperature at a rate not exceeding 100°F (38°C) per hour.
8. Hold for steaming (see note).

Note: If steaming of the lining is evident at any time during heat-up, hold the temperature until steaming subsides.

INSTALLING RAMMING MIXES

Overview

Rigid forms are required when ramming vertical walls, roofs, or arches and care must be taken to prevent deflection of the forms during the ramming operation. Ram at the most acute angle possible to the hot face.

RAMMING

An anvil-type or reciprocating air rammer having a metal ramming head should be used to install Harbison-Walker ramming mixes. Metal ramming heads are of various shapes and sizes. The type of installation involved determines which is appropriate. Serrated ramming heads have been used for some installations.

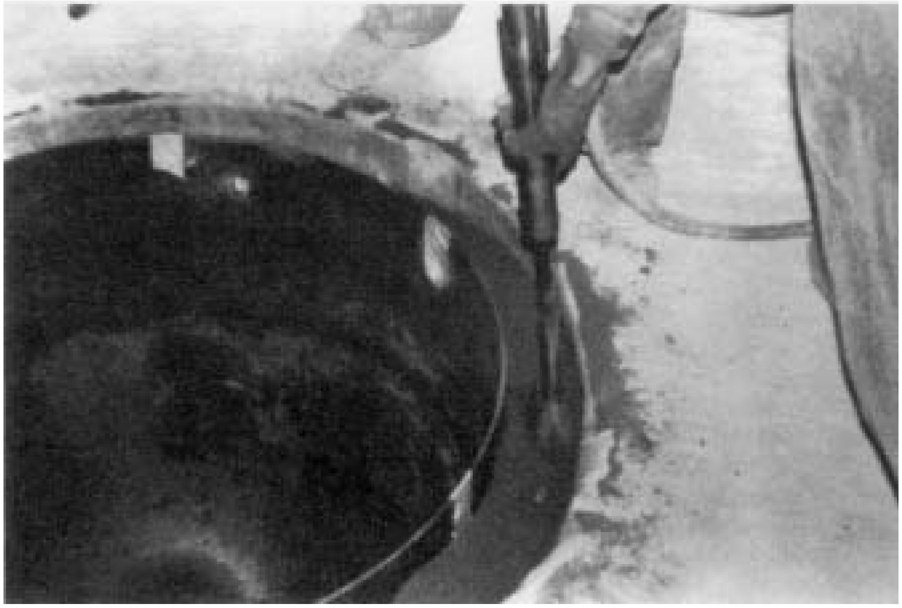
Continuous feeding of the mix during ramming is preferable to batch feeding. When batch feeding the material, the smooth surface formed by the rammer should be roughened with a small trowel or small rake to eliminate laminations and provide a continuous bond from batch to batch. Score each layer to approximately ¼-inch depth to assure knitting of the subsequent layer. The blows of the rammer should be directed in such a manner that lamination planes are not parallel to the hot face of the ramming mix.

Proper installation of Harbison-Walker ramming mixes will provide a dense, lamination-free structure. A good indication that the material has been rammed sufficiently, is when the rammer head leaves noticeable tracks in the top face of the layer. The surface should then be scored and additional material rammed. The installation should be finished in one continuous operation, if possible. If it is necessary to interrupt the ramming operation for more than one hour, cover the unfinished area with a damp cloth so that the face will remain moist and new material will bond to it properly.

HEAT-UP

Bring temperature up slowly, at a rate of no more than 75°F (40°C) per hour and hold at 500°F (260°C) for at least one hour for every inch of thickness. Temperatures then can be increased at a rate of no more than 100°F (55°C) per hour until operating temperatures are reached.

Installing ramming mix in top cap of coreless induction furnace.



FURNACE REFRACTORY LINING & CONSTRUCTION

Overview

Sound furnace refractory lining and construction — whether carried out by experienced masonry specialists working on a high production furnace or a contractor building a municipal incinerator — begins with a few fundamental ideas required to produce satisfactory performance.

FOUNDATION

The foundation must function at the temperature produced by the furnace. For many industrial furnaces, contractors build foundations of concrete, consisting of a crushed stone aggregate, sand and binder of hydrated Portland cement. Under normal conditions, Portland cement concrete has been safely used for furnace foundations up to 700°F (371°C). When the temperature reaches 900°F (483°C), dehydration of the cement reaches a point where the concrete retains little mechanical strength.

Ordinary aggregates include quartz pebbles, silica gravel, crushed silica rock and/or crushed limestone. An aggregate of silica rock in any form will expand sufficiently at temperatures up to 1000°F (538°C) to set up stresses in the concrete and weaken the foundation. Limestone or dolomite rock in an aggregate will calcine at somewhat higher temperatures and weaken considerably. For temperatures above 700°F (371°C), good practice points to the choice of a castable refractory for the foundation. Calcined fireclay, in sizes up to 1 inch, can be substituted for conventional aggregate. Its thermal expansion is low, and it will not shrink at the highest temperature to which concrete can be subjected.

High temperature furnace operation also calls for ventilation in the lower courses of brickwork or the upper part of the foundation. Good furnace design often requires placement of the furnace on plates, girders or low brick piers, so that air circulates under the vessel. Sometimes, cross flues are formed in the top of the concrete foundation. At others, pipes, 3 inches in diameter or larger, are embedded in the foundation.

Building furnaces is a specialized branch of masonry, best placed in the hands of bricklayers experienced in furnace construction. Walls, arches and other furnace details should be designed and constructed to assure structural stability. Otherwise, a return on your refractory investment may not be realized.

WALL CONSTRUCTION

Courses of brick laid in a wall so that the lengths parallel the face of the wall are called stretchers. Brick with lengths running at right angles to the face are headers. In soldier courses, the brick stand on end, and in row-lock courses, they lie on one edge (See illustration, UR - 20).

Header courses tend to spall less than stretchers at the hot face of a furnace wall because they expose a smaller area to high temperature. However, stretcher courses expose fewer joints than headers, and this provides an advantage in applications where joints tend to wear more rapidly than brick.

Bonding, or tightening construction through combinations of headers and stretchers and off-setting vertical joints, strengthens and stabilizes furnace walls. The type of bond selected for any particular furnace will depend upon the design of the furnace, thickness of the walls, the need for gas-tight construction, severity of operating conditions and the need for easy maintenance.

In any case, the wall should be bonded so that loads will be transferred to the cooler part of the wall when the inner, hotter portion loses its ability to carry them. Walls must be designed to carry structural loads at high temperatures.

Stretcher walls — one brick thick — usually have the least structural stability, but they are sometimes used in smaller furnaces and in furnaces where heat must pass through the walls. Double tongue and groove brick provide stability for thin walls.

Alternate header and stretcher courses probably provide the most common arrangement for standard industrial furnaces. Large 9-inch brick break joints, start ends of walls and turn corners.

Courses consisting mostly of headers are often used advantageously in 9 and 13½-inch walls subject to high temperatures, heavy loads and slag attack. This construction is usually preferred for basic brick walls. The bond provides stability and easy replacement, but most expansion joints pass entirely through 9-inch walls.

Courses consisting mainly or entirely of headers on the inner face and mainly stretchers on the cold face are sometimes considered desirable when spalling conditions are severe. Three or four stretcher courses to one header provide a wall to which a 4½-inch skin wall can be tied for repairs. However, it should not be used where stretcher courses may fall into the furnace.

In composite wall construction consisting of two or more kinds of brick in inner and outer courses, the courses are sometimes tied together. Usually, the more refractory brick go into the interlocking courses.

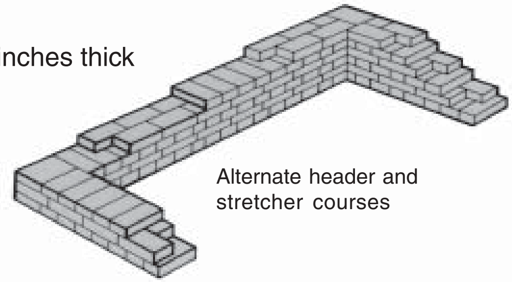
However, when brick have marked differences in rates of thermal expansion, the backup courses should not be tied to the inner courses. This is especially true when the temperature gradient through the wall makes a significant difference in total expansion.

The number of refractory straights required to build a simple wall can be determined from the chart on UR - 21. Multiply brick per square foot from the appropriate row, depending on wall thickness, by the area of the wall to provide the brick count. For walls not of simple rectangular shapes, determine the volume in cubic feet from the appropriate formula on this page and multiply by the number of brick per cubic foot.

Wall thickness must bear some relation to height and unsupported

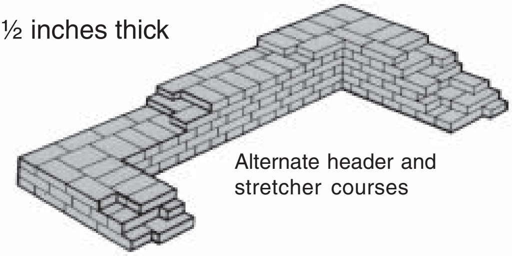
BONDING OF WALLS BUILT WITH RECTANGULAR BRICK

Wall 9 inches thick



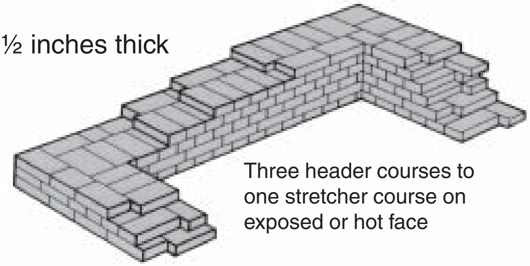
Alternate header and stretcher courses

Wall 13½ inches thick



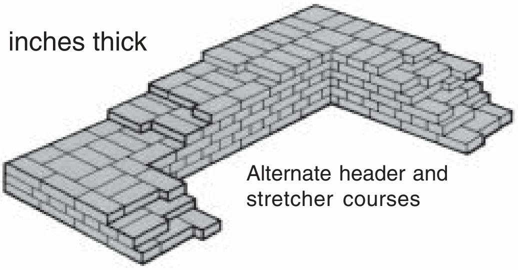
Alternate header and stretcher courses

Wall 13½ inches thick



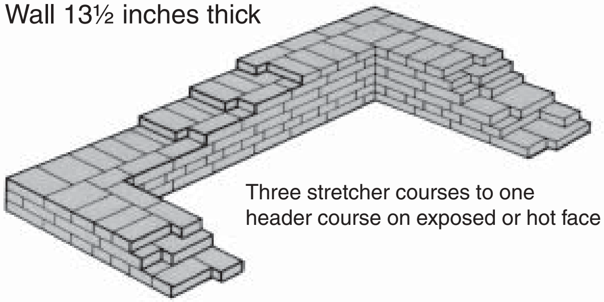
Three header courses to one stretcher course on exposed or hot face

Wall 18 inches thick



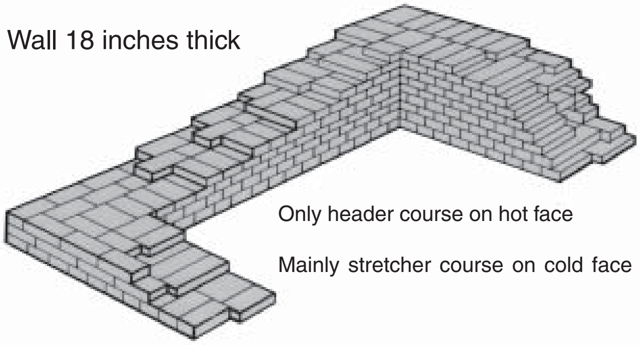
Alternate header and stretcher courses

Wall 13½ inches thick



Three stretcher courses to one header course on exposed or hot face

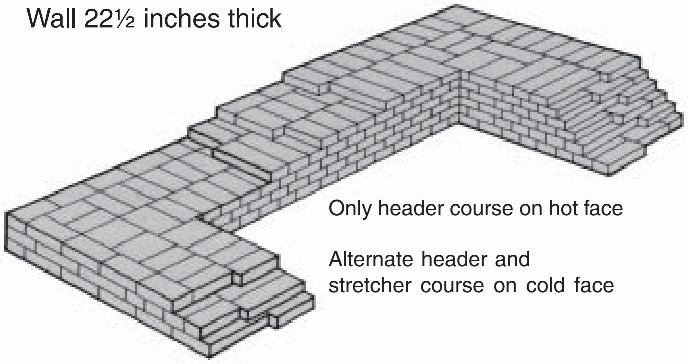
Wall 18 inches thick



Only header course on hot face

Mainly stretcher course on cold face

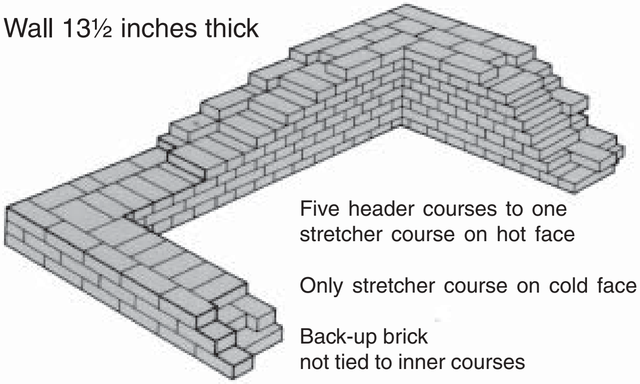
Wall 22½ inches thick



Only header course on hot face

Alternate header and stretcher course on cold face

Wall 13½ inches thick



Five header courses to one stretcher course on hot face

Only stretcher course on cold face

Back-up brick
not tied to inner courses

length. In unsupported straight walls, a 4½-inch thickness will carry heights up to 3 feet; 9 inches will carry heights of 3 to 8 feet; 13½ inches, 8 to 12 feet; and 18 inches, walls higher than 12 feet.

Walls with unsupported length more than one and one half times their heights should be somewhat thicker, and thermal spalling conditions may indicate additional thickness. Walls of cylindrical furnaces and stacks, with adequate backing, may be somewhat thinner for a given height than straight walls.

Cylindrical walls, arches and domes are built with brick tapered to turn circles. Arch brick slope from edge to edge so that the length of the brick parallels the furnace wall like a stretcher, while the wedge tapers from end to end so that it faces into the furnace like a header. A 9 x 4½ x 2½-inch arch brick makes a 4½-inch lining, while the same wedge shape makes a 9-inch lining. In basic brick, key brick shapes may also taper along the edges. Combinations of these shapes taper in two dimensions to turn domes.

JOINT CONSIDERATIONS

In many cases, brick sizes and shapes or the type of bond will be chosen to minimize the number of joints in the lining. Monoliths — not without construction or thermal expansion joints – present the fewest joints and opportunities for penetration by metal, slag or furnace gases.

Ramming mixes or castable refractory materials are often used to fill places where brick would be cut to fit. For example, ramming mixes or dry refractory materials can be used to protect the toe of the skewback (See discussion of Arch Construction, UR - 22). On many installations, the irregular space between electric furnace roof brick and electrode ports is filled with ramming mix or castable refractories.

The thickness of joints between refractory brick depends on the brick, the mortar, the need for preventing gas leakage or slag penetration, and the requirements for thermal expansion. When there is no need for an especially strong bond, the brick are laid without mortar. In some cases, the fusion that takes place on the hot face will provide the bond required. Generally, however, the use of mortar is desirable to level courses and to provide smooth bedding for the brick.

Brickwork laid with heat-setting mortars should have thin joints, either dipped or poured. The brick should be rubbed or tapped into place to produce as much brick-to-brick contact as possible. Joints made with an air-setting mortar generally can be somewhat thicker, but such joints should be completely filled.

In furnace construction, proper allowance must be made for thermal expansion. Usually, vertical expansion allowances permit walls to move freely upward and horizontal expansion allowances appear at joints in the brick. The subject is covered in some detail in the discussion of thermal expansion which begins on UR-4.

HEARTHS

The construction of furnace hearths presents special problems. Some furnace bottoms must withstand impact and abrasion from a charge of scrap metal. Liquid pressure may tend to float brick. Many hearths must resist penetration by metal or slag accompanied by corrosion or erosion.

Furnace hearths, in many cases, are built of refractory brick, usually seated on a monolithic refractory bed. Others have sub-bottoms built of brick with working hearths composed of monolithic refractories, such as dead-burned magnesite or a ramming mix.

Construction details, as well as the refractories themselves, depend on applications. Even different furnaces within the same application area may perform more efficiently with a different refractory design.

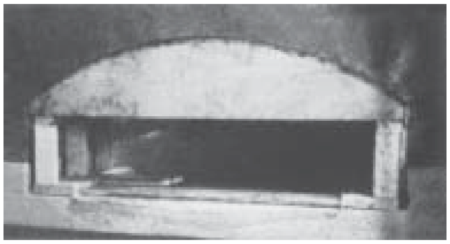
Sophisticated applications for refractories call for specialists in refractories design. A number of engineering firms specialize in high temperature process design, and many contractor/installer organizations concentrate on refractory construction.

Harbison-Walker maintains close contact with these organizations, lending its engineering skills and applications know-how to the search for solutions to any problem involving the use of refractories.

Number of Refractory Straights Required Per Square Foot of Wall or Floor

Thickness, Inches	9 x 4½ x 3” Brick
3	3.6
4½	5.3
6	7.2
7½	8.9
9	10.7
12	14.2
13½	16.0
18	21.4
27	32.1

Rammed plastic refractories used for arch construction minimize the number of joints.



ARCH CONSTRUCTION

Overview

Arches form the roofs of most furnaces, combustion chambers and flues. Providing the standard solution to the problem of spanning the high temperature process with refractories. In some application, arches span wall openings, and sometimes they carry the weight of walls or checkerwork. Most arches are built of brick, but monolithic materials are gaining popularity throughout the industry.

TYPES OF ARCHES

Sprung Arches

In a true arch, the design of the whole determines the shape of each block or structural unit. Theoretically, each joint is a small piece of the radius of the circle of which the arch is a segment. Each end of the arch rests on a skewback. The arch becomes self-supporting after all of the pieces go into place, but it must be supported until the final, center shapes the keys go into place. When it is complete, the arch springs from the sloping faces of the skewback shapes. The skewbacks cut off the arc of the circle on the outside radii of the arc.

The sprung arch exerts a downward vertical force and an outward horizontal force on the skewbacks, essentially a distribution of its weight. The vertical force may be carried by steel beams or by the furnace walls or a combination of walls and steel buttresses. The horizontal thrust of a roof arch travels through the skewbacks to a steel supporting system known as the binding which is composed of beams and tie rods. The tie rods, usually above the furnace, link one side of the furnace to the other, and balance opposing forces, one against the other.

In traditional furnace design, the binding consists of:

1. *Horizontal buttress beams running lengthwise to the furnace in contact with the skewbacks where possible;*
2. *Vertical beams, or backstays, spaced at intervals along the concrete; and*
3. *Horizontal tie rods, I-beams, or channels extending across the furnace above the roof to connect the upper ends of opposite buckstays.*

Ring Arches

In ring arches, each course of brick forms a separate ring running across the roof and the joints are continuous across the roof. Ring arches require somewhat less labor for initial construction. Cold repairs are easier to make and they offer better resistance to spalling. However, ring arches require support at the end of the furnace to forestall outward displacement.

In bonded construction, all joints are broken and the rings help bond one another in a stronger construction. Bonded roofs are better adapted for hot repairs but they demand more skill of the brick masons and more uniformity in the brick.

Sometimes, furnace designers strengthen ring arch roofs by using a longer brick in every third or fourth ring. This construction creates ribs across the roof, which remain strong when the thinner parts of the roof wear away. The strength of the ribs also helps when roofs must be patched.

Suspended Arches

In suspended arches, a steel superstructure helps carry the weight of the roof, otherwise distributed through the arch to the walls and binding. Suspended arches are often used with dense, heavy basic brick. Harbison-Walker has basic brick brands to provide a method for attaching the brick to an overhead steel superstructure.

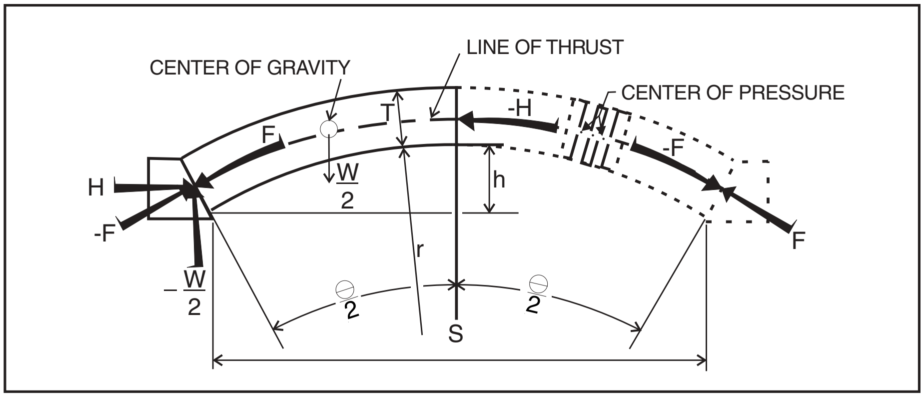
In suspended construction, refractories carry smaller loads and therefore, suffer less deformation at high temperatures than they otherwise might. Using suspended construction, it is also easier to make allowance for thermal expansion to avoid thermal stresses and pinch spalling.

Monolithic Arches

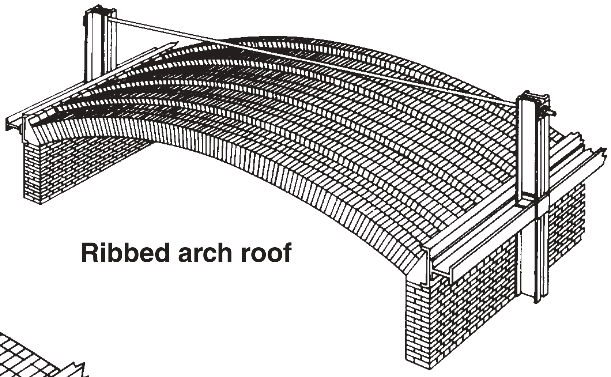
Monolithic arches–cast over forms much like those required for brick arches–have replaced brick in some applications. Skews may be eliminated in monolithic arches, but design considerations remain the same as those for brick arches. A monolithic arch provides all of the advantages monolithic construction, including reduced cost and downtime.

ARCH GEOMETRY

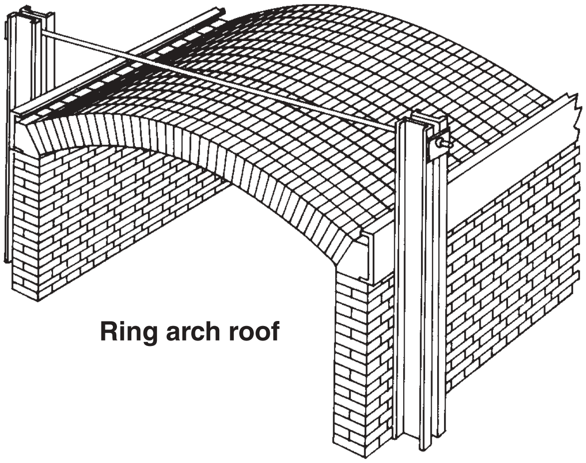
Arch geometry determines all design characteristics. From the viewpoint of arch design, the outside and inside arcs, or surfaces of the roof, are segments of concentric circles separated by the thickness of the roof. The skewback slope cuts the arc, and its angular value equals half the included central angle of the arch. The rise of the arch measures the distance from the inner chord - equal to the span and cutting the inside arc to the center of the roof at midspan.



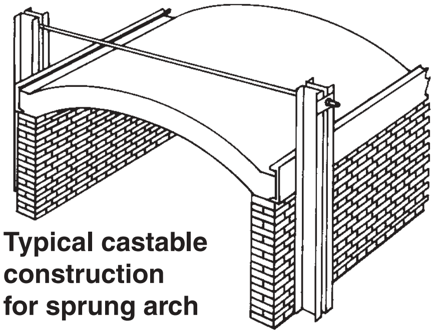
Hypothetical position of thurst in a simple sprung arch, when the bricks are in full contact at joints.



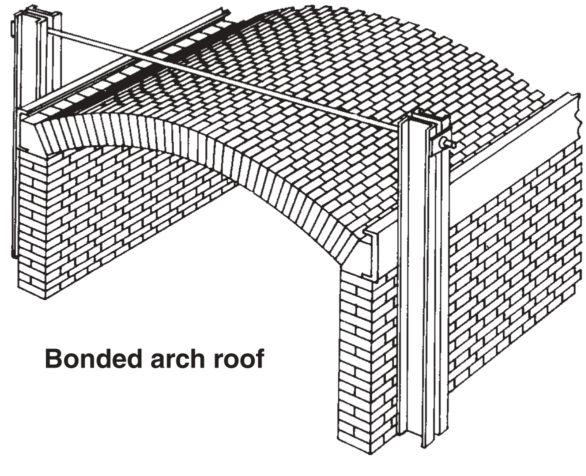
Ribbed arch roof



Ring arch roof



Typical castable construction for sprung arch



Bonded arch roof

ARCH CONSTRUCTION

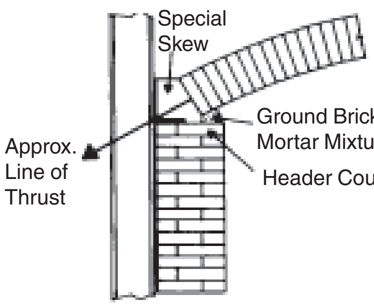
When span, thickness and rise are established, all other dimensions can be calculated using the formulas in this section.

The stability of any arch will depend on its rise, thickness and weight, as well as the thermal properties of the refractories. Hot strength and thermal expansion are particularly important. Good arch design must take these factors into consideration.

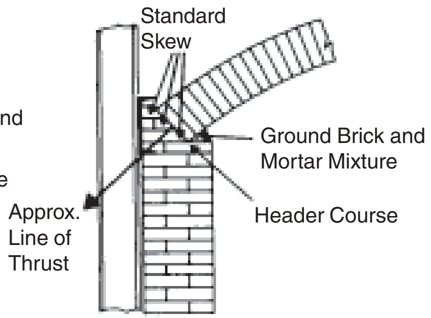
Rise is normally expressed in inches per foot of span, or in terms of the central angle. They are directly related. It should be easy to visualize a larger angle including a higher rise and a shorter radius. On the other hand, the flatter roof with a smaller rise indicates a smaller included central angle and a longer radius.

Experiences suggests that a simple roof arch should rise not less than one nor more than three inches per foot of span. For any particular furnace, the rise selected should depend on operating conditions, chiefly temperature, thermal cycling and the refractories used.

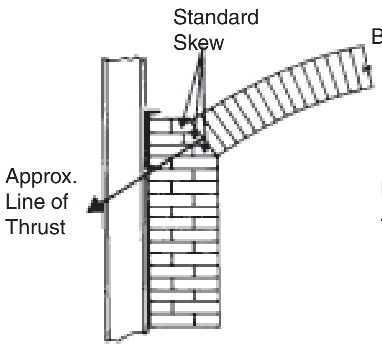
Typically, stable fireclay arches rise from $1^{1}/_{2}$ to three inches per foot of span. High temperatures and soaking heat call for higher values. Silica roofs made with brick that maintain dimensional stability and hot strength almost to their melting point, normally rise from one to two inches per foot.



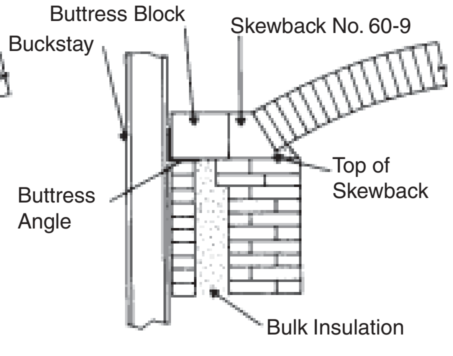
Special skewback
A recommened construction



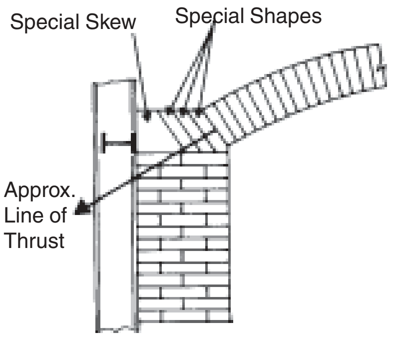
Built-up skewback
A recommened construction



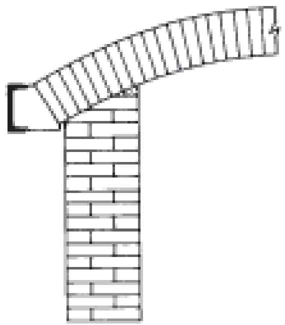
Built-up skewback
A construction to be avoided.



A 60° skewback with
buttress block.



Special skewback
A construction occasionaly used



Arch with skewbacks
supported outside of walls

Note: A stretcher course should never be used immediately below the skewback.

High-alumina refractories used in arch construction call for at least 1.608 inch per rise per foot of span. Basic refractories need $2^{1}/_{4}$ to three inches of rise in sprung arches. Insulating firebrick, which give up hot strength in exchange for low thermal conductivity, call for two to three inches of rise per foot of span.

For many applications, a 1.608 inch rise, about $1^{5}/_{8}$-inch, is a logical standard in that it meets normal requirements for strength and stability. The 60° central angle equals one sixth of a circle and the span equals the inside radius, so the number of brick required to build the roof is easy to calculate.

The reaction of refractory brick to furnace operation, i.e., heat-up, establishes the practical limit for roof rise. Operation and thermal expansion tend to push the brick upward, opening joints at the top and pinching brick at the bottom. Brick that soften at operating temperatures may become permanently deformed, shortening the radius of the arc and increasing the rise.

As the arch rises on heat-up, the line of thrust, the line of force along which the arch distributes the vertical and horizontal elements of its weight, shifts downward. As the line of thrust approaches a horizontal position in the arch, the horizontal force approaches its maximum value.

In some furnaces allowance for thermal expansion of the brick will limit upward movement of the arch. Steel casings can provide an allowance for expansion. Paperboard placed between brick will burn out and make room for expansion. In some cases, horizontal tie rods arc spring loaded or manually adjusted to permit thermal expansion of the refractories.

Without adequate provision for thermal expansion, the relationship between arch thickness and rise* of the cold arch must be such that the line of thrust does not drop out of the arch when it is heated. If it does, the arch will not be stable.

The line of thrust in a cold arch should lie within the middle third of the brick. Generally, selecting the proper combination of brick shapes and doing a professional job to assure face-to-face contact between brick will keep the thrust where it belongs.

In practical construction problems, the vertical and horizontal components are more important than the resultant force. The walls, with or without steel supports, must carry the vertical force, and the horizontal binding, including buckstays and tie rods, must contain the horizontal force.

ARCH CONSTRUCTION CALCULATIONS

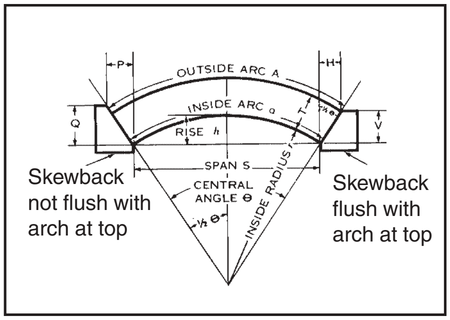
The brick count for many sizes can be calculated from the tables of brick combinations for rings, since simple sprung arches are segments of circles.

Calculation of arch parameters, the arch numbers, is sometimes lengthy, but not difficult, especially when carried out with a pocket calculator. Equations required to produce the necessary values are included in this section.

Suppose that a furnace design calls for an arch with a 12 foot span, $13^1/_2$ inches thick built of NARMAG® 60DB brand brick, on a furnace 20 feet long. NARMAG® 60DB basic brick, requires a minimum rise of $2^1/_4$ inches per foot of span.

The table of Arch Constants below provides data to develop the required design values. For a $2^1/_4$ inch rise, multiply the span by 0.76042 to determine the inside radius, in this case, 9.125 or 9 feet, $1^1/_2$ inches. That means the arch is a segment of a circle with an 18 foot, three inch inside diameter, twice the inside radius.

The table also indicates that the central angle for this arch will be 82° 13.4’, equal to 2,284 ten thousandths of a circle.



On page IR - 45 the tables of brick combinations for rings for 13½ inch linings show that an 18 foot, 3 inch ring can be built with:

82 pieces, No. 2 Wedge and
176 pieces, No. 1 Wedge

If this design calls for 2,284 ten thousandths of a ring, then:

0.2284 x 82 = 18.73 or 19 pieces,
No. 2 Wedge
0.2284 x 176 = 40.2 or 41 pieces,
No. 1 Wedge

If the design specifies 13½ x 6 x 3 inch shapes, then two rings will cover a running foot on the 20 foot roof, and 40 rings will roof the furnace. Thus, the design calls for 40 times 19, a total of 760 pieces, No. 2 Wedge, and 40 times 41, a total of 1,640 pieces, No. 1 Wedge.

---

* Assuming that the absolute lower limit for the rise of the line of thrust is $^1/_4$ inch ($^1/_{48}$) per foot of span, the rise (h) must exceed thickness (T) times the of the cosine of the central angle (θ)plus $^1/_{48}$ span (S). This implies that T should not exceed:

$$\frac{h-{}^1/_{48}S}{\text{Cosine } \theta/2}$$

For a more complete discussion of arch stresses see: J. Spotts Mcdowell, “Sprung-Arch Roots for High Temperature furnaces,” Blast Furnace and Steel Plant, September 1939.

Arch Constants for Given Rises per Foot of Span

Rise Inches Per Foot of Span (d)	Inside Radius (r)	Central Angle θ		Inside Arc (a_a)	Difference Between Outside & Inside Arc ($A_a - a_a$)	Skewback		
		Degress	Part of Circle			H	V	F
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
1	1.54167S	37° 50.9’	0.10514	1.01840S	0.66059T	0.32432T	0.94595T	0.34286Q
$1^1/_4$	1.25208S	47° 4.4’	0.13076	1.02868S	0.82157T	0.39933T	0.91681T	0.43557Q
$1^1/_2$	1.06250S	56° 8.7’	0.15596	1.04117S	0.97992T	0.47059T	0.88235T	0.53333Q
1.608	1.00000S	60° 0.0’	0.16667	1.04720S	1.04720T	0.50000T	0.86603T	0.57735Q
$1^3/_4$	0.93006S	65° 2.5’	0.18067	1.05579S	1.13519T	0.53760T	0.84320T	0.63757Q
2	0.83333S	73° 44.4’	0.20483	1.07251S	1.28701T	0.60000T	0.80000T	0.75000Q
$2^1/_4$	0.76042S	82° 13.4’	0.22840	1.09125S	1.43507T	0.65753T	0.75342T	0.87273Q
2.302	0.74742S	83° 58.5’	0.23326	1.09544S	1.46563T	0.66896T	0.74329T	0.90000Q
$2^1/_2$	0.70417S	90° 28.8’	0.25133	1.11200S	1.57918T	0.71006T	0.70414T	1.00840Q
$2^3/_4$	0.66004S	98° 29.7’	0.27360	1.13464S	1.71906T	0.75753T	0.65280T	1.160444Q
3	0.62500S	106° 15.6’	0.29517	1.15912S	1.85459T	0.80000T	0.60000T	1.333334Q

NOTE: The factors in the above tables are the following functions of θ: Column 2, $^1/_2$ cosecant $^1/_2$ θ; column 4, Ø divided by 360°; column 5; $^1/_2$ cosecant $^1/_2$ θ

SKEWBACK DESIGN

Skewbacks may be built-up combinations of rectangular brick sizes, as previously illustrated, or one-piece special skews designed to fit the arch. Built-up skews satisfy the requirements of narrow spans, four feet or less, but the one-piece skewback generally provides greater strength and better support at the buttress.

The slope of the skewback must be designed to match the central angle of the arch, determined by the rise and span. When the skewback is carried on a channel or angle, the line of thrust should pass through, or slightly above, the corner of the supporting steel.

Skewback dimensions can be determined from the table of Arch Constants below. From the example above, a 2¼ inch rise produces a central angle of 82° 13.4'. The slope equals half the central angle, amounting to 41° 6.6' in this example. Other dimensions can be calculated from constants in the same table.

The V dimension is 0.75342 times the thickness of an arch with a 2¼ inch rise. In this example above, 0.75342 times 13.5 equals approximately 10.17 inches. Other skewback dimensions can be determined in the same way.

The amount of stress in a furnace can be only approximated because of the following variables: (1) the exact position of the line of thrust, even when the arch is cold, is not known, (2) workmanship in construction of the arch may be less than perfect, (3) the position of the line of thrust will change when the furnace is heated, (4) tie rods can stretch and the furnace can settle, changing arch parameters, and (5) arch stresses can be increased by the weight of material adhering to, or absorbed by the bricks. The force acting against the skewbacks depends primarily on the span, rise and thickness of the arch, the weight of the brick, and conditions in the furnace. Vertical force equals one half the weight of the arch per running foot.

The horizontal force depends on the weight of the arch and on the span and rise.

The resultant thrust (F) acting at the skewback equals the square root of the sum of the squares of horizontal (H) and vertical (W) forces, that is:

$$F=\sqrt{H^2+(W/2)^2}$$

However, the stresses of a cold arch, in which all adjoining brick are in full contact, can be approximately determined from the table below. The limiting value which the horizontal thrust approaches in a heated arch, H_{max}, can be calculated approximately from the constants in the table of Maximum Values on the following page.

Consider the NARMAG® 60DB brick arch design described earlier in this chapter. Its design parameters are:

Span (S) = 12 ft

Thickness (T)= 1.125 ft

Inside Radius (r) = 9.125 ft

Density of NARMAG® 60DB (D) = 192 lb/ft^3

Rise (h) = 2.25 inches per foot of span=12 x 2.25 = 27 inches=2.25 ft

Outside radius (R+T) = 10.25 ft

Central Angle (θ) = 82°13.4'

The following calculations are based on the assumption that the line of thrust passes from the center of arch thickness at midspan to the center of arch thickness at the skewbacks.

As shown in the table below, the weight of the arch equals 1.17 DST. That is, for this arch, 1.17 times 192 times 12 times 1.125 equals 3032.64 pounds per foot of arch length. Since W/2 equals 1516.32, the vertical force that the walls and buttresses must carry amounts to 1516.32 pounds per foot of arch length.

From the same table, the horizontal thrust of cold arch with a 2¼ inch rise per foot of span equals 0.64 time its weight (W). For the arch under consideration, 0.64 times 3032.64 equals 1940.89 pounds per foot of arch length.

Constants for Calculation of Stresses in Unheated Arches

Rise in Inches Per Foot of Span	Central Angle (θ)	Forces Per Foot of Arch Length		
		W Weight	H Horizonal Thrust	F Resultant Thrust at Skewback
1	37° 50.9’	1.05 DST	1.49 W	1.57 W
1¼	47° 4.4’	1.07 DST	1.18 W	1.28 W
1½	56° 8.7’	1.09 DST	0.98 W	1.10 W
1.608	60° 0.0’	1.10 DST	0.91 W	1.04 W
1¾	65° 2.5’	1.11 DST	0.83 W	0.97 W
2	73° 44.4’	1.14 DST	0.72 W	0.88 W
2¼	82° 13.4’	1.17 DST	0.64 W	0.81 W
2.302	83° 58.5’	1.17 DST	0.62 W	0.80 W
2½	90° 28.8’	1.19 DST	0.57 W	0.76 W
2¾	98° 29.7’	1.22 DST	0.51 W	0.71 W
3	106° 15.6’	1.25 DST	0.46 W	0.68 W

D= Density of brick in pounds per cubic foot. S=Span in feet. T=Thickness of arch in feet. W=Weight of brick per foot of arch length. The constants given in this table are based on the assumption that the line of thrust passes from the center of the arch thickness at the point of midspan, to the center of arch thickness at the skewbacks.

The resultant force, also determined from the table above, is 0.81 times 3032.64 equals 2546.44 pounds per foot of arch length.

Maximum values approached by horizontal thrust can be determined from the factors listed in the table. These data indicate that the maximum value approached by horizontal thrust for a heated arch free to rise can be determined by multiplying the cold arch horizontal thrust by a factor dependent on the ratio of thickness to span. In the example considered earlier, thickness equals 9% of span, that is, 1.125/12 equals 0.09. For a 2¼ inch rise, maximum thrust approaches 1.84H, or 1.84 times 1940.89 equals 3571.24 pounds per foot of arch length. This value is an approximation, but it lies well within the requirements of practical furnace design.

The safety factor used in furnace binding design is ordinarily higher than that used in conventional steel structural design because the furnace binding may become overheated. For ordinary structural steel bindings, many furnace designers limit tensile stress to 12,000 pounds per square inch.

COMPLEX REFRACTORY DESIGN PROBLEMS

Customers who design or build refractory structures often tap Harbison-Walker resources, e.g., engineering skills and advanced refractories technology, for solutions to complex problems involving refractory applications. Harbison- Walker engineers have developed computer programs, which are used with customers, that can produce complex arch or dome design parameters in a few minutes, often saving many man-hours of calculation. For assistance with your difficult design problems, please call your Harbison-Walker representative.

Initial Heat-Up Considerations

In most cases, a new furnace should be heated slowly with enough air circulating over the walls to remove moisture. Steam trapped in the pores of brick or mortar may damage the brickwork. Good practice permits a furnace to dry out thoroughly at a temperature not over 250°F(121°C) for 24 hours or longer, depending on the size of the vessel and the refractories in use. Temperatures above 400°F to 600°F (205°C to 316°C) should be avoided until all steaming ceases.

Furnace builders and refractory consumers should understand the requirements of the brands that line their furnaces. Careful drying of linings built of magnesia and some of its compounds is especially important. Water vapor or steam under pressure can cause hydration of the magnesia.

Flame impingement on brickwork during heat-up can cause rapid, localized expansion with consequent spalling. Silica and basic brick, especially, tend to spall when subjected to excessively rapid changes in temperature.

In low temperature furnaces, it is often good practice to heat the refractories to a higher temperature than that required for operation for a short period of time. This preliminary heat-up develops the ceramic bond in mortared joints and increases their mechanical strength.

Maximum Value Approached by Horizonal Thrust in Heated Arch Free to Rise

Inches Per Foot of Span	Central Angle (Θ)	H_{max} Per Foot of Arch Length Thickness of Arch in Precent of Span						
		4%	5%	6%	7%	8%	9%	10%
1	37° 50.9’	1.88 H*	2.41 H	3.29 H	5.0 H	**	**	**
1¼	47° 4.4’	1.61 H	1.86 H	2.29 H	2.80 H	3.73 H	5.34 H	**
1½	56° 8.7’	1.47 H	1.63 H	1.94 H	2.14 H	2.55 H	3.06 H	3.88 H
1.608	60° 0.0’	1.43 H	1.59 H	1.79 H	1.98 H	2.31 H	2.75 H	3.30 H
1¾	65° 2.5’	1.39 H	1.52 H	1.67 H	1.93 H	2.17 H	2.41 H	2.77 H
2	73° 44.4’	1.33 H	1.43 H	1.56 H	1.69 H	1.86 H	2.04 H	2.22 H
2¼	82°13.4’	1.29 H	1.38 H	1.47 H	1.58 H	1.70 H	1.84 H	2.00 H
2.302	83° 58.5’	1.28 H	1.37 H	1.46 H	1.57 H	1.69 H	1.81 H	1.95 H
2½	90° 28.8’	1.26 H	1.33 H	1.42 H	1.51 H	1.60 H	1.72 H	1.82 H
2¾	98° 29.7’	1.24 H	1.29 H	1.37 H	1.45 H	1.53 H	1.63 H	1.73 H
3	106° 15.6’	1.22 H	1.26 H	1.33 H	1.41 H	1.48 H	1.57 H	1.63 H

* H = Horizonal thrust, as determined from the previous table.
** Stress excessive.

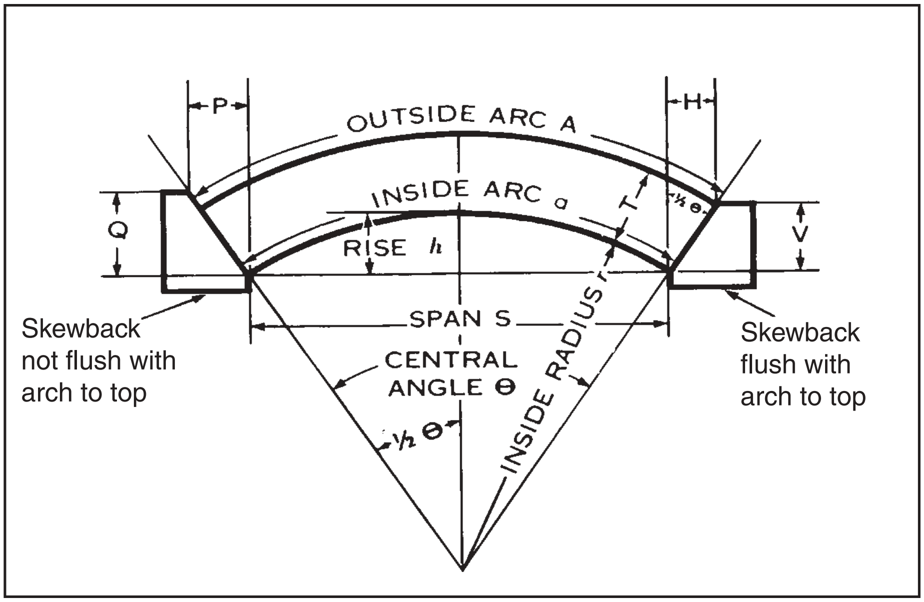
ARCH CONSTRUCTION

REFRACTORY CONSTRUCTION CALCULATIONS

Calculations to determine the dimensions or numerical characteristics of refractory structures are not difficult. Generally, they involve three steps: (1) pick out the formula that produces the dimension or other number that you need; (2) substitute the numbers in your problem that fit the letter-variables in the formula; and (3) perform the arithmetic operations required by the formula. Remember, once the span and rise of an arch are decided, all other dimensions follow.

To use these formulas, all the algebra you need to know is that parentheses tell you to perform the arithmetic operation inside before carrying out the other operations.

All you have to know about trigonometry is that each sine, cosine or tangent is a *particular number* associated with one *particular angle*, and that an arcsine, arccosine or arctangent is a particular *angle* associated with a particular number. That allows you to go from number to angle, or from angle to number, or back and forth, depending on the requirements of the problem. Sines, cosines or tangents are found in tables of trigonometric functions or in pocket calculators.



Arches

Many pocket calculators will make calculation of arch parameters, i.e. numerical characteristics such as dimensions, quick and easy. Sine, cosine and tangent values are literally at your fingertips on many models. Solutions to arch problems involve nothing more than substituting numbers into the formulas and pushing buttons on the calculator. For example in the design previously specified:

Sine ½θ =S/2r = 12 (2 x 9.125)
= 0.6575
Arcsine 0.6575 = 41.11°
= ½ The Central Angle
The Central Angle = 82.22° = 82° 13'

The problem is no more difficult with paper, pencil and a table of trigonometric functions, but the multiplication, division and reference to the table take more time.

Arch Formulas

1. $r = S^2/8h + h/2$
2. $R = r+T$
3. $h = r - \sqrt{r^2-(S/2)^2}$
4. Sine ½ θ = S/2r
5. Tan ¼ θ = 2h/S
6. Tan ¼ θ = d/6
7. Part of circle = θ/360°
8. H = T Sine ½θ
9. d = 6 Tan ¼θ
10. $a_a = 6.2832r\,(\theta/360°)$
11. $A_a = 6.2832R\,(6/360°)$
12. V=T Cos½θ
13. P=QTan ½θ

Arch Symbols

The following symbols and variables are used in the arch formulas:

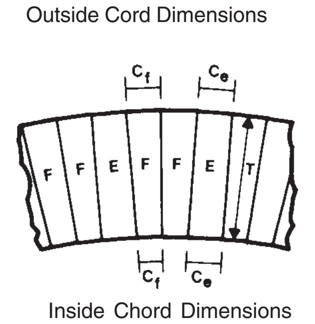
a_a = Length of inside arc
A_a = Length of outside arc
R = Outside radius of arch
r = Inside radius of arch
S = Span of arch
d = Rise in inches per foot of span
h = Total rise of arch
T = Thickness of arch
θ = Central Angle (Theta)
H, V, P, Q = Skewback dimensions indicated in the Arch Constants table.

ARCH CONSTRUCTION

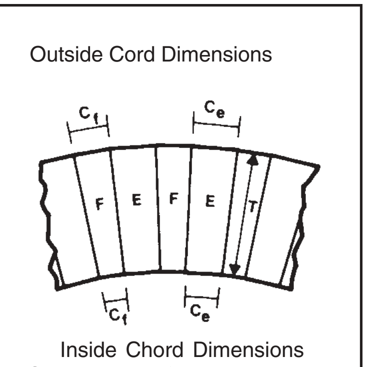
Rings

The number of brick of two sizes to form a ring can be calculated from formulas listed below. When one brick, E, is a straight, and the other, F, is a radial, use Formulas 1-a, 1-b and 1-c. When both brick, E and F, are radial with outside chord dimensions and inside chord dimensions unequal, use Formulas 2-a, 2-b, and 2-c. When both brick, E and F. are radial and the inside and outside chord dimensions of E differ from those of F, use Formulas 3-a, 3-b and 3-c for a single combination, and 4-a, 4-b, and 4-c for a series of combinations.

Ring Calculations



Combination of a Straight Brick (E) and a Radial Brick (F) to Form a Ring



Combination of Two Radial Brick (E and F) to Form a Ring. Brick E Turns a Large Diameter than Brick F

Ring Formulas

$$\text{(1-a)}\ N_f = \frac{2\pi T}{C_f - c_f}$$

$$\text{(2-a)}\ N_t = \frac{\pi D_g}{C_e} = \frac{\pi D_g}{C_f}$$

$$\text{(3-a)}\ N_e c_e + N_f C_f = \pi D_g$$

$$\text{(4-a)}\ N_e = \frac{N_x}{D_e - D_f}\ (D_g - D_f)$$

$$\text{(1-b)}\ N_e = \frac{\pi D_g - N_f C_f}{C_e}$$

$$\text{(2-b)}\ N_e = \frac{\pi D_g - N_f c_f}{c_e - c_f}$$

$$\text{(3-b)}\ N_e c_e + N_f c_f = \pi d_g$$

$$\text{(4-b)}\ N_f = \frac{N_y}{D_e - D_f}\ (D_e - D_g)$$

$$\text{(1-c)}\ N_t = N_e + N_f$$

$$\text{(2-c)}\ N_f = N_t - N_e$$

$$\text{(3-c)}\ N_t = N_e + N_f$$

$$\text{(4-c)}\ N_t = N_e + N_f$$

Ring Symbols

E = Either a straight brick or a radial brick used with a companion brick F; when brick E is radial it turns a larger diameter than brick F.

F = A radial brick, used with a companion brick E which may be either straight or radial; in the latter case, brick F turns a smaller diameter than brick E.

T = Radial dimension common to both brick E and F.

D_e = Outside diameter of ring formed by brick E.

D_f = Outside diameter of ring formed by brick F.

D_g = A given outside diameter larger than D_f, if brick E is radial D_g must lie between D_e and D_f.

d_g = A given inside diameter.

C_e= Outside chord dimension of brick E.

C_f = Outside chord dimension of brick F.

c_e= Inside chord dimension of brick E.

c_f= Inside chord dimension of brick F.

N_e=Number of pieces of brick E, when used in combination with brick F, to form a ring having a given outside diameter D_g.

N_f=Number of pieces of brick F, when used in combination with brick E, to form a ring having a given out side diameter D_g.

N_t=Total number of pieces of brick E and F used in combination to form a ring having a given outside diameter D_g.

N_x=Number of pieces of brick E required to form a complete ring having an outside diameter D_e.

N_y=Number of pieces of brick F required to form a complete ring having an outside diameter D_f.

SECTION 5

Monolithic and Ceramic Fiber Products

*In order to provide current data to the users on this handbook, we have chosen to use an on-line link to our website, www.hwr.com. If you are not able to access the website, please contact your local sales representative to secure the required data sheets.

MORTAR MATERIALS

Overview

Since masonry built of refractory brick consists of many relatively small units, the strength of the masonry depends on the strength of the individual brick, the manner in which they are laid together, and the nature of the mortar materials used in the joints. Mortar fills the joints, bonds individual brick together, and protects the joints from attack by slag and other fluxes. Mortar material should be selected as carefully as the brick with which it is to be used, and it must be chosen for compatibility with the composition of the brick.

A bonding mortar often must meet extremely exacting conditions while in service, which may require an adjusted balance of properties. A mortar should have good working properties for both economy and convenience in laying when mixed to either dipping or trowelling consistency.

Mortar should not shrink excessively upon drying or heating, nor should it overfire and become vesicular at the maximum service temperature.

Thermal expansion of the mortar should be approximately the same as that of the brick with which it is used; otherwise, temperature changes will affect the bond between brick and cause surface coatings to crack or peel.

In some applications, strong joints are desired. Consequently, brick and mortar should develop a strong bond. Refractoriness must be sufficiently high so that mortar will not melt or flow from the joints at high temperatures. However, for laying brick walls that are subjected alternately to soaking heat and cooling cycles, mortars that do not develop a strong bond are often desirable.

Refractory mortar materials are generally divided into two classes: heat-setting mortars and air-setting mortars.

Heat-setting mortars develop a ceramic set with a strong bond only at furnace temperatures. These mortars provide flexibility in expansion and contraction as furnace temperature rises and falls. Heat-setting mortars may also compensate for the high thermal expansion of certain brick, and for differences in thermal expansion between brick of different types used in the same furnace. Available in various compositions, heat-setting mortars are supplied for laying refractory brick in applications where full or solid joints with minimum shrinkage are especially desirable; or where a very strong bond through the entire wall thickness is not an essential requirement.

Air-setting mortars take a rigid set when dried. Prepared from suitable refractory materials by proper selection and combination, chemical binders impart air-setting properties, and maintain the strength of the bond up to the temperature at which the ceramic bond takes effect. Air-setting mortars form mechanically strong joints with high resistance to abrasion and erosion. The wall is bonded throughout, from the hot to the cold surface.

The following product descriptions of Harbison-Walaker's mortar materials refractories are categorized by their classification. This listing represents the major brands supplied for a wide variety of furnaces and applications.

MORTAR MATERIALS

BASIC MORTARS

THERMOLITH®

An air-setting, high temperature bonding material with a chrome ore base, THERMOLITH® possesses excellent resistance to corrosive slags and fumes through a wide range of temperatures. It is used to lay basic brick of all types or as a neutral layer between brick of any type.

FIRECLAY MORTARS

HARWACO BOND®

Shipped wet or dry, HARWACO BOND® refractory mortar consists of high fired, high-alumina calcines and smooth working plastic clays. It combines high refractoriness, volume stability, and smooth trowelling qualities.

’SAIRSET®

A wet, high strength, air-setting, high temperature mortar. This mortar is formulated for trowelled joint, but can be thinned for dipping by adding water.

’SAIRBOND®

A dry, air-setting version of ’SAIRSET®, for use at temperatures up to 3000°F. ’SAIRBOND® has excellent trowelling characteristics.

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Technical Data Sheets
or go to www.hwr.com

PHOSPHATE-BONDED HIGH-ALUMINA MORTARS

PHOXBOND®

This phosphate-bonded, wet mortar provides high bonding strength and excellent resistance to corrosion and erosion. PHOXBOND® refractory mortar can be sprayed or brush coated over refractory walls to reduce permeability without peeling. PHOXBOND® mortar should not be thinned unless absolutely necessary, and then very cautiously. Rolling the drums prior to opening will help bring the mortar to working consistency. Heating to a minimum of 500°F (260°C) is necessary to develop full strength.

GREENSET® -85-P

A wet, phosphate bonded, high alumina mortar, with smooth working characteristics, and good resistance to slag attack.

GREENSET®-94-P

A wet, 94% alumina, phosphate-bonded mortar with excellent refractoriness. GREENSET®-94-P has excellent resistance to aluminum reaction, smooth working characteristics, and resistance to slag attack. It is especially effective in laying extra high-alumina brick and as a coating in a variety of applications.

HIGH-ALUMINA MORTARS

CORALITE® BOND

A dry high-alumina based air-setting mortar. Develops high strength and has excellent working properties. CORALITE® BOND his high refractoriness and excellent resistance to attack by corrosive slags

No. 36 REFRACTORY CEMENT®

No. 36 REFRACTORY CEMENT® is a wet, air-setting, high temperature cement with good bonding strength and refractoriness. It can be used for all types of high-alumina brick where extra bond strength is needed in the joints for structural stability.

HIGH-ALUMINA MORTARS Con’t

KORUNDAL® BOND

High-Alumina air-setting mortar based on high purity alumina aggregate. It is suitable for use at temperatures up to 3200°F (1760°C).

KORUNDAL® MORTAR

A heat-setting mortar with extremely high refractoriness, KORUNDAL® MORTAR provides excellent service at temperatures up to 3400°F (1873°C). It also has exceptional stability and load-bearing ability at high temperatures and is very resistant to corrosion by volatile alkalies and slags in all types of furnaces.

TUFLINE® MORTAR

A dry, high purity 95% alumina mortar. TUFLINE® MORTAR has very good trowelling characteristics. It is intended for use with TUFLINE® 95 DM and TUFLINE® 98 DM in applications requiring materials with very low silica contents.

GREENPATCH 421

An air setting high-alumina patching plaster. It is used primarily for repairing fiber lined furnaces.

GREFPATCH® 85 & WET

A phosphate-bonded, 84% alumina patching plaster. GREFPATCH® 85 can be applied by trowelling or hand packing of areas that have spalled or eroded. Formulated to minimize shrinkage. A WET version, tempered to a higher workability is also available.

MORTAR MATERIALS

ALUMINA-CHROME MORTARS

AUREX® BOND

A 75% chromic oxide containing, phosphated bonded mortar . AUREX® BOND is used in highly corrosive applications such as slagging gasifiers.

RUBY® MORTAR

Phosphate-bonded mortar with 10% chromic oxide. High bond strength; excellent resistance to corrosion by non-ferrous and ferrous metals.

RUBY® BOND

A unique air set alumina-chrome mortar with excellent corrosion resistance and high temperature strength

SILICA MORTARS

FUSIL® MORTAR

A high purity, air-setting fused silica mortar. Available dry with a separate liquid component. For varying consistency, a special liquid thinner is available.

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Technical Data Sheets
or go to www.hwr.com

PLASTIC REFRACTORIES

Overview

Plastic refractories are mixtures of refractory materials prepared in stiff, extruded condition for application without mixing. They are generally rammed into place with pneumatic hammers, but they can also be pounded with a mallet, gunned or vibrated into place. Plastic refractories are especially adaptable for making quick, economical, emergency repairs and are easily installed to any shape or contour, eliminating the need to cut special shapes.

The ease with which plastic refractory materials can be installed qualifies them for many applications. Typically, these include soaking pits, boilers, forging furnaces, annealing ovens, aluminum furnaces, cupolas, incinerators, ladles, bake ovens, and many other industrial applications.

In the group of plastic refractories, those that are "air-setting" take a firm set as they dry out at ambient temperatures. "Heat-setting" refractories remain relatively soft, as most clay-bonded materials do until heated. After heating, both types take the strong ceramic set typical of refractories.

Harbison-Walker's ramming plastic refractories are precut into slabs for easy use, and packaged in 55 or 100 pound cartons for shipping. Gunning plastics are granulated to accommodate charging the BSM gun, and packaged in 3000 pound boxes. Vibratable plastics are packaged in 55 pound sacks for easy handling on the job site. Each of these types of plastic refractories is enclosed in polyethylene prior to packaging to preserve its moisture content.

For shipment during cold weather, Harbison-Walker "winterizes" its non-phosphate bonded plastic refractories. Winterizing the mix suppresses the freezing point a few degrees and permits storage of the refractory at lower temperatures, but has no effect on refractory properties.

The following product descriptions of Harbison-Walker's plastic refractories are categorized by their classification. This listing represents the major brands supplied for a wide variety of furnaces and applications.

FIRECLAY PLASTICS (Air-Set)

SUPER HYBOND® PLUS

An air-setting, super-duty fireclay plastic. Its special bonding system provides additional strength at lower temperatures. It has excellent adhesion properties and low shrinkage.

FIRECLAY PLASTICS (Heat-Set)

SUPER G

A 50% alumina, heat-set plastic. It exhibits excellent resistance to thermal shock from rapid heating or cooling furnace conditions. It is very volume stable at high furnace operating conditions.

HIGH-ALUMINA PLASTICS (Air-Set)

SUPER HYBOND® 60 PLUS

An air-set, 60% alumina plastic based on high purity bauxite. It exhibits increased strength and volume stability throughout its temperature range. Exceptional purity provides maximum resistance to slag attack and outstanding ability to withstand load at operating temperatures. Also develops moderate strength upon drying.

SUPER HYBOND® 80

An air-setting, 80% alumina, plastic refractory. SUPER HYBOND® 80 remains refractory at high temperatures. It offers excellent resistance to fluxing oxides and slags and good volume stability up to its maximum service temperature, 3200°F (1761°C).

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HIGH-ALUMINA PLASTICS (Phosphate Bonded)

GREENPAK 50-P PLUS

A 50% alumina, phosphate bonded plastic based on high purity bauxitic kaolin. It exhibits higher strengths to withstand mechanical abuse and has better alkali resistance than conventional, heat-setting plastics.

H-W® BULL RAM PLASTIC

A highly workable and cohesive 70% alumina/mullite phosphate bonded plastic. H-W® BULL RAM PLASTIC is used in a wide range of applications, including incinerators, boilers, heat treating furnaces, ferrous and non-ferrous metals furnaces, and rotary kiln firing hoods.

NARMUL® P PLASTIC

A 70% alumina, mullite plastic. It has high purity for outstanding corrosion resistance. NARMUL® P PLASTIC also has high density and good hot strength.

NARPHOS™ 85P PLASTIC

An 85% alumina, phosphate-bonded, plastic, NARPHOS™ 85P PLASTIC provides high strength and density combined with excellent volume stability throughout its entire temperature range. It displays non-wetting characteristics to provide outstanding resistance to erosion from slag and metal wash. This product is used where excellent resistance to temperatures, slag, thermal shock, and abrasion is required.

NARPHOS™ 85 TP

An 85% alumina, phosphate-bonded, trowelling plastic. It has excellent physical properties, and workability characteristics. NARPHOS 85 TP is ideal for patching and veneering thin linings.

CORAL PLASTIC® (28-82)

An 85% alumina, phosphate-bonded, plastic. CORAL PLASTIC® (28-82) provides high strength and density combined with excellent volume stability throughout its entire temperature range. It displays non-wetting characteristics to provide outstanding resistance to erosion from slag and metal wash. This product is used where excellent resistance to temperatures, slag, thermal shock, and abrasion is required.

GREENPAK 85-P PLUS

GREENPAK 85-P PLUS is a high alumina, phosphate bonded plastic with excellent strength, outstanding slag resistance, good workability, and volume stability at high temperatures. It demonstrates good resistance to alkali attack.

GREENPAK 85-MP PLUS

This is an economical version of GREENPAK 85-P PLUS. It is phosphate-bonded and shows improved strength at intermediate operating temperature.

GREENPAK 85-PF PLUS

A fine grind, 85% alumina, phosphate bonded plastic refractory. It features high refractoriness, excellent workability, high strength, slag resistance and low shrinkage. It was developed for use as a patching material in areas of severe abrasion and erosion. Typical applications include induction furnaces, spouts, tundish and foundry ladles, troughs and tap-out areas, cyclones, and catalyst lines.

KORUNDAL® PLASTIC

A phosphate-bonded, tabular alumina based plastic with exceptional refractoriness. It is used in applications where high strength at high temperature is needed.

GREENPAK 90-P PLUS

GREENPAK 90-P PLUS is an extra high alumina, phosphate bonded plastic. It exhibits high density and excellent strength.

ALUMINA-CHROME PLASTICS

RUBY® PLASTIC AMC

An economical, high strength, phosphate-bonded, corrosion resistant alumina-chrome plastic. Its high chromic oxide content gives it outstanding resistance to acid and neutral slags. The presence of mullite grain allows for earlier sintering, making it ideal for slagging applications between 2500˚F (1371˚C) and 2900˚F (1593˚C). Applications include foundry troughs, ladles, induction furnaces and pulp mill recovery boilers.

RUBY® PLASTIC S

A phosphate-bonded, high-alumina chromic oxide containing plastic formulated to optimize slag erosion resistance and iron oxide penetration resistance while retaining high hot strengths and low open porosity. RUBY PLASTIC S has extremely good resistance to high iron oxide slags of an acid to neutral nature and to attack by coal slag. Typical uses include iron and steel troughs, dams, impact areas, spouts, and tap holes, industrial incinerators, boiler bottoms, and lower side walls in slagging areas over tubes.

RUBY® PLASTIC

A phosphate-bonded, alumina-chrome plastic with very high strength at high temperatures. At high temperatures, RUBY PLASTIC forms an alumina-chrome solid solution bond which has extremely good resistance to high iron oxide slags of an acid to neutral nature and to attack by coal slag. Applications include dams, impact areas, industrial incinerators, boiler bottoms, and slagging areas over tubes.

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PLASTIC REFRACTORIES

ALUMINA-CHROME PLASTICS con't

RUBY® PLASTIC 20

High strength, phosphate-bonded alumina-chrome plastic with 20% chromic oxide content. With high strength at elevated temperatures, this plastic has enhanced resistance to iron oxide and coal slag, beyond standard phosphate-bonded plastics.

SHAMROCK® 885 PLASTIC

A phosphate-bonded, alumina-chrome refractory plastic. Its 30% chromic oxide content, and very high density provide outstanding corrosion resistance. Typical applications include patching glass contact and stack areas of wool insulation furnaces, and extreme-service areas in wet-slag, coal-fired boilers.

AUREX 65 PLASTIC

A phosphate-bonded, chrome-alumina plastic refractory. AUREX 65 PLASTIC utilizes a fused chrome-alumina grain to achieve the maximum possible resistance to highly corrosive slags. Applications include coal gasifiers and chemical incinerators.

GUNNING PLASTICS

GREENGUN™ 70-P PLUS

A high alumina, phosphate bonded plastic gunning mix with high strength, low porosity, and good abrasion and alkali resistance. Typical applications are incinerator linings, cement plant firing hoods and fluid bed combustor cyclones.

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GREENGUN™ 80

An 80% alumina, air-setting gunning plastic. It exhibits excellent resistance to thermal shock from rapid heating or cooling furnace conditions. It is very volume stable under high temperature conditions. Typical applications are rotary kiln feed and discharge hoods, combustion chambers, boilers, forge furnace sidewalls and roofs, high temperature dryers, reheat furnace soak zones, and brass reverberatory furnace upper sidewalls.

GREENGUN™ 85-P PLUS

A high density, phosphate bonded, high alumina gunning plastic that exhibits excellent thermal shock resistance, high strength, and excellent abrasion resistance. It is an excellent choice for both hot and cold repairs.

GREENGUN™ ECLIPSE® 73-P PLUS

A phosphate bonded gunning plastic containing approximately 73% silicon carbide. It is specially formulated to gun on studded tubes in cyclone boilers, on water-wall tubes in waste-to-energy units, and on other heat recovery units.

GREENGUN™ JADE PLUS

An alumina-chrome, phosphate bonded, gunning plastic. With its high purity alumina and chromic oxide, it has extremely high refractoriness and resistance to acidic and slightly basic slags. It is used in many applications including reheat furnaces, waste heat boilers, incinerators, and recovery boilers.

SILICON CARBIDE PLASTICS

ECLIPSE® 60-P ADTECH®

A phosphate-bonded silicon carbide plastic that forms an aluminum phosphate bond. It has high conductivity and abrasion resistance as well as non-wetting properties to many acid slags and nonferrous metals. Principal applications include municipal incinerators, fluid-beds, boiler tube protection and high abrasion.

ECLIPSE® 70-P ADTECH®

A phosphate-bonded 70% silicon carbide plastic. It is especially formulated for ramming on studded tubes in cyclone boilers, on water-wall tubes in waste-to-energy units, and other heat recovery units.

ECLIPSE® 80-P ADTECH®

A phosphate-bonded 80% silicon carbide plastic. Its high silicon carbide content provides high thermal conductivity and outstanding strength and abrasion resistance.

HARBIDE PLASTIC 70 AL

A high purity silicon carbide, phosphate bonded refractory plastic containing a penetration inhibitor for improved aluminum resistance. It shows excellent strengths, good thermal shock resistance, excellent penetration resistance and good abrasion resistance.

VIBRATABLE PLASTICS

GREFVIBE 700

A phosphate-bonded, 70% alumina plastic refractory. GREFVIBE 700 has been developed so that it can be quickly vibrated into place behind steel forms. With this characteristic and the low temperature bonding at 700-1200˚F (370-650˚C), GREFVIBE 700 is specially suited for lining iron foundry and steel foundry ladles which must be lined quickly with minimum labor cost.

GREFVIBE 850

A high alumina, phosphate bonded vibratable plastic which features very fast installation and turn-around time. GREFVIBE 850 has high refractoriness, high density and is resistant to ferrous and non-ferrous metal penetration, corrosive slags and abrasion.

TASIL® 570 LM VIBRATABLE

A 70% alumina, air/heat set vibratable plastic. It is phosphate free, pre-densified and ready to install. It is used in iron and steel ladles, tundishes, troughs, runners, arc furnaces, channel furnace upper cases and special shapes.

SiC & CARBON CONTAINING PLASTICS

SUPER NARCARB PLASTIC

Based on fused alumina with SiC and oxidation inhibitors. This yields very low porosity for enhanced corrosion resistance to cupola slags. SUPER NARCARB PLASTIC is intended for extended cupola campaigns and the most severe service conditions. It offers the highest level of carbon containing, non-wetting components, and a more environmentally friendly bond system than the phenolic resin bonded materials.

NARCARB ZP PLASTIC

This phenolic resin bonded plastic provides high strengths at iron producing temperatures. It contains SiC with oxidation inhibitors. NARCARB ZP provides excellent performance in extended cupola campaigns under severe conditions.

SUPER GRAPHPAK-85

This air-setting, SiC and graphite containing, oxidation resistant plastic contains no pitch or resins. As a result, it does not give off polluting emissions. This plastic possesses good resistance to hot metal and slag erosion and represents an economical alternative to NARCARB ZP and SUPER NARCARB in less severe conditions.

GRAPHPAK-45 & PLUS

A super-duty fireclay plastic refractory containing graphite. It exhibits better resistance to molten iron or iron slag penetration than conventional super-duty plastics.

GRAPHPAK-85 & PLUS

A high alumina plastic containing graphite. It exhibits good resistance to molten iron or iron slag penetration. It is ideally suited for high temperature molten iron up to 2850°F (1566°C) metal temperature.

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GUNNING MIXES

Overview

Gunning mixes are granular refractory mixtures designed for application with air-placement guns. A variety of air guns are used to spray the mixes at high velocity and pressure to form homogeneous, compact linings, essentially free from lamination and cracks.

Gunning mixes are either air-setting or heat-setting and some allow repairs to refractory furnace linings without greatly reducing the furnace temperature. Lightweight gunning mixes normally are used for insulation, while denser mixes are used in the more severe applications. Some compositions combine relatively low heat losses with good strength.

Although gunning requires more skill than pouring castables, it can place a higher volume of material in less time than any other method. Gunning also makes it possible to line horizontal, vertical, overhead or irregular structures without forms.

The properties of Harbison-Walker's gunning mixes vary considerably and, thus, encompass a wide range of applications. The mixes perform very well in both original linings and maintenance applications within a service temperature range of 1600°F (872°C) to 3300°F (1817°C). In many applications, they represent the most economical choice for a refractory lining.

The following product descriptions of Harbison-Walker's gunning mixes are categorized by their classification. This listing represents the major brands supplied for a wide variety of furnaces and applications.

FIRECLAY GUNNING MIXES

GREENCAST® 12 GR PLUS

A high strength castable for withstanding severe abrasion at temperatures up to 1200°F. It is CO resistant and displays excellent gunning characteristics.

NARCO® GUNCRETE

A high strength, fireclay gun mix that displays excellent gunning characteristics.

NARCO® GUNCRETE AR

Abrasion resistant version of NARCO® GUNCRETE.

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TUFSHOT® LI/OT ADTECH®

An extra strength, low iron fireclay gunning mix characterized by very low rebounds. Used in boilers, incinerators, process heaters, stacks, breechings and other medium service areas.

KS-4® GR PLUS

A specially formulated fireclay gunning mix with good strength and corrosion and abrasion resistance. It has low rebound and good setting characteristics. Good for thinner linings in large areas.

GREFCOTE® 50 PLUS

GREFCOTE® 50 PLUS is a 50% alumina, cold or hot gunning mix for maintenance of refractory linings. It displays good adhesion to walls that are hot or cold. It can be gunned to thickness to maintain the original contour of the refractory lining. Typical applications are: hot gunning of iron torpedo ladle lips, aluminum furnace upper sidewall and roof areas, soaking pit linings and reheat furnace sidewalls.

CONVENTIONAL HIGH- ALUMINA GUN MIXES

LO-ABRADE® GR PLUS

A fireclay based, dense abrasion resistant gunning mix. It exhibits exceptional resistance to abrasion, erosion, high-energy impact, and temperature.

GREENCAST® 94 GR PLUS

A high strength, 94% alumina, high purity gun mix with good abrasion resistance. Excellent strength and chemical purity allow it to withstand severe environments with a maximum service temperature of 3400°F (1820°C).

NARCOGUN® LC-95

NARCOGUN® LC-95 is a high alumina, low cement, low moisture gun mix. This product shows excellent gunning characteristics with below average rebound loss.

KRUZITE® GR PLUS

KRUZITE® GR PLUS is a 70% alumina, dense, 3200°F (1760°C) maximum service temperature gunning castable. It exhibits excellent strengths and high densities.

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GUNNING MIXES

LOW CEMENT FIRECLAY GUNNING MIXES

VERSAGUN® BF

A high strength, low cement gun mix based on a high-fired, low-iron, fireclay aggregate. Used in applications requiring resistance to abrasion and reducing environments.

VERSAGUN® PH

VERSAGUN® PH is a high strength, low cement gun mix based on selected superduty fireclays and a lower cement content. It has excellent abrasion resistance and high refractoriness to 2800°F (1538°C).

LOW CEMENT HIGH- ALUMINA GUNNING MIXES

VERSAGUN® 50 ADTECH®

A high strength gun mix based on high-fired fireclay aggregate and a reduced content of high purity cement. Used in applications requiring high strength and abrasion resistance.

VERSAGUN® 60 ADTECH®

A 60% alumina low cement gunning mix based on hard fired calcined kaolins and a reduced lime content. VERSAGUN® 60 ADTECH® features excellent strengths, very good abrasion resistance, and improved refractoriness.

MIZZOU® GR® PLUS

60% alumina gunning castable. MIZZOU® GR® PLUS is a 3000°F (1650°C) gunning refractory with low iron content, good slag resistance, and excellent volume stability. Developed especially for gun placement to allow quick installations and/or repairs with minimum downtime.

VERSAGUN® 60Z ADTECH®

A 60% alumina low cement gunning mix based on Alabama bauxitic calcines and with the addition of zircon. Excellent abrasion resistance, hot strength and thermal shock resistance.

VERSAGUN® 70 ADTECH®

A 70% alumina, low cement gunning mix having a reduced lime content, based on hard fired calcined kaolins. It has excellent strengths, very good abrasion resistance, improved refractoriness & hot strengths.

VERSAGUN® 70/AL

A 70% alumina, low cement gun mix, containing an aluminum penetration inhibitor that installs with conventional gunning equipment. Excellent physical properties in the 1500°F (816°C) range and permits fast and effective repairs to metal line areas.

NARCOGUN® BSC-DS

NARCOGUN® BSC-DS is a bauxite based trough mix that is totally dust suppressed to eliminate any dusting at the nozzle or gun. This is a SiC containing material.

DENSE MAGNESITE GUN MIXES

MAGSHOT®

MAGSHOT® is a magnesite based gunning refractory. It is based on a dicalcium silicate natural magnesite that has good resistance to molten smelt and soda. This unique formulation does not require lengthy cure time or slow heat-up schedules.

MAGNAMIX 85G

MAGNAMIX 85G is a basic gun mix of the 85% MgO class. Primary use in repairing and maintaining electric furnace linings in the small to medium sized foundries.

SPECIAL PURPOSE GUNNING MIXES

VERSAGUN® THERMAX® ADTECH™

A high strength, vitreous silica gun mix with reduced cement content. It has a special fortified matrix to provide excellent strength and abrasion resistance, along with unmatched thermal shock resistance.

NARCOGUN® SiC 80 AR

A strong, low cement, silicon carbide gunning mix. The reduced cement content yields improved abrasion resistance.

INSULATING GUNNING MIXES

KAST-O-LITE® 22 G PLUS

(Formerly CASTABLE INSULATION #22 GR)

An insulating gun mix designed for a maximum service temperature of 2200°F (1205°C).

KAST-O-LITE® 26 LI G PLUS

(Formerly H-W® LT WT GUN MIX 26)

A low iron, medium density gun mix designed for a maximum service temperature of 2600°F (1427°C).

KAST-O-LITE® 30 LI G PLUS

A low iron, gun mix designed for a maximun service temperatures of 3000°F (1650°C).

GREENLITE 45 L GR

A 2500°F insulating gunning mix with high strength and low density.

HPV™ GUN MIX

A high strength, lightweight, insulating gunning mix with exceptionally high strength and abrasion resistance.

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Gunning Mixes

SPRAY MIXES

PNEUCRETE® BF ADTECH®

PNEUCRETE® BF ADTECH® is a super duty fireclay based low cement spray mix for use in abrasion environments and carbon monoxide environments. It has the unique property that when combined with an activator at the nozzle it can be applied by standard shotcreting methods. PNECRETE® BF ADTECH® can be used for blast furnace repairs, minerals processing, and other applications requiring high strength, low cement compositions.

PNEUCRETE® 45 ADTECH ®

PNEUCRETE® 45 ADTECH® is a fireclay based low cement spray mix for use in abrasion environments. It has the unique property that when combined with an activator at the nozzle it can be applied by standard shotcreting methods. PNEUCRETE® 45 ADTECH® can be used for minerals processing, chemical industry applications, and incineration and aluminum furnace backup linings.

PNEUCRETE® THERMAX®

Unique vitreous silica based low cement spray mix. Nearly dust free installation with minimal rebounds. It has the unique property that when combined with an activator at the nozzle it can be applied by standard shotcreting methods. Lower density than conventional extra strength castables, outstanding thermal shock resistance in cycling applications, low coefficient of thermal expansion and good abrasion resistance.

PNEULITE® SPRAY 22

PNEULITE® SPRAY 22 ADTECH® is a uniquely formulated refractory specifically for spray application that lowers dust and permits virtually no rebounds. Used primarily to replace conventional gunning mixes as insulation for petroleum heaters or as insulation backup lining in two component linings for many applications.

PNEULITE® SPRAY 26 ADTECH®

PNEULITE® SPRAY 26 is a uniquely formulated refractory specifically for spray application that lowers dust and permits virtually no rebounds. Used primarily to replace conventional gunning mixes applied in FCCU regenerating vessels, naphtha reformers and other process furnaces requiring semi-insulating, one spray linings.

PNEUCRETE® 55/AR ADTECH®

A 55% alumina low cement spray mix for use in high alkali and abrasion environments. Features nearly dust free installation with minimal rebounds. It has the unique property that when combined with an activator at the nozzle it can be applied by standard shotcreting methods.

PNEUCRETE® 60 ADTECH®

A 60% alumina, low-cement spray mix for use in a wide variety of applications. Nearly dust free installation with minimal rebounds. It has the unique property that when combined with an activator at the nozzle it can be applied by standard shotcreting methods. PNEUCRETE® 60 ADTECH® can be used in cement and lime plant maintenance and other applications requiring high strength, low cement compositions.

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Overview

Often called refractory concretes, castable refractories are furnished dry to be mixed with water before installation. Usually cast or vibrated in the same manner as ordinary concrete, castables can also be installed by trowelling, pneumatic gunning or occasionally ramming.

The growing use of castables stems directly from their economic and handling advantages. Castables reduce installation costs, go into place quickly and easily, and mixing, conveying and placement can be mechanized. They also save time formerly spent cutting brick to fit and eliminate inventories of special shapes.

Along with ease of installation, castables offer several performance advantages. They are less permeable, partly because of the nature of the hydraulic bond and partly because cast walls, roofs and floors have fewer joints. Thus, castables often provide the best lining for vessels or chambers at other than atmospheric pressures. Many castable refractories have good resistance to impact and mechanical abuse; and most castables offer good volume stability within the specified temperature range.

The service capability of any refractory is determined by its major ingredients – fireclay, alumina, silica or basic materials such as magnesite and chrome ore. Properties of the binders, i.e., hydraulic cements that give castables an air-set, are designed to match those of the refractory base materials. They include standard calcium-aluminate cements, low iron oxide cements, high purity cements, and high strength, high purity cements. Some special castables use sodium silicate or portland cement binders.

The following product descriptions of Harbison-Walker's castable refractories are categorized by their classification. This listing represents the major brands supplied for a wide variety of furnaces and applications.

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CONVENTIONAL FIRECLAY CASTABLES

MC-25® PLUS

A high strength, coarse aggregate castable for temperatures to 2250°F. MC-25® possesses two-to-three times the strength of regular dense castables, has excellent resistance to thermal shock, and withstands heavy loads and mechanical abuse.

KS-4® PLUS

A dense, strong general purpose castable refractory for use at temperatures up to 2550°F. It combines high strength with abrasion resistance.

KS-4T

A more plastic material than most refractory castables. It is preferred for use as a plastering material to repair boiler baffles. It is recommended for use in relatively thin sections. It can also be used for overhead gunning repairs where thickness is required.

KS-4V PLUS

A general purpose castable for use to temperatures to 2600°F. KS-4V features good resistance to abrasion, a low iron content, and minimal shrinkage, even when used in large patches.

EXPRESS®-27 PLUS

EXPRESS®-27 PLUS is a 2700ºF, dense, free-flowing refractory castable that can also be vibration cast using reduced water levels to provide vibrated product with properties superior to those attained at self flowing consistency. Its density together with very good abrasion resistance makes it an ideal hot face lining material.

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EXPRESS® 27 C PLUS

A coarse, fireclay based, conventional cement castable for use where high strength and high impact resistance are required up to 2700°F (1482°C). It features improved impact resistance over conventional extra-strength castables or fireclay plastics. It is easy to install by pumping, vibcasting and conventional casting techniques. EXPRESS® 27 C PLUS can also be installed at a self leveling consistency.

HARCAST® ES ADTECH

A very high strength, super-duty castable with high purity binder. Excellent for applications up to 2800°F.

HYDROCRETE®

A 2200°F maximum service temperature, dense, general purpose castable. It easily conforms to irregular furnace shells to increase the speed of installation versus conventional brick linings. Its moderate density allows for reduced energy loss through the refractory lining.

SUPER KAST-SET® PLUS

A 2800°F general purpose castable. It has good permanent volume characteristics and high strength to produce stable linings for long service.

CONVENTIONAL HIGH-ALUMINA CASTABLES

LO-ABRADE® PLUS

A 2600°F castable with excellent resistance to abrasion and erosion. Its low iron content makes it particularly good for use in specialized atmosphere furnaces. It is recommended for use where abrasion is encountered.

MIZZOU CASTABLE® PLUS

A high strength 60% alumina castable, with excellent resistance to slag penetration and spalling. It is used for many applications such as combustion chambers, low temperature incinerators, air heaters, boilers, burner blocks, aluminum furnace upper sidewalls and roof regions, forge furnaces, and iron foundry ladles.

EXPRESS®-30 PLUS

A 3000°F (1647°C), dense free flowing refractory castable. It can either be cast or pumped. Its density together with very good abrasion resistance makes it an ideal hot face lining material. If reduced water content is used, cast vibrated properties are superior to free-flowing properties. EXPRESS® 30 QS is a quick setting version, designed for quick turnaround. It is ideal for precast shapes.

KRUZITE® CASTABLE PLUS

A general purpose 3200°F castable, displaying high refractoriness and moderate strength. Applications include foundry ladles, burner blocks, high temperature boilers, and induction furnace covers.

GREENCAST®-94 & PLUS

A high strength, high purity calcium aluminate bonded 94% alumina castable with extremely high refractoriness. Used in conditions requiring high abrasion and chemical resistance.

NARCOCAST® LM95 G

A high purity, conventional cement castable employing a low moisture design. NARCOCAST® LM95 G has extremely high strength at temperatures up to 3000°F. It has excellent resistance to molten metal erosion, abrasion and mechanical abuse. It has significantly higher density and lower porosity than conventional castables. Due to its fine grained design, NARCOCAST® LM95 G is especially well suited as a grout material. Also ideal for thin walled castings requiring improved properties.

SPECIAL HIGH ALUMINA CASTABLE ADTECH

SHAC is a high purity, extra high alumina, hydraulic setting castable the forms a dense, high strength monolithic lining. It has excellent abrasion and erosion resistance. SHAC also possesses good volume stability and is resistant to carbon monoxide disintegration.

CASTABLE REFRACTORIES

CONVENTIONAL HIGH-ALUMINA CASTABLES con't.

TAYCOR® 414-FH HYDROCAST

High purity, fine grained, extra-high alumina, conventional cement castable. High refractoriness, strength and grain sizing make TAYCOR® 414-FH HYDROCAST especially well suited for thin walled castings. Excellent choice for coil grouting in coreless induction furnaces melting steel alloys.

GREENCAST® 97 PLUS

GREENCAST® 97 PLUS is a 97% alumina dense castable for temperatures up to 3400°F (1870°C). It is based on very high purity ingredients, low in silica, iron oxide, and alkalies.

LOW CEMENT FIRECLAY

VERSAFLOW® 45 PLUS

A fireclay based low cement castable, with versatile installation capability. This product features good strengths. An excellent utility castable for use in high abrasion areas.

VERSAFLOW® 45C ADTECH®

A coarse aggregate, fireclay based low cement castable. Its coarse aggregate improves thermal shock, abrasion and impact resistance.

ULTRA LOW CEMENT FIRECLAY

ULTRA-GREEN 45

A 45% alumina, ultra-low cement, vibratable castable. Features excellent strength, outstanding hot load bearing ability, superior corrosion resistance, low porosity and high density. Can be used as original linings, to repair existing linings, and as pre-cast shapes, non-ferrous furnaces and ladles, cement kilns, coolers and rings, boilers and in the chemical processing industry.

ULTRA-EXPRESS 45

A 50% alumina, flint-based, dense, self-flowing, ultra-low cement castable. It has the unique property that vibration is not required to remove air voids. This versatile product can be either cast or pumped.

LOW CEMENT HIGH-ALUMINA CASTABLES

KALAKAST AR® ADTECH®

A 60% alumina casting mix. KALAKAST AR® ADTECH® has exceptional resistance to alkali attack. Other benefits include better abrasion resistance than 60% alumina fired brick, castables, and phosphate-bonded plastics after curing. High hot strengths at elevated temperatures. Designed to replace brick and plastic where joints are undesirable.

VERSAFLOW® 60 PLUS

A 60% alumina low cement castable based on bauxite calcines, which has versatile installation capability - from vib-casting to pump casting. This product has excellent abrasion resistance, high hot strengths at 2500°F. An excellent all purpose castable for applications such as incinerator charge zones, burners, and rotary kilns.

VERSAFLOW® 55/AR ADTECH®

A unique castable refractory of 60% alumina class with exceptional resistance to alkali attack and abrasion. Typical applications include incinerators and aluminum furnace upper sidewalls and roofs.

VERSAFLOW® 55/AR C ADTECH®

A 55% alumina, low cement, coarse grain castable based on bauxitic calcines. Specifically designed for impact and abrasion resistance in high alkali environments. Typical uses include incinerators and aluminum furnace roofs.

VERSAFLOW® 57A

A 60% alumina, andalusite based, self-flowing castable with excellent thermal shock and alkali resistance. This versatile product can be cast or pumped.

NARCON 65 CASTABLE

A low moisture mullite castable for use to 3200°F (1760°C). The low cement content provides extremely high strengths to withstand the erosive effects of hot dust laden gases. Its homogeneity of structure makes NARCON 65 much less susceptible to thermal shock damage than conventional castables.

NARCON 70 CASTABLE

A low moisture mullite castable for use to 3250°F (1788°C). The low cement content provides extremely high strengths to withstand the erosive effects of hot dust laden gases. Its homogeneity of structure and coarse grain sizing makes NARCON 70 much less susceptible to thermal shock damage than conventional castables.

VERSAFLOW® 70 ADTECH®

A 70 % Alumina low cement castable based on Alabama bauxitic calcines which can be installed in several ways, from vibcast consistency to pump casting techniques. It features excellent abrasion resistance, high hot strengths at 2500°F (1371°C), and high refractoriness.

VERSAFLOW® 70 C ADTECH®

A 70% alumina, coarse grain castable with high strength, high refractoriness and excellent abrasion and impact resistance. Typical uses include foundry ladles, rotary kiln nose rings and lifters, incinerator charge zones, and precast tundish furniture.

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LOW CEMENT HIGH-ALUMINA CASTABLES con't.

VERSAFLOW® 70/CU ADTECH®

A 70% alumina low cement castable containing a special penetration inhibitor for increased resistance to metal penetration. It can be vibcast, poured, or pumped and is suited for service temperatures up to 2850°F (1566°C). Designed specifically for copper and iron foundry applications.

VERSAFLOW® 80 C ADTECH®

VERSAFLOW® 80 C ADTECH is a coarse, 80% alumina low cement castable based on calcined bauxite, which can be pumped or vibration cast. It has excellent impact resistance and outstanding thermal shock resistance.

FASKAST 80

An 80% alumina, low cement castable with a high purity mullite matrix. It has a relatively fast set time and good hot strengths and outstanding flow. Ideal for field casting in areas such as ladle lip rings.

GREFCON® 85

GREFCON® 85 is a high-alumina low cement, low moisture castable characterized by its high density, low porosity, and high hot strength. GREFCON® 85 can be installed by ramming, vibration cast, hand casting, or pumping by varying the amount of water.

D-CAST 85 TM CASTABLE

An 85% alumina low cement castable with a higher purity matrix than other castables in this class. High density and low porosity result in increased slag resistance. Typical applications include kiln car tops; kiln nose rings, foundry ladles, coke calcining and alumina kiln burning zones. D-CAST 85 TM uses special gas forming technology to create gas channels for easier drying.

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D-CAST 85 TM-CC CASTABLE

An equivalent product compared with D-CAST 85 TM in regards to base aggregate and matrix additions. However, D-CAST 85 TM-CC CASTABLE does not employ the gas channel technology but relies on an organic fiber addition to aid in drying. The 'CC' is designed for custom casting applications where a more controlled dry out can be conducted.

D-CAST 85 HS CASTABLE

This specially designed low-cement, high alumina castable offers high density and high hot strengths. Based on a higher purity aggregate and matrix system than the other D-CAST castables, D-CAST 85 HS CASTABLE exhibits excellent slag corrosion and metal penetration resistance resulting in longer campaign life and easier cleaning of ladles, troughs, and runners.

TAYCOR® 414-C HYDROCAST

This is a coarse grained 96% alumina castable with intermediate cement content. This coarse grained structure provides for very good thermal shock resistance.

GREFCON® 98

GREFCON® 98 is a volume stable 98% alumina, low cement, low-moisture castable, characterized by its high density, low porosity, high hot and cold strengths, and excellent abrasion resistance.

GREFCON® 98 SP

An extra-high alumina, high purity, low moisture castable that contains spinel additions for slag penetration resistance and excellent high temperature strength.

GREFCON® 98 T

A tabular alumina based castable with high purity and high refractoriness. This product has exceptional strength and abrasion resistance, and is an ideal choice for many metal-contact areas.

ULTRA LOW CEMENT HIGH-ALUMINA

ULTRA-GREEN 57A

ULTRA-GREEN 57A is a 57% alumina, andalusite based, ultra low cement castable with outstanding thermal shock resistance in applications having extreme cyclic temperature conditions. ULTRA-GREEN 57A also features high hot strength, low porosity, and high density superior or equal to fired brick of similar composition.

ULTRA-GREEN 60 & PLUS

ULTRA-GREEN 60 is a 60% alumina low cement castable characterized by its high density, low porosity and high hot strength. ULTRA-GREEN 60 is designed for placement by ramming, vibration cast, hand casting, or pumping by varying the amount of water.

ULTRA-GREEN 70 ADTECH®

ULTRA-GREEN 70 is a 70% alumina, ultra-low cement, vibratable castable. Features excellent strength, outstanding hot load bearing ability, superior corrosion resistance, and low porosity-high density.

ULTRA-EXPRESS 70 ADTECH®

A dense, free-flowing, ultra-low cement refractory castable. It has the unique property that vibration is not required to remove air voids. It can be either cast or pumped. Its density together with very good abrasion resistance makes it an ideal hot face lining material.

ULTRA-GREEN 80

An 80% alumina, ultra-low cement castable with high hot strength for resistance to hot load, abrasion and hot metal erosion. Typical applications are cyclones, burners, and nose rings.

ULTRA EXPRESS 80

ULTRA EXPRESS 80 is an 80% alumina, dense self-flowing, ultra low cement castable. It has the unique property that vibration is not required to remove air voids. It can either be cast or pumped.

ULTRA LOW CEMENT HIGH-ALUMINA con't.

ULTRA-GREEN SR

ULTRA-GREEN SR is a tabular alumina based, 86% alumina, ultra-low cement, vibrating castable. This product displays high hot strength for resistance to hot load deformation and hot abrasion. Maximum operating temperature is 3400°F (1870°C). Its addition of andalusite gives it thermal shock resistance superior to conventional ultra-low cement tabular alumina castables.

HP-CAST ULTRA

Low moisture, low-cement, spinel forming 96% alumina castable. With a 3400°F service temperature and outstanding hot strengths this castable is ideally suited for steel contact and precast shapes.

HP-CAST 93S

Low moisture, low-cement, spinel containing 94% alumina castable. Excellent hot strengths and thermal shock resistance. Its spinel addition and outstanding hot properties combine to provide improved slag and metal erosion resistance in ladle impact pads and other precast shape.

HP-CAST 94MA-C

Coarse grained, low cement castable based on high purity alumina aggregates. HP-CAST 94MA-C contains preformed magnesia-alumina spinel for optimum slag resistance. Coarse grain technology provides excellent thermal shock resistance. High density, low porosity and high hot strengths help resist metal and slag attack at steel processing temperatures.

HP-CAST MAXIMA

Low moisture, low-cement 92% alumina castable with patented bond. Contains both preformed and in-situ spinel additions for optimum slag resistance. Ideally suited for impact pads, well blocks and other high wear areas.

HP-CAST 93Z3

A high purity, thermal shock resistant, ultra low cement castable. It has high hot strength, low hot load deformation, and low porosity. Typical applications include ammonia plant secondary reformers and transfer lines, carbon black reactors, nozzles, burner blocks and channel induction furnace linings.

CEMENT - FREE HIGH-ALUMINA CASTABLES

NOVACON® 65 ADTECH®

A 65% alumina, lime free monolith with excellent creep resistance. Relative to conventional castables, this monolith has superior hot strengths at high temperatures, in addition to reduced dry-out time. This monolith provides resistance to alkali and chloride attack. It has problem - solving capabilities in numerous applications.

NOVACON® 85

An 85% alumina, lime free monolith with exceptional refractoriness load resistance, and superior hot strengths between 2000 and 2700°F compared to conventional castables. The lime free binder allows for reduced dry-out time, in addition to resistance to chlorine environments. For use in hearths, incinerators, and precast shapes.

NOVACON® 95

A 95% alumina, lime free monolith with exceptional refractoriness and purity. This product has excellent hot strengths at high temperatures and good chemical resistance. It has problem solving capabilities for pre cast shapes and burner blocks.

NOVACON® S

A 97% silica cement-free monolith based on vitreous silica aggregate with outstanding thermal shock resistance. This product has high hot strength and volume stability, as well as excellent resistance to alkali and chlorine attack.

FASTDRY 8 CASTABLE

This is a high alumina, cement free castable with an alumina rich spinel matrix. It offers good resistance to steel and iron slags. The cement free formulation provides exceptional strength at high temperatures and allows the dry out to begin sooner than for cement containing castables.

CHEMICALLY BONDED CASTABLES

EXCELERATE™ ABR PLUS

EXCELERATE ABR PLUS is a phosphate bonded, chemical setting castable that can be rammed, vib-cast, hand packed, or gunned hot and cold. It develops a quick set and can be heated within 4 hours of installation to minimize furnace downtime. This castable displays outstanding strengths and abrasion resistance.

VITREOUS/FUSED SILICA CASTABLES

ATM-2000

A high purity, fused silica castable. It features volume stability, thermal shock resistance, and low thermal conductivity. ATM-2000 is designed for easy placement in inaccessible places and for shapes that are difficult to manufacture by conventional methods.

DESCON® S97 ADTECH®

A vitreous silica based casting mix with outstanding thermal shock resistance. DESCON® S97 ADTECH® features chemistry, refractoriness, density, and porosity equivalent to high quality fired silica brick, and is ideal for hot repair work and manufacture of large and/or complicated shapes. Typical uses include glass tanks, coke oven maintenance, hot patching of glass tank crown and burner blocks.

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CASTABLE REFRACTORIES

VITREOUS/FUSED SILICA CASTABLES con't.

FUSIL® CASTABLE 820I

A fine grained, fused silica castable utilizing a high purity, hydraulic setting cement binder. FUSIL® CASTABLE 820 I has exceptional volume stability, thermal shock resistance, low thermal conductivity, and light weight.

HPV ESX CASTABLE

A high purity, fused silica castable. It has volume stability which leads to outstanding thermal shock resistance. HPV ESX is an excellent choice for burner blocks and other thermally cyclical applications.

VISIL® ES CASTABLE ADTECH®

A refractory castable employing a blended mixture of carefully sized vitreous silica aggregate and hydraulic binder. It features extremely low thermal expansion resulting in excellent resistance to cracking due to thermal shock. Easily installed by casting, trowelling or air placement gun. Primary applications include furnaces in which severe cycling conditions exist and maximum temperature does not exceed 2000°F (1093°C).

VERSAFLOW® THERMAX® PLUS

A unique, extra-strength, low cement vitreous silica castable with a high purity binder and reinforced matrix. Its low density and thermal conductivity along with high strength and abrasion resistance allow it to be used as a single component lining where a dense castable, lightweight castable combination may be used.

VERSAFLOW® THERMAX® AL ADTECH®

A vitreous silica based low-cement castable with an aluminum penetration inhibitor. VERSAFLOW® THERMAX® AL ADTECH® offers exceptional thermal shock and abrasion resistance, as well as volume stability.

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EXPRESS® THERMAX® ADTECH®

A unique low cement refractory containing a fortified matrix and unique vitreous silica aggregate. Ideally suited for installation in several ways-from vibcast consistency to pump casting techniques. This refractory is self leveling when tempered at the high end of the recommended water range. This product has excellent abrasion resistance.

ZIRCON CASTABLES

NARCON ZRAL

A 60% zirconia castable with excellent corundum resistance. Zoning aluminum furnace belly bands with NARCON ZRAL has proven to be very successful in furnaces prone to corundum formation.

THOR AZSP ADTECH®

A pumpable, low-moisture fused zirconia-mullite castable with a silicon carbide addition. The zircon is tied up with the mullite and will not reduce. It has exceptional resistance to alkalis, chlorides and sulfates. It has excellent abrasion high refractoriness.

ALUMINA-CHROME CASTABLES

FUSECRETE® C

FUSECRETE® C is a high alumina castable refractory characterized by high cold compressive strength, erosion resistance and containing 3% chromic oxide for resistance to slag erosion.

FUSECRETE® C10

A high alumina castable refractory with high chromic oxide content for resistance to corrosion by ferrous and non-ferrous slags.

FUSECRETE® C6

FUSECRETE® C6 is a high alumina castable refractory that has high chromic oxide content for resistance to corrosion by ferrous and non-ferrous slags.

AUREX® 70 CASTABLE

A chrome-alumina castable based on AUREX® and NOVACON® technology. It has excellent corrosion resistance and contains a spall inhibitor for improved resistance to thermal shock.

DENSE MAGNESITE CASTABLES

GR-FG® CASTABLE

A chemically bonded basic castable that employs fused magnesium-chromate spinel aggregate that provides excellent resistance to slag penetration in both ferrous and non-ferrous applications. GR-FG® CASTABLE has the ability to be applied by both casting and pneumatic gunning techniques.

HARCHROME® CASTABLE

A chrome ore base castable refractory using a standard calcium aluminate hydraulic binder. It features outstanding strength and abrasion resistance. It also has high resistance to chemical attack and thermal spalling. HARCHROME® CASTABLE can be installed by casting, gunning, or ramming.

H-W® CHROMEPAK®

A chrome magnesite mix with a silicate bond. H-W CHROMEPAK is a strong, volume stable refractory and can be cast or gunned.

NARMAG® FG CASTABLE

Fused grain, Magnesia-Chrome castable with excellent resistance to erosion by basic slags. NARMAG® FG CASTABLE has high density and low permeability to help prevent penetration by molten metals, slags and gases.

NOVUS® CASTABLE

A magnesia chrome spinel castable, which does not contain a calcium aluminate binder. It features outstanding resistance to chemical attack by fluxes and slags due to purity of raw materials. Typical uses include AOD hoods or covers, steel or ductile iron ladle linings, lance sections, collector nozzles, and copper applications.

DENSE MAGNESITE CASTABLES cont.

MAGSHOT® CASTABLE

MAGSHOT® CASTABLE is based on a dicalcium silicate natural magnesite that has good resistance to molten smelt and soda. This unique formulation does not require lengthy cure time or slow heat up schedules. It offers excellent casting characteristics.

NARMAG® 95LS CASTABLE

A 96% magnesia castable with high density and strength. It is intended for basic steel and iron operations.

DENSE SILICON CARBIDE

THOR 30 ADTECH®

A low cement, 30% silicon carbide containing castable that can be installed by vibration casting, shotgunning, or shotcreting. A reduced cement content with a special additive package helps improve alkali resistance.

THOR 60 ADTECH®

A low cement, 60% silicon carbide containing castable that can be installed by vibration casting, shotgunning, or shotcreting. A reduced cement content with a special additive package helps improve alkali resistance.

THOR 60 ABR ADTECH®

A 60% silicon carbide castable with very high strength and abrasion resistance. Used primarily in the aluminum industry, it is a proven problem solver in hearths, ramps and sills.

SILICON CARBIDE CONTAINING CASTABLES

D-CAST XZR-OR and XZR-OR-CC CASTABLE

A low cement, high alumina, silicon carbide containing castable. Resistant to abrasion by hot flowing molten metals. D-CAST XZR-OR has excellent thermal shock resistance, high density, low hot load deformation, and excellent oxidation resistance. Typical applications include copper and brass furnace linings and launders, cupola front slaggers and holders, and foundry ladles and slag runners. To aid in drying, the 'CC' version contains an organic fiber addition while the standard version employs gas forming technology. Can be applied using SHOTKAST technology.

D-CAST TRC-SR

A low cement, high alumina, silicon carbide and carbon containing castable developed for optimum slag resistance. The combination and sizing of the silicon carbide and carbon additions make D-CAST TRC-SR extremely resistant to hot flowing molten metals and slags. Outstanding hot properties and low permeability also make the composition resistant to corrosive and dust laden gases. Typical applications include cupola wells, troughs and slag runners. Can be applied using SHOTKAST technology.

D-CAST TRC-OR and TRC-OR-CC CASTABLE

A low cement, high alumina, silicon carbide and carbon containing castable developed for improved oxidation resistance. An anti-oxidant addition is provided to protect the silicon carbide and carbon additions from oxidation. D-CAST TRC-OR features good thermal shock resistance, low porosity and permeability, and volume stability for negligible sintering cracks during service. These properties combine to provide resistance to abrasion by hot flowing molten metals and slags and to limit corrosion and penetration of liquid metals, slags, and gases. To aid in drying, the 'CC' version contains an organic fiber addition while the standard version employs gas forming technology. Can be applied using SHOTKAST technology.

D-CAST TRC-OR PLUS

A low cement, high alumina, silicon carbide and carbon containing castable. Contains the same oxidation resistant technology as D-CAST TRC-OR. The PLUS designation is a separate addition for improved slag resistance. Low porosity and permeability combined with the non-wetting and PLUS additions make D-CAST TRC-OR PLUS the most slag resistant D-CAST TRC material. Typical applications include cupola wells and tapholes and casthouse applications in ironmaking. Can be applied using SHOTKAST technology.

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CASTABLE REFRACTORIES

INSULATING CASTABLES

KAST-O-LITE® 16 PLUS

A 1600°F insulating castable with outstanding low density and very low thermal conductivity that can be applied by casting or gunning.

KAST-O-LITE® 19L PLUS

A 1900°F (1037°C) maximum service temperature insulating castable. It exhibits greater crushing strengths than traditional mineral wool block insulation and can conform to irregular shell configurations. It is used ideally as a back-up lining behind hot face linings to reduce shell temperatures.

KAST-O-LITE® 20 PLUS

A 2000°F (1095°C) insulating castable usable in direct contact with hot gases under continuous or intermittent operation without loss of thermal efficiency.

KAST-O-LITE® 20 LI ADTECH®

A low iron insulating castable with a maximum service temperature of 2000°F (1093°C).

KAST-O-LITE® 22 PLUS

A lightweight castable for temperatures to 2200°F (1205°C). It features low thermal conductivity and good strength for such a lightweight material.

KAST-O-LITE® 23LI PLUS

KAST-O-LITE® 23LI PLUS is a 2300°F (1260°C) maximum service temperature insulating castable. It contains low iron to resist detrimental reducing furnace conditions. Typical applications are: flues, stacks, breechings, controlled atmosphere furnaces, petroleum transfer and riser back-up linings, catalytic reformer linings behind stainless steel shroud and waste heat boilers.

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KAST-O-LITE® 23 ES ADTECH®

An intermediate strength insulating castable with a maximum service temperature of 2300°F (1260°C).

KAST-O-LITE® 50-25

A 2500°F (1370°C) insulating castable with good strength and low thermal conductivity. KAST-O-LITE 50-25 can be installed by pouring, pumping, or gunning.

KAST-O-LITE® 26 LI PLUS

A low iron insulating castable with a maximum service temperature of 2600°F (1427°C).

MC-28L PLUS

A 2800°F insulating castable combining the features of an extra strength castable in a lightweight, insulating material. It has high strength, low shrinkage, and low iron.

KAST-O-LITE® 30 LI PLUS

A lightweight insulating castable with high purity cement and a maximum service temperature of 3000°F (1649°C).

KAST-O-LITE® 97L PLUS

A 3300°F (1815°C) maximum service temperature insulating castable. It contains bubble alumina for high strength and moderate density. It has a very low silica content to resist detrimental hydrogen atmospheres. Typical applications are secondary ammonia reformer back-up linings, carbon black reactor back up linings, very high temperature back-up linings, waste heat boiler tube sheets, and controlled atmosphere furnace linings.

GREENLITE 75-28 PLUS

A lightweight, super-duty, hydraulic setting castable with high strength. GREENLITE 75-28 is rated to 2800°F.

GREENLITE EXPRESS 24 PLUS

A 2400°F, self-flowing, insulating refractory castable. It has the unique property that vibration is not required to remove air voids. It can be conventionally cast, or pumped using a Putzmeister pneumatic pump.

GREENLITE CASTABLE 22 PLUS

GREENLITE CASTABLE 22 PLUS is a 2200°F (1203°C) maximum service temperature insulating castable that can be cast or gunned. It has moderate density, good strengths, and a low permanent linear change after heating to 1500°F (816°C).

GREENLITE-45-L PLUS

A 2500°F insulating castable, with high strength and low density. GREENLITE-45-L can be pumped using a Putzmeister pneumatic pump.

HPV™ CASTABLE

A high strength, lightweight, insulating castable with exceptionally high strength and abrasion resistance.

ALUMINUM RESISTANT CASTABLES

GREENLITE-45-L AL

This lightweight castable has a very high strength to weight ratio. It is ideally suited for insulating Aluminum sub-hearths and crucibles.

HYDROCRETE® AL

An aluminum resistant version of the standard HYDROCRETE®. It has high strength and a moderate density. HYDROCRETE® AL is an attractive, economical choice for aluminum furnace sub-hearths.

H-W® ES CASTABLE C AL

An industry standard for aluminum furnace safety linings, H-W® ES CASTABLE C AL is a coarse aggregate castable with excellent impact and thermal shock resistance.

VERSAFLOW® 45/AL ADTECH®

A 45% alumina, pumpable, low-cement castable with improved strength versus conventional castables.

ALUMINUM RESISTANT CASTABLES con't.

GREENKLEEN 60 PLUS

Is a 60% alumina, low cement castable containing andalusite. GREENKLEEN 60 PLUS displays outstanding abrasion resistance, thermal shock resistance, and resistance to aluminum penetration. It can be vibration cast or pumped as required. GREENKLEEN 60 PLUS contains special additives which enable it to be fired more quickly than regular castables. It is non-wetting in contact with aluminum, and slag resistant in waste-to-energy boilers.

VERSAFLOW® 65/AL PLUS

A 65% alumina, low cement castable with high strength and versatile installation characteristics.

VERSAFLOW® 65/AL C ADTECH®

A 65% alumina, aluminum resistant, coarse grain castable. For use in high wear areas in aluminum contact such as ramps, sill and cruce bottoms. Its coarse aggregate improves its thermal shock and impact resistance.

NARCOTUFF™ SUPER AL

With a minor zircon addition, NARCOTUFF SUPER AL is an excellent choice for the lower sidewall or bellyband in an aluminum furnace with slight corundum growth.

ARMORKAST™ 65AL

A very high purity low cement castable. Its unique bonding matrix provides exceptionally high strength and ultimate corrosion resistance.

ARMORKAST™ 70 AL

An economical, low cement, 70% alumina, aluminum resistant castable. It has good strength and resistance to molten aluminum alloys.

ULTRA-EXPRESS 70 AL

An ultra-low cement, 70% alumina castable designed with enhanced flow, and self-leveling characteristics. ULTRA-EXPRESS 70 AL is very strong and is ideal for pumping over long distances and for casting into intricate form patterns.

ARMORKAST™ 80AL ADTECH®

This high purity, pumpable, 80% alumina castable is built for corrosion resistance. It has exceptional strength and aluminum resistance. ARMORKAST™ 80AL is designed for the most severe aluminum contact applications.

ALSTOP GREFCON® 80 A

An industry standard for more than 15 years, ALSTOP GREFCON® 80A is a high strength, high corrosion resistance, 80% alumina low cement castable.

ARMORKAST™ XPUR/AL ADTECH®

This tabular alumina based castable is also silica-free, and is designed combat corundum formation. It shows very high strength and excellent aluminum resistance.

HP-CAST™ 96AL

A high purity, tabular alumina based, aluminum resistant castable. It has high hot strength and very low porosity. It is well suited for melting and holding furnaces where pure metal chemistry is of extreme importance.

HIGH TOUGHNESS CASTABLES

2-TOUGH® HP ADTECH®

The combination of a coarse tabular alumina aggregate and a fine tabular alumina matrix gives this high purity mix outstanding corrosion resistance. 2-TOUGH® HP ADTECH® has set a record in the impact test, surviving almost 70 impacts!! This unique product has solved severe wear problems in several steel applications including well blocks, ladle bottoms and electric furnace deltas.

2-TOUGH® FA ADTECH®

Exceptionally high strength and impact resistance characterize this product. Its fused alumina coarse aggregate has a higher density than tabular alumina, resulting in significantly lower porosity than traditional 90% alumina castables. Typical uses for 2-TOUGH® FA ADTECH® include ladle bottoms, aluminum furnace jambs and lintels, and rotary kiln lifters.

2-TOUGH® AL ADTECH®

2-TOUGH® AL ADTECH® is specifically designed for use in aluminum contact. It is essentially silica free, and contains an aluminum penetration inhibitor. This makes it very resistant to aluminum corrosion. Typical used include precast hearths, ramps, and sills, belly bands, troughs, and cruces.

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RAMMING MIXES

Overview

Ramming mixes typically consist of ground refractory grog materials in a wide range of chemical composition, carefully graded as to relative proportions of different particle sizes, with minor amounts of other materials added to make the mixes workable and self-bonding.

Most ramming mixes are supplied dry, but some are shipped in ready-to-use, wet form. Dry mixes are prepared for use by adding water and mixing. Some ramming mixes can be applied successfully with air-placement guns. Others, known as dry-vibratibles, are specifically designed to vibrated into place.

Once rammed, gunned or vibrated into place, dried and heated, ramming mixes form dense, strong monolithic structures. Ramming mixes are particularly suitable for forming dense monolithic hearths.

The following product descriptions of Harbison-Walker's ramming mixes are categorized by their classification. This listing represents the major brands supplied for a wide variety of furnaces and applications.

HIGH-ALUMINA RAMMING MIXES

BRIKRAM® 57 RB

A phosphate-bonded, high alumina ramming mix with high hot strength and excellent resistance to deformation under load.

HARMIX® AL

An air-setting, high purity alumina ramming mix with excellent strengths at all temperatures within its use range. Resists spalling and has remarkable linear and volume stability up to its temperature limit. HARMIX AL is ideally suited for inductor blocks.

NARPHOS 55R (FINE) RAM

An economical, phosphate bonded, high-alumina ramming mix. It has high strength and excellent installation characteristics.

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NARPHOS 85R RAM

An 85% alumina class, phosphate-bonded, ramming mix, NARPHOS 85R RAM provides high strength and density combined with excellent volume stability throughout its entire temperature range. It displays non-wetting characteristics to provide outstanding resistance to erosion from slag and metal wash. This product is used where excellent resistance to temperatures, slag, thermal shock, and abrasion is required.

NARPHOS 90R RAM

NARPHOS 90 R RAM is a high purity, extra high alumina, phosphate bonded ramming mix. It exhibits high density and excellent strength.

RAMAL® 80

A high alumina air-setting ramming mixture furnished in wet form, ready for use. It features excellent resistance to shrinkage and thermal spalling at high temperatures. Typical uses include burner rings, electric furnace roofs, and ladle linings for ferrous and nonferrous industries

TAYCOR® 245-D RAM MIX

A dry ramming mix based on high purity sintered alumina. In-situ spinel formation provides improved slag and metal resistance and volume stability at elevated temperatures.

ALUMINA-CHROME RAMMING MIXES

RUBY® RAMMING MIX

A phosphate-bonded, high purity alumina-chrome ramming mix with exceptional intermediate and high temperature strengths. Resists attack by acid and neutral slags and is especially suited for use where the refractory is exposed to coal ash and coal slag.

MAGNESITE & MAG-CHROME RAMMING MIXES

GREFMAG® 95R

A high quality, magnesia based, chemically bonded ramming mix available in the dry form. When mixed with water, GREFMAG® 95R develops good plastic workability so it can be rammed to the highest density. Typical applications include the working linings of coreless induction furnaces, bottoms and working linings of Electric Arc furnaces, and steel ladles.

HARMIX FE®

A high purity magnesite ramming mix with exceptional stability for use in coreless induction furnaces melting steel and alloys.

H-W® C MIX

A high purity, chemically bonded ramming mix for electric furnace hearths, subhearths and other leveling purposes in process vessels.

MAGNAMIX® 95

A versatile, high purity periclase mix which can be installed by ramming, gunning, or vibration casting. For new construction of electric furnace hearths and maintenance of electric furnace and BOF tapholes.

GR-FG RAMMING MIX

An organic bonded, magnesite-chrome, fused grain ramming mix. It features exceptionally high density and strength and volume stability throughout temperature range.

MAGNESITE & MAG-CHROME RAMMING MIXES con't.

OXIMIX®

A carbon containing magnesia ramming mix for increased resistance to penetration by ferrous metals.

SiC & CARBON CONTAINING PLASTICS & RAMMING MIXES

RAMAL 85 G

This is a fused grain containing, high alumina wet ramming mix with a high amount of graphite. The high purity aggregate and graphite addition combine to provide resistance to slag and metal erosion. RAMAL 85 G is especially well suited for cupola bottoms, troughs, and runners.

SUPER NARCARB RAM

Based on fused alumina with SiC and oxidation inhibitors. This yields very low porosity for enhanced corrosion resistance to cupola slags. SUPER NARCARB RAM is intended for extended cupola campaigns and the most severe service conditions. It offers the highest level of carbon containing, non-wetting components, and a more environmentally friendly bond system than the phenolic resin bonded materials.

NARCARB™ XZR RAM

This is a phenolic resin-bonded ramming mix with the second highest amount of non-wetting components. This mix offers high density, low porosity and high hot strengths. NARCARB™ XZR RAM provides excellent performance in maintenance situations or as the original lining in Cupola bottoms and troughs.

NARCARB™ XZR-HS RAM

This phenolic resin-bonded ramming mix is a high strength, oxidation resistant upgrade to NARCARB™ XZR RAM. The improved properties, combined with its high amount of non-wetting components, make this mix extremely resistante to metal erosion and slag attack. This mix is ideally suited for cupola taphole applications.

GREFITE R

GREFITE R is a damp fireclay based, high quality graphitic ramming mix possessing good resistance to slag and molten iron. It has non-wetting characteristics that permit easy removal of skulls which results in cleaner linings and metal. Typical uses include cupola breasts, wells, and runners, gray and malleable iron ladles, blast furnace troughs and runners.

HARMIX CU®

A mullite bonded, high alumina based ramming mix with a penetration and corrosion inhibitor. It offers excellent dimensional stability and has a combination of physical and chemical properties particularly adapted to resist wetting, penetration and corrosion by molten copper and copper alloys. Typical uses include linings for copper induction furnaces. It is also suitable for some high carbon steels.

DRY VIBRATABLES

NARCOVIBE 82A FINE

A bauxite-based, dry vibratable for use as a fill material between brick working and backup linings of steel ladles. This material will not sinter in service providing for easier lining removal during ladle tearouts.

NARCOVIBE S

An alumina-magnesia spinel dry vibratable refractory designed for the coreless induction melting of steel alloys. Based on sintered alumina and high purity magnesia, its high bond strength and high purity raw materials provide extreme resistance to the erosion created by high temperatures and corrosive alloys. Designed for smaller furnaces with installations of less than 5-inches of sidewall thickness.

NARCOVIBE SD

An alumina-magnesia spinel dry vibratable refractory designed for the coreless induction melting of steel alloys. Based on sintered alumina and high purity magnesia, it is engineered for deeper sintering and higher strength development to protect against lining fracture during the charging procedure. Designed for larger furnaces with installations of greater than 5-inches of sidewall thickness.

NARCOVIBE XL

An alumina-magnesia spinel dry vibratable refractory designed for the coreless induction melting of steel alloys. Based on sintered alumina and high purity magnesia, it is engineered to provide intermediate sintering for large or small size furnaces. Contains a spinel addition for improved corrosion resistance.

NARCOVIBE TOP CAP

An alumina-magnesia spinel dry vibratable refractory designed for top cap of coreless induction furnaces melting steel alloys. Designed for deep sintering at 1000°F or greater to protect against damage from charging the furnace. Engineered to sinter and bond with the hot face lining.

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CERAMIC FIBER PRODUCTS

Overview

INSWOOL® Ceramic Fibers are a family of products that are manufactured from alumina-silica materials into several product forms. Those products are made from spun fibers that provide low thermal conductivity, low heat storage, excellent thermal shock resistance, high temperature stability, lightweight and excellent sound absorption.

The INSWOOL® Ceramic Fiber Product line has a wide temperature range for applications from 1500° F to 3000° F. These products also offer excellent chemical stability and resistance to chemical attack from most corrosive agents. The exceptions are phosphoric acid, hydrofluoric acid and strong alkalies.

INSWOOL® Ceramic Fibers come in various product forms which include:

- Blankets
- Modules
- Bulk
- Board
- Paper
- Moldable and Pumpable
- Rope and Braids

INSBOARD®

INSBOARD is a vacuum formed ceramic fiber board with excellent insulating characteristics, as well as thermal stability. It can be used as a hot face or back up insulation material. Applications include petro-chemical, ceramics, steel, aluminum, waste incineration, and the glass industry. INSBOARD is available in 2300, 2600, and 3000 degree board.

INSBOARD® HD

INSBOARD HD is a high density, vacuum formed ceramic fiber board with excellent insulating characteristics and increased mechanical strength. It is often used as a hot face insulation in high velocity applications. Applications include petro-chemical, steel, glass, ceramics, aluminum, and waste incineration. INSBOARD is available in 2300, 2600, 2800, and 3000 degree board.

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INSBOARD® 2300 LW

INSBOARD 2300 LW is a lightweight vacuum formed ceramic fiber board with excellent insulating characteristics, thermal stability, and machinability where special shaped boards are required. Its lightweight enables easy cutting and machining in the field. Applications include areas where high quality back up insulation is required.

INSWOOL® Ropes and Braids

H-W provides a family of ropes and braids for industrial use in temperatures up to 2300°F (1260°C). Typical applications for these products include gasketing, packing and sealing in and around high-temperature heating equipment. Produced from ceramic fibers, these products exhibit excellent chemical stability, resisting attack from most corrosive agents. Exceptions are hydrofluoric and phosphoric acids and concentrated alkalies. These fiber ropes and braids also resist oxidation and reduction. If wet by water or steam, thermal properties are completely restored upon drying. No water of hydration is present.

INSWOOL® CG BLANKET

INSWOOL CG is an alumina silica blanket used in applications up to 2000°F. It is a high quality product that can be used as back up insulation for most furnace applications.

INSWOOL® HP BLANKET

INSWOOL HP BLANKET is a low iron, high purity ceramic fiber blanket developed especially for use in highly reducing atmospheres. It is lightweight, flexible and suitable for operating temperatures to 2400°F. INSWOOL HP BLANKET retains a soft fibrous structure right up to its maximum usage temperature, and even the most extreme temperature changes will not affect its ability to insulate and stay in place. INSWOOL HP BLANKET was developed to meet the demand for a high temperature, flexible blanket insulation with a low iron content of less than 1%. INSWOOL HP BLANKET has excellent strength, both hot and cold. It remains in place on the furnace anchors even at high temperatures and can resist damage even when subjected to normal mistreatment in shipment and handling.

INSWOOL® HP BULK

INSWOOL HP BULK is a low iron, high purity alumina-silica bulk ceramic fiber which can be used at temperatures to 2400°F. INSWOOL HP BULK demonstrates excellent high temperature resistance, thermal stability and resistance to vibration, as well as outstanding low thermal conductivity and low heat storage. It is resistant to attack under reducing atmospheres. It is attacked by acids and concentrated alkalis. The thermal and physical properties of INSWOOL HP BULK are completely restored upon drying if it becomes wet by water, steam, or oil.

INSWOOL® HP MODULES

INSWOOL HP MODULES are a family of 12" x 12" modules up to 12" thick. Special shapes are available upon request. These modules will resist temperatures up to 2400°F (1315°C) for intermittent use and up to 2250°F (1230°C) for continuous use. INSWOOL HP MODULES will reduce energy losses through the lining more effectively than insulating firebrick, and insulating castables. Typical applications include oil heaters, annealing furnaces, reformer sidewalls and end walls, and homogenizing furnaces. DO NOT use for linings in contact with molten metal, abrasive, alkali laden, and high positive pressure conditions.

INSWOOL® HTZ BLANKET

INSWOOL HTZ BLANKET is a 2700°F related alumina-silica-zirconia ceramic fiber blanket. It displays very low thermal conductivity, excellent thermal shock resistance, low heat storage, and good sound absorption. Typical applications are glass furnace crown insulation, expansion joint seals, furnace doors and shields.

INSWOOL® HTZ BULK

INSWOOL HTZ BULK is an alumina-silica-zirconia bulk ceramic spun fiber which can be used at temperatures to 2700°F. INSWOOL HTZ BULK demonstrates excellent high temperature resistance, thermal stability and resistance to vibration, as well as outstanding low thermal conductivity and low heat storage. It is resistant to attack under reducing atmospheres. It is attacked by acids and concentrated alkalis. The thermal and physical properties of INSWOOL HTZ BULK are completely restored upon drying if it becomes wet by water, steam, or oil.

INSWOOL® HTZ MODULES

INSWOOL HTZ MODULES are a family of 12" x 12" modules up to 12" thick. Special shapes are available upon request. These modules will resist temperatures up to 2700°F (1480°C) for intermittent use and up to 2450°F (1345°C) for continuous use. INSWOOL HTZ MODULES will reduce energy losses through the lining more effectively than insulating firebrick, and insulating castables. Typical applications include oil heaters, annealing furnaces, reformer sidewalls and end walls, and homogenizing furnaces. DO NOT use for linings in contact with molten metal, abrasive, alkali laden, and high positive pressure conditions.

INSWOOL® UTILITY BLANKET

INSWOOL UTILITY BLANKET is a Kaolin based ceramic fiber blanket. It is lightweight, flexible and suitable for operating temperatures to 2300°F. It has relatively low shot content and excellent conductivity. INSWOOL UTILITY BLANKET exhibits moderate tensile strength and handling characteristics.

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INSWOOL® MOLDABLE

INSWOOL MOLDABLE is a 2300°F ceramic fiber, putty-like consistency material, used for linings up to three inches thick, to pack large voids, or even fill thin cracks.
It can be troweled or hand packed into place. INSWOOL MOLDABLE is light weight, with very low thermal conductivity, and therefore a good insulator, yet it develops a strong hot face surface to withstand physical abuse and high air velocities as compared to conventional ceramic fiber products. It is also used as a high temperature gasket material, and as a general purpose patching product. Its ability to compress makes INSWOOL MOLDABLE an excellent material for expansion joints and for filling contraction cracks. It is also an ideal material to fill ceramic cuplock anchors for ceramic fiber blanket linings, and can be used in contact with molten aluminum. INSWOOL MOLDABLE has excellent thermal shock resistance, and can be dried or put into service immediately with no pre-heat required, with the exception of direct molten metal contact.

INSWOOL® PUMPABLE

INSWOOL PUMPABLE is a 2300°F ceramic fiber, putty like consistency material, especially formulated for pumping with special equipment. It is usually used for pumping behind existing hot face linings for insulating purposes, however it can be used to fill small voids and thin cracks.
INSWOOL PUMPABLE is a light weight material with very low thermal conductivity, and therefore a good insulator. It dries to a firm, board-like consistency, for good sturdy integrity. Its ability to compress makes it ideal for expansion joints, and for filling contraction cracks. In addition it is used in contact with molten metal. Although normally used as a back up material, as mentioned above, when used as a hot face material, the INSWOOL PUMPABLE has excellent thermal shock resistance, and can be dried or put into service immediately with no pre-heat required, with the exception of direct molten metal contact.

INSWOOL® PAPER

INSWOOL PAPER is a lightweight, refractory material processed from alumina-silica ceramic fibers formed in a flexible sheet. It is recommended for continuous use at temperatures to 2300°F. INSWOOL PAPER is clean and efficient, containing no unfiberized shot. It is especially noted for having exceptional low thermal conductivity and good handling strength. Its highly uniform structure assures equal thermal conductivity throughout and its clean, smooth surface makes it ideal as a gasket, seal and spacer material.

INSWOOL® UTILITY PAPER

INSWOOL UTILITY PAPER is a lightweight, refractory material processed from alumina-silica ceramic fibers formed into a flexible sheet. It is recommended for continuous use at temperatures to 2300°F. INSWOOL UTILTITY PAPER is a commercial grade of ceramic paper. It is especially noted for having exceptional low thermal conductivity and good handling strength. Its highly uniform structure assures equal thermal conductivity throughout and its clean, smooth surface makes it ideal as a gasket, seal, and spacer material.

INSBLOK-19

INSBLOK-19 is a 1900°F maximum service temperature lightweight mineral wool block insulation. INSBLOK-19 exhibits very low thermal conductivity, good moisture resistance, easy handling, and easy cutting. Its organic binder gives INSBLOK-19 excellent cold strength but will dissipate above 475°F. INSBLOK-19 meets the ASTM C612 Class 5 specification. Its principal application is as a backup lining to lower furnace shell temperatures.

INSFORM PREFIRED MODULE

INSFORM PREFIRED MODULE is a vacuum formed, pre-fired ceramic fiber module. INSFORM's module shell is a pre-fired vacuum formed five sided box. This box or shell, open at the back, is manufactured from a wide range of ceramic fiber mixes designed to withstand specified service conditions. Normal box size is 18" x 12", but special sizes as required are available. Thickness range from 4" to 12".

INSFORM ADHESIVE GRADE 2

INSFORM ADHESIVE GRADE 2 is a finely ground alumino-silicate and inert binder based compound. Excellent chemical resistance and resistance to wetting by most non-ferrous metals. Excellent thermal shock resistance, thermal reflectance and dielectric strength properties. When exposed to temperatures above 1562°F (850°C) it undergoes an increase in strength due to formation of the ceramic bond.

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SECTION 6

Brick Products

*In order to provide current data to the users on this handbook, we have chosen to use an on-line link to our website, www.hwr.com. If you are not able to access the website, please contact your local sales representative to secure the required data sheets.

BASIC BRICK

Overview

Basic refractories are those based on magnesite (MgO). The term basic refractory refers to refractory materials composed primarily of basic (non-acidic) oxides. At high temperatures, basic refractories are highly resistant to the corrosive action of chemically basic slags, solid or liquid oxides, dusts, and fumes. Consequently, they are the refractory materials of choice when one or more of these conditions are present. As the technology of basic refractories has advanced, the application for these products has broadened to include non-basic conditions, e.g., furnaces in the copper industry where siliceous (acidic) slags are present. Development of new and improved basic refractories continues at a rapid pace driven by equally rapid technological changes occurring in the industries they serve.

The following product descriptions of Harbison-Walker's basic brick refractories are categorized by their classification. This listing represents the major brands supplied for a wide variety of furnaces and applications.

BURNED MAGNESITE BRICK

SUPER NARMAG® B

Outstanding hot strength and good resistance to alkali attack are features of SUPER NARMAG® B a 98% magnesia refractory brick. SUPER NARMAGr B brand brick provide unusual resistance to oxidation-reduction reactions as well as slag attack.

NOKROME 87 LK

NOKROME 87 LK has very low thermal conductivity and lends itself to applications to reduce shell temperature. It is standard product for applications in upper and lower transition zones of cement kilns under normal operations.

NOKROME 92 LK

NOKROME 92 LK has good coatability characteristics and performs well in all zones of kilns under normal operations. Its coatability makes it a good performer in the burning zone.

DIRECT-BONDED MAGNESITE-CHROME BRICK

SUPER NARMAG® FG

This is a burned 100% fused MG-Cr grain brick with chrome enhancement. This yields extremely low porosity, very high density, and excellent strength. SUPER NARMAG® FG is intended for the most basic iron and steel containing conditions with regards to slag corrosiveness and temperature.

NARMAG® FG

This is a burned 100% fused Mg-Cr grain brick. This yields excellent porosity, density, and strength. NARMAG® FG is intended for extreme basic iron and steel containing conditions.

SUPER NARMAG® 142

This is a burned 20% fused Mg-Cr grain brick. It offers very good porosity, density, and strength. This product is for normal basic iron and steel containing conditions.

NARMAG® 142

High-fired, direct bonded, magnesite-chrome brick based on high purity magnesite and chrome ore. NARMAG® 142 features excellent hot strength and good corrosion resistance at steel-melting temperatures.

NARMAG® 60 DB

High-fired, direct-bonded basic brick of approximately 60% magnesia content, NARMAG® 60 DB features excellent hot strength and good corrosion and spalling resistance elevated temperatures. NARMAG® 60 DB brick are made from high purity periclase and beneficiated chrome ore.

SUPER NARMAG® 145

High fired, direct-bonded, magnesite-chrome brick based on high purity magnesite and chrome ore with 50% fused grain. SUPER NARMAG® 145 offers improved resistance to slag and load at high temperatures as well as higher hot strength.

TOMAHAWK®

High-fired, rebonded, magnesite-chrome brick based on high purity fused magnesia-chrome spinel grain. TOMAHAWK® also has secondary direct-bonding for improved thermal shock resistance.

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MAGNESITE-SPINEL BRICK

ANKRAL R17

This is a burnt magnesia aluminate spinel brick. It has great resistance against alkali and sulphur attack, as well as a great mechanical flexibility.

MAGNEL® RS

This magnesia aluminate spinel-containing refractory is based on high purity magnesite with a reinforced spinel bond for higher hot strength. It has low thermal expansion and thermal conductivity for a basic brick, as well as excellent spalling resistance.

MAGNEL® N/XT

A combination of high purity synthetic magnesite and fused spinel give MAGNEL® N/XT its excellent physical properties.

MAGNEL® RSV

A combination of high purity synthetic magnesite, fused spinel and a matrix of reinforced spinel gives MAGNEL® RSV its excellent physical properties at a cost effective price. The moderate amount of spinel yields a product that has excellent ressitance to clinker liquids while maintaining lower thermal conductivity and thermal expansion than similar products of the same class. MAGNEL® RSV can be used in all basic zones, but is best suited for lower transition and burning zone areas.

MAGNEL® HF

MAGNEL® HF is composed of crystalline magnesia with a bond of magnesium-aluminate spinel. It offers improved spalling resistance and good hot strength. This brick is typically used for vacuum induction furnace melting.

MAGNESITE-CARBON BRICK

COMANCHE®

An alumina-magnesia-carbon brick designed for steel ladle barrels and bottoms. COMANCHE® undergoes a gradual permanent expansion at the hot face during service. Ladles lined with COMANCHE®® will maintain tight brick joints throughout the entire ladle campaign without the need for mortar.

EAF

EAF series magnesite carbon refractories are high density, premium carbon bonded refractory brick based on high purity magnesite. This broad product offering makes it possible to design zoned refractory linings. Specialized products contain high purity graphites, metal antioxidants and fused refractory grains.e brick are designed to have good slag resistance and retain high temperature stability, i.e. the ability of the brick to resist internal oxidation-reduction reactions that can reduce hot strength and otherwise adversely affect the physical integrity of the brick at high temperature.

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HIGH-ALUMINA BRICK

Overview

High-alumina brick belong to the alumina-silica group containing more than 47.5% alumina. These multi-purpose refractories are available with alumina contents of up to 99+% and are useful for service extending to about 3300°F (1817°C). Their refractoriness is generally in proportion to their alumina content.

Often chosen for their resistance to spalling, impact, abrasion, or load, high-alumina brick's broadest appeal lies in its high refractoriness and excellent corrosion resistance to acid and neutral slags at high temperatures.

Harbison-Walker manufactures high-alumina brick of all classes, including mullite, corundum and alumina-chrome brick. The product line covers a wide range in refractoriness and other properties, and meets the requirements of a great variety of service conditions in many different types of furnaces.

Harbison-Walker's continually improving manufacturing techniques, coupled with the company's use of high purity domestic raw materials, has led to the manufacture of high-alumina refractories unequaled in economic service life.

The following product descriptions of Harbison-Walker's high-alumina refractories are categorized by their classification. This listing represents the major brands supplied for a wide variety of incinerator and industrial furnace applications.

BURNED HIGH ALUMINA BRICK

50% ALUMINA CLASS

KALA®

High purity, 50% alumina refractory with low porosity and exceptional resistance to alkali attack and creep under sustained loads. Primary applications include carbon baking flues, glass tank regenerators rider arches, blast furnace stoves and incinerators.

KALA® SR

A 50% alumina refractory with andalusite to enhance load and thermal shock resistance. KALA SR provides improved service in applications where temperature swings are common

60% AND 65% ALUMINA CLASS

UFALA®

This product manufactured from high purity bauxitic kaolin displays low porosity, very good hot strength, and superior resistance to thermal shock and alkali attack. Major applications are in checker settings of blast furnace stoves, along with incinerators and rotary kilns.

UFALA® XCR

An upgraded version of UFALA® CR, this high-alumina brick is based on high purity bauxitic kaolins and andalusite. UFALA® XCR offers improved load resistance and thermal shock resistance over conventional 60% alumina products.

ARCO® 60 A 60% alumina firebrick exhibiting good properties for continuous temperatures up to 2650°F (1450°C).

UFALA® UCR

This brick is the premium quality member of the UFALA® family of andalusite containing refractories. Ultimate creep resistance and excellent thermal shock resistance make UFALA® UCR an ideal choice for applications involving high loading and temperature cycling.

NIKE™ 60 AR

This 60% alumina brick, with andalusite, shows good strength and excellent resistance to alkali attack.

RESISTAL SM 60C

An andalusite containing, low porosity 60% alumina brick with a phosphorus pentoxide addition to yield increased thermal shock resistance and alkali resistance.

RESISTAL® S 65 W A

An andalusite containing chemically bonded 65% alumina brick with very high strength and alkali resistance.

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HIGH-ALUMINA BRICK

70% ALUMINA CLASS

KRUZITE® 70

A dense, low-porosity 70% alumina brick with excellent spalling resistance, hot load strength and the ability to withstand attack by corrosive slags and metals. Successful applications include cement kilns, electric furnace roofs, soaking pits, ladles, incinerators, reheat furnaces and many ferrous and non-ferrous melting furnaces.

70% AND 75% ALUMINA CLASS

VALOR™ P70

A 70% alumina phosphate containing burned alumina brick.

ALTEX® 75B

A 75% alumina, burned, phosphate bonded brick that exhibits low porosity and high hot strengths.

80% AND 85% ALUMINA CLASS

GREENAL-80-P

An 80% alumina, mullite bonded, burned brick containing phosphate. Excellent alkali rating from 2200°F to 2500°F. Good thermal shock resistance.

ALADIN® 80

Based on calcined bauxites, ALADIN® 80 has good strength, reheat expansion and thermal shock resistance along with lower porosity than any other brick in this class. Resistant to most slag conditions in steel ladles, ALADIN 80 is an economical refractory.

DV-38

DV-38 is an extra high strength, low apparent porosity, high alumina, burned phosphate-bonded brick featuring excellent alkali resistance. Withstands the penetration of fluid slags, metals, and fluxes. DV-38 is an excellent choice for abrasive environments at low temperatures.

Click here for Technical Data Sheets or go to www.hwr.com

GREENAL-80

An 80% alumina burned brick containing premium bauxite. This bauxite results in less vitrification at temperatures in excess of 3000°F (1650°C)

ALADIN® 85

This brick features high density and higher strengths than most 80% alumina brick. Based on calcined bauxite with very low alkali levels, ALADIN® 85 offers improved performance potential over other conventional products typically used for steel ladle applications.

90% - 99% ALUMINA CLASS

KORUNDAL XD®

High purity ingredients and a high purity mullite bond make KORUNDAL XD a premium refractory brick, capable of handling very difficult applications. It has been the acknowledged standard for 90% alumina brick since the mid-1960's. These brick carry a substantial load at temperatures above 3000°F (1650°C), and also offer excellent resistance to penetration and corrosion by molten slags and other fluxes. It has served successfully in many applications, such as slagging rotary kilns, where it resists corrosion and penetration by slag and in constructions where heavy loads and high temperatures prevail.

KORUNDAL XD® DM

This is a mullite-bonded high purity corundum refractory with Densified Matrix (DM). Characterized by low porosity, high hot strength, and good resistance to acid slags. KORUNDAL XD DM has provided longer campaign life in channel induction furnaces for the foundry industry.

GREENAL-90

A mullite bonded, 90% alumina brick containing phosphorous pentoxide additions. It exhibits excellent alkali, slag, and abrasion resistance.

TUFLINE® 90

A dense 90% alumina refractory with high hot strength, exceptional thermal shock resistance and low porosity.

TUFLINE® 90 DM

A 90% alumina refractory with a Densified Matrix (DM) and mullite bond characterized by exceptional slag resistance and resistance to thermal shock.

TUFLINE® 95 DM

High purity corundum bonded extra high-alumina brick with Densified Matrix (DM). Features are high strength, low porosity and improved refractoriness. TUFLINE® 95 DM has excellent thermal shock resistance.

TUFLINE® 98 DM

A 98% high purity corundum bonded brick with the lowest porosity and silica content in its class, along with significant thermal shock resistance.

H-W® CORUNDUM DM

A high-alumina brick product consisting of high purity corundum. It is used in applications where the high melting point, i.e., about 3700°F (2040°C) and stability and inertness of alumina are required.

ALADIN® 90

A 90% alumina brick with high density and hot strengths.

HIGH-ALUMINA BRICK

PHOSPHATE BONDED HIGH ALUMINA BRICK

ALTEX® 75B

This 75% alumina, phosphate bonded, burned brick has high strength and low porosity. It is well suited for use in alkali environments needing resistance to mechanical abuse.

CORAL® BP

Featuring low porosity, high strength and volume stability at high temperatures, these burned, phosphate-bonded brick provide good resistance to wetting, penetration and reaction by molten metals.

BURNED ALUMINA-CHROME BRICK

RESISTAL® KR 85 C

This 85% alumina, 5% chromic oxide, chemically bonded brick has very high strength. The chromic oxide addition provides enhanced resistance to corrosive incinerator slags.

RUBY® SR

This is a solid solution bonded, alumina-chromic-oxide brick, designed for extremely high temperature service, where it provides extraordinary resistance to chemical attack, corrosion and thermal shock. Typical applications include slag pools of rotary incinerators. Also available in custom brick shapes as RUBY® SR/C.

RUBY®

A solid-solution bonded, alumina-chromic oxide brick designed for extremely high temperature service where it provides extraordinary resistance to chemical attack, corrosion and severe slag attack. Typical applications include the slag lines of induction furnaces and carbon black reactors.

RUBY® DM

An alumina-chrome refractory with a densified matrix and a solid-solution bond.

BURNED CHROME-ALUMINA BRICK

AUREX® 20 SR

A high purity, corundum-based refractory with 20% chromic oxide and solid-solution bond. This brick has exceptional resistance to thermal spalling.

AUREX® 30 SR

A high purity, fused grain refractory containing 30% chromic oxide and solid-solution bond with good spall resistance.

AUREX® 75

This very dense, high purity, fused grain refractory contains 75% chromic-oxide with a solid solution bond Also available in custom brick shapes as AUREX® 75/C.

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AUREX® 75SR An upgraded version of AUREX® 75 with improved resistance to thermal spalling. Also available in custom brick shapes as AUREX 75SR/C.

AUREX® 90 An extremely dense, fused-grain refractory containing 90% chromic oxide. This brick features outstanding resistance to iron-silica slags and excellent stability at very high temperatures.

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FIRECLAY BRICK

Overview

The five standard classes of fireclay brick are super-duty, high-duty, semi-silica, medium-duty, and low-duty. Fireclay brick in these classes cover the approximate range of about 18% to 44% alumina, and from 50% to 80% silica.

High-duty and super-duty fireclay brick are commonly made of a blend of clays. Flint clays and high-grade kaolins impart high refractoriness; plastic clays facilitate forming and impart bonding strength; calcined clays control drying and firing shrinkages. The relative proportions of these used in a blend depend upon the character and quality of the ware to be made. Some fireclay brick, especially those of the medium and low-duty class, are made of a single clay.

The following product descriptions of Harbison-Walker's fireclay refractories are categorized by their classification. This listing represents the major brands supplied to a wide variety of applications.

HIGH-DUTY FIRECLAY

EMPIRE® S

An economical, dry-pressed, high-duty fireclay brick meeting ASTM regular type classification. It is suitable for boilers, dense brick back-up linings, air heaters, and other areas encountering moderate operating temperatures. Not suggested for abrasive conditions.

SUPER-DUTY FIRECLAY

ALAMO®

An economical, dry-pressed, super-duty fireclay brick. It is intended for general service conditions. ALAMO® is available in 9" x 4½" x 3"and 2½" sizes.

CLIPPER® DP

A dry pressed super-duty brick with good strength, low shrinkage, and good resistance to thermal shock. Typical applications included air heaters, combustion chambers, flue and duct linings, furnace stacks, rotary kilns and graphitizing furnaces.

KX-99®-BF

A high fired dry pressed, coarse grain, super-duty brick with low porosity, high strength, good alkali resistance, and good resistance to carbon monoxide disintegration.

KX-99®

Is a high fired, super-duty, dry pressed firebrick that exhibits low porosity, high strength, good alkali resistance, and resistance to carbon monoxide disintegration. Typical applications include glass tank lower checkers, boilers, stacks, charcoal furnaces, zinc galvanizing pots, and cyclones.

Click here for Technical Data Sheets or go to www.hwr.com

Overview

Insulating refractory brick are lightweight, porous materials with much lower density, thermal conductivity, and heat storage capacity than other refractories. The American Society for Testing Materials (ASTM) classifies insulating fireclay brick (IFB) into groups 16, 20, 23, 26, and 28. The group number, multiplied by 100 represents the nominal maximum temperature to which the refractory can be exposed in service at the hot face. IFB's with temperature rating of 3000°F are also available. Typically a 150 to 200°F safety factor is used in selecting the appropriate brick. Special insulating refractories offering significantly higher strength than standard IFB's are also available. These can be used in applications requiring load bearing ability. Another type of insulating brick are those based on high purity hollow sphere alumina. These products can be used in high temperature ceramic kiln application and some high corrosive applications as either hot face or back up lining materials.

Harbison-Walker also manufacturers a full range of insulating castable, gunning mixes, and ceramic fiber products to provide additional insulating lining options. These materials are covered in other sections.

The following product descriptions of Harbison-Walker insulating refractory brick are categorized by their classification.

INSULATING ALUMINA-CHROME REFRACTORIES

RUBY® LW

A unique lightweight alumina-chrome brick intended for very severe service in both hot face and back up applications.

INSULATING HIGH-ALUMINA REFRACTORIES

TUFLINE® LW

This 99% alumina, corundum-bonded insulating brick is intended for service conditions involving hydrogen and fluorine containing atmospheres.

GREENLITE® HS

This is a 2600°F rated, high strength insulating brick that is used back up in two layer paper kiln burning zones and as full thickness liners in intermediate zone. It is available in RKB as well as standard sizes. GREENLITE® HS is appropriate for other applications requiring higher strength than standard insulating firebrick.

INSULATING FIRECLAY REFRACTORIES

LOTHERM® RK

This brick is the original high strength, semi-insulating brick for rotary kiln service. It offers slightly higher refractoriness than GREENLITE® HS.

GREENLITE® 27

This is a 2700°F rated, high strength insulating brick. It offers lower density and better insulating value than the HS version listed above. It is not suggested for rotary kiln service.

G-Series Insulating Firebrick

Harbison-Walker's low iron insulating firebrick are available at five service temperature ratings between 2000°F and 3000°F. They offer excellent insulating value along with traditional chemical and physical properties.

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Technical Data Sheets
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SPECIAL PURPOSE REFRACTORIES

Overview

Materials that surpass commonly used refractories in one or more of their essential properties are often required in industrial processes. Chemical-resistant brick and tile, silicon carbide, and zircon refractories are examples of products with extraordinary properties for special applications.

The following product descriptions of Harbison-Walker's special purpose refractories are categorized by their classification. This listing represents the major brands supplied for a wide variety of furnaces and applications.

VIB-TECH SHAPES

Harbison-Walker manufactures VIB-TECH shapes for application requiring high-performance, complex shapes. They are thixotropic cast, ceramic bonded, high-fired shapes that provide the unique characteristics of several of our premium brick brands. They are designated by the /C suffix. These brands include KORUNDAL® XD/C, TUFLINE® 90 DM/C, TUFLINE® 98 DM/C, TUFLINE® DM/C AL, H-W® CORUNDUM DM/C, RUBY® SR /C, and AUREX® 75 /C. In addition to these alumina and alumina-chrome products, we also manufacture vitreous silica, VISIL /C®, and silicon carbide, HARBIDE® /C, shapes.

ZIRCON REFRACTORIES

This family of brick, mortars, and patching mixes, designated by the TZB name, have been the standard of the industry for many years. They are suited for applications involving siliceous fluxes including glass.

VITREOUS SILICA

VISIL® is a vitreous silica brick that provides exceptional resistance to thermal cycling at temperatures below 2000°F. It also offer excellent resistance to many acidic slags and chemicals.

SILICON CARBIDE

HARBIDE® is a clay bonded silicon carbide brick that offers excellent resistance to abrasion and high thermal conductivity.

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SECTION 7

Installation References

BRICK SIZES AND SHAPES

Wherever furnace construction and operating conditions permit, refractory linings are typically constructed with brick of standard sizes and shapes. Standard materials cost less than larger, more intricate shapes and frequently are more serviceable. They are also more accessible, in that they are likely to be routinely stocked by the manufacturer.

The most widely used standard size for all types of refractory brick is 9 x 4^1/2 by 3 inches. Most brands offer larger sizes, as well. Special shapes, such as skewback brick, are important in the construction of numerous kinds of furnaces having sprung arches.

This section provides a comprehensive listing of standard brick sizes and shapes for a variety of furnace applications, as well as ring and arch combinations for standard size refractory brick. Additional sections address special shapes such as semi-universal ladle brick, brick counts for rotary kilns and rotary kiln brick shapes, including ISO, VDZ and CR two-shape systems for combination linings. Together, offer refractory users a ready reference of information governing furnace refractory lining and construction.

If you require a special shape which is not included in this booklet, please contact your Harbison-Walker representative. Harbison-Walker manufactures special shapes based on customer designs showing shape details and assembly in the furnace lining.

BRICK SIZES AND SHAPES

OVERVIEW

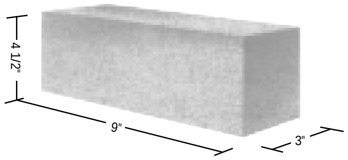
Refractory brick are classified on the basis of their form as Rectangular Shapes or Special Shapes.

Rectangular Sizes are brick of relatively simple design, with certain definite shapes, that are marketed in sufficient amounts to permit quantity production. Rectangular sizes are preferred wherever furnace construction and operating conditions permit. These brick cost less than longer and more intricate shapes.

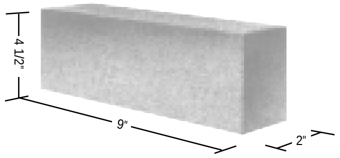
Special Shapes are refractory brick of special design of either simple or intricate form. Some special shapes may be considered as modifications of rectangular tile having the same overall dimensions.

For initial orders of special shapes, drawings showing complete details of the shapes, as well as their assembly in the furnace, should be included. The drawing and shape numbers should be provided on all subsequent orders.

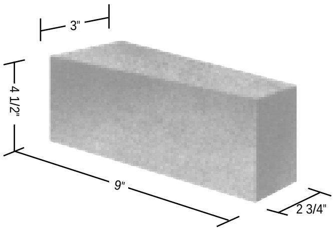
Nine-Inch Sizes (9 X $4^1/_2$ X 3)



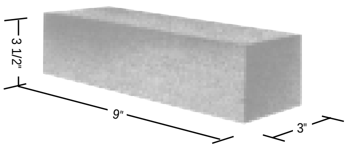
9 Inch Straight
9 X $4^1/_2$ X 3



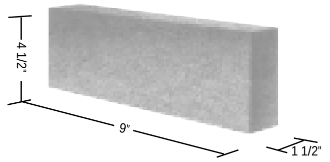
9 – 2 Inch Split
9 X $4^1/_2$ X 2



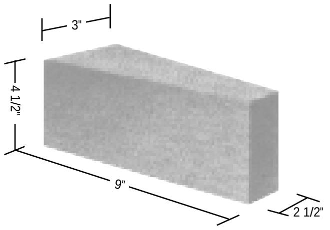
9 Inch No. 1 Wedge
9 X $4^1/_2$ X (3 – $2^3/_4$)



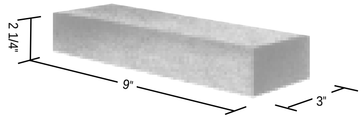
Small 9 Inch Straight
9 X $3^1/_2$ X 3



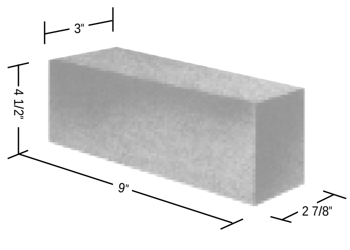
9 Inch Split
9 X $4^1/_2$ X $1^1/_2$



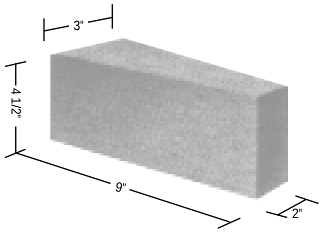
9 Inch No. 2 Wedge
9 X $4^1/_2$ X (3 – $2^1/_2$)



9 Inch Soap
9 X $2^1/_4$ X 3



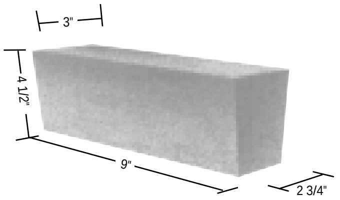
9 Inch No. 1-X Wedge
9 X $4^1/_2$ X (3 – $2^7/_8$)



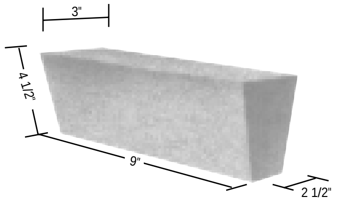
9 Inch No. 3 Wedge
9 X $4^1/_2$ X (3 – 2)

BRICK SIZES AND SHAPES

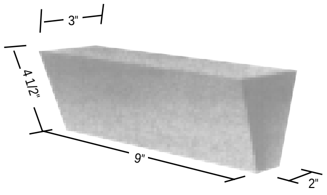
Nine-Inch Sizes (9 X 4 1/2 X 3)



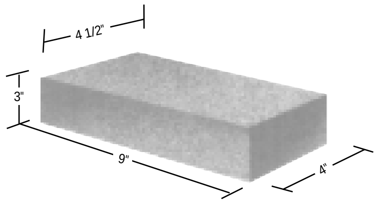
9 Inch No. 1 Arch
9 X 4 1/2 X (3 – 2 3/4)



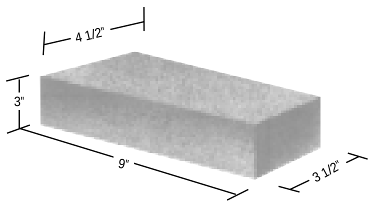
9 Inch No. 2 Arch
9 X 4 1/2 X (3 – 2 1/2)



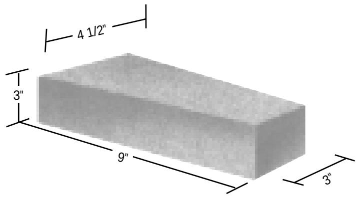
9 Inch No. 3 Arch
9 X 4 1/2 X (3 – 2)



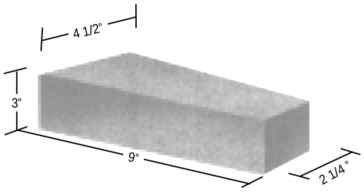
9 Inch No. 1 Key
9 X (4 1/2 – 4) X 3



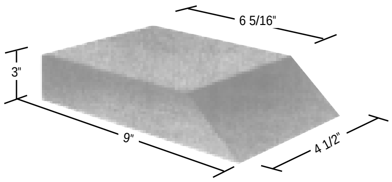
9 Inch No. 2 Key
9 X (4 1/2 – 3 1/2) X 3



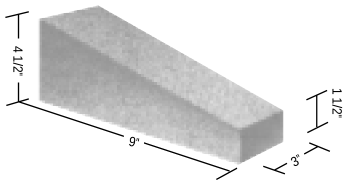
9 Inch No. 3 Key
9 X (4 1/2 – 3) X 3



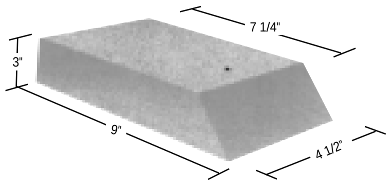
9 Inch No. 4 Key
9 X (4 1/2 – 2 1/4) X 3



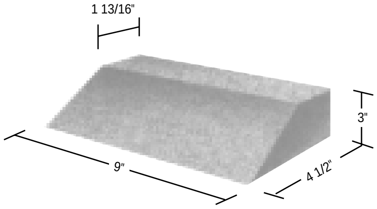
9 Inch – 48° End Skew
(9 – 6 5/16) X 4 1/2 X 3



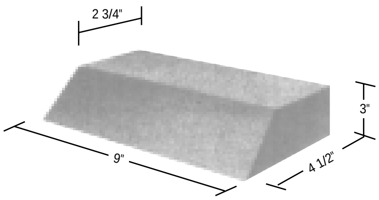
9 Inch Edge Skew
9 X (4 1/2 – 1 1/2) X 3



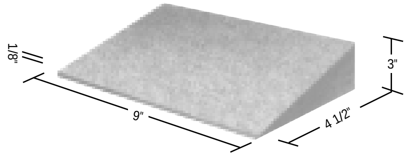
9 Inch – 60° End Skew
(9 – 7 1/4) X 4 1/2 X 3



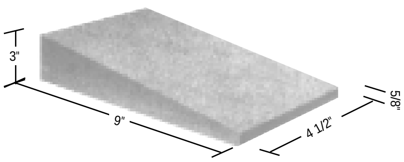
9 Inch – 48° Side Skew
9 X (4 1/2 – 1 13/16) X 3



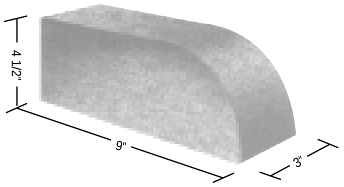
9 Inch – 60° Side Skew
9 X (4 1/2 – 2 3/4) X 3



9 Inch Featheredge
9 X 4 1/2 X (3 – 1/8)



9 Inch Neck
9 X 4 1/2 X (3 – 5/8)

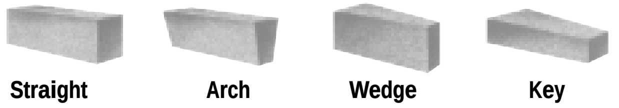


9 Inch Jamb
9 X 4 1/2 X 3

BRICK SIZES AND SHAPES

High-Alumina, Basic and Silica Brick

TYPICAL STRAIGHT, ARCH, WEDGE AND KEY BRICK



Sizes	Name	Dimensions (In.)	Equivalent
9 x 4 1/2 x 2 1/2	Straight	9 x 4 1/2 x 2 1/2	1.00
9 x 3 1/2 x 2 1/2	Soap	9 x 2 1/4 x 2 1/2	0.50
9 x 2 1/4 x 2 1/2	2" Split	9 x 4 1/2 x 2 1/2	0.80
9 x 4 1/2 x 2 1/2	Split	9 x 4 1/2 x 1 1/4	0.50
9 x 4 1/2 x 2 1/2	No. 1-X Wedge	9 x 4 1/2 x (2 1/2-2 1/4)	0.95
	No. 1 Wedge	9 x 4 1/2 x (2 1/2-1 7/8)	0.88
	No. 2 Wedge	9 x 4 1/2 x (2 1/2-1 1/2)	0.80
	No. 1 Arch	9 x 4 1/2 x (2 1/2-2 1/8)	0.93
	No. 2 Arch	9 x 4 1/2 x (2 1/2-1 3/4)	0.85
	No. 3 Arch	9 x 4 1/2 x (2 1/2-1)	0.70
	No. 1 Key	9 x (4 1/2-4) x 2 1/2	0.94
	No. 2 Key	9 x (4 1/2-3 1/2) x 2 1/2	0.89
	No. 3 Key	9 x (4 1/2-3) x 2 1/2	0.83
	No. 4 Key	9 x (4 1/2-2 1/4) x 2 1/2	0.75
9 x 4 1/2 x 2 1/2	48° End Skew	(9-6 3/4) x 4 1/2 x 2 1/2	0.88
	60° End Skew	(9-7 9/16) x 4 1/2 x 2 1/2	0.92
	48° Side Skew	9 x (4 1/2-2 1/4) x 2 1/2	0.75
	60° Side Skew	9 x (4 1/2-3 1/16) x 2 1/2	0.84
	Edge Skew	9 x (4 1/2-1 1/2) x 2 1/2	0.67
	Featheredge	9 x 4 1/2 x (2 1/2-1/8)	0.53
	Neck	9 x 4 1/2 x (2 1/2-5/8)	0.63
	Jamb	9 x 4 1/2 x 2 1/2	0.89
9 x 4 1/2 x 3	Straight	9 x 4 1/2 x 3	1.20
9 x 3 1/2 x 3	Sm. Straight	9 x 3 1/2 x 3	0.93
9 x 2 1/4 x 3	Soap	9 x 2 1/4 x 3	0.60
9 x 4 1/2 x 1 1/2	Split	9 x 4 1/2 x 1 1/2	0.60
9 x 4 1/2 x 3	No. 1 Arch	9 x 4 1/2 x (3-2 3/4)	1.15
	No. 2 Arch	9 x 4 1/2 x (3-2 1/2)	1.10
	No. 3 Arch	9 x 4 1/2 x (3-2)	1.00
	No. 4 Arch	9 x 4 1/2 x (3-1)	0.80
	No. 1-X Wedge	9 x 4 1/2 x (3-2 7/8)	1.17
	No. 1 Wedge	9 x 4 1/2 x (3-2 3/4)	1.15
	No. 2 Wedge	9 x 4 1/2 x (3-2 1/2)	1.10
	No. 3 Wedge	9 x 4 1/2 x (3-2)	1.00
	No. 1 Key	9 x (4 1/2-4) x 3	1.13
	No. 2 Key	9 x (4 1/2-3 1/2) x 3	1.07
	No. 3 Key	9 x (4 1/2-3) x 3	1.00
	No. 4 Key	9 x (4 1/2-2 1/4) x 3	0.90
9 x 4 1/2 x 3	48° End Skew	(9-6 5/16) x 4 1/2 x 3	1.02
	60° End Skew	(9-7 1/4) x 4 1/2 x 3	1.08
	48° Side Skew	9 x (4 1/2-1 13/16) x 3	0.84
	60° Side Skew	9 x (4 1/2-2 3/4) x 3	0.97
	Edge Skew	9 x (4 1/2-1 1/2) x 3	0.80
	Featheredge	9 x 4 1/2 x (3-1/8)	0.63
	Neck	9 x 4 1/2 x (3-5/8)	0.73
	Jamb	9 x 4 1/2 x 3	1.07
9 x 6 **Flat Back**	Straight	9 x 6 x 2 1/2	1.33
	Split	9 x 6 x 1 1/4	0.67
	No. 1 Arch	9 x 6 x (3 1/2-2 1/2)	1.60
	No. 2 Arch	9 x 6 x (3 1/2-2)	1.47

Sizes	Name	Dimensions (In.)	Equivalent
9 x 6 x 3	Straight	9 x 6 x 3	1.60
	No. 1 Arch	9 x 6 x (3-2 3/4)	1.53
	No. 2 Arch	9 x 6 x (3-2 1/2)	1.47
	No. 3 Arch	9 x 6 x (3-2)	1.33
	No. 1-X Wedge	9 x 6 x (3-2 7/8)	1.57
	No. 1 Wedge	9 x 6 x (3-2 3/4)	1.53
	No. 2 Wedge	9 x 6 x (3-2 1/2)	1.47
	No. 3 Wedge	9 x 6 x (3-2)	1.33
	No. 1 Key	9 x (6-5 3/8) x 3	1.52
	No. 2 Key	9 x (6-4 13/16) x 3	1.44
	No. 3 Key	9 x (6-3) x 3	1.20
9 x 6 3/4 x 3	Straight	9 x 6 3/4 x 3	1.80
	No. 1-X Wedge	9 x 6 3/4 x (3-2 7/8)	1.76
	No. 1 Wedge	9 x 6 3/4 x (3-2 3/4)	1.72
	No. 2 Wedge	9 x 6 3/4 x (3-2 1/2)	1.65
	No. 3 Wedge	9 x 6 3/4 x (3-2)	1.50
9 x 9 x 3	Straight	9 x 9 x 3	2.40
	No. 1-X Wedge	9 x 9 x (3-2 7/8)	2.35
	No. 1 Wedge	9 x 9 x (3-2 3/4)	2.30
	No. 2 Wedge	9 x 9 x (3-2 1/2)	2.20
	No. 3 Wedge	9 x 9 x (3-2)	2.00
12 x 4 1/2 x 3	Straight	12 x 4 1/2 x 3	1.60
	No. 1 Arch	12 x 4 1/2 x (3-2 3/4)	1.53
	No. 2 Arch	12 x 4 1/2 x (3-2 1/2)	1.47
	No. 3 Arch	12 x 4 1/2 x (3-2)	1.33
	No. 1-X Wedge	12 x 4 1/2 x (3-2 7/8)	1.57
	No. 1 Wedge	12 x 4 1/2 x (3-2 3/4)	1.53
	No. 2 Wedge	12 x 4 1/2 x (3-2 1/2)	1.47
	No. 3 Wedge	12 x 4 1/2 x (3-2)	1.33
12 x 6 x 3	Straight	12 x 6 x 3	2.13
	No. 1 Arch	12 x 6 x (3-2 3/4)	2.04
	No. 2 Arch	12 x 6 x (3-2 1/2)	1.96
	No. 3 Arch	12 x 6 x (3-2)	1.78
	No. 1-X Wedge	12 x 6 x (3-2 7/8)	2.09
	No. 1 Wedge	12 x 6 x (3-2 3/4)	2.04
	No. 2 Wedge	12 x 6 x (3-2 1/2)	1.96
	No. 3 Wedge	12 x 6 x (3-2)	1.78
	No. 1 Key	12 x (6-5 1/2) x 3	2.04
	No. 2 Key	12 x (6-5) x 3	1.96
	No. 3 Key	12 x (6-3) x 3	1.87
12 x 6 3/4 x 3	Straight	12 x 6 3/4 x 3	2.40
	No. 1-X Wedge	12 x 6 3/4 x (3-2 7/8)	2.35
	No. 1 Wedge	12 x 6 3/4 x (3-2 3/4)	2.30
	No. 2 Wedge	12 x 6 3/4 x (3-2 1/2)	2.20
	No. 3 Wedge	12 x 6 3/4 x (3-2)	2.00
12 x 9 x 3	No. 1 Arch	12 x 9 x (3-2 3/4)	3.07
	No. 2 Arch	12 x 9 x (3-2 1/2)	2.93
	No. 3 Arch	12 x 9 x (3-2)	2.67
	Straight	12 x 9 x 3	3.20
	No. 1-X Wedge	12 x 9 x (3-2 7/8)	3.13
	No. 1 Wedge	12 x 9 x (3-2 3/4)	3.07
	No. 2 Wedge	12 x 9 x (3-2 1/2)	2.93
	No. 3 Wedge	12 x 9 x (3-2)	2.67

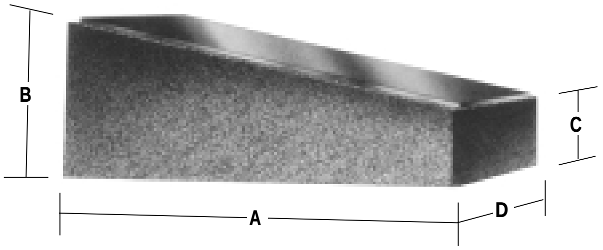
BRICK SIZES AND SHAPES

Sizes	Name	Dimensions (In.)	Equivalent
13½ x 4½ x 3	Straight	13½ x 4½ x 3	1.80
	No. 1 Arch	13½ x 4½ x (3-2¾)	1.72
	No. 2 Arch	13½ x 4½ x (3-2½)	1.65
	No. 3 Arch	13½ x 4½ x (3-2)	1.50
	No. 1 Key	13½ x (4½-4) x 3	1.70
	No. 2 Key	13½ x (4½-3½) x 3	1.60
	No. 3 Key	13½ x (4½-3) x 3	1.50
	No. 4 Key	13½ x (4½-2¼) x 3	1.35
13½ x 6 x 3	Straight	13½ x 6 x 3	2.40
	No. 1 Arch	13½ x 6 x (3-2¾)	2.30
	No. 2 Arch	13½ x 6 x (3-2½)	2.20
	No. 3 Arch	13½ x 6 x (3-2)	2.00
	No. 1-X Wedge	13½ x 6 x (3-2⅞)	2.35
	No. 1 Wedge	13½ x 6 x (3-2¾)	2.30
	No. 2 Wedge	13½ x 6 x (3-2½)	2.20
	No. 3 Wedge	13½ x 6 x (3-2)	2.00
	No. 1 Key	13½ x (6-5) x 3	2.20
	No. 2 Key	13½ x (6-4⅜) x 3	2.07
	No. 3 Key	13½ x (6-3) x 3	1.80
13½ x 6¾ x 3	Straight	13½ x 6¾ x 3	2.70
	No. 1-X Wedge	13½ x 6¾ x (3-2⅞)	2.64
	No. 1 Wedge	13½ x 6¾ x (3-2¾)	2.59
	No. 2 Wedge	13½ x 6¾ x (3-2½)	2.47
	No. 3 Wedge	13½ x 6¾ x (3-2)	2.25
13½ x 9 x 3	Straight	13½ x 9 x 3	3.60
	No. 1 Arch	13½ x 9 x (3-2¾)	3.45
	No. 2 Arch	13½ x 9 x (3-2½)	3.30
	No. 3 Arch	13½ x 9 x (3-2)	3.00
	No. 1-X Wedge	13½ x 9 x (3-2⅞)	3.52
	No. 1 Wedge	13½ x 9 x (3-2¾)	3.45
	No. 2 Wedge	13½ x 9 x (3-2½)	3.30
	No. 3 Wedge	13½ x 9 x (3-2)	3.00
15 x 4½ x 3	Straight	15 x 4½ x 3	2.00
	No. 1 Arch	15 x 4½ x (3-2¾)	1.92
	No. 2 Arch	15 x 4½ x (3-2½)	1.83
	No. 3 Arch	15 x 4½ x (3-2)	1.67
	No. 1-X Wedge	15 x 4½ x (3-2⅞)	1.96
	No. 1 Wedge	15 x 4½ x (3-2¾)	1.92
	No. 2 Wedge	15 x 4½ x (3-2½)	1.83
	No. 3 Wedge	15 x 4½ x (3-2)	1.67
15 x 6 x 3	Straight	15 x 6 x 3	2.67
	No. 1-X Wedge	15 x 6 x (3-2⅞)	2.61
	No. 1 Wedge	15 x 6 x (3-2¾)	2.56
	No. 2 Wedge	15 x 6 x (3-2½)	2.44
	No. 3 Wedge	15 x 6 x (3-2)	2.22
	No. 1 Key	15 x (6-5) x 3	2.56
	No. 2 Key	15 x (6-4⅜) x 3	2.31
	No. 3 Key	15 x (6-3) x 3	2.00
15 x 9 x 3	Straight	15 x 9 x 3	4.00
	No. 1-X Wedge	15 x 9 x (3-2⅞)	3.92
	No. 1 Wedge	15 x 9 x (3-2¾)	3.83
	No. 2 Wedge	15 x 9 x (3-2½)	3.67
	No. 3 Wedge	15 x 9 x (3-2)	3.33

Sizes	Name	Dimensions (In.)	Equivalent
18 x 4½ x 3	Straight	18 x 4½ x 3	2.40
	No. 1-X Wedge	18 x 4½ x (3-2⅞)	2.35
	No. 1 Wedge	18 x 4½ x (3-2¾)	2.30
	No. 2 Wedge	18 x 4½ x (3-2½)	2.20
	No. 3 Wedge	18 x 4½ x (3-2)	2.00
18 x 6 x 3	Straight	18 x 6 x 3	3.20
	No. 1-X Wedge	18 x 6 x (3-2⅞)	3.13
	No. 1 Wedge	18 x 6 x (3-2¾)	3.07
	No. 2 Wedge	18 x 6 x (3-2½)	2.93
	No. 3 Wedge	18 x 6 x (3-2)	2.67
18 x 9 x 3	Straight	18 x 9 x 3	4.80
	No. 1-X Wedge	18 x 9 x (3-2⅞)	4.70
	No. 1 Wedge	18 x 9 x (3-2¾)	4.60
	No. 2 Wedge	18 x 9 x (3-2½)	4.40
	No. 3 Wedge	18 x 9 x (3-2)	4.00
21 x 6 x 3	Straight	21 x 6 x 3	3.73
	No. 1-X Wedge	21 x 6 x (3-2⅞)	3.65
	No. 1 Wedge	21 x 6 x (3-2¾)	3.58
	No. 2 Wedge	21 x 6 x (3-2½)	3.42
	No. 3 Wedge	21 x 6 x (3-2)	3.11
21 x 9 x 3	Straight	21 x 9 x 3	5.60
	No. 1-X Wedge	21 x 9 x (3-2⅞)	5.48
	No. 1 Wedge	21 x 9 x (3-2¾)	5.37
	No. 2 Wedge	21 x 9 x (3-2½)	5.13
	No. 3 Wedge	21 x 9 x (3-2)	4.67
Misc. Straights	Straight	9 x 6 x 2	1.07
	Straight	9 x 7 x 2	1.24
	Straight	9 x 7½ x 2	1.33
	Straight	10½ x 4½ x 3	1.39
	Straight	10½ x 4½ x 4½	2.10
	Straight	13½ x 4½ x 4½	2.70
	Straight	18 x 6¾ x 3	3.60
	Straight	18 x 9 x 4½	7.20

EAF DOOR JAMBS/ BLAST FURNACE

METALKASE DOOR JAMB BRICK



Name	A (In)	B (In)	C (In)	D (In)
DJ-1-3	9	4 1/2	11/2	3
DJ-2-3	9	6 3/4	3 3/4	3
DJ-3-3	9	9	6	3
BS-115-3	13 1/2	6 3/4	2 3/4	3
BS-116-3	13 1/2	9	5	3
DJ-18-1-3	18	6 3/4	2 3/4	3
DJ-18-2-3	18	9	5	3

BLAST-FURNACE BOTTOM BLOCKS

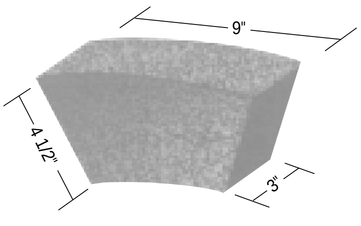
(18 X 9 X 4 1/2 Inches)

Number per course for blocks laid on end

Diameter of Hearth Jacket (Ft	In)	No. of Blocks	Diameter of Hearth Jacket (Ft	In)	No. of Blocks
17	6	897	27	6	2176
18	0	947	28	0	2255
18	6	999	28	6	2335
19	0	1053	29	0	2417
19	6	1108	29	6	2500
20	0	1164	30	0	2584
20	6	1222	30	6	2669
21	0	1281	31	0	2756
21	6	1342	31	6	2845
22	0	1403	32	0	2935
22	6	1467	32	6	3026
23	0	1531	33	0	3119
23	6	1598	33	6	3213
24	0	1665	34	0	3308
24	6	1734	34	6	3405
25	0	1804	35	0	3503
25	6	1876	35	6	3603
26	0	1949	36	0	3704
26	6	2023	36	6	3806
27	0	2099	37	0	3909

High-Alumina Circle Brick

Nine-Inch Sizes (9 X 4 1/2 X 3)

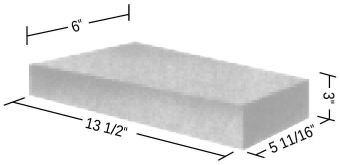


Circle Brick Number* (3 Inch)	Chord (Inch)	Number Per Ring
24 - 33 - 3	6 17/32	12
36 - 45 - 3	7 3/16	16
48 - 57 - 3	7 19/32	20
60 - 69 - 3	7 13/16	24
72 - 81 - 3	8	29
84 - 93 - 3	8 1/8	33
96 - 105 - 3	8 7/32	37
108 - 117 - 3	8 5/16	41
120 - 129 - 3	8 3/8	45

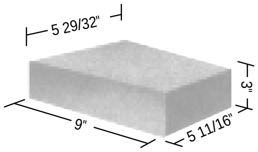
* The first two numbers of the Circle Number indicate the inside and outside diameters, respectively, of the ring produced by each shape. For example, 24 - 33 - 3 Circle Brick will produce a ring with a 24-inch inside diameter and 33-inch outside diameter for a 41/2 inch lining.

BLAST FURNACE KEYS

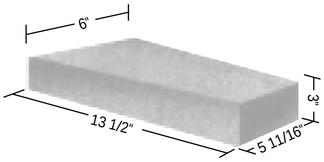
SHAPES FOR ALL-KEY BLAST FURNACE LININGS



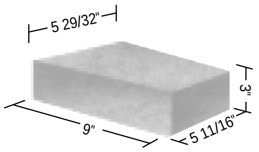
13 1/2-Inch – X-1



9-Inch – X-1



13 1/2-Inch – X-2



9-Inch – X-2

NOTE: Blast Furnace keys X-1 and X-2 are also regulary manufactured in 6, 10 1/2 and 15-inch lengths. The brick combinations for rings (see Brick Combinations for All-Key Linings table) are applicable for X-1 and X-2 keys of all lengths.

BRICK COMBINATIONS FOR ALL-KEY LININGS

Diameter Inside Brickwork		Number Required Per Ring		
(Ft	In)	X-2	X-1	Total
13	3	98	—	98
13	6	96	3	99
13	9	95	6	101
14	0	95	8	103
14	6	93	13	106
15	0	91	18	109
15	6	89	23	112
16	0	87	28	115
16	6	85	33	118
17	0	84	37	121
17	6	82	42	124
18	0	80	48	128
18	6	79	52	131
19	0	77	57	134
19	6	75	62	137
20	0	73	67	140
20	6	71	72	143
21	0	70	76	146
21	6	68	82	150
22	0	66	87	153
22	6	65	91	156
23	0	63	96	159
23	6	61	101	162
24	0	59	106	165
24	6	57	111	168
25	0	56	116	172
25	6	54	121	175
26	0	52	126	178
26	6	51	130	181
27	0	49	135	t84
27	6	47	140	187
28	0	45	145	190
28	6	44	150	194
29	0	42	155	197
29	6	40	160	200
30	0	38	165	203
30	6	37	169	206
31	0	35	174	209
31	6	33	179	212
32	0	32	184	216
32	6	30	189	219
33	0	28	194	222
33	6	26	199	225
34	0	24	204	228
34	6	23	208	231
35	0	21	213	234
35	6	19	219	238
36	0	18	223	241
36	6	16	228	244
37	0	14	233	247
37	6	12	238	250
38	0	10	243	253
38	6	9	247	256
39	0	7	253	260
39	6	5	258	263
40	0	4	262	266
40	6	2	267	269
41	0	—	272	272

ELECTRIC FURNACE ROOF SHAPES

OVERVIEW

Electric furnace roofs may be constructed using many different shapes and combinations. The combination of standard size key-arch and key-wedge shapes with standard shapes design, and the two-shape (arch-key-wedge) brick design are the most common in electric furnace roof construction.

Annular rings are laid from the combinations for your specific roof design. Consideration must be given to the best design to provide cost-effective service life. The two-shape, triple taper brick uses two bricks that conform to the roof contour. Bricklaying is simplified using only two shapes, in that inventory levels may be reduced and faster installation is possible.

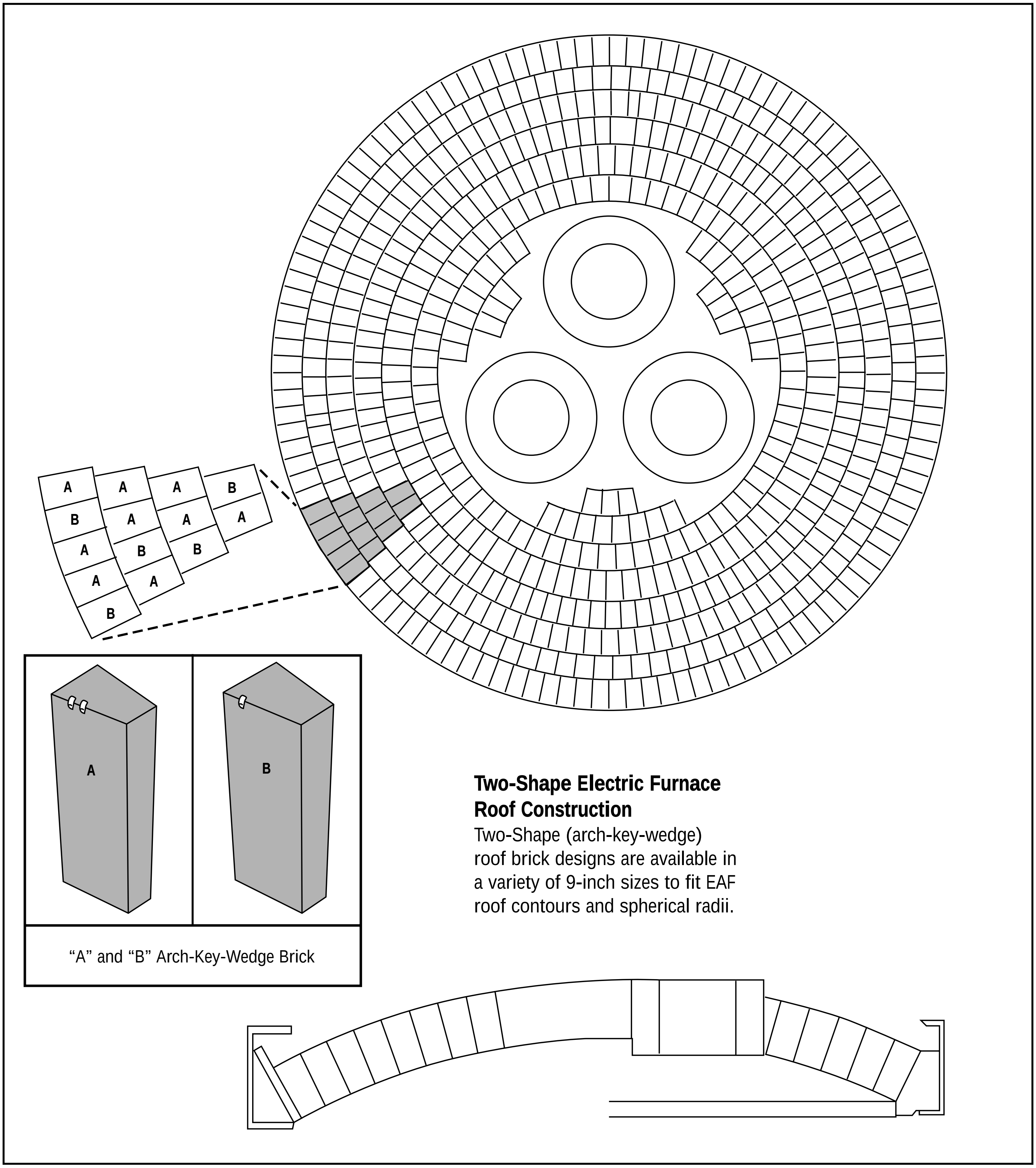
The chart below displays two-shape electric furnace roof brick combinations for 9-inch roof thicknesses. By combining both shapes, all annular rings for a given diameter can be calculated. The center of the range indicates the ideal spherical radius for the given system. Shape identification is done by a notching system at the cold end of the brick shape, as illustrated on p. IR-9. The two-shape system is also available in 13 1/2-inch sizes for larger electric furnace roofs.

Providing your Harbison-Walker representatives with the dimensions of your electric furnace roof or a current drawing of your roof enables them to produce an accurate ring count and assembly detail.

ELECTRIC FURNACE ROOF-SHAPES
9 X 4 1/2 X 3-Inch Arch-Key-Wedge Shapes

Spherical Radius Range	H-W Shape Designations
6’6” to 7’9”	HW-2721-B HW-2721-S
7’9” to 9’6”	HW-2746-B HW-2746-A
9’6” to 12’6”	HW-2745-B HW-2745-A
12’6” to 16’0”	HW-2592-B HW-2592-A
16’0” to 22’4”	HW-2704-B HW-2704-A

ELECTRIC FURNACE ROOF SHAPES



“A” and “B” Arch-Key-Wedge Brick

Two-Shape Electric Furnace Roof Construction

Two-Shape (arch-key-wedge) roof brick designs are available in a variety of 9-inch sizes to fit EAF roof contours and spherical radii.

SEMI-UNIVERSAL LADLE BRICK (SULB)

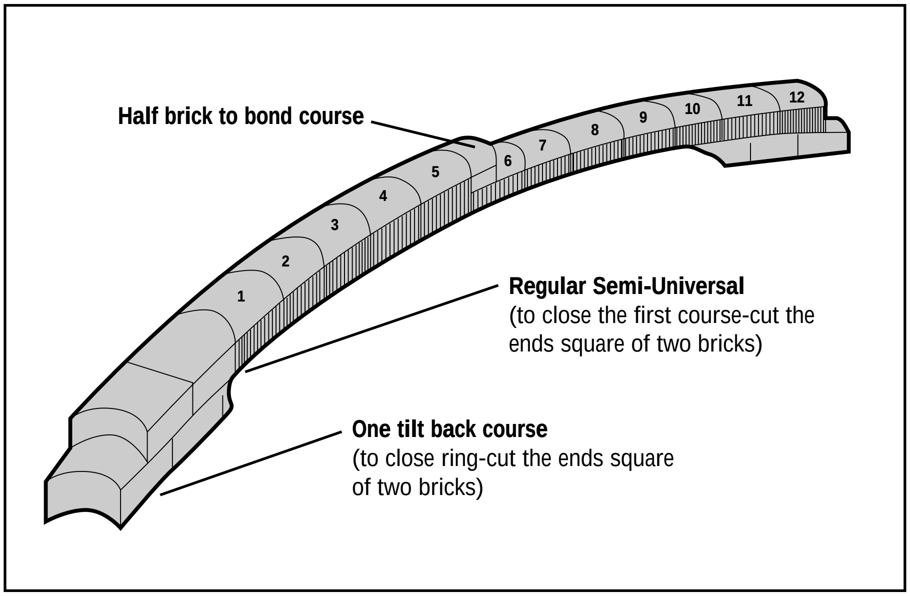
OVERVIEW

Harbison-Walker manufactures Semi-Universal Ladle Brick (SULB) in fireclay, high-alumina and basic refractories in four series of brick to line sidewalls of iron and steel teeming ladles of various diameters and configurations. All series can be produced in widths to construct linings 3 to 9 inches thick. A SULB lining usually includes a tilt back course to lay the rings square against the sloping sides of a ladle and one or more starter sets to start the upward spiral. For guidance in selecting the proper series for any ladle, the following chart identifies

Series	Ladle Diameter (Inch)
SU - ☐ - 20	45 to 70
SU - ☐ - 30	70 to 100
SU - ☐ - 45	100 to 140
SU - ☐ - 60	140 and Up

In all four series, the width of the brick, equivalent to the thickness of the lining, is positioned in the rectangular frame ☐. For example, a 5-inch thick lining in a ladle about 120 inches in diameter would require an SU 5-45 series brick. SULB's are also available in two additional thicknesses — 4-inch and 100 mm. A universal starter set that suits all series and wall thicknesses up to 7 inches is available. The 12-piece UL-7-SS12 set is illustrated below. A regular 18-piece starter set for 9-inch thick walls is also available.

The number of SULB shapes required for a lining can be calculated by multiplying the average diameter of the ladle by 3.1416, then dividing by 8.25 (length of brick) to find the number per ring. The height in inches of the ladle wall divided by 3 equals the number of rings. The number of pieces per ring times the number of rings equals the total number of SULB shapes required.



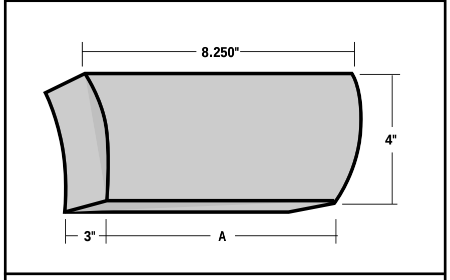
For a ladle with an average diameter of 120 inches (outside diameter of SULB lining) and a height of 96 inches, the calculations follow:

$$\frac{3.1416 \times 120}{8.25} = 46 \text{ pieces per ring}$$

$$\frac{96}{3} = 32 \text{ rings}$$

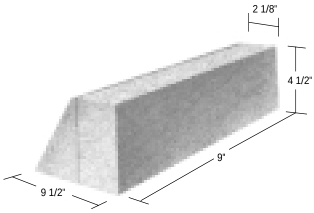
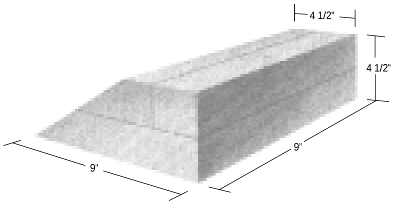
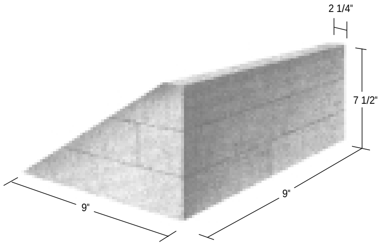
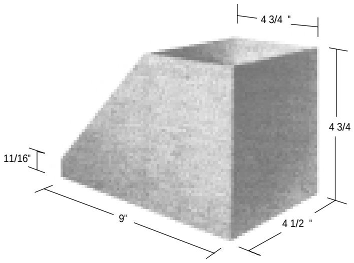
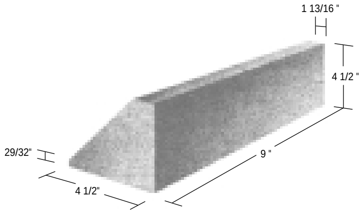
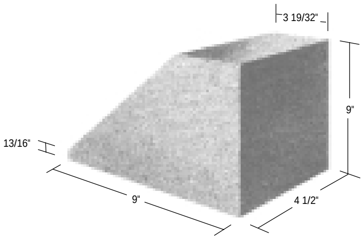
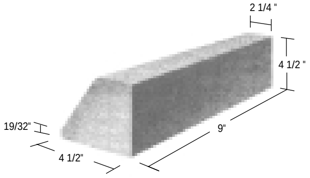
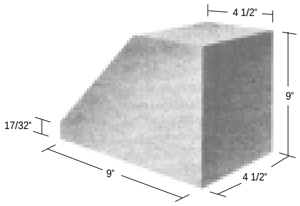
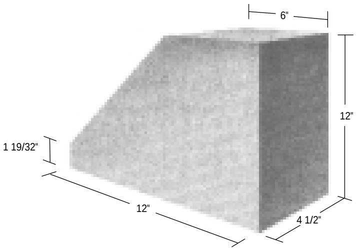
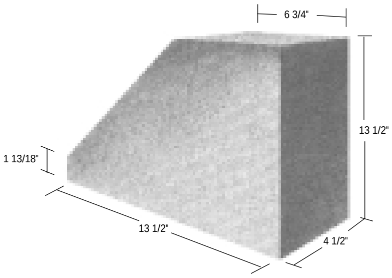
46 x 32 = 1472 SULB brick
per lining

(All series for a 4-inch thick wall)



A	
Name	Size
SU 4-20	6.983
SU 4-30	7.414
SU 4-45	7.690
SU 4-60	7.831

SKEWBACK SHAPES

NINE-INCH SIZES	ADDITIONAL SIZES	FOR ARCHES WITH 60° CENTRAL ANGLE
 For Arch 4 1/2 Inches Thick Rise 1 1/2 Inches Per Foot of Span Central Angle 56° 8.7' Skewback Consists of 1–9 Inch – 2 Inch Split 1–9 Inch Featheredge  For Arch 4 1/2 Inches ThickRise 2.302 (2 5/16) Inches Per Foot of Span, Central Angle 83° 58.5' Skewback Consists of 2–9 Inch – 48° End Skew 1–9 Inch – 48° Side Skew 1–9 Inch Soap  For Arch 9 Inches Thick Rise 2.302 (2 5/16) Inches Per Foot of Span, Central Angle 83° 58.5' Skewback Consists of 2 – 9 Inch – 48° End Skew 2 – 9 Inch – 48° Side Skew 1 – 9 Inch Soap	 Shape 56-9 For Arch 9 Inches Thick Rise 1 1/2 Inches Per Foot of Span Central Angle 56° 8.7'  Shape 74-4 1/2 For Arch 4 1/2 Inches Thick Rise 2 Inches Per Foot of Span Central Angle 73° 44.4'  Shape 74-9 For Arch 9 Inches Thick Rise 2 Inches Per Foot of Span Central Angle 73° 44.4'	**Rise 1.608 (1 19/32) Inches Per Foot of Span**  Shape No. 60-40 1/2 for Arch 4 1/2 Inches Thick  Shape No. 60-9 for Arch 9 Inches Thick  Shape No. 60-12 for Arch 12  Shape No. 60-13 1/2 for Arch 13 1/2 Inches Thick

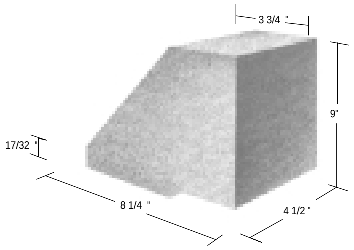
SKEWBACK SHAPES

SKEWBACK BRICK WITH CUTOUTS FOR STEEL ANGLE AND CHANNEL SUPPORTING FRAMEWORK

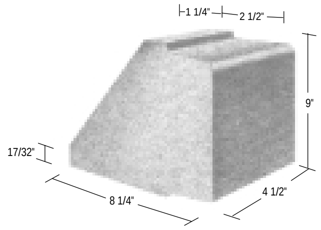
For Arches with 60° Central Angle
Rise 1.608 (1 19/32) Inches Per Foot of Span

STEEL ANGLE Maximum Dimensions		
Skewback	**Shorter Leg (in)**	**Thickness (in)**
60-9-A	4	3/4
60-12-A	6	1
60-13 1/2-A	8	1 1/8

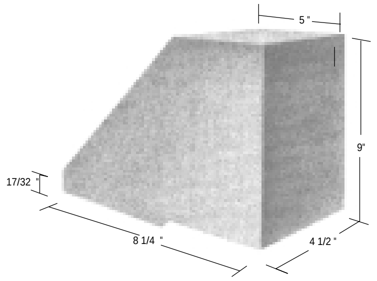
STEEL CHANNEL Maximum Dimensions			
Skewback	**Channel Size (in)**	**Flange Width (in)**	**Web Thickness (in)**
60-9-C	12	3 13/32	3/4
60-12-C	12	3 13/32	3/4
60-13 1/2-C	15	3 13/16	13/16



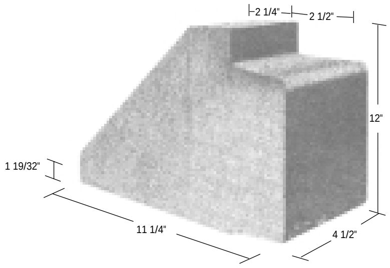
Shape No. 60-9-A
For Arch 9 Inches Thick



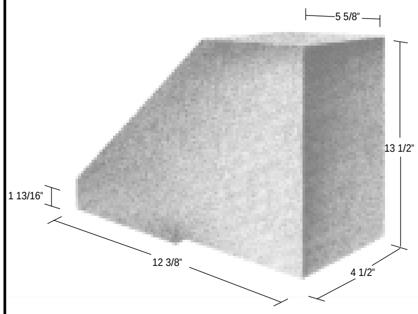
Shape No. 60-9-C
For Arch 9 Inches Thick



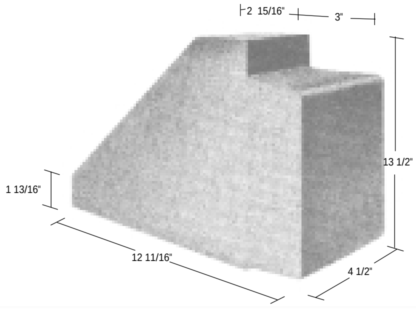
Shape No. 60-12-A
For Arch 12 Inches Thick



Shape No. 60-12-C
For Arch 12 Inches Thick



Shape No. 60-13 1/2-A
For Arch 13 1/2 Inches Thick



Shape No. 60-13 1/2-C
For Arch 13 1/2 Inches Thick

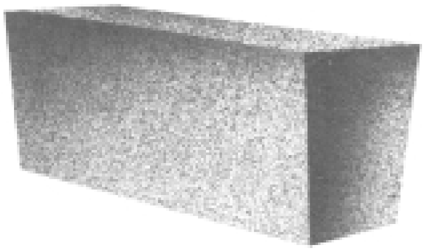
Note:
Brick Combinations required for arch construction are detailed in the tables starting on pages IR - 52. These tables are useful for estimating the quantities of brick required for the construction of arches.

BRICK COUNTS FOR ROTARY KILNS

HIGH-ALUMINA BRICK

ROTARY KILN BLOCKS
Arch-Type (9 x 6 x 3 1/2)

The numbers in the RKB column indicate the inside and outside diameters, respectively, of the ring produced by the shape. For example, RKB 162-A-174 will produce a ring with a 162-inch inside diameter and 174-inch outside diameter.



Ins. Dia. Kiln Shell	RKB Number	Inside Chord (In.)	Number Per Ring
3'-6"	30-A-42	2 1/2	37
4'-0"	36-A-48	2 5/8	42
4'-6"	42-A-54	2 23/32	47
5'-0"	48-A-600	2 13/16	52
5'-6"	54-A-66	2 7/8	58
6'-0"	60-A-72	2 29/32	63
6'-6"	66-A-78	2 31/32	68
7'-0"	72-A-84	3	74
7'-6"	78-A-90	3 1/32	79
8'-0"	84-A-96	3 1/16	84
8'-6"	90-A-102	3 3/32	89
9'-0"	96-A-108	3 1/8	95
9'-6"	102-A-114	3 1/8	100
10'-0"	108-A-120	3 5/32	105
10'-6"	114-A-126	3 5/32	111
11'-0"	120-A-132	3 3/16	116
11'-3"	123-A-135	3 3/16	119
11'-6"	126-A-138	3 3/16	121
12'-0"	132-A-144	3 7/32	126
12'-6"	138-A-150	3 7/32	132
13'-0"	144-A-156	3 7/32	137
13'-6"	150-A-162	3 1/4	142
14'-0"	156-A-168	3 1/4	148
14'-6"	162-A-174	3 1/4	153
15'-0"	168-A-180	3 9/32	158
15'-6"	174-A-186	3 9/32	164
16'-0"	180-A-192	3 9/32	169
16'-6"	186-A-198	3 9/32	174
17'-0"	192-A-204	3 9/32	179
17'-6"	198-A-210	3 5/16	185
18'-0"	204-A-216	3 5/16	190

To facilitate the keying of arch-type rotary kiln blocks, keying bricks of two-thirds thickness, RKA-2/3, and of three-quarters thickness, RKA-3/4, are made. Two of each keying brick should be ordered for each ring.

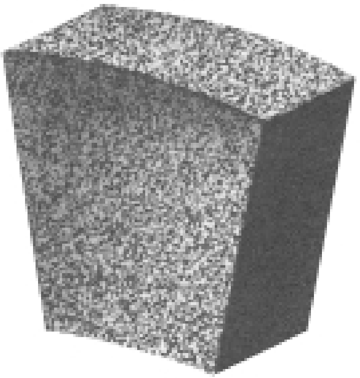
* All brick quantities per ring have been calculated from theoretical diameter turned by the brick to which a steel plate (1.5 mm thickness) has been attached.

BRICK COUNTS FOR ROTARY KILNS

HIGH-ALUMINA BRICK

ROTARY KILN BLOCKS
Nine-Inch Size (9 x 9 x 4)

The numbers in the RKB column indicate the inside and outside diameters, respectively, of the ring produced by the shape. For example, 48-66 RKB will produce a ring with a 48-inch inside diameter and 66-inch outside diameter for a 9-inch lining.



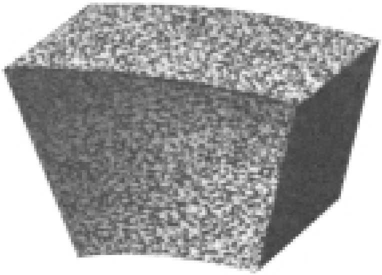
Ins. Dia. Kiln Shell	RKB Number	Inside Chord (In.)	Number Per Ring
5’-6”	48-66	6 17/32	23
6’-0”	54-72	6 3/4	26
6’-6”	60-78	6 17/16	28
7’-0”	66-84	7 1/16	30
7’-6”	72-90	7 3/16	32
8’-0”	78-96	7 5/16	34
8’-6”	84-102	7 13/32	36
9’-0”	90-108	7 1/2	38
9’-6”	96-114	7 19/32	40
10’-0”	102-120	7 21/32	42
10’-6”	108-126	7 23/32	44
11’-0”	114-132	7 25/32	46
11’-3”	117-135	7 13/16	48
11’-6”	120-138	7 13/16	49
12’-0”	126-144	7 7/8	51
12’-6”	132-150	7 29/32	53
13’-0”	138-156	7 31/32	55
13’-6”	144-162	8	57
14’-0”	150-168	8 1/32	59
14’-6”	156-174	8 1/16	61
15’-0”	162-180	8 3/32	63
15’-6”	168-186	8 1/8	65
16’-0”	174-192	8 5/32	67
16’-6”	180-198	8 3/16	70
17’-0”	186-204	8 7/32	72
17’-6”	192-210	8 7/32	74
18’-0”	198-216	8 1/4	76
18’-6”	204-222	8 9/32	78
19’-0”	210-228	8 9/32	80
19’-6”	216-234	8 5/16	82
20’-0”	222-240	8 5/16	84
20’-6”	228-246	8 11/32	86
21’-0”	234-252	8 11/32	88
21’-6”	240-258	8 3/8	90

BRICK COUNTS FOR ROTARY KILNS

HIGH-ALUMINA BRICK

ROTARY KILN BLOCKS
Six-Inch Size (9 x 6 x 4)

The numbers under the RKB column indicate the inside and outside diameters, respectively, of the ring produced by each shape. For example, 144-156 RKB will produce a ring with a 144-inch inside diameter and 156-inch outside diameter for a 6-inch lining.



Ins. Dia. Kiln Shell	RKB Number	Inside Chord (In.)	Number Per Ring
3’-6”	30-42	6 7/16	15
4’-0”	36-48	6 3/4	17
4’-6”	42-54	7	19
5’-0”	48-60	7 3/16	21
5’-6”	54-66	7 3/8	23
6’-0”	60-72	7 1/2	26
6’-6”	66-78	7 5/8	28
7’-0”	72-84	7 23/32	30
7’-6”	78-90	7 13/16	32
8’-0”	84-96	7 7/8	34
8’-6”	90-102	7 15/16	36
9’-0”	96-108	8	38
9’-6”	102-114	8 1/16	40
10’-0”	108-120	8 3/32	42
10’-6”	114-126	8 5/32	44
11’-0”	120-132	8 3/16	46
11’-3”	123-135	8 3/16	48
11’-6”	126-138	8 7/32	49
12’-0”	132-144	8 1/4	51
12’-6”	138-150	8 9/32	53
13’-0”	144-156	8 5/16	55
13’-6”	150-162	8 11/32	57
14’-0”	156-168	8 11/32	59
14’-6”	162-174	8 3/8	61
15’-0”	168-180	8 13/32	63
15’-6”	174-186	8 13/32	65
16’-0”	180-192	8 7/16	67
16’-6”	186-198	8 15/32	70
17’-0”	192-204	8 15/32	72
17’-6”	198-210	8 1/2	74
18’-0”	204-216	8 1/2	76
18’-6”	210-222	8 1/2	78
19’-0”	216-228	8 17/32	80
19’-6”	222-234	8 17/32	82
20’-0”	228-240	8 9/16	84
20’-6”	234-246	8 9/16	86
21’-0”	240-252	8 9/16	88

KA AND KW BLOCKS FOR ROTARY KILNS

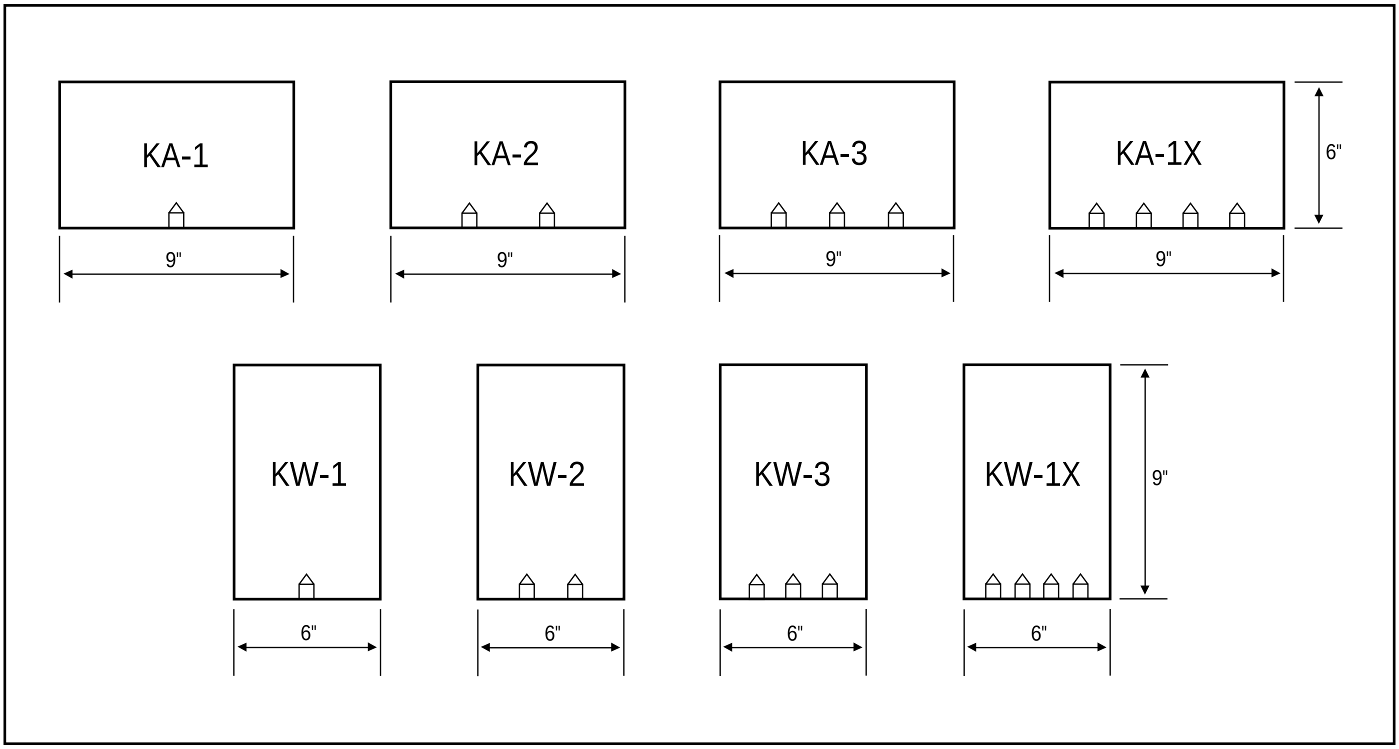
Harbison-Walker developed the KA and KW system to simplify and eliminate problems associated with the linings of rotary kilns. KA and KW blocks are 9 x 6 x 4-inch kiln liners made in the arch or wedge shape for high-alumina brick. Each shape is furnished in four sizes, two of which will line any kiln (see chart below).

In addition, two thirds and three quarter splits are designed to work with all KA and KW linings to eliminate the need for cutting keys.

Using the proper combination of KA and KW blocks also can reduce shimming, thereby producing a tighter lining with less chance of dropout or spiraling. Because these shapes fit kilns of many sizes, operators with kilns of different sizes can reduce their in-plant inventories.

Kiln Diameter Combinations

	6 to 8 feet	8 to 13 feet	13 to 21 feet
Linings 6 inches thick	KA-3, KA-2	KA-2, KA-I	KA-I, KA-IX
Linings 9 inches thick	KW-3, KW-2	KW-2, KW-I	KW-I, KW-IX



COMBINATION LININGS FOR ROTARY KILNS

Number of KA Blocks Required for Kilns

Diameters				Number Required Per Ring					Number Required Per Linear Ft				
Inside Lining		Inside Shell											
Ft	In	Ft	In	KA-3	KA-2	KA-1	KA-1X	Total	KA-3	KA-2	KA-1	KA-1X	Total
5	0	6	0	50	7	—	—	57	67	10	—	—	77
5	3	6	3	44	15	—	—	59	59	20	—	—	79
5	6	6	6	38	24	—	—	62	51	32	—	—	83
5	9	6	9	32	32	—	—	64	43	43	—	—	86
6	0	7	0	25	41	—	—	66	34	55	—	—	89
6	3	7	3	19	50	—	—	69	26	67	—	—	93
6	6	7	6	13	58	—	—	71	18	78	—	—	96
6	9	7	9	6	67	—	—	73	8	90	—	—	98
7	0	8	0	—	76	—	—	76	—	102	—	—	102
7	3	8	3	—	72	6	—	78	—	96	8	—	104
7	6	8	6	—	68	13	—	81	—	91	18	—	109
7	9	8	9	—	64	19	—	83	—	86	26	—	112
8	0	9	0	—	60	25	—	85	—	80	34	—	114
8	3	9	3	—	56	32	—	88	—	75	43	—	118
8	6	9	6	—	52	38	—	90	—	70	51	—	121
8	9	9	9	—	48	44	—	92	—	64	59	—	123
9	0	10	0	—	44	51	—	95	—	59	68	—	127
9	3	10	3	—	40	57	—	97	—	54	76	—	130
9	6	10	6	—	36	63	—	99	—	48	84	—	132
9	9	10	9	—	33	69	—	102	—	44	92	—	136
10	0	11	0	—	28	76	—	104	—	38	102	—	140
10	3	11	3	—	24	82	—	106	—	32	110	—	142
10	6	11	6	—	21	88	—	109	—	28	118	—	146
10	9	11	9	—	17	94	—	111	—	23	126	—	149
11	0	12	0	—	13	100	—	113	—	18	134	—	152
11	3	12	3	—	9	107	—	116	—	12	143	—	155
11	6	12	6	—	5	113	—	118	—	7	151	—	158
11	9	12	9	—	1	119	—	120	—	1	159	—	160
12	0	13	0	—	—	118	5	123	—	—	157	7	164
12	3	13	3	—	—	114	11	125	—	—	152	15	167
12	6	13	6	—	—	111	17	128	—	—	148	23	171
12	9	13	9	—	—	107	23	130	—	—	143	31	174
13	0	14	0	—	—	104	28	132	—	—	139	37	176
13	3	14	3	—	—	100	35	135	—	—	133	47	180
13	6	14	6	—	—	97	40	137	—	—	130	53	183
13	9	14	9	—	—	93	46	139	—	—	124	62	186
14	0	15	0	—	—	90	52	142	—	—	120	70	190
14	3	15	3	—	—	86	58	144	—	—	115	77	192
14	6	15	6	—	—	82	64	146	—	—	110	85	195
14	9	15	9	—	—	79	70	149	—	—	106	93	199
15	0	16	0	—	—	76	75	151	—	—	102	100	202
15	3	16	3	—	—	72	82	154	—	—	96	110	206
15	6	16	6	—	—	69	87	156	—	—	92	116	208
15	9	16	9	—	—	65	93	158	—	—	87	124	211
16	0	17	0	—	—	62	99	161	—	—	83	132	215
16	3	17	3	—	—	58	105	163	—	—	78	140	218
16	6	17	6	—	—	54	111	165	—	—	72	148	220
16	9	17	9	—	—	51	117	168	—	—	68	156	224
17	0	18	0	—	—	47	123	170	—	—	63	164	227
17	3	18	3	—	—	44	128	172	—	—	59	171	230
17	6	18	6	—	—	40	135	175	—	—	54	180	234
17	9	18	9	—	—	37	140	177	—	—	49	187	236
18	0	19	0	—	—	33	146	179	—	—	44	195	239
18	3	19	3	—	—	30	152	182	—	—	40	203	243
18	6	19	6	—	—	26	158	184	—	—	35	211	246
18	9	19	9	—	—	23	164	187	—	—	31	219	250
19	0	20	0	—	—	19	170	189	—	—	25	227	252
19	3	20	3	—	—	15	176	191	—	—	20	235	255
19	6	20	6	—	—	12	182	194	—	—	16	243	259
19	9	20	9	—	—	8	188	196	—	—	11	251	262
20	0	21	0	—	—	5	193	198	—	—	7	257	264
20	3	21	3	—	—	2	199	201	—	—	3	265	268

NOTE: When using KA - 1x shape, order two pieces each ring KW - 2/3 x and KW - 3/4 x to facilitate keying.

COMBINATION LININGS FOR ROTARY KILNS

Number of KW Blocks Required for Kilns

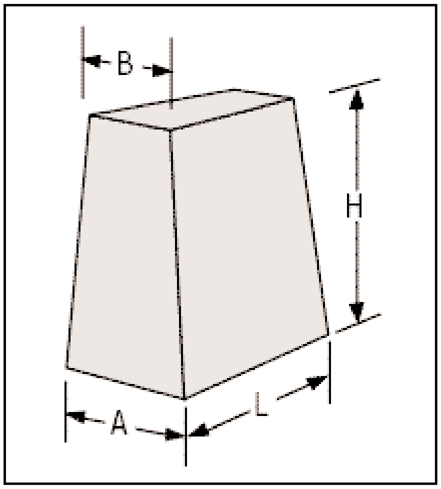
Diameters				Number Required Per Ring					Number Required Per Linear Ft				
Inside Lining		Inside Shell											
Ft	In	Ft	In	KW-3	KW-2	KW-1	KW-1X	Total	KW-3	KW-2	KW-1	KW-1X	Total
4	6	6	0	50	7	—	—	57	100	14	—	—	114
4	9	6	3	44	15	—	—	59	88	30	—	—	118
5	0	6	6	38	24	—	—	62	76	48	—	—	124
5	3	6	9	32	32	—	—	64	64	64	—	—	128
5	6	7	0	25	41	—	—	66	50	82	—	—	132
5	9	7	3	19	50	—	—	69	38	100	—	—	138
6	0	7	6	13	58	—	—	71	26	116	—	—	142
6	3	7	9	6	67	—	—	73	12	134	—	—	146
6	6	8	0	—	76	—	—	76	—	152	—	—	152
6	9	8	3	—	72	6	—	78	—	144	12	—	156
7	0	8	6	—	68	13	—	81	—	136	26	—	162
7	3	8	9	—	64	19	—	83	—	128	38	—	166
7	6	9	0	—	60	25	—	85	—	120	50	—	170
7	9	9	3	—	56	32	—	88	—	112	64	—	176
8	0	9	6	—	52	38	—	90	—	104	76	—	180
8	3	9	9	—	48	44	—	92	—	96	88	—	184
8	6	10	0	—	44	51	—	95	—	88	102	—	190
8	9	10	3	—	40	57	—	97	—	80	114	—	194
9	0	10	6	—	36	63	—	99	—	72	126	—	198
9	3	10	9	—	33	69	—	102	—	66	138	—	204
9	6	11	0	—	28	76	—	104	—	56	152	—	208
9	9	11	3	—	24	82	—	106	—	48	164	—	212
10	0	11	6	—	21	88	—	109	—	42	176	—	218
10	3	11	9	—	17	94	—	111	—	34	188	—	222
10	6	12	0	—	13	100	—	113	—	26	200	—	226
10	9	12	3	—	9	107	—	116	—	18	214	—	232
11	0	12	6	—	5	113	—	118	—	10	226	—	236
11	3	12	9	—	1	119	—	120	—	2	238	—	240
11	6	13	0	—	—	117	6	123	—	—	234	12	246
11	9	13	3	—	—	112	13	125	—	—	224	26	250
12	0	13	6	—	—	108	20	128	—	—	216	40	256
12	3	13	9	—	—	103	27	130	—	—	206	54	260
12	6	14	0	—	—	98	34	132	—	—	196	68	264
12	9	14	3	—	—	94	41	135	—	—	188	82	270
13	0	14	6	—	—	89	48	137	—	—	178	96	274
13	3	14	9	—	—	84	55	139	—	—	168	110	278
13	6	15	0	—	—	79	63	142	—	—	158	126	284
13	9	15	3	—	—	75	69	144	—	—	150	138	288
14	0	15	6	—	—	70	76	146	—	—	140	152	292
14	3	15	9	—	—	65	84	149	—	—	130	168	298
14	6	16	0	—	—	60	91	151	—	—	120	182	302
14	9	16	3	—	—	56	98	154	—	—	112	196	308
15	0	16	6	—	—	51	105	156	—	—	102	210	312
15	3	16	9	—	—	46	112	158	—	—	92	224	316
15	6	17	0	—	—	42	119	161	—	—	84	238	322
15	9	17	3	—	—	37	126	163	—	—	74	252	326
16	0	17	6	—	—	32	133	165	—	—	64	266	330
16	3	17	9	—	—	28	140	168	—	—	56	280	336
16	6	18	0	—	—	23	147	170	—	—	46	294	340
16	9	18	3	—	—	18	154	172	—	—	36	308	344
17	0	18	6	—	—	14	161	175	—	—	28	322	350
17	3	18	9	—	—	9	168	177	—	—	18	336	354
17	6	19	0	—	—	4	175	179	—	—	8	350	358
17	9	19	3	—	—	—	182	182	—	—	—	364	364

NOTE: When using KA - 1x shape, order two pieces each ring KW - 2/3 x and KW - 3/4 x to facilitate keying.

COMBINATION LININGS FOR ROTARY KILNS

CR COMBINATION LININGS

CR (Combination Ring) rotary kiln brick are designed to line kilns from 8 to 24 feet in diameter for a 9-inch lining thickness. The appropriate combinations of the two kiln liners are calculated for the best fit for the given diameter.



CR Series **Dimensions (Inches)**				
SHAPE	**A**	**B**	**L**	**H**
CR-89	$3^{1}/_{2}$	$2^{13}/_{16}$	6	9
CR-249	$3^{1}/_{2}$	$3^{9}/_{32}$	6	9

Combination Linings – CR Series

Kiln Diameter			
Feet	**Meters**	**CR-89**	**CR-249**
9’-10”	3.00	72	33
10’- 0”	3.04	71	35
10’- 2”	3.10	71	37
10’- 6”	3.20	69	43
10’-10”	3.30	67	48
11’- 0”	3.36	67	50
11’- 2”	3.40	66	53
11’- 6”	3.50	64	58
11’-10”	3.60	63	63
12’- 0”	3.66	61	66
12’- 2”	3.70	61	66
12’- 6”	3.80	59	74
12’-10”	3.90	57	79
13’- 0”	3.96	57	81
13’- 1”	4.00	56	83
13’- 5”	4.10	54	89
13’- 6”	4.12	54	90
13’- 9”	4.20	53	94
14’- 0”	4.26	51	99
14’- 1”	4.30	51	99
14’- 3”	4.34	50	102
14’- 5”	4.40	50	103
14’- 6”	4.42	49	105
14’- 9”	4.50	48	109
15’- 0”	4.58	47	112
15’- 1”	4.60	46	114
15’- 5”	4.70	45	119
15’- 6”	4.72	44	121
15’- 9”	4.80	43	124
16’- 0”	4.88	42	128
16’- 1”	4.90	41	130
16’- 5”	5.00	40	134
16’- 6”	5.02	39	136
16’- 9”	5.10	38	140
17’- 0”	5.18	37	143
17’- 1”	5.20	36	145
17’- 5”	5.30	35	150
17’- 6”	5.34	34	152
17’- 9”	5.40	33	155
18’- 0”	5.48	32	159
18’- 1”	5.50	32	160
18’- 4”	5.60	30	165
18’- 6”	5.64	29	167
18’- 8”	5.70	29	169
19’- 0”	5.80	27	175

To facilitate the keying of wedge-type rotary kiln blocks, keying bricks of two-thirds thickness, RKW-2/3, and of three-quarters thickness, RKW-3/4, are made. Two of each keying brick should be ordered for each ring.

ISO and VDZ Combination Linings

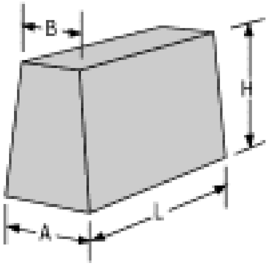
Standard practice in many North American minerals processing plants is to use one brick of a size manufactured to fit a specific rotary kiln diameter. On the other hand, international practice is to use combination linings. Within practical limits, any rotary kiln can be lined with an appropriate combination of two kiln liners, one of which fits a kiln of larger diameter and the other a kiln of smaller diameter.

As good engineering practice, Harbison-Walker suggests brick blending ratios between 3:1 and 1:3 for the two-shapes. This helps to minimize the small amount of stepping which can occur, allowing for a better fit.

The principal advantages of combination linings are:

- *In plants which have several kiln sizes, the number of kiln liner shapes can be reduced, since two shapes in appropriate combintions will fit many kilns.*
- *Liner to liner contact is maintained, while following minor deformations in kiln shells. This results in a tight lining and minimizes the need for correcting shims.*

The charts for combination linings on the following pages provide several liner options – ISO (International Standards Organization) metric linings, and VDZ (Verein Deutscher Zementwerke) combination linings.

	ISO Series - Dimensions (mm)	
	**L** - running LENGTH	198
	H - lining THICKNESS	160 180 200 220 250
	A - BACK Chord (cold face)	103
	B - INSIDE Chord (hot face)	VARIABLE

EXAMPLE: Designation 320 ISO

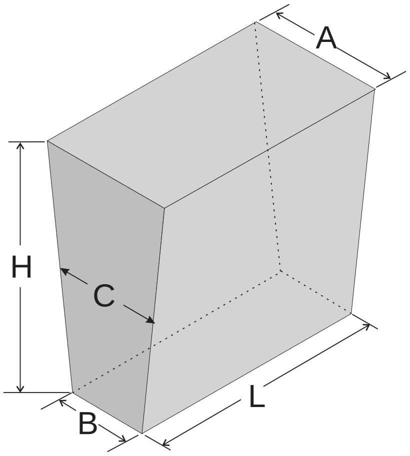
The first digit (3) denotes tapered brick which turn a circle of 3.0 meters diameter outside brickwork.

The last two digits (20) denote a lining thickness of 200 mm.

Using ISO series combination lining charts, combinations are made using outside diameter brickwork dimensions. A chart showing a 2M, 6M brick combination is for tapered brick which turn a diameter between 2.0 meters to 6.0 meters, in any lining thickness from 160 mm to 250 mm.

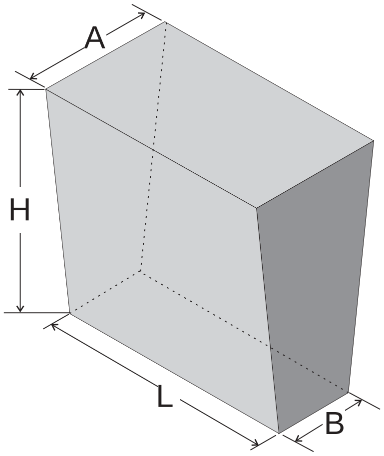
ISO AND VDZ COMBINATION LININGS

International System

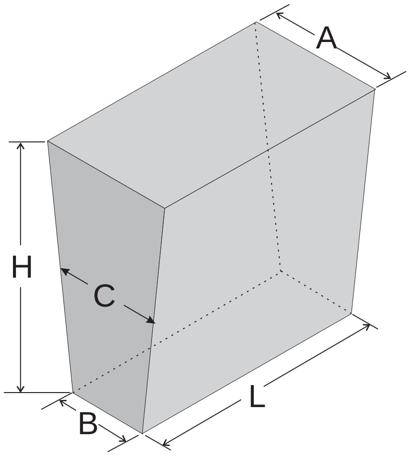


INTERNATIONAL SYSTEM			
		ISO	**VDZ**
BACK CHORD	(A)	103	VARIABLE
INSIDE CHORD	(B)	VARIABLE	VARIABLE
MIDDLE CHORD	(C)	VARIABLE	71.5
LENGTH	(L)	198	198
HEIGHT	(H)	160 180 200 220 250	160 180 200 220 250
BASIC LINING			X
NON-BASIC LINING		X	

Schematic diagram showing critical dimensions of ISO and VDZ shapes



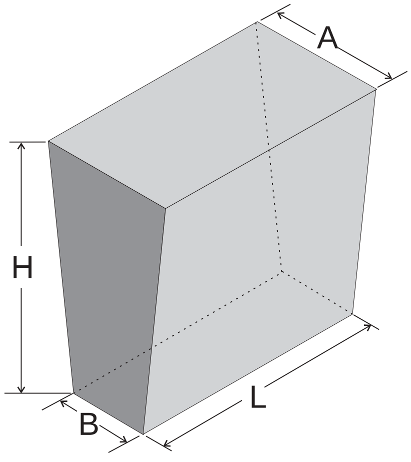
ISO brick outside chord (A) dimension is constant at 103mm (4.05”)



VDZ brick mean chord (C) dimension is constant at 71.5mm (2.81”)

ISO AND VDZ COMBINATION LININGS

ISO Shapes



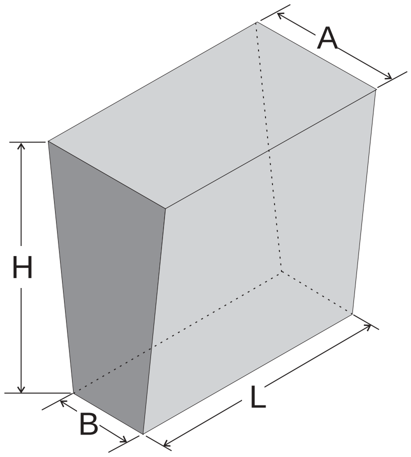
ISO SHAPES						
SHAPE No.	DIMENSIONS				VOL.	TAPER
	A	B	H	L	dm³	
216	103	86	160	198	2.99	17
716	103	98.3			3.19	4.7
218	103	84	180		3.33	19
718	103	97.7			3.58	5.3
320	103	89	200		3.80	21
820	103	97.8			3.98	5.2
222	103	80	220		3.99	23
322	103	88			4.16	15
622	103	95.5			4.33	11.5
822	103	97.3			4.36	5.7

MIXING RATIO FOR ISO SHAPES
ALUMINA LINING
JOINT THICKNESS - 0mm
DRY LAYED
THICK = 198 mm

KILN DIAMETER	6.30" 160mm		7.09" 180mm		7.87" 200mm		8.66" 220mm		8.66" 220mm		8.66" 220mm	
	216	716	218	718	320	820	322	622	322	822	222	622
SHAPE No:	06085	05807	06088	05808	06091	06093	05810	06095	05810	06096	06552	06095
6'-6"											60	1
7'-0"	57	8	58	8							58	7
7'-6"	55	14	56	14							56	14
8'-0"	54	21	54	21							53	21
8'-6"	52	28	52	27							51	28
9'-0"	50	34	50	34							49	35
9'-6"	48	40	49	40							47	42
10'-0"	46	47	47	46	88	5	92	2	92	1	44	49
10'-6"	45	53	45	53	85	13	87	11	89	9	42	56
11'-0"	43	60	43	59	83	20	82	20	86	16	40	63
11'-6"	41	66	41	66	80	27	78	30	83	24	38	70
12'-0"	39	73	40	72	77	35	73	39	80	31	35	76
12'-6"	38	79	38	79	74	42	68	48	78	39	33	83
13'-0"	36	85	36	85	72	50	64	57	75	46	31	90
13'-6"	34	92	34	92	69	57	59	67	72	54	29	97
14'-0"	32	98	32	98	66	64	54	76	69	61	26	104
14'-6"	30	105	31	104	63	72	50	85	66	69	24	111
15'-0"	29	111	29	111	61	79	45	95	63	76	22	118
15'-6"	27	118	27	117	58	87	40	104	61	84	20	125
16'-0"	25	124	25	124	55	94	36	113	58	91	17	132
16'-6"	23	130	23	130	52	101	31	123	55	99	15	139
17'-0"	22	137	22	137	50	109	26	132	52	106	13	145
17'-6"					47	116			49	114	11	152
18'-0"					44	124			46	121	8	159
18'-6"					41	131			43	129	6	166
19'-0"					39	138			41	136	4	173
KEY BRICKS	P-160		P-180		P-200		P-220		P-250			
	P-161		P-181		P-201		P-221		P-251			
	P-162		P-182		P-202		P-222					

ISO AND VDZ COMBINATION LININGS

VDZ Shapes



VDZ SHAPES						
SHAPE No.	DIMENSIONS				VOL.	TAPER
	A	B	H	L	dm^3	
B-216	78	65	160	198	2.27	13
B-416	75	68			2.27	7
B-218	78	65	180		2.55	13
B-418	75	68			2.55	7
B-220	78	65	200		2.83	13
B-620	74	69			2.83	5
B-222	78	65	220		3.11	13
B-322	76.5	66.5			3.11	10
B-622	74	69			3.11	5

MIXING RATIO FOR VDZ SHAPES
BASIC LINING
JOINT THICKNESS - 0mm
DRY LAYED
THICK = 198 mm + 1mm (cardboard) = 199mm

KILN DIAMETER	6.30" 160mm		7.09" 180mm		7.87" 200mm		8.66" 220mm		8.66" 220mm	
	B-216	B-716	B-218	B-618	B-220	B-620	B-322	B-622	B-222	B-622
SHAPE No:	02474	05807	02476	02478	02479	02481	16484	06080	06078	06080
6'-6"	77	4								
7'-0"	75	12								
7'-6"	73	21	84	9						
8'-0"	71	30	80	20						
8'-6"	69	38	75	31	92	14				
9'-0"	67	47	71	42	87	25				
9'-6"	65	56	67	53	83	35			100	18
10'-0"	63	65	63	63	79	46			95	29
10'-6"	61	73	59	74	75	57			91	40
11'-0"	59	82	54	85	71	68			87	51
11'-6"	57	91	50	96	67	79			83	62
12'-0"	55	99	46	107	62	90	126	26	79	73
12'-6"	53	108	42	118	58	101	119	39	74	84
13'-0"	51	117	38	129	54	112	112	52	70	95
13'-6"	49	125	34	140	50	123	106	66	66	105
14'-0"	47	134	29	151	46	133	99	79	62	116
14'-6"	45	143	25	161	41	144	92	93	58	127
15'-0"	43	152	21	172	37	155	85	106	53	138
15'-6"	41	160	17	183	33	166	79	119	49	149
16'-0"	39	169	13	194	29	177	72	133	45	160
16'-6"					25	188	65	146	41	171
17'-0"					20	199	59	160	37	182
17'-6"							52	173	33	192
18'-0"							45	186	28	203
18'-6"							39	200		
19'-0"							32	213		
KEY BRICKS	P-160		P-180		P-200		P-220		P-250	
	P-161		P-181		P-201		P-221		P-251	
	P-162		P-182		P-202		P-222			

RECOMMENDED LINING THICKNESS

RECOMMENDED LINING THICKNESS	
ROTARY KILN DIAMETER	*RECOMMENDED BRICK THICK
<3.6M (12'-0") I.D.	160 mm
Up to 4M (13'-6") I.D.	180 mm
Up to 4.5M (16'-6") I.D.	200 mm
Up to 5.8M (19'-0") I.D.	220 mm
Over 5.8M (19'-0") I.D.	250mm
*Recommendations are based on kiln diameter only, not taking operating data into consideration.	

RING COMBINATIONS

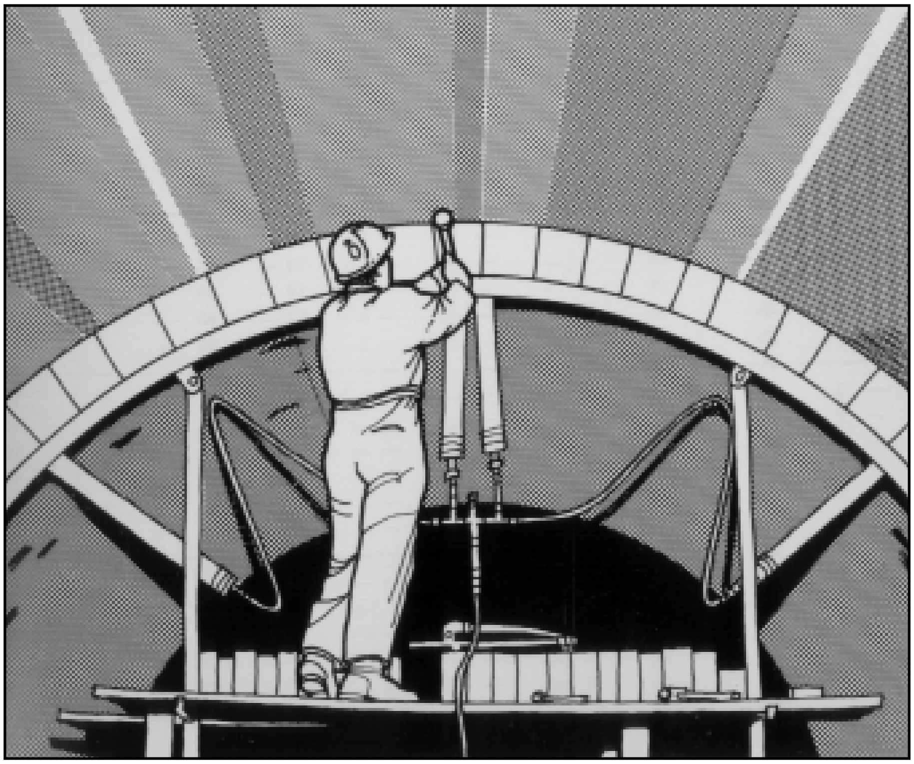
BRICK COMBINATIONS REQUIRED FOR RINGS

The tables on the following pages are useful in estimating the quantities of brick required for the construction of circular linings, roofs and arches. These tables give the combinations of brick sizes required for rings of given diameters.

In calculating the tables, no allowance was made for mortar or expansion joints or for size deviations of the brick. Fractional parts equal to or greater than one tenth of a brick were counted as an entire brick. For these reasons, the brick combinations shown may lay up to diameters which differ slightly from the theoretical diameters. The number of brick required for a ring, as given in the tables, may be slightly in excess of the number actually required.

In laying a ring course of brick, it is often necessary to cut one or two pieces, and in some instances several pieces, to complete the ring.

For brick combinations required for rings not shown in the following tables, or to calculate the ring combinations for brick of two different sizes, refer to the formulas found on page UR - 29 which covers ring calculations.



RING COMBINATIONS

4½ Inch Lining - 2½ Inch Arch Brick
9 x 4½ x 2½ or 13½ x 4½ x 2½ Inch

Diam. Inside Brickwork		Number Required per Ring				
Ft.	In.	No.3 Arch	No.2 Arch	No.1 Arch	Straight	Total
0	6	19	—	—	—	19
0	7	18	3	—	—	21
0	8	17	5	—	—	22
0	9	15	8	—	—	23
0	10	14	10	—	—	24
0	11	13	13	—	—	26
1	0	12	15	—	—	27
1	1	10	18	—	—	28
1	2	9	20	—	—	29
1	3	8	23	—	—	31
1	4	7	25	—	—	32
1	5	5	28	—	—	33
1	6	4	30	—	—	34
1	7	3	33	—	—	36
1	8	2	35	—	—	37
1	9	—	38	—	—	38
1	10	—	36	3	—	39
1	11	—	36	5	—	41
2	0	—	34	8	—	42
2	1	—	33	10	—	43
2	2	—	31	13	—	44
2	3	—	31	15	—	46
2	4	—	29	18	—	47
2	5	—	28	20	—	48
2	6	—	26	23	—	49
2	7	—	26	25	—	51
2	8	—	24	28	—	52
2	9	—	23	30	—	53
2	10	—	21	33	—	54
2	11	—	20	36	—	56
3	0	—	19	38	—	57
3	1	—	18	40	—	58
3	2	—	16	43	—	59
3	3	—	15	46	—	61
3	4	—	14	48	—	62
3	5	—	13	50	—	63
3	6	—	11	53	—	64
3	7	—	10	56	—	66
3	8	—	9	58	—	67
3	9	—	8	60	—	68
3	10	—	7	63	—	70
3	11	—	5	66	—	71
4	0	—	4	68	—	72
4	1	—	3	70	—	73
4	2	—	2	73	—	75
4	3	—	—	76	—	76
4	4	—	—	76	1	77
4	6	—	—	76	4	80
4	8	—	—	76	6	82
4	10	—	—	76	9	85
5	0	—	—	76	11	87
5	2	—	—	76	14	90
5	4	—	—	76	16	92
5	6	—	—	76	19	95
5	8	—	—	76	21	97
5	10	—	—	76	24	100

4½ Inch Lining - 2½ Inch Arch Brick
9 x 4½ x 2½ or 13½ x 4½ x 2½ Inch

Diam. Inside Brickwork		Number Required per Ring				
Ft.	In.	No.3 Arch	No.2 Arch	No.1 Arch	Straight	Total
6	0	—	—	76	26	102
6	2	—	—	76	29	105
6	4	—	—	76	31	107
6	6	—	—	76	34	110
6	8	—	—	76	36	112
6	10	—	—	76	39	115
7	0	—	—	76	41	117
7	2	—	—	76	44	120
7	4	—	—	76	46	122
7	6	—	—	76	49	125
7	8	—	—	76	51	127
7	10	—	—	76	54	130
8	0	—	—	76	56	132
8	2	—	—	76	59	135
8	4	—	—	76	61	137
8	6	—	—	76	64	140
8	8	—	—	76	66	142
8	10	—	—	76	69	145
9	0	—	—	76	71	147
9	2	—	—	76	74	150
9	4	—	—	76	76	152
9	6	—	—	76	79	155
9	8	—	—	76	81	157
9	10	—	—	76	84	160
10	0	—	—	76	87	163
10	2	—	—	76	89	165
10	4	—	—	76	92	168
10	6	—	—	76	94	170
10	8	—	—	76	97	173
10	10	—	—	76	99	175
11	0	—	—	76	102	178
11	2	—	—	76	104	180
11	4	—	—	76	107	183
11	6	—	—	76	109	185
11	8	—	—	76	112	188
11	10	—	—	76	114	190
12	0	—	—	76	117	193
12	2	—	—	76	119	195
12	4	—	—	76	122	198
12	6	—	—	76	124	200
12	8	—	—	76	127	203
12	10	—	—	76	129	205
13	0	—	—	76	132	208
13	2	—	—	76	134	210
13	4	—	—	76	137	213
13	6	—	—	76	139	215
13	8	—	—	76	142	218
13	10	—	—	76	144	220
14	0	—	—	76	147	223
14	2	—	—	76	149	225
14	4	—	—	76	152	228
14	6	—	—	76	154	230
14	8	—	—	76	157	233
14	10	—	—	76	159	235
15	0	—	—	76	162	238

RING COMBINATIONS

9 Inch Lining - 2$^{1}/_{2}$ Inch Wedge Brick
9 x 4$^{1}/_{2}$ x 2$^{1}/_{2}$, 9 x 6$^{3}/_{4}$ x 2$^{1}/_{2}$ or 9 x 9 x 2$^{1}/_{2}$ Inch

Diam. Inside Brickwork		Number Required per Ring				
Ft.	In.	No.2 Wedge	No.1 Wedge	No.1-X Wedge	Straight	Total
2	3	57	—	—	—	57
2	4	55	3	—	—	58
2	5	52	7	—	—	59
2	6	51	10	—	—	61
2	7	48	14	—	—	62
2	8	46	17	—	—	63
2	9	44	20	—	—	64
2	10	42	24	—	—	66
2	11	40	27	—	—	67
3	0	38	30	—	—	68
3	1	36	34	—	—	70
3	2	34	37	—	—	71
3	3	32	40	—	—	72
3	4	29	44	—	—	73
3	5	28	47	—	—	75
3	6	25	51	—	—	76
3	7	23	54	—	—	77
3	8	21	57	—	—	78
3	9	19	61	—	—	80
3	10	17	64	—	—	81
3	11	15	67	—	—	82
4	0	13	70	—	—	83
4	1	11	74	—	—	85
4	2	9	77	—	—	86
4	3	6	81	—	—	87
4	4	4	84	—	—	88
4	5	2	88	—	—	90
4	6	—	91	—	—	91
4	7	—	90	2	—	92
4	8	—	89	4	—	93
4	9	—	88	7	—	95
4	10	—	87	9	—	96
4	11	—	86	11	—	97
5	0	—	85	13	—	98
5	1	—	85	15	—	100
5	2	—	84	17	—	101
5	3	—	83	19	—	102
5	4	—	82	21	—	103
5	5	—	82	23	—	105
5	6	—	81	25	—	106
5	7	—	80	27	—	107
5	8	—	79	29	—	108
5	9	—	78	32	—	110
5	10	—	77	34	—	111
5	11	—	76	36	—	112
6	0	—	75	38	—	113
6	1	—	75	40	—	115
6	2	—	74	42	—	116
6	3	—	73	44	—	117
6	4	—	72	47	—	119
6	5	—	72	48	—	120
6	6	—	71	50	—	121
6	7	—	70	52	—	122
6	8	—	69	55	—	124
6	9	—	68	57	—	125
6	10	—	67	59	—	126

9 Inch Lining - 2$^{1}/_{2}$ Inch Wedge Brick
9 x 4$^{1}/_{2}$ x 2$^{1}/_{2}$, 9 x 6$^{3}/_{4}$ x 2$^{1}/_{2}$ or 9 x 9 x 2$^{1}/_{2}$ Inch

Diam. Inside Brickwork		Number Required per Ring				
Ft.	In.	No.2 Wedge	No.1 Wedge	No.1-X Wedge	Straight	Total
7	0	—	66	63	—	129
7	1	—	65	65	—	130
7	2	—	64	67	—	131
7	3	—	63	69	—	132
7	4	—	62	72	—	134
7	5	—	61	74	—	135
7	6	—	60	76	—	136
7	7	—	59	78	—	137
7	8	—	59	80	—	139
7	9	—	58	82	—	140
7	10	—	57	84	—	141
7	11	—	56	86	—	142
8	0	—	56	88	—	144
8	1	—	55	90	—	145
8	2	—	54	92	—	146
8	3	—	53	94	—	147
8	4	—	52	97	—	149
8	5	—	51	99	—	150
8	6	—	50	101	—	151
8	7	—	49	103	—	152
8	8	—	49	105	—	154
8	9	—	48	107	—	155
8	10	—	47	109	—	156
8	11	—	46	111	—	157
9	0	—	46	113	—	159
9	1	—	45	115	—	160
9	2	—	44	117	—	161
9	3	—	43	120	—	163
9	4	—	42	122	—	164
9	5	—	41	124	—	165
9	6	—	40	126	—	166
9	7	—	40	128	—	168
9	8	—	39	130	—	169
9	9	—	38	132	—	170
9	10	—	37	134	—	171
9	11	—	36	137	—	173
10	0	—	35	139	—	174
10	1	—	35	140	—	175
10	2	—	34	142	—	176
10	3	—	33	145	—	178
10	4	—	32	147	—	179
10	5	—	31	149	—	180
10	6	—	30	151	—	181
10	7	—	30	153	—	183
10	8	—	29	155	—	184
10	9	—	28	157	—	185
10	10	—	27	159	—	186
10	11	—	26	162	—	188
11	0	—	25	164	—	189
11	1	—	24	166	—	190
11	2	—	23	168	—	191
11	3	—	23	170	—	193
11	4	—	22	172	—	194
11	5	—	21	174	—	195

RING COMBINATIONS

9 Inch Lining - $2^{1}/_{2}$ Inch Wedge Brick
9 x $4^{1}/_{2}$ x $2^{1}/_{2}$, 9 x $6^{3}/_{4}$ x $2^{1}/_{2}$ or 9 x 9 x $2^{1}/_{2}$ Inch

Diam. Inside Brickwork		Number Required per Ring				
Ft.	In.	No.2 Wedge	No.1 Wedge	No.1-X Wedge	Straight	Total
11	6	—	20	176	—	196
11	7	—	20	178	—	198
11	8	—	19	180	—	199
11	9	—	18	182	—	200
11	10	—	17	184	—	201
11	11	—	16	187	—	203
12	0	—	15	189	—	204
12	1	—	14	191	—	205
12	2	—	13	193	—	206
12	3	—	13	195	—	208
12	4	—	12	197	—	209
12	5	—	11	199	—	210
12	6	—	10	202	—	212
12	7	—	10	203	—	213
12	8	—	9	205	—	214
12	9	—	8	207	—	215
12	10	—	7	210	—	217
12	11	—	6	212	—	218
13	0	—	5	214	—	219
13	1	—	4	216	—	220
13	2	—	4	218	—	222
13	3	—	3	220	—	223
13	4	—	2	222	—	224
13	5	—	1	224	—	225
13	6	—	—	227	—	227
13	7	—	—	227	1	228
13	8	—	—	227	2	229
13	9	—	—	227	3	230
13	10	—	—	227	5	232
13	11	—	—	227	6	233
14	0	—	—	227	7	234
14	6	—	—	227	15	242
15	0	—	—	227	22	249
15	6	—	—	227	30	257
16	0	—	—	227	37	264
16	6	—	—	227	45	272
17	0	—	—	227	52	279
17	6	—	—	227	60	287
18	0	—	—	227	67	294
18	6	—	—	227	75	302
19	0	—	—	227	83	310
19	6	—	—	227	90	317

9 Inch Lining - $2^{1}/_{2}$ Inch Wedge Brick
9 x $4^{1}/_{2}$ x $2^{3}/_{4}$, 9 x $6^{3}/_{4}$ x $2^{1}/_{2}$ or 9 x 9 x $2^{1}/_{2}$ Inch

Diam. Inside Brickwork		Number Required per Ring				
Ft.	In.	No.2 Wedge	No.1 Wedge	No.1-X Wedge	Straight	Total
20	0	—	—	227	98	325
20	6	—	—	227	105	332
21	0	—	—	227	113	340
21	6	—	—	227	120	347
22	0	—	—	227	128	355
22	6	—	—	227	135	362
23	0	—	—	227	143	370
23	6	—	—	227	150	377
24	0	—	—	227	158	385
24	6	—	—	227	165	392
25	0	—	—	227	173	400
25	6	—	—	227	181	408
26	0	—	—	227	188	415
26	6	—	—	227	196	423
27	0	—	—	227	203	430
27	6	—	—	227	211	438
28	0	—	—	227	218	445
28	6	—	—	227	226	453
29	0	—	—	227	233	460
29	6	—	—	227	241	468
30	0	—	—	227	248	475
30	6	—	—	227	256	483
31	0	—	—	227	263	490
31	6	—	—	227	271	498
32	0	—	—	227	279	506
32	6	—	—	227	286	513
33	0	—	—	227	294	521
33	6	—	—	227	301	528
34	0	—	—	227	309	536
34	6	—	—	227	316	543
35	0	—	—	227	324	551
35	6	—	—	227	331	558
36	0	—	—	227	339	566
36	6	—	—	227	346	573
37	0	—	—	227	354	581
37	6	—	—	227	362	589
38	0	—	—	227	369	596
38	6	—	—	227	377	604
39	0	—	—	227	384	611
39	6	—	—	227	392	619
40	0	—	—	227	399	626
40	6	—	—	227	407	634
41	0	—	—	227	414	641
41	6	—	—	227	422	649
42	0	—	—	227	429	656
42	6	—	—	227	437	664
43	0	—	—	227	444	671
43	6	—	—	227	452	679
44	0	—	—	227	460	687
44	6	—	—	227	467	694
45	0	—	—	227	475	702

RING COMBINATIONS

4½ Inch Lining — 3 Inch Arch Brick
9 x 4½ x 3 or 13½ x 4½ x 3 Inch

Diam. Inside Brickwork		Number Required Per Ring					
Ft	In	No. 4 Arch	No. 3 Arch	No. 2 Arch	No. 1 Arch	Straight	Total
0	4½	15	—	—	—	—	15
0	5	14	1	—	—	—	15
0	6	13	3	—	—	—	16
0	7	12	5	—	—	—	17
0	8	11	7	—	—	—	18
0	9	10	9	—	—	—	19
0	10	8	12	—	—	—	20
0	11	7	14	—	—	—	21
1	0	6	16	—	—	—	22
1	1	5	18	—	—	—	23
1	2	4	20	—	—	—	24
1	3	4	22	—	—	—	26
1	4	3	24	—	—	—	27
1	5	1	27	—	—	—	28
1	6	—	29	—	—	—	29
1	7	—	28	2	—	—	30
1	8	—	26	5	—	—	31
1	9	—	25	7	—	—	32
1	10	—	24	9	—	—	33
1	11	—	23	11	—	—	34
2	0	—	22	13	—	—	35
2	1	—	21	15	—	—	36
2	2	—	20	17	—	—	37
2	3	—	19	19	—	—	38
2	4	—	18	21	—	—	39
2	5	—	17	23	—	—	40
2	6	—	16	25	—	—	41
2	7	—	15	27	—	—	42
2	8	—	14	29	—	—	43
2	9	—	13	31	—	—	44
2	10	—	12	33	—	—	45
2	11	—	10	36	—	—	46
3	0	—	10	38	—	—	48
3	1	—	9	40	—	—	49
3	2	—	8	42	—	—	50
3	3	—	7	44	—	—	51
3	4	—	6	46	—	—	52
3	5	—	5	48	—	—	53
3	6	—	3	51	—	—	54
3	7	—	2	53	—	—	55
3	8	—	1	55	—	—	56
3	9	—	—	57	—	—	57
3	10	—	—	56	2	—	58
3	11	—	—	55	4	—	59
4	0	—	—	54	6	—	60
4	1	—	—	52	9	—	61
4	2	—	—	51	11	—	62
4	3	—	—	50	13	—	63
4	4	—	—	49	15	—	64
4	5	—	—	48	17	—	65

4½ Inch Lining — 3 Inch Arch Brick
9 x 4½ x 3 or 13½ x 4½ x 3 Inch — Continued

Diam. Inside Brickwork		Number Required Per Ring					
Ft	In	No. 4 Arch	No. 3 Arch	No. 2 Arch	No. 1 Arch	Straight	Total
4	6	—	—	47	19	—	66
4	7	—	—	46	21	—	67
4	8	—	—	45	23	—	68
4	9	—	—	44	26	—	70
4	10	—	—	43	28	—	71
4	11	—	—	42	30	—	72
5	0	—	—	41	32	—	73
5	1	—	—	40	34	—	74
5	2	—	—	39	36	—	75
5	3	—	—	38	38	—	76
5	4	—	—	37	40	—	77
5	5	—	—	36	42	—	78
5	6	—	—	35	44	—	79
5	7	—	—	34	46	—	80
5	8	—	—	33	48	—	81
5	9	—	—	32	50	—	82
5	10	—	—	31	52	—	83
5	11	—	—	29	55	—	84
6	0	—	—	28	57	—	85
6	1	—	—	27	59	—	86
6	2	—	—	26	61	—	87
6	3	—	—	25	63	—	88
6	4	—	—	24	65	—	89
6	5	—	—	23	67	—	90
6	6	—	—	22	70	—	92
6	7	—	—	21	72	—	93
6	8	—	—	20	74	—	94
6	9	—	—	19	76	—	95
6	10	—	—	18	78	—	96
6	11	—	—	17	80	—	97
7	0	—	—	16	82	—	98
7	1	—	—	15	84	—	99
7	2	—	—	14	86	—	100
7	3	—	—	13	88	—	101
7	4	—	—	12	90	—	102
7	5	—	—	11	92	—	103
7	6	—	—	10	94	—	104
7	7	—	—	9	96	—	105
7	8	—	—	7	99	—	106
7	9	—	—	6	101	—	107
7	10	—	—	5	103	—	108
7	11	—	—	4	105	—	109
8	0	—	—	3	107	—	110
8	1	—	—	2	109	—	111
8	2	—	—	1	111	—	112
8	3	—	—	—	113	—	113
8	6	—	—	—	113	4	117
9	0	—	—	—	113	10	123
10	0	—	—	—	113	22	135
11	0	—	—	—	113	35	148
12	0	—	—	—	113	48	161
13	0	—	—	—	113	60	173
14	0	—	—	—	113	73	186
15	0	—	—	—	113	85	198

RING COMBINATIONS

4½ Inch Lining — 3 Inch Circle Brick
9 x 4½ x 3 Inch

Diam. Inside Brickwork		Number Required Per Ring					
Ft	In	24-33-3 Circle	36-45-3 Circle	48-57-3 Circle	60-69-3 Circle	72-81-3 Circle	Total
2	0	12	—	—	—	—	12
2	1	11	1	—	—	—	12
2	2	10	3	—	—	—	13
2	3	9	4	—	—	—	13
2	4	8	5	—	—	—	13
2	5	7	7	—	—	—	14
2	6	6	8	—	—	—	14
2	7	5	9	—	—	—	14
2	8	4	11	—	—	—	15
2	9	3	12	—	—	—	15
2	10	2	13	—	—	—	15
2	11	1	15	—	—	—	16
3	0	—	16	—	—	—	16
3	1	—	14	2	—	—	16
3	2	—	13	4	—	—	17
3	3	—	12	5	—	—	17
3	4	—	11	7	—	—	18
3	5	—	9	9	—	—	18
3	6	—	8	10	—	—	18
3	7	—	7	12	—	—	19
3	8	—	5	14	—	—	19
3	9	—	4	15	—	—	19
3	10	—	3	17	—	—	20
3	11	—	2	18	—	—	20
4	0	—	—	20	—	—	20
4	1	—	—	19	2	—	21
4	2	—	—	17	4	—	21
4	3	—	—	15	6	—	21
4	4	—	—	14	8	—	22
4	5	—	—	12	10	—	22
4	6	—	—	10	12	—	22
4	7	—	—	9	14	—	23
4	8	—	—	7	16	—	23
4	9	—	—	5	18	—	23
4	10	—	—	4	20	—	24
4	11	—	—	2	22	—	24
5	0	—	—	—	24	—	24
5	1	—	—	—	22	3	25
5	2	—	—	—	20	5	25
5	3	—	—	—	18	8	26
5	4	—	—	—	16	10	26
5	5	—	—	—	14	12	26
5	6	—	—	—	12	15	27
5	7	—	—	—	10	17	27
5	8	—	—	—	8	19	27
5	9	—	—	—	6	22	28
5	10	—	—	—	4	24	28
5	11	—	—	—	2	26	28

4½ Inch Lining — 3 Inch Circle Brick
9 x 4½ x 3 Inch — Continued

Diam. Inside Brickwork		Number Required Per Ring					
Ft	In	72-81-3 Circle	84-93-3 Circle	96-105-3 Circle	108-117-3 Circle	120-129-3 Circle	Total
6	0	29	—	—	—	—	29
6	1	26	3	—	—	—	29
6	2	24	5	—	—	—	29
6	3	22	8	—	—	—	30
6	4	19	11	—	—	—	30
6	5	16	14	—	—	—	30
6	6	14	17	—	—	—	31
6	7	12	19	—	—	—	31
6	8	9	22	—	—	—	31
6	9	7	25	—	—	—	32
6	10	5	27	—	—	—	32
6	11	3	30	—	—	—	33
7	0	—	33	—	—	—	33
7	1	—	30	3	—	—	33
7	2	—	27	7	—	—	34
7	3	—	25	9	—	—	34
7	4	—	22	12	—	—	34
7	5	—	19	16	—	—	35
7	6	—	16	19	—	—	35
7	7	—	14	21	—	—	35
7	8	—	11	25	—	—	36
7	9	—	8	28	—	—	36
7	10	—	5	31	—	—	36
7	11	—	3	34	—	—	37
8	0	—	—	37	—	—	37
8	1	—	—	34	3	—	37
8	2	—	—	31	7	—	38
8	3	—	—	28	10	—	38
8	4	—	—	24	14	—	38
8	5	—	—	22	17	—	39
8	6	—	—	18	21	—	39
8	7	—	—	15	24	—	39
8	8	—	—	12	28	—	40
8	9	—	—	9	31	—	40
8	10	—	—	7	34	—	41
8	11	—	—	3	38	—	41
9	0	—	—	—	41	—	41
9	1	—	—	—	38	4	42
9	2	—	—	—	34	8	42
9	3	—	—	—	31	11	42
9	4	—	—	—	28	15	43
9	5	—	—	—	24	19	43
9	6	—	—	—	20	23	43
9	7	—	—	—	17	27	44
9	8	—	—	—	14	30	44
9	9	—	—	—	10	34	44
9	10	—	—	—	7	38	45
9	11	—	—	—	4	41	45
10	0	—	—	—	—	45	45

RING COMBINATIONS

6 Inch Lining — 3 Inch Arch Brick
12 x 6 x 3 or 13½ x 6 x 3 Inch

Diam. Inside Brickwork		Number Required Per Ring				
Ft	In	No. 3 Arch	No. 2 Arch	No. 1 Arch	Straight	Total
2	0	38	—	—	—	38
2	1	37	2	—	—	39
2	2	36	4	—	—	40
2	3	35	6	—	—	41
2	4	34	8	—	—	42
2	5	32	11	—	—	43
2	6	31	13	—	—	44
2	7	30	15	—	—	45
2	8	29	17	—	—	46
2	9	29	19	—	—	48
2	10	28	21	—	—	49
2	11	27	23	—	—	50
3	0	26	25	—	—	51
3	1	24	28	—	—	52
3	2	23	30	—	—	53
3	3	22	32	—	—	54
3	4	21	34	—	—	55
3	5	20	36	—	—	56
3	6	19	38	—	—	57
3	7	18	40	—	—	58
3	8	17	42	—	—	59
3	9	16	44	—	—	60
3	10	15	46	—	—	61
3	11	14	48	—	—	62
4	0	13	50	—	—	63
4	1	12	52	—	—	64
4	2	11	54	—	—	65
4	3	9	57	—	—	66
4	4	8	59	—	—	67
4	5	7	61	—	—	68
4	6	7	63	—	—	70
4	7	6	65	—	—	71
4	8	5	67	—	—	72
4	9	4	69	—	—	73
4	10	2	72	—	—	74
4	11	1	74	—	—	75
5	0	—	76	—	—	76
5	1	—	75	2	—	77
5	2	—	74	4	—	78
5	3	—	72	7	—	79
5	4	—	71	9	—	80
5	5	—	70	11	—	81
5	6	—	69	13	—	82
5	7	—	68	15	—	83
5	8	—	67	17	—	84
5	9	—	66	19	—	85
5	10	—	65	21	—	86
5	11	—	64	23	—	87
6	0	—	63	25	—	88
6	1	—	62	27	—	89
6	2	—	61	29	—	90
6	3	—	60	32	—	92
6	4	—	59	34	—	93
6	5	—	58	36	—	94
6	6	—	57	38	—	95
6	7	—	56	40	—	96

6 Inch Lining — 3 Inch Arch Brick
12 x 6 x 3 or 13½ x 6 x 3 Inch — Continued

Diam. Inside Brickwork		Number Required Per Ring				
Ft	In	No. 3 Arch	No. 2 Arch	No. 1 Arch	Straight	Total
6	8	—	55	42	—	97
6	9	—	54	44	—	98
6	10	—	53	46	—	99
6	11	—	52	48	—	100
7	0	—	51	50	—	101
7	1	—	49	53	—	102
7	2	—	48	55	—	103
7	3	—	47	57	—	104
7	4	—	46	59	—	105
7	5	—	45	61	—	106
7	6	—	44	63	—	107
7	7	—	43	65	—	108
7	8	—	42	67	—	109
7	9	—	41	69	—	110
7	10	—	40	71	—	111
7	11	—	39	73	—	112
8	0	—	38	75	—	113
8	1	—	37	78	—	115
8	2	—	36	80	—	116
8	3	—	35	82	—	117
8	4	—	34	84	—	118
8	5	—	33	86	—	119
8	6	—	32	88	—	120
8	7	—	31	90	—	121
8	8	—	30	92	—	122
8	9	—	29	94	—	123
8	10	—	27	97	—	124
8	11	—	26	99	—	125
9	0	—	25	101	—	126
9	1	—	24	103	—	127
9	2	—	23	105	—	128
9	3	—	22	107	—	129
9	4	—	21	109	—	130
9	5	—	20	111	—	131
9	6	—	19	113	—	132
9	7	—	18	115	—	133
9	8	—	17	117	—	134
9	9	—	16	119	—	135
9	10	—	15	122	—	137
9	11	—	14	124	—	138
10	0	—	13	126	—	139
10	1	—	12	128	—	140
10	2	—	11	130	—	141
10	3	—	10	132	—	142
10	4	—	9	134	—	143
10	5	—	8	136	—	144
10	6	—	7	138	—	145
10	7	—	5	141	—	146
10	8	—	4	143	—	147
10	9	—	3	145	—	148
10	10	—	2	147	—	149
10	11	—	1	149	—	150
11	0	—	—	151	—	151
12	0	—	—	151	13	164
13	0	—	—	151	25	176
14	0	—	—	151	38	189

RING COMBINATIONS

6 Inch Lining — Rotary Kiln or Cupola Blocks
9 x 6 x 4 Inch

Diam. Inside Brickwork Ft	In	Number Required Per Ring		Total
		54-66	**60-72**	
4	6	23	—	23
4	7	20	4	24
4	8	15	9	24
4	9	11	13	24
4	10	8	17	25
4	11	4	21	25
		60-72	**66-78**	
5	0	26	—	26
5	1	21	5	26
5	2	17	9	26
5	3	13	14	27
5	4	9	18	27
5	5	4	23	27
		66-78	**72-84**	
5	6	28	—	28
5	7	23	5	28
5	8	18	10	28
5	9	14	15	29
5	10	9	20	29
5	11	5	24	29
		72-84	**78-90**	
6	0	30	—	30
6	1	25	5	30
6	2	20	10	30
6	3	15	16	31
6	4	10	21	31
6	5	5	26	31
		78-90	**84-96**	
6	6	32	—	32
6	7	26	6	32
6	8	21	12	33
6	9	16	17	33
6	10	11	22	33
6	11	6	28	34
		84-96	**90-102**	
7	0	34	—	34
7	1	28	6	34
7	2	23	12	35
7	3	17	18	35
7	4	11	24	35
7	5	6	30	36
		90-102	**96-108**	
7	6	36	—	36
7	7	30	6	36
7	8	24	13	37
7	9	18	19	37
7	10	12	25	37
7	11	6	32	38
		96-108	**102-114**	
8	0	38	—	38
8	1	31	7	38
8	2	25	14	39
8	3	19	20	39
8	4	13	26	39
8	5	7	33	40

NOTE: In orders, the complete names of the blocks desired should be given, as for example “54-66 RKB” or “60-72 Cupola.”

6 Inch Lining — Rotary Kiln or Cupola Blocks
9 x 6 x 4 Inch — Continued

Diam. Inside Brickwork Ft	In	Number Required Per Ring		Total
		102-114	**108-120**	
8	6	40	—	40
8	7	34	7	41
8	8	27	14	41
8	9	20	21	41
8	10	14	28	42
8	11	7	35	42
		108-120	**114-126**	
9	0	42	—	42
9	1	35	8	43
9	2	28	15	43
9	3	21	22	43
9	4	14	30	44
9	5	7	37	44
		114-126	**120-132**	
9	6	44	—	44
9	7	37	8	45
9	8	29	16	45
9	9	22	23	45
9	10	15	31	46
9	11	7	39	46
		120-132	**123-135**	
10	0	46	—	46
10	1	31	16	47
10	2	15	32	47
		123-135	**126-138**	
10	3	48	—	48
10	4	32	16	48
10	5	16	32	48
		126-138	**132-144**	
10	6	49	—	49
10	7	40	9	49
10	8	32	17	49
10	9	24	26	50
10	10	16	34	50
10	11	8	42	50
		132-144	**138-150**	
11	0	51	—	51
11	1	42	9	51
11	2	34	17	51
11	3	25	27	52
11	4	17	35	52
11	5	8	44	52

NOTE: In orders, the complete names of the blocks desired should be given, as for example “102-114 RKB” or “102-114 Cupola.”

RING COMBINATIONS

6 Inch Lining — Rotary Kiln or Cupola Blocks 9 x 6 x 4 Inch — Continued

Diam. Inside Brickwork		Number Required Per Ring		
Ft	In			Total
		138-150	**144-156**	
11	6	53	—	53
11	7	44	9	53
11	8	35	18	53
11	9	26	28	54
11	10	18	36	54
11	11	9	46	55
		144-156	**150-162**	
12	0	55	—	55
12	1	45	10	55
12	2	37	19	56
12	3	27	29	56
12	4	18	38	56
12	5	9	48	57
		150-162	**156-168**	
12	6	57	—	57
12	7	47	10	57
12	8	38	20	58
12	9	28	30	58
12	10	19	39	58
12	11	10	49	59
		156-168	**162-174**	
13	0	59	—	59
13	1	49	10	59
13	2	39	21	60
13	3	29	31	60
13	4	20	40	60
13	5	10	51	61
		162-174	**168-180**	
13	6	61	—	61
13	7	51	10	61
13	8	41	21	62
13	9	30	32	62
13	10	21	42	63
13	11	10	53	63
		168-180	**174-186**	
14	0	63	—	63
14	1	53	11	64
14	2	42	22	64
14	3	31	33	64
14	4	21	44	65
14	5	11	54	65

NOTE: In orders, the complete names of the blocks desired should be given, as for example “138-150 RKB” or “138-150 Cupola.”

6 Inch Lining — Rotary Kiln or Cupola Blocks 9 x 6 x 4 Inch — Continued

Diam. Inside Brickwork		Number Required Per Ring		
Ft	In			Total
		174-186	**180-192**	
14	6	65	—	65
14	7	54	12	66
14	8	43	23	66
14	9	32	34	66
14	10	22	45	67
14	11	11	56	67
		180-192	**186-198**	
15	0	67	—	67
15	1	56	12	68
15	2	45	23	68
15	3	33	35	68
15	4	23	46	69
15	5	11	58	69
		186-198	**192-204**	
15	6	70	—	70
15	7	58	12	70
15	8	46	24	70
15	9	35	36	71
15	10	23	48	71
15	11	12	59	71
		192-204	**198-210**	
16	0	72	—	72
16	1	60	12	72
16	2	48	24	72
16	3	36	37	73
16	4	24	49	73
16	5	12	61	73
		198-210	**204-216**	
16	6	74	—	74
16	7	61	13	74
16	8	49	25	74
16	9	37	38	75
16	10	25	50	75
16	11	12	63	75
		204-216	**210-222**	
17	0	76	—	76

NOTE: In orders, the complete names of the blocks desired should be given, as for example “174-186 RKB” or “174-186 Cupola.”

RING COMBINATIONS

6 Inch Lining — Rotary Kiln Blocks
9 x 6 x 4 Inch Arch Type —Two Shape System

Inside Lining		Inside Shell		Number Required Per Ring				
Ft	In	Ft	In	KW-3	KW-2	KW-1	KW-1X	Total
5	0	6	0	50	7	—	—	57
5	3	6	3	44	15	—	—	59
5	6	6	6	38	24	—	—	62
5	9	6	9	32	32	—	—	64
6	0	7	0	25	41	—	—	66
6	3	7	3	19	50	—	—	69
6	6	7	6	13	58	—	—	71
6	9	7	9	6	67	—	—	73
7	0	8	0	—	76	—	—	76
7	3	8	3	—	72	6	—	78
7	6	8	6	—	68	13	—	81
7	9	8	9	—	64	19	—	83
8	0	9	0	—	60	25	—	85
8	3	9	3	—	56	32	—	88
8	6	9	6	—	52	38	—	90
8	9	9	9	—	48	44	—	92
9	0	10	0	—	44	51	—	95
9	3	10	3	—	40	57	—	97
9	6	10	6	—	36	63	—	99
9	9	10	9	—	33	69	—	102
10	0	11	0	—	28	76	—	104
10	3	11	3	—	24	82	—	106
10	6	11	6	—	21	88	—	109
10	9	11	9	—	17	94	—	111
11	0	12	0	—	13	100	—	113
11	3	12	3	—	9	107	—	116
11	6	12	6	—	5	113	—	118
11	9	12	9	—	1	119	—	120
12	0	13	0	—	—	118	5	123
12	3	13	3	—	—	114	11	125
12	6	13	6	—	—	111	17	128
12	9	13	9	—	—	107	23	130
13	0	14	0	—	—	104	28	132
13	3	14	3	—	—	100	35	135
13	6	14	6	—	—	97	40	137
13	9	14	9	—	—	93	46	139
14	0	15	0	—	—	90	52	142
14	3	15	3	—	—	86	58	144
14	6	15	6	—	—	82	64	146
14	9	15	9	—	—	79	70	149
15	0	16	0	—	—	76	75	151
15	3	16	3	—	—	72	82	154
15	6	16	6	—	—	69	87	156
15	9	16	9	—	—	65	93	158
16	0	17	0	—	—	62	99	161
16	3	17	3	—	—	58	105	163
16	6	17	6	—	—	54	111	165
16	9	17	9	—	—	51	117	168
17	0	18	0	—	—	47	123	170
17	3	18	3	—	—	44	128	172
17	6	18	6	—	—	40	135	175
17	9	18	9	—	—	37	140	177
18	0	19	0	—	—	33	146	179
18	3	19	3	—	—	30	152	182

NOTE: For each ring, order two (2) pieces each KA-$^2/_3$ and KA-$^3/_4$ to facilitate keying. For additional information, see discussion of KA and KW Blocks for Rotary Kilns.

9 Inch Lining — 3 Inch Wedge Brick
9 x 4$^1/_2$ x 3, 9 x 6 $^3/_4$ x 3 or 9 x 9 x 3 Inch

Diam. Inside Brickwork		Number Required Per Ring				
Ft	In	No. 3 Wedge	No. 2 Wedge	No. 1 Wedge	Straight	Total
3	0	57	—	—	—	57
3	1	56	2	—	—	58
3	2	55	4	—	—	59
3	3	54	6	—	—	60
3	4	52	9	—	—	61
3	5	51	11	—	—	62
3	6	50	13	—	—	63
3	7	49	15	—	—	64
3	8	48	17	—	—	65
3	9	47	19	—	—	66
3	10	46	21	—	—	67
3	11	45	23	—	—	68
4	0	44	26	—	—	70
4	1	43	28	—	—	71
4	2	42	30	—	—	72
4	3	41	32	—	—	73
4	4	40	34	—	—	74
4	5	39	36	—	—	75
4	6	38	38	—	—	76
4	7	37	40	—	—	77
4	8	36	42	—	—	78
4	9	35	44	—	—	79
4	10	34	46	—	—	80
4	11	33	48	—	—	81
5	0	32	50	—	—	82
5	1	31	52	—	—	83
5	2	29	55	—	—	84
5	3	28	57	—	—	85
5	4	27	59	—	—	86
5	5	26	61	—	—	87
5	6	25	63	—	—	88
5	7	24	65	—	—	89
5	8	23	67	—	—	90
5	9	22	70	—	—	92
5	10	21	72	—	—	93
5	11	20	74	—	—	94
6	0	19	76	—	—	95
6	1	18	78	—	—	96
6	2	17	80	—	—	97
6	3	16	82	—	—	98
6	4	15	84	—	—	99
6	5	14	86	—	—	100
6	6	13	88	—	—	101
6	7	12	90	—	—	102
6	8	11	92	—	—	103
6	9	10	94	—	—	104
6	10	9	96	—	—	105
6	11	7	99	—	—	106

NOTE: This table can be used also for 13$^1/_2$ x 9 x 3 inch arch brick by substituting Nos. 1, 2 and 3 arch brick for the corresponding wedge brick.

RING COMBINATIONS

9 Inch Lining — 3 Inch Wedge Brick
9 x $4^1/_2$ x 3, 9 x $6^3/_4$ x 3 or 9 x 9 x 3 Inch–Cont'd.

Diam. Inside Brickwork		Number Required Per Ring				
Ft	In	No. 3 Wedge	No. 2 Wedge	No. 1 Wedge	Straight	Total
7	0	6	101	—	—	107
7	1	5	103	—	—	108
7	2	4	105	—	—	109
7	3	3	107	—	—	110
7	4	2	109	—	—	111
7	5	1	111	—	—	112
7	6	—	113	—	—	113
7	7	—	112	3	—	115
7	8	—	111	5	—	116
7	9	—	110	7	—	117
7	10	—	109	9	—	118
7	11	—	108	11	—	119
8	0	—	107	13	—	120
8	1	—	106	15	—	121
8	2	—	105	17	—	122
8	3	—	104	19	—	123
8	4	—	103	21	—	124
8	5	—	102	23	—	125
8	6	—	101	25	—	126
8	7	—	100	27	—	127
8	8	—	99	29	—	128
8	9	—	97	32	—	129
8	10	—	96	34	—	130
8	11	—	95	36	—	131
9	0	—	94	38	—	132
9	1	—	93	40	—	133
9	2	—	92	42	—	134
9	3	—	91	44	—	135
9	4	—	90	47	—	137
9	5	—	89	49	—	138
9	6	—	88	51	—	139
9	7	—	87	53	—	140
9	8	—	86	55	—	141
9	9	—	85	57	—	142
9	10	—	84	59	—	143
9	11	—	83	61	—	144
10	0	—	82	63	—	145
10	1	—	81	65	—	146
10	2	—	80	67	—	147
10	3	—	79	69	—	148
10	4	—	78	71	—	149
10	5	—	77	73	—	150
10	6	—	76	75	—	151
10	7	—	74	78	—	152
10	8	—	73	80	—	153
10	9	—	72	82	—	154
10	10	—	71	84	—	155
10	11	—	70	86	—	156

NOTE: This table can be used also for $13^1/_2$ x 9 x 3 inch arch brick by substituting Nos. 1, 2 and 3 arch brick for the corresponding wedge brick.

9 Inch Lining — 3 Inch Wedge Brick
9 x $4^1/_2$ x 3, 9 x $6^3/_4$ x 3 or 9 x 9 x 3 Inch–Cont'd.

Diam. Inside Brickwork		Number Required Per Ring				
Ft	In	No. 3 Wedge	No. 2 Wedge	No. 1 Wedge	Straight	Total
11	0	—	69	88	—	157
11	1	—	69	90	—	159
11	2	—	67	93	—	160
11	3	—	66	95	—	161
11	4	—	65	97	—	162
11	5	—	64	99	—	163
11	6	—	63	101	—	164
11	7	—	62	103	—	165
11	8	—	61	105	—	166
11	9	—	60	107	—	167
11	10	—	59	109	—	168
11	11	—	58	111	—	169
12	0	—	57	113	—	170
12	1	—	56	115	—	171
12	2	—	55	117	—	172
12	3	—	54	119	—	173
12	4	—	52	122	—	174
12	5	—	51	124	—	175
12	6	—	50	126	—	176
12	7	—	49	128	—	177
12	8	—	48	130	—	178
12	9	—	47	132	—	179
12	10	—	47	134	—	181
12	11	—	45	137	—	182
13	0	—	44	139	—	183
13	1	—	43	141	—	184
13	2	—	42	143	—	185
13	3	—	41	145	—	186
13	4	—	40	147	—	187
13	5	—	39	149	—	188
13	6	—	38	151	—	189
13	7	—	37	153	—	190
13	8	—	36	155	—	191
13	9	—	35	157	—	192
13	10	—	34	159	—	193
13	11	—	33	161	—	194
14	0	—	32	163	—	195
14	1	—	30	166	—	196
14	2	—	29	168	—	197
14	3	—	28	170	—	198
14	4	—	27	172	—	199
14	5	—	26	174	—	200
14	6	—	25	176	—	201
14	7	—	25	178	—	203
14	8	—	23	181	—	204
14	9	—	22	183	—	205
14	10	—	21	185	—	206
14	11	—	20	187	—	207
15	0	—	19	189	—	208
15	1	—	18	191	—	209
15	2	—	17	193	—	210
15	3	—	16	195	—	211
15	4	—	15	197	—	212
15	5	—	14	199	—	213

NOTE: This table can be used also for $13^1/_2$ x 9 x 3 inch arch brick by substituting Nos. 1, 2 and 3 arch brick for the corresponding wedge brick.

RING COMBINATIONS

9 Inch Lining — 3 Inch Wedge Brick
9 x 4½ x 3, 9 x 6¾ x 3 or 9 x 9 x 3 Inch–Cont'd.

Diam. Inside Brickwork		Number Required Per Ring				
Ft	In	No. 3 Wedge	No. 2 Wedge	No. 1 Wedge	Straight	Total
15	6	—	13	201	—	214
15	7	—	12	203	—	215
15	8	—	11	205	—	216
15	9	—	10	207	—	217
15	10	—	8	210	—	218
15	11	—	7	212	—	219
16	0	—	6	214	—	220
16	1	—	5	216	—	221
16	2	—	4	218	—	222
16	3	—	3	220	—	223
16	4	—	3	222	—	225
16	5	—	1	225	—	226
16	6	—	—	227	—	227
17	0	—	—	227	6	233
17	6	—	—	227	12	239
18	0	—	—	227	18	245
18	6	—	—	227	25	252
19	0	—	—	227	31	258
19	6	—	—	227	37	264
20	0	—	—	227	44	271
20	6	—	—	227	50	277
21	0	—	—	227	56	283
21	6	—	—	227	62	289
22	0	—	—	227	69	296
22	6	—	—	227	75	302
23	0	—	—	227	81	308
23	6	—	—	227	88	315
24	0	—	—	227	94	321
24	6	—	—	227	100	327
25	0	—	—	227	106	333
25	6	—	—	227	113	340
26	0	—	—	227	119	346
26	6	—	—	227	125	352
27	0	—	—	227	132	359
27	6	—	—	227	138	365
28	0	—	—	227	144	371
28	6	—	—	227	150	377
29	0	—	—	227	157	384
29	6	—	—	227	163	390
30	0	—	—	227	169	396
30	6	—	—	227	176	403
31	0	—	—	227	182	409
31	6	—	—	227	188	415
32	0	—	—	227	194	421
32	6	—	—	227	201	428
33	0	—	—	227	207	434
33	6	—	—	227	213	440
34	0	—	—	227	220	447
34	6	—	—	227	226	453
35	0	—	—	227	232	459
35	6	—	—	227	238	465
36	0	—	—	227	245	472
36	6	—	—	227	251	478

NOTE: This table can be used also for 13½ x 9 x 3 inch arch brick by substituting Nos. 1, 2 and 3 arch brick for the corresponding wedge brick.

9 Inch Lining — 3 Inch Key Brick
9 x 4½ x 3 Inch

Diam. Inside Brickwork		Number Required Per Ring					
Ft	In	No. 4 Key	No. 3 Key	No. 2 Key	No. 1 Key	Straight	Total
1	6	26	—	—	—	—	26
1	8	23	4	—	—	—	27
1	10	20	8	—	—	—	28
2	0	17	13	—	—	—	30
2	2	14	17	—	—	—	31
2	4	12	21	—	—	—	33
2	6	9	25	—	—	—	34
2	8	6	29	—	—	—	35
2	10	3	34	—	—	—	37
3	0	—	38	—	—	—	38
3	2	—	35	4	—	—	39
3	4	—	32	9	—	—	41
3	6	—	29	13	—	—	42
3	8	—	27	17	—	—	44
3	10	—	24	21	—	—	45
4	0	—	21	25	—	—	46
4	2	—	18	30	—	—	48
4	4	—	15	34	—	—	49
4	6	—	13	38	—	—	51
4	8	—	10	42	—	—	52
4	10	—	7	46	—	—	53
5	0	—	4	51	—	—	55
5	2	—	1	55	—	—	56
5	3	—	—	57	—	—	57
5	4	—	—	56	2	—	58
5	6	—	—	55	4	—	59
5	8	—	—	53	7	—	60
5	10	—	—	52	10	—	62
6	0	—	—	50	13	—	63
6	2	—	—	49	16	—	65
6	4	—	—	48	18	—	66
6	6	—	—	46	21	—	67
6	8	—	—	45	24	—	69
6	10	—	—	43	27	—	70
7	0	—	—	42	30	—	72
7	2	—	—	41	32	—	73
7	4	—	—	39	35	—	74
7	6	—	—	38	38	—	76
7	8	—	—	36	41	—	77
7	10	—	—	35	44	—	79
8	0	—	—	34	46	—	80
8	2	—	—	32	49	—	81
8	4	—	—	31	52	—	83
8	6	—	—	29	55	—	84
8	8	—	—	28	58	—	86
8	10	—	—	27	60	—	87
9	0	—	—	25	63	—	88
9	2	—	—	24	66	—	90
9	4	—	—	22	69	—	91
9	6	—	—	21	72	—	93
9	8	—	—	20	74	—	94
9	10	—	—	18	77	—	95
10	0	—	—	17	80	—	97
10	2	—	—	15	83	—	98
10	4	—	—	14	86	—	100

RING COMBINATIONS

9 Inch Lining — 3 Inch Key Brick
9 x 4$^1/_2$ x 3 Inch — Continued

Diam. Inside Brickwork		Number Required Per Ring					
Ft	In	No. 4 Key	No. 3 Key	No. 2 Key	No. 1 Key	Straight	Total
10	6	—	—	13	88	—	101
10	8	—	—	11	91	—	102
10	10	—	—	10	94	—	104
11	0	—	—	9	96	—	105
11	2	—	—	7	100	—	107
11	4	—	—	6	102	—	108
11	6	—	—	4	105	—	109
11	8	—	—	3	108	—	111
11	10	—	—	2	110	—	112
12	0	—	—	—	113	—	113
12	6	—	—	—	113	5	118
13	0	—	—	—	113	9	122
13	6	—	—	—	113	13	126
14	0	—	—	—	113	17	130
14	6	—	—	—	113	21	134
15	0	—	—	—	113	26	139
15	6	—	—	—	113	30	143
16	0	—	—	—	113	34	147
16	6	—	—	—	113	38	151
17	0	—	—	—	113	42	155
17	6	—	—	—	113	47	160
18	0	—	—	—	113	51	164
18	6	—	—	—	113	55	168
19	0	—	—	—	113	59	172
19	6	—	—	—	113	63	176
20	0	—	—	—	113	68	181
20	6	—	—	—	113	72	185
21	0	—	—	—	113	76	189
21	6	—	—	—	113	80	193
22	0	—	—	—	113	84	197
22	6	—	—	—	113	88	201
23	0	—	—	—	113	93	206
23	6	—	—	—	113	97	210
24	0	—	—	—	113	101	214
24	6	—	—	—	113	105	218
25	0	—	—	—	113	109	222
25	6	—	—	—	113	114	227
26	0	—	—	—	113	118	231
26	6	—	—	—	113	122	235
27	0	—	—	—	113	126	239
27	6	—	—	—	113	130	243
28	0	—	—	—	113	135	248
28	6	—	—	—	113	139	252
29	0	—	—	—	113	143	256
29	6	—	—	—	113	147	260
30	0	—	—	—	113	151	264
30	6	—	—	—	113	155	268
31	0	—	—	—	113	160	273
31	6	—	—	—	113	164	277
32	0	—	—	—	113	168	281
32	6	—	—	—	113	172	285
33	0	—	—	—	113	176	289
33	6	—	—	—	113	181	294
34	0	—	—	—	113	185	298
35	0	—	—	—	113	193	306

9 Inch Lining — 3 Inch Key Brick
9 x 6 x 3 Inch

Diam. Inside Brickwork		Number Required Per Ring				
Ft	In	No. 3 Key	No. 2 Key	No. 1 Key	Straight	Total
1	6	19	—	—	—	19
1	8	18	2	—	—	20
1	10	18	3	—	—	21
2	0	17	5	—	—	22
2	2	16	7	—	—	23
2	4	15	9	—	—	24
2	6	15	11	—	—	26
2	8	14	13	—	—	27
2	10	14	14	—	—	28
3	0	13	16	—	—	29
3	2	12	18	—	—	30
3	4	12	19	—	—	31
3	6	11	21	—	—	32
3	8	10	23	—	—	33
3	10	9	25	—	—	34
4	0	9	26	—	—	35
4	2	8	28	—	—	36
4	4	7	30	—	—	37
4	6	7	31	—	—	38
4	8	6	33	—	—	39
4	10	5	35	—	—	40
5	0	5	36	—	—	41
5	2	4	38	—	—	42
5	4	3	40	—	—	43
5	6	2	42	—	—	44
5	8	2	43	—	—	45
5	10	1	45	—	—	46
6	0	—	48	—	—	48
6	2	—	47	2	—	49
6	4	—	46	4	—	50
6	6	—	45	6	—	51
6	8	—	44	8	—	52
6	10	—	43	10	—	53
7	0	—	41	13	—	54
7	2	—	40	15	—	55
7	4	—	39	17	—	56
7	6	—	38	19	—	57
7	8	—	37	21	—	58
7	10	—	36	23	—	59
8	0	—	34	26	—	60
8	2	—	33	28	—	61
8	4	—	32	30	—	62
8	6	—	31	32	—	63
8	8	—	30	34	—	64
8	10	—	28	37	—	65
9	0	—	27	39	—	66
9	2	—	26	41	—	67
9	4	—	25	43	—	68
9	6	—	24	46	—	70
9	8	—	23	48	—	71
9	10	—	22	50	—	72

*NOTE: For brickwork of inside diameters less than 6 feet, involving the use of 9 x 6 inch No. 3 Keys which have a very sharp taper, a better bricklaying fit can be obtained by the use of the 9 x 4$^1/_2$ inch Key-brick combinations.

RING COMBINATIONS

9 Inch Lining — 3 Inch Key Brick
9 x 6 x 3 Inch — Continued

Diam. Inside Brickwork		Number Required Per Ring				
Ft	In	No. 3 Key	No. 2 Key	No. 1 Key	Straight	Total
10	0	—	21	52	—	73
10	2	—	19	55	—	74
10	4	—	18	57	—	75
10	6	—	17	59	—	76
10	8	—	16	61	—	77
10	10	—	15	63	—	78
11	0	—	13	66	—	79
11	2	—	12	68	—	80
11	4	—	11	70	—	81
11	6	—	10	72	—	82
11	8	—	9	74	—	83
11	10	—	8	76	—	84
12	0	—	6	79	—	85
12	2	—	5	81	—	86
12	4	—	4	83	—	87
12	6	—	3	85	—	88
12	8	—	2	87	—	89
12	10	—	—	90	—	90
13	0	—	—	91	—	91
13	6	—	—	91	4	95
14	0	—	—	91	7	98
14	6	—	—	91	10	101
15	0	—	—	91	13	104
15	6	—	—	91	16	107
16	0	—	—	91	19	110
16	6	—	—	91	22	113
17	0	—	—	91	26	117
17	6	—	—	91	29	120
18	0	—	—	91	32	123
18	6	—	—	91	35	126
19	0	—	—	91	38	129
20	0	—	—	91	44	135
21	0	—	—	91	51	142
22	0	—	—	91	57	148
23	0	—	—	91	63	154
24	0	—	—	91	70	161
25	0	—	—	91	76	167
26	0	—	—	91	82	173
27	0	—	—	91	88	179
28	0	—	—	91	95	186
29	0	—	—	91	101	192
30	0	—	—	91	107	198
31	0	—	—	91	114	205
32	0	—	—	91	120	211
33	0	—	—	91	126	217
34	0	—	—	91	132	223
35	0	—	—	91	139	230
36	0	—	—	91	145	236
37	0	—	—	91	151	242
38	0	—	—	91	158	249
39	0	—	—	91	164	255
40	0	—	—	91	170	261
41	0	—	—	91	176	267

9 Inch Lining — Rotary Kiln Blocks
9 x 9 x 4 Inch

Diam. Inside Brickwork		Number Required Per Ring		
Ft	In			Total
		60-78	**66-84**	
5	0	28	—	28
5	1	23	5	28
5	2	18	10	28
5	3	14	15	29
5	4	9	20	29
5	5	5	24	29
		66-84	**72-90**	
5	6	30	—	30
5	7	25	5	30
5	8	20	10	30
5	9	15	16	31
5	10	10	21	31
5	11	5	26	31
		72-90	**78-96**	
6	0	32	—	32
6	1	26	6	32
6	2	21	12	33
6	3	16	17	33
6	4	11	22	33
6	5	6	28	34
		78-96	**84-102**	
6	6	34	—	34
6	7	28	6	34
6	8	23	12	35
6	9	17	18	35
6	10	11	24	35
6	11	6	30	36
		82-102	**90-108**	
7	0	36	—	36
7	1	30	6	36
7	2	24	13	37
7	3	18	19	37
7	4	12	25	37
7	5	6	32	38
		90-108	**96-114**	
7	6	38	—	38
7	7	31	7	38
7	8	25	14	39
7	9	19	20	39
7	10	13	26	39
7	11	7	33	40

NOTE: In orders, the complete names of the blocks should be given, as for example "60-78 RKB."

9 Inch Lining — Rotary Kiln Blocks
9 x 9 x 4 Inch — Continued

Diam. Inside Brickwork Ft	In	Number Required Per Ring		Total
		96-114	**102-120**	
8	0	40	—	40
8	1	34	7	41
8	2	27	14	41
8	3	20	21	41
8	4	14	28	42
8	5	7	35	42
		102-120	**108-126**	
8	6	42	—	42
8	7	35	8	43
8	8	28	15	43
8	9	21	22	43
8	10	14	30	44
8	11	7	37	44
		108-126	**114-132**	
9	0	44	—	44
9	1	37	8	45
9	2	29	16	45
9	3	22	23	45
9	4	15	31	46
9	5	7	39	46
		114-132	**117-135**	
9	6	46	—	46
9	7	31	16	47
9	8	15	32	47
		117-135	**120-138**	
9	9	48	—	48
9	10	32	16	48
9	11	16	32	48
		120-138	**123-141**	
10	0	49	—	49
10	1	32	17	49
10	2	16	13	49

NOTE: In orders, the complete names of the blocks should be given, as for example “84-102 RKB.”

9 Inch Lining — Rotary Kiln Blocks
9 x 9 x 4 Inch — Continued

Diam. Inside Brickwork Ft	In	Number Required Per Ring		Total
		123-141	**126-144**	
10	3	50	—	50
10	4	33	17	50
10	5	16	34	50
		126-144	**132-150**	
10	6	51	—	51
10	7	42	9	51
10	8	34	17	51
10	9	25	27	52
10	10	17	35	52
10	11	8	44	52
		132-150	**138-156**	
11	0	53	—	53
11	1	44	9	53
11	2	35	18	53
11	3	26	28	54
11	4	18	36	54
11	5	9	46	55
		138-156	**144-162**	
11	6	55	—	55
11	7	45	10	55
11	8	37	19	56
11	9	27	29	56
11	10	18	38	56
11	11	9	48	57
		144-162	**150-168**	
12	0	57	—	57
12	1	47	10	57
12	2	38	20	58
12	3	28	30	58
12	4	19	39	58
12	5	10	49	59
		150-168	**156-174**	
12	6	59	—	59
12	7	49	10	59
12	8	39	21	60
12	9	29	31	60
12	10	20	40	60
12	11	10	51	61
		156-174	**162-180**	
13	0	61	—	61
13	1	51	10	61
13	2	41	21	62
13	3	30	32	62
13	4	21	42	63
13	5	10	53	63

NOTE: In orders, the complete names of the blocks should be given, as for example “123-141 RKB.”

RING COMBINATIONS

9 Inch Lining — Rotary Kiln Blocks
9 x 9 x 4 Inch — Continued

Diam. Inside Brickwork		Number Required Per Ring		
Ft	In			Total
		162-180	**168-186**	
13	6	63	—	63
13	7	53	11	64
13	8	42	22	64
13	9	31	33	64
13	10	21	44	65
13	11	11	54	65
		168-186	**174-192**	
14	0	65	—	65
14	1	54	12	66
14	2	43	23	66
14	3	32	34	66
14	4	22	45	67
14	5	11	56	67
		174-192	**180-198**	
14	6	67	—	67
14	7	56	12	68
14	8	45	23	68
14	9	33	35	68
14	10	23	46	69
14	11	11	58	69
		180-198	**186-204**	
15	0	70	—	70
15	1	58	12	70
15	2	46	24	70
15	3	35	36	71
15	4	23	48	71
15	5	12	59	71
		186-204	**192-210**	
15	6	72	—	72
15	7	60	12	72
15	8	48	24	72
15	9	36	37	73
15	10	24	49	73
15	11	12	61	73
		192-210	**198-216**	
16	0	74	—	74
16	1	61	13	74
16	2	49	25	74
16	3	37	38	75
16	4	25	50	75
16	5	12	63	75
		198-216	**204-222**	
16	6	76	—	76
16	7	63	13	76
16	8	50	26	76
16	9	38	39	77
16	10	25	52	77
16	11	13	65	78

NOTE: In orders, the complete names of the blocks should be given, as for example "162-180 RKB."

9 Inch Lining — Rotary Kiln Blocks
9 x 9 x 4 Inch — Continued

Diam. Inside Brickwork		Number Required Per Ring		
Ft	In			Total
		204-222	**210-228**	
17	0	78	—	78
17	1	65	13	78
17	2	52	27	79
17	3	39	40	79
17	4	26	53	79
17	5	13	67	80
		210-228	**216-234**	
17	6	80	—	80
17	7	66	14	80
17	8	53	28	81
17	9	40	41	81
17	10	27	54	81
17	11	14	68	82
		216-234	**222-240**	
18	0	82	—	82
18	1	68	14	82
18	2	55	28	83
18	3	41	42	83
18	4	27	56	83
18	5	14	70	84
		222-240	**228-246**	
18	6	84	—	84
18	7	70	15	85
18	8	56	29	85
18	9	42	43	85
18	10	28	58	86
18	11	14	72	86
		228-246	**234-252**	
19	0	86	—	86
19	1	72	15	87
19	2	57	30	87
19	3	43	44	87
19	4	29	59	88
19	5	14	74	88
		234-252	**240-258**	
19	6	88	—	88
19	7	74	15	89
19	8	59	30	89
19	9	44	45	89
19	10	30	60	90
19	11	15	75	90
		240-258	—	
20	0	90	—	90
—				

NOTE: In orders, the complete names of the blocks should be given, as for example "204-222 RKB."

RING COMBINATIONS

9 Inch Lining — Rotary Kiln Blocks
9 x 6 x 4 Inch Wedge Type —Two Shape System

Inside Lining		Inside Shell		Number Required Per Ring				
Ft	In	Ft	In	KW-3	KW-2	KW-1	KW-1X	Total
4	6	6	0	50	7	—	—	57
4	9	6	3	44	15	—	—	59
5	0	6	6	38	24	—	—	62
5	3	6	9	32	32	—	—	64
5	6	7	0	25	41	—	—	66
5	9	7	3	19	50	—	—	69
6	0	7	6	13	58	—	—	71
6	3	7	9	6	67	—	—	73
6	6	8	0	—	76	—	—	76
6	9	8	3	—	72	6	—	78
7	0	8	6	—	68	13	—	81
7	3	8	9	—	64	19	—	83
7	6	9	0	—	60	25	—	85
7	9	9	3	—	56	32	—	88
8	0	9	6	—	52	38	—	90
8	3	9	9	—	48	44	—	92
8	6	10	0	—	44	51	—	95
8	9	10	3	—	40	57	—	97
9	0	10	6	—	36	63	—	99
9	3	10	9	—	33	69	—	102
9	6	11	0	—	28	76	—	104
9	9	11	3	—	24	82	—	106
10	0	11	6	—	21	88	—	109
10	3	11	9	—	17	94	—	111
10	6	12	0	—	13	100	—	113
10	9	12	3	—	9	107	—	116
11	0	12	6	—	5	113	—	118
11	3	12	9	—	1	119	—	120
11	6	13	0	—	—	117	6	123
11	9	13	3	—	—	112	13	125
12	0	13	6	—	—	108	20	128
12	3	13	9	—	—	103	27	130
12	6	14	0	—	—	98	34	132
12	9	14	3	—	—	94	41	135
13	0	14	6	—	—	89	48	137
13	3	14	9	—	—	84	55	139
13	6	15	0	—	—	79	63	142
13	9	15	3	—	—	75	69	144
14	0	15	6	—	—	70	76	146
14	3	15	9	—	—	65	84	149
14	6	16	0	—	—	60	91	151
14	9	16	3	—	—	56	98	154
15	0	16	6	—	—	51	105	156
15	3	16	9	—	—	46	112	158
15	6	17	0	—	—	42	119	161
15	9	17	3	—	—	37	126	163
16	0	17	6	—	—	32	133	165
16	3	17	9	—	—	28	140	168
16	6	18	0	—	—	23	147	170
16	9	18	3	—	—	18	154	172
17	0	18	6	—	—	14	161	175
17	3	18	9	—	—	9	168	177
17	6	19	0	—	—	4	175	179
17	9	19	3	—	—	—	182	182

NOTE: For each ring, order two (2) pieces each KW-$^2/_3$ and KW-$^3/_4$ to facilitate keying. For additional information, see discussion of KA and KW blocks for Rotary Kilns.

12 Inch Lining — 3 Inch Wedge Brick
12 x 4$^1/_2$ x 3, 12 x 6 x 3 or 12 x 9 x 3 Inch

Diam. Inside Brickwork		Number Required Per Ring					
Ft	In	No. 3 Wedge	No. 2 Wedge	No. 1 Wedge	No. 1-X Wedge	Straight	Total
4	0	76	—	—	—	—	76
4	3	72	7	—	—	—	79
4	6	69	13	—	—	—	82
4	9	66	19	—	—	—	85
5	0	63	25	—	—	—	88
5	3	60	32	—	—	—	92
5	6	57	38	—	—	—	95
5	9	54	44	—	—	—	98
6	0	51	50	—	—	—	101
6	3	47	57	—	—	—	104
6	6	44	63	—	—	—	107
6	9	41	69	—	—	—	110
7	0	38	75	—	—	—	113
7	3	35	82	—	—	—	117
7	6	32	88	—	—	—	120
7	9	29	94	—	—	—	123
8	0	25	101	—	—	—	126
8	3	22	107	—	—	—	129
8	6	19	113	—	—	—	132
8	9	16	119	—	—	—	135
9	0	13	126	—	—	—	139
9	3	10	132	—	—	—	142
9	6	7	138	—	—	—	145
9	9	3	145	—	—	—	148
10	0	—	151	—	—	—	151
10	3	—	148	6	—	—	154
10	6	—	144	13	—	—	157
10	9	—	142	19	—	—	161
11	0	—	139	25	—	—	164
11	3	—	135	32	—	—	167
11	6	—	132	38	—	—	170
11	9	—	129	44	—	—	173
12	0	—	126	50	—	—	176
12	3	—	122	57	—	—	179
12	6	—	120	63	—	—	183
12	9	—	117	69	—	—	186
13	0	—	113	76	—	—	189
13	3	—	110	82	—	—	192
13	6	—	107	88	—	—	195
13	9	—	104	94	—	—	198
14	0	—	101	100	—	—	201
14	3	—	98	107	—	—	205
14	6	—	95	113	—	—	208
14	9	—	91	120	—	—	211
15	0	—	88	126	—	—	214
15	3	—	85	132	—	—	217
15	6	—	82	138	—	—	220
15	9	—	79	144	—	—	223

12 Inch Lining — 3 Inch Wedge Brick
12 x 4½ x 3, 12 x 6 x 3 or 12 x 9 x 3 Inch–Cont'd.

Diam. Inside Brickwork		Number Required Per Ring					
Ft	In	No. 3 Wedge	No. 2 Wedge	No. 1 Wedge	No. 1-X Wedge	Straight	Total
16	0	—	76	151	—	—	227
16	3	—	73	157	—	—	230
16	6	—	69	164	—	—	233
16	9	—	66	170	—	—	236
17	0	—	63	176	—	—	239
17	3	—	60	182	—	—	242
17	6	—	57	188	—	—	245
17	9	—	54	195	—	—	249
18	0	—	51	201	—	—	252
18	3	—	47	208	—	—	255
18	6	—	44	214	—	—	258
18	9	—	41	220	—	—	261
19	0	—	38	226	—	—	264
19	3	—	35	232	—	—	267
19	6	—	32	239	—	—	271
19	9	—	29	245	—	—	274
20	0	—	25	252	—	—	277
20	3	—	22	258	—	—	280
20	6	—	19	264	—	—	283
20	9	—	16	270	—	—	286
21	0	—	13	276	—	—	289
21	3	—	10	283	—	—	293
21	6	—	7	289	—	—	296
21	9	—	3	296	—	—	299
22	0	—	—	302	—	—	302
22	3	—	—	299	6	—	305
22	6	—	—	295	13	—	308
22	9	—	—	292	19	—	311
23	0	—	—	289	26	—	315
23	3	—	—	286	32	—	318
23	6	—	—	283	38	—	321
23	9	—	—	280	44	—	324
24	0	—	—	277	50	—	327
24	3	—	—	273	57	—	330
24	6	—	—	270	63	—	333
24	9	—	—	267	70	—	337
25	0	—	—	264	76	—	340
25	3	—	—	261	82	—	343
25	6	—	—	258	88	—	346
25	9	—	—	255	94	—	349
26	0	—	—	251	101	—	352
26	3	—	—	248	107	—	355
26	6	—	—	245	114	—	359
26	9	—	—	242	120	—	362
27	0	—	—	239	126	—	365
27	3	—	—	236	132	—	368
27	6	—	—	233	138	—	371
27	9	—	—	229	145	—	374

12 Inch Lining — 3 Inch Wedge Brick
12 x 4½ x 3, 12 x 6 x 3 or 12 x 9 x 3 Inch–Cont'd.

Diam. Inside Brickwork		Number Required Per Ring					
Ft	In	No. 3 Wedge	No. 2 Wedge	No. 1 Wedge	No. 1-X Wedge	Straight	Total
28	0	—	—	226	151	—	377
28	3	—	—	223	158	—	381
28	6	—	—	220	164	—	384
28	9	—	—	217	170	—	387
29	0	—	—	214	176	—	390
29	3	—	—	211	182	—	393
29	6	—	—	207	189	—	396
29	9	—	—	204	195	—	399
30	0	—	—	202	201	—	403
30	3	—	—	198	208	—	406
30	6	—	—	195	214	—	409
30	9	—	—	192	220	—	412
31	0	—	—	189	226	—	415
31	3	—	—	185	233	—	418
31	6	—	—	182	239	—	421
31	9	—	—	180	245	—	425
32	0	—	—	176	252	—	428
32	3	—	—	173	258	—	431
32	6	—	—	170	264	—	434
32	9	—	—	167	270	—	437
33	0	—	—	163	277	—	440
33	3	—	—	160	283	—	443
33	6	—	—	158	289	—	447
33	9	—	—	154	296	—	450
34	0	—	—	151	302	—	453
34	3	—	—	148	308	—	456
34	6	—	—	145	314	—	459
34	9	—	—	141	321	—	462
35	0	—	—	138	327	—	465
35	3	—	—	135	333	—	468
35	6	—	—	132	340	—	472
35	9	—	—	129	346	—	475
36	0	—	—	126	352	—	478
36	3	—	—	123	358	—	481
36	6	—	—	119	365	—	484
36	9	—	—	116	371	—	487
37	0	—	—	113	377	—	490
37	3	—	—	110	384	—	494
37	6	—	—	107	390	—	497
37	9	—	—	104	396	—	500
38	0	—	—	101	402	—	503
38	3	—	—	97	409	—	506
38	6	—	—	94	415	—	509
38	9	—	—	91	421	—	512
39	0	—	—	88	428	—	516
39	3	—	—	85	434	—	519
39	6	—	—	82	440	—	522
39	9	—	—	79	446	—	525

RING COMBINATIONS

12 Inch Lining — 3 Inch Wedge Brick
12 x 4½ x 3, 12 x 6 x 3 or 12 x 9 x 3 Inch–Cont'd.

Diam. Inside Brickwork		Number Required Per Ring					
Ft	In	No. 3 Wedge	No. 2 Wedge	No. 1 Wedge	No. 1-X Wedge	Straight	Total
40	0	—	—	76	452	—	528
40	3	—	—	72	459	—	531
40	6	—	—	69	465	—	534
40	9	—	—	66	472	—	538
41	0	—	—	63	478	—	541
41	3	—	—	60	484	—	544
41	6	—	—	57	490	—	547
41	9	—	—	54	496	—	550
42	0	—	—	50	503	—	553
42	3	—	—	47	509	—	556
42	6	—	—	44	516	—	560
42	9	—	—	41	522	—	563
43	0	—	—	38	528	—	566
43	3	—	—	35	534	—	569
43	6	—	—	32	540	—	572
43	9	—	—	28	547	—	575
44	0	—	—	25	553	—	578
44	3	—	—	22	560	—	582
44	6	—	—	19	566	—	585
44	9	—	—	16	572	—	588
45	0	—	—	13	578	—	591
45	3	—	—	10	584	—	594
45	6	—	—	6	591	—	597
45	9	—	—	3	597	—	600
46	0	—	—	—	604	—	604
46	3	—	—	—	604	3	607
46	6	—	—	—	604	6	610
46	9	—	—	—	604	9	613
47	0	—	—	—	604	12	616
47	3	—	—	—	604	15	619
47	6	—	—	—	604	18	622
47	9	—	—	—	604	22	626
48	0	—	—	—	604	25	629
48	3	—	—	—	604	28	632
48	6	—	—	—	604	31	635
48	9	—	—	—	604	34	638
49	0	—	—	—	604	37	641
49	6	—	—	—	604	44	648
50	0	—	—	—	604	50	654
50	6	—	—	—	604	56	660
51	0	—	—	—	604	62	666
51	6	—	—	—	604	69	673
52	0	—	—	—	604	75	679
52	6	—	—	—	604	81	685
53	0	—	—	—	604	88	692
53	6	—	—	—	604	94	698
54	0	—	—	—	604	100	704
54	6	—	—	—	604	106	710

12 Inch Lining — 3 Inch Key Brick
12 x 6 x 3 Inch

Diam. Inside Brickwork		Number Required Per Ring			
Ft	In	No.2 Key	No. 1 Key	Straight	Total
10	0	76	—	—	76
10	2	75	2	—	77
10	4	74	4	—	78
10	6	72	7	—	79
10	8	71	9	—	80
10	10	70	11	—	81
11	0	69	13	—	82
11	2	68	15	—	83
11	4	67	17	—	84
11	6	66	19	—	85
11	8	65	21	—	86
11	10	64	23	—	87
12	0	63	25	—	88
12	2	62	27	—	89
12	4	61	29	—	90
12	6	60	32	—	92
12	8	59	34	—	93
12	10	58	36	—	94
13	0	57	38	—	95
13	2	56	40	—	96
13	4	55	42	—	97
13	6	54	44	—	98
13	8	53	46	—	99
13	10	52	48	—	100
14	0	51	50	—	101
14	2	49	53	—	102
14	4	48	55	—	103
14	6	47	57	—	104
14	8	46	59	—	105
14	10	45	61	—	106
15	0	44	63	—	107
15	2	43	65	—	108
15	4	42	67	—	109
15	6	41	69	—	110
15	8	40	71	—	111
15	10	39	73	—	112
16	0	38	75	—	113
16	2	37	78	—	115
16	4	36	80	—	116
16	6	35	82	—	117
16	8	34	84	—	118
16	10	33	86	—	119
17	0	32	88	—	120
17	2	31	90	—	121
17	4	30	92	—	122
17	6	29	94	—	123
17	8	27	97	—	124
17	10	26	99	—	125
18	0	25	101	—	126
18	2	24	103	—	127
18	4	23	105	—	128
18	6	22	107	—	129
18	8	21	109	—	130
18	10	20	111	—	131

RING COMBINATIONS

12 Inch Lining — 3 Inch Key Brick
12 x 6 x 3 Inch — Continued

Diam. Inside Brickwork		Number Required Per Ring			
Ft	In	No. 2 Key	No. 1 Key	Straight	Total
19	0	19	113	—	132
19	2	18	115	—	133
19	4	17	117	—	134
19	6	16	119	—	135
19	8	15	122	—	137
19	10	14	124	—	138
20	0	13	126	—	139
20	2	12	128	—	140
20	4	11	130	—	141
20	6	10	132	—	142
20	8	9	134	—	143
20	10	8	136	—	144
21	0	7	138	—	145
21	2	5	141	—	146
21	4	4	143	—	147
21	6	3	145	—	148
21	8	2	147	—	149
21	10	1	149	—	150
22	0	—	151	—	151
22	2	—	151	1	152
22	4	—	151	2	153
22	6	—	151	3	154
23	0	—	151	6	157
23	6	—	151	10	161
24	0	—	151	13	164
24	6	—	151	16	167
25	0	—	151	19	170
25	6	—	151	22	173
26	0	—	151	25	176
26	6	—	151	28	179
27	0	—	151	32	183
27	6	—	151	35	186
28	0	—	151	38	189
28	6	—	151	41	192
29	0	—	151	44	195
29	6	—	151	47	198
30	0	—	151	50	201
30	6	—	151	54	205
31	0	—	151	57	208
31	6	—	151	60	211
32	0	—	151	63	214
32	6	—	151	66	217
33	0	—	151	69	220
33	6	—	151	72	223
34	0	—	151	76	227
34	6	—	151	79	230
35	0	—	151	82	233
35	6	—	151	85	236
36	0	—	151	88	239
36	6	—	151	91	242
37	0	—	151	94	245
37	6	—	151	98	249
38	0	—	151	101	252
38	6	—	151	104	255

13½ Inch Lining — 3 Inch Wedge Brick
13½ x 4½ x 3, 13½ x 6 x 3 or 13½ x 9 x 3 Inch

Diam. Inside Brickwork		Number Required Per Ring					
Ft	In	No. 3 Wedge	No. 2 Wedge	No. 1 Wedge	No. 1-X Wedge	Straight	Total
4	6	85	—	—	—	—	85
4	9	82	6	—	—	—	88
5	0	79	13	—	—	—	92
5	3	76	19	—	—	—	95
5	6	73	25	—	—	—	98
5	9	69	32	—	—	—	101
6	0	66	38	—	—	—	104
6	3	63	44	—	—	—	107
6	6	60	50	—	—	—	110
6	9	57	56	—	—	—	113
7	0	54	63	—	—	—	117
7	3	51	69	—	—	—	120
7	6	47	76	—	—	—	123
7	9	44	82	—	—	—	126
8	0	41	88	—	—	—	129
8	3	38	94	—	—	—	132
8	6	35	100	—	—	—	135
8	9	32	107	—	—	—	139
9	0	29	113	—	—	—	142
9	3	25	120	—	—	—	145
9	6	22	126	—	—	—	148
9	9	19	132	—	—	—	151
10	0	16	138	—	—	—	154
10	3	13	144	—	—	—	157
10	6	10	151	—	—	—	161
10	9	7	157	—	—	—	164
11	0	3	164	—	—	—	167
11	3	—	170	—	—	—	170
11	6	—	167	6	—	—	173
11	9	—	163	13	—	—	176
12	0	—	160	19	—	—	179
12	3	—	157	26	—	—	183
12	6	—	154	32	—	—	186
12	9	—	151	38	—	—	189
13	0	—	148	44	—	—	192
13	3	—	145	50	—	—	195
13	6	—	141	57	—	—	198
13	9	—	138	63	—	—	201
14	0	—	135	70	—	—	205
14	3	—	132	76	—	—	208
14	6	—	129	82	—	—	211
14	9	—	126	88	—	—	214
15	0	—	123	94	—	—	217
15	3	—	119	101	—	—	220
15	6	—	116	107	—	—	223
15	9	—	113	114	—	—	227

RING COMBINATIONS

13½ Inch Lining — 3 Inch Wedge Brick 13½ x 4½ x 3, 13½ x 6 x 3 or 13½ x 9 x 3 Inch – Continued

Diam. Inside Brickwork		Number Required Per Ring					
Ft	In	No. 3 Wedge	No. 2 Wedge	No. 1 Wedge	No. 1-X Wedge	Straight	Total
16	0	—	110	120	—	—	230
16	3	—	107	126	—	—	233
16	6	—	104	132	—	—	236
16	9	—	101	138	—	—	239
17	0	—	97	145	—	—	242
17	3	—	94	151	—	—	245
17	6	—	92	157	—	—	249
17	9	—	88	164	—	—	252
18	0	—	85	170	—	—	255
18	3	—	82	176	—	—	258
18	6	—	79	182	—	—	261
18	9	—	75	189	—	—	264
19	0	—	72	195	—	—	267
19	3	—	70	201	—	—	271
19	6	—	66	208	—	—	274
19	9	—	63	214	—	—	277
20	0	—	60	220	—	—	280
20	3	—	57	226	—	—	283
20	6	—	53	233	—	—	286
20	9	—	50	239	—	—	289
21	0	—	48	245	—	—	293
21	3	—	44	252	—	—	296
21	6	—	41	258	—	—	299
21	9	—	38	264	—	—	302
22	0	—	35	270	—	—	305
22	3	—	31	277	—	—	308
22	6	—	28	283	—	—	311
22	9	—	26	289	—	—	315
23	0	—	22	296	—	—	318
23	3	—	19	302	—	—	321
23	6	—	16	308	—	—	324
23	9	—	13	314	—	—	327
24	0	—	9	321	—	—	330
24	3	—	6	327	—	—	333
24	6	—	4	333	—	—	337
24	9	—	—	340	—	—	340
25	0	—	—	336	7	—	343
25	3	—	—	333	13	—	346
25	6	—	—	330	19	—	349
25	9	—	—	327	25	—	352
26	0	—	—	324	31	—	355
26	3	—	—	321	38	—	359
26	6	—	—	318	44	—	362
26	9	—	—	314	51	—	365
27	0	—	—	311	57	—	368
27	3	—	—	308	63	—	371
27	6	—	—	305	69	—	374
27	9	—	—	302	75	—	377

13½ Inch Lining — 3 Inch Wedge Brick 13½ x 4½ x 3, 13½ x 6 x 3 or 13½ x 9 x 3 Inch – Continued

Diam. Inside Brickwork		Number Required Per Ring					
Ft	In	No. 3 Wedge	No. 2 Wedge	No. 1 Wedge	No. 1-X Wedge	Straight	Total
28	0	—	—	299	82	—	381
28	3	—	—	296	88	—	384
28	6	—	—	292	95	—	387
28	9	—	—	289	101	—	390
29	0	—	—	286	107	—	393
29	3	—	—	283	113	—	396
29	6	—	—	280	119	—	399
29	9	—	—	277	126	—	403
30	0	—	—	274	132	—	406
30	3	—	—	270	139	—	409
30	6	—	—	267	145	—	412
30	9	—	—	264	151	—	415
31	0	—	—	261	157	—	418
31	3	—	—	258	163	—	421
31	6	—	—	255	170	—	425
31	9	—	—	252	176	—	428
32	0	—	—	248	183	—	431
32	3	—	—	245	189	—	434
32	6	—	—	242	195	—	437
32	9	—	—	239	201	—	440
33	0	—	—	236	207	—	443
33	3	—	—	233	214	—	447
33	6	—	—	230	220	—	450
33	9	—	—	227	226	—	453
34	0	—	—	223	233	—	456
34	3	—	—	220	239	—	459
34	6	—	—	217	245	—	462
34	9	—	—	214	251	—	465
35	0	—	—	210	258	—	468
35	3	—	—	208	264	—	472
35	6	—	—	205	270	—	475
35	9	—	—	201	277	—	478
36	0	—	—	198	283	—	481
36	3	—	—	195	289	—	484
36	6	—	—	192	295	—	487
36	9	—	—	188	302	—	490
37	0	—	—	186	308	—	494
37	3	—	—	183	314	—	497
37	6	—	—	179	321	—	500
37	9	—	—	176	327	—	503
38	0	—	—	173	333	—	506
38	3	—	—	170	339	—	509
38	6	—	—	166	346	—	512
38	9	—	—	164	352	—	516
39	0	—	—	161	358	—	519
39	3	—	—	157	365	—	522
39	6	—	—	154	371	—	525
39	9	—	—	151	377	—	528

RING COMBINATIONS

13½ Inch Lining — 3 Inch Wedge Brick
13½ x 4½ x 3, 13½ x 6 x 3 or
13½ x 9 x 3 Inch – Continued

Diam. Inside Brickwork		Number Required Per Ring					
Ft	In	No. 3 Wedge	No. 2 Wedge	No. 1 Wedge	No. 1-X Wedge	Straight	Total
40	0	—	—	148	383	—	531
40	3	—	—	144	390	—	534
40	6	—	—	142	396	—	538
40	9	—	—	139	402	—	541
41	0	—	—	135	409	—	544
41	3	—	—	132	415	—	547
41	6	—	—	129	421	—	550
41	9	—	—	126	427	—	553
42	0	—	—	122	434	—	556
42	3	—	—	120	440	—	560
42	6	—	—	117	446	—	563
42	9	—	—	113	453	—	566
43	0	—	—	110	459	—	569
43	3	—	—	107	465	—	572
43	6	—	—	104	471	—	575
43	9	—	—	101	477	—	578
44	0	—	—	98	484	—	582
44	3	—	—	95	490	—	585
44	6	—	—	91	497	—	588
44	9	—	—	88	503	—	591
45	0	—	—	85	509	—	594
45	3	—	—	82	515	—	597
45	6	—	—	79	521	—	600
45	9	—	—	76	528	—	604
46	0	—	—	73	534	—	607
46	3	—	—	69	541	—	610
46	6	—	—	66	547	—	613
46	9	—	—	63	553	—	616
47	0	—	—	60	559	—	619
47	3	—	—	57	565	—	622
47	6	—	—	54	572	—	626
47	9	—	—	51	578	—	629
48	0	—	—	47	585	—	632
48	3	—	—	44	591	—	635
48	6	—	—	41	597	—	638
48	9	—	—	38	603	—	641
49	0	—	—	35	609	—	644
49	3	—	—	32	616	—	648
49	6	—	—	29	622	—	651
49	9	—	—	25	629	—	654
50	0	—	—	22	635	—	657
50	3	—	—	19	641	—	660
50	6	—	—	16	647	—	663
50	9	—	—	13	653	—	666
51	0	—	—	10	660	—	670
51	3	—	—	7	666	—	673
51	6	—	—	3	673	—	676
51	9	—	—	—	679	—	679

13½ Inch Lining — 3 Inch Key Brick
13½ x 6 x 3 Inch

Diam. Inside Brickwork		Number Required Per Ring				
Ft	In	No. 3 Key	No. 2 Key	No. 1 Key	Straight	Total
2	3	29	—	—	—	29
2	4	28	1	—	—	29
2	6	26	4	—	—	30
2	8	25	6	—	—	31
2	10	24	8	—	—	32
3	0	23	10	—	—	33
3	2	21	13	—	—	34
3	4	20	15	—	—	35
3	6	19	18	—	—	37
3	8	18	20	—	—	38
3	10	17	22	—	—	39
4	0	16	24	—	—	40
4	2	14	27	—	—	41
4	4	13	29	—	—	42
4	6	12	31	—	—	43
4	8	11	33	—	—	44
4	10	9	36	—	—	45
5	0	8	38	—	—	46
5	2	7	40	—	—	47
5	4	6	42	—	—	48
5	6	4	45	—	—	49
5	8	3	47	—	—	50
5	10	2	49	—	—	51
6	0	—	52	—	—	52
6	2	—	51	2	—	53
6	4	—	49	5	—	54
6	6	—	48	7	—	55
6	8	—	46	10	—	56
6	10	—	44	13	—	57
7	0	—	43	16	—	59
7	2	—	41	19	—	60
7	4	—	40	21	—	61
7	6	—	38	24	—	62
7	8	—	36	27	—	63
7	10	—	35	29	—	64
8	0	—	33	32	—	65
8	2	—	31	35	—	66
8	4	—	30	37	—	67
8	6	—	28	40	—	68
8	8	—	26	43	—	69
8	10	—	24	46	—	70
9	0	—	23	48	—	71
9	2	—	21	51	—	72
9	4	—	19	54	—	73
9	6	—	18	56	—	74
9	8	—	16	59	—	75
9	10	—	14	62	—	76
10	0	—	13	64	—	77
10	2	—	11	67	—	78
10	4	—	9	70	—	79
10	6	—	8	73	—	81
10	8	—	6	76	—	82
10	10	—	5	78	—	83

*NOTE: For brickwork of inside diameters less than 6 feet, involving the use of 13½ x 6 inch No. 3 Keys which have a very sharp taper, appreciable cutting may be necessary in some cases to secure the best bricklaying fit.

RING COMBINATIONS

13½ Inch Lining — 3 Inch Key Brick
13½ x 6 x 3 Inch — Continued

Diam. Inside Brickwork		Number Required Per Ring				
Ft	In	No. 3 Key	No. 2 Key	No. 1 Key	Straight	Total
11	0	—	3	81	—	84
11	2	—	1	84	—	85
11	3	—	—	85	—	85
11	6	—	—	85	2	87
12	0	—	—	85	5	90
12	6	—	—	85	8	93
13	0	—	—	85	11	96
13	6	—	—	85	14	99
14	0	—	—	85	18	103
14	6	—	—	85	21	106
15	0	—	—	85	24	109
15	6	—	—	85	27	112
16	0	—	—	85	30	115
16	6	—	—	85	33	118
17	0	—	—	85	36	121
17	6	—	—	85	39	124
18	0	—	—	85	43	128
18	6	—	—	85	46	131
19	0	—	—	85	49	134
19	6	—	—	85	52	137
20	0	—	—	85	55	140
20	6	—	—	85	58	143
21	0	—	—	85	61	146
21	6	—	—	85	65	150
22	0	—	—	85	68	153
22	6	—	—	85	71	156
23	0	—	—	85	74	159
23	6	—	—	85	77	162
24	0	—	—	85	80	165
24	6	—	—	85	83	168
25	0	—	—	85	87	172
25	6	—	—	85	90	175
26	0	—	—	85	93	178
26	6	—	—	85	96	181
27	0	—	—	85	99	184
27	6	—	—	85	102	187
28	0	—	—	85	105	190
28	6	—	—	85	109	194
29	0	—	—	85	112	197
29	6	—	—	85	115	200
30	0	—	—	85	118	203
30	6	—	—	85	121	206
31	0	—	—	85	124	209
31	6	—	—	85	127	212
32	0	—	—	85	131	216
33	0	—	—	85	137	222
34	0	—	—	85	143	228
35	0	—	—	85	149	234
36	0	—	—	85	156	241
37	0	—	—	85	162	247
38	0	—	—	85	168	253
39	0	—	—	85	175	260
40	0	—	—	85	181	266

15 Inch Lining — 3 Inch Wedge Brick
15 x 6 x 3 or 15 x 9 x 3 Inch

Diam. Inside Brickwork		Number Required Per Ring			
Ft	In	No. 3 Wedge	No.2 Wedge	No.1 Wedge	Total
5	0	95	—	—	95
5	1	94	2	—	96
5	3	91	7	—	98
5	6	88	13	—	101
5	9	85	19	—	104
6	0	82	25	—	107
6	3	79	31	—	110
6	6	75	38	—	113
6	9	73	44	—	117
7	0	69	51	—	120
7	3	66	57	—	123
7	6	63	63	—	126
7	9	60	69	—	129
8	0	57	75	—	132
8	3	53	82	—	135
8	6	51	88	—	139
8	9	47	95	—	142
9	0	44	101	—	145
9	3	41	107	—	148
9	6	38	113	—	151
9	9	35	119	—	154
10	0	31	126	—	157
10	3	29	132	—	161
10	6	25	139	—	164
10	9	22	145	—	167
11	0	19	151	—	170
11	3	16	157	—	173
11	6	13	163	—	176
11	9	9	170	—	179
12	0	7	176	—	183
12	3	3	183	—	186
12	6	—	189	—	189
12	9	—	186	6	192
13	0	—	182	13	195
13	3	—	179	19	198
13	6	—	176	25	201
13	9	—	173	32	205
14	0	—	170	38	208
14	3	—	167	44	211
14	6	—	164	50	214
14	9	—	160	57	217
15	0	—	157	63	220
15	3	—	154	69	223
15	6	—	151	76	227
15	9	—	148	82	230
16	0	—	145	88	233
16	3	—	142	94	236
16	6	—	138	101	239
16	9	—	135	107	242

RING COMBINATIONS

15 Inch Lining — 3 Inch Wedge Brick
15 x 6 x 3 or 15 x 9 x 3 Inch — Continued

Diam. Inside Brickwork		Number Required Per Ring			
Ft	In	No. 2 Wedge	No. 1 Wedge	No. 1-X Wedge	Total
17	0	132	113	—	245
17	3	129	120	—	249
17	6	126	126	—	252
17	9	123	132	—	255
18	0	120	138	—	258
18	3	116	145	—	261
18	6	113	151	—	264
18	9	110	157	—	267
19	0	107	164	—	271
19	3	104	170	—	274
19	6	101	176	—	277
19	9	98	182	—	280
20	0	94	189	—	283
20	3	91	195	—	286
20	6	88	201	—	289
20	9	85	208	—	293
21	0	82	214	—	296
21	3	79	220	—	299
21	6	76	226	—	302
21	9	72	233	—	305
22	0	69	239	—	308
22	3	66	245	—	311
22	6	63	252	—	315
22	9	60	258	—	318
23	0	57	264	—	321
23	3	54	270	—	324
23	6	50	277	—	327
23	9	47	283	—	330
24	0	44	289	—	333
24	3	41	296	—	337
24	6	38	302	—	340
24	9	35	308	—	343
25	0	32	314	—	346
25	3	28	321	—	349
25	6	25	327	—	352
25	9	22	333	—	355
26	0	19	340	—	359
26	3	16	346	—	362
26	6	13	352	—	365
26	9	10	358	—	368
27	0	6	365	—	371
27	3	3	371	—	374
27	6	—	377	—	377
27	9	—	374	7	381
28	0	—	371	13	384
28	3	—	368	19	387
28	6	—	365	25	390
28	9	—	361	32	393

15 Inch Lining — 3 Inch Wedge Brick
15 x 6 x 3 or 15 x 9 x 3 Inch — Continued

Diam. Inside Brickwork		Number Required Per Ring		
Ft	In	No. 1 Wedge	No. 1-X Wedge	Total
29	0	358	38	396
29	3	355	44	399
29	6	352	51	403
29	9	349	57	406
30	0	346	63	409
30	3	343	69	412
30	6	339	76	415
30	9	336	82	418
31	0	333	88	421
31	3	330	95	425
31	6	327	101	428
31	9	324	107	431
32	0	321	113	434
32	3	317	120	437
32	6	314	126	440
32	9	311	132	443
33	0	308	139	447
33	3	305	145	450
33	6	302	151	453
33	9	299	157	456
34	0	295	164	459
34	3	292	170	462
34	6	289	176	465
34	9	286	182	468
35	0	283	189	472
35	3	280	195	475
35	6	277	201	478
35	9	273	208	481
36	0	270	214	484
36	3	267	220	487
36	6	264	226	490
36	9	261	233	494
37	0	258	239	497
37	3	255	245	500
37	6	252	251	503
37	9	248	258	506
38	0	245	264	509
38	3	242	270	512
38	6	239	277	516
38	9	236	283	519
39	0	233	289	522
39	3	230	295	525
39	6	226	302	528
39	9	223	308	531
40	0	220	314	534
40	3	217	321	538
40	6	214	327	541
40	9	211	333	544
41	0	208	339	547
41	3	204	346	550
41	6	201	352	553
41	9	198	358	556

RING COMBINATIONS

15 Inch Lining — 3 Inch Wedge Brick
15 x 6 x 3 or 15 x 9 x 3 Inch — Continued

Diam. Inside Brickwork		Number Required Per Ring			
Ft	In	No. 1 Wedge	No. 1-X Wedge	Straight	Total
42	0	195	365	—	560
42	3	192	371	—	563
42	6	189	377	—	566
42	9	186	383	—	569
43	0	182	390	—	572
43	3	179	396	—	575
43	6	176	402	—	578
43	9	173	409	—	582
44	0	170	415	—	585
44	3	167	421	—	588
44	6	164	427	—	591
44	9	160	434	—	594
45	0	157	440	—	597
45	3	154	446	—	600
45	6	151	453	—	604
45	9	148	459	—	607
46	0	145	465	—	610
46	3	142	471	—	613
46	6	138	478	—	616
46	9	135	484	—	619
47	0	132	490	—	622
47	3	129	497	—	626
47	6	126	503	—	629
47	9	123	509	—	632
48	0	120	515	—	635
48	3	116	522	—	638
48	6	113	528	—	641
48	9	110	534	—	644
49	0	107	541	—	648
49	3	104	547	—	651
49	6	101	553	—	654
49	9	98	559	—	657
50	0	94	566	—	660
50	3	91	572	—	663
50	6	88	578	—	666
50	9	85	585	—	670
51	0	82	591	—	673
51	6	76	603	—	679
52	0	69	616	—	685
52	6	63	629	—	692
53	0	57	641	—	698
53	6	50	654	—	704
54	0	44	666	—	710
54	6	38	679	—	717
55	0	32	691	—	723
55	6	25	704	—	729
56	0	19	717	—	736
56	6	13	729	—	742
57	0	6	742	—	748
57	6	—	754	—	754
58	0	—	754	7	761
58	6	—	754	13	767

18 Inch Lining — 3 Inch Wedge Brick
18 x 6 x 3 or 18 x 9 x 3 Inch

Diam. Inside Brickwork		Number Required Per Ring			
Ft	In	No. 3 Wedge	No. 2 Wedge	No. 1 Wedge	Total
6	0	113	—	—	113
6	1	112	3	—	115
6	2	111	5	—	116
6	3	110	7	—	117
6	6	107	13	—	120
6	9	104	19	—	123
7	0	101	25	—	126
7	3	97	32	—	129
7	6	94	38	—	132
7	9	91	44	—	135
8	0	88	51	—	139
8	3	85	57	—	142
8	6	82	63	—	145
8	9	79	69	—	148
9	0	76	75	—	151
9	3	72	82	—	154
9	6	69	88	—	157
9	9	66	95	—	161
10	0	63	101	—	164
10	3	60	107	—	167
10	6	57	113	—	170
10	9	54	119	—	173
11	0	50	126	—	176
11	3	47	132	—	179
11	6	44	139	—	183
11	9	41	145	—	186
12	0	38	151	—	189
12	3	35	157	—	192
12	6	32	163	—	195
12	9	28	170	—	198
13	0	25	176	—	201
13	3	22	183	—	205
13	6	19	189	—	208
13	9	16	195	—	211
14	0	13	201	—	214
14	3	10	207	—	217
14	6	6	214	—	220
14	9	3	220	—	223
15	0	—	227	—	227
15	3	—	223	7	230
15	6	—	220	13	233
15	9	—	217	19	236
16	0	—	214	25	239
16	3	—	211	31	242
16	6	—	207	38	245
16	9	—	205	44	249
17	0	—	201	51	252
17	3	—	198	57	255
17	6	—	195	63	258
17	9	—	192	69	261

RING COMBINATIONS

18 Inch Lining — 3 Inch Wedge Brick
18 x 6 x 3 or 18 x 9 x 3 Inch — Continued

Diam. Inside Brickwork		Number Required Per Ring			
Ft	In	No. 2 Wedge	No. 1 Wedge	No. 1-X Wedge	Total
18	0	189	75	—	264
18	3	185	82	—	267
18	6	183	88	—	271
18	9	179	95	—	274
19	0	176	101	—	277
19	3	173	107	—	280
19	6	170	113	—	283
19	9	167	119	—	286
20	0	163	126	—	289
20	3	161	132	—	293
20	6	157	139	—	296
20	9	154	145	—	299
21	0	151	151	—	302
21	3	148	157	—	305
21	6	145	163	—	308
21	9	141	170	—	311
22	0	139	176	—	315
22	3	135	183	—	318
22	6	132	189	—	321
22	9	129	195	—	324
23	0	126	201	—	327
23	3	123	207	—	330
23	6	119	214	—	333
23	9	117	220	—	337
24	0	113	227	—	340
24	3	110	233	—	343
24	6	107	239	—	346
24	9	104	245	—	349
25	0	101	251	—	352
25	3	97	258	—	355
25	6	95	264	—	359
25	9	91	271	—	362
26	0	88	277	—	365
26	3	85	283	—	368
26	6	82	289	—	371
26	9	79	295	—	374
27	0	75	302	—	377
27	3	73	308	—	381
27	6	69	315	—	384
27	9	66	321	—	387
28	0	63	327	—	390
28	3	60	333	—	393
28	6	57	339	—	396
28	9	53	346	—	399
29	0	51	352	—	403
29	3	47	359	—	406
29	6	44	365	—	409
29	9	41	371	—	412

18 Inch Lining — 3 Inch Wedge Brick
18 x 6 x 3 or 18 x 9 x 3 Inch — Continued

Diam. Inside Brickwork		Number Required Per Ring			
Ft	In	No. 2 Wedge	No. 1 Wedge	No. 1-X Wedge	Total
30	0	38	377	—	415
30	3	35	383	—	418
30	6	31	390	—	421
30	9	29	396	—	425
31	0	26	402	—	428
31	3	22	409	—	431
31	6	19	415	—	434
31	9	16	421	—	437
32	0	13	427	—	440
32	3	9	434	—	443
32	6	7	440	—	447
32	9	4	446	—	450
33	0	—	453	—	453
33	3	—	449	7	456
33	6	—	446	13	459
33	9	—	443	19	462
34	0	—	440	25	465
34	3	—	437	31	468
34	6	—	434	38	472
34	9	—	431	44	475
35	0	—	427	51	478
35	3	—	424	57	481
35	6	—	421	63	484
35	9	—	418	69	487
36	0	—	415	75	490
36	3	—	412	82	494
36	6	—	409	88	497
36	9	—	406	94	500
37	0	—	402	101	503
37	3	—	399	107	506
37	6	—	396	113	509
37	9	—	393	119	512
38	0	—	390	126	516
38	3	—	387	132	519
38	6	—	384	138	522
38	9	—	380	145	525
39	0	—	377	151	528
39	3	—	374	157	531
39	6	—	371	163	534
39	9	—	368	170	538
40	0	—	365	176	541
40	3	—	362	182	544
40	6	—	358	189	547
40	9	—	355	195	550
41	0	—	352	201	553
41	3	—	349	207	556
41	6	—	346	214	560
41	9	—	343	220	563
42	0	—	340	226	566
42	3	—	336	233	569
42	6	—	333	239	572
42	9	—	330	245	575

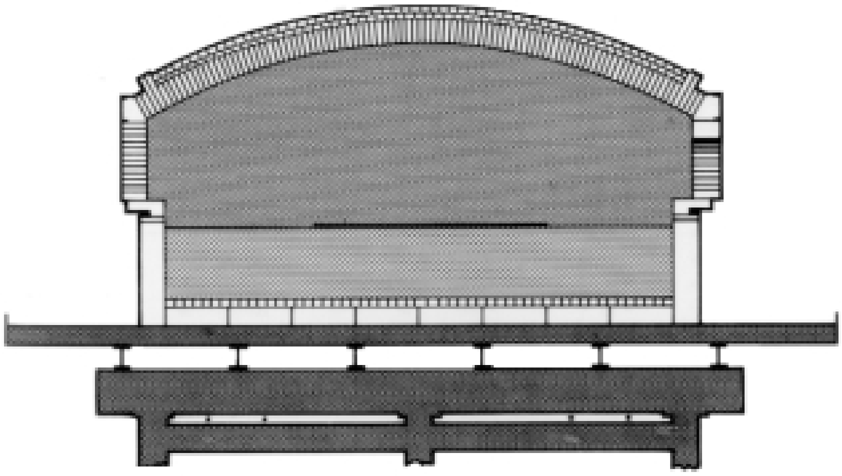
BRICK COMBINATIONS REQUIRED FOR ARCHES

The following tables are useful in estimating the quantities of brick required for the construction of arches. These tables give the combinations of brick sizes required for arches of given spans and rises.

In calculating the tables, no allowance was made for mortar or expansion joints or for size deviations of the brick. Fractional parts equal to or greater than one tenth of a brick were counted as an entire brick. For these reasons, the number of brick required for an arch, as given in the tables, may be slightly in excess of the number actually required.

In laying an arch course of brick, it is often necessary to cut one or two pieces, and in some instances several pieces, to complete the course.

For the brick combinations required for arches not included in the following tables, or to determine the dimensions or other numerical characteristics of arches, refer to the arch formulas found on page UR - 28, which detail arch calculations.



ARCH COMBINATIONS

4 1/2 Inch Arch Thickness — 3 Inch Arch Brick
9 x 4 1/2 x 3 or 13 1/2 x 4 1/2 x 3 Inch
2 Inch Rise Per Foot of Span

Span		Rise		Inside Radius		Number Required Per Course				
Ft	In	Ft	In	Ft	In	No. 3 Arch	No. 2 Arch	No. 1 Arch	Straight	Total
1	0		2		10	6	1	—	—	7
1	1		2 5/32		10 27/32	5	2	—	—	7
1	2		2 11/32		11 21/32	5	2	—	—	7
1	3		2 1/2	1	0 1/2	5	3	—	—	8
1	4		2 21/32	1	1 11/32	4	4	—	—	8
1	5		2 27/32	1	2 5/32	4	4	—	—	8
1	6		3	1	3	4	5	—	—	9
1	7		3 5/32	1	3 27/32	3	6	—	—	9
1	8		3 11/32	1	4 21/32	2	7	—	—	9
1	9		3 1/2	1	5 1/2	2	8	—	—	10
1	10		3 21/32	1	6 11/32	2	8	—	—	10
1	11		3 27/32	1	7 5/32	2	9	—	—	11
2	0		4	1	8	1	10	—	—	11
2	1		4 5/32	1	8 27/32	1	10	—	—	11
2	2		4 11/32	1	9 21/32	1	11	—	—	12
2	3		4 1/2	1	10 1/2	—	12	—	—	12
2	4		4 21/32	1	11 11/32	—	11	1	—	12
2	5		4 27/32	2	0 5/32	—	11	2	—	13
2	6		5	2	1	—	11	2	—	13
2	7		5 5/32	2	1 27/32	—	10	3	—	13
2	8		5 11/32	2	2 21/32	—	10	4	—	14
2	9		5 1/2	2	3 1/2	—	10	4	—	14
2	10		5 21/32	2	4 11/32	—	9	5	—	14
2	11		5 27/32	2	5 5/32	—	9	6	—	15
3	0		6	2	6	—	8	7	—	15
3	2		6 11/32	2	7 21/32	—	8	8	—	16
3	4		6 21/32	2	9 11/32	—	7	10	—	17
3	6		7	2	11	—	6	11	—	17
3	8		7 11/32	3	0 21/32	—	6	12	—	18
3	10		7 21/32	3	2 11/32	—	5	14	—	19
4	0		8	3	4	—	4	15	—	19
4	2		8 11/32	3	5 21/32	—	3	17	—	20
4	4		8 21/32	3	7 11/32	—	3	18	—	21
4	6		9	3	9	—	2	20	—	22
4	8		9 11/32	3	10 21/32	—	1	21	—	22
4	10		9 21/32	4	0 11/32	—	1	22	—	23
4	11		9 27/32	4	1 5/32	—	—	23	—	23
5	0		10	4	2	—	—	23	1	24
5	6		11	4	7	—	—	23	3	26
6	0	1	0	5	0	—	—	23	5	28
6	6	1	1	5	5	—	—	23	7	30

4 1/2 Inch Arch Thickness — 3 Inch Arch Brick
9 x 4 1/2 x 3 or 13 1/2 x 4 1/2 x 3 Inch
1.608 Inch (1 19/32 Inch) Rise Per Foot of Span
(60° Central Angle)

Span		Rise		Inside Radius		Number Required Per Course				
Ft	In	Ft	In	Ft	In	No. 3 Arch	No. 2 Arch	No. 1 Arch	Straight	Total
1	0		1 19/32	1	0	4	2	—	—	6
1	1		1 3/4	1	1	4	3	—	—	7
1	2		1 7/8	1	2	3	4	—	—	7
1	3		2	1	3	3	4	—	—	7
1	4		2 5/32	1	4	3	5	—	—	8
1	5		2 9/32	1	5	2	6	—	—	8
1	6		2 13/32	1	6	2	6	—	—	8
1	7		2 17/32	1	7	2	7	—	—	9
1	8		2 11/16	1	8	1	8	—	—	9
1	9		2 13/16	1	9	1	8	—	—	9
1	10		2 15/16	1	10	1	9	—	—	10
1	11		3 3/32	1	11	—	9	1	—	10
2	0		3 7/32	2	0	—	9	1	—	10
2	1		3 11/32	2	1	—	9	2	—	11
2	2		3 15/32	2	2	—	8	3	—	11
2	3		3 5/8	2	3	—	8	3	—	11
2	4		3 3/4	2	4	—	8	4	—	12
2	5		3 7/8	2	5	—	7	5	—	12
2	6		4 1/32	2	6	—	7	5	—	12
2	7		4 5/32	2	7	—	7	6	—	13
2	8		4 9/32	2	8	—	6	7	—	13
2	9		4 7/16	2	9	—	6	7	—	13
2	10		4 9/16	2	10	—	6	8	—	14
2	11		4 11/16	2	11	—	5	9	—	14
3	0		4 13/16	3	0	—	5	10	—	15
3	1		4 31/32	3	1	—	5	10	—	15
3	2		5 3/32	3	2	—	4	11	—	15
3	3		5 7/32	3	3	—	4	12	—	16
3	4		5 11/32	3	4	—	4	12	—	16
3	5		5 1/2	3	5	—	3	13	—	16
3	6		5 5/8	3	6	—	3	14	—	17
3	7		5 3/4	3	7	—	2	15	—	17
3	8		5 29/32	3	8	—	2	15	—	17
3	9		6 1/32	3	9	—	2	16	—	18
3	10		6 5/32	3	10	—	1	17	—	18
3	11		6 9/32	3	11	—	1	17	—	18
4	0		6 7/16	4	0	—	1	18	—	19
4	1		6 9/16	4	1	—	—	19	—	19
4	2		6 11/16	4	2	—	—	19	—	19
4	3		6 27/32	4	3	—	—	19	1	20
4	6		7 1/4	4	6	—	—	19	2	21
5	0		8 1/32	5	0	—	—	19	4	23
5	6		8 27/32	5	6	—	—	19	6	25
6	0		9 21/32	6	0	—	—	19	8	27
6	6		10 7/16	6	6	—	—	19	10	29

ARCH COMBINATIONS

4 1/2 Inch Arch Thickness — 3 Inch Arch Brick
9 x 4 1/2 x 3 or 13 1/2 x 4 1/2 x 3 Inch
1 1/2 Inch Rise Per Foot of Span

Span		Rise		Inside Radius		Number Required Per Course				
Ft	In	Ft	In	Ft	In	No. 3 Arch	No. 2 Arch	No. 1 Arch	Straight	Total
1	0		1 1/2	1	0 3/4	3	3	—	—	6
1	1		1 5/8	1	1 13/16	3	3	—	—	6
1	2		1 3/4	1	2 7/8	3	4	—	—	7
1	3		1 7/8	1	3 15/16	2	5	—	—	7
1	4		2	1	5	2	5	—	—	7
1	5		2 1/8	1	6 1/16	2	6	—	—	8
1	6		2 1/4	1	7 1/8	1	7	—	—	8
1	7		2 3/8	1	8 3/16	1	7	—	—	8
1	8		2 1/2	1	9 1/4	1	8	—	—	9
1	9		2 5/8	1	10 5/16	—	9	—	—	9
1	10		2 3/4	1	11 3/8	—	9	1	—	10
1	11		2 7/8	2	0 7/16	—	8	2	—	10
2	0		3	2	1 1/2	—	8	2	—	10
2	1		3 1/8	2	2 9/16	—	8	3	—	11
2	2		3 1/4	2	3 5/8	—	7	4	—	11
2	3		3 3/8	2	4 11/16	—	7	4	—	11
2	4		3 1/2	2	5 3/4	—	7	5	—	12
2	5		3 5/8	2	6 3/16	—	6	6	—	12
2	6		3 3/4	2	7 7/8	—	6	6	—	12
2	7		3 7/8	2	8 15/16	—	6	7	—	13
2	8		4	2	10	—	5	8	—	13
2	9		4 1/8	2	11 1/16	—	5	8	—	13
2	10		4 1/4	3	0 1/8	—	5	9	—	14
2	11		4 3/8	3	1 3/16	—	4	10	—	14
3	0		4 1/2	3	2 1/4	—	4	10	—	14
3	1		4 5/8	3	3 5/16	—	4	11	—	15
3	2		4 3/4	3	4 3/8	—	3	12	—	15
3	3		4 7/8	3	5 7/16	—	3	12	—	15
3	4		5	3	6 1/2	—	3	13	—	16
3	5		5 1/8	3	7 9/16	—	2	14	—	16
3	6		5 1/4	3	8 5/8	—	2	14	—	16
3	7		5 3/8	3	9 11/16	—	2	15	—	17
3	8		5 1/2	3	10 3/4	—	1	16	—	17
3	9		5 5/8	3	11 13/16	—	—	17	—	17
3	10		5 3/4	4	0 7/8	—	—	18	—	18
3	11		5 7/8	4	1 15/16	—	—	18	—	18
4	0		6	4	3	—	—	18	1	19
4	3		6 3/8	4	6 3/16	—	—	18	2	20
4	6		6 3/4	4	9 3/8	—	—	18	3	21
4	9		7 1/8	5	0 9/16	—	—	18	4	22
5	0		7 1/2	5	3 3/4	—	—	18	5	23
5	3		7 7/8	5	6 15/16	—	—	18	6	24
5	6		8 1/4	5	10 1/8	—	—	18	7	25
5	9		8 5/8	6	1 5/16	—	—	18	8	26
6	0		9	6	4 1/2	—	—	18	9	27
6	6		9 3/4	6	10 7/8	—	—	18	11	29

4 1/2 Inch Arch Thickness — 3 Inch Arch Brick
9 x 4 1/2 x 3 or 13 1/2 x 4 1/2 x 3 Inch
2.302 Inch (2 5/16 Inch) Rise Per Foot of Span

Span		Rise		Inside Radius		Number Required Per Course				
Ft	In	Ft	In	Ft	In	No. 3 Arch	No. 2 Arch	No. 1 Arch	Straight	Total
1	0		2 5/16		8 31/32	7	—	—	—	7
1	1		2 1/2		9 23/32	6	1	—	—	7
1	2		2 11/16		10 15/32	6	2	—	—	8
1	3		2 7/8		11 7/32	6	2	—	—	8
1	4		3 1/16		11 31/32	5	3	—	—	8
1	5		3 1/4	1	0 23/32	5	4	—	—	9
1	6		3 15/32	1	1 15/32	5	4	—	—	9
1	7		3 21/32	1	2 3/16	4	6	—	—	10
1	8		3 27/32	1	2 15/16	4	6	—	—	10
1	9		4 1/32	1	3 11/16	3	7	—	—	10
1	10		4 7/32	1	4 7/16	3	8	—	—	11
1	11		4 13/32	1	5 3/16	3	8	—	—	11
2	0		4 19/32	1	5 15/16	2	9	—	—	11
2	1		4 25/32	1	6 11/16	2	10	—	—	12
2	2		5	1	7 7/16	2	10	—	—	12
2	3		5 3/16	1	8 3/16	1	11	—	—	12
2	4		5 3/8	1	8 15/16	1	12	—	—	13
2	6		5 3/4	1	10 7/16	—	14	—	—	14
2	8		6 1/8	1	11 29/32	—	13	1	—	14
2	10		6 17/32	2	1 13/32	—	12	3	—	15
3	0		6 29/32	2	2 29/32	—	11	5	—	16
3	2		7 9/32	2	4 13/32	—	10	6	—	16
3	4		7 11/16	2	5 29/32	—	10	7	—	17
3	6		8 1/16	2	7 13/32	—	9	9	—	18
3	8		8 7/16	2	8 7/8	—	8	11	—	19
3	10		8 13/16	2	10 3/8	—	7	12	—	19
4	0		9 7/32	2	11 7/8	—	7	13	—	20
4	2		9 19/32	3	1 3/8	—	6	15	—	21
4	4		9 31/32	3	2 7/8	—	6	16	—	22
4	6		10 3/8	3	4 3/8	—	5	17	—	22
4	8		10 3/4	3	5 27/32	—	4	19	—	23
4	10		11 1/8	3	7 11/32	—	3	21	—	24
5	0		11 1/2	3	8 27/32	—	3	22	—	25
5	2		11 29/32	3	10 11/32	—	2	23	—	25
5	4	1	0 9/32	3	11 27/32	—	1	25	—	26
5	6	1	0 21/32	4	1 11/32	—	—	27	—	27
5	8	1	1 1/16	4	2 13/16	—	—	27	—	27
5	10	1	1 7/16	4	4 5/16	—	—	27	1	28
6	0	1	1 13/16	4	5 13/16	—	—	27	2	29
6	6	1	2 31/32	4	10 5/16	—	—	27	4	31

ARCH COMBINATIONS

9 Inch Arch Thickness — 3 Inch Wedge Brick
9 x 4 1/2 x 3, 9 x 6 3/4 x 3 or 9 x 9 x 3 Inch
1 1/2 Inch Rise Per Foot of Span

Span		Rise		Inside Radius		Number Required Per Course			
Ft	In	Ft	In	Ft	In	No. 3 Wedge	No. 2 Wedge	No. 1 Wedge	Total
1	6		2 1/4	1	7 1/8	9	1	—	10
1	7		2 3/8	1	8 3/16	8	2	—	10
1	8		2 1/2	1	9 1/4	8	2	—	10
1	9		2 5/8	1	10 5/16	8	3	—	11
1	10		2 3/4	1	11 3/8	7	4	—	11
1	11		2 7/8	2	0 7/16	7	4	—	11
2	0		3	2	1 1/2	7	5	—	12
2	1		3 1/8	2	2 9/16	6	6	—	12
2	2		3 1/4	2	3 5/8	6	6	—	12
2	3		3 3/8	2	4 11/16	6	7	—	13
2	4		3 1/2	2	5 3/4	5	8	—	13
2	5		3 5/8	2	6 13/16	5	8	—	13
2	6		3 3/4	2	7 7/8	5	9	—	14
2	7		3 7/8	2	8 15/16	4	10	—	14
2	8		4	2	10	4	10	—	14
2	9		4 1/8	2	11 1/16	4	11	—	15
2	10		4 1/4	3	0 1/8	3	12	—	15
2	11		4 3/8	3	1 3/16	3	12	—	15
3	0		4 1/2	3	2 1/4	3	13	—	16
3	1		4 5/8	3	3 5/16	2	14	—	16
3	2		4 3/4	3	4 3/8	2	15	—	17
3	3		4 7/8	3	5 7/16	1	16	—	17
3	4		5	3	6 1/2	1	16	—	17
3	5		5 1/8	3	7 9/16	1	17	—	18
3	6		5 1/4	3	8 5/8	—	18	—	18
3	7		5 3/8	3	9 11/16	—	18	—	18
3	8		5 1/2	3	10 3/4	—	17	2	19
3	9		5 5/8	3	11 13/16	—	17	2	19
3	10		5 3/4	4	0 7/8	—	16	3	19
3	11		5 7/8	4	1 15/16	—	16	4	20
4	0		6	4	3	—	16	4	20
4	1		6 1/8	4	4 1/16	—	15	5	20
4	2		6 1/4	4	5 1/8	—	15	6	21
4	3		6 3/8	4	6 3/16	—	15	6	21
4	4		6 1/2	4	7 1/4	—	14	7	21
4	5		6 5/8	4	8 5/16	—	14	8	22
4	6		6 3/4	4	9 3/8	—	14	8	22
4	7		6 7/8	4	10 7/16	—	13	9	22
4	8		7	4	11 1/2	—	13	10	23
4	9		7 1/8	5	0 9/16	—	13	10	23
4	10		7 1/4	5	1 5/8	—	12	11	23
4	11		7 3/8	5	2 11/16	—	12	12	24
5	0		7 1/2	5	3 3/4	—	12	12	24
5	1		7 5/8	5	4 13/16	—	12	13	25
5	2		7 3/4	5	5 7/8	—	11	14	25
5	3		7 7/8	5	6 15/16	—	11	14	25
5	4		8	5	8	—	11	15	26
5	5		8 1/8	5	9 1/16	—	10	16	26

NOTE: This table can be used also for 13 1/2 x 9 x 3 inch arch brick by substituting
No. 1, 2, and 3 arch brick for the corresponding wedge brick.

9 Inch Arch Thickness — 3 Inch Wedge Brick
9 x 4 1/2 x 3, 9 x 6 3/4 x 3 or 9 x 9 x 3 Inch–Cont'd.
1 1/2 Inch Rise Per Foot of Span

Span		Rise		Inside Radius		Number Required Per Course			
Ft	In	Ft	In	Ft	In	No. 2 Wedge	No. 1 Wedge	Straight	Total
5	6		8 1/4	5	10 1/8	10	16	—	26
5	7		8 3/8	5	11 3/16	9	18	—	27
5	8		8 1/2	6	0 1/4	9	18	—	27
5	9		8 5/8	6	1 5/16	8	19	—	27
5	10		8 3/4	6	2 3/8	8	20	—	28
5	11		8 7/8	6	3 7/16	8	20	—	28
6	0		9	6	4 1/2	7	21	—	28
6	1		9 1/8	6	5 9/16	7	22	—	29
6	2		9 1/4	6	6 5/8	7	22	—	29
6	3		9 3/8	6	7 11/16	6	23	—	29
6	4		9 1/2	6	8 3/4	6	24	—	30
6	5		9 5/8	6	9 13/16	6	24	—	30
6	6		9 3/4	6	10 7/8	5	25	—	30
6	7		9 7/8	6	11 15/16	5	26	—	31
6	8		10	7	1	5	26	—	31
6	9		10 1/8	7	2 1/16	4	27	—	31
6	10		10 1/4	7	3 1/8	4	28	—	32
6	11		10 3/8	7	4 3/16	4	28	—	32
7	0		10 1/2	7	5 1/4	3	29	—	32
7	1		10 5/8	7	6 5/16	3	30	—	33
7	2		10 3/4	7	7 3/8	3	30	—	33
7	3		10 7/8	7	8 7/16	3	31	—	34
7	4		11	7	9 1/2	2	32	—	34
7	5		11 1/8	7	10 9/16	2	32	—	34
7	6		11 1/4	7	11 5/8	2	33	—	35
7	7		11 3/8	8	0 11/16	1	34	—	35
7	8		11 1/2	8	1 3/4	1	34	—	35
7	9		11 5/8	8	2 13/16	—	36	—	36
7	10		11 3/4	8	3 7/8	—	36	—	36
7	11		11 7/8	8	4 15/16	—	36	—	36
8	0	1	0	8	6	—	36	1	37
8	6	1	0 3/4	9	0 3/8	—	36	3	39
9	0	1	1 1/2	9	6 3/4	—	36	5	41
9	6	1	2 1/4	10	1 1/8	—	36	7	43
10	0	1	3	10	7 1/2	—	36	9	45
10	6	1	3 3/4	11	1 7/8	—	36	11	47
11	0	1	4 1/2	11	8 1/4	—	36	13	49
11	6	1	5 1/4	12	2 5/8	—	36	15	51
12	0	1	6	12	9	—	36	17	53
12	6	1	6 3/4	13	3 3/8	—	36	19	55
13	0	1	7 1/2	13	9 3/4	—	36	21	57
13	6	1	8 1/4	14	4 1/8	—	36	24	60
14	0	1	9	14	10 1/2	—	36	26	62
14	6	1	9 3/4	15	4 7/8	—	36	28	64
15	0	1	10 1/2	15	11 1/4	—	36	30	66

NOTE: This table can be used also for 13 1/2 x 9 x 3 inch arch brick by substituting
No. 1 and 2 arch brick for the corresponding wedge brick.

ARCH COMBINATIONS

9 Inch Arch Thickness — 3 Inch Wedge Brick 9 x 4 1/2 x 3, 9 x 6 3/4 x 3 or 9 x 9 x 3 Inch 1·608 Inch (1 19/32 Inch)Rise Per Foot of Span (60° Center Angle)

Span Ft	Span In	Rise Ft	Rise In	Inside Radius Ft	Inside Radius In	Number Required Per Course: No. 3 Wedge	No. 2 Wedge	No. 1 Wedge	Total
1	6		2 13/32	1	6	10	—	—	10
1	7		2 17/32	1	7	9	1	—	10
1	8		2 11/16	1	8	9	2	—	11
1	9		2 13/16	1	9	9	2	—	11
1	10		2 15/16	1	10	8	3	—	11
1	11		3 3/32	2	11	8	4	—	12
2	0		3 7/32	2	0	8	4	—	12
2	1		3 11/32	2	1	7	5	—	12
2	2		3 15/32	2	2	7	6	—	13
2	3		3 5/8	2	3	7	6	—	13
2	4		3 3/4	2	4	6	7	—	13
2	5		3 7/8	2	5	6	8	—	14
2	6		3 1/32	2	6	5	9	—	14
2	7		3 5/32	2	7	5	9	—	14
2	8		4 9/32	2	8	5	10	—	15
2	9		4 7/16	2	9	4	11	—	15
2	10		4 9/16	3	10	4	11	—	15
2	11		4 11/16	3	11	4	12	—	16
3	0		4 13/16	3	0	3	13	—	16
3	1		4 31/32	3	1	3	13	—	16
3	2		5 3/32	3	2	3	14	—	17
3	3		5 7/32	3	3	2	15	—	17
3	4		5 11/32	3	4	2	16	—	18
3	5		5 1/2	3	5	2	16	—	18
3	6		5 5/8	3	6	1	17	—	18
3	7		5 3/4	3	7	1	18	—	19
3	8		5 29/32	3	8	1	18	—	19
3	9		6 1/8	3	9	—	19	—	19
3	10		6 5/32	4	10	—	19	1	20
3	11		6 9/32	3	11	—	18	2	20
4	0		6 7/16	4	0	—	18	2	20
4	1		6 9/16	4	1	—	18	3	21
4	2		6 11/16	4	2	—	17	4	21
4	3		6 27/32	4	3	—	17	4	21
4	4		6 31/32	4	4	—	17	5	22
4	5		7 3/32	4	5	—	16	6	22
4	6		7 1/4	4	6	—	16	6	22
4	7		7 3/8	4	7	—	16	7	23
4	8		7 1/2	4	8	—	15	8	23
4	9		7 5/8	5	9	—	15	8	23
4	10		7 25/32	5	10	—	15	9	24
4	11		7 29/32	5	11	—	14	10	24
5	0		8 1/32	5	0	—	14	10	24
5	1		8 3/16	5	1	—	14	11	25
5	2		8 5/16	5	2	—	13	12	25
5	3		8 7/16	5	3	—	13	13	26
5	4		8 9/16	5	4	—	12	14	26
5	5		8 23/32	5	5	—	12	14	26

NOTE: This table can be used also for 13 1/2 x 9 x 3 inch arch brick by substituting No. 1, 2, and 3 arch brick for the corresponding wedge brick.

9 Inch Arch Thickness — 3 Inch Wedge Brick 9 x 4 1/2 x 3, 9 x 6 3/4 x 3 or 9 x 9 x 3 Inch–Cont'd. 1·608 Inch (1 19/32 Inch)Rise Per Foot of Span (60° Center Angle)

Span Ft	Span In	Rise Ft	Rise In	Inside Radius Ft	Inside Radius In	Number Required Per Course: No. 2 Wedge	No. 1 Wedge	Straight	Total
5	6		8 27/32	5	6	12	15	—	27
5	7		8 31/32	5	7	11	16	—	27
5	8		9 1/8	6	8	11	16	—	27
5	9		9 1/4	6	9	11	17	—	28
5	10		9 3/8	6	10	10	18	—	28
5	11		9 1/2	6	11	10	18	—	28
6	0		9 21/32	6	0	10	19	—	29
6	1		9 25/32	6	1	9	20	—	29
6	2		9 29/32	6	2	9	20	—	29
6	3		10 1/16	6	3	9	21	—	30
6	4		10 3/16	6	4	8	22	—	30
6	5		10 5/16	6	5	8	22	—	30
6	6		10 7/16	6	6	8	23	—	31
6	7		10 19/32	6	7	7	24	—	31
6	8		10 23/32	7	8	7	24	—	31
6	9		10 27/32	7	9	7	25	—	32
6	10		11	7	10	6	26	—	32
6	11		11 1/8	7	11	6	27	—	33
7	0		11 1/4	7	0	6	27	—	33
7	1		11 3/8	7	1	5	28	—	33
7	2		11 17/32	7	2	5	29	—	34
7	3		11 21/32	7	3	4	30	—	34
7	4		11 25/32	7	4	4	30	—	34
7	5		11 15/16	7	5	4	31	—	35
7	6	1	0 1/16	7	6	3	32	—	35
7	7	1	0 3/16	7	7	3	32	—	35
7	8	1	0 5/16	7	8	3	33	—	36
7	9	1	0 15/32	7	9	2	34	—	36
7	10	1	0 19/32	7	10	2	34	—	36
7	11	1	0 23/32	7	11	2	35	—	37
8	0	1	0 7/8	8	0	1	36	—	37
8	1	1	1	8	1	1	36	—	37
8	2	1	1 1/8	8	2	1	37	—	38
8	3	1	1 1/4	8	3	—	38	—	38
8	6	1	1 21/32	8	6	—	38	1	39
9	0	1	2 15/32	9	0	—	38	3	41
9	6	1	3 9/16	9	6	—	38	5	43
10	0	1	4 1/16	10	0	—	38	7	45
10	6	1	4 7/8	10	6	—	38	10	48
11	0	1	5 11/16	11	0	—	38	12	50
11	6	1	6 1/2	11	6	—	38	14	52
12	0	1	7 9/32	12	0	—	38	16	54
12	6	1	8 3/32	12	6	—	38	18	56
13	0	1	8 29/32	13	0	—	38	20	58
13	6	1	9 11/16	13	6	—	38	22	60
14	0	1	10 1/2	14	0	—	38	24	62
14	6	1	11 5/16	14	6	—	38	26	64
15	0	2	0 1/8	15	0	—	38	28	66

NOTE: This table can be used also for 13 1/2 x 9 x 3 inch arch brick by substituting No. 1 and 2 arch brick for the corresponding wedge brick.

ARCH COMBINATIONS

9 Inch Arch Thickness — 3 Inch Wedge Brick
9 x 4 1/2 x 3, 9 x 6 3/4 x 3 or 9 x 9 x 3 Inch
2 Inch Rise Per Foot of Span

Span		Rise		Inside Radius		Number Required Per Course			
Ft	In	Ft	In	Ft	In	No. 3 Wedge	No. 2 Wedge	No. 1 Wedge	Total
1	10		3 21/32	1	6 11/32	12	—	—	12
1	11		3 27/32	1	7 5/32	11	1	—	12
2	0		4	1	8	11	2	—	13
2	1		4 5/32	1	8 27/32	10	3	—	13
2	2		4 11/32	1	9 21/32	10	4	—	14
2	3		4 1/2	1	10 1/2	10	4	—	14
2	4		4 21/32	1	11 11/32	9	5	—	14
2	5		4 27/32	2	0 5/32	9	6	—	15
2	6		5	2	1	9	6	—	15
2	7		5 5/32	2	1 27/32	8	7	—	15
2	8		5 11/32	2	2 21/32	8	8	—	16
2	9		5 1/2	2	3 1/2	8	8	—	16
2	10		5 21/32	2	4 11/32	7	9	—	16
2	11		5 27/32	2	5 5/32	7	10	—	17
3	0		6	2	6	7	10	—	17
3	1		6 5/32	2	6 27/32	6	11	—	17
3	2		6 11/32	2	7 21/32	6	12	—	18
3	3		6 1/2	2	8 1/2	5	13	—	18
3	4		6 21/32	2	9 11/32	5	14	—	19
3	5		6 27/32	2	10 5/32	5	14	—	19
3	6		7	2	11	4	15	—	19
3	7		7 5/32	2	11 27/32	4	16	—	20
3	8		7 11/32	3	0 21/32	4	16	—	20
3	9		7 1/2	3	1 1/2	3	17	—	20
3	10		7 21/32	3	2 11/32	3	18	—	21
3	11		7 27/32	3	3 5/32	3	18	—	21
4	0		8	3	4	2	19	—	21
4	1		8 5/32	3	4 27/32	2	20	—	22
4	2		8 11/32	3	5 21/32	2	20	—	22
4	3		8 1/2	3	6 1/2	1	21	—	22
4	4		8 21/32	3	7 11/32	1	22	—	23
4	5		8 27/32	3	8 5/32	1	22	—	23
4	6		9	3	9	—	24	—	24
4	7		9 5/32	3	9 27/32	—	23	1	24
4	8		9 11/32	3	10 21/32	—	23	1	24
4	9		9 1/2	3	11 1/2	—	22	3	25
4	10		9 21/32	4	0 11/32	—	22	3	25
4	11		9 27/32	4	1 5/32	—	21	4	25
5	0		10	4	2	—	21	5	26
5	1		10 5/32	4	2 27/32	—	21	5	26
5	2		10 11/32	4	3 21/32	—	20	6	26
5	3		10 1/2	4	4 1/2	—	20	7	27
5	4		10 21/32	4	5 11/32	—	20	7	27
5	5		10 27/32	4	6 5/32	—	19	8	27
5	6		11	4	7	—	19	9	28
5	7		11 5/32	4	7 27/32	—	19	9	28
5	8		11 11/32	4	8 21/32	—	19	10	29
5	9		11 1/2	4	9 1/2	—	18	11	29
5	10		11 21/32	4	10 11/32	—	18	11	29
5	11		11 27/32	4	11 5/32	—	17	13	30

NOTE: This table can be used also for 13 1/2 x 9 x 3 inch arch brick by substituting
No. 1, 2, and 3 arch brick for the corresponding wedge brick.

9 Inch Arch Thickness — 3 Inch Wedge Brick
9 x 4 1/2 x 3, 9 x 6 3/4 x 3 or 9 x 9 x 3 Inch–Cont'd.
2 Inch Rise Per Foot of Span

Span		Rise		Inside Radius		Number Required Per Course			
Ft	In	Ft	In	Ft	In	No. 2 Wedge	No. 1 Wedge	Straight	Total
6	0	1	0	5	0	17	13	—	30
6	1	1	0 5/32	5	0 27/32	16	14	—	30
6	2	1	0 11/32	5	1 21/32	16	15	—	31
6	3	1	0 1/2	5	2 1/2	16	15	—	31
6	4	1	0 21/32	5	3 11/32	15	16	—	31
6	5	1	0 27/32	5	4 5/32	15	17	—	32
6	6	1	1	5	5	15	17	—	32
6	7	1	1 5/32	5	5 27/32	15	18	—	33
6	8	1	1 11/32	5	6 21/32	14	19	—	33
6	9	1	1 1/2	5	7 1/2	14	19	—	33
6	10	1	1 21/32	5	8 11/32	14	20	—	34
6	11	1	1 27/32	5	9 5/32	13	21	—	34
7	0	1	2	5	10	13	21	—	34
7	1	1	2 5/32	5	10 27/32	12	23	—	35
7	2	1	2 11/32	5	11 21/32	12	23	—	35
7	3	1	2 1/2	6	0 1/2	11	24	—	35
7	4	1	2 21/32	6	1 11/32	11	25	—	36
7	5	1	2 27/32	6	2 5/32	11	25	—	36
7	6	1	3	6	3	10	26	—	36
7	7	1	3 5/32	6	3 27/32	10	27	—	37
7	8	1	3 11/32	6	4 21/32	10	27	—	37
7	9	1	3 1/2	6	5 1/2	10	28	—	38
7	10	1	3 21/32	6	6 11/32	9	29	—	38
7	11	1	3 27/32	6	7 5/32	9	29	—	38
8	0	1	4	6	8	9	30	—	39
8	1	1	4 5/32	6	8 27/32	8	31	—	39
8	2	1	4 11/32	6	9 21/32	8	31	—	39
8	3	1	4 1/2	6	10 1/2	7	33	—	40
8	4	1	4 21/32	6	11 11/32	7	33	—	40
8	5	1	4 27/32	7	0 5/32	6	34	—	40
8	6	1	5	7	1	6	35	—	41
8	7	1	5 5/32	7	1 27/32	6	35	—	41
8	8	1	5 11/32	7	2 21/32	5	36	—	41
8	9	1	5 1/2	7	3 1/2	5	37	—	42
8	10	1	5 21/32	7	4 11/32	5	37	—	42
8	11	1	5 27/32	7	5 5/32	5	38	—	43
9	0	1	6	7	6	4	39	—	43
9	2	1	6 11/32	7	7 21/32	4	40	—	44
9	4	1	6 21/32	7	9 11/32	3	41	—	44
9	6	1	7	7	11	2	43	—	45
9	8	1	7 11/32	8	0 21/32	1	45	—	46
9	10	1	7 21/32	8	2 11/32	—	46	—	46
10	0	1	8	8	4	—	47	—	47
10	6	1	9	8	9	—	47	2	49
11	0	1	10	9	2	—	47	4	51
12	0	2	0	10	0	—	47	9	56
13	0	2	2	10	10	—	47	13	60
14	0	2	4	11	8	—	47	17	64
15	0	2	6	12	6	—	47	22	69

NOTE: This table can be used also for 13 1/2 x 9 x 3 inch arch brick by substituting
No. 1 and 2 arch brick for the corresponding wedge brick.

ARCH COMBINATIONS

9 Inch Arch Thickness — 3 Inch Wedge Brick
9 x 4 1/2 x 3, 9 x 6 3/4 x 3 or 9 x 9 x 3 Inch
2.302 Inch (2 5/16 Inch) Rise Per Foot of Span

Span		Rise		Inside Radius		Number Required Per Course			
Ft	In	Ft	In	Ft	In	No. 3 Wedge	No. 2 Wedge	No. 1 Wedge	Total
2	0		4 19/32	1	5 15/16	14	—	—	14
2	1		4 25/32	1	6 11/16	13	1	—	14
2	2		5	1	7 7/16	13	1	—	14
2	3		5 3/16	1	8 3/16	12	3	—	15
2	4		5 3/8	1	8 15/16	12	3	—	15
2	5		5 9/16	1	9 11/16	11	4	—	15
2	6		5 3/4	1	10 7/16	11	5	—	16
2	7		5 15/16	1	11 5/32	11	5	—	16
2	8		6 1/8	1	11 29/32	10	6	—	16
2	9		6 11/32	2	0 21/32	10	7	—	17
2	10		6 17/32	2	1 13/32	10	7	—	17
2	11		6 23/32	2	2 5/32	10	8	—	18
3	0		6 29/32	2	2 29/32	9	9	—	18
3	1		7 3/32	2	3 21/32	9	9	—	18
3	2		7 9/32	2	4 13/32	8	11	—	19
3	3		7 15/32	2	5 5/32	8	11	—	19
3	4		7 11/16	2	5 29/32	7	12	—	19
3	5		7 7/8	2	6 21/32	7	13	—	20
3	6		8 1/16	2	7 13/32	7	13	—	20
3	7		8 1/4	2	8 1/8	6	14	—	20
3	8		8 7/16	2	8 7/8	6	15	—	21
3	9		8 5/8	2	9 5/8	6	15	—	21
3	10		8 13/16	2	10 3/8	6	16	—	22
3	11		9 1/32	2	11 1/8	5	17	—	22
4	0		9 7/32	2	11 7/8	4	18	—	22
4	1		9 13/32	3	0 5/8	4	19	—	23
4	2		9 19/32	3	1 3/8	4	19	—	23
4	3		9 25/32	3	2 1/8	3	20	—	23
4	4		9 31/32	3	2 7/8	3	21	—	24
4	5		10 5/32	3	3 5/8	3	21	—	24
4	6		10 3/8	3	4 3/8	3	22	—	25
4	7		10 9/16	3	5 3/32	2	23	—	25
4	8		10 3/4	3	5 27/32	2	23	—	25
4	9		10 15/16	3	6 19/32	2	24	—	26
4	10		11 1/8	3	7 11/32	1	25	—	26
4	11		11 5/16	3	8 3/32	—	26	—	26
5	0		11 1/2	3	8 27/32	—	27	—	27
5	1		11 23/32	3	9 19/32	—	26	1	27
5	2		11 29/32	3	10 11/32	—	26	1	27
5	3	1	0 3/32	3	11 3/32	—	26	2	28
5	4	1	0 9/32	3	11 27/32	—	25	3	28
5	5	1	0 15/32	4	0 19/32	—	25	4	29
5	6	1	0 21/32	4	1 11/32	—	25	4	29
5	7	1	0 27/32	4	2 1/16	—	24	5	29
5	8	1	1 1/16	4	2 13/16	—	24	6	30
5	9	1	1 1/4	4	3 9/16	—	23	7	30
5	10	1	1 7/16	4	4 5/16	—	23	7	30
5	11	1	1 5/8	4	5 1/16	—	23	8	31

NOTE: This table can be used also for 13 1/2 x 9 x 3 inch arch brick by substituting No. 1, 2 and 3 arch brick for the corresponding wedge brick.

9 Inch Arch Thickness—3 Inch Wedge Brick
9 x 4 1/2 x 3, 9 x 6 3/4 x 3 or 9 x 9 x 3 Inch–Cont'd.
2.302 Inch (2 5/16 Inch) Rise Per Foot of Span

Span		Rise		Inside Radius		Number Required Per Course			
Ft	In	Ft	In	Ft	In	No. 2 Wedge	No. 1 Wedge	Straight	Total
6	0	1	1 13/16	4	5 13/16	22	9	—	31
6	1	1	2	4	6 9/16	22	9	—	31
6	2	1	2 3/16	4	7 5/16	22	10	—	32
6	3	1	2 3/8	4	8 1/16	21	11	—	32
6	4	1	2 19/32	4	8 13/16	21	12	—	33
6	5	1	2 25/32	4	9 9/16	20	13	—	33
6	6	1	2 31/32	4	10 5/16	20	13	—	33
6	7	1	3 5/32	4	11 1/32	20	14	—	34
6	8	1	3 11/32	4	11 25/32	19	15	—	34
6	9	1	3 17/32	5	0 17/32	19	15	—	34
6	10	1	3 23/32	5	1 9/32	19	16	—	35
6	11	1	3 15/16	5	2 1/32	18	17	—	35
7	0	1	4 1/8	5	2 25/32	18	17	—	35
7	1	1	4 5/16	5	3 17/32	18	18	—	36
7	2	1	4 1/2	5	4 9/32	17	19	—	36
7	3	1	4 11/16	5	5 1/32	17	20	—	37
7	4	1	4 7/8	5	5 25/32	16	21	—	37
7	5	1	5 1/16	5	6 17/32	16	21	—	37
7	6	1	5 9/32	5	7 9/32	16	22	—	38
7	7	1	5 15/32	5	8 1/32	15	23	—	38
7	8	1	5 21/32	5	8 3/4	15	23	—	38
7	9	1	5 27/32	5	9 1/2	15	24	—	39
7	10	1	6 1/32	5	10 1/4	14	25	—	39
7	11	1	6 7/32	5	11	14	25	—	39
8	0	1	6 13/32	5	11 3/4	14	26	—	40
8	2	1	6 13/16	6	1 1/4	13	28	—	41
8	4	1	7 3/16	6	2 3/4	12	29	—	41
8	6	1	7 9/16	6	4 1/4	11	31	—	42
8	8	1	7 31/32	6	5 23/32	11	32	—	43
8	10	1	8 11/32	6	7 7/32	10	34	—	44
9	0	1	8 23/32	6	8 23/32	9	35	—	44
9	2	1	9 3/32	6	10 7/32	8	37	—	45
9	4	1	9 1/2	6	11 23/32	8	38	—	46
9	6	1	9 7/8	7	1 7/32	7	39	—	46
9	8	1	10 1/4	7	2 11/16	6	41	—	47
9	10	1	10 5/8	7	4 3/16	6	42	—	48
10	0	1	11 1/32	7	5 11/16	5	44	—	49
10	2	1	11 13/32	7	7 3/16	4	45	—	49
10	4	1	11 25/32	7	8 11/16	3	47	—	50
10	6	2	0 3/16	7	10 3/16	3	48	—	51
10	8	2	0 9/16	7	11 21/32	2	50	—	52
10	10	2	0 15/16	8	1 5/32	1	51	—	52
11	0	2	1 5/16	8	2 21/32	—	53	—	53
11	6	2	2 15/32	8	7 5/32	—	53	2	55
12	0	2	3 5/8	8	11 5/8	—	53	4	57
13	0	2	5 15/16	9	8 19/32	—	53	9	62
14	0	2	8 1/4	10	5 9/16	—	53	13	66
15	0	2	10 17/32	11	2 17/32	—	53	18	71

NOTE: This table can be used also for 13 1/2 x 9 x 3 inch arch brick by substituting No. 1 and 2 arch brick for the corresponding wedge brick.

ARCH COMBINATIONS

12 Inch Arch Thickness — 3 Inch Wedge Brick
12 x 4 1/2 x 3, 12 x 6 x 3 or 12 x 9 x 3 Inch
1.608 Inch (1 19/32 Inch) Rise Per Foot of Span
(60° Central Angle)

Span		Rise		Inside Radius		Number Required Per Course			
Ft	In	Ft	In	Ft	In	No. 2 Wedge	No. 1 Wedge	No. 1-X Wedge	Total
6	0		9 21/32	6	0	21	9	—	30
6	3		10 1/16	6	3	20	11	—	31
6	6		10 7/16	6	6	19	13	—	32
6	9		10 27/32	6	9	18	15	—	33
7	0		11 1/4	7	0	17	17	—	34
7	3		11 21/32	7	3	16	19	—	35
7	6	1	0 1/16	7	6	15	21	—	36
7	9	1	0 15/32	7	9	14	23	—	37
8	0	1	0 7/8	8	0	13	25	—	38
8	3	1	1 1/4	8	3	12	27	—	39
8	6	1	1 21/32	8	6	11	29	—	40
8	9	1	2 1/16	8	9	10	31	—	41
9	0	1	2 15/32	9	0	8	34	—	42
9	3	1	2 7/8	9	3	7	36	—	43
9	6	1	3 9/32	9	6	6	38	—	44
9	9	1	3 11/16	9	9	5	40	—	45
10	0	1	4 1/16	10	0	4	42	—	46
10	3	1	4 15/32	10	3	4	44	—	48
10	6	1	4 7/8	10	6	3	46	—	49
10	9	1	5 9/32	10	9	1	49	—	50
11	0	1	5 11/16	11	0	—	51	—	51
11	3	1	6 3/32	11	3	—	50	2	52
11	6	1	6 1/2	11	6	—	48	5	53
11	9	1	6 7/8	11	9	—	47	7	54
12	0	1	7 9/32	12	0	—	46	9	55
12	3	1	7 11/16	12	3	—	45	11	56
12	6	1	8 3/32	12	6	—	44	13	57
12	9	1	8 1/2	12	9	—	43	15	58
13	0	1	8 29/32	13	0	—	42	17	59
13	3	1	9 5/16	13	3	—	41	19	60
13	6	1	9 11/16	13	6	—	40	21	61
13	9	1	10 3/32	13	9	—	39	23	62
14	0	1	10 1/2	14	0	—	38	25	63
14	3	1	10 29/32	14	3	—	37	27	64
14	6	1	11 5/16	14	6	—	36	29	65
14	9	1	11 23/32	14	9	—	35	31	66
15	0	2	0 1/8	15	0	—	34	33	67
15	3	2	0 17/32	15	3	—	32	36	68
15	6	2	0 29/32	15	6	—	32	38	70
15	9	2	1 5/16	15	9	—	31	40	71

12 Inch Arch Thickness — 3 Inch Wedge Brick
12 x 4 1/2 x 3, 12 x 6 x 3 or 12 x 9 x 3 Inch–Cont'd.
1.608 Inch (1 19/32 Inch) Rise Per Foot of Span
(60° Central Angle)

Span		Rise		Inside Radius		Number Required Per Course			
Ft	In	Ft	In	Ft	In	No. 1 Wedge	No. 1-X Wedge	Straight	Total
16	0	2	1 23/32	16	0	30	42	—	72
16	3	2	2 1/8	16	3	29	44	—	73
16	6	2	2 17/32	16	6	28	46	—	74
16	9	2	2 15/16	16	9	27	48	—	75
17	0	2	3 11/32	17	0	25	51	—	76
17	3	2	3 23/32	17	3	24	53	—	77
17	6	2	4 1/8	17	6	23	55	—	78
17	9	2	4 17/32	17	9	22	57	—	79
18	0	2	4 15/16	18	0	21	59	—	80
18	3	2	5 11/32	18	3	20	61	—	81
18	6	2	5 3/4	18	6	19	63	—	82
18	9	2	6 5/32	18	9	18	65	—	83
19	0	2	6 17/32	19	0	17	67	—	84
19	3	2	6 15/16	19	3	16	69	—	85
19	6	2	7 11/32	19	6	15	71	—	86
19	9	2	7 3/4	19	9	14	73	—	87
20	0	2	8 5/32	20	0	13	75	—	88
20	3	2	8 9/16	20	3	12	77	—	89
20	6	2	8 31/32	20	6	10	80	—	90
20	9	2	9 11/32	20	9	10	82	—	92
21	0	2	9 3/4	21	0	9	84	—	93
21	3	2	10 5/32	21	3	8	86	—	94
21	6	2	10 9/16	21	6	7	88	—	95
21	9	2	10 31/32	21	9	6	90	—	96
22	0	2	11 3/8	22	0	5	92	—	97
22	3	2	11 25/32	22	3	3	95	—	98
22	6	3	0 3/16	22	6	2	97	—	99
22	9	3	0 9/16	22	9	1	99	—	100
23	0	3	0 31/32	23	0	—	101	—	101
23	3	3	1 3/8	23	3	—	101	1	102
23	6	3	1 25/32	23	6	—	101	2	103
23	9	3	2 3/16	23	9	—	101	3	104
24	0	3	2 19/32	24	0	—	101	4	105
24	3	3	3	24	3	—	101	5	106
24	6	3	3 3/8	24	6	—	101	6	107
24	9	3	3 25/32	24	9	—	101	7	108
25	0	3	4 3/16	25	0	—	101	8	109
25	3	3	4 19/32	25	3	—	101	9	110
25	6	3	5	25	6	—	101	10	111
25	9	3	5 13/32	25	9	—	101	11	112

ARCH COMBINATIONS

13 1/2 Inch Arch Thickness — 3 Inch Wedge Brick
13 1/2 x 4 1/2 x 3, 13 1/2 x 6 x 3 or
13 1/2 x 9 x 3 Inch
1.608 Inch (1 19/32 Inch) Rise Per Foot of Span
(60° Central Angle)

Span		Rise		Inside Radius		Number Required Per Course			
Ft	In	Ft	In	Ft	In	No. 2 Wedge	No. 1 Wedge	No. 1-X Wedge	Total
6	0		9 21/32	6	0	27	3	—	30
6	3		10 1/16	6	3	26	5	—	31
6	6		10 7/16	6	6	25	7	—	32
6	9		10 27/32	6	9	24	9	—	33
7	0		11 1/4	7	0	22	12	—	34
7	3		11 21/32	7	3	21	14	—	35
7	6	1	0 1/16	7	6	21	16	—	37
7	9	1	0 15/32	7	9	20	18	—	38
8	0	1	0 7/8	8	0	19	20	—	39
8	3	1	1 1/4	8	3	18	22	—	40
8	6	1	1 21/32	8	6	17	24	—	41
8	9	1	2 1/16	8	9	16	26	—	42
9	0	1	2 15/32	9	0	14	29	—	43
9	3	1	2 7/8	9	3	13	31	—	44
9	6	1	3 9/32	9	6	12	33	—	45
9	9	1	3 11/16	9	9	11	35	—	46
10	0	1	4 1/16	10	0	10	37	—	47
10	3	1	4 15/32	10	3	9	39	—	48
10	6	1	4 7/8	10	6	8	41	—	49
10	9	1	5 9/32	10	9	7	43	—	50
11	0	1	5 11/16	11	0	6	45	—	51
11	3	1	6 3/32	11	3	5	47	—	52
11	6	1	6 1/2	11	6	4	49	—	53
11	9	1	6 7/8	11	9	3	51	—	54
12	0	1	7 9/32	12	0	2	53	—	55
12	3	1	7 11/16	12	3	1	55	—	56
12	4 1/2	1	7 29/32	12	4 1/2	—	57	—	57
12	6	1	8 3/32	12	6	—	56	1	57
12	9	1	8 1/2	12	9	—	55	4	59
13	0	1	8 29/32	13	0	—	54	6	60
13	3	1	9 5/16	13	3	—	53	8	61
13	6	1	9 11/16	13	6	—	52	10	62
13	9	1	10 3/32	13	9	—	51	12	63
14	0	1	10 1/2	14	0	—	50	14	64
14	3	1	10 29/32	14	3	—	49	16	65
14	6	1	11 5/16	14	6	—	48	18	66
14	9	1	11 23/32	14	9	—	47	20	67
15	0	2	0 1/8	15	0	—	46	22	68
15	3	2	0 17/32	15	3	—	45	24	69
15	6	2	0 29/32	15	6	—	44	26	70
15	9	2	1 5/16	15	9	—	43	28	71
16	0	2	1 23/32	16	0	—	41	31	72
16	3	2	2 1/8	16	3	—	40	33	73
16	6	2	2 17/32	16	6	—	39	35	74
16	9	2	2 15/16	16	9	—	38	37	75

13 1/2 Inch Arch Thickness — 3 Inch Wedge Brick
13 1/2 x 4 1/2 x 3, 13 1/2 x 6 x 3 or
13 1/2 x 9 x 3 Inch – Continued
1.608 Inch (1 19/32 Inch) Rise Per Foot of Span
(60° Central Angle)

Span		Rise		Inside Radius		Number Required Per Course			
Ft	In	Ft	In	Ft	In	No. 1 Wedge	No. 1-X Wedge	Straight	Total
17	0	2	3 11/32	17	0	37	39	—	76
17	3	2	3 23/32	17	3	36	41	—	77
17	6	2	4 1/8	17	6	35	43	—	78
17	9	2	4 17/32	17	9	34	45	—	79
18	0	2	4 15/16	18	0	33	48	—	81
18	3	2	5 11/32	18	3	32	50	—	82
18	6	2	5 3/4	18	6	31	52	—	83
18	9	2	6 5/32	18	9	30	54	—	84
19	0	2	6 17/32	19	0	29	56	—	85
19	3	2	6 15/16	19	3	28	58	—	86
19	6	2	7 11/32	19	6	27	60	—	87
19	9	2	7 3/4	19	9	26	62	—	88
20	0	2	8 5/32	20	0	25	64	—	89
20	3	2	8 9/16	20	3	24	66	—	90
20	6	2	8 31/32	20	6	23	68	—	91
20	9	2	9 11/32	20	9	22	70	—	92
21	0	2	9 3/4	21	0	21	72	—	93
21	3	2	10 5/32	21	3	19	75	—	94
21	6	2	10 9/16	21	6	18	77	—	95
21	9	2	10 31/32	21	9	17	79	—	96
22	0	2	11 3/8	22	0	16	81	—	97
22	3	2	11 25/32	22	3	15	83	—	98
22	6	3	0 3/16	22	6	14	85	—	99
22	9	3	0 9/16	22	9	13	87	—	100
23	0	3	0 31/32	23	0	12	89	—	101
23	3	3	1 3/8	23	3	12	91	—	103
23	6	3	1 25/32	23	6	10	94	—	104
23	9	3	2 3/16	23	9	9	96	—	105
24	0	3	2 19/32	24	0	8	98	—	106
24	3	3	3	24	3	7	100	—	107
24	6	3	3 3/8	24	6	6	102	—	108
24	9	3	3 25/32	24	9	5	104	—	109
25	0	3	4 3/16	25	0	4	106	—	110
25	6	3	5	25	6	2	110	—	112
26	0	3	5 13/16	26	0	—	113	1	114
26	6	3	6 19/32	26	6	—	113	3	116
27	0	3	7 13/32	27	0	—	113	5	118
27	6	3	8 7/32	27	6	—	113	7	120
28	0	3	9	28	0	—	113	9	122
28	6	3	9 13/16	28	6	—	113	11	124
29	0	3	10 5/8	29	0	—	113	14	127
29	6	3	11 7/16	29	6	—	113	16	129
30	0	4	0 7/32	30	0	—	113	18	131
30	6	4	1 1/32	30	6	—	113	20	133

15 Inch Arch Thickness — 3 Inch Wedge Brick
15 x 6 x 3 or 15 x 9 x 3 Inch
1.608 Inch (1 19/32 Inch) Rise Per Foot of Span
(60° Central Angle)

Span		Rise		Inside Radius		Number Required Per Course			
Ft	In	Ft	In	Ft	In	No. 2 Wedge	No. 1 Wedge	No. 1-X Wedge	Total
6	3		10 1/16	6	3	32	—	—	32
6	6		10 7/16	6	6	31	2	—	33
6	9		10 27/32	6	9	30	4	—	34
7	0		11 1/4	7	0	28	7	—	35
7	3		11 21/32	7	3	27	9	—	36
7	6	1	0 1/16	7	6	26	11	—	37
7	9	1	0 15/32	7	9	25	13	—	38
8	0	1	0 7/8	8	0	24	15	—	39
8	3	1	1 1/4	8	3	23	17	—	40
8	6	1	1 21/32	8	6	22	19	—	41
8	9	1	2 1/16	8	9	21	21	—	42
9	0	1	2 15/32	9	0	20	23	—	43
9	3	1	2 7/8	9	3	19	25	—	44
9	6	1	3 9/32	9	6	18	27	—	45
9	9	1	3 11/16	9	9	17	29	—	46
10	0	1	4 1/16	10	0	16	32	—	48
10	3	1	4 15/32	10	3	15	34	—	49
10	6	1	4 7/8	10	6	14	36	—	50
10	9	1	5 9/32	10	9	13	38	—	51
11	0	1	5 11/16	11	0	12	40	—	52
11	3	1	6 3/32	11	3	11	42	—	53
11	6	1	6 1/2	11	6	10	44	—	54
11	9	1	6 7/8	11	9	9	46	—	55
12	0	1	7 9/32	12	0	8	48	—	56
12	3	1	7 11/16	12	3	7	50	—	57
12	6	1	8 3/32	12	6	5	53	—	58
12	9	1	8 1/2	12	9	4	55	—	59
13	0	1	8 29/32	13	0	3	57	—	60
13	3	1	9 5/16	13	3	2	59	—	61
13	6	1	9 11/16	13	6	1	61	—	62
13	9	1	10 3/32	13	9	—	63	—	63
14	0	1	10 1/2	14	0	—	62	2	64
14	3	1	10 29/32	14	3	—	61	4	65
14	6	1	11 5/16	14	6	—	60	6	66
14	9	1	11 23/32	14	9	—	59	8	67
15	0	2	0 1/8	15	0	—	58	10	68
15	3	2	0 17/32	15	3	—	57	13	70
15	6	2	0 29/32	15	6	—	56	15	71
15	9	2	1 5/16	15	9	—	55	17	72
16	0	2	1 23/32	16	0	—	54	19	73
16	3	2	2 1/8	16	3	—	53	21	74
16	6	2	2 17/32	16	6	—	52	23	75
16	9	2	2 15/16	16	9	—	51	25	76
17	0	2	3 11/32	17	0	—	49	28	77
17	3	2	3 23/32	17	3	—	48	30	78
17	6	2	4 1/8	17	6	—	47	32	79
17	9	2	4 17/32	17	9	—	46	34	80

15 Inch Arch Thickness — 3 Inch Wedge Brick
15 x 6 x 3 or 15 x 9 x 3 Inch — Continued
1.608 Inch (1 19/32 Inch) Rise Per Foot of Span
(60° Central Angle)

Span		Rise		Inside Radius		Number Required Per Course			
Ft	In	Ft	In	Ft	In	No. 1 Wedge	No. 1-X Wedge	Straight	Total
18	0	2	4 15/16	18	0	45	36	—	81
18	3	2	5 11/32	18	3	44	38	—	82
18	6	2	5 3/4	18	6	43	40	—	83
18	9	2	6 5/32	18	9	42	42	—	84
19	0	2	6 17/32	19	0	41	44	—	85
19	3	2	6 15/16	19	3	40	46	—	86
19	6	2	7 11/32	19	6	39	48	—	87
19	9	2	7 3/4	19	9	38	50	—	88
20	0	2	8 5/32	20	0	37	52	—	89
20	3	2	8 9/16	20	3	36	54	—	90
20	6	2	8 31/32	20	6	35	57	—	92
20	9	2	9 11/32	20	9	34	59	—	93
21	0	2	9 3/4	21	0	33	61	—	94
21	3	2	10 5/32	21	3	32	63	—	95
21	6	2	10 9/16	21	6	31	65	—	96
21	9	2	10 31/32	21	9	30	67	—	97
22	0	2	11 3/8	22	0	29	69	—	98
22	3	2	11 25/32	22	3	28	71	—	99
22	6	3	0 3/16	22	6	26	74	—	100
22	9	3	0 9/16	22	9	25	76	—	101
23	0	3	0 31/32	23	0	24	78	—	102
23	3	3	1 3/8	23	3	23	80	—	103
23	6	3	1 25/32	23	6	22	82	—	104
23	9	3	2 3/16	23	9	21	84	—	105
24	0	3	2 19/32	24	0	20	86	—	106
24	3	3	3	24	3	19	88	—	107
24	6	3	3 3/8	24	6	18	90	—	108
24	9	3	3 25/32	24	9	17	92	—	109
25	0	3	4 3/16	25	0	16	94	—	110
25	3	3	4 19/32	25	3	15	96	—	111
25	6	3	5	25	6	14	98	—	112
25	9	3	5 13/32	25	9	13	100	—	113
26	0	3	5 13/16	26	0	12	103	—	115
26	3	3	6 3/16	26	3	11	105	—	116
26	6	3	6 19/32	26	6	10	107	—	117
26	9	3	7	26	9	9	109	—	118
27	0	3	7 13/32	27	0	8	111	—	119
27	3	3	7 13/16	27	3	7	113	—	120
27	6	3	8 7/32	27	6	6	115	—	121
27	9	3	8 5/8	27	9	4	118	—	122
28	0	3	9	28	0	3	120	—	123
28	3	3	9 13/32	28	3	2	122	—	124
28	6	3	9 13/16	28	6	1	124	—	125
28	9	3	10 7/32	28	9	—	126	—	126
29	0	3	10 5/8	29	0	—	126	1	127
29	6	3	11 7/16	29	6	—	126	3	129
30	0	4	0 7/32	30	0	—	126	5	131
31	0	4	1 27/32	31	0	—	126	9	135

ARCH COMBINATIONS

18 Inch Arch Thickness — 3 Inch Wedge Brick
18 x 6 x 3 or 18 x 9 x 3 Inch
1.608 Inch (1 19/32 Inch) Rise Per Foot of Span
(60° Central Angle)

Span		Rise		Inside Radius		Number Required Per Course			
Ft	In	Ft	In	Ft	In	No. 2 Wedge	No. 1 Wedge	No. 1-X Wedge	Total
8	0	1	0 7/8	8	0	36	4	—	40
8	3	1	1 1/4	8	3	35	6	—	41
8	6	1	1 21/32	8	6	34	8	—	42
8	9	1	2 1/16	8	9	32	11	—	43
9	0	1	2 15/32	9	0	31	13	—	44
9	3	1	2 7/8	9	3	30	15	—	45
9	6	1	3 9/32	9	6	29	17	—	46
9	9	1	3 11/16	9	9	29	19	—	48
10	0	1	4 1/16	10	0	28	21	—	49
10	3	1	4 15/32	10	3	27	23	—	50
10	6	1	4 7/8	10	6	25	26	—	51
10	9	1	5 9/32	10	9	24	28	—	52
11	0	1	5 11/16	11	0	23	30	—	53
11	3	1	6 3/32	11	3	22	32	—	54
11	6	1	6 1/2	11	6	21	34	—	55
11	9	1	6 7/8	11	9	20	36	—	56
12	0	1	7 9/32	12	0	19	38	—	57
12	3	1	7 11/16	12	3	18	40	—	58
12	6	1	8 3/32	12	6	17	42	—	59
12	9	1	8 1/2	12	9	16	44	—	60
13	0	1	8 29/32	13	0	15	46	—	61
13	3	1	9 5/16	13	3	14	48	—	62
13	6	1	9 11/16	13	6	13	50	—	63
13	9	1	10 3/32	13	9	12	52	—	64
14	0	1	10 1/2	14	0	11	54	—	65
14	3	1	10 29/32	14	3	9	57	—	66
14	6	1	11 5/16	14	6	8	59	—	67
14	9	1	11 23/32	14	9	7	61	—	68
15	0	2	0 1/8	15	0	7	63	—	70
15	3	2	0 17/32	15	3	6	65	—	71
15	6	2	0 29/32	15	6	5	67	—	72
15	9	2	1 5/16	15	9	4	69	—	73
16	0	2	1 23/32	16	0	2	72	—	74
16	3	2	2 1/8	16	3	1	74	—	75
16	6	2	2 17/32	16	6	—	76	—	76
16	9	2	2 15/16	16	9	—	75	2	77
17	0	2	3 11/32	17	0	—	74	4	78
17	3	2	3 23/32	17	3	—	72	7	79
17	6	2	4 1/8	17	6	—	71	9	80
17	9	2	4 17/32	17	9	—	70	11	81
18	0	2	4 15/16	18	0	—	69	13	82
18	3	2	5 11/32	18	3	—	68	15	83
18	6	2	5 3/4	18	6	—	67	17	84
18	9	2	6 5/32	18	9	—	66	19	85
19	0	2	6 17/32	19	0	—	65	21	86
19	3	2	6 15/16	19	3	—	64	23	87
19	6	2	7 11/32	19	6	—	63	25	88
19	9	2	7 3/4	19	9	—	62	27	89

18 Inch Arch Thickness — 3 Inch Wedge Brick
18 x 6 x 3 or 18 x 9 x 3 Inch — Continued
1.608 Inch (1 19/32 Inch) Rise Per Foot of Span
(60° Central Angle)

Span		Rise		Inside Radius		Number Required Per Course			
Ft	In	Ft	In	Ft	In	No. 2 Wedge	No. 1 Wedge	No. 1-X Wedge	Total
20	0	2	8 5/32	20	0	—	61	29	90
20	3	2	8 9/16	20	3	—	60	32	92
20	6	2	8 31/32	20	6	—	59	34	93
20	9	2	9 11/32	20	9	—	58	36	94
21	0	2	9 3/4	21	0	—	57	38	95
21	3	2	10 5/32	21	3	—	56	40	96
21	6	2	10 9/16	21	6	—	55	42	97
21	9	2	10 31/32	21	9	—	54	44	98
22	0	2	11 3/8	22	0	—	53	46	99
22	3	2	11 25/32	22	3	—	52	48	100
22	6	3	0 3/16	22	6	—	50	51	101
22	9	3	0 9/16	22	9	—	49	53	102
23	0	3	0 31/32	23	0	—	48	55	103
23	3	3	1 3/8	23	3	—	47	57	104
23	6	3	1 25/32	23	6	—	46	59	105
23	9	3	2 3/16	23	9	—	45	61	106
24	0	3	2 19/32	24	0	—	44	63	107
24	3	3	3	24	3	—	43	65	108
24	6	3	3 3/8	24	6	—	42	67	109
24	9	3	3 25/32	24	9	—	41	69	110
25	0	3	4 3/16	25	0	—	40	71	111
25	3	3	4 19/32	25	3	—	39	73	112
25	6	3	5	25	6	—	38	75	113
25	9	3	5 13/32	25	9	—	37	78	115
26	0	3	5 13/16	26	0	—	36	80	116
26	3	3	6 3/16	26	3	—	35	82	117
26	6	3	6 19/32	26	6	—	34	84	118
26	9	3	7	26	9	—	33	86	119
27	0	3	7 13/32	27	0	—	32	88	120
27	3	3	7 13/16	27	3	—	31	90	121
27	6	3	8 7/32	27	6	—	30	92	122
27	9	3	8 5/8	27	9	—	29	94	123
28	0	3	9	28	0	—	27	97	124
28	3	3	9 13/32	28	3	—	26	99	125
28	6	3	9 13/16	28	6	—	25	101	126
28	9	3	10 7/32	28	9	—	24	103	127
29	0	3	10 5/8	29	0	—	23	105	128
29	3	3	11 1/32	29	3	—	22	107	129
29	6	3	11 7/16	29	6	—	21	109	130
29	9	3	11 13/16	29	9	—	20	111	131
30	0	4	0 7/32	30	0	—	19	113	132
30	3	4	0 5/8	30	3	—	18	115	133
30	6	4	1 1/32	30	6	—	17	117	134
30	9	4	1 7/16	30	9	—	16	119	135
31	0	4	1 27/32	31	0	—	15	122	137
31	3	4	2 1/4	31	3	—	14	124	138
31	6	4	2 21/32	31	6	—	13	126	139
31	9	4	3 1/32	31	9	—	12	128	140
32	0	4	3 7/16	32	0	—	11	130	141

ANCHORING REFRACTORIES

Overview

This information is presented as a general guide to selection and installation of Harbison-Walker anchors and anchoring systems. Please contact your Harbison-Walker Marketing Representative at any time for more specific information on the use of ceramic and metallic anchors in your application.

INTRODUCTION

Since castable and plastic refractories were introduced, there has been a constant search for improved methods of holding these extremely useful products in place under varying service conditions. At first, monoliths were typically used for the temporary repair of small areas of damaged brickwork. Over the years, however, monolithic refractory technology has expanded far beyond simple patchwork. Today, entire installations are lined with castables, plastics, and anchoring has emerged as a technology of its own.

As a recognized leader in refractory technology, Harbison-Walker has compiled the following information as an overview of this complex and important subject. Since refractory installations vary, however, and each operation is subject to unique service conditions, this material is provided only as a guideline.

This section provides a partial listing of Harbison-Walker's anchor products. Please contact your Harbison-Walker Marketing Representative if you need additional information.

SELECTION GUIDELINES

The primary function of any anchoring system is to retain the refractory mass in place. In order to perform this requirement successfully, anchoring systems must be selected and installed to match the service conditions under which the process vessels will operate. Installation parameters will differ according to a number of variables including:

- Type of refractory being installed
- Lining thickness and number of lining components
- Method of refractory installation (gunning, ramming, casting, or shotcreting)
- Process vessel geometry
- Maximum and continuous vessel operating temperatures
- Vibration and/or severity of vessel operation
- Structural stability of vessel shell, bindings or support structure
- Exterior insulation
- Operating atmosphere or process
- Whether or not portions of existing lining remain or brick lining exist

WIRE ANCHORS

Wire Anchors

Many anchoring systems for castable and gunned linings utilize the V-type alloy wire anchors they provide adequate support and holding power for the refractory, which also offers economy through simple installation.

Wire anchors are used for most anchor applications where the service temperatures do need exceed 2000°F(1904°C). Metallic components should be based on the temperatures of the lining and should be installed in ways which will allow heat dissipation by conduction and/or circulation.

Harbison-Walker supplies wire anchors for a broad range of monolithic anchoring situations. Harbison-Walker wire anchors come in mild steel, 304, 309 or 310 stainless steels. The wire anchors presented represent the most commonly used types. Other available options include color coding anchor by metal type, using color plastic tips, stamping metal type and supply in special packaging upon request. Harbison-Walker also supplies custom made anchors to meet special requirements.

Anchor Spacing

Distance between anchors should be considered carefully. Edges, roofs, nose, and areas where vibration, mechanical movement or gravity impose loads on the lining, require more anchors. Standard spacing for various areas is suggested in the table below and indicated in the accompanying illustration. Anchors should be welded in a square pattern, rotating the anchor tines 90° from neighboring anchors.

Wire and Rod Anchor Spacing

Locations	Lining Thickness (in.)	Anchor Centers (in.)
Walls,	2-4	6
Cylinders,	4-6	9
Slopes	6-13½	12
Overhead,	2-4	6
Roofs,	4-7	9
Bullnoses	7-9	12
Floors	2-5	9
	5-9	15
	9+	24

Anchor Length

Length of wire anchors should be 0.8 times the thickness of the lining. This figure is generally rounded up to the nearest half-inch. For example, a 6-inch lining times 0.8 equals 4.8 or 5 inches of anchor length.

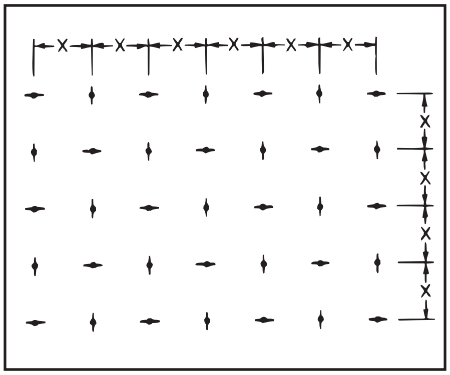
Estimating Anchor Quantities

To determine the total number of anchors required, multiply the anchors per square foot by the total number of square feet in the lining. Anchor quantities based on typical anchor centers are shown in the table.

Estimating Anchor Quantities

Anchor Spacing	Anchors/Sq Ft
6 x 6	4
8 x 8	2.3
9 x 9	1.8
9 x 12	1.33
10 x 10	1.44
12 x 12	1
12 x 18	0.67

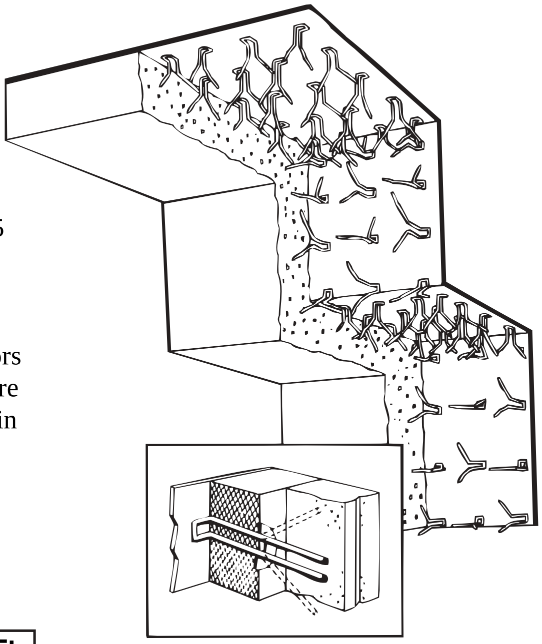
Typical Spacing Pattern



Wire Anchor Dimensions

Anchor	Available Lengths, (in)*
1A	2 to 7
2A	3 to 9
3A	5 to 15
4A	5 to 11
1L	1 to 7
2L	1 to 7

* Lengths vary in ½-inch increments

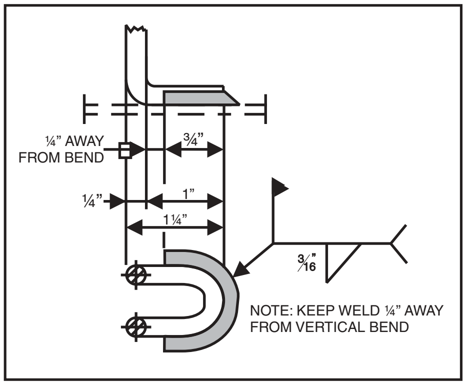


The majority of wire anchor installation linings are 9 inches thick or less. The inset illustration details the installation of a 4A wire anchor. The metal washer allows the anchor tines to be spread to retain the block insulation.

Anchor Welding

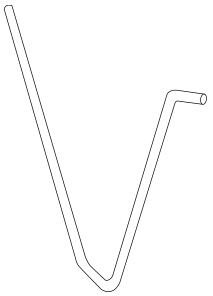
Wire anchors require at least a half inch of weld fillet on both sides. Tack welding is not enough for wire anchors. Heavier rod anchors also may require more fillet weld on both sides of the leg.

Welds can be tested by striking half of them with a hammer. A ringing sound indicates a good weld. A dull thud indicates a potential failure. Then bend flat one of every 100 anchors to insure weld does not fail. If the test shows poor welds, check all the anchors and replace those that fail.

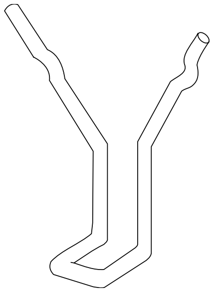


WIRE ANCHORS

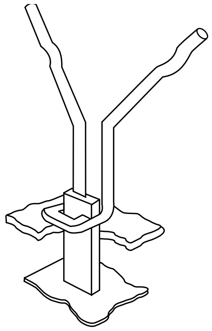
1A



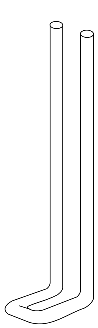
2A & 3A



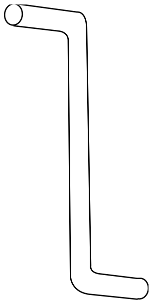
1L & 2L CLIPS
FOR 2A & 3A ANCHORS



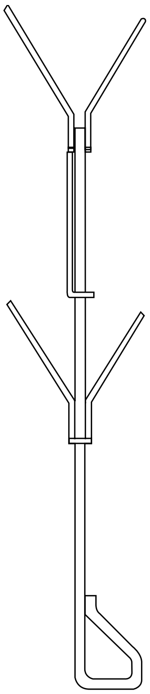
4A



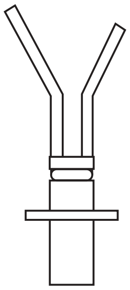
5A & 6A



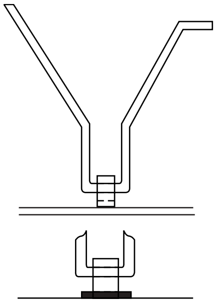
7A



3R



KL



Grades of Steel Required for High Temperature Service

Type of Steel	Color Code	Maximum Temp of Metallic Components °F
Carbon Steel	Blue	1000
304 SS	No Color	1600
309 SS	Red	1650
310 SS	Yellow	1700

Wire Anchors

1A – This ¼ inch diameter anchor is designed for economical use with linings 5 inches or less. It may also be used with lightweight materials where loads are not high.

2A – This ¼ inch diameter anchor can be used for thicker linings where additional holding power is needed. An anchor configuration designed for holding power and a foot designed for added weld strength give the 2A the versatility needed for use with high density materials. A anchors can be used in high density linings 7 inches thick or less and for lightweight linings.

3A – This 5/16-inch diameter anchor is a larger version of the 2A. Also incorporating a foot for added weld strength, the 3A handles thick dense linings up to 9 inches, heavy overhead loads and areas subject to movement or vibration..

3A-3/8 – This 3/8 inch 3A anchor is designed for dense thick linings from 6 to 16 inches thick, heavy overhead loads areas subject to movement and vibration. The foot provides additional weld strength.

1L & 2L Clips – These metal clips are used with the 3A and 2A anchors respectively, for installing 2 component linings. 1L clips have a 5/16-inch notch for use with the 3A anchor. 2L clips have a 1/4- inch notch for incorporating the 2A anchors. In the 2 component lining application, the clip permits the first component to be installed before the 3A or 2A anchors are attached and the hot face lining is installed.

4A – This ¼ inch diameter anchor is intended for use with monolithic linings with backup insulation. A washer is furnished with the anchor which permits the anchor tines to be spread after the insulation is in place. The 4A is typically used in linings with a total thickness of 4 to 12 inches.

5A & 6A – These ¼ inch and 5/16 inch anchors are typically used for light duty monolithic linings. In lengths from 3 to 10 inches, they are typically used for anchoring in door framings, corners, pockets and small voids.

7A – The "Christmas Tree" anchor, available in heights from 13 to 40 inches are typically used in specific applications where massive installations of refractories occur. Examples include rotary kiln dams and lifters.

KL – This 3/8 inch diameter anchor is for use in rotary kiln linings 4 ½ to 9 inches thick. The plate supplied with the anchor is welded to the shell. The tack weld between the plate and the anchor can break during operation and thus allow limited movement between lining and shell. Expansion and contraction in the lining is assured while the lining is retained in place.

WIRE ANCHORS

STANDARD WIRE ANCHORS					
TOTAL LINING THICKNESS	1A-	2A-	3A-	3A-3/8-	7A-
2"	1 ½"				
2 ½"	2"				
3"	2 ½"				
3 ½"	3"				
4"	3"				
4 ½"	3 ½"	3 ½"			
5"	4"	4"			
5 ½"		4½"			
6"		5"	5"		
6 ½"		5"	5"		
7"		5 ½"	5 ½"		
7 ½"		6"	6"		
8"		6 ½"	6 ½"		
8 ½"			7"	7"	
9"			7”	7"	
9 ½"			7½"	7½"	
10"			8"	8"	
10 ½"				8½"	
11"				9"	
11 ½"				9"	
12"				9½"	
12 ½"				10"	
13"				10 ½"	
13½"				11"	
14"				11"	
14½"				11½"	
15"				12"	
15½"				12½"	13"
16"					13"
>16"- 48"					>13"- 40"

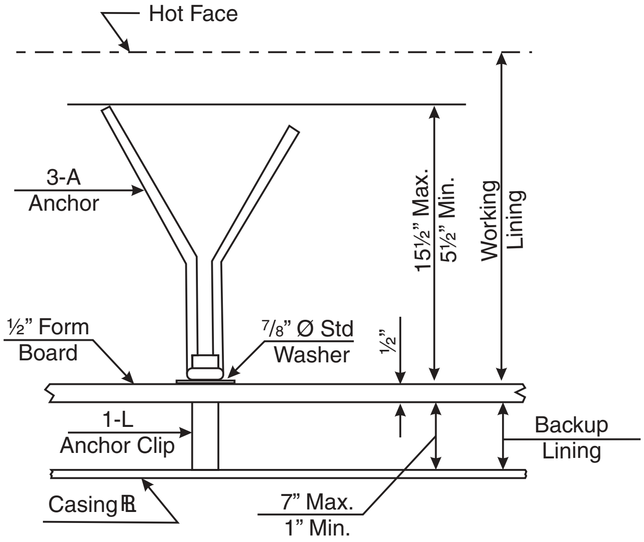
STANDARD WIRE ANCHORS		
TOTAL LINING THICKNESS	5A-	6A-
3 ½"	3"	3"
4"	3 ½"	3 ½"
4 1/2"	4"	4"
5"	4"	4"
5 ½"	4 ½"	4 ½"
6"	5"	5"
6 ½"	5 ½"	5 ½"
7"	6"	6"
7 ½"	6"	6"
8"	6 ½"	6 ½"
8 ½"	7"	7"
9"	7 ½"	7"
9 ½"	8"	8"
10"	8"	8"
10 ½"	8 ½"	8 ½"
11"	9"	9"
11 ½"	9"	9"
12"	10"	10"
12 ½"	10"	10"

KL ANCHORS	
TOTAL LINING THICKNESS	KL-
5 ½"	4 ½"
6"	5"
7"	5 ½"
7 ½"	6"
8"	6 ½"
8 ½"	7"
9"	7"
9 ½"	7 ½"
10"	8"
10 ½"	8 ½"
11"	9"
12"	9"
12 ½"	10"
13 ½"	10 ½"

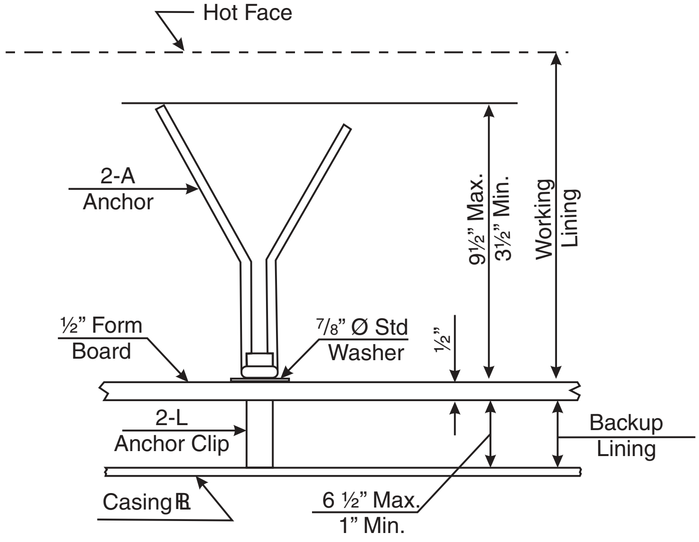
SUGGESTED USE FOR 4A ANCHOR							
TOTAL LINING THICKNESS	TOTAL LENGTH OF UNBENT ANCHOR WITH						
	1" Block	1 ½ “ Block	2” Block	2 ½ “ Block	3” Block	3 ½" Block	4" Block
4"	4"	4"					
4 ½"	4"	4"	4"				
5"	4 ½"	4 ½"	4 ½"	4 ½"			
5 ½"	5"	5"	5"	4 ½"	4 ½"		
6"	5 ½"	5 ½"	5"	5"	5"		
6 ½"	6"	6"	5 ½"	5 1½"	5 ½"	5 ½"	
7"	6 1/2"	6"	6"	6"	6"	6"	
7 ½"	7"	7"	6 ½"	6 ½"	6 ½"	6 ½"	6 ½"
8"	7"	7"	7"	7"	7"	7"	7"
8 ½"	7 ½"	7 ½"	7 ½"	7 ½"	7 ½"	7 ½"	7 ½"
9"	8"	8"	8"	8"	8"	8"	8"
9 ½"	8 ½"	8 ½"	8 ½"	8 ½"	8 ½"	8 ½"	8 ½"
10"	9"	9"	9"	8 ½"	8 ½"	8 ½"	8 ½"
10 ½"	9 ½"	9 ½"	9 "	9"	9"	9"	9"
11"	10"	10"	10"	9 ½"	9 ½"	9 ½"	9 ½"
11 ½"	10 ½"	10 ½"	10 ½"	10"	10"	10"	10"
12"	11"	11"	11"	10 ½"	10 ½"	10 ½"	10 ½"
12 ½"	11 ½"	11 ½"	11 ½"	11"	11"	11"	11"
13"	11 ½"	11 ½"	11 ½"	11 ½"	11 ½"	11 ½"	11 ½"
13 ½"	12"	12"	12"	12"	12"	12"	12"

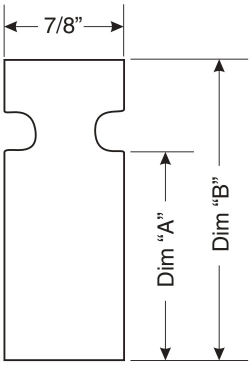
WIRE ANCHORS

3A Anchor and 1-L Clip Arrangement
For 2 Component Cast Lining

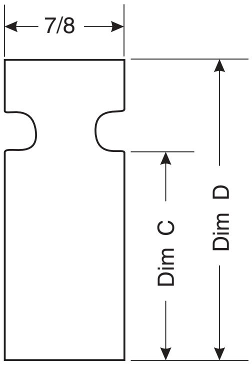


2A Anchor and 2-L Clip Arrangement
For 2 Component Cast Lining





1-L CLIP



2-L CLIP

1-L CLIPS

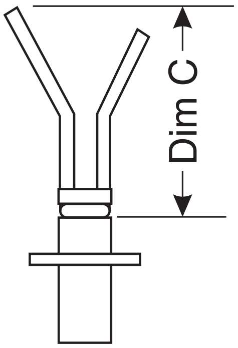
Anchor	Dim A	Dim B
1-L-1	1	1 11/16
1-L-1 1/2	1 1/2	2 3/16
1-L-2	2	2 11/16
1-L-2 1/2	2 1/2	3 3/16
1-L-3	3	3 11/16
1-L-3 1/2	3 1/2	4 3/16
1-L-4	4	4 11/16
1-L-4 1/2	4 1/2	5 3/16
1-L-5	5	5 11/16
1-L-5 1/2	5 1/2	6 3/16
1-L-6	6	6 11/16
1-L-6 1/2	6 1/2	7 3/16
1-L-7	7	7 11/16
1-L-7 1/2	7 1/2	8 3/16

2-L CLIPS

Anchor	Dim C	Dim D
2-L-1	1	1 5/8
2-L-1 1/2	1 1/2	2 1/8
2-L-2	2	2 5/8
2-L-2 1/2	2 1/2	3 1/8
2-L-3	3	3 5/8
2-L-3 1/2	3 1/2	4 1/8
2-L-4	4	4 5/8
2-L-4 1/2	4 1/2	5 1/8
2-L-5	5	5 5/8
2-L-5 1/2	5 1/2	6 1/8
2-L-6	6	6 5/8
2-L-6 1/2	6 1/2	7 1/8
2-L-7	7	7 5/8

Wire Anchors

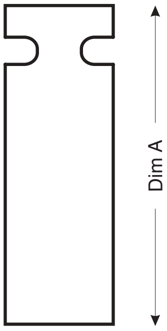
3-R Anchor assembly to be used with two component lining (Gunned)



Detail of 3-R Anchor and
1-R or 1-R-T Clip Assembly

3-R ANCHOR

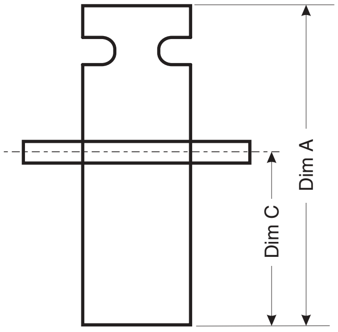
Shape No.	Dim C	Shape No.	Dim C
3-R-2	2.00	3-R-8.5	8.50
3-R-2.5	2.50	3-R-9	9.00
3-R-3	3.00	3-R-9.5	9.50
3-R-3.5	3.50	3-R-10	10.00
3-R-4	4.00	3-R-10.5	10.50
3-R-4.5	4.50	3-R-11	11.00
3-R-5	5.00	3-R-11.5	11.50
3-R-5.5	5.50	3-R-12	12.00
3-R-6	6.00	3-R-12.5	12.50
3-R-6.5	6.50	3-R-13	13.00
3-R-7	7.00	3-R-13.5	13.50
3-R-7.5	7.50	3-R-14	14.00
3-R-8	8.00	3-R-15	15.00



1-R Clip

1-R CLIP

Shape No.	Dim D
1-R-1	1.00
1-R-1.5	1.50
1-R-2	2.00
1-R-2.5	2.50
1-R-3	3.00
1-R-3.5	3.50
1-R-4	4.00
1-R-4.5	4.50
1-R-5	5.00
1-R-5.5	5.50
1-R-6	6.00
1-R-6.5	6.50
1-R-7	7.00
1-R-7.5	7.50



1-R-T Clip

1-R-T CLIP

Shape No.	Dim A	Dim C
1-R-T-3	3.00	2.00
1-R-T-3.5	3.50	2.50
1-R-T-4	4.00	3.00
1-R-T-4.5	4.50	3.50
1-R-T-5	5.00	4.00
1-R-T-5.5	5.50	4.50
1-R-T-6	6.00	5.00
1-R-T-6.5	6.50	5.50
1-R-T-7	7.00	6.00
1-R-T-7.5	7.50	6.50

Harbison-Walker Standard Stock Anchors for Castable and Plastic Refractories

REFRACTORY ANCHORS

Refractory Anchor Solid (RAS) are ceramic anchors for flat suspended roof and wall applications.

Refractory Anchor with Hole (RAH) are ceramic anchors for wall applications.

Rotary Kiln Anchor (RKA) are ceramic anchors for rotary kiln applications and wall applications.

Ceramic Anchor Systems

Most castable and refractory installations operating at temperatures above 2000°F are best served by selecting anchors made of refractory materials compatible with the refractory being installed. Included in the selection of stock H-W ceramic anchors are Refractory Anchor Solid (RAS), Refractory Anchor with Hole (RAH), Rotary Kiln Anchor (RKA) and a choice of special H-W custom produced ceramic anchors. Harbison-Walker ceramic anchors should be used in all installations where temperatures in the furnace will routinely exceed 2000°F (1094°C).

Generally, castable and plastic refractory lining thicknesses for heavy-duty service range between approximately 9 and 19 inches. For these types of constructions, fired H-W ceramic anchors are recommended. Ceramic anchors have several advantages over other types of anchoring components. They extend through the refractory mass to the hot face, providing an extra measure of retention. The design of H-W stock ceramic anchors also provides more surface area in contact with the refractory mass for greater holding power than most metal anchors.

The overall length of ceramic anchors should place the cold face end of the anchor as close as possible to the vessel shell or supporting steelwork. When the ceramic anchor is attached in this manner, the metallic hanger bracket, which secures it, will then be exposed to lower temperatures.

The portion of the metal hanger which engages the overhead I-beam, or suspension rod, should remain exposed to ambient air to permit heat dissipation. Insulation placed over the cold face of the roof should not cover the anchor clip.

Anchor Brackets and Clips

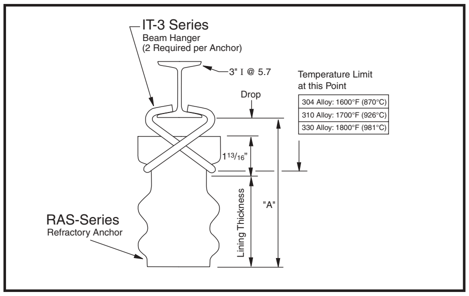
Refractory anchors are normally used in monolithic refractory installations where operating temperatures routinely exceed 2000F (1094C). H-W ceramic anchors for castable and plastic refractories are designed to accept C-Clips which are welded or bolted to the shell, Slip-On castings and Ice-Tong Clips for overhead attachment to a standard I-beam. Some installations may use U-Series Rod with nut welded to steel shell wall or bolt and nut assembly positioned within Rotary Kiln Anchor that is welded to steel wall. A certain amount of movement can occur between the refractory anchor and its metal attachment to accommodate expansion and contraction of the lining. The following pages illustrate a variety of anchor arrangements, primarily for roof construction and sidewall installations.

CC-Series Anchor Clips (see page IR-72)

These are used to attach the RAS refractory ceramic anchors directly to the steel shell. They are available in several metal types to accommodate a range of service conditions. When installed, they are typically welded to the vessel shell. They are available in three standard lengths to handle the many lining thicknesses with standard anchors. The RAS anchor charts show the combinations of the longest anchor and the shortest metallics for the lining thickness shown.

Ice Tong Anchor Clips (see page IR-73)

Ice tong anchor clips are designed to support RAS refractory ceramic anchors for overhead attachment to standard 3 or 4 –inch I beams. They allow for some movement of the anchor system during heat-up and subsequent operation. When ordering, it is necessary to specify the size and alloy to be used. An example would be IT-3-1.5-304. These specs are called out in the anchor charts.



Refractory Anchor Length and Anchor Spacing

The length of refractory anchors usually equals the lining thickness. Suggested spacing for ceramic anchors is covered in the Anchor spacing chart. Distance between anchors should be considered carefully. Edges, roof and nose, and areas where vibration, mechanical movement or gravity impose loads on the lining, require more anchors.

Suggested Spacing for Ceramic Refractory Anchors

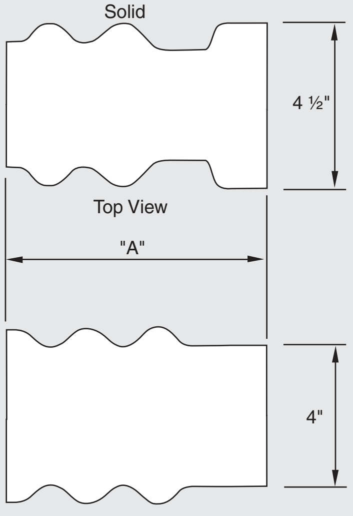
Locations	Lining Thickness (In.)	Anchoring Spacing (in.)
Vertical and circular units	9-12	15
	12-15	18
	15+	24
Roofs, noses and arches	6+	12

REFRACTORY ANCHORS RAH & RAS SERIES

Refractory Anchor with Hole Series (RAH) *for Wall Applications*
and Refractory Anchor Solid Series (RAS) *for Flat Suspended Roof and Wall Applications*

RAH & RAS-Series Anchor Lengths and Anchor Spacing Selection Charts

RAS
Refractory
Anchor
Solid



Side View

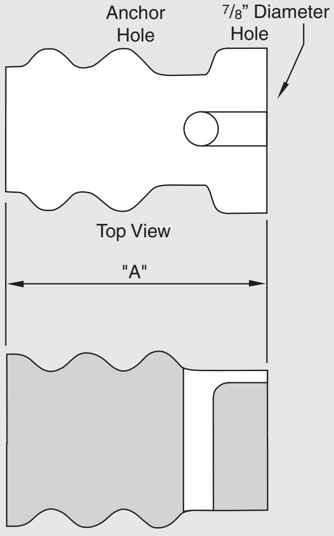
RAH & RAS Series Anchors in 9

RAH-Series Anchor	RAS-Series Anchor	"A" (In.)
RAH-7.5	RAS-7.5	$7^{9}/_{16}$
RAH-9	RAS-9	$8^{15}/_{16}$
RAH-10.5	RAS-10.5	$10^{5}/_{16}$
RAH-12	RAS-12	$11^{13}/_{16}$
	RAS-13.5	$13^{5}/_{16}$
	RAS-15	$14^{13}/_{16}$
	RAS-16.5	$16^{5}/_{16}$
	RAS-18	$17^{13}/_{16}$
	RAS-20	$19^{13}/_{16}$

Anchor Spacing Chart

Location	Thickness (In.)	Centers	
		Vert. (In.)	Horiz. (In.)
Castable Linings			
Walls & Slopes	6 - 13½	15	18
Arches & Bullnoses	6 - 13½	12	15
Plastic Linings			
Walls & Slopes	6 - 13½	15	18
Arches & Bullnoses	All Thicknesses	12	12

RAH
Refractory
Anchor
Hole

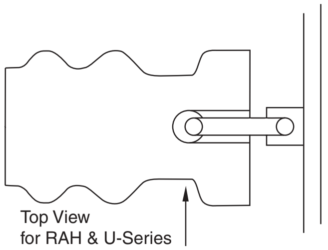


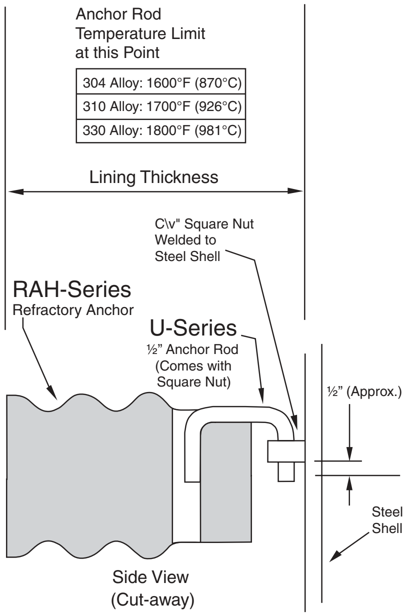
Side View
(Cut-away)

Note:
Anchors will be stocked in CORAL® BP brands.
Other brands available on a made-to-order basis.

REFRACTORY ANCHORS RAH-U SERIES

RAH & U-Series / Z-Series Anchor Rods



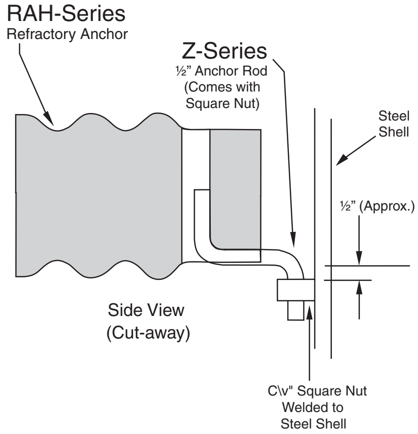


Lining Thickness (In.)	Refractory Anchor	Anchor Rod
8.5	RAH-7.5	U-1 or Z-1
9	RAH-7.5	U-1.5 or Z-1.5
9.5	RAH-7.5	U-2 or Z-2
10	RAH-7.5	U-2.5 or Z-2.5
10.5	RAH-7.5	U-3 or Z-3
10	RAH-9	U-1 or Z-1
10.5	RAH-9	U-1.5 or Z-1.5
11	RAH-9	U-2 or Z-2
11.5	RAH-9	U-2.5 or Z-2.5
12	RAH-9	U-3 or Z-3
11.5	RAH-10.5	U-1 or Z-1
12	RAH-10.5	U-1.5 or Z-1.5
12.5	RAH-10.5	U-2 or Z-2
13	RAH-10.5	U-2.5 or Z-2.5
13.5	RAH-10.5	U-3 or Z-3
13	RAH-12	U-1 or Z-1
13.5	RAH-12	U-1.5 or Z-1.5
14	RAH-12	U-2 or Z-2
14.5	RAH-12	U-2.5 or Z-2.5
15	RAH-12	U-3 or Z-3

Note: The combinations above provide the longest anchor and the shortest metallics for the lining thickness shown.

Other sizes of U-Series and Z-Series Rods are available.

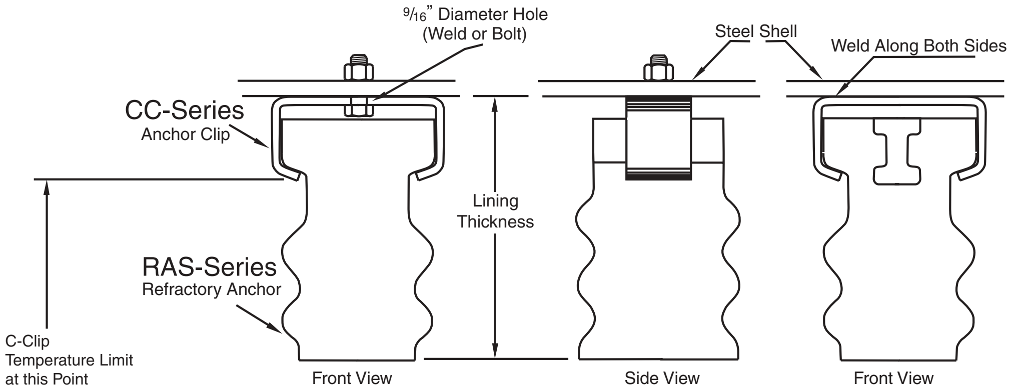
Other RAH refractory anchors lengths are available but not for standard stock, and are available on a made to order basis.



Ordering Information

When ordering U-Series or Z-Series Rods the alloy must be specified (Example U-2-304).

REFRACTORY ANCHORS RAS & H-W 3184 SERIES



304 Alloy: 1600°F (870°C)
310 Alloy: 1700°F (926°C)
330 Alloy: 1800°F (981°C)

Lining Thickness (In.)	Refractory Anchor	Anchor Clip
6	HW-3184	CC-A
6.5	HW-3184	CC-C
7	HW-3184	CC-E
8	RAS-7.5	CC-0.5
8.5	RAS-7.5	CC-1
9	RAS-7.5	CC-1.5
9.5	RAS-9	CC-0.5
10	RAS-9	CC-1
10.5	RAS-9	CC-1.5
11	RAS-10.5	CC-0.5
11.5	RAS-10.5	CC-1
12	RAS-10.5	CC-1.5
12.5	RAS-12	CC-0.5
13	RAS-12	CC-1
13.5	RAS-12	CC-1.5
14	RAS-13.5	CC-0.5
14.5	RAS-13.5	CC-1
15	RAS-13.5	CC-1.5
15.5	RAS-15	CC-0.5
16	RAS-15	CC-1
16.5	RAS-15	CC-1.5
17	RAS-16.5	CC-0.5
17.5	RAS-16.5	CC-1
18	RAS-16.5	CC-1.5
18.5	RAS-18	CC-0.5
19	RAS-18	CC-1
19.5	RAS-18	CC-1.5

Note: The combinations above provide the longest anchor and the shortest metallics for the lining thickness shown.

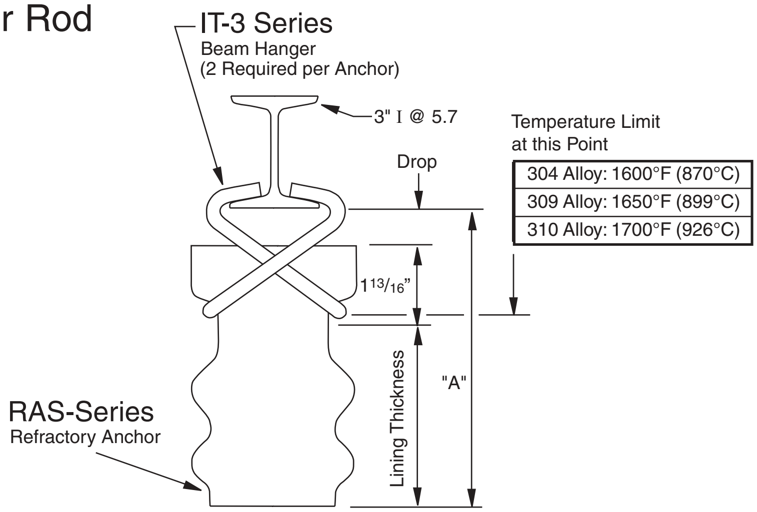
Ordering Information

When ordering CC-Series Anchor Clips the alloy must be specified (Example CC-1-304).

Refractory Anchor Solid Series (RAS)

for Flat Suspended Roof Applications

RAS-Series & IT-3 Series Anchor Rod

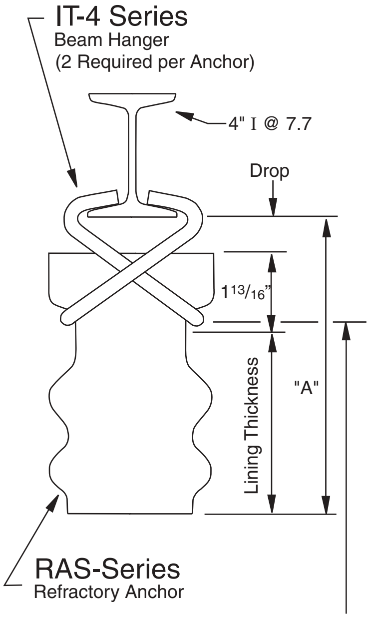


Maximum Lining Thickness (In.)	"A" (In.)	Refractory Anchor	Anchor Rod	Drop (In.)
5.5	8	RAS-7.5	IT-3-0.5	11/16
	8.5		IT-3-1	1 3/16
	9		IT-3-1.5	1 11/16
7	9.5	RAS-9	IT-3-0.5	11/16
	10		IT-3-1	1 3/16
	10.5		IT-3-1.5	1 11/16
8.5	11	RAS-10.5	IT-3-0.5	11/16
	11.5		IT-3-1	1 3/16
	12		IT-3-1.5	1 11/16
10	12.5	RAS-12	IT-3-0.5	11/16
	13		IT-3-1	1 3/16
	13.5		IT-3-1.5	1 11/16
11.5	14	RAS-13.5	IT-3-0.5	11/16
	14.5		IT-3-1	1 3/16
	15		IT-3-1.5	1 11/16
13	15.5	RAS-15	IT-3-0.5	11/16
	16		IT-3-1	1 3/16
	16.5		IT-3-1.5	1 11/16
14.5	17	RAS-16.5	IT-3-0.5	11/16
	17.5		IT-3-1	1 3/16
	18		IT-3-1.5	1 11/16
16	18.5	RAS-18	IT-3-0.5	11/16
	19		IT-3-1	1 3/16
	19.5		IT-3-1.5	1 11/16

Ordering Information

When ordering
IT-3 Series Beam
Hangers
the alloy must
be specified
(Example: IT-3-1.5-304).

RAS-Series & IT-4 Series Anchor Rod



Temperature Limit at this Point

304 Alloy: 1600°F (870°C)
309 Alloy: 1650°F (899°C)
310 Alloy: 1700°F (926°C)

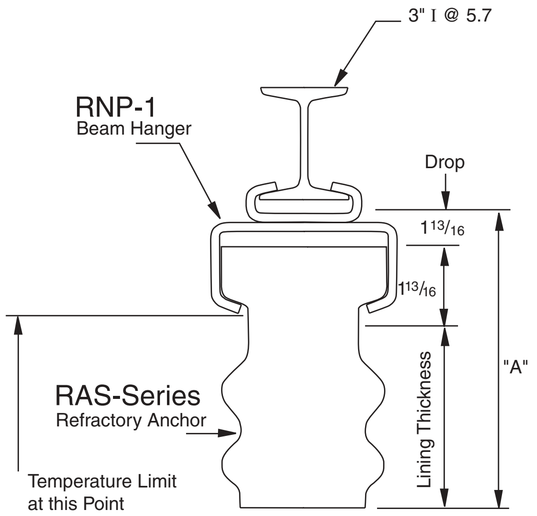
Maximum Lining Thickness (In.)	"A" (In.)	Refractory Anchor	Anchor Rod	Drop (In.)
5.5	8	RAS-7.5	IT-4-0.5	$^{11}/_{16}$
	8.5		IT-4-1	$1^{3}/_{16}$
	9		IT-4-1.5	$1^{11}/_{16}$
7	9.5	RAS-9	IT-4-0.5	$^{11}/_{16}$
	10		IT-4-1	$1^{3}/_{16}$
	10.5		IT-4-1.5	$1^{11}/_{16}$
8.5	11	RAS-10.5	IT-4-0.5	$^{11}/_{16}$
	11.5		IT-4-1	$1^{3}/_{16}$
	12		IT-4-1.5	$1^{11}/_{16}$
10	12.5	RAS-12	IT-4-0.5	$^{11}/_{16}$
	13		IT-4-1	$1^{3}/_{16}$
	13.5		IT-4-1.5	$1^{11}/_{16}$
11.5	14	RAS-13.5	IT-4-0.5	$^{11}/_{16}$
	14.5		IT-4-1	$1^{3}/_{16}$
	15		IT-4-1.5	$1^{11}/_{16}$
13	15.5	RAS-15	IT-4-0.5	$^{11}/_{16}$
	16		IT-4-1	$1^{3}/_{16}$
	16.5		IT-4-1.5	$1^{11}/_{16}$
14.5	17	RAS-16.5	IT-4-0.5	$^{11}/_{16}$
	17.5		IT-4-1	$1^{3}/_{16}$
	18		IT-4-1.5	$1^{11}/_{16}$
16	18.5	RAS-18	IT-4-0.5	$^{11}/_{16}$
	19		IT-4-1	$1^{3}/_{16}$
	19.5		IT-4-1.5	$1^{11}/_{16}$

Ordering Information

When ordering
IT-4 Series Beam Hangers
the alloy must
be specified
(Example: IT-4-1.5-304).

REFRACTORY ANCHORS RAS & H-W 3184 SERIES

RAS-Series & RNP-1 Beam Hanger



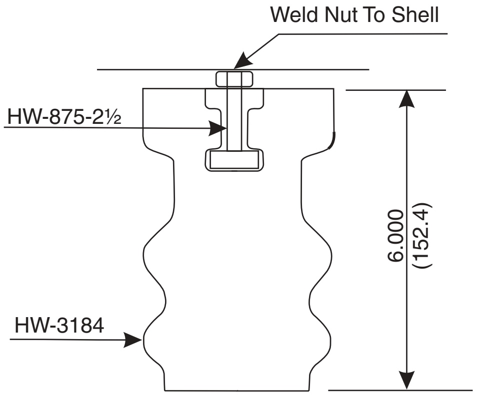
304 Alloy: 1600°F (870°C)	
309 Alloy: 1650°F (899°C)	
310 Alloy: 1700°F (926°C)	

Ordering Information

When ordering RNP-1 Beam Hangers the alloy must be specified (Example: RNP-1-304).

Maximum Lining Thickness (In.)	"A" (In.)	Refractory Anchor
5.5	8.5	RAS-7.5
7	10	RAS-9
8.5	11.5	RAS-10.5
10	13	RAS-12
11.5	14.5	RAS-13.5
13	16	RAS-15
14.5	17.5	RAS-16.5
16	19	RAS-18

HW-3184 Anchor Assembly Bolt Arrangement



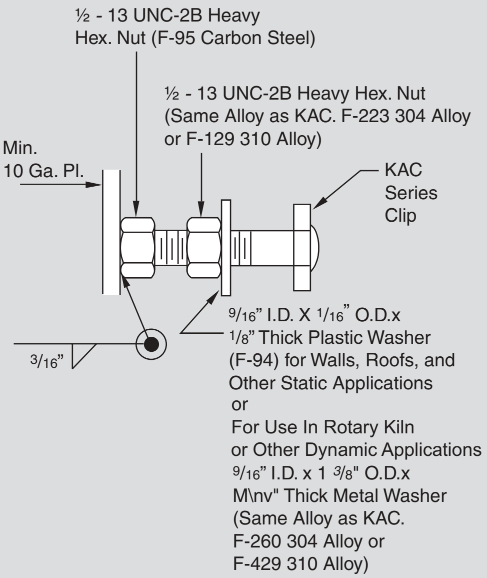
Front View

Lining Thickness (in.)	Refractory Anchor	Anchor Bolt
6	H-W 3184	HW-878-2½
6.5	H-W 3184	HW-878-3
7	H-W 3184	HW-878-3½

Rotary Kiln Anchor Series (RKA)

for Wall Applications

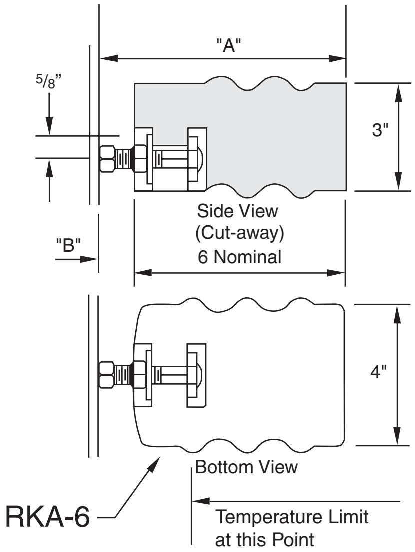
Hardware Assembly Data



Ordering Information

1. When ordering KAC-Series Clips the alloy must be specified. (Example: KAC-2.5-304)
2. Other lengths of KAC Clips can be manufactured upon request.
3. RKA-6, 9, 12 & KAC uses one F-95 Carbon Steel Nut & F-38 Carbon Steel Washer.

RKA-6/KAC Series



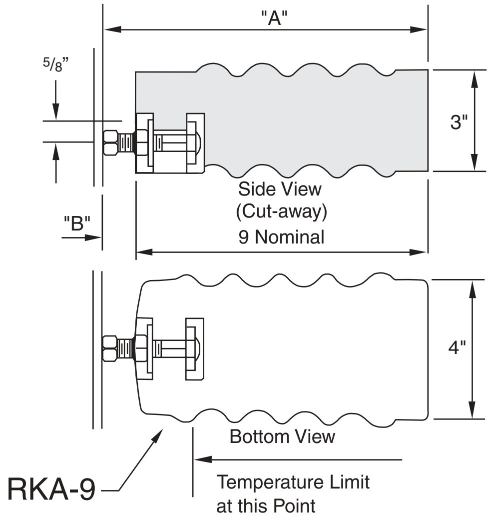
304 Alloy: 1600°F (870°C)
309 Alloy: 1650°F (899°C)
310 Alloy: 1700°F (926°C)

Clip*	“A” (In.)	“B” (In.)
KAC	6	0
KAC-1	7	1
KAC-1.5	7.5	1.5
KAC-2	8	2
KAC-2.5	8.5	2.5
KAC-3	9	3
KAC-3.5	9.5	3.5
KAC-4	10	4
KAC-4.5	10.5	4.5
KAC-5	11	5
KAC-5.5	11.5	5.5
KAC-6	12	6
KAC-6.5	12.5	6.5
KAC-7	13	7
KAC-7.5	13.5	7.5
KAC-8	14	8
KAC-9	15	9

*See Ordering Information at Left.

REFRACTORY ANCHORS RKA/KAC SERIES

RKA-9/KAC Series



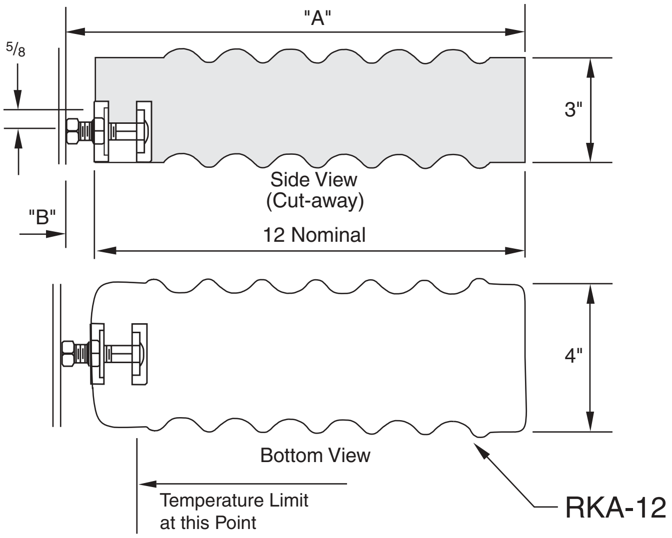
304 Alloy:	1600°F (870°C)
309 Alloy:	1650°F (899°C)
310 Alloy:	1700°F (926°C)

Clip*	"A" (In.)	"B" (In.)
KAC	9	0
KAC-1	10	1
KAC-1.5	10.5	1.5
KAC-2	11	2
KAC-2.5	11.5	2.5
KAC-3	12	3
KAC-3.5	12.5	3.5
KAC-4	13	4
KAC-4.5	13.5	4.5
KAC-5	14	5
KAC-5.5	14.5	5.5
KAC-6	15	6
KAC-7	16	7
KAC-7.5	16.5	7.5
KAC-8	17	8
KAC-9	18	9

Ordering Information

1. When ordering KAC-Series Clips the alloy must be specified. (Example: KAC-2.5-304)
2. Other lengths of KAC Clips can be manufactured upon request.
3. RKA-6, 9, 12 & KAC uses one F-95 Carbon Steel Nut & F-38 Carbon Steel Washer.

RKA-12/KAC Series



304 Alloy:	1600°F (870°C)
309 Alloy:	1650°F (899°C)
310 Alloy:	1700°F (926°C)

Clip*	"A" (In.)	"B" (In.)
KAC	12	0
KAC-1	13	1
KAC-1.5	13.5	1.5
KAC-2	14	2
KAC-2.5	14.5	2.5
KAC-3	15	3
KAC-3.5	15.5	3.5
KAC-4	16	4
KAC-4.5	16.5	4.5
KAC-5	17	5
KAC-5.5	17.5	5.5
KAC-6	18	6
KAC-7	19	7
KAC-7.5	19.5	7.5
KAC-8	20	8
KAC-9	21	9

Ordering Information

1. When ordering KAC-Series Clips the alloy must be specified. (Example: KAC-2.5-304)
2. Other lengths of KAC Clips can be manufactured upon request.
3. RKA-6, 9, 12 & KAC uses one F-95 Carbon Steel Nut & F-38 Carbon Steel Washer.

CUSTOM ANCHORS

Roof Anchors

Harbison-Walker supplies a variety of pre-welded metal anchor assemblies referred to as the HW 20 Series. Although these assembles are adaptable for wall construction, they are most often used in roofs, suspended from supporting steelwork.

Bullnose Anchors

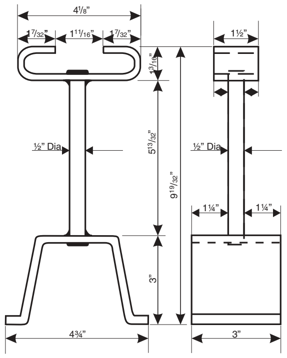
Pre-welded metal anchor assemblies can be used where the shell geometry does not allow for conventional ceramic anchor or wire anchors to be used. These are generally fabricated from 310ss.

Special Roof Anchors

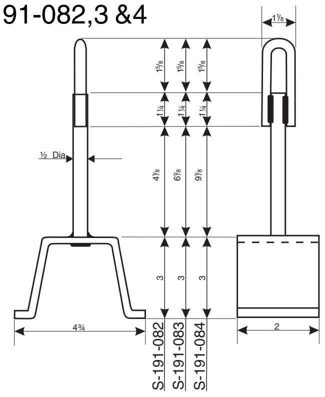
Other available roof anchor assemblies include the S-191-075 pre-welded assembly and the S-191-082, S-191-083, S-191-084 special nose anchors shown below.

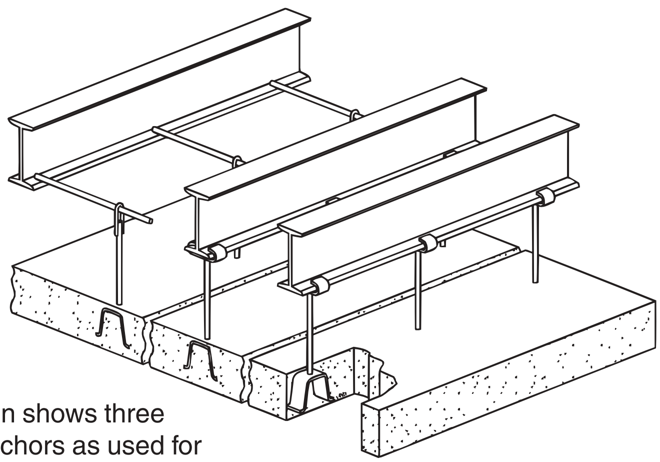
Contact your local H-W representative for more detailed anchor drawings.

S-191-075

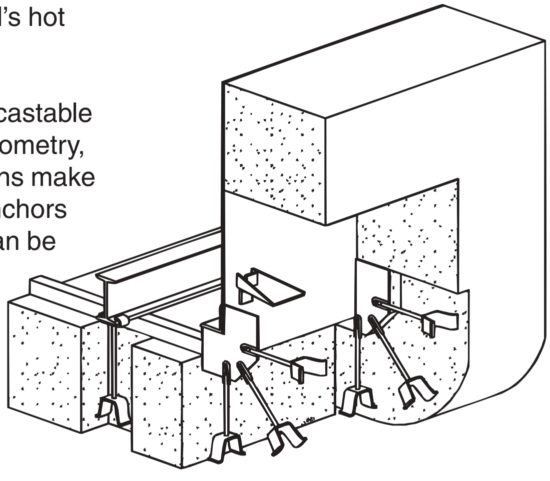


S-191-082,3 &4





(Above) Illustration shows three different metal anchors as used for roof construction. The metallic anchors are suspended from overhead rods, pipes or I-beams and extend into the refractory mass to within approximately one inch of the vessel's hot face.



(Below) In some plastic and castable installations where vessel geometry, loading or other considerations make the use of wire or ceramic anchors impractical, metal anchors can be used. An example of this usage is the bull nose configuration illustrated.

Special Roof Anchors

Assembly No.	Dim A	Dim B	Typical Support Member
HW-20-247-F	6 11/16"	3 15/16"	3 or 4-inch I-beam
HW-20-247-F-90			
HW-20-249-F	8 9/16"	5 13/16"	3 or 4-inch I-beam
HW-20-249-F-90			
HW-20-2412-F	11 7/16"	8 11/16"	3 or 4-inch I-beam
HW-20-2412-F-90			
HW-20-548-F	9 3/4"	7"	5-inch I-beam
HW-20-548-F-90			

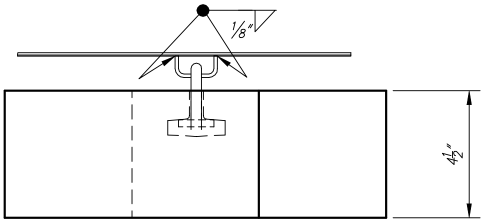
3-inch I-beam, 5.7 pounds per foot; 4-inch I-beam, 7.7 pounds per foot
"90" assembly indicates anchor shank is turned 90 degrees to assembly without "90"

Suggested Spacing for Ceramic Refractory Anchors

Locations	Lining Thickness (In.)	Anchoring Spacing (in.)
Vertical and circular units	9-12	15
	12-15	18
	15+	24
Roofs, noses and arches	6+	12

ANCHORS TIE BACK SYSTEM

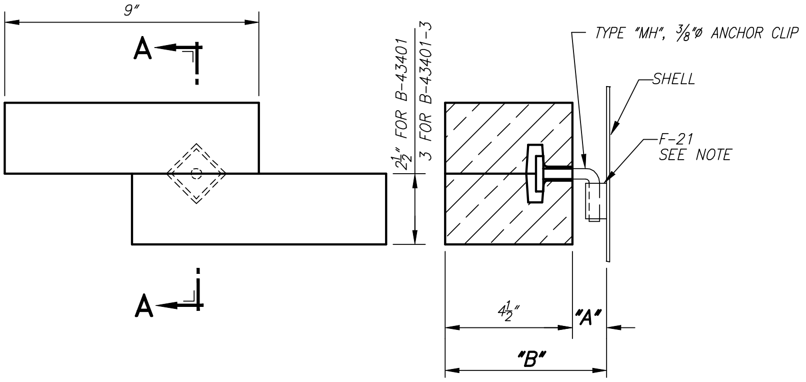
B-43401 & B-43401-3
Anchor Assembly



PLAN VIEW

NOTE:
To insure proper location of brick anchors, weld F-21 clip to steel shell as brickwork progress.

"A"	"B"	PART NO.
1"	5½"	MH-100
1½"	6"	MH-200
2"	6½"	MH-205
2½"	7"	MH-300
3"	7½"	MH-301
3½"	8"	MH-401
4"	8½"	MH-403
4½"	8½"	MH-501
5½"	10"	MH-601
6"	10½"	MH-607

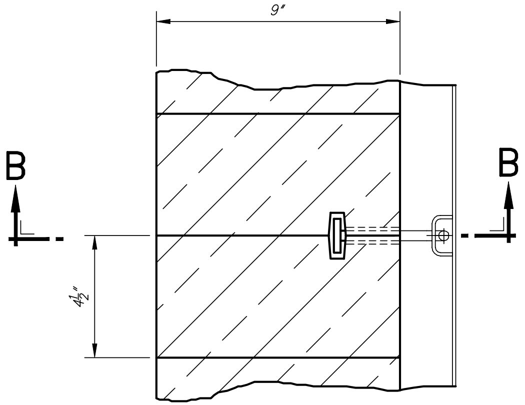


SECTION A-A

B-43401 (2½" STRAIGHTS)
B-43401-3 (3" STRAIGHTS)

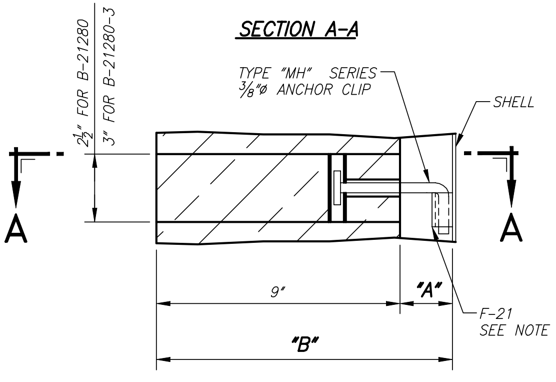
B-21280 & B-2180-3
Anchor Assembly

NOTE:
To insure proper location of B-2180 anchors, weld F-21 clip to steel shell as brickwork progress.



SECTION A-A

"A"	"B"	PART NO.
1"	10"	MH-204
2"	11"	MH-302
2½"	11½"	MH-400
3"	12"	MH-402
3½"	12½"	MH-500
4½"	13½"	MH-600
5"	14"	MH-608



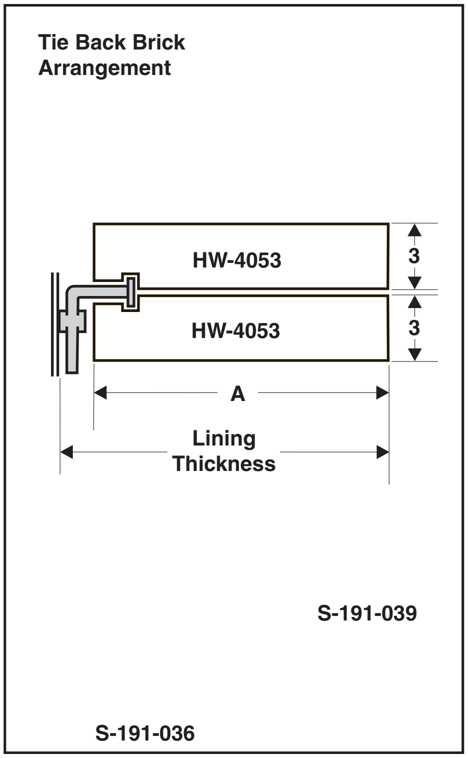
SECTION B-B

B-21280 (2½" STRAIGHTS)
B-21280-3 (3" STRAIGHTS)

HW-4053– Wall Tie-Back Brick–

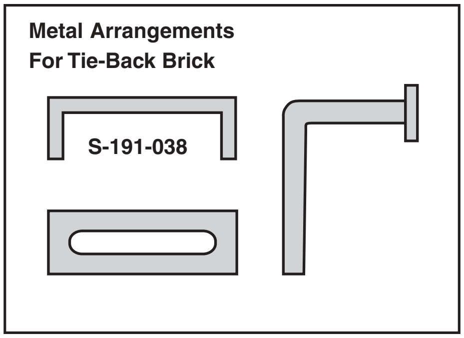
In large refractory brick walls or those subject to particularly severe operational problems, tie-back brick are used to help maintain the structural integrity of the brick wall. Harbison-Walker supplies the HW-4053 brick shape in several refractory compositions and lengths. Tie-back plates and clip assembly (S-191-038/039) are used.

Tie-back brick may be located at intervals as close as 12 inches on the vertical and 2 to 3 feet on the horizontal, and are dependent on structural and load considerations. Please review these arrangements with your Harbison-Walker representative.



Tie Back Brick Arrangement

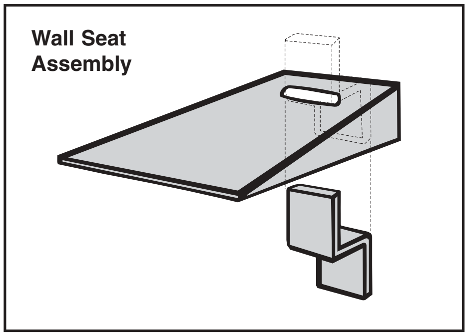
HW-4053		
Shape Number	Lining Thickness	A
HW-4053-6	6	4½
HW-4053-9	9	7½
HW-4053-10½	10½	9
HW-4053-12	12	10½
HW-4053-13½	13½	12
HW-4053-15	15	13½
HW-4053-18	18	16½



Metal Arrangements For Tie-Back Brick

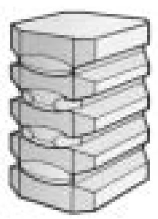
Wall Seat Assembly

To reduce the stresses placed on anchors, wall seat assemblies like H-W WS Wall Seat with WSC Clip's should be used where extremely heavy vertical or sloping wall loads are encountered. Wall seat are also important in areas above arches, ports or bull noses that might collapse under heavy loading. Consider wall seats when using a dense monolith over 6 inches thick and /or 4 feet or more in height. Wall seats are available in lengths from 5 to 10 inches. The HW WSC can be welded to the vessel shell.

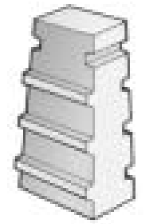


Wall Seat Assembly

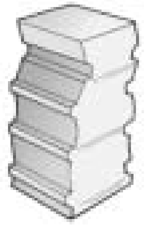
NON-STANDARD CREAMIC ANCHORS & “V” METALLIC ANCHORS



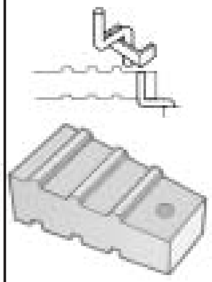
876 Series



TC Series



WC Series



TI Anchor

The ceramic anchor systems shown here are nonstandard systems that can be ordered. Standard stock ceramic anchors are available in the RAS, RAH and RKA series.

Ceramic Anchors

876 Series
Refractory anchor designed to accept slipover castings. Primary use is in roof construction, but this anchor may be used in wall construction applications with the use of C-Clips.

WC Series
Refractory wiggle anchor made in UFALA® brand only. This anchor maintains a constant cross section of 4½" x 4½". This is primarily a roof and bullnose anchor.

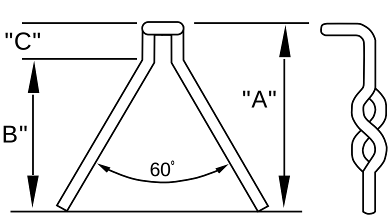
TC Series
Refractory tapered anchor for use in roof construction. Made in UFALA® brand, this anchor accepts a variety of C-Clip and slipover castings, depending on application. The tapered design helps wedge the refractory lining in addition to the tongues and grooves.

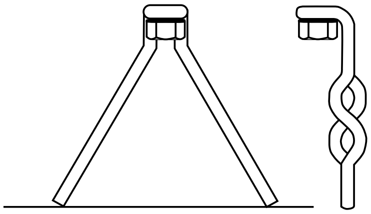
TI Series
Refractory tapered anchors for use in wall construction. Available in UFALA® brand, these anchors are attached with Z-RODS to the sidewall. They provide flexible attachment to accommodate lining thicknesses from 9 to 18 inches. There are

“V” Metallic Anchor Series (VS) and (QVS)

for Roof and Wall Applications

VS and QVS Series





VS or QVS Series
with Welded Nut

Bolting

“VS” & “QVS” (-N-Series) anchors, -80-N and smaller, use ⅜” diameter bolt or stud.
“VS” & “QVS” (-N-Series) anchors, -90-N and longer, use ½” diameter bolt or stud.

Rod Diameters

“QVS”-15 thru -100 (-N-Series) anchors are all ¼” diameter rod.
“VS”-15 thru -80 (-N-Series) anchors are 5/16” diameter rod.
“VS”-90 thru -200 (-N-Series) anchors are ⅜” diameter rod.

Dimension Table (In.)

Brand	Brand	Brand	Brand	“A”	“B”	“C”
VS-15/10	QVS-15/10	VS-15	QVS-15	1½	1½	
VS-20/15	QVS-20/15	VS-20	QVS-20	2⅛	2⅛	
VS-25/20	QVS-25/20	VS-25	QVS-25	2⅝	2⅝	
VS-30/25	QVS-30/25	VS-30	QVS-30	3⅛	3⅛	
VS-35/30	QVS-35/30	VS-35	QVS-35	3⅝	2⅝	1
VS-40/35	QVS-40/35	VS-40	QVS-40	4¼	3½	¾
VS-50/45	QVS-50/45	VS-50	QVS-50	5	4	1
VS-60/55	QVS-60/55	VS-60	QVS-60	6	4	2
VS-70/65	QVS-70/65	VS-70	QVS-70	7	4	3
VS-80/75	QVS-80/75	VS-80	QVS-80	8	4	4
VS-90/85	QVS-90/85	VS-90	QVS-90	9	4	5
VS-100/95	QVS-100/95	VS-100	QVS-100	10	5	5
VS-110/105		VS-110		11	6	5
VS-120/115		VS-120		12	6	6

Note: These anchors are not standard stock.
When ordering “VS” & “QVS” (-N-Series) anchors alloy must be specified.
(Example VS-50-N-304)

Cross refrerence chart is on page IR-82

CROSS REFERENCE

Cross Reference Table for Single Component Wire Anchors

H-W ANCHOR	ANCHOR DIA.	BRAND	BRAND	BRAND	BRAND
1A-1 ½	¼" DIA.	VS-15/10	VS-15	QVS-15/10	QVS-15
1A-2	¼" DIA.	VS-20/15	VS-20	QVS-20/15	QVS-20
1A-2 ½	¼" DIA.	VS-25/20	VS-25	QVS-25/20	QVS-25
1A-3	¼" DIA.	VS-30/25	VS-30	QVS-30/25	QVS-30
2A-3 ½	¼" DIA.	VS-35/30	VS-35	QVS-35/30	QVS-35
2A-4	¼" DIA.	VS-40/35	VS-40	QVS-40/35	QVS-40
2A-5	5⁄16" DIA.	VS-50/45	VS-50	QVS-50/45	QVS-50
3A-6	5⁄16" DIA.	VS-60/55	VS-60	QVS-60/55	QVS-60
3A-7	5⁄16" DIA.	VS-70/65	VS-70	QVS-70/65	QVS-70
3A-8	3⁄8" DIA.	VS-80/75	VS-80	QVS-80/75	QVS-80
3A-9- 3⁄8	3⁄8" DIA.	VS-90/85	VS-90	QVS-90/85	QVS-90
3A-10- 3⁄8	3⁄8" DIA.	VS-100/95	VS-100	QVS-100/95	QVS-100
3A-11- 3⁄8	3⁄8" DIA.	VS-110/105	VS-110		
3A-12- 3⁄8	3⁄8" DIA.	VS-120/115	VS-120		
3A-12 ½- 3⁄8	3⁄8" DIA.				
3A-13- 3⁄8	3⁄8" DIA.				

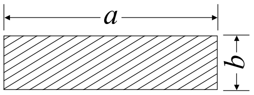
SECTION 8

Appendix

AREA AND VOLUME

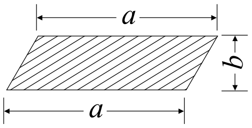
The following simple formulas make it possible to calculate the area and volume associated with most refractory structures. No matter how complex the shape of a figure, it is possible to derive a working approximation by dividing it by straight lines and arcs into a distinct number of units whose areas may be calculated and summed by simple arithmetic. Volumes of regular figures will equal the area of a surface multiplied by its length or height. Volumes of shells are inside volume subtracted from outside volume.

RECTANGLE



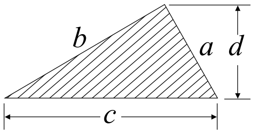
Area = ab

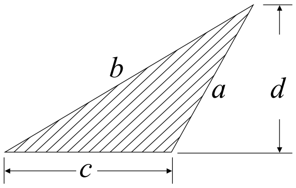
PARALLELOGRAM



Area = ab

TRIANGLE



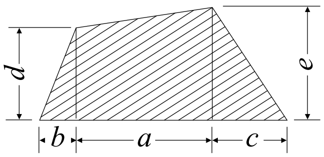


Area = ½cd

Area = $\sqrt{s(s-a)\ (s-b)\ (s-c)}$

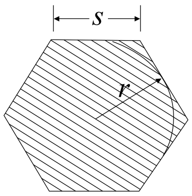
when s = ½(a + b+ c)

TRAPEZIUM



Area = ½ [s(e+d)+bd+ce]

REGULAR POLYGON

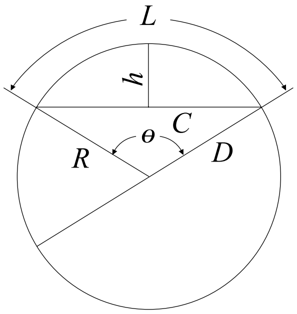


Area = ½ nsr

when n = Number of sides

Number of Sides	Area
6	2.5981s^2 = 3.4641r^2
6	4.8284s^2 = 3.3137r^2
6	6.1818s^2 = 3.2757r^2
10	7.6942s^2 = 3.2492r^2
12	11.1962s^2 = 3.2154r^2

CIRCLE



θ (Theta) = included angle in degrees.

π (pi) = 3.1416

Circumference =
$\pi D = 2\pi R = 2\sqrt{\pi \text{ x Area}}$

Diameter, $D = 2R = 2\sqrt{\text{Area} \div \pi}$

Radius, $R = \frac{1}{2} D = \sqrt{\text{Area} \div \pi}$

Radius, $R = \text{Circumference} \div 2\pi$

Radius, $R = \dfrac{(C \div 2)^2 + h^2}{2h}$

Area = $0.7854D^2 = \pi R^2$

Chord. C = $2\sqrt{h(D-h)} = 2R \text{ x sine } \frac{1}{2}\theta$

Height of Arc, $h = R - \sqrt{R^2 - (C \div 2)^2}$

Height of Arc, $h = R - \frac{1}{2}\sqrt{(2R+C)\ (2R-C)}$

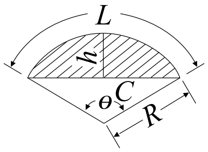
Length of Arc, $L = \dfrac{\theta}{360} \text{ x } 2\pi R = 0.017453R\ \theta$

$\frac{1}{2}\theta = 28.648L \div R$

Sine $\frac{1}{2}\theta = C \div 2R$

$1^\circ = 0.017453$ Radians, 1 radian $= 57.296^\circ$

SEGMENT OF A CIRCLE

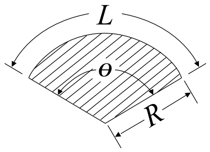


Tangent $\frac{1}{4}\theta = \dfrac{2h}{C}$

Area = $\frac{1}{2}\left[LR - C(R-h)\right]$

Area = $\pi R^2 \text{ x } \dfrac{\theta}{360} - \dfrac{C(R-h)}{2}$

SECTOF OF A CIRCLE

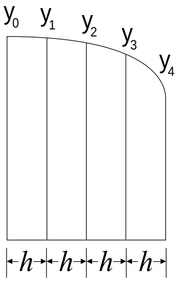


Area = $\frac{1}{2} LR$

Area = $\pi R^2 \text{ x } \dfrac{\theta}{360}$

Area = $0.0087266R^2\ \theta$

THE TRAPEZOIDAL RULE

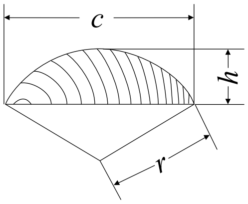


Area = $h(\frac{1}{2}y_0 + y_1 + y_2 + y_3 + \frac{1}{2}y_4)$ approximately

h = distance between equally spaced ordinates

y_n = length of appropriate ordinate

SEGMENT OF A SPHERE



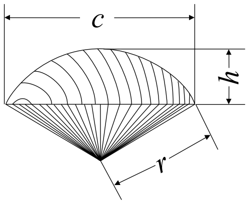
Spherical Surface =
$2\pi rh = 0.7854(c^2+4h^2)$

Total Surface = $0.7854(c^2 + 8rh)$

Volume = $\frac{1}{3}\pi h^2(3r - h) = 1.0472h^2(3r - h)$

Volume = $\frac{1}{24}\pi h(3c^2 + 4h^2) = 0.1309h(3c^2 + 4h^2)$

SEGTOR OR A SPHERE

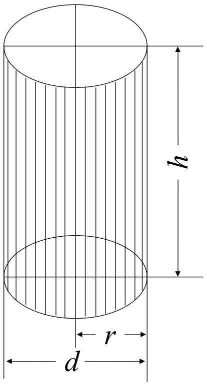


Total Surface = $1.5708r(4h + c)$

Volume = $\frac{2}{3}\pi r^2h = 2.0944r^2h$

CYLINDER

Volume = $\pi h^2(3r - h) = 1.0472h^2(3r - h)$



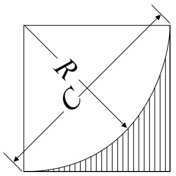
Cylindrical Surface =
$\pi dh = 2\pi rh = 6.2832rh$

Total Surface =
$2\pi r(r + h) = 6.2832r(r + h)$

Volume =
$\pi r^2h = \frac{1}{4}\pi d^2h = 0.7854d^2h$

AREA AND VOLUME

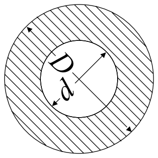
SPANDREL



$\text{Area} = 0.2146R^2$

$\text{Area} = 0.1073C^2$

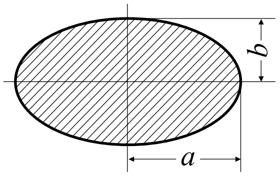
CIRCULAR RING



$\text{Area} = 0.7854(D^2 - d^2)$

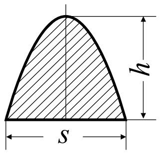
$\text{Area} = 0.7854(D+d)\ (D-d)$

ELLIPSE



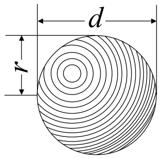
$\text{Area} = \pi ab = 3.1416ab$

PARABOLIC SEGMENT



$\text{Area} = \tfrac{2}{3}\,sh$

SPHERE

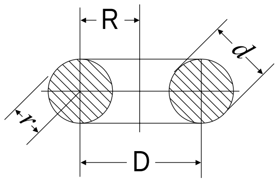


$\text{Surface} = 4\pi r^2 = 12.566r^2 = \pi d^2$

$\text{Volume} = \tfrac{4}{3}\,\pi r^3 = 4.1888r^3$

$\text{Volume} = \tfrac{1}{6}\,\pi d^3 = 0.5236d^3$

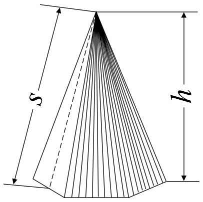
RING OF CIRCULAR CROSS SECTION (Torus)



$\text{Area of Surface} = 4\pi^2 Rr = 39.478Rr$

$\text{Volume} = 2\pi^2 Rr^2 = 19.739Rr^2$

PYRAMID



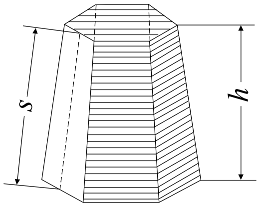
A = area of base

P = perimeter of base

Lateral Area = $\frac{1}{2}Ps$

Volume = $\frac{1}{3}$ Ah

FRUSTUM OF A PYRAMID



a = Area of base

a = Area of top

m = Area of midsection

P = Perimeter of base

p = Perimeter of top

Lateral Area = $\frac{1}{2}s(P+p)$

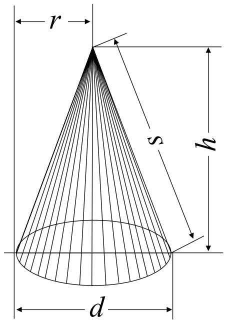
Volume = $\frac{1}{3}h(a+A+\sqrt{aA})$

Volume = $\frac{1}{6}h(a+A+4m)$

CONE

Conical Area =
$\pi rs = \pi r\sqrt{r^2+h^2}$

Volume = $\frac{1}{3}\pi r^2 h$ =
$1.0472r^2h$ = $0.2618d^2h$



FRUSTUM OF A CONE

A = Area of base

a = Area of top

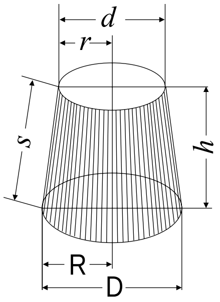
m = Area of midsection

Area of Conical Surface = $\frac{1}{2} \pi s(D+d)$

Volume = $\frac{1}{3} \pi h(r^2 + rR + R^2)$

Volume = $h(a + \sqrt{aA} + A)$

Volume = $\frac{1}{6} h(a + 4m + A)$



REFERENCE TABLE

Decimal Fractions of an Inch for Each 1/64

Common Fraction	Decimal	Common Fraction	Decimal
		1/2	.5
1/64	.015625	33/64	.515625
1/32	.03125	17/32	.53125
3/64	.046875	35/64	.546875
1/16	.0625	9/16	.5625
5/64	.078125	37/64	.578125
3/32	.09375	19/32	.59375
7/64	.109325	39/64	.609375
1/8	.125	5/8	.625
9/64	.140625	41/64	.640625
5/32	.15625	21/32	.65625
11/64	.171875	43/64	.671875
3/16	.1875	11/16	.6875
13/64	.203125	45/64	.703125
7/32	.21875	23/32	.71875
15/64	.234375	47/64	.734375
1/4	.25	3/4	.75
17/64	.265625	49/64	.765625
9/32	.28125	25/32	.78125
19/64	.296875	51/64	.796875
5/16	.3125	13/16	.8125
21/64	.328125	53/64	.828125
11/32	.34375	27/32	.84375
23/64	.359375	55/64	.859375
3/8	.375	7/8	.875
25/64	.390625	57/64	.890625
13/32	.40625	29/32	.90625
27/64	.421875	59/64	.921875
7/16	.4375	15/16	.9375
29/64	.453125	61/64	.953125
15/32	.46875	31/32	.96875
31/64	.484375	63/64	.984375

Atomic Weights of Selected Elements*

Name	Symbol	Atomic Number	Weight
Aluminum	Al	13	26.9815
Antimony	Sb	51	121.75
Argon	Ar	18	39.948
Arsenic	As	33	74.9216
Barium	Ba	56	137.34
Beryllium	Be	4	9.01218
Bismuth	Bi	83	208.9806
Boron	B	5	10.81
Bromine	Br	35	79.904
Cadmium	Cd	48	112.40
Calcium	Ca	20	40.08
Carbon	C	6	12.011
Chlorine	Cl	17	35.453
Chromium	Cr	24	51.996
Cobalt	Co	27	58.9332
Copper	Cu	29	63.54
Fluorine	F	9	18.9984
Gold	Au	79	196.9665
Helium	He	2	4.003
Hydrogen	H	1	1.0079
Iodine	I	53	126.9045
Iron	Fe	26	55.84
Krypton	Kr	36	83.80
Lead	Pb	82	207.2
Lithium	Li	3	6.941
Magnesium	Mg	12	24.305
Manganese	Mn	25	54.9380
Mercury	Hg	80	200.59
Molybdenum	Mo	42	95.94
Neon	Ne	10	20.17
Nickel	Ni	28	58.70
Nitrogen	N	7	14.0067
Oxygen	O	8	15.9994
Phosphorous	P	15	30.9738
Platinum	Pt	78	195.09
Potassium	K	19	39.098
Silicon	Si	14	28.08
Silver	Ag	47	107.868
Sodium	Na	11	22.9898
Sulfur	S	16	32.06
Tin	Sn	50	118.69
Titanium	Ti	22	47.90
Tungsten	W	74	183.85
Uranium	U	92	238.029
Vanadium	V	23	50.9414
Xenon	Xe	54	131.30
Zinc	Zn	30	65.38
Zirconium	Zr	40	91.22

*International Atomic Weights (1970).

Melting Points of Selected Metals and Alloys*

	Degrees Fahrenheit	Degrees Centigrade	Degrees Kelvin
Aluminum	1220	660	933
Antimony	1166.9	630.5	903.6
Beryllium	2341	1283	1556
Cadmium	609.6	320.9	594.258
Chromium	~3445	~1895	2130
Cobalt	2718	1492	1768
Columbium	4380	2415	2743
Copper			
(reducing atmosphere)	1981	1083	1366.6
Gold	1945.4	1063.0	1336.2
Iridium	4430	2443	2727
Iron, pure	2795	1535	1809
Cast iron, white	~2100	~1150	~1423
Cast iron, gray	~2245	~1230	~1503
Steel, plain carbon			
(1% carbon and less)	~2680	~1470	
Lead	621.1	327.3	600.58
Magnesium	1202	650	922±0.5
Molybdenum	~4750	~2620	~2892±10
Nickel	2647	1453	1744
Palladium	2826	1552	1827
Platinum	3216	1769	2045
Rhodium	3560	1960	2236
Silver	1761.4	960.8	1235.08
Tantalum	5425	2996	3258±10
Tin	449.4	231.9	505.1181
Titanium	~3034	~1668	1933±10
Tungsten	6115	3380	3660±20
Uranium	2071	1133	
Vanadium	~3450	~1900	~2190
Zinc	787.1	419.5	692.73
Zirconium	~3360	~1850	2125±20

Melting Points of Selected Mineral Oxides*

Chromic Oxide	(Cr_2O_3)	~4080	~2250	2603±15
Corundum	(Al_2O_3)	~3720	~2050	2327±6
Cristobalite	(SiO_2)	3133	1723	1996±5
Lime	(CaO)	~4660	~2570	~3200±50
Magnetite	(Fe_3O_4)	2901	1594	1864±5
Periclase	(MgO)	~5070	~2800	3098±20
Rutile	(TiO_2)	3326	1830	2130±20
Zirconia				
Unstabilized	(ZrO_2)	4890	2700	3123
5% Calcia stabilized	(ZrO_2)	4710	2599	~2872
7% Calcia stabilized	(ZrO_2)	4532	2500	~2773

* In converting temperatures from Centigrade to Fahrenheit, temperatures above 3,300°F are given to the nearest five degrees.
~ = Approximate.

REFERENCE TABLE

Conversion Table

To Convert	Multiply By:	To Obtain:
BTU	7.7816 x 10^{2}	foot-pounds
BTU	2.52 x 10^{2}	gram-calories
BTU	2.52 x 10^{-1}	kilogram-calories
BTU/Hr	7.0 x 10^{-2}	gram-cal/sec
°C	(°C x 1.8) + 32	Fahrenheit
centimeters	3.281 x 10^{-2}	feet
centimeters	3.937 x 10^{-2}	inches
cubic centimeters	3.531 x 10^{-5}	cubic feet
cubic centimeters	6.102 x 10^{-2}	cubic inches
cubic centimeters	1.308 x 10^{-6}	cubic yards
cubic centimeters	2.642 x 10^{-4}	gallons (U.S. liquid)
cubic centimeters	1.0 x 10^{-3}	liters
cubic feet	2.832 x 10^{4}	cubic centimeters
cubic feet	1.728 x 10^{3}	cubic inches
cubic feet	2.832 x 10^{-2}	cubic meters
cubic feet	3.704 x 10^{-2}	cubic yards
cubic inches	16.39	cubic centimeters
cubic inches	5.787 x 10^{-4}	cubic feet
cubic inches	1.639 x 10^{-5}	cubic meters
cubic inches	2.143 x 10^{-5}	cubic yards
cubic meters	35.31	cubic feet
cubic meters	6.102 x 10^{4}	cubic inches
cubic meters	1.308	cubic yards
cubic meters	1.0 x 10^{3}	liters
cubic meters	2.642 x 10^{2}	gallons (U.S. liquid)
cubic yards	7.646 x 10^{5}	cubic centimeters
cubic yards	27	cubic feet
cubic yards	0.7646	cubic meters
°Fahrenheit	.556(F-32)	Centigrade or Celsius
feet	30.48	centimeters
feet	0.3048	meters
feet	3.048 x 10^{2}	millimeters
gallons	3.785 x 10^{3}	cubic centimeters
gallons	0.134	cubic feet
gallons	3.785 x 10^{-3}	cubic meters
gallons	4.951 x 10^{-3}	cubic yards
gallons	3.785	liters
grams	3.527 x 10^{-2}	ounces (avdp.)
grams	2.205 x 10^{-3}	pounds
grams/cm^{3}	62.43	pounds/ft^{3}
grams/cm^{2}	2.0481	pounds/sq/ft
grams-calories	3.968 x 10^{-3}	BTU

Conversion Table - continued		
To Convert	**Multiply By:**	**To Obtain:**
inches inches	2.540 25.4	centimeters millimeters
kilograms kilograms/meters^3 kilometers	2.2046 6.243×10^{-2} 0.6214	pounds pounds/ft^3 miles (statute)
liters liters liters liters liters	3.531×10^{-2} 61.02 1.0×10^{-3} 1.308×10^{-3} 0.2642	cubic feet cubic inches cubic meters cubic yards gallons (U.S. liquid)
miles (statute) millimeters	1.609 3.937×10^{-2}	kilometers inches
ounces	28.349	grams
pounds pounds pounds of water pounds of water pounds/ft^3 pounds/ft^3 pounds/in^3 pounds/in^2 quarts (liquid) quarts (liquid) quarts (liquid) quarts (liquid)	4.536×10^{2} 0.4536 27.68 0.1198 1.602×10^{-2} 16.02 27.68 7.03×10^{-2} 9.464×10^{2} 3.342×10^{-2} 1.238×10^{-3} 0.9463	grams kilograms cubic inches gallons grams/cm^3 kgs/meter^3 grams/cm^3 kgs/cm^2 cubic centimeters cubic feet cubic yards liters
square centimeters square feet square inches	0.1550 9.29×10^{2} 6.452	square inches square centimeters square centimeters
tons (metric) tons (metric) tons (short) tons (short)	1000 2.205×10^{3} 9.0718×10^{2} 0.9078	kilograms pounds kilograms tons (metric)
yards	0.9144	meters

Temperature Scale Conversions

to ^{0}C	Convert ← F or C →	to ^{0}F
-17.78	**0**	32
-12.22	**10**	50
-6.67	**20**	68
-1.11	**30**	86
0.00	**32**	90
4.44	**40**	104
10.00	**50**	122
15.56	**60**	140
21.11	**70**	158
26.67	**80**	176
32.22	**90**	194
37.78	**100**	212
43.33	**110**	230
48.89	**120**	248
54.44	**130**	266
60.00	**140**	284
65.56	**150**	302
71.11	**160**	320
76.67	**170**	338
82.22	**180**	356
87.78	**190**	374
93.33	**200**	392
98.89	**210**	410
100.0	**212**	414
104.4	**220**	428
110.0	**230**	446
115.6	**240**	464
121.1	**250**	482
126.7	**260**	500
132.2	**270**	518
137.8	**280**	536
143.3	**290**	554
148.9	**300**	572
154.4	**310**	590
160.0	**320**	608
165.6	**330**	626
171.1	**340**	644
176.7	**350**	662
182.2	**360**	680
187.8	**370**	698
193.3	**380**	716
198.9	**390**	734
204.4	**400**	752
215.6	**420**	788
226.7	**440**	824
237.8	**460**	860
248.9	**480**	896
260.0	**500**	932
271.1	**520**	968
282.2	**540**	1004
293.3	**560**	1040
304.4	**580**	1076
315.6	**600**	1112
326.7	**620**	1148
337.8	**640**	1184
348.9	**660**	1220
360.0	**680**	1256
371.1	**700**	1292
398.9	**750**	1382
426.7	**800**	1472
454.4	**850**	1562
482.2	**900**	1652
510.0	**950**	1742
537.9	**1000**	1832
565.6	**1050**	1922
593.3	**1100**	2012
621.1	**1150**	2102
648.9	**1200**	2192
676.7	**1250**	2282
704.4	**1300**	2372
732.2	**1350**	2462
760.0	**1400**	2552
787.8	**1450**	2642
815.6	**1500**	2732
843.3	**1550**	2922
871.1	**1600**	2912
898.9	**1650**	3002
926.7	**1700**	3092
954.4	**1750**	3182
982.2	**1800**	3272
1010	**1850**	3362
1038	**1900**	3452
1066	**1950**	3542
1093	**2000**	3632
1121	**2050**	3722
1149	**2100**	3812
1177	**2150**	3902
1204	**2200**	3992
1232	**2250**	4082
1260	**2300**	4172
1288	**2350**	4262
1316	**2400**	4352
1343	**2450**	4442
1371	**2500**	4532
1427	**2600**	4712
1482	**2700**	4892
1538	**2800**	5072
1593	**2900**	5252
1649	**3000**	5432
1704	**3100**	5612
1760	**3200**	5792
1816	**3300**	5972
1871	**3400**	6152
1927	**3500**	6332
1982	**3600**	6512

GLOSSARY

Abrasion of Refractories: Wearing away of the surfaces of refractory bodies in service by the scouring action of moving solids.

Absorption: As applied to ceramic products, the weight of water which can be absorbed by the ware, expressed as a percentage of the weight of the dry ware.

Abutment: The structural portion of a furnace which withstands the thrust of an arch.

Acid-Proof Brick: Brick having low porosity and permeability, and high resistance to chemical attack or penetration by most commercial acids and some other corrosive chemicals.

Acid Refractories: Refractories such as silica brick which contain a substantial proportion of free silica and which when heated, can react chemically with basic refractories, slags and fluxes.

Aggregate: As applied to refractories, a ground mineral material, consisting of particles of various sizes, used with much finer sizes for making formed or monolithic bodies.

Air-Ramming*: A method of forming refractory shapes, furnace hearths, or other furnace parts by means of pneumatic hammers.

Air-Setting Refractories: Compositions of ground refractory materials which develop a strong bond upon drying. These refractories include mortars, plastic refractories, ramming mixes and gunning mixes. They are marketed in both wet and dry condition. The dry compositions require tempering with water to develop the necessary consistency.

Alumina: Al_2O_3, the oxide of aluminum; melting point 3,720°F (2,050°C); in combination with H_2O (water), alumina forms the minerals diaspore, bauxite and gibbsite; in combination with SiO_2 and H_2O, alumina forms kaolinite and other clay minerals.

Alumina-Silica Refractories: Refractories consisting essentially of alumina and silica, and including high-alumina, fireclay and kaolin refractories.

Amorphous: Lacking crystalline structure or definite molecular arrangement; without definite external form.

Andalusite: A brown, yellow, green, red or gray orthorhombic mineral; Al_2SiO_5. Specific gravity 3.1 - 3.2. Decomposes on heating, beginning at about 2,460°F (1,350°C) to form mullite ($Al_6Si_2O_{13}$) and free silica.

Anneal: To remove internal stress by first heating and then cooling slowly.

Arc: As applied to circles, any portion of a circumference; as applied to electricity, the luminous bridge formed by the passage of a current across a gap between two conductors or terminals.

Arch, Flat: In furnace construction, a flat structure spanning an opening and supported by abutments at its extremities. The arch is formed by a number of special tapered brick, and the brick assembly is held in place by the keying action of the brick. Also called a jack arch.

Arch, Sprung: In furnace construction, a bowed or curved structure which is supported by abutments at the sides or ends only, and which usually spans an opening or space between two walls.

Arch, Suspended: A furnace roof consisting of brick shapes suspended from overhead supporting members.

Arch Brick: A brick shape having six plane faces (two sides, two edges and two ends), in which two faces (the sides) are inclined toward each other and one edge face is narrower than the other.

Ash: The noncombustible residue which remains after burning a fuel or other combustible material.

Attrition: Wearing away by friction; abrasion.

Auger Machine: A machine for extruding ground clays in moist and stiffly plastic form, through a die by means of a revolving screw or auger.

Baddeleyite: A mineral composed of zirconia (ZrO_2). Specific gravity 5.8. Melting point 4,890°F (2,700°C).
Bagasse: The fibrous material remaining after the extraction of the juice from sugar cane.

Ball Clay: A highly plastic refractory bond clay of very fine grain, which has a wide range of vitrification and which burns to a light color. Often high in carbonaceous matter.

Basic Refractories: Refractories which consist essentially of magnesia, lime, chrome ore or mixtures of two or more of these and, when heated, can react chemically with acid refractories, slags and fluxes.

Bauxite: An off-white, grayish, brown, yellow, or reddish-brown rock composed of a mixture of various amorphous or crystalline hydrous aluminum oxides and aluminum hydroxides (principally gibbsite, some boehmite), and containing impurities in the form of free silica, silt, iron hydroxides, and especially clay minerals; a highly aluminous laterite.

Bauxitic Clay: A natural mixture of bauxite and clay containing not less than 47% nor more than 65% alumina on a calcined basis.

Bentonite: A kind of clay derived from volcanic ash and characterized by extreme fineness of grain. Its main constituent is the clay mineral montmorillonite. It is somewhat variable in composition and usually contains 5 to 10% of alkalies or alkaline earth oxides. One type has the capacity for absorption of large amounts of water, with enormous increase in volume.

Bessemer Process: An older process for making steel by blowing air through molten pig iron, whereby most of the carbon and impurities are removed by
oxidation. The process is carried out in a vessel known as a converter.

Bloating: Swelling of a refractory when in the thermo-plastic state, caused by temperatures in excess of that for which the material is intended. Bloating impairs the useful properties of refractories. An exception to this rule occurs in one type of ladle brick (See Secondary Expansion).

British Thermal Unit (BTU): The amount of heat required to raise the temperature of one pound of water one degree Fahrenheit at standard barometric pressure.

Brucite: A mineral having the composition $Mg(OH)_2$. Specific gravity 2.38 - 2.40. A soft, waxy, translucent mineral which dissociates at moderate temperatures with the formation of MgO.

Bunker Oil: A heavy fuel oil formed by stabilization of the residual oil remaining after the cracking of crude petroleum.

Burn: The degree of heat treatment to which refractory brick are subjected in the firing

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* ASTM Standard Definitions C 71-88; or ASTM “Tentative Definitions” are used where applicable.

process. Also, the degree to which desired physical and chemical changes have been developed in the firing of a refractory material.

Burning (Firing) of Refractories*: The final heat treatment in a kiln to which refractory brick are subjected in the process of manufacture, for the purpose of developing bond and other necessary physical and chemical properties.

Calcination: A heat treatment to which many ceramic raw materials are subjected, preparatory to further processing or use, for the purpose of driving off volatile chemically combined components and affecting physical changes.

Calcite: A mineral having the composition $CaCO_3$. Specific gravity 2.71 for pure calcite crystals. Calcite is the essential constituent of limestone, chalk and marble and a minor constituent of many other rocks.

Calorie (Large): One thousand small calories.

Calorie (Small): The amount of heat required to raise the temperature of one gram of water one degree Centigrade at standard barometric pressure.

Cap or Crown: The arched roof of a furnace, especially a glass tank furnace.

Carbon Deposition: The deposition of amorphous carbon, resulting from the decomposition of carbon monoxide gas into carbon dioxide and carbon within a critical temperature range. When deposited within the pores of refractory brick, carbon can build up sufficient pressure to destroy the bond and cause the brick to disintegrate.

Carbon Refractory*: A manufactured refractory comprised substantially or entirely of carbon (including graphite).

Carbon-Ceramic Refractory*: A manufactured refractory comprised of carbon (including graphite) and one or more ceramic materials such as fire clay and silicon carbide.

Castable Refractory: A mixture of a heat-resistant aggregate and a heat-resistant hydraulic cement. For use, it is mixed with water and rammed, cast or gunned into place.

Catalyst: A substance which causes or accelerates a chemical change without being permanently affected by the reaction.

Cement: A finely divided substance which is workable when first prepared, but which becomes hard and stonelike as a result of chemical reaction or crystallization; also, the compact groundmass which surrounds and binds together the larger fragments or particles in sedimentary rocks.

Ceramic Bond: In a ceramic body, the mechanical strength developed by a heat treatment which causes the cohesion of adjacent particles.

Ceramics: Originally, ware formed from clay and hardened by the action of heat; the art of making such ware. Current usage includes all refractory materials, cement, lime, plaster, pottery, glass, enamels, glazes, abrasives, electrical insulating products and thermal insulating products made from clay or from other inorganic, nonmetallic mineral substances.

Checkers: Brick used in furnace regenerators to recover heat from outgoing hot gases and later to transmit the heat to cold air or gas entering the furnace; so-called because the brick are arranged in checkerboard patterns, with alternating brick units and open spaces.

Chemically-Bonded Brick: Brick manufactured by processes in which mechanical strength is imparted by chemical bonding agents instead of by firing.

Chord: As applied to circles, a straight line joining any two points on a circumference.

Chrome Brick*: A refractory brick manufactured substantially or entirely of chrome ore.

Chrome-Magnesite Brick: A refractory brick which can be either fired or chemically bonded, manufactured substantially of a mixture of chrome ore and dead-burned magnesite, in which the chrome ore predominates by weight.

Chrome Ore: A rock having as its essential constituent the mineral chromite or chrome spinel, which is a combination of FeO and MgO with Cr_2O_3, Al_2O_3, and usually a small proportion of Fe_2O_3. The composition, which is represented by the formula $(Fe, Mg) (Cr, Al)_2 O_4$, is extremely variable. Refractory grade chrome ore has only minor amounts of accessory minerals and has physical properties that are suitable for the manufacture of refractory products.

Clay: A natural mineral aggregate, consisting essentially of hydrous aluminum silicates (See also Fire Clay).

Colloid: (1) A particle-size range of less than 0.00024 mm, i.e. smaller than clay size; (2) originally, any finely divided substance that does not occur in crystalline form; in a more modern sense, any fine-grained material in suspension, or any such material that can be easily suspended.

Conductivity: The property of conducting heat, electricity or sound.

Congruent Melting: The change of a substance, when heated, from the solid form to a liquid of the same composition. The melting of ice is an example of congruent melting.

Convection: The transfer of heat by the circulation or movement of the heated parts of a liquid or gas.

Corbel: A supporting projection of the face of a wall; an arrangement of brick in a wall in which each course projects beyond the one immediately below it to form a support, baffle or shelf.

Corrosion of Refractories: Deterioration or wearing away of refractory bodies largely at their surface through chemical action of external agencies.

Corundum: A natural or synthetic mineral theoretically consisting solely of alumina (Al_2O_3). Specific gravity 4.00 - 4.02. Melting point 3,720°F (2,050°C). Hardness 9.

Course: A horizontal layer or row of brick in a structure.

Cristobalite: A mineral form of silica (SiO_2); stable from 2,678°F (1,470°C) to the melting point, 3,133°F (1,723°C). Specific gravity 2.32. Cristobalite is an important constituent of silica brick.

Crown: A furnace roof, especially one which is dome-shaped; the highest point of an arch.

Cryptocrystalline: A crystalline structure in which the individual crystals are so small that they cannot be made visible by means of the petrographic microscope, but can be seen with an electron microscope. Various so-called amorphous minerals are actually cryptocrystalline.

Crystal: (1) A homogeneous, solid body of a chemical element, compound or isomorphous mixture having a regularly repeating atomic arrangement that can be outwardly expressed by plane faces; (2) rock crystal.

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* ASTM Standard Definitions C 71-88; or ASTM “Tentative Definitions” are used where applicable.

Crystalline: Composed of crystals.

Dead-Burned Dolomite: A coarsely granular refractory material prepared by firing raw dolomite with or without additives, to a temperature above 2,800°F (1,538°C), so as to form primarily lime and magnesia in a matrix that provides resistance to hydration and carbonation.

Dead-Burned Magnesite: A coarsely granular dense refractory material composed essentially of periclase (crystalline magnesium oxide); prepared by firing raw magnesite (or other substances convertible to magnesia) at temperatures sufficiently high to drive off practically all of the volatile materials, and to affect complete shrinkage of the resultant magnesia, thereby producing hard dense grains which are entirely inert to atmospheric hydration and carbonation and free from excessive shrinkage when again subjected to a high temperature.

De-airing: Removal of air from firebrick mixes in an auger machine before extrusion by means of a partial vacuum.

Density: The mass of a unit volume of a substance. It is usually expressed either in grams per cubic centimeter or in pounds per cubic foot.

Devitrification: The change from a glassy to a crystalline condition.

Diaspore: A mineral having the theoretical composition $Al_2O_3 \cdot H_2O$ (85% alumina; 15% water). Specific gravity 3.45.

Diaspore Clay: A rock consisting essentially of diaspore bonded by flint clay. Commercial diaspore clay of the purest grade usually contains between 70 and 80% alumina after calcination.

Diatomaceous Earth: A hydrous form of silica which is soft, light in weight and consists mainly of microscopic shells of diatoms or other marine organisms. It is widely used for furnace insulation.

Direct Bonded Basic Brick: A fired refractory in which the grains are joined predominantly by a solid state of diffusion mechanism.

Direct Bonded Magnesite-Chrome Brick: A term applied to fired magnesite-chrome compositions when the amount of bonding mineral phase (silicates, forsterite, etc.) present in the matrix is sufficiently low that under microscopic examination the chrome ore grains appear to be bonded “directly” to the magnesite grains. The actual bonding mechanism in this instance is usually a combination of types, of which one may be direct (diffusion) bonding.

Division Wall: Wall dividing any two major sections of a furnace.

Dobie: A molded block of ground clay or other refractory material, usually crudely formed and either raw or fired.

Dolomite: The mineral calcium-magnesium carbonate, $CaMg(CO_3)_2$. Specific gravity 2.85 - 2.95. The rock called dolomite consists mainly of the mineral of that name and can also contain a large amount of the mineral calcite ($CaCO_3$).

Dry Pan: A pan-type rotating grinding machine, equipped with heavy steel rollers or mullers which do the grinding and having slotted plates in the bottom through which the ground material passes out.

Dusting: Conversion of a refractory material, either wholly or in part, into fine powder or dust. Dusting usually results from (1) chemical reactions such as hydration; or (2) mineral inversion accompanied by large and abrupt change in volume, such as the inversion of beta to gamma dicalcium silicate upon cooling.

Dutch Oven: A combustion chamber built outside and connected with a furnace.

Electron Beam Furnace: A furnace in which metals are melted in a vacuum at very high temperatures by bombardment with electrons.

Emissivity, Thermal: The capacity of a material for radiating heat; commonly expressed as a fraction or percentage of the ideal “black body” radiation of heat which is the maximum theoretically possible.

Erosion of Refractories: Mechanical wearing away of the surfaces of refractory bodies in service by the washing action of moving liquids, such as molten slags or metals.

Eutectic Temperature: The lowest melting temperature in a series of mixtures of two or more components.

Exfoliate: To expand and separate into rudely parallel layers or sheets, under the action of physical, thermal or chemical forces producing differential stresses.

Extrusion: A process in which plastic material is forced through a die by the application of pressure.

Fayalite: A mineral having the composition Fe_2SiO_4. Specific gravity 4.0 - 4.1. Melting point 2,201°F (1,205°C).

Feldspar: A group of aluminum silicate minerals with a general formula $MAl(Al,Si)_3O_8$ where M=K, Na, Ca, Br, Rb, Sr and Fe. The most important feldspars are: (1) the potash group, of which orthoclase and microcline (K) are the most common, and (2) the soda-lime group, of which albite (Na) and anorthite (Ca) form the end members of a continuous series of solid solutions. Specific gravity 2.55 - 2.76. Melting points 2,050 to 2,820°F (1,120° to 1,550°C).

Fillet: The concave curve junction of two surfaces which would otherwise meet at an angle. Fillets are used at re-entrant angles in the design of brick shapes to lessen the danger of cracking.

Firebrick: Refractory brick of any type.

Fire Clay: An earthy or stony mineral aggregate which has as the essential constituent hydrous silicates of aluminum with or without free silica; plastic when sufficiently pulverized and wetted, rigid when subsequently dried, and of sufficient purity and refractoriness for use in commercial refractory products.

Fireclay Brick: A refractory brick manufactured substantially or entirely from fire clay.

Flat Arch: An arch in which both outer and inner surfaces are horizontal planes.

Flint: A hard, fine-grained cryto-crystalline rock, composed essentially of silica.

Flint Clay: A hard or flint-like fire clay which has very low natural plasticity and which usually breaks with a smooth or shell-like fracture. Its principal clay mineral is halloysite.

Flux: A substance or mixture which promotes fusion of a solid material by chemical action.

Fluxing: Fusion or melting of a substance as a result of chemical action.

* ASTM Standard Definitions C 71-88; or ASTM “Tentative Definitions” are used where applicable.

Forsterite: A mineral having the composition Mg_2SiO_4. Specific gravity 3.21. Melting point approximately 3,450°F (1,900°C).

Freeze-Plane: An irregular plane lying between the hot face and cold face of a refractory lining — any point on which the temperature corresponds to the freezing point of a liquid phase present on the hot face side of the plane.

Friable: Easily reduced to a granular or powdery condition.

Furnace Chrome: A mortar material prepared from finely ground chrome ore, suitable for laying brick or for patching or daubing in furnaces.

Furnace Magnesite: A mortar material prepared from finely ground dead-burned magnesite, suitable for use as a joint material in laying magnesite brick, and for patching or daubing furnace masonry.

Fused-Cast Refractories: Refractories formed by electrical fusion followed by casting and annealing.

Fused Quartz: Silica in the glassy state produced by melting clear quartz crystalline feed. It is clear without entrapped gas bubbles or other impurities or diluents. Synonyms include quartz glass and vitreous quartz.

Fused Silica: Silica in the glassy or vitreous state produced by arc-melting sand. It always contains gas bubbles. Synonyms include vitreous silica and silica glass.

Fusion: A state of fluidity or flowing in consequence of heat; the softening of a solid body, either through heat alone or through heat and the action of a flux, to such a degree that it will no longer support its own weight, but will slump or flow. Also the union or blending of materials, such as metals, upon melting, with the formation of alloys.

Fusion Point: The temperature at which melting takes place. Most refractory materials have no definite melting points, but soften gradually over a range of temperatures.

Ganister: A dense, high-silica rock (quartzite), suitable for the manufacture of silica brick. Confusion sometimes results from the use of this term, because it is also applied in some parts of the United States to crushed firebrick or to mixtures of either crushed firebrick or silica rock with clay, for use in tamped linings.

Gibbsite: A white or tinted monoclinic mineral; $Al(OH)_3$. Specific gravity 2.3 - 2.4.

Glass*: An inorganic product of fusion which has cooled to a rigid condition without crystallizing.

Grain Magnesite: Dead-burned magnesite in the form of granules, generally ranging in size from about 5/8 inch in diameter to very fine particles.

Grain Size: As applied to ground refractory materials, the relative proportions of particles of different sizes; usually determined by separation into a series of fractions by screening.

Grog: A granular product produced by crushing and grinding calcined or burned refractory material, usually of alumina-silica composition.

Ground Fire Clay: Fire clay or a mixture of fire clays that have been subjected to no mechanical treatment other than crushing and grinding.

Grout: A suspension of mortar material in water, of such consistency that it will flow into vertical open joints when it is poured on horizontal courses of brick masonry.

Gunning: The application of monolithic refractories by means of air-placement guns.

Halloysite: One of the clay minerals; a hydrated silicate of alumina similar in composition to kaolinite, but amorphous and containing more water; $Al_2Si_2O_5(OH)_4 \cdot 2H_2O$.

Header: A brick laid on flat with its longest dimension perpendicular to the face of a wall.

Heat-Setting Refractories: Compositions of ground refractory materials which require relatively high temperatures for the development of an adequate bond, commonly called the ceramic bond.

Hematite: The mineral Fe_2O_3 (red iron ore). Specific gravity 4.9 - 5.3.

High-Alumina Refractories: Alumina-silica refractories containing 45 % or more alumina. The materials used in their production include diaspore, bauxite, gibbsite, kyanite, sillimanite, andalusite and fused alumina (artificial corundum).

High-Duty Fireclay Brick: Fireclay brick which have a PCE not lower than Cone 31½ or above 32½ - 33.

Hydrate (verb): To combine chemically with water.

Hydraulic-Setting Refractories: Compositions of ground refractory materials in which some of the components react chemically with water to form a strong hydraulic bond. These refractories are commonly known as castables.

Illite: A group of three-layer, mica-like minerals of small particle size, intermediate in composition and structure between muscovite and montmorillonite.

Impact Pressing: A process for forming refractory shapes in which the ground particles of refractory material are packed closely together by rapid vibration.

Incongruent Melting: Dissociation of a compound on heating, with the formation of another compound and a liquid of different composition from the original compound.

Ingot Mold: A mold in which ingots are cast.

Insulating Refractories: Lightweight, porous refractories with much lower thermal conductivity and heat-storage capacity than other refractories. Used mostly as backing for brick of higher refractoriness and higher thermal conductivity. These materials provide fuel economy through lower heat losses, increased production due to shorter heat-up time, economy of space (size and weight) because of thinner walls and improved working conditions. Insulating refractories are available as brick or monoliths.

Inversion: A change in crystal form without change in chemical composition; as for example, the change from low-quartz to high-quartz, or, the change from quartz to cristobalite.

Isomorphous Mixture: A type of solid solution in which mineral compounds of analogous chemical composition and closely related crystal habit crystallize together in various proportions.

Jack Arch: See Arch, Flat.

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* ASTM Standard Definitions C 71-88; or ASTM "Tentative Definitions" are used where applicable.

GLOSSARY

Jamb: (1) A vertical structural member forming the side of an opening in a furnace wall; (2) a type of brick shape intended for use in the sides of wall openings.

Kaldo Process (Stora): An oxygen process for making steel.

Kaliophilite: A hexagonal mineral of volcanic origin; $KAlSiO_4$.

Kaolin: A white-burning clay having kaolinite as its chief constituent. Specific gravity 2.4 - 2.6. The PCE of most commercial kaolins ranges from Cone 33 to 35.

Kaolinite: A common white to grayish or yellowish clay mineral; $Al_2Si_2O_5\ (OH)_4$. Kaolinite is the principal constituent of most kaolins and fire clays. Specific gravity is 2.59. The PCE of pure kaolinite is Cone 35.

Key: In furnace construction, the uppermost or the closing brick of a curved arch.

Key Brick: A brick shape having six plane faces (two sides, two edges and two ends), in which two faces (the edges) are inclined toward each other and one of the end faces is narrower than the other.

K-factor: The thermal conductivity of a material, expressed in standard units.

Kyanite (Cyanite): A blue or light-green triclinic mineral; Al_2SiO_5. Specific gravity 3.56 - 3.67. Decomposition begins at about 2,415°F (1,325°C) with the formation of mullite and free silica.

Ladle: A refractory-lined vessel used for the temporary storage or transfer of molten metals.

L-D Process: A process for making steel by blowing oxygen on or through molten pig iron, whereby most of the carbon and impurities are removed by oxidation.

Limestone: A sedimentary rock composed essentially of the mineral calcite ($CaCO_3$) or of calcite mixed with dolomite, $CaMg(CO_3)_2$. Specific gravity 2.6 - 2.8.

Limonite: A mineral consisting of hydrous ferric oxides; the essential component of "brown ore." Specific gravity 3.6 - 4.0.

Lintel: A horizontal member spanning a wall opening.

Loss on Ignition: As applied to chemical analyses, the loss in weight which results from heating a sample of material to a high temperature, after preliminary drying at a temperature just above the boiling point of water. The loss in weight upon drying is called "free moisture"; that which occurs above the boiling point, "loss on ignition."

Low-Duty Fireclay Brick: Fireclay brick which have a PCE not lower than Cone 15 nor higher than 28 - 29.

Magnesioferrite: One of the spinel group of minerals; $(Mg,Fe)Fe_2O_4$. Rarely found in nature; usually constitutes the brown coloring material in magnesite brick. Specific gravity 4.57 - 4.65.

Magnesite: A mineral consisting of magnesium carbonate; $MgCO_3$. A rock containing the mineral magnesite as its essential constituent (See also Magnesite, Caustic and Dead-Burned Magnesite).

Magnesite Brick: A refractory brick manufactured substantially or entirely of dead-burned magnesite which consists essentially of magnesia in crystalline form (periclase).

Magnesite-Carbon Brick: A refractory brick manufactured of substantially magnesite (dead-burned, fused, or a combination thereof) and carbon, which may be in the form of various carbon-bearing materials. Conventional tar-bonded and tar-impregnated brick do not fall into this class. Magnesite-carbon brick are distinct in that carbon is present in the composition to provide specific refractory properties beyond filling pores or acting as a bond.

Magnesite, Caustic: The product obtained by calcining magnesite, or other substances convertible to magnesia, upon heating at a temperature generally not exceeding 2,200°F (1,205°C). The product is readily reactive to water and to atmospheric moisture and carbon dioxide.

Magnesite-Chrome Brick: A refractory brick which can be either fired or chemically bonded, manufactured substantially of a mixture of dead-burned magnesite (magnesia) and refractory chrome ore, in which the magnesite predominates by weight.

Magnesium Hydroxide: The compound of magnesium oxide and chemically combined water; $Mg(OH)_2$. Naturally occurring magnesium hydroxide is known as brucite.

Magnetite: A black, isometric, strongly magnetic, opaque mineral of the spinel group; $(Fe,\ Mg)\ Fe_2O_4$. Specific gravity 5.17 - 5.18. Melting point about 2,901°F (1,594°C).

Medium-Duty Fireclay Brick: A fireclay brick with a PCE value not lower than Cone 29 nor higher than 31 - 31½.

Melting Point: The temperature at which crystalline and liquid phases having the same composition coexist in equilibrium. Metals and most pure crystalline materials have sharp melting points, i.e. they change abruptly from solid to liquid at definite temperatures. However, most refractory materials have no true melting points, but melt progressively over a relatively wide range of temperatures.

Metalkase Brick: Basic brick provided with thin steel casings.

Mica: A group of rock minerals having nearly perfect cleavage in one direction and consisting of thin elastic plates. The most common varieties are muscovite and biotite.

Micron: The one-thousandth part of a millimeter (0.001 mm); a unit of measurement used in microscopy.

Mineral: A mineral species is a natural inorganic substance which is either definite in chemical composition and physical characteristics or which varies in these respects within definite natural limits. Most minerals have a definite crystalline structure; a few are amorphous.

Modulus of Elasticity (Physics): A measure of the elasticity of a solid body; the ratio of stress (force) to strain (deformation) within the elastic limit.

Modulus of Rupture: A measure of the transverse or "crossbreaking" strength of a solid body.

Monolithic Lining: A furnace lining without joints, formed of material which is rammed, cast, gunned or sintered into place.

Monticellite: A colorless or gray mineral related to olivine; $CaMgSiO_4$. Specific gravity 3.1 - 3.25. Melts incongruently at 2,730°F (1,499°C) to form MgO and a liquid.

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* ASTM Standard Definitions C 71-88; or ASTM "Tentative Definitions" are used where applicable.

Montmorillonite: A group of expanding-lattice clay minerals containing variable percentages of one or more of the cations of magnesium, potassium, sodium and calcium. A common constituent of bentonites.

Mortar (Refractory): A finely ground refractory material which becomes plastic when mixed with water and is suitable for use in laying refractory brick.

Mullite: A rare orthorhombic mineral; $Al_6Si_2O_{13}$. Specific gravity 3.15. An important constituent of fireclay and high-alumina brick. Melting point under equilibrium conditions approximately 3,362°F (1,850°C).

Mullite Refractories*: Refractory products consisting predominantly of mullite ($Al_6Si_2O_{13}$) crystals formed either by conversion of one or more of the sillimanite group of minerals or by synthesis from appropriate materials employing either melting or sintering processes.

Muscovite: A mineral of the mica group; $KA_{12}(AlSi_3)O_{10}(OH)_2$. It is usually colorless, whitish or pale brown and is a common mineral in metamorphic and igneous rocks and in some sedimentary rocks.

Nepheline (Nephelite): A hexagonal mineral of the feldspathoid group; $(Na,K)AlSiO_4$. A common reaction product in furnaces wherein slags or vapors of high soda content come into contact with fireclay or high-alumina brick. Stable at 2,278°F (1,248°C) at which temperature it inverts to the artificial mineral carnegieite, which has the same composition, but a different crystalline form. Natural nepheline contains a small amount of potash. Specific gravity 2.67.

Neutral Refractory: A refractory material which is neither acid nor base, such as carbon, chrome or mullite.

Nine Inch Equivalent: A brick volume equal to that of a 9 x 4 $^1/_2$ x 2 $^1/_2$ inch straight brick (101.25 cubic inches); the unit of measurement of brick quantities in the refractories industry.

Nodule Clay: A rock containing aluminous or ferruginous nodules, or both, bonded by flint clay; called “burley” clay or “burley flint” clay in some districts.

Nosean (Noselite): A feldspathoid mineral of the sodalite group; $Na_8Al_6Si_6O_{24}(SO_4)$. It is grayish, bluish or brownish and is related to hauyne.

Nozzle Brick: A tubular refractory shape used in a ladle; contains a hole through which steel is teemed at the bottom of the ladle, the upper end of the shape serving as a seat for the stopper.

Olivine: (l) An olive-green, grayish-green or brown orthorhombic mineral; $(Mg,Fe)2SiO_4$. It comprises the isomorphous solid-solution series forsterite-fayalite. (2) A name applied to a group of minerals forming the isomorphous system $(Mg,Fe,Mn,Ca)\ 2SiO_4$, including forsterite, fayalite, tephroite and a hypothetical calcium orthosilicate. Specific gravity 3.27 - 3.37, increasing with the amount of iron present.

Overfiring: A heat treatment which causes deformation or bloating of clay or clay ware.

Oxiduction: Alternate oxidation and reduction.

Oxygen Process: A process for making steel in which oxygen is blown on or through molten pig iron, whereby most of the carbon and impurities are removed by oxidation.

Periclase: An isometric mineral; MgO. Specific gravity 3.58. Melting point approximately 5,070°F (2,800°C).

Perlite: A siliceous glassy rock composed of small spheroids varying in size from small shot to peas; combined water content 3 to 4 %. When heated to a suitable temperature, perlite expands to form a lightweight glassy material with a cellular structure.

Permeability: The property of porous materials which permits the passage of gases and liquids under pressure. The permeability of a body is largely dependent upon the number, size and shape of the open connecting pores and is measured by the rate of flow of a standard fluid under definite pressure.

Plasma Jet: Ionized gas produced by passing an inert gas through a high-intensity arc causing temperatures up to tens of thousands of degrees centigrade.

Plastic Chrome Ore: An air-setting ramming material having a base of refractory chrome ore and shipped in plastic form ready for use.

Plastic Fire Clay: A fire clay which has sufficient natural plasticity to bond together other materials which have little or no plasticity.

Plastic Refractory: A blend of ground refractory materials in plastic form, suitable for ramming into place to form monolithic linings.

Plasticity: That property of a material that enables it to be molded into desired forms which are retained after the pressure of molding has been released.

Pores: As applied to refractories, the small voids between solid particles. Pores are described as “open” if permeable to fluids; “sealed” if impermeable.

Porosity of Refractories: The ratio of the volume of the pores or voids in a body to the total volume, usually expressed as a percentage. The “true porosity” is based on the total pore-volume; “apparent porosity” on the open pore-volume only.

Power Pressing: The forming of refractory brick shapes from ground refractory material containing an optimum amount of added water by means of high pressure applied vertically in a power-driven press.

Pug Mill: A machine used for blending and tempering clays in a moist or stiffly plastic condition.

Pyrite: The most common sulfide mineral; FeS_2. Specific gravity 4.9 - 5.2. Color, brass-yellow. Used mainly for making sulfuric acid and sulfates.

Pyrometric Cone: One of a series of pyramidal-shaped pieces consisting of mineral mixtures and used for measuring time-temperature effect. A standard pyrometric cone is a three-sided truncated pyramid; and is approximately either 2$^5/_8$ inches high by $^5/_8$ inch wide at the base or 1$^1/_8$ inches high by $^3/_8$ inch wide at the base. Each cone is of a definite mineral composition and has a number stamped on one face; when heated under standard conditions it bends at a definite temperature.

Pyrometric Cone Equivalent (PCE)*: The number of that Standard Pyrometric Cone whose tip would touch the supporting plaque simultaneously with a cone of the refractory material being investigated when tested in accordance with the Method of Test for Pyrometric Cone Equivalent (PCE) of Refractory Materials (ASTM Designation C24).

Pyrophyllite: A mineral consisting of hydrated silicate of aluminum; $AlSi_2O_5(OH)$.

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* ASTM Standard Definitions C 71-88; or ASTM “Tentative Definitions” are used where applicable.

Pyroplasticity: The physical state induced by soaking heat which permits a refractory body to be readily deformed under pressure or by its own weight.

Quartz: A common mineral consisting of silica (SiO_2). Sandstones and quartzites are composed largely of quartz. Specific gravity 2.65.

Quartzite: A hard compact rock consisting predominantly of quartz. There are two types: (1) metaquartzite, a metamorphic rock usually derived from sandstone; and (2) orthoquartzite, a sedimentary rock consisting of grains of silica sand cemented together by at least 10 % of precipitated silica.

Ramming Mix: A ground refractory material which is mixed with water and rammed into place for patching shapes or for forming monolithic furnace linings; usually of a less plastic nature than plastic refractories.

Recuperator: A system of thin-walled refractory ducts used for the purpose of transferring heat from a heated gas to colder air or gas.

Refractories: Nonmetallic materials suitable for use at high temperatures in furnace construction. While their primary function is resistance to high temperature, they are usually called on to resist other destructive influences such as abrasion, pressure, chemical attack and rapid changes in temperature.

Refractory (adj.): Chemically and physically stable at high temperatures.

Refractory Clay: An earthy or stony mineral aggregate which has as the essential constituent hydrous silicates of aluminum with or without free silica; plastic when sufficiently pulverized and wetted, rigid when subsequently dried and of sufficient purity and refractoriness for use in commercial refractory products.

Regenerator: A refractory structure in which thermal energy from hot furnace gases is alternately absorbed by checker brick work and released to cold air or gas.

Regenerator Checkers: Brick used in furnace regenerators to recover heat from hot outgoing gases and later to release this heat to cold air or gas entering the furnace; so-called because of the checkerboard pattern in which the brick are arranged.

Rise of Arches: The vertical distance between the level of the spring lines and the highest point of the under surface of an arch.

Rock: A naturally occurring mineral aggregate consisting of one or more minerals. For example, quartzite rock is an aggregate consisting essentially of crystals of the mineral quartz; granite is an aggregate consisting essentially of spar and quartz.

Rotary Kiln: A cylindrical, refractory-lined, gas-fired kiln that rotates at an angle and in which the charge is introduced into the higher end and travels down the slope of the kiln to the discharge end.

Rowlock Course: A course of brick laid on edge with their longest dimensions perpendicular to the face of a wall.

Rutile: A mineral consisting of titanium dioxide (Ti_2O). Specific gravity 4.18 - 4.25.

Screen Analysis: The size distribution of noncohering particles as determined by screening through a series of standard screens.

Secondary Expansion: The property exhibited by some fireclay and high-alumina refractories of developing permanent expansion at temperatures within their useful range; not the same as overfiring. A behavior not to be confused with the bloating caused by excessive temperatures which impair the useful properties of a refractory.

Semi-Silica Fireclay Brick: A fireclay brick containing not less than 72% silica.

Serpentine: A group of rock forming minerals; $(Mg,Fe)_3Si_2O_5(OH)_4$. Specific gravity 2.5 - 2.7. Also, a common rock consisting essentially of serpentine minerals.

Silica: SiO_2, the oxide of silicon. Quartz and chalcedony are common silica materials; quartzite, sandstone and sand are composed largely of free silica in the form of quartz.

Silica Brick: A fired refractory consisting essentially of silica and usually made from quartzite bonded with about 1.8 to 3.5 % of added lime.

Silica Fire Clay*: A refractory mortar consisting of a finely ground mixture of quartzite, silica brick and fire clay of various proportions; often called silica cement.

Silicon Carbide: A compound of silicon and carbon; SiC.

Silicon Carbide Refractories*: Refractory products consisting predominantly of silicon carbide.

Sillimanite: A brown, grayish, pale-green or white orthorhombic mineral; Al_2SiO_5. Specific gravity 3.24. At about 2,785°F (1,530°C) it begins to dissociate into mullite and free silica.

Sintering: A heat treatment which causes adjacent particles of material to cohere at a temperature below that of complete melting.

Skewback: The course of brick, having an inclined face, from which an arch is sprung.

Slag: A substance formed in any one of several ways by chemical action and fusion at furnace operating temperatures: (1) in smelting operations, through the combination of a flux, such as limestone, with the gangue or waste portion of the ore; (2) in the refining metals, by substances, such as lime, added for the purpose of effecting or aiding the refining; (3) by chemical reaction between refractories and fluxing agents, such as coal, ash or between two different types of refractories.

Slagging of Refractories*: Destructive chemical action between refractories and external agencies at high temperatures resulting in the formation of a liquid.

Sleeves: Tubular refractory shapes used to protect the metal rod which holds the stopper head in the valve assembly of a bottom-pouring ladle.

Slurry: A suspension of finely pulverized solid material in water of creamy consistency.

Soapstone: A metamorphic rock consisting mainly of talc and derived from the alteration of ferromagnesian silicate minerals.

Soldier Course: A course of brick set on end; little used in the case of refractories except in the bottoms of some types of furnaces.

Solid Solution: A homogeneous crystalline phase with a variable composition. The most common solid solutions involve two or more substances having the same crystalline structure. However, the term can also refer to the solution of small proportions of a material in a seemingly unrelated substance.

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* ASTM Standard Definitions C 71-88; or ASTM “Tentative Definitions” are used where applicable.

Spalling of Refractories: The loss of fragments (spalls) from the face of a refractory structure, through cracking and rupture, with exposure of inner portions of the original refractory mass.

Specific Gravity: The ratio between the weight of a unit volume of a substance and that of some other standard substance under standard conditions of temperature and pressure. For solids and liquids the specific gravity is based on water as the standard. The “true specific gravity” of a body is based on the volume of solid material excluding all pores. The bulk or volume specific gravity is based on the volume as a whole, i.e. the solid material with all included pores. The apparent specific gravity is based on the volume of the solid material plus the volume of the sealed pores.

Specific Heat: The quantity of heat required to raise the temperature of a unit mass of a substance one degree.

Spinel: (1) The mineral composed of magnesium aluminate; $MgAl_2O_4$. Specific gravity 3.6. Melting point 3,875°F (2,135°C). (2) A group of minerals of general formula; AB_2O_4 where A represents magnesium, ferrous iron, zinc or manganese or any combination of these minerals and B represents aluminum ferric iron or chromium.

Spring Line: The line of contact between the inside surface of an arch and the skewback.

Sprung Arch: An arch which is supported by abutments at the side or ends only.

Stack Losses: The flue gas loss, the sensible heat carried away by the dry flue gas plus the sensible heat and latent heat carried away by the water vapor in the flue gas.

Stretcher: A brick laid on flat with its length parallel to the face of the wall.

Superduty Fireclay Brick: Fireclay brick which have a PCE not lower than Cone 33 and which meet certain other requirements as outlined in ASTM Designation C 27-84.

Suspended Arch: An arch in which the brick shapes are suspended from overhead supporting members.

Taconite: A compact ferruginous chert or slate in which the iron oxide is so finely disseminated that substantially all of the iron-bearing particles are smaller than 20 mesh. Typical analyses of the ore grade show total iron at 32%.

Talc: A hydrous magnesium silicate mineral; $Mg_3Si_4O_{10}(OH)_2$. Specific gravity 2.7 - 2.8. Hardness 1.

Thermal Conductivity: The property of matter by virtue of which heat energy is transmitted through particles in contact.

Thermal Expansion: The increase in linear dimensions and volume which occurs when materials are heated and which is counterbalanced by contraction of equal amount when the materials are cooled.

Thermal Shock: A sudden transient temperature change.

Tolerance: The permissible deviation in a dimension or property of a material from an established standard or from an average value.

Tridymite: A mineral form of silica; SiO2. Stable from 1,598 to 2,678°F (870 to 1,470°C). Specific gravity 2.26. An important constituent of silica brick.

Tweel: A refractory shape used to control the flow of molten glass from the glass tank to the tin bath in the float glass process.

Trough: An open receptacle through which molten metal is conveyed from a holding device or furnace to a casting mold or another receptacle.

Tuyere Brick: A refractory shape containing one or more holes through which air and other gases are introduced into a furnace.

TREFOIL® Heat Exchanger: A refractory construction in a rotary kiln with three openings which in cross-section are clover-shaped. Over its length, the TREFOIL heat exchanger divides the kiln into three equal parts, thus improving heat exchange between the charge and the hot combustion gases.

Vacuum Pressing: A method of forming brick shapes by which they are subjected to a partial vacuum during pressing in a power press.

Vermiculite: A group of micaceous minerals, all hydrated silicates, varying widely in composition; $(Mg,Fe,Al)_3 (AlSi)_4O_{10}(OH)_2 - 4H_2O$. When heated above 302°F (150°C), vermiculite exfoliates and increases greatly in volume.

Vesicular: Having a cellular structure; applied to fire clays which have become bloated by overfiring.

Vibratory Pressing: A process for forming refractory shapes in which the ground particles of refractory material are packed closely together by rapid impact-type vibrations of the top and bottom dies; also called impact pressing.

Vitrification: A process of permanent chemical and physical change at high temperatures in a ceramic body, such as fire clay, with the development of a substantial proportion of glass.

Warpage: The deviation of the surface of a refractory shape from that intended, caused by bending or bowing during manufacture.

Wedge Brick: A brick shape having six plane faces (two sides, two edges and two ends), in which two faces (the sides) are inclined toward each other and one end face is narrower than the other.

Wetting: The adherence of a film of liquid to the surface of a solid.

Wollastonite: A triclinic mineral; $CaSiO_3$. Specific gravity 2.9. Inverts at 2,192°F (1,200°C) to pseudowollastonite. Melts incongruently at 2,811°F (1,544°C).

Young’s Modulus: In mechanics, the ratio of tensile stress to elongation within the elastic limit; the modulus of elasticity.

Zircon: A mineral; $ZrSiO_4$. Specific gravity 4.7. Begins to melt incongruently at 3,045°F (1,685°C) forming ZrO_2 solid solution plus liquid; completely melted at about 4,800°F (2,650°C).

Zirconia: Zirconium oxide; ZrO_2. Specific gravity 5.8. Melting point 4,890°F (2,700°C). Its chief source is the mineral baddeleyite.

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Harbison-Walker Refractories Company Distribution Centers

Offering A.P. Green, NARCO and Harbison-Walker products

H-W Refractories maintains stocks of a variety of standard brick, mortars, IFB, plastics, castables, gun mixes, patching materials, ceramic fiber, insulating board, gasketing, metallic anchors, and associated products at distribution centers throughout the U.S. If you need material to complete a repair or for an emergency, give us a call. We are nearby and ready to service you. Call 1-800-887-5555 to reach the location nearest you.

Atlanta, (Doraville) GA	(770) 448-6266
Baton Rouge, (Gonzales) LA	(225) 644-2111
Birmingham, AL	(205) 788-1685
Buffalo, (Tonawanda) NY	(716) 692-1761
Charlotte, NC	(704) 599-6540
Chicago, (Calumet City) IL	(708) 474-5350
Cincinnati, (Milford) OH	(513) 576-6240
Cleveland, OH	(216) 398-1790
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Davenport, IA	(563) 445-1244
Detroit, (Taylor) MI	(734) 287-2150
Houston, TX	(713) 635-3200
Kansas City, (Lenexa) MO	(913) 888-0425
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Los Angeles, (Pico Rivera) CA	(562) 942-2151
New Haven, (West Haven) CT	(203) 934-7960
New York, (Rahway) NJ	(732) 388-8686
Philadelphia, (Trevose) PA	(215) 364-5555
Pittsburgh, (Leetsdale) PA	(412) 741-3200
Portland, OR	(503) 227-7944
Roanoke, (Salem) VA	(540) 375-2107
Salt Lake City, UT	(801) 886-0545
San Francisco, (Richmond) CA	(510) 236-7415
St Louis, MO	(314) 521-3314
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Harbison-Walker Refractories Company
STANDARD TERMS OF SALE

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A. Seller's prices are based on these sales terms and (i) this document, together with any additional writings signed by Seller, represents a final, complete and exclusive statement of the agreement between the parties and may not be modified, supplemented, explained or waived by parole evidence, Buyer's purchase order, a course of dealing, Seller's performance or delivery, or in any other way except in writing signed by an authorized representative of Seller, and (if) these terms are intended to cover all activity of Seller and Buyer hereunder, including sales and use of products and all related matters including technical advice and services. Any references by Seller to Buyer's specifications and similar requirements are only to describe the products covered hereby and no warranties or other terms therein shall have any force or effect. Catalogs, circulars and similar pamphlets of the Seller are issued for general information purposes only and shall not be deemed to modify the provisions hereof.

B. The agreement formed hereby and the language herein shall be construed and enforced under the Uniform Commercial Code as in effect in the State of Pennsylvania on the date hereof.

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Any sales, use or other similar type taxes imposed on this sale or on this transaction are not included in the price. Such taxes shall be billed separately to the Buyer. Seller will accept a valid exemption certificate from the Buyer if applicable, however, if an exemption certificate previously accepted is not recognized by the governmental taxing authority involved and the Seller is required to pay the tax covered by such exemption certificate, Buyer agrees to promptly reimburse Seller for the taxes paid.

3. PERFORMANCE, INSPECTION AND ACCEPTANCE

A. Unless Seller specifically assumes responsibility for work, all products shall be finally inspected and accepted within ten (10) days after arrival at point of delivery. All claims whatsoever by Buyer (including claims for shortages) excepting only those provided for under the WARRANTY AND LIMITATION OF REMEDY AND LIABILITY and PATENTS Clauses hereof must be asserted in writing by Buyer within said ten (10) day period or they are waived. If this contract involves partial performances, all such claims must be asserted within said ten (10) day period for each partial performance. There shall be no revocation of acceptance. Rejection may be only for defects substantially impairing the value of products or work and Buyer's remedy for lesser defects shall be those provided for under the WARRANTY AND LIMITATION OF REMEDY AND LIABILITY Clause.

B. Seller shall not be responsible for nonperformance or delays in performance occasioned by any causes beyond Seller's reasonable control, including, but not limited to, labor difficulties, delays of vendors or carriers, fires, governmental actions and material shortages. Any delays so occasioned shall effect a corresponding extension of Seller's performance dates which are, in any event understood to be approximate. In no event shall Buyer be entitled to incidental or consequential damages for late performance or a failure to perform.

C. If Buyer wrongfully rejects or revokes acceptance of items tendered under this agreement or fails to make a payment due on or before delivery or repudiates this agreement, Seller shall at its option have a right to recover as damages either the price as stated herein (upon recovery of the price the items involved shall become the property of the Buyer) or the profit (including reasonable overhead) which the Seller would have made from full performance together with incidental damages and reasonable costs.

4. TITLE AND RISK OF LOSS

Full risk of loss (including transportation delays and losses) shall pass to the Buyer upon delivery of products to the f.o.b. point. However, Seller retains title, for security purposes only, to all products until paid for in full in cash and Seller may, at Seller's option repossess the same upon Buyer's default in payment hereunder and charge Buyer with any deficiency.

5. WARRANTY AND LIMITATION OF REMEDY AND LIABILITY

A. Seller warrants only that its products, when shipped, will meet all applicable specifications and other specific product requirements (including those of performance), if any, of this agreement and will be free from defects in material and workmanship. Drawing Services furnished hereunder shall conform to the standards of practice customary in the refractories business for drawing services of a similar nature. All claims under this warranty must be made in writing immediately upon discovery and, in any event within one (1) year from shipment of the applicable product or drawing. Defective and nonconforming items must be held for Seller's inspection and returned to the original f.o.b. point upon request. THE FOREGOING IS EXPRESSLY IN LIEU OF ALL OTHER WARRANTIES WHATSOEVER, EXPRESS IMPLIED AND STATUTORY, INCLUDING, WITHOUT LIMITATION, THE IMPLIED WARRANTIES OF MERCHANTABILITY AND FITNESS. Technical advice is furnished as an accommodation to the Buyer. Seller assumes no liability therefor, and Buyer accepts such advice at Buyer's sole risk

B. Upon Buyer's submission of a claim as provided above and its substantiation, Seller shall at its option either (i) repair o replace its product or work at the original F.O.B. point or (ii) refund an equitable portion of the purchase price or (iii) reperform drawing services at no cost to customers.

C. THE FOREGOING IS SELLER'S ONLY OBLIGATION AND BUYER'S EXCLUSIVE REMEDY FOR BREACH OF WARRANTY AND, EXCEPT FOR GROSS NEGLIGENCE, WILLFUL MISCONDUCT AND REMEDIES PERMITTED UNDER THE PERFORMANCE INSPECTION AND ACCEPTANCE AND THE PATENTS CLAUSES HEREOF, THE FOREGOING IS BUYER'S EXCLUSIVE REMEDY AGAINST SELLER FOR ALL CLAIMS ARISING HEREUNDER OR RELATING HERETO WHETHER SUCH CLAIMS ARE BASED ON BREACH OF CONTRACT, TORT (INCLUDING NEGLIGENCE AND STRICT LIABILITY) OR OTHER THEORIES. BUYER'S FAILURE TO SUBMIT A CLAIM AS PROVIDED ABOVE SHALL SPECIFICALLY WAIVE ALL CLAIMS FOR DAMAGES OR OTHER RELIEF, INCLUDING BUT NOT LIMITED TO CLAIMS BASED ON LATENT DEFECTS. IN NO EVENT SHALL BUYER BE ENTITLED TO INCIDENTAL OR CONSEQUENTIAL DAMAGES. ANY ACTION BY BUYER ARISING HEREUNDER OR RELATING HERETO, WHETHER BASED ON BREACH OF CONTRACT, TORT (INCLUDING NEGLIGENCE AND STRICT LIABILITY) OR OTHER THEORIES, MUST BE COMMENCED WITHIN ONE (1) YEAR AFTER THE CAUSE OF ACTION ACCRUES OR IT SHALL BE BARRED.

D. Refractory brick and shapes should be handled with care to avoid scuffing and breaking. All refractories should be stored in a dry place, protected against weather, especially in seasons when alternate freezing and thawing occur.

6. PATENTS

Seller agrees to assume the defense of any suit for infringement of any United Stales patents brought against Buyer to the extent such suit charges infringement of an apparatus or product claim by Seller's product in and of itself provided (i) said product is built entirely to Seller's design, (ii) Buyer notifies Seller in writing of the filing of such suit within ten (10) days after the service of process thereof and (iii) Seller is given complete control of the defense of such suit including the right to defend, settle and make changes in the product for the purpose of avoiding infringement Seller assumes no responsibility for charges of infringement of any process o method claims unless infringement of such claims is the result of following specific instructions furnished by Seller.

7. SPECIAL TOOLING

Notwithstanding any molds, outfits, tool, die or pattern changes or amortization in connection herewith, all special tooling and related items shall be and remain the property of Seller.

8. ALLOWABLE VARIATION, OVERSHIPMENT AND PALLET RETURNS

A. Allowable variations from specified dimensions are plus 2% to minus 2% on dimensions over 4'' and plus 3% to minus 3% on dimensions of 4'' or less.

B. Overage shall be allowable on all shipments of sizes and shapes that are not carried in stock in accordance with the following: 1-100: 10%, but not less than one shape or, if in sets, one complete set- 101 -1,000: 7%, 1,001- 5,000:3%, 5,001-10,000 – 2%, Over- 10,000 – 1%.

C. Before returning any pallets, Buyer should communicate with Seller, for consigning and routing instructions. Only standard pallets suitable for reuse are acceptable.

9. MINIMUM INVOICE CHARGE

Individual orders or shipments from any of seller's plants will be subject to a minimum charge of $250.00.

10. PALLET BREAKAGE CHARGE

Individual orders or shipments from Seller's plant warehouse or service center requiring less than a full pallet are subject to a charge of $25.00 for each pallet less than a full pallet.

11. DRAWING SERVICES

Drawing Services are quoted and provided to offer suggested methods of installation. Buyer's approval of drawings and/or Buyer's decision to rely upon them for construction purposes is at the sole risk of Buyer/Installer. Buyer's payment for any drawing services recognizes that the information contained in the drawings is proprietary and is the intellectual property of Harbison-Walker. Buyer agrees to keep the information confidential and shall not reproduce or make the drawings available to third parties.

12. NOTICE

Harbison-Walker Refractories Company values highly the confidence and good will of its customers and suppliers. We offer our products only on their merit and we expect our customers to judge and purchase our products and services solely on the basis of quality, price, delivery and service. Likewise, Harbison-Walker buys only on merit and we judge and purchase solely on the basis of quality, price, delivery and service. This Harbison-Walker Company policy applies in all relationships with our customers and suppliers.

SECTION 9

Literature

H-W Industrial Products

Alumina-Chrome Brick

Coarse Aggregate Castables

- VERSAFLOW® C & 2-TOUGH®

Emisshield™

EXCELrate

Extra-High Alumina Brick

High Alumina Brick

INSWOOL® Blanket Products

INSBOARD Ceramic Fiber Boards

INSWOOL® Fiber Modules

INSWOOL® Utility Paper

INSWOOL® 2300 Paper

INSWOOL® Rope and Braids

INSWOOL® Pumpable

MAGSHOT® Gun Mix

Super-Duty Fireclay Brick

VIB-TECH Engineered Shapes

Aluminum Industry

- Aluminum Melting/Holding Furnaces
- Aluminum Transfer Trough

Cement & Lime

- H-W Long Brick for Rotary Kilns
- High Alumina & Basic Brick for Rotary Kiln Systems
- Light Weight Castable/Gunning for Rotary Kiln
- MAGSHOT® for Cement & Line
- Refractories for the Lime Industry
- THOR AZS/AZSP for Cement Nose Ring
- THOR AZSP Pumpable Castable for Cement & Lime
- TZ 352 DRY MORTAR Anti-Buildup for Existing Linings
- VERSAFLOW® 70 ADTECH® for Cement Kiln Nose Ring

Industrial Foundry

- AOD Refractories for Industrial Foundries
- Breast Wall & Trough CUPOLA
- Channel Induction Refractories for Industrial Foundries
- Electric Arc Furnace for Industrial Foundries
- Ladle Refractories for Industrial Foundries
- NARGON® Porous Plugs for Industrial Foundries
- Upper Stack to Melt Zone for CUPOLA

Pulp & Paper Industry

- Lime Recovery Kiln
- MAGSHOT® Gun Mix

Petroleum Refining

- Fluid Cat Cracking Unit
- Sulfur Recovery Units

Power Industry

- Ash Hopper Refractories
- Boiler Refractory Applications
- Coal Fired Cyclone Boilers
- Refractory Block Slag Dam

Alumina-Chrome Brick

Harbison-Walker Refractories Company

Alumina-Chrome Brick

Harbison-Walker Refractories Company's alumina-chrome brick consist of combinations of the two oxides fired to develop a solid-solution bond. This means that all ratios of alumina and chrome can be combined without the formation of any low-melting eutectic phases. Equally important is the absence of any silicate bond phases. The solid solution bond developed in firing results in brick with exceptional hot strength and load bearing ability. The chromic oxide is very resistant to many corrosive agents encountered in ferrous foundry, slagging gasifier, and chemical incinerator service.

Brick are available with chromic oxide content ranging from 5 to 95%. Following is a summary of selected products

RUBY®: This is a 10% chromic oxide, 90% alumina brick, designed for extremely high temperature and corrosive service. It provides extraordinary resistance to chemical attack, corrosion and severe slag attack.

RUBY® DM: A version of RUBY utilizing the Densified Matrix (DM) technology to achieve lower porosity and improved slag resistance.

RUBY® SR: A version of RUBY utilizing the Shock Resistance (SR) technology to provide excellent resistance to thermal shock. In prism spall testing, consisting of cycling from 2200˚F to a water quench, RUBY SR withstands 25 cycles, compared to 3 for the standard RUBY product.

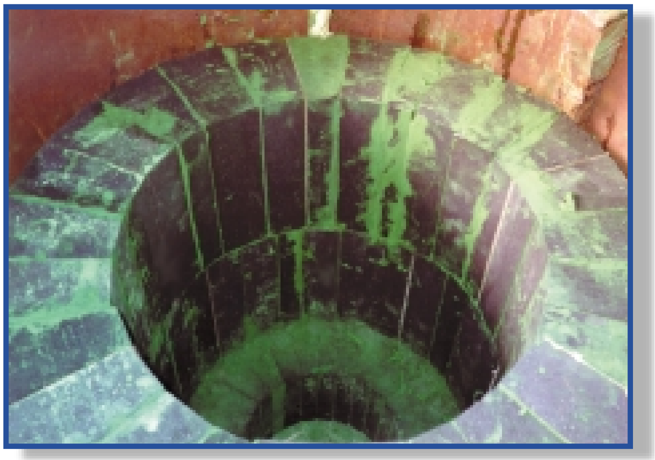
RUBY® LW: A lightweight version of RUBY intended for service in corrosive hot face and back-up applications.

AUREX® 20 SR: A shock resistant alumina-chrome brick with 20% chromic oxide to provide enhanced corrosion resistance.

AUREX® 30 SR: A high purity thermal shock resistant product with 30% chromic oxide. Used in the burning zone of chemical incinerators.

AUREX® 75 & AUREX® 75 SR: This is a very dense, high purity, fused grain refractory containing 75% chromic oxide. Available in the regular and shock resistant (SR) versions. These products are used in coal gasifiers and other highly corrosive applications.

SERV 80, AUREX® 90 and AUREX® 95: These extremely dense, refractories containing 80 to 95% chromic oxide for exceptional corrosion resistance and refractoriness. These products are used in the highest wear areas of coal gasifiers. Contact your H-W Sales Representative for information on these products.



Alumina-Chrome Brick

	RUBY®	**RUBY® DM**	**RUBY® SR**	**RUBY® LW**
Bulk Density, pcf	201	213	200	124
Apparent porosity, %	17.2	12.6	17.5	49.9
Modulus of Rupture, psi				
At 70°F	5,400	7,150	1,650	1,660
At 2,700°F	1,890	4,000	1,490	–
Chemical Analysis %: Approx. (Calcined Basis)				
Silica (SiO_2)	0.5	0.3	2.0	0.4
Alumina (Al_2O_3)	89.7	89.6	83.0	89.4
Titania (TiO_2)	0.1	Trace	Trace	Trace
Iron Oxide (Fe_2O_3)	0.2	0.1	0.1	0.2
Lime (CaO)	0.3	0.1	0.1	Trace
Magnesia (MgO)	0.1	Trace	Trace	0.1
Alkalies ($Na_2O + K_2O$)	0.1	0.1	0.2	0.1
Chromic Oxide (Cr_2O_3)	9.0	9.8	11.2	9.8
Other Oxides	–	–	3.4	–

	AUREX® 20 SR	AUREX® 30 SR	AUREX® 75	AUREX® 75 SR
Bulk Density, pcf	204	217	258	151
Apparent porosity, %	17.5	15.5	14.4	15.4
Modulus of Rupture, psi				
At 70°F	1,520	1,350	3,850	1,900
At 2,700°F	2,200	–	2,250	2,600
Chemical Analysis %: Approx. (Calcined Basis)				
Silica (SiO_2)	0.4	2.1	0.2	0.3
Alumina (Al_2O_3)	75.6	64.9	22.1	24.2
Titania (TiO_2)	0.1	1.9	Trace	Trace
Iron Oxide (Fe_2O_3)	0.1	0.1	0.1	0.2
Lime (CaO)	0.1	0.1	0.2	0.2
Magnesia (MgO)	Trace	0.2	0.1	0.1
Alkalies ($Na_2O + K_2O$)	0.1	0.2	Trace	Trace
Chromic Oxide (Cr_2O_3)	19.1	27.7	77.3	74.5
Other Oxides	3.3	2.8	–	–

The data given above are based on averages of test results on samples selected from routine plant production by standard A.S.T.M. procedures where applicable. Variation from the above data may occur in individual test. These results cannot be taken as minima or maxima for specification purposes. All statements, information, and data given herein are believed to be accurate and reliable but are presented without guarantee, warranty, or responsibility of any kind, expressed or implied.

Statements or suggestions concerning possible use of our products are made without representation or warranty that any such product is fit for such use or that such use is free of patent infringement of a third party. The suggested use assumes that all safety measures are taken by the user.

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COARSE AGGREGATE CASTABLES

Harbison~Walker Refractories Company

VERSAFLOW® C & 2-TOUGH™ Castables

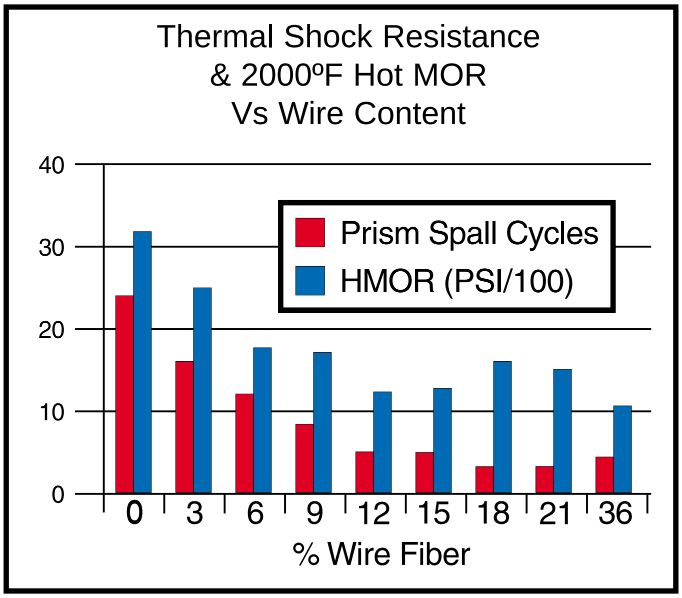
High Strength Castables
for
Mechanical Abuse at High Temperature

What makes a refractory castable durable enough to withstand the abuse of high mechanical impact applications? Toughness.

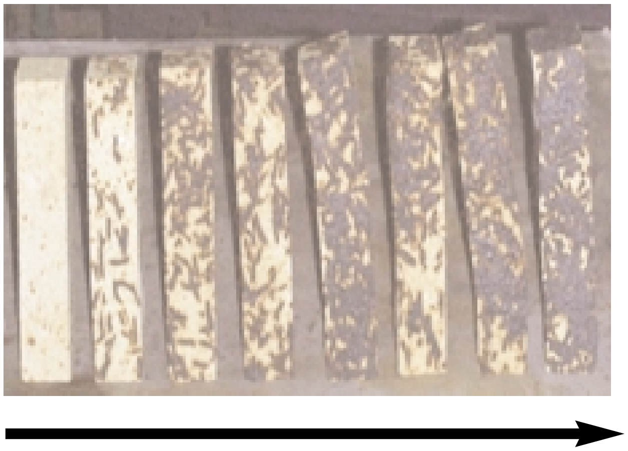
The conventional method of increasing toughness is adding wire fibers. Wire fibers are compressible, and flexible. They help to dissipate the force of an impact over a larger surface area, reducing the potential for cracking. They also oxidize and adversely affect thermal shock resistance.

What makes a refractory castable tough enough to withstand the abuse of high mechanical impact at high temperatures? Coarse Aggregates.

Similar to wire fibers, coarse aggregates aid in the dissipation of the force of an impact. At high temperatures, coarse aggregate-containing castables have significant advantages over wire fiber-containing products...



Thermal Shock Resistance
& 2000ºF Hot MOR
Vs Wire Content



Increasing Wire Fiber Content.
After Firing to 2910°F

VERSAFLOW® C Castables

VERSAFLOW® C family of castables offer multiple benefits:

Installation

VERSAFLOW® C castables can be mixed, within a specific water range, from a vibcast to a pumpable consistency with little effect on physical properties. This means you can select the installation method best suited to your application, whether it's vibration casting, conventional casting, or pumping.

Versatility

VERSAFLOW® C castables feature an excellent balance of physical properties. Each is specially engineered to combat the problems associated with today's demanding furnace environments.

Impact Resistant

At our Technology Center West Mifflin, we test impact resistance by repeatedly firing a $^1/_2$ -inch projectile at a refractory sample, heated to 2000°F. **VERSAFLOW® C** castables survive close to 40 cycles in this test, compared to traditional low cement castables which typically fail after 15 to 20 cycles.

Special Features

VERSAFLOW® C castables are available in a variety of compositions to meet your specific needs. Formulations range from fireclay to 80% alumina, and include both aluminum and alkali resistant variations.

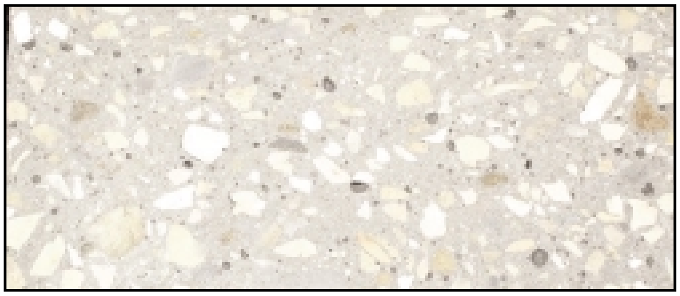
VERSAFLOW® 65/AL C ADTECH® - Aluminum Cup Test

VERSAFLOW® 45 C ADTECH®
Fireclay-based low cement castable for use in high impact and abrasion environments up to 2700ºF. Typical uses; chain sections, ash hoppers and ladle covers.

VERSAFLOW® 55/AR C ADTECH®
A 55% alumina low cement, coarse grain castable based on bauxitic calcines. Specifically designed for impact and abrasion resistance in high alkali environments. Typical uses; incinerators and aluminum furnace roofs.

VERSAFLOW® 65/AL C ADTECH® (pictured left)
A 65% alumina, aluminum resistant, coarse grain castable. For use in high wear areas in aluminum contact such as ramps, sills and cruce bottoms.

VERSAFLOW® 70 C ADTECH®
70% alumina, coarse grain castable with high strength, high refractoriness and excellent abrasion and impact resistance. Typical uses; foundry ladles, rotary kiln nose rings and lifters, incinerator charge zones, and precast tundish furniture.



VERSAFLOW® 80 C ADTECH®

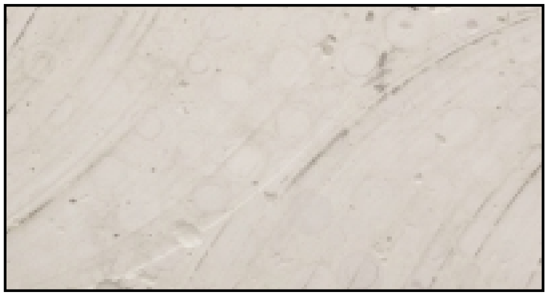
VERSAFLOW® 80 C ADTECH® (pictured above)
An 80% alumina low cement coarse castable with excellent strength. Typical uses; rotary kiln lifters and feed ends, aluminum furnace jambs and lintels, and reheat furnace skid block.

2-TOUGH™ Castables

2-TOUGH™ Castables take the coarse grain concept to the next level. They were developed for the most severe mechanical abuse environments.

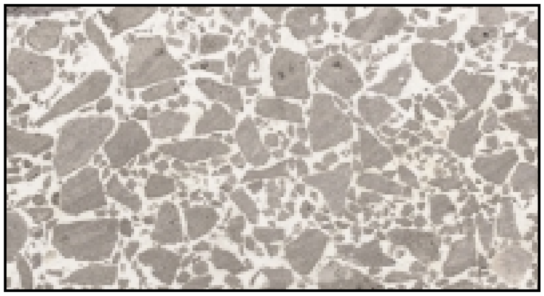
2-TOUGH™ castables are comprised of 50% coarse grain having a diameter up to about 1-inch. The other 50% of the product is a high purity, EXPRESS®-type bonding matrix. Even though **2-TOUGH™** products utilize EXPRESS® technology, they still require vibration to achieve their full density.

	Density (pcf)
2-TOUGH™ HP ADTECH®	200
2-TOUGH™ FA ADTECH®	208
2-TOUGH™ AL ADTECH®	210



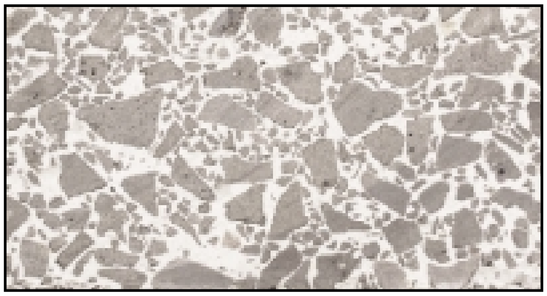
2-TOUGH™ HP ADTECH®

2-TOUGH™ HP ADTECH®
The combination of a coarse tabular alumina aggregate and a fine tabular alumina matrix gives this high purity mix outstanding corrosion resistance. **2-TOUGH™ HP ADTECH®** has set a record in the impact test, surviving almost 70 impacts!! This unique product has solved severe wear problems in several steel applications including well blocks, ladle bottoms and electric furnace deltas.



2-TOUGH™ FA ADTECH®

2-TOUGH™ FA ADTECH®
Exceptionally high strength and impact resistance characterize this product. Its fused alumina coarse aggregate has a higher density than tabular alumina, resulting in significantly lower porosity than traditional 90% alumina castables. Typical uses for **2-TOUGH™ FA ADTECH®** include ladle bottoms, aluminum furnace jambs and lintels, and rotary kiln lifters.



2-TOUGH™ AL ADTECH®

2-TOUGH™ AL ADTECH®
Rounding out the product line, **2-TOUGH™ AL ADTECH®** is specifically designed for use in aluminum contact. It is essentially silica free, and contains an aluminum penetration inhibitor. This makes it very resistant to aluminum corrosion. Typical used include precast hearths, ramps and sills, belly bands, troughs, and cruces.

2-TOUGH™ AL ADTECH® - Aluminum Cup Test

TECHNICAL DATA			VERSAFLOW®		
	45 C ADTECH®	55/AR C ADTECH®	65/AL C ADTECH®	70 C ADTECH®	80 C ADTECH®
Maximum Service Temperature (°F)	2700	3000	2400	3100	2800
Density (lb/ft³)					
After drying at 230 °F	135	152	168	171	175
Modulus of Rupture (psi)					
After drying at 230 °F	1560	2300	1570	2000	2100
After heating at 1500 °F	1410	2520	1670	1800	2100
Cold Crush Strength (psi)					
After drying at 230 °F	9470	9470	13870	8300	12000
After heating at 1500 °F	7620	7620	10760	11800	14000
Abrasion Resistance (cc loss)					
After heating at 1500 °F	9.6	–	–	–	3.8
Chemical Analysis,%:					
Al_2O_3	44.6	56.0	67.0	71.9	80.0
SiO_2	49.4	38.0	25.0	22.9	12.5
TiO_2	2.2	2.0	2.2	2.5	2.8
Fe_2O_3	0.7	0.9	1.0	1.0	1.4
CaO	2.4	2.8	3.2	1.4	2.4
MgO	0.2	0.1	0.2	0.1	0.2
P_2O_5	–	–	–	–	0.4
Na_2O & K_2O	0.5	0.2	0.4	0.2	0.3
Other Oxides	–	–	1.0	–	–

TECHNICAL DATA	2-TOUGH™ HP ADTECH®	2-TOUGH™ FA ADTECH®	2-TOUGH™ AL ADTECH®
Maximum Service Temperature (°F)	3300	3200	2500
Density (lb/ft³)			
After drying at 230 °F	200	208	210
Modulus of Rupture (psi)			
After drying at 230 °F	800	2000	1900
After heating at 1500 °F	900	–	–
Cold Crush Strength (psi)			
After drying at 230 °F	7000	12400	9800
After heating at 1500 °F	5000	–	–
After heating at 2500 °F	17000	11000	–
Hot Modulus of Rupture (psi)			
At 2700 °F	1500	–	–
Chemical Analysis (%):			
Al_2O_3	95.5	92.2	90.0
SiO_2	0.1	0.9	1.1
TiO_2	–	2.3	2.6
Fe_2O_3	–	0.2	0.1
CaO	1.4	1.6	2.3
MgO	2.7	2.8	0.8
Na_2O & K_2O	0.3	0.1	0.1
Other Oxides	–	–	3.0

The data given above are based on averages of tests results on samples selected from routine plant production by standard ASTM procedures where applicable. Variation from the above data may occur in individual tests. These results cannot be taken as minima or maxima for specification purposes. All statements, information, and data given herein are believed to be accurate and reliable but are presented without guarantee, warranty, or responsibility of any kind, expressed or implied.
Statements or suggestions concerning possible use of our products are made without representation or warranty that any such product is fit for such use or that such use is free of patent infringement of a third party. The suggested use assumes that all safety measures are taken by the user.

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Emisshield™

NASA Technology

Emisshield™ was developed and refined from NASA technology used to protect the next generation of Space Orbiters (X-33, X-34, etc.) from the extreme tempertures and abrasion of atmospheric reentry. Emisshield™ coatings may be applied to many materials where heat and thermal degradation are factors.

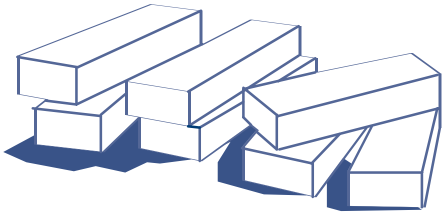
Most substrates have a relatively high emissivity value at room temperature. However when temperatures increase, these values fall dramatically. Emisshield™ not only has an emissivity value of 0.8 - 0.9 at room temperature, it maintains that value at temperatures up to 3000º F and beyond.

Emissivity - the absorption and release of energy rated on a scale of 0.0 - (Low) to 1.0 - (High)

Benefits of Emisshield™ Coatings

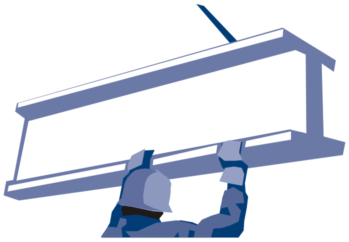
Refractories/Ceramic

Emisshield™ ST coatings reduce the temperature exposure of refractories and ceramics by absorbing and re-radiating thermal energy to the furnace load. They protect them from corrosion by acids, alkalies, slags, and many molten metals, especially aluminum, and provide increased abrasion resistance. The use of Emisshield™ coatings will provide longer refractory life and reduced operating costs.



Metals **(Patent Pending)**

Emisshield™ STG and M coatings can be applied to most ferrous and non-ferrous alloys to protect them from high temperatures, oxidation, corrosion, and abrasion. These coatings can withstand process temperatures in excess of 3000ºF and can extend the use temperature of metal components in high temperature industrial processes. The use of Emisshield™ will increase thermal transfer to water tubes in boilers and power generation units.



Harbison-Walker Refractories Company

Emisshield™

Technical Information

Emisshield™ utilizes the property of emissivity, a material's ability to absorb and re-radiate energy. Emissivity is measured on a scale of 0.0 to 1.0, where 1.0 is a perfect black body, absorbing and re-radiating all radiant energy that hits its surface. Emisshield™ exhibits a relatively constant emissivity of 0.85 to 0.90 through the entire temperature range from room temperature to over 3000ºF. Many substrate materials have a high emissivity at lower temperatures, but their emissivity drops dramatically at elevated temperatures. Unlike other high emissivity coatings, Emisshield™ will maintain its high emissivity during prolonged high temperature service.

The equation describing the relationship between re-radiated energy and emissivity is shown in the next column:

$$Q = E_w \sigma (T_s^4 - T_{sur}^4)$$

Where: Q is measured in units of Btu/hour-ft^2

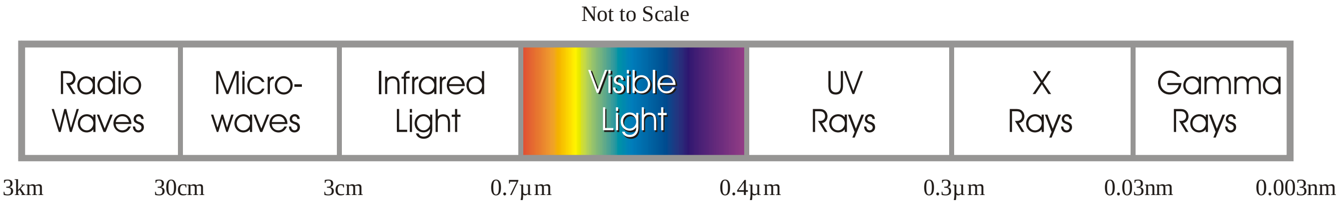
E_w = emissivity of substrate coating

σ = Stefan-Boltzmann Constant

T_s = surface temperature

T_{sur} = surrounding temperature

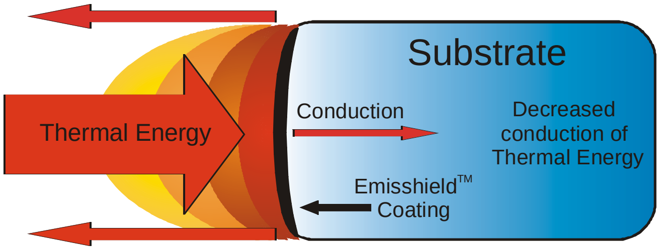
The amount of energy re-radiated increases with increasing emissivity and rises exponentially as the difference between the surface temperature of the Emisshield™ and the temperature of the cooler furnace load increases. At a very low ΔT and in applications such as boilers and power generation units where the furnace atmosphere or load is hotter than the coating, Emisshield™ will increase the amount of heat conducted through the substrate. This causes furnaces to cool faster and increases the amount of energy conducted through water tubes.



The value of emissivity assigned to a substrate indicates its ability to absorb and reradiate energy in relation to the electromagnetic spectrum. A substrate that has an emissivity value of 1.0 is known as a black body. A black body will absorb all energy regardless of wavelength. A black body will also reradiate all of the energy it absorbs. To date, no such perfect black body exists. Those that come close to black body capabilities, with emissivity values of 0.85 to 0.9, are known as grey bodies. Emisshield™ coatings are grey bodies. In other words, a black body is 100% efficient at absorbing and reradiating the same energy; thus the rating of 1.0. An Emisshield™ coating will absorb and reradiate the same energy at an 85% to 90% efficiency rate and therefore has an emissivity value of 0.85 to 0.9.

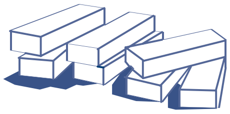
All energy (heat) has a measured wavelength that corresponds to a point on the electromagnetic spectrum. Humans can see visible light, ranging in color from red to purple. Red light has a wavelength of about 0.7µm while purple light has a wavelength of about 0.4µm in the visible spectrum. When white light is refracted through a prism to show all the visible colors (red through purple) and temperatures are taken of the refracted light, the red measures hotter in temperature than the purple. Friedrick William Herschel discovered the infrared portion of the eletromagnetic spectrum. While measuring the temperatures of the visible spectrum, he moved his thermometer past the visible red and noticed the temperature rose still. The majority of thermal energy falls into this infrared zone.

According to the second law of thermodynamics, energy will always flow from hot to cold. Therefore, Emisshield™ coatings will always reradiate the absorbed energy to the coolest surrounding. This can have a major benefit in productivity, safety for people, decreasing fuel consumption and protection of the underlying substrate.



Conduction of energy through a substrate can be greatly reduced with application of an Emisshield™ coating when a colder load is present. This redirection of heat can save energy and increase production. By protecting the substrate from the high heat, Emisshield™ will prolong the life of the substrate which will result in reduced maintenance and operating costs.

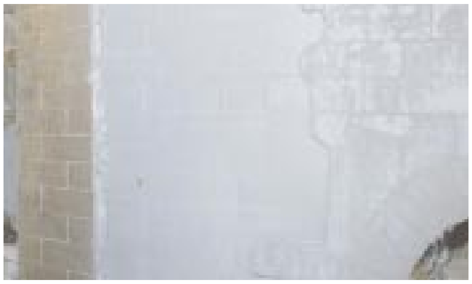
Refractory/Ceramic



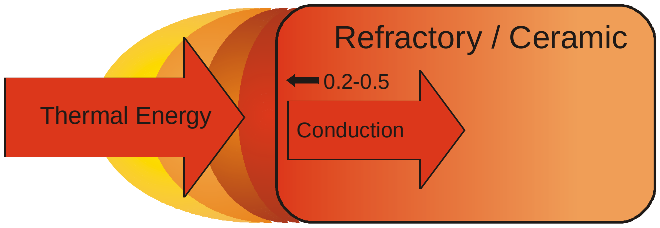
Using space age technology licensed from NASA, Wessex Incorporated has created Emisshield™ Coatings. These coatings have many beneficial uses in the Refractory/Ceramic industry that help save time and money. The technology that NASA developed and Emisshield™ uses is based upon the property of emissivity, but the Emisshirld™ products are unique and different than previous emissive coatings.

Emissivity is defined as a refractory's ability to absorb and subsequently release energy from its surface to a furnace load. Emissivity is rated on a scale of 0.0 (low) to 1.0 (high). While many refractories have a high emissivity value at ambient temperatures, most refractories will steadily lose their ability to reradiate that energy as the temperature increases, particularly in the infrared zone of the electromagnetic spectrum where 90% of radiant energy is found. As determined by NASA scientists, Emisshield™ not only has an emissivity value of 0.85 to 0.9 at ambient temperature, it maintains that level of emissivity as temperatures increase above 3000°F. At these high temperatures, refractories will only have an emissivity value of 0.2 to 0.5 depending on their composition.

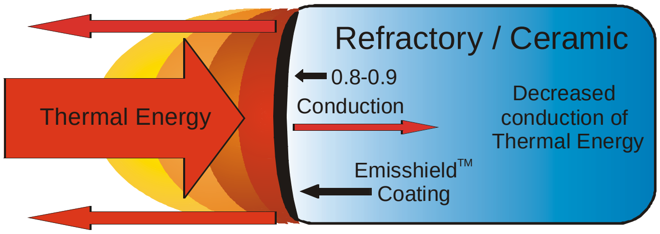
One of the benefits of Emisshield™ is the ability to keep the substrate it is protecting cooler. By reradiating energy back to a cooler load, Emisshield™ prevents heat transfer via conduction through the furnace wall. This results in decreased energy usage and lower operating costs. In addition, the cooler refractory temperature prolongs the life of the refractory and reduces maintenance costs.



Emisshield™ coated brick (right) in a tunnel kiln preheat zone abut uncoated brick in firing zone.



If a refractory is not protected with an Emisshield™ coating, a large portion of thermal energy will conduct throughout the refractory.



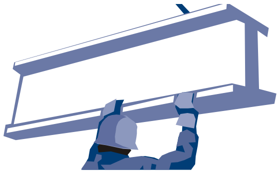
Conduction of energy through a substrate can be greatly reduced with application of an Emisshield™ coating when a colder load is present. This redirection of heat can save energy and increase production. By protecting the substrate from the high heat, Emisshield™ will prolong the life of the substrate which will result in reduced maintenance and operating costs.

One of the distinguishing features of Emisshield™ compared to previous high emissivity coatings is its binder system. There are numerous Emisshield™ products that have been designed specifically for dense refractories, lightweight refractories, and refractory fiber products. These binders are totally inorganic and emit no hydrocarbon volatiles or combustion products. In addition, the binders, combined with the emissivity agent, provide improved resistance to alkali and acid attack, and good resistance to reactions with ferrous and non-ferrous metals, particularly aluminum. In service, Emisshield™ compositions form strong, highly abrasion-resistant, crystalline or glassy coatings that can reduce erosion caused by high velocity gases and particulates.

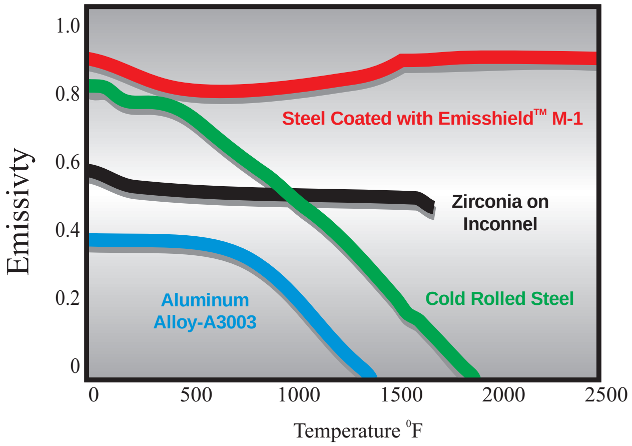
Emisshield™ is a trademark of WESSEX INCORPORATED

Emisshield™

Metal



Several Emisshield™ products have been designed specifically for metal substrates. These coatings will provide the same high emissivity properties as the refractory/ceramic compositions, but they also protect metal substrates from oxidation and chemical attack. The Emisshield™ STG- and M-series of coatings for metal substrates will adhere to most ferrous and non-ferrous alloys, raising the effective service temperatures of all alloys. Many metals and alloys have relatively high emissivities at room temperature, however their emissivities decrease markedly at higher temperatures. Metals that easily oxidize, such as carbon steel and aluminum, are particularly prone to severe emissivity degradation at high temperatures.



When a cooler furnace load or atmosphere is available, an Emisshield™ coating on metal will absorb and emit the heat to the load, preventing heat loss through the metal and thermal oxidation of the substrate. Typical applications for Emisshield™ STG and M formulations include water-cooled electric furnace roofs, rotary kiln nose ring castings, air blasters and grates, ladle retaining rings, kiln car skirts, alloy injector tubes, metal slag and dross removal tools, and exposed furnace structural steel.

Emisshield™ coated steel kiln car skirts resist oxidation and warping

For applications where there is not a cooler load present to absorb the emitted heat energy, Emisshield™ will conduct the absorbed heat through to the metal substrate which conducts the heat to the cold face of the substrate. Applications where this property of Emisshield™ is particularly effective include boiler tubes and water wall tubes in power plants. Emisshield™ will increase the conductive heat transfer to these tubes, improving the uniformity of heating and the efficiency of steam generation. Coating these tubes with Emisshield™ also prevents scale buildup and increases the service life of the tubes.

Emisshield™ manufactured under license from NASA by WESSEX INCORPORATED.

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WESSEX INCORPORATED

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Cat# HW 150 (5/04)

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EXCELERATE ABR PLUS

Description:

- A one-component, 80% alumina, phosphate bonded monolithic refractory that takes an air set. This product can be rammed, hand packed, cast, or gunned.

Features and Benefits:

- Maximum continuous service temperature of 2400°F
- One component requires the addition of water only
- Can be vib-cast, rammed, hand packed, gunned.
- Cement free, yielding good performance in exposure to alkali/salt conditions
- Set in four hours, no air cure required, can be heated immediately after set
- Rapid dryout
- Superior abrasion resistance
- Suitable for manufacturing precast shapes

Typical Uses:

- Non-ferrous ladles and crucibles
- FCCU cyclones, air rings, feed lines, slide valves, regenerator return lines
- CFB cyclones, down comers, return lines
- Precast shapes
- Air Heaters
- Cement preheaters
- Paper kiln firing hoods, dams, nose rings
- Brass rotary and induction furnace repairs
- Incinerators feed chutes, firing hoods
- Boilers
- Annealing furnace
- Coke calciners
- General repairs

Packaging:

- Shipped in 55lb bags

TECHNICAL DATA

EXCELERATE ABR PLUS

Physical Properties; (Typical)

VIBRATION CAST

	English Units		Si Units
Maximum Service Temperature:	2400°F		1316°C
Approximate Amount of Water Required			
Per 55 lbs., U.S. Pints	3.5		
Per 24.95 kg., Liters			1.6
Dry Weight Required for Installing	lb/tf^3		kg/m^3
	172		2,754
Bulk Density	.		
After Drying at 230°F (110°C)	179		2,866
After Heating at 1500°F (816°C)	172		2,745
Modulus of Rupture	lb/in^2		MPa
After Drying at 230°F (110°C)	1650		11.3
After Heating at 1500°F (816°C)	2200		15.1
Crushing Strength			
After Drying at 230°F (110°C)	13,400		91.8
After Heating at 1500°F (816°C)	14,950		102.5
Apparent Porosity, %			
After Drying at 230°F (110°C)		16.5	
After Heating at 1500°F (816°C)		21.4	
Abrasion Test -ASTM C-704 (cc loss)			
After Heating at 1500°F (816°C)		4.0	
Permanent Linear Change			
After Drying at 230°F (110°C)		Negligible	
After Heating at 1500°F (816°C)		-0.3	

Chemical Analysis: (Approximate)
(Calcined Basis)

Silica	(SiO_2)	8.4%
Alumina	(Al_2O_3)	77.9
Titania	(TiO_2)	2.6
Iron Oxide	(Fe_2O_3)	1.0
Lime	(CaO)	2.9
Magnesia	(MgO)	1.9
Alkalies	(Na_2O)	1.9
Phosphorus Pentoxide	(P_2O_5)	3.4

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Extra-High Alumina Brick

Harbison~Walker Refractories Company

The term extra-high alumina brick refers to refractory brick based on high-purity alumina and having an overall alumina content of more than 80%. Those products with silica additions rely on the development of mullite as the bonding phase. Other products rely on corundum as the bonding phase. Special versions of these products, members of the **TUFLINE®** Family, have enhanced resistance to thermal shock. All of these extra-high alumina brick possess excellent hot strength as measured by hot modulus of rupture, load test, and creep test. The high purity formulation and low porosity of the DM (dense matrix) technology yields excellent resistance to corrosive slags, particularly those containing iron oxide.

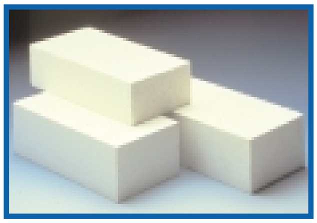
The members of this family of extra-high alumina brick include:

GREENAL 80 P: This is a burned, phos-added 80% alumina brick based on tabular alumina. It offers enhanced resistance to alkali.

TUFLINE® 90: This is an economical, thermal shock resistant extra-high alumina brick. Its high purity matrix provides excellent physical properties.

GREENAL 90: A 90% alumina, mullite bonded brick, with phosphorous pentoxide addition. This brick has high refractoriness and excellent physical properties.

KORUNDAL XD®: This product has been the premier mullite-bonded 90% alumina brick since the 1960's. It continues to offer the best hot load strength in the industry. **KORUNDAL XD** is used in a wide range of applications including ferrous foundry, ceramic kilns, chemical processing units, and incinerators.



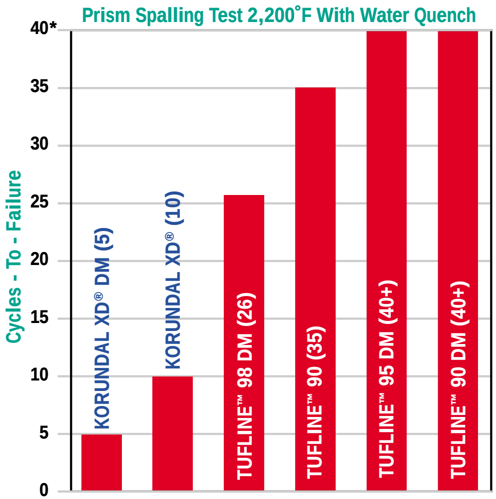
KORUNDAL XD® DM: A version of **KORUNDAL XD** offering the proprietary dense matrix (DM) formulation. This product provides even lower porosity and better hot strength than the standard product.

TUFLINE® 90 DM: A version of **KORUNDAL XD** offering both the DM technology and enhanced resistance to thermal shock.

TUFLINE® 95 DM: This is a high-purity, corundum-bonded product offering both the DM and thermal shock resistance technology. This product is primarily used in chemical incinerators and quench chambers of incinerators processing fluorine-containing waste.

TUFLINE® 98 DM: This product is the highest purity member of our corundum-bonded TUFLINE Family. It offers excellent high temperature strength and thermal shock resistance along with low porosity. The very low silica content makes it suitable for service in corrosive environments such as to fluorine and hydrogen atmospheres.

H-W® CORUNDUM DM: A 99% alumina refractory brick, which utilizes the DM technology to achieve, improved bonding and lower porosity. Also available without DM technology.



* Test concluded with maximum of 40 cycles.

Extra-High Alumina Brick

	GREENAL 80P	TUFLINE® 90	GREENAL 90	KORUNDAL XD®	KORUNDAL XD® DM
Bulk Density, pcf	177	182	189	186	195
Apparent porosity, %	15.5	17.6	13.0	16.1	12.4
Modulus of Rupture, psi					
At 70°F	2,990	1,730	4,000	2,330	3,840
At 2,700˚F	2,230	1,050	2,500	1,320	1,930
Chemical Analysis: % Approximate (Calcined Basis)					
Silica (SiO_2)	14.2	9.7	7.7	9.5	9.2
Alumina (Al_2O_3)	81.4	89.3	90.0	90.1	90.3
Titania (TiO_2)	1.2	0.6	Trace	Trace	Trace
Iron Oxide (Fe_2O_3)	0.5	0.3	0.1	0.1	0.1
Lime (CaO)	<0.1	0.1	0.1	0.1	0.1
Magnesia (MgO)	<0.1	Trace	Trace	Trace	0.1
Alkalies ($Na_2O + K_2O$)	0.1	0.1	0.2	0.2	0.2
Phosphorus Pentoxide (P_2O_5)	2.6	–	1.9	–	–

	TUFLINE® 90 DM	TUFLINE® 95 DM	TUFLINE® 98 DM	H-W® CORUNDUM DM	H-W® CORUNDUM
Bulk Density, pcf	199	205	210	208	192
Apparent porosity, %	13.1	13.4	12.0	12.9	19.4
Modulus of Rupture, psi					
At 70°F	2,210	2,040	2,760	4,500	2,800
At 2,700˚F	1,370	1,070	1,080	810	–
Chemical Analysis: % Approximate (Calcined Basis)					
Silica (SiO_2)	6.3	2.1	0.1	0.2	0.2
Alumina (Al_2O_3)	89.9	94.1	97.5	99.6	99.6
Titania (TiO_2)	Trace	Trace	0.1	Trace	Trace
Iron Oxide (Fe_2O_3)	0.1	0.1	0.1	0.1	0.1
Lime (CaO)	0.1	Trace	Trace	Trace	Trace
Magnesia (MgO)	Trace	0.2	0.2	Trace	Trace
Other Oxides	3.5	3.4	1.9	–	–
Alkalies ($Na_2O + K_2O$)	0.1	0.1	0.1	0.1	0.1

The data given above are based on averages of test results on samples selected from routine plant production by standard A.S.T.M. procedures where applicable. Variation from the above data may occur in individual test. These results cannot be taken as minima or maxima for specification purposes. All statements, information, and data given herein are believed to be accurate and reliable but are presented without guarantee, warranty, or responsibility of any kind, expressed or implied.

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High Alumina Brick

High Alumina Brick (50 to 70% Al_2O_3)

The term high-alumina brick refers to refractory brick having an alumina content of 47.5% or higher. This descriptive title distinguishes them from brick made predominantly of clay or other alumino-silicates which have a lower alumina content. Brick of this class typically are based on low alkali, bauxitic kaolins. The principle bond phase is mullite with some amount of free silica and glass. The presence of certain impurities is critical in determining refractoriness. Most naturally occurring minerals contain amounts of alkalies (soda, potash and lithia), iron oxide and titania. Alkalies can be particularly harmful since they ultimately react with silica to form a low melting glass when the brick are fired or reach high temperatures in service. The properties of these brick an be modified by the addition of other materials. Of particular interest is the addition of andalusite which enhances the load bearing ability. The minor addition of phosphoric acid can improve the alkali resistance of these products.

KALA®: High-purity, 50% alumina refractory with low porosity and exceptional resistance to alkali attack and creep under sustained loads. Primary applications include carbon-baking flues, glass tank regenerators, and incinerators.

KALA® SR: A shock resistant version of KALA .It possesses a similar degree of alkali and creep resistance, but with much improved resistance to thermal cycling.

ARCO® 60: Is a 60% alumina firebrick exhibiting good properties for use at intermediate temperatures.

UFALA®: This product manufactured from high purity bauxitic kaolin displays low porosity, very good hot strength, and good resistance to thermal shock and alkali attack. Major applications are chemical incinerators and lime sludge kilns.

NIKE 60 AR: A 60% alumina andalusite contening brick,with excellent creep and abrasion resistance. This product has good acceptance in CFB's and incinerators.

UFALA® XCR: A further improvement to UFALA with additional andalusite. This product has been widely used in applications requiring excellent creep resistance such as sodium silicate melter and regenerator crowns.

UFALA® UCR: A special version of this family utilizing a high-purity mullite bond. This product offers excellent resistance to both thermal cycling and creep. It's principle use has been in carbon black reactor quench zones.

RESISTAL SM60C: This andalusite contening, phosphorus pentoxide added, 60% alumina brick shows very good physical properties and corrosion resistance.

KRUZITE® -70: Is a dense, low porosity, 70% alumina brick with, good spalling resistance, hot load strength, and the ability to withstand attack by corrosive slags.

VALOR® 70P: this burned 70% alumina brick utlizes an addition of phosphoric acid. This redues porosity and enhances alkali resistance. It also offers excellent thermal shock resistance.

High Alumina Brick

	KALA®	KALA® SR	ARCO® 60	UFALA®	NIKE 60 AR
Density, pcf	153	153	155	157	159
Modulus of Rupture, psi	2,060	1,500	1,600	2,640	2,400
Load Test, 25 psi At 2,640°F Subsidence, %	0.3	2.9	1.2	0.6	0.4
Prism Spalling Test At 2,200°F with Water Quench Cycles to Failure	5-8	37-40	–	10-13	18-21
Chemical Analysis %					
Alumina (Al_2O_3)	50.0	51.6	61.0	58.1	63.0
Phosphorus Pentoxide (P_2O_5)	–	–	–	–	–
Alkalies ($Na_2O + K_2O$)	0.1	0.4	0.7	0.1	0.2

	UFALA® XCR	UFALA® UCR	RESISTAL SM60C	KRUZITE® -70	VALOR® P70
Density, pcf	159	160	155	165	166
Modulus of Rupture, psi	2,200	2,150	2,820	1,700	2,350
Load Test, 25 psi At 2,640°F Subsidence, %	0.2	0.0	–	1.0	–
Prism Spalling Test At 2,200°F with Water Quench Cycles to Failure	18-21	37-40	–	19-22	23-36
Chemical Analysis %					
Alumina (Al_2O_3)	60.3	62.3	60.8	71.0	69.3
Phosphorus Pentoxide (P_2O_5)	–	–	2.0	–	1.6
Alkalies ($Na_2O + K_2O$)	0.3	0.4	0.3	0.6	0.2

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Cat# HW 91R (11/02) 3C

INSWOOL®

Blanket products

Harbison-Walker Refractories Company

INSWOOL® Ceramic Fiber Blankets are a complete product line for applications temperatures up to 2600°F. These products are produced from a spun ceramic fiber which is needled into lightweight, flexible blankets. INSWOOL® Ceramic Fiber Blankets provide excellent handling strength, low thermal conductivity, low heat storage and are resistant to thermal shock.

- Lower Thermal Conductivity
  - Heat losses are reduced at high temperatures
- Lower Heat Storage
  - Faster heat up and cool down for increased productivity
  - Reduces Fuel Consumption
  - Lowers Operating Costs
- Thermal Shock Resistance
  - Lightweight
  - Allows for extreme change in temperatures
  - Longer furnace campaigns
  - Allows flexibility in firing cycles
- Completely inorganic with no binders

INSWOOL® blanket products are easy to install. No special forming is required and plant personnel can be used to install the product. Furnace structures can be made lighter and furnace components can be shop fabricated with fiber linings. Also, there is no curing or dry out time when using INSWOOL® ceramic fiber blankets. These linings can be fired to peak operating temperature immediately after installation.

INSWOOL® fiber blankets have excellent chemical stability and are unaffected by most chemicals. The only exceptions are hydrofluoric and phosphoric acid.

INSWOOL® HP is a high purity blanket that is made from a 50/50 blend of alumina and silica that has superior tensile strength and handling capabilities. This product can be used in applications up to 2300 °F and is available in 4, 6 and 8 pound densities.

INSWOOL® HTZ is a blanket used in higher temperature applications up to 2600 °F with low shrinkage characteristics. The product is made from a blend of alumina, silica and zirconia.

INSWOOL® CG is an alumina silica blanket used in applications up to 2000 °F. It is a high quality product that can be used as back up insulation for most furnace applications.

Typical Applications

INSWOOL® HP

- Furnace Linings for Ceramic, Petrochemical and Metals Markets
- Removable Insulating Blankets & Pads
- Furnace & Boiler Repair
- Furnace Door Linings
- Glass Furnace Crown Insulation
- Soaking Pit Seals
- Flexible High Temperature Pipe Insulation
- Insulation for Steam & Gas Turbines
- Expansion Joint Seals
- High Temperature Gasketing

INSWOOL® HTZ

- Reheat Furnaces
- Soaking Pit Seals
- Refractory and Ceramic Kilns
- Boiler Linings
- Glass Furnace Crown Insulation
- Refractory Kilns
- Furnace Linings & Seals

INSWOOL® CG

- Backup for Fiber Linings
- Expansion Joint Material
- Insulation Pads
- Furnace Packing Material

TECHNICAL DATA

Typical Physical Properties

	INSWOOL® HP	INSWOOL® HTZ	INSWOOL® CG
Color:	white	white	white
Maximum Recommended Temperture:			
Intermittent Use, °F:	2300	2600	2000
Continous Use, °F:	2150	2450	1800
Melting Point, °F:	3200	3200	2750
Fiber Diameter, microns:	3	3	3 - 4.5
Average Fiber Length, inches:	3	3	3
Tensile Strength - 8lb/ft^{2,} 1 in.:			
Machine Direction, lb./in^2:	10	10	8
Cross Direction, lb./in^2:	6	6	5
Chemical Analysis: (approximate), %			
(Calcined Basis)			
Alumina (Al_2O_3)	45.0	36.0	44.0
Silica (SiO_2)	54.3	48.0	54.0
Zirconia (ZrO_2)	--	15.4	--
Iron Oxide (Fe_2O_3)	0.2	0.1	<1.2
Lime (CaO)	0.1	0.1	--
Titania (TiO_2	0.1	0.1	--
Magnesia (MgO)	0.1	0.1	--
Alkalies (Na_2O+K_2O)	0.2	0.2	<0.5

Typical Thermal Conductivity, BTU-in/ hr ft^2 °F: INSWOOL® HP and INSWOOL® HTZ BLANKET

	600°F	800°F	1000°F	1200°F	1400°F	1600°F
Blanket Density						
4#	0.63	0.85	1.16	1.4	1.8	2.2
6#	0.56	0.73	0.97	1.2	1.55	1.85
8#	0.43	0.7	0.78	1.0	1.2	1.43

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INSWOOL® Ceramic Fiber MODULES

INSWOOL® Ceramic Fiber Modules are a product line designed for full thickness linings in furnace applications. The **CSW** (Center Stud Weld) and **FQW** (Folded Quick Weld) modules are made from high quality spun INSWOOL® HP and HTZ blanket. Spun INSWOOL® blanket has superior handling characteristic and strength characteristics. Both attachment systems provide for quick installation and less downtime for the installer.

Standard sizes for both types of modules are 12" long x 12" wide. Special size modules are also available upon request. Various densities are available; 9.3# is standard. 8#, 10#, 10.7# and 12# densities are available. The modules are compressed to the specific density's to prevent shrinkage for longer module life and durability.

CSW Modules (Center Stud Weld)

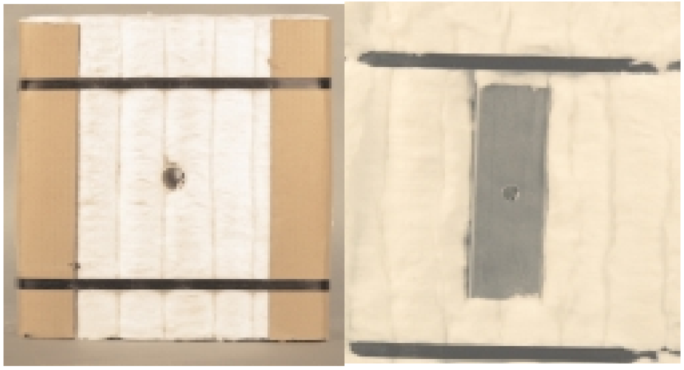
The **CSW** Module system is a module using a 304 stainless steel channel and two rods that runs through the blanket. This module is installed by using a pre-positioned stud pattern. This is done by welding a 304 stainless steel 3/8" stud to the furnace wall. Each **CSW** module is then attached over the stud and tightened with a bolt.

CSW modules linings can be installed in parquet or soldier course pattern using batten strips. Dual studs and holes attachments can be added for larger size **CSW** modules upon request.

FQW Modules (Folded Quick Weld)

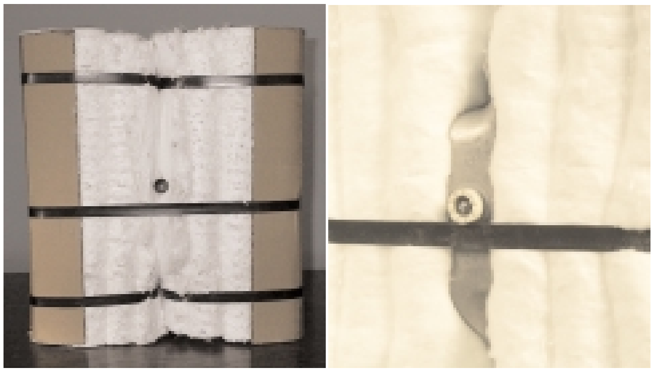
The **FQW** Module system is a folded blanket module that is made into 2 halves with a Quick Weld attachment. This new design provides for no blind welds in the lining design. The advantage to the **FQW** module is the speed of installation. It requires no stud pattern or layout. Using a quick weld stud gun, simply place the module on the wall and pull the trigger. **FQW** modules can be installed in a parquet or soldier course pattern using batten strips.

CSW Modules



Hot Face Cold Face

FQW Modules



Hot Face Cold Face

INSWOOL® Ceramic Fiber Modules

Applications

- Stress Relieving Furnaces
- Annealing Furnaces
- Car Bottom Furnaces
- Process Heaters
- Refinery Heaters
- Reheat Furnaces
- Furnace Linings for Kilns & Boilers
- Soaking Pit Covers
- Pre- heat Ladles Covers
- Forge Furnaces

Specifications

Blanket Options
- HP - 1500°F - 2150°F
- HTZ - > 2150°F

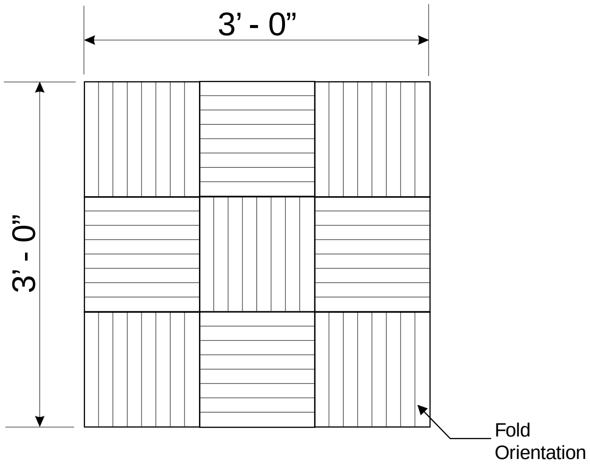
Thickness
- 4" -12" Thick

Sizes
- CSW - 12" x 12", 12" x 24"
- FQW - 12" x 12"
- Sidewalls only 24" x 24"
- Special sizes available upon request

Density
- 8#, 9.3#, 10#, 10.7# & 12#

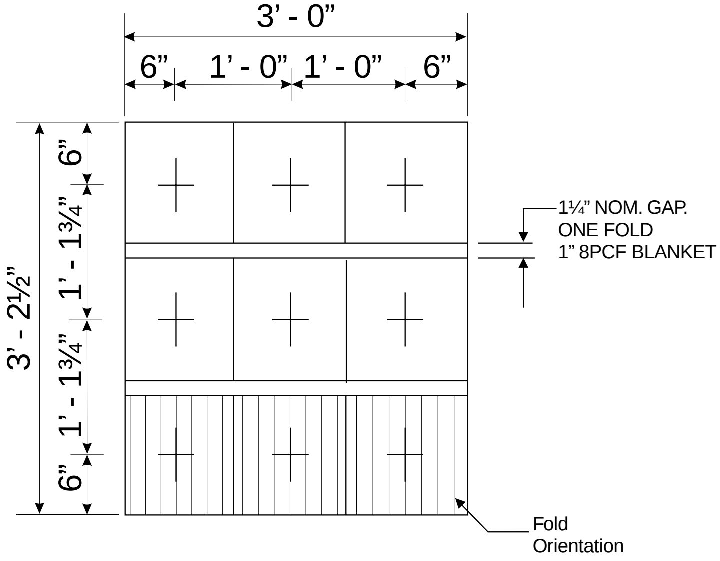
Hardware
- 304 SS Standard Base and Rods
- Special Hardware available upon request
  - o 310SS, 316SS, 330SS and Inconel - add 2-3 weeks delivery for special hardware

Furnace Design Perimeters



PARQUET

Parquet Design - For applications of 2000° F and less



WELD STUD ASSEMBLY - SOLDIER

Soldier Course Design- For applications of 2000° F to 2150°F use one batten strip -over 2150°F use a double batten strip

Harbison-Walker Refractories Company
400 Fairway Drive
Moon Township, PA 15108

Cat# HW 96 (05/04) 25C

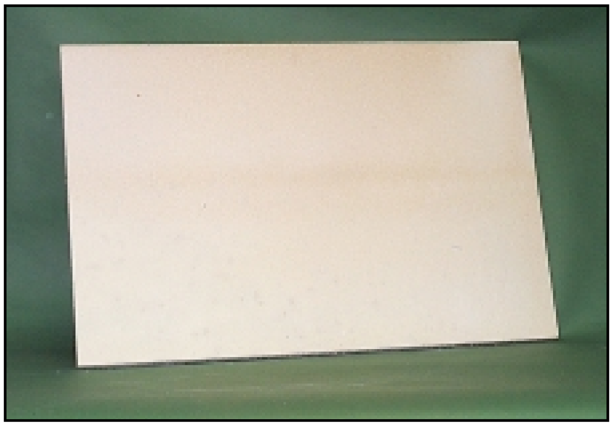
INSBOARD®

Ceramic Fiber Boards

Harbison-Walker Refractories Company

INSBOARD® is a family of vacuum-formed, ceramic fiber boards with excellent insulating properties and high mechanical strength. They offer good thermal stability. It is manufactured from bulk ceramic fiber and special binders. This yields a strong, dense product that has low thermal conductivity and excellent resistance to thermal shock and chemical attack.

INSBOARD® is an excellent choice for applications with high velocity, vibration or mechanical stress. The products possess superior strength and good handling characteristics. INSBOARD® is lightweight and easy to install. These products are rigid and self supporting which makes installation simple. INSBOARD® products can also be machined or cut into shapes.



INSBOARD® comes in standard size of 36" x 48" with thicknesses of $^1/_4$", $^1/_2$", 1", 1$^1/_2$" and 2". The product line has three types of products for applications that range from 2300°F to 3000°F.

Applications	2300LW	2300HD	2600	3000
Full Thickness Furnace Linings		x	x	x
Board over Blanket Linings	x	x	x	x
Refractory Backup Insulation	x	x	x	x
Rigid High Temperature Gaskets	x	x		
Hot Face Linings for Ceramic Kilns & Petrochemical Furnaces			x	x
Glass Tank Side & End Wall Insulation	x	x	x	x
Insulation with High Velocities	x	x	x	x
Hot Gas Duct Linings	x	x	x	x
Expansion Joint Material	x	x		
Heat Shields for Personnel Protection	x	x	x	x
Pouring Forms for Castable	x			
Combustion Chambers	x	x	x	x
High Temperatures Dryers	x	x	x	x
Industrial Heat Shields	x	x	x	x
Flue & Chimney Linings / Kilns & Furnaces	x	x	x	x
High Temperature Muffles	x	x	x	
Heat Treating Furnaces	x			

TECHNICAL DATA

Physical Properties	INSBOARD®			
	2300 LW	**2300 HD**	**2600**	**3000**
Density, lbs/ft^2:	14-18	26	18	12
Continuous Use Limit, °F:	2300	2300	2600	3000
Recommended Use Limit, °F:	2100	2100	2400	2700
Melting Point, °F:	3200	3200	3200	3200
Modulus of Rupture, psi:	75	200	120	70
Compressive Strength, psi:				
10% Deformation:	20	50	30	18
25% Deformation:	65	110	50	30
Hardness, lbs.:				
10% Deformation:	18	50	30	15
25% Deformation:	40	120	60	40
Shrinkage (24hrs.), %:				
After 2000°F	2.4	2.3	–	–
After 2200°F	3.1	2.8	2.8	–
After 2400°F	–	–	2.9	1.5
After 2600°F	–	–	3.1	1.9
After 2800°F	–	–	–	2.6
After 3000°F	–	–	–	3.4
Thermal Conductivity, Btu-in/hr-ft^2 - °F:				
400°F	0.3	0.4	–	–
800°F	0.6	0.6	0.6	0.6
1200°F	0.8	0.8	0.8	0.9
1600°F	1.0	1.0	1.0	1.4
2000°F	1.2	1.2	1.2	1.9
2400°F	–	–	–	2.4

Harbison-Walker Refractories Company
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INSWOOL®
Utility Paper

INSWOOL® Utility Paper is processed from unwashed spun, high purity alumina-silica fibers formed into a highly flexible sheet. It is recommended for continuous use at temperatures up to 2300^{o}F in applications where insulating efficiency is less critical. INSWOOL® Utility Paper is designed for use primarily in applications where thermal stability and high temperature protection up to 2300^{o}F are most important. It is avaiable in two grades, UG-F and UG-J

INSWOOL® Utility Paper contains an organic binder to provide increased handling strength at room temperature. It possesses excellent chemical stability and resists attack from corrosive agents. Exceptions are hydrofluoric and phosphoric acids and concentrated alkalis. Because of its high-purity chemistry, INSWOOL® Utility Paper resists both oxidation and reduction. If it becomes wet due to water, steam, or oil, its thermal and physical properties with return upon drying.

	UG-F	UG-J
Tensile Strength - gms.in.		
Machine Direction:	3500	5800
Cross Direction:	2400	5000
Mullen Burst - lbs./in^2:	8	22
Thickness Specifications		
Nominal:	1/16"	1/8"

Features

- Easy to Cut, Wrap or Form
- Low Thermal Conductivity
- Thermal Shock Resistant
- Temperature Stability
- Resilient
- Lightweight
- Low Heat Storage
- Good Dielectric Strength
- Excellent Corrosion Resistance
- High Heat Reflectance

Applications

- Ware Separator
  - Ceramic and Glass
  - Metal Clad Brick
  - Glass Tank Backup
  - Kiln Car Deck Covering
- Petrochemical
  - Transfer Line Protection
  - Welding & Brazing Protection
- Steel & Nonferrous
  - Investment Casting Mold Wrap
  - Ladle Refractory Backup
  - Backup Linings for Metal Troughs
  - Hot Top Linings
  - Coke Oven Door Seals

TECHNICAL DATA

Typical Physical Properties

		INSWOOL® Utility Paper
Melting Point, °F:		3200
Maximum Use Temperature, °F:		2300
Chemical Analysis: (approximate), % (Calcined Basis)		
Alumina	(Al_2O_3)	47.0
Silica	(SiO_2)	52.6
Alkalies	(Na_2O)	0.18
Iron Oxide	(Fe_2O_3)	0.03
Others		0.17
Loss on Ignition, LOI:		8%
Density lbs/ft^2:		6-9
Dielectric Strength:		50
Thermal Conductivity, Btu-in/hr-ft^2 - °F: Mean Temperature °F		
500		0.47
800		0.71
1300		1.19
1600		1.67

The data given above are based on averages of test results on samples selected from routine plant production by standard A.S.T.M. procedures where applicable. Variation from the above data may occur in individual test. These results cannot be taken as minima or maxima for specification purposes. All statements, information, and data given herein are believed to be accurate and reliable but are presented without guarantee, warranty, or responsibility of any kind, expressed or implied.

Statements or suggestions concerning possible use of our products are made without representation or warranty that any such product is fit for such use or that such use is free of patent infringement of a third party. The suggested use assumes that all safety measures are taken by the user.

Harbison-Walker Refractories Company
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Moon Township, PA 15108

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Cat# HW 97 (09/03) 3C

INSWOOL®

2300 Paper

Harbison-Walker Refractories Company

INSWOOL® 2300 Paper is processed from washed, spun, high purity fibers formed into highly flexible sheet. It is recommended for continuous use at temperatures up to 2300°F in applications where insulating efficiency and high strength are important. It is available in three grades, A, F, and J.

Because it is processed from washed fiber, INSWOOL® 2300 Paper is clean, has low shot content and offers low thermal conductivity. It's highly uniform structure assures homogeneous thermal conductivity throughout, and its high tensile strength makes it ideal as a gasket, seal or spacer material.

INSWOOL® 2300 Paper contains an organic binder to provide increased handling strength at room temperature. It possesses excellent chemical stability and resists attack from most corrosive agents. Exceptions are hydrofluoric and phosphoric acids and concentrated alkalis. Because of its high purity chemistry, INSWOOL® 2300 Paper resists both oxidation and reduction. If it becomes wet due to water, steam or oil, its thermal and physical properties will return upon drying.

	INSWOOL® 2300 Paper		
	A	**F**	**J**
Tensile Strength - gms.in.			
Machine Direction	2400	3200	6000
Cross Direction	2200	2700	5200
Mullen Burst - lbs./in^2	7	10	24
Thickness Specifications			
Nominal	1/32"	1/16"	1/8"

Features

- Easy to Cut, Wrap or Form
- Low Thermal Conductivity
- Thermal Shock Resistant
- Temperature Stability
- Resilient
- Lightweight
- Low Heat Storage
- Good Dielectric Strength
- Excellent Corrosion Resistance
- High Heat Reflectance

Applications

- Ware Separator
  - Ceramic and Glass
  - Metal Clad Brick
  - Glass Tank Backup
  - Kiln Car Deck Covering
- Petrochemical
  - Transfer Line Protection
  - Welding & Brazing Protection
- Steel & Nonferrous
  - Investment Casting Mold Wrap
  - Ladle Refractory Backup
  - Backup Linings for Metal Troughs
  - Hot Top Linings
  - Coke Oven Door Seals

TECHNICAL DATA

Typical Physical Properties

INSWOOL® 2300 Paper

Melting Point, °F:		3200
Maximum Use Temperature, °F:		2300
Chemical Analysis: (approximate), % (Calcined Basis)		
Alumina	(Al_2O_3)	47.0
Silica	(SiO_2)	52.6
Alkalies	(Na_2O)	0.18
Iron Oxide	(Fe_2O_3)	0.03
Others		0.17
Loss on Ignition, LOI:		8%
Density lbs/ft^2:		6-9
Dielectric Strength:		50
Thermal Conductivity, Btu-in/hr-ft^2 - °F: Mean Temperature °F		
	500	0.39
	800	0.55
	1300	0.87
	1600	1.05

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Cat# HW 98 (05/03) 3C

INSWOOL®

Ropes & Braids

INSWOOL® Ropes and Braids

H-W Refractories provides a family of ropes and braids for industrial use in temperatures up to 2300°F (1260°C). Typical applications for these products include gasketing, packing and sealing in and around high-temperature heating equipment. Produced from ceramic fibers, these products exhibit excellent chemical stability, resisting attack from most corrosive agents. Exceptions are hydrofluoric and phosphoric acids and concentrated alkalies. These fiber ropes and braids also resist oxidation and reduction. If wet by water or steam, thermal properties are completely restored upon drying. No water of hydration is present.

In choosing the most appropriate product for a particular application, the following product descriptions should be considered:

3-Ply Twisted Rope

Produced by twisting 3-plys of ceramic fiber wicking, this product is relatively soft and lower in density than other ropes or braids. 3-ply Twisted Rope is the most economical choice. This product is also available with an inconel insert which drastically increases resistance to mechanical abuse.

High Density Rope

High Density Rope is made from many strands of ceramic fiber yarn formed into three plys and then twisted, resulting in a product that is higher in density and thus more durable than 3-ply Twisted Rope.

Round Braid and Square Braid

The highest density of all our rope offerings, the ceramic fiber is braided to provide maximum resistance to mechanical abuse. Aside from its superior strength, round and square braids also exhibit minimal unravelling when cut.

INSWOOL® ROPES AND BRAIDS

Product Availabilty

3-Ply Twisted Rope

Diameter of Section (Inches)	Feet Per Roll	Approximate Yield (Feet/Lb.)
1/4	2250	110
1/4	900	110
3/8	1300	45
3/8	500	45
1/2	725	30
1/2	300	30
5/8	525	18.6
3/4	375	16.2
7/8	275	11.8
1	225	10.3
1-1/4	175	6.5
1-1/2	125	4.3
2	50	2.4

High Density Twisted Rope

Diameter of Section (Inches)	Feet Per Roll	Approximate Yield (Feet/Lb.)
1/4	500	101.3
3/8	300	51.3
1/2	200	28.6
5/8	200	21.3
3/4	100	15.0
7/8	100	10.6
1	50	8.8
1-1/4	75	6.2
1-1/2	50	4.4
2	50	2.0

Round Braid

Diameter of Section (Inches)	Feet Per Roll	Approximate Yield (Feet/Lb.)
1/4	1700	91.9
1/4	700	91.9
3/8	900	42.5
3/8	400	42.5
1/2	500	23.5
1/2	200	23.5
5/8	350	11.2
3/4	250	9.1
7/8	175	7.1
1	125	5.1
1-1/4	100	3.5
1-1/2	75	2.4
2	50	1.5

Square Braid

Diameter of Section (Inches)	Feet Per Roll	Approximate Yield (Feet/Lb.)
1/4	1075	58.1
1/4	450	58.1
3/8	575	26.3
3/8	250	26.3
1/2	325	17.8
1/2	150	17.8
5/8	250	9.5
3/4	175	7.3
7/8	125	5.7
1	100	4.1
1-1/4	75	2.8
1-1/2	50	2.0
2	35	1.3

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Cat# HW 100 (9/02) 3C

INSWOOL®
PUMPABLE

Harbison-Walker Refractories Company

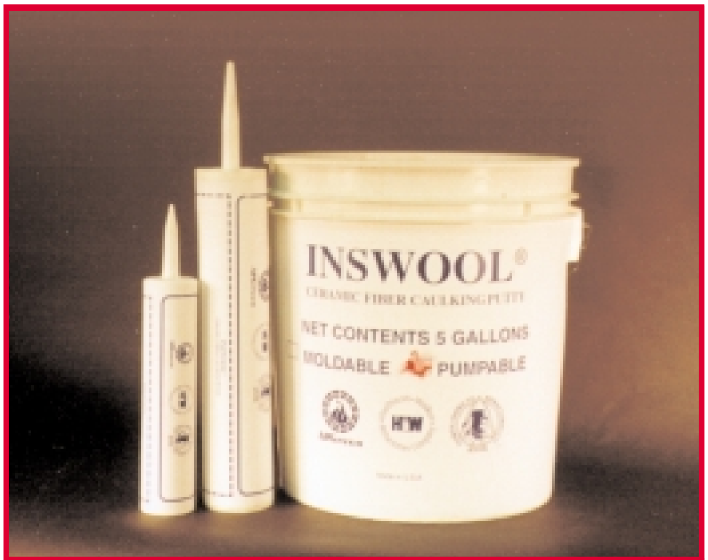
INSWOOL® PUMPABLE 2300^{0}F Ceramic Fiber Pumpable Material

- High temperature caulking putty
- Now available in standard 10$^1/_2$ oz. and 29 oz.caulking tube in addition to standard 5 gallon buckets
- Ready to use
- Easy to apply

INSWOOL® PUMPABLE is a 2300^{0}F ceramic fiber, putty-like consistency material and was especially formulated for pumping with special equipment. It is now available in 10$^1/_2$ oz. caulking tube (12 per case) and 29 oz. caulking tubes (6 per case) and are available through our Plant or Distribution Centers. It can be used to fill hot spots behind existing hot face lining or can be used to fill small voids and thin cracks.

INSWOOL® PUMPABLE is a lightweight material with very low thermal conductivity. It is an excellent thermal insulator. It dries to a firm, but compressible board-like consistency. It is suitable for expansion joints, and for filling contraction cracks.

INSWOOL® PUMPABLE has excellent thermal shock resistance, and can generally be dried or put into heat containment service without preheating.



Physical Properties

Maximum temperature ratings:		2300^{0}F
Wet Density (lbs./ft.^{3}):		68
Dried Density (lbs./ft.^{3}):		27
Permanent Linear Change:		
After heating to 1500^{0}F		+ 0.1%
After heating to 2000^{0}F		-3.1%
Chemical Analysis - Calcined basis		
Silica	SiO_2	60.0%
Alumina	Al_2O_3	31.6%
Iron Oxides	Fe_2O_3	0.2%
Lime	CaO	7.3%
Alkalies	$Na_2O + K_2O$	0.9%

Exclusively serving the iron and steelmaking industries…

North American Refractories Company (NARCO) is a leading supplier of refractory solutions to the iron and steel industries. The company makes high-performance products for BOFs, EAFs, LMFs, ladles, finishing, alternative ironmaking, casthouses, blast furnaces, and flow control applications. In addition to providing complete technical support services, NARCO also can design and implement a turnkey refractory management program to meet your facility's specialized requirements.

Exclusively serving the non-ferrous metals, ferrous foundry, glass, hydrocarbon, incineration, minerals processing and other industries…

Harbison-Walker Refractories Company (H-W) provides high-performance refractory solutions to all non-steel-related industries. In addition to its own outstanding line of products, many of which have become industry standards, H-W is recognized worldwide for its technical support and expertise. Founded in 1875, the company is North America's oldest refractory maker.

Manufacturing products exclusively for NARCO and Harbison-Walker…

A.P. Green Refractories (APG) makes products for the iron and steel, aluminum, cement, copper, glass, and hydrocarbon and minerals processing industries. The company also has one of the world's top capabilities for customized pre-cast shapes, along with a full line of insulating ceramic fibers.

Products from all these companies are available through:

For Industrial Sales:

Harbison-Walker Refractories Company
400 Fairway Drive
Moon Township, PA 15108
Phone: (412) 375-6600
Fax: (412) 375-6783

Cat. # HW106 (8/02) 3C

MAGSHOT®

Harbison-Walker Refractories Company

MAGSHOT® GUN MIX

Magnesite-based chrome-free gun mix, proven to give superior life in recovery boiler systems in pulp and paper mills.

- **Superior Smelt Resistance**
- **Chrome-Free Composition**
- **Good Thermal Conductivity**
- **Ease of Installation**
- **Proven Track Record**

MAGSHOT was developed to help meet the environmental and performance needs of the pulp and paper industry. Its chrome-free composition eliminates concerns about disposal of possibly hazardous chrome-containing refractory waste. As for performance, laboratory tests have shown that this unique dicalcium silicate bonded magnesite product provides an exceptional level of chemical resistance to molten smelt.

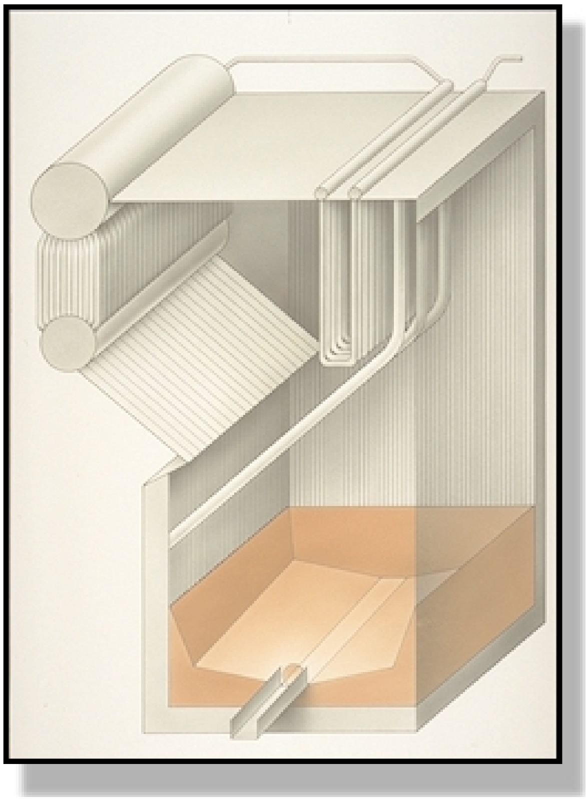
A long record of success in numerous recovery boiler systems throughout the industry testifies to the durability of MAGSHOT where it matters most – under demanding field conditions.

Superior Smelt Resistance Demonstrated in Drip Slag Tests

Samples After Drip Test:

MAGSHOT
Remarks: No Erosion, No Alteration, No Build-up

Typical 80% Alumina-Phosphate Bonded Plastic
Remarks: Eroded, Cracked, Bloated Slag Build-up



MAGSHOT installed in the lower section of a recovery boiler.

Ease of Installation

Ease of installation makes **MAGSHOT®** the product of choice for quick-turnaround repairs. It can be gunned, hand-packed, or cast. For larger cast installations this product is available as **MAGSHOT® CASTABLE**. Both products require minimal curing time – heat-up (100°F/hr.) can begin two hours after installation. Other features include:

- **Low dust and rebounds**
- **Quick dry-out schedule**
- **Up to one year shelf life**

MAGSHOT

TECHNICAL DATA

	MAGSHOT®	MAGSHOT® CASTABLE
Physical Properties; (Typical)		
Maximum Service Temperature, ˚F	2700°F	2700°F
Bulk Density, pcf		
After 230°F	160	179
Modulus of Rupture, psi		
After 230°F	1,690	1,510
After 1500°F	1,560	1,480
Crushing Strength, psi		
After 230°F	5,870	10,100
After 1500°F	5,930	7,000
Chemical Analysis, % Approximate (Calcined Basis)		
Silica (SiO_2)	7.2	5.8
Alumina (Al_2O_3)	1.9	1.7
Titania (TiO_2)	0.1	0.1
Iron Oxide (Fe_2O_3)	5.8	10.0
Lime (CaO)	6.1	9.5
Magnesia (MgO)	76.7	68.7
Alkalies ($Na_2O + K_2O$)	0.7	1.2
Phosphorous Pentoxide (P_2O_5)	1.5	2.9

The data given above are based on averages of test results on samples selected from routine plant production by standard A.S.T.M. procedures where applicable. Variation from the above data may occur in individual test. These results cannot be taken as minima or maxima for specification purposes. All statements, information, and data given herein are believed to be accurate and reliable but are presented without guarantee, warranty, or responsibility of any kind, expressed or implied.

Statements or suggestions concerning possible use of our products are made without representation or warranty that any such product is fit for such use or that such use is free of patent infringement of a third party. The suggested use assumes that all safety measures are taken by the user.

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Super-Duty Fireclay Brick

KX-99®-BF is our high fired dry-pressed coarse grain super-duty fireclay brick. It exhibits very good thermal shock resistance for this type brick. KX-99®-BF provides very high strength and excellent resistance to attack by alkalies and carbon monoxide. KX-99®-BF is available in a large number of sizes and shapes.

KX-99® is our high fired dry-pressed super-duty fireclay brick. It is similar to KX-99®-BF but without the coarse grains. KX-99® offers similar strength and resistance to alkalies and carbon monoxide as does KX-99®-BF. It is available in a large number of sizes and shapes.

CLIPPER® DP is our regular fired premium dry-pressed super-duty fireclay brick. It offers very good resistance to thermal shock and alkali attack. CLIPPER® DP also provides excellent strength to better resist conditions such as impact from process feed. CLIPPER® DP is available in a large number of sizes and shapes.

ALAMO® is our regular fired conventionally dry-pressed super-duty fireclay brick. It is intended for general service conditions. ALAMO® is available in standard 9 x 4.5 x 2.5" and 3" sizes.

Typical Applications

	KX-99®-BF	KX-99®	CLIPPER® DP	ALAMO®
Stacks	●	●	●	●
Boiler Linings	●	●	●	●
Air Heaters	●	●	●	●
Charcoal Furnaces	●	●		
Hot Gas Ducts			●	●
Rotary Kilns			●	
Zinc Galvanizing Furnaces	●	●		
Low Temp Incinerators	●		●	
Blast Furnace Stoves	●			
Blast Furnace Sidewalls	●			
Checkers	●	●		
Oil Heater Division Walls	●	●		
Oil Heater Floors	●	●	●	●
Low Temp Metal Ladles	●		●	●
Floors Around Furnaces			●	●
Heat Exchangers	●		●	●
Cement Preheaters			●	●

H-W Super-Duty Fireclay Brick

Physical properties	KX-99®-BF	KX-99®	CLIPPER® DP	ALAMO®
Type	High Fired Coarse Aggregate	High Fired	Regular Fired	Regular Fired
Bulk Density, lbs/ft³:	142	143	142	141
g/cm³:	2.28	2.29	2.27	2.26
Apparent Porosity, %:	12.2	12.7	15.3	16.1
Modulus of Rupture, lbs/in²:	1950	2050	1350	1000
Cold Crushing Strength, lbs/in²:	8000	8500	6300	4000
Pyrometric Cone Equivalent Orton Standard Cones:	33-34	33-34	33-34	33-34
Permanent Linear Change After 2910°F, %:	-0.3	-0.4	-0.3	+0.5
Hot Load, 2640°F, % subsidence:	0.7	0.6	1.3	1.7
Chemistry Analysis, Approximate (Calcined Basis), %:				
Alumina Al_2O_3	42.2	42.2	42.2	42.6
Silica $Si0_2$	52.6	52.6	52.6	52.3
Iron Oxide Fe_2O_3	1.4	1.4	1.4	1.4
Titania TiO_2	2.3	2.3	2.3	2.2
Lime CaO	0.2	0.2	0.2	0.3
Magnesia MgO	0.3	0.3	0.3	0.3
Alkalies Na_2O+K_2O	0.9	0.9	0.9	0.9

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Statements or suggestions concerning possible use of our products are made without representation or warranty that any such product is fit for such use or that such use is free of patent infringement of a third party. The suggested use assumes that all safety measures are taken by the user.

Harbison-Walker Refractories Company
400 Fairway Drive
Moon Township, PA 15108

www.hwr.com
Phone: (412) 375-6600 ◆ Fax: (412) 375-6783

VIB-TECH

Engineered Shapes

Harbison-Walker Refractories Company

Shapes for High Performace

VIB-TECH shapes from Harbison-Walker provide our customers with complex shapes made from the same proven compositions found in Harbison-Walker's high-performace refractory bricks.

PRODUCTS

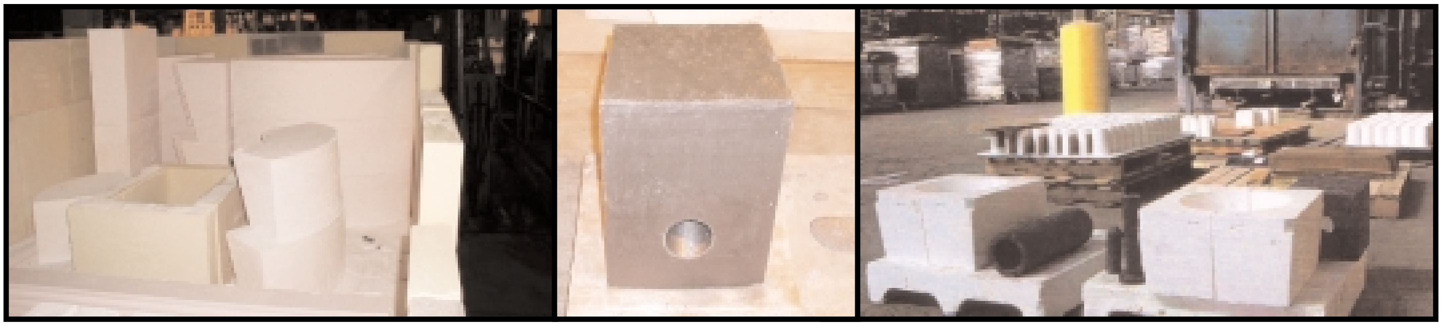
- **KORUNDAL® XD/C**
- **TUFLINE® 90 DM/C**
- **TUFLINE® 95 DM/C**
- **TUFLINE® 98 DM/C**
- **TUFLINE® DM/C AL**
- **H-W® CORUNDUM DM/C**
- **RUBY® SR/C**
- **AUREX® 75 SR/C**
- **AUREX® 75/C**
- **VISIL/C®**
- **HARBIDE® /C**

Engineered Complex Shapes

- **Thixotropic-Formed Shapes**
- **High Fired/Ceramic Bond**
- **Brick-Like Properties**
- **Improved Properties**
  - **– Density**
  - **– Porosity**
  - **– Strength**
- **Execellent Thermal Shock Resistant**

The Ultimate Combination of Products and Processes

When compared to traditional shape forming techniques, such as air ramming or cement-bonded precast shapes, Harbison-Walker's VIB-TECH family of fired ceramic-bonded shapes yield dramatic improvement in density, hot strength and thermal shock resistance. They can be manufactured in intricate shapes.



VIB-TECH *Family of Proven Products*

Three current commercial methods of special shape manufacture are shown in the table below. Only the VIB-TECH shapes from Harbison-Walker combine outstanding hot strenth with excellent thermal shock resistance.

TUFLINE® 90 DM/C vs.CONVENTIONAL PRODUCTS

Properties	**TUFLINE 90 DM/C***	**90%AL_2O_3 AIR RAMMED SHAPE****	**90% AL_2O_3 ULTRA-LOW CASTABLE****
Heat Treatment	Fired (ceramic bond)	Fired (ceramic bond)	Dried
Density (pcf)	195	186	184
Porosity (%)	14.5	16-18	15-17
Hot MOR @ 2700°F (psi)	1,500	1,000-1,200	600-800
Shock Resistance	Excellent	Fair	Fair to Good
Shape Complexlly	Excellent	Poor to Fair	Fair to Good

*Data subject to reasonable deviation and should not be used for specification purposes.
**Typical data meant to represent comparable air rammed and cast product.

Harbison-Walker currently manufactures VIB-TECH shapes in the following high performance brick compostions:

VIB-TECH Products

Products*	**Density pcf**	**Porosity %**	**MOR psi**	**CCS psi**	**Major Chemistry**
AUREX® 75/C	258	14.4	3,850	12,820	77.3% Cr_2O_3 22.1% Al_2O_3
AUREX® 75 SR/C`	262	13.5	1,560	8,840	73.4 Cr_2O_3 20.1 Al_2O_3
H-W® CORUNDUM DM/C	198	16.9	1,160	-	99.5% Al_2O_3
HARBIDE® /C	157	17.0	4,080	16,400	82.7% SIC
KORUNDAL® XD/C	188	14.5	4,140	12,700	90.1% Al_2O_3
RUBY®SR/C	204	15.5	1,380	12,900	83.1% Al_2O_3 11.1% Cr_2O_3
TUFLINE® 90 DM/C	197	14.6	1,710	11,120	89.3%Al_2O_3
TUFLINE® 95 DM/C	200	15.8	1,720	8,590	94.2% Al_2O_3
TUFLINE® 98 DM/C	203	16.0	-	-	97.6% Al_2O_3
TUFLINE® DM/C AL	211	14.2	2,250	-	91.0% Al_2O_3
VISIL/C®	118	14.7	620	5,520	99.5% SiC

Note: Data subject to reasonable variation and should not be used for specification purposes.
Consult your local sales representative for additional information.

Harbison-Walker Refractories Company
400 Fairway Drive
Moon Township, PA 15108

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Phone: (412) 375-6600 w Fax: (412) 375-6783

Cat# HW 105 (3/03) 2C

ALUMINUM

Melting/Holding Furnace

Many modern aluminum melting and holding furnaces are continuously being pushed harder and harder to produce more metal in shorter time. In many cases, the furnaces are being pushed to produce a variety of different aluminum alloys. These operating conditions have created a demand for refractories that can withstand the more severe environment.

Some of the destructive conditions that these modern operating practices generate include:

Temperature

Temperature is generally the simplest method of increasing throughput. While higher temperatures do decrease melt times, they can cause problems. Higher temperatures increase the rates of reaction between the metal and the refractories, leading to corundum formation and accelerated wear.

Fluxing

Fluxing practices, while necessary for efficient metal melting, are damaging to refractories. Alkali based fluxes can have the same effect on alumino-silicate refractories as they have on aluminum metal. Chlorine containing fluxes can degrade the bond system of cement-bonded refractory castables.

Charging

Scrap quality and charging practice can also be detrimental to refractory performance. Painted or other contaminated scrap can introduce components that are highly reactive with refractory linings. The size and charging method can be abusive too. Pushing large scrap into the furnace causes abrasion on the sill, and results in high mechanical impact on the ramp and hearth.

Alloys

Various alloying components can degrade refractories. Silicon alloys tend to be highly fluid and can penetrate further into furnace linings. Magnesium alloys are prone to thermiting which produces extremely high temperatures, and can lead to corundum formation. Zinc alloys also tend to promote corundum formation.

Cleaning

In all cases, it is very important to employ thorough furnace cleaning practices. Good furnace cleaning can help minimize corundum growth, and refractory wear. Efficient cleaning can also help to improve heat transfer to the bath, reducing thermal gradients and melt losses.

Harbison-Walker Castables for Aluminum Melting/Holding Furnaces

FIRECLAY CASTABLES

VERSAFLOW® 45/AL ADTECH®
A 45% alumina, pumpable, low-cement castable with improved strength versus conventional castables.

H-W® ES CASTABLE C AL
An industry standard for aluminum furnace safety linings, H-W® ES CASTABLE C AL is a coarse aggregate castable with excellent impact and thermal shock resistance.

60-65% ALUMINA CASTABLES

ARMORKAST 65AL
ARMORKAST 65AL is a very high purity low cement castable. Its unique bonding matrix provides exceptionally high strength and ultimate corrosion resistance.

VERSAFLOW® 65/AL PLUS®
A 65% alumina, low cement castable with high strength and versatile installation characteristics. VERSAFLOW® 65/AL C ADTECH® is the coarse aggregate containing version. Coarse aggregates provide improved impact and thermal shock resistance.

NARCOTUFF™ SUPER AL
With a minor zircon addition, NARCOTUFF™ SUPER AL is an excellent choice for the lower sidewall or belly band in a furnace with slight corundum growth.

GREENKLEEN-60 PLUS
Among the most popular maintenance materials available, GREENKLEEN-60 PLUS is a 60% alumina, andalusite containing, low cement castable. It has high strength and excellent aluminum resistance.

70-80% ALUMINA CASTABLES

ARMORKAST 80AL ADTECH®
This high purity, pumpable, 80% alumina castable is built for corrosion resistance. It has exceptional strength and aluminum resistance. ARMORKAST 80AL is designed for the most severe aluminum contact applications.

ALSTOP GREFCON® 80 A
An industry standard for more than 15 years, ALSTOP GREFCON® 80A is a high strength, high corrosion resistance, 80% alumina low cement castable.

ULTRA-EXPRESS 70 AL
An ultra-low cement, 70% alumina castable designed with enhanced flow, and self-leveling characteristics. ULTRA-EXPRESS 70 AL is very strong and is ideal for pumping over long distances and for casting into intricate form patterns.

90+% ALUMINA CASTABLES

VERSAFLOW® XPUR/AL ADTECH®
A tabular alumina based, silica-free, pumpable, low cement castable. VERSAFLOW® XPUR/AL ADTECH® has excellent strength and non-wetting characteristics. Because it is silica free, it is an excellent choice for high corundum belly bands.

ARMORKAST XPUR/AL ADTECH®
This tabular alumina based castable is also silica-free, and is designed to be a more cost effective corundum fighter. It also shows very high strength and excellent aluminum resistance.

MISCELLANEOUS CASTABLES

GREENLITE®-45-L AL
This lightweight castable has a very high strength to weight ratio. It is ideally suited for insulating sub-hearths, and crucibles.

VERSAFLOW® THERMAX® AL ADTECH®
A vitreous silica based low cement castable. It has exceptional thermal shock and abrasion resistance. VERSAFLOW® THERMAX® AL ADTECH® is an excellent choice for troughs.

THOR 60 ABR ADTECH®
60% silicon carbide castable with very high strength and abrasion resistance. THOR 60 ABR ADTECH® is a proven problem solver in hearths, ramps and sills.

NARCON ZRAL
A 60% zirconia castable with excellent corundum resistance. Zoning belly bands with NARCON ZRAL has proven to be very successful in furnaces prone to corundum formation.

Harbison-Walker Refractories Company

	VERSAFLOW® 45/AL ADTECH®	H-W® ES CASTABLE C AL	ARMORKAST 65AL	NARCOTUFF™ SUPER AL	VERSAFLOW® 65/AL PLUS®	GREENKLEEN-60 PLUS	ARMORKAST 80AL ADTECH®	ULTRA-EXPRESS 70 AL	ALSTOP GREFCON® 80 A	VERSAFLOW® XPUR/AL ADTECH®	ARMORKAST XPUR/AL ADTECH®	GREENLITE®-45-L AL	VERSAFLOW® THERMAX® AL ADTECH®	THOR 60 ABR ADTECH®	NARCON ZRAL
Typical Applications															
Sub-Hearth	●	●	●		●	●						●			
Hearth	●		●	●	●	●	●	●	●	●	●			●	
Lower Sidewall	●		●	●	●	●	●	●	●	●	●			●	●
Belly Band			●	●	●	●	●	●	●	●	●			●	●
Tap Blocks			●	●	●	●	●	●	●	●	●			●	
Trough	●	●	●	●	●	●	●	●	●	●	●	●	●	●	
Crucibles	●	●	●	●	●	●	●	●	●	●	●	●		●	
Aluminum Resistance	Good	Good	Excellent	Excellent	Good	Good	Excellent	Excellent	Good	Excellent	Excellent	Good	Good	Excellent	Excellent
Corundum Resistance	Fair	Fair	Excellent	Excellent	Good	Good	Excellent	Good	Good	Excellent	Excellent	Fair	Poor	Good	Excellent
Density (lb/ft^3)															
After drying at 230 °F	144	136	163	162	161	161	171	169	176	193	196	74	129	165	214
Modulus of Rupture (psi)															
After drying at 230 °F	1520	970	1900	1800	1790	2350	1850	1500	1600	1680	1500	500	1660	2400	2100
After heating at 1500 °F	1770	380	2300	2200	2800	2000	2200	2800	1600	1330	-	320	1650	-	2600
Hot Modulus of Rupture (psi)															
At 1500 °F	-	-	4000	4650	3300	3800	3250	5000	3000	-	-	-	-	4900	3600
Cold Crush Strength (psi)															
After drying at 230 °F	9840	7100	-	11500	16820	15000	10900	7000	6300	9220	-	3000	11370	-	11000
After heating at 1500 °F	6970	4100	10000	13000	14780	10000	10900	22000	7700	10800	-	1450	8630	15000	13000
Chemical Analysis,%:															
Al_2O_3	42.4	49.1	62.5	57.6	64.0	59.6	80.4	69.1	81.6	92.2	90.8	42.5	23.8	23.4	7.3
SiO_2	49.8	37.7	27.7	30.6	29.3	34.0	10.8	24.4	8.2	0.3	0.8	38.3	72.0	14.4	33.4
TiO_2	1.9	2.5	1.3	1.4	2.1	1.3	1.7	1.6	2.6	0.1	1.7	2.5	0.1	-	0.5
Fe_2O_3	0.8	1.1	0.7	0.9	0.8	0.8	0.8	1.0	1.1	0.1	0.1	2.5	0.1	0.1	0.1
CaO	3.2	8.9	1.4	1.4	3.5	3.8	2.4	2.6	1.3	3.2	3.2	10.2	2.8	2.7	1.1
MgO	0.2	0.3	-	0.1	0.1	0.2	0.2	0.1	0.1	0.1	0.2	0.2	0.1	-	-
Na_2O & K_2O	0.7	0.4	0.2	0.1	0.2	0.3	0.2	0.2	-	0.3	0.1	0.8	0.1	0.2	0.1
ZrO_2	-	-	-	3.2	-	-	-	-	-	-	-	-	-	-	57.4
SiC	-	-	-	-	-	-	-	-	-	-	-	-	-	59.0	-
Other	1.0	-	6.2	-	-	-	3.5	-	5.0	3.7	3.1	3.0	1.0	-	-

Exclusively serving the glass, iron and steelmaking industries…

North American Refractories Company (NARCO) is a leading supplier of refractory solutions to the iron and steel industries. The company makes high-performance products for BOFs, EAFs, LMFs, ladles, finishing, alternative ironmaking, casthouses, and blast furnaces. In addition to providing complete technical support services, NARCO also can design and implement a turnkey refractory management program to meet your facility's specialized requirements.

Exclusively serving the non-ferrous metals, ferrous foundry, hydrocarbon, incineration, minerals processing and other industries…

Harbison-Walker Refractories Company (H-W) provides high-performance refractory solutions to all non-steel-related industries. In addition to its own outstanding line of products, many of which have become industry standards, H-W is recognized worldwide for its technical support and expertise. Founded in 1875, the company is North America's oldest refractory maker.

Manufacturing products exclusively for NARCO and Harbison-Walker…

A.P. Green Refractories (APG) makes products for the iron and steel, aluminum, cement, copper, glass, and hydrocarbon and minerals processing industries. The company also has one of the world's top capabilities for customized pre-cast shapes, along with a full line of insulating ceramic fibers.

Products from all these companies are available through:

For Industrial Sales:

Harbison-Walker Refractories Company
400 Fairway Drive
Moon Township, PA 15108
Phone: 1-800-377-4497
Fax: (412) 375-6826

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ALUMINUM
TRANSFER TROUGHS

Harbison-Walker Refractories Company

Transfer Trough Conditions:

- **Erosion**
- **Abrasion**
- **Thermal Shock**
- **Aluminum Penetration**
- **Mechanical Abuse**

Harbison-Walker offers a complete line of refractory castables, plastics and shapes for aluminum transfer troughs.

GREENKLEEN-60 PLUS

A 60% alumina, andalusite containing castable. GREENKLEEN-60 PLUS has excellent resistance to molten aluminum, and has been a standard for aluminum troughs for more than 10 years.

ARMORKAST 65AL

A 65% alumina, low cement, pumpable castable. ARMORKAST 65AL has a very high purity bonding matrix, leading to very high physical properties, and outstanding corrosion resistance.

ULTRA-EXPRESS 70 AL

An ultra-low cement, 70% alumina castable designed with enhanced flow, and self-leveling characteristics. ULTRA-EXPRESS 70 AL is very strong and is ideal for pumping over long distances and for casting into intricate form patterns.

2-TOUGH™ AL ADTECH®

A silica free, coarse aggregate containing castable, designed for precast trough sections. This 2-component mix contains 50% coarse aggregate, providing outstanding thermal shock, impact and abrasion resistance.

THOR 60 ABR ADTECH®

A 60% silicon carbide castable. SiC offers improved thermal shock and abrasion resistance. THOR 60 ABR ADTECH® has exceptional resistance to molten aluminum.

HARBIDE® PLASTIC 70 AL

A 70% silicon carbide, phosphate bonded plastic with an aluminum penetration inhibitor. HARBIDE® PLASTIC 70 AL is an excellent choice for patching.

NOVACON® S

NOVACON® S is a cement-free, vitreous silica based castable. It shows outstanding hot properties, as well as thermal shock and abrasion resistance.

VERSAFLOW® THERMAX® AL ADTECH®

A vitreous silica based, low-cement castable with an aluminum penetration inhibitor. VERSAFLOW® THERMAX® AL ADTECH® offers exceptional thermal shock and abrasion resistance, as well as volume stability.

VISIL®/C AL

A unique, vitreous silica product developed for custom shapes. VISIL®/C AL has excellent thermal shock and abrasion resistance and volume stability.

GREENLITE®-45-L AL

A lightweight, insulating mix, with an exceptional strength to density ratio. GREENLITE®- 45-L AL also contains a penetration inhibitor, which provides resistance to molten aluminum.

TECHNICAL DATA

	GREENKLEEN-60 PLUS	ARMORKAST 65AL	ULTRA-EXPRESS 70 AL		2-TOUGH™ AL ADTECH®	THOR 60 ABR ADTECH®
Form	Castable	Castable	Self-Flowing	Vib-Cast	Castable	Castable
Density, pcf						
After 230˚F	161	163	158	169	210	165
Ater 1500˚F	157	160	157	169	--	162
Modulus of Rupture, psi						
After 230˚F	2,350	1,900	1,000	1,500	1,900	2,400
After 1500˚F	5,000	2,300	2,700	2,800	--	--
@ 1500˚F	3,800	4,000	4,700	5,000	--	4,900
@2000˚F	--	3,000	--	--	--	5,500
C-704 Abrasion Test						
CC Loss After 1500˚F	6	--	4	3	--	6
Chemical Analysis, % **(Approximate)**						
Silica (SiO_2)	34.0	27.7	24.4		1.1	14.4
Alumina (Al_2O_3)	59.6	62.5	69.1		90.0	23.4
Silicon Carbide (SiC)	--	--	--		--	59.0

	HARBIDE® PLASTIC 70 AL	NOVACON® S	VERSAFLOW® THERMAX® AL ADTECH®	VISIL®/C AL	GREENLITE®-45-L AL	
Form	Plastic	Castable	Castable	Shape	Castable	Vib-Cast
Density, pcf						
After 500˚F	57	113	129	117	69	74
After 1500˚F	--	--	--	64	67	--
Apparent Porosity, %	--	--	14	--	--	--
Modulus of Rupture, psi						
After 500˚F	--	--	--	620	400	500
After 1500˚F	2,230	1,060	1,650	--	250	320
@ 1500˚F	--	--	--	--	--	--
C-704 Abrasion Test						
CC Loss After 1500˚F	4.5	--	--	--	--	--
Chemical Analysis, % **(Approximate)**						
Silica (SiO_2)	6.5	96.9	72.0	96.4	38.3	
Alumina (Al_2O_3)	20.4	2.1	23.8	0.6	42.5	
Silicon Carbide (SiC)	67.0	--	--	--	--	

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Harbison-Walker Refractories Company
400 Fairway Drive
Moon Township, PA 15108

www.hwr.com
Phone: (412) 375-6600 w Fax: (412) 375-6783

Cat# HW 192 (07/03))

H-W LONG BRICK

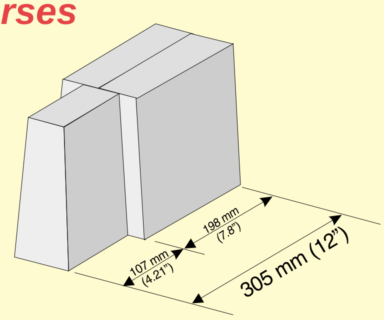
For Rotary Kilns

Harbison-Walker Refractories Company

Long Brick from Harbison-Walker

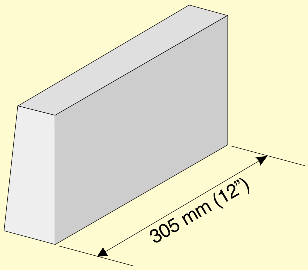
- Eliminates double cuts
- Use for your cut rows 8” up to 12”
- Greater flexibility when old section is spiraled
- Reduce the number of rings to install
- Reduce downtime - Labor savings
- Available in High Alumina and Basic Brick qualities

Closure Courses



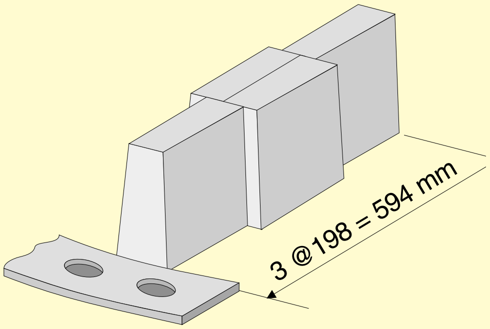
From two courses

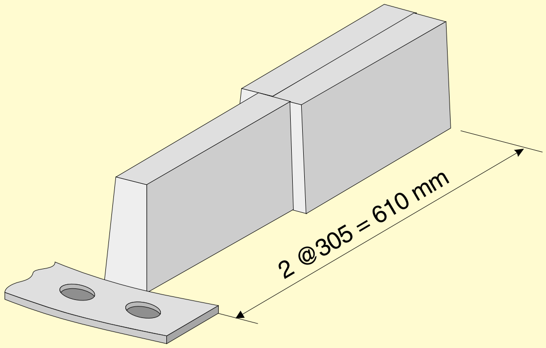
to



One 12” (305 mm) brick

Retainer Rings





- More stable construction
- More mass
- More Strength

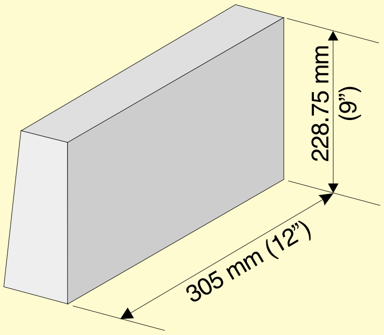
H-W LONG BRICK for Rotary Kilns

H-W Long brick are available in the following sizes:

Manufactured in U.S.A.

Shape #
- B-222-L
- B-322-L
- B-622-L
- B-822-L

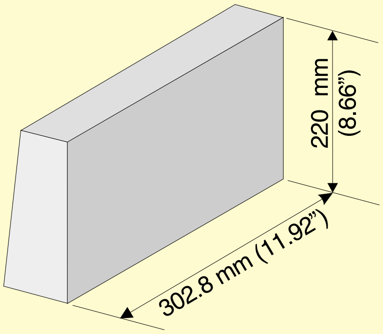
Key-Ups
- B-228-L-K-1
- B-228-L-K-2



Manufactured in Canada

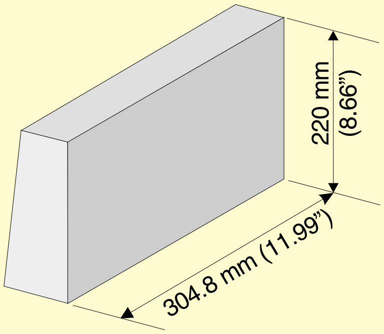
Shape #
- VDZ B222/30
- VDZ B322/30
- VDZ B622/30

Key-Ups
- P220/30
- P221/30



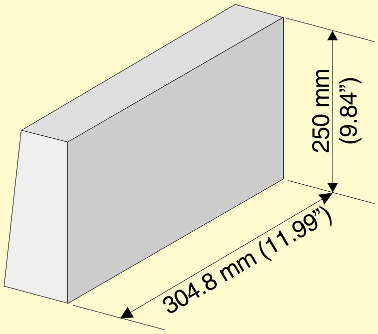
Shape #
- ISO 222/30
- ISO 322/30
- ISO 822/30

Key-Ups
- P221/30
- P222/30



Shape #
- ISO 325/30
- ISO 825/30

Key-Ups
- P251/30A
- P252/30A



* All ring counts follow standard ring combinations

Harbison-Walker Refractories Company
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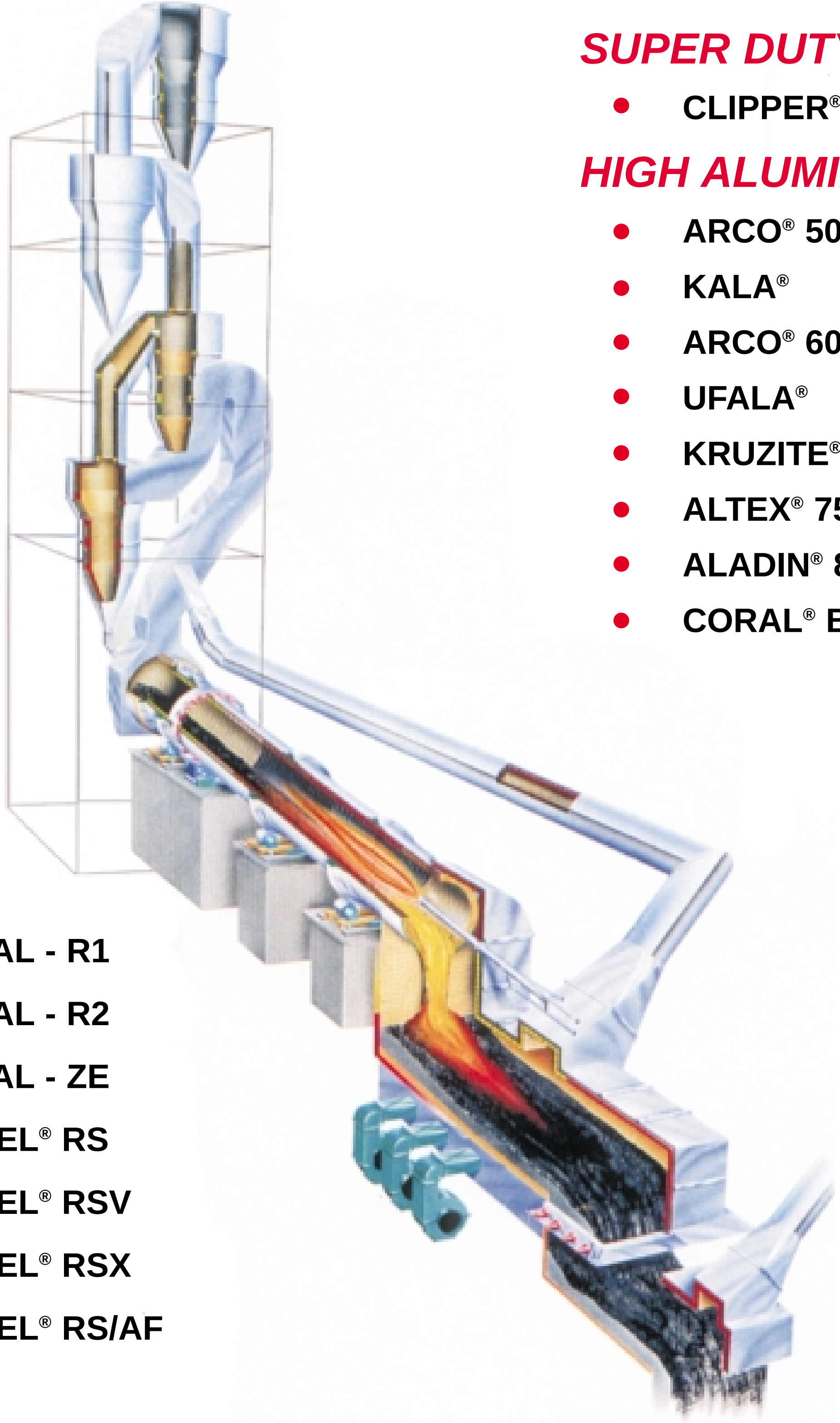
Moon Township, PA 15108
Phone: (412) 375-6600 ● 1-800-377-4497
Fax: (412) 375-6846

Cat# HW131 R(8/02) 2C

High Alumina & Basic Bricks
For Rotary Kiln Systems

Harbison-Walker Refractories Company



SUPER DUTY

- CLIPPER® DP

HIGH ALUMINA

- ARCO® 50
- KALA®
- ARCO® 60
- UFALA®
- KRUZITE® - 70
- ALTEX® 75B
- ALADIN® 80
- CORAL® BP

BASIC

- ANKRAL - R1
- ANKRAL - R2
- ANKRAL - ZE
- MAGNEL® RS
- MAGNEL® RSV
- MAGNEL® RSX
- MAGNEL® RS/AF

ALUMINA BRICK	CLIPPER® DP (SUPER DUTY)	ARCO® 50	KALA®	ARCO® 60	UFALA®	KRUZITE® 70	ALTEX® 75B	ALADIN® 80	CORAL® BP
Bulk Density, lb/ft^3	142	149	153	155	157	165	175	170	177
Apparent Porosity, %	15.3	17.0	13.8	17.5	14.3	18.7	15.0	19.5	17.4
Crushing Strength, lb/in^2 At 70°F (21°C)	6,300	7,100	8,700	7,000	8,410	8,500	13,000	9,610	20,750
Modulus of Rupture, lb/in^2 At 70°F (21°C)	1,350	1,700	2,060	1,600	2,640	1,700	2,700	1,610	3,320
Reheat Test Permanent Linear Change, % After Heating at 2910°F (1600°C)	-0.3	+1.5	+0.8	+3.4	-0.1	+4.5	+2.3	+1.2	-0.6
Chemical Analysis: (Approximate) (Calcined Basis)									
Silica (SiO_2)	52.6%	42.1%	46.6%	32.6%	38.2%	23.0%	15.5%	15.2%	7.2%
Alumina (Al_2O_3)	42.2	51.5	49.6	61.0	58.1	71.0	76.0	78.6	83.3
Titania (TiO_2)	2.3	3.3	2.2	3.3	2.2	3.4	3.2	3.4	2.7
Iron Oxide (Fe_2O_3)	1.4	1.8	1.3	1.8	1.2	1.6	1.4	1.8	1.3
Lime (CaO)	0.2	0.3	0.1	0.3	0.1	0.2	0.2	0.3	0.2
Magnesia (MgO)	0.3	0.3	0.1	0.3	0.1	0.2	0.2	0.3	0.1
Alkalies (Na_2O+K_2O)	0.9	0.7	0.1	0.7	0.1	0.6	0.5	0.4	0.2
Phosphorous Pentoxide (P_2O_3)	—	—	—	—	—	—	3.0	—	5.0

CLIPPER® DP A dry-pressed, superduty brick that exhibits good strengths, low shrinkage, and good thermal shock resistance. Used in the preheating zones of long wet and long dry process kilns and preheater tower vessels.

ARCO® 50 A conventional 50% alumina brick that has good physical properties up to 2600°F. Can be used in preheating zones of long wet and long dry kilns and preheater tower vessels.

KALA® A high purity 50% alumina brick with low porosity and excellent high temperature strength. Ideally suited for use in preheating and calcining zones where alkali salts are present. Can also be used as an upgrade to conventional fireclay brick in preheater vessels.

ARCO® 60 A conventional 60% alumina brick manufactured from imported bauxitic calcines. A cost effective alternative to higher purity 60% alumina products. Can be used in preheating zones along with selected calcining zones.

UFALA® A 60% alumina brick manufactured from high purity domestic calcines. Exhibits excellent resistance to alkali salt attack and has good thermal shock resistance. Can be used in preheating and calcining zones where chemical attack is prevalent.

KRUZITE® – 70 A conventional 70% alumina brick manufactured from imported bauxitic calcines. Ideally suited for use in calcining and cooling zones where normal operating conditions are present.

ALTEX® 75B A 75% alumina, burned, phosphate-bonded brick with high hot strengths and low porosity. It's low porosity gives it excellent resistance to alkali salt attack. It also exhibits excellent resistance to mechanical abuse from abrasion and impact. Can be used in the lower calcining zone and the cooling zone.

ALADIN® 80 An 80% alumina brick produced from imported calcined bauxite. Has good hot strength, predictable reheat expansion characteristics, and good thermal shock resistance. Can be used in the lower calcining and cooling zones where greater refractoriness is required.

CORAL® BP An 80% alumina, phosphate-bonded, burned brick that has excellent high temperature strength and low porosity. High degree of phosphate bonding gives this product excellent strength and abrasion resistance throughout all temperature ranges. Ideally suited for use in the cooling zones and selected lower calcining zones areas.

BASIC BRICK	ANKRAL R1	ANKRAL R2	ANKRAL ZE	MAGNEL® RS	MAGNEL® RSV	MAGNEL® RSX	MAGNEL® RS/AF
Bulk Densit,y lb/ft^3	187	186	187	182	187	187	188
Apparent Porosity, %	14.5	15.0	16.0	17.4	15.0	15.0	15.0
Crushing Strength, lb/in^2							
At 70°F (21°C)	8,000*	8,700*	10,700*	4,000	7,100	9,100	5,950
Modulus of Rupture, lb/in^2							
At 70°F (21°C)	800	870	900	690	840	1,250	670
At 2300°F (1260°C)	--	--	--	920	1,100	1,100	910
Reheat Test Permanent Linear Change, % After Heating at 2910°F (1600°C)	--	--	--	0.0	0.0	0.0	0.0
Chemical Analysis: (Approximate) (Calcined Basis)							
Silica (SiO_2)	0.2%	0.2%	0.5%	0.4%	0.3%	0.3%	0.4%
Alumina (Al_2O_3)	7.4	10.5	2.6	15.2	9.6	5.0	14.4
Titania (TiO_2)	--	--	--	0.3	0.1	0.1	0.3
Iron Oxide (Fe_2O_3)	0.5	0.5	6.3	0.2	0.2	0.2	0.5
Lime (CaO)	1.2	1.1	1.3	1.5	1.4	1.5	1.1
Magnesia (MgO)	90.7	87.7	89.0	82.4	88.4	92.9	83.4

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*-DIN Test

Statements or suggestions concerning possible use of our products are made without representation or warranty that any such product is fit for such use or that such use is

ANKRAL-R1 Manufactured from high purity magnesite and spinel grains. Ideally suited for high thermal stress zones of rotary cement kilns. It is highly resistant to cyclical redox conditions and attack by sulfur, alkali salts, and chlorine. The unique spinel formation and subsequent distribution within the matrix makes this product extremely coating friendly. Can be used in all areas of the lower and upper transition zones and the burning zone.

ANKRAL-R2 A high-purity synthetic sintered magnesite and sintered spinel makes this product well suited for lower and upper transition zones where alkalis and sulfates are present.

ANRKAL-ZE This product is manufactured from natural sintered magnesia and a fused spinel consisting of iron and alumina (hercynite). This patented combination yields a product that is exceptionally coating friendly. It is extremely flexible and has excellent corrosion resistance. It is ideally suited for burning and upper transition zones. It's mechanical flexibility is important when higher than normal shell flexing is present.

MAGNEL® RS A combination high-purity synthetic magnesite, fused spinel, and a matrix of reinforced spinel (RS) give this product its excellent physical properties. The high amount of fused spinel provides low thermal conductivity and low thermal expansion. The matrix spinel aids in the formation and retention of coating. Ideally suited for all areas of the basic zone of a cement and lime kiln.

MAGNEL® RSV A combination high-purity synthetic magnesite, fused spinel, and a matrix of reinforced spinel give this product its excellent physical properties at a cost-effective price. The moderate amount of spinel yields a product that has excellent resistance to clinker liquids while maintaining lower thermal conductivity and thermal expansion than similar products of the same class. Can be used in all basic zones but best suited for lower transition and burning zones areas.

MAGNEL® RSX Manufactured from the same raw materials as MAGNEL RS and MAGNEL RSV. Lower spinel levels in conjunction with the higher magnesia levels yields a product that is highly resistant to clinker liquid infiltration and alkali salt attack. Low permeability values also give it excellent resistance to sulfur and chlorine.

MAGNEL® RS/AF A combination high-purity synthetic magnesite, fused magnesite, fused spinel and a matrix of reinforced spinel make this patented product unique. Large crystalline magnesia grains make it extremely corrosion resistant. Designed for use in the high wear areas of the lower transition zones of kilns burning waste fuel and/or high levels of petroleum coke. Also well suited for kilns utilizing oxygen enrichment.

Exclusively serving the iron and steelmaking industries…

North American Refractories Company (NARCO) is a leading supplier of refractory solutions to the iron and steel industries. The company makes high-performance products for BOFs, EAFs, LMFs, ladles, finishing, alternative ironmaking, casthouses, blast furnaces, and flow control applications. In addition to providing complete technical support services, NARCO also can design and implement a turnkey refractory management program to meet your facility's specialized requirements.

Exclusively serving the non-ferrous metals, ferrous foundry, glass, hydrocarbon, incineration, minerals processing and other industries…

Harbison-Walker Refractories Company (H-W) provides high-performance refractory solutions to all non-steel-related industries. In addition to its own outstanding line of products, many of which have become industry standards, H-W is recognized worldwide for its technical support and expertise. Founded in 1875, the company is North America's oldest refractory maker.

Manufacturing products exclusively for NARCO and Harbison-Walker…

A.P. Green Refractories (APG) makes products for the iron and steel, aluminum, cement, copper, glass, and hydrocarbon and minerals processing industries. The company also has one of the world's top capabilities for customized pre-cast shapes, along with a full line of insulating ceramic fibers.

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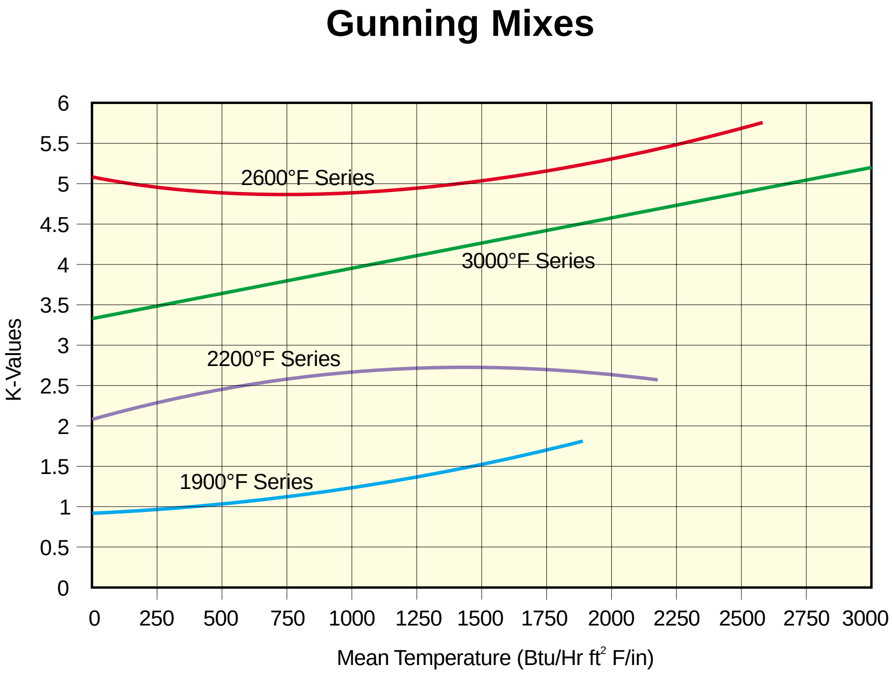
Cat. # HW132 R(7/03) 3C

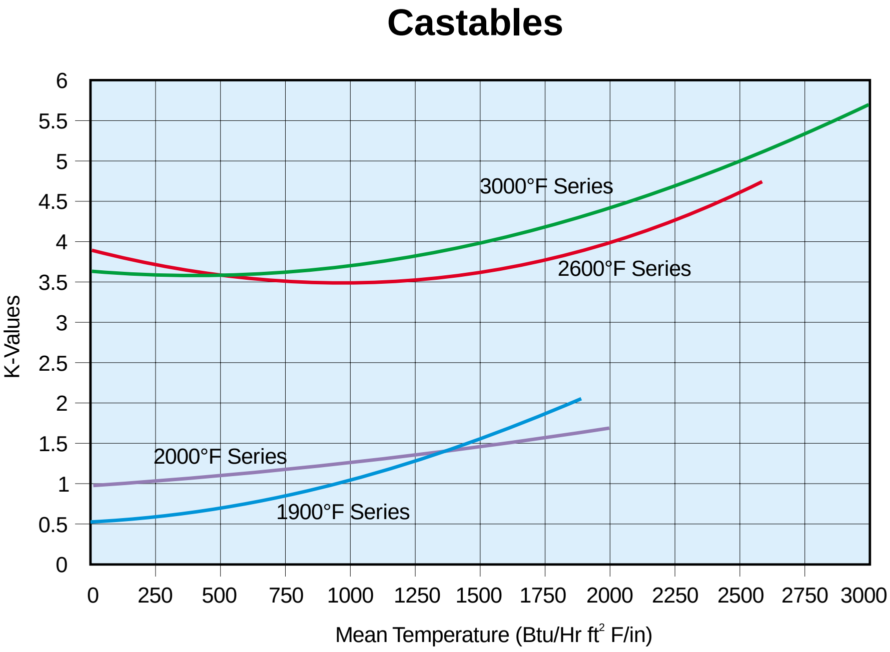
LIGHTWEIGHT CASTABLES AND GUNNING MIXES

FOR ROTARY KILN SYSTEMS

GUNNING MIXES

- GREENLITE® -45-L GR
- KAST-O-LITE® 19 L
- KAST-O-LITE® 22 G
- KAST-O-LITE® 26 LI G
- KAST-O-LITE® 30 LI G





CASTABLES

- KAST-O-LITE® 20
- KAST-O-LITE® 20 LI
- KAST-O-LITE® 20-45
- KAST-O-LITE® 22
- KAST-O-LITE® 23 ES
- KAST-O-LITE® 23 LI
- KAST-O-LITE® 26 LI
- KAST-O-LITE® 30 LI

LIGHTWEIGHT GUNNING MIXES	GREENLITE® 45-L GR	KAST-O-LITE® 19 L	KAST-O-LITE® 20	KAST-O-LITE® 20 LI	KAST-O-LITE® 20-45	KAST-O-LITE® 22
Bulk Density, lb/ft^3	-	-	36	41	50	53
Maximum Service Temperature, ˚F	2500	1900	2000	2000	2000	2200
Crushing Strength, lb/in^2						
At 220˚F (105˚C)	3200	35	150	310	200	575
Modulus of Rupture, lb/in^2						
At 220˚F (105˚C)	600	20	75	100	150	140
Reheat Test						
Permanent Linear Change,						
After Heating at 1500˚F (815˚C)	-0.2%	-0.6%	-0.5%	-0.7%	-0.5%	-0.8%
Chemical Analysis: (Approximate)						
(Calcined Basis)						
Silica (SiO_2)	40.0%	26.3%	25.0%	43.9%	46.2%	34.0%
Alumina (Al_2O_3)	45.0	31.5	42.0	39.3	30.5	41.0
Titania (TiO_2)	2.0	2.2	2.0	0.2	1.1	2.0
Iron Oxide (Fe_2O_3)	1.3	6.7	2.5	0.6	3.4	4.0
Lime (CaO)	10.0	20.0	21.0	12.7	16.6	17.0
Magnesia (MgO)	0.3	11.0	6.0	0.2	0.2	0.4
Alkalies (Na_2O+K_2O)	1.0	2.3	1.5	3.1	2.0	1.5

GREENLITE® -45-L GR is a 2,500˚F insulating gunning castable combining exceptional strengths and low densities. It is an ideal candidate for fluid catalytic cracking units, fluid coking units and other industrial linings requiring low densities and high strength.

KAST-O-LITE® 19 L is an insulating castable that can easily conform to an irregular shell and will not smoke. It is ideally used as a gunned or cast back-up lining behind other hot face refractory lining to lower shell temperatures.

KAST-O-LITE® 20 is a hydraulic setting insulating castable that can be installed by pouring, pumping or gunning. Ideal for back-up linings behind dense refractories or as an exposed lining where slagging, flame impingement or mechanical wear does not present a problem.

KAST-O-LITE® 20 LI is a high efficiency insulating castable usable in direct contact with hot gases under continuous or intermittent operation without loss of thermal efficiency. KAST-O-LITE® 20 LI can be used to 2,000°F (1,095°C) is extremely resistant to thermal shock and has low thermal conductivity.

KAST-O-LITE® 20-45 is a hydraulic setting insulating castable that can be installed by pouring or gunning. It is ideal for back-up linings behind dense refractories or as an exposed lining where slagging, flame impingement or mechanical wear does not present a problem.

KAST-O-LITE® 22 is a lightweight castable for temperatures to 2,200°F (1,205°C). It features low thermal conductivity and good strength for such a lightweight material. Recommendations include oil stills and heaters, lightweight panel construction, flue and duct linings, complete monolithic linings, and as a back-up material.

KAST-O-LITE® 22 G is an economical 2,200°F (1,205°C) insulating gunning castable. It is especially formulated for gunability, easily flowing through the hose with minimum rebound. KAST-O-LITE® 22 G is ideal for overhead gunning applications.

LIGHTWEIGHT GUNNING MIXES	KAST-O-LITE® 22 G	KAST-O-LITE® 23 ES	KAST-O-LITE® 23 LI	KAST-O-LITE® 26 LI	KAST-O-LITE® 26 LI G	KAST-O-LITE® 30 LI	KAST-O-LITE® 30 LI G
Bulk Density, lb/ft^3	76	86	53	92	111	95	102
Maximum Service Temperature, ˚F	2200	2300	2300	2600	2600	3000	3000
Crushing Strength, lb/in^2							
At 220˚F (105˚C)	810	2350	300	3000	2400	2850	2200
Modulus of Rupture, lb/in^2							
At 220˚F (105˚C)	460	490	90	700	720	550	525
Reheat Test							
Permanent Linear Change,							
After Heating at 1500˚F (815˚C)	-0.4%	-0.3%	-0.8%	-0.2%	-0.2%	-0.3%	-0.1%
Chemical Analysis: (Approximate)							
(Calcined Basis)							
Silica (SiO_2)	34.1%	39.0%	54.8%	38.2%	44.6%	35.5%	35.0%
Alumina (Al_2O_3)	41.2	36.3	33.5	46.5	44.5	57.5	57.0
Titania (TiO_2)	2.0	1.7	0.7	2.0	2.3	1.5	1.5
Iron Oxide (Fe_2O_3)	3.3	5.1	0.7	1.3	1.0	0.7	0.9
Lime (CaO)	15.4	14.6	8.5	10.5	6.4	4.2	4.7
Magnesia (MgO)	2.5	1.2	0.2	0.4	0.3	0.2	0.2
Alkalies (Na_2O+K_2O)	1.5	2.1	1.6	1.0	0.9	0.4	0.7

KAST-O-LITE® 23 ES is an intermediate strength insulating castable with standard calcium-aluminate binder. It combines good strength with high insulating value and excellent volume stability. KAST-O-LITE® 23 ES may be cast or gunned in place and is suitable for hot face or back-up linings.

KAST-O-LITE® 23 LI is a 2,300°F (1,260°C) maximum service temperature insulating castable. It contains low iron to resist detrimental reducing furnace conditions. Typical applications are: flues, stacks, breechings, controlled atmosphere furnaces, petrochem transfer and riser back-up linings, catalytic reforming linings behind stainless steel shroud, and waste heat boilers.

KAST-O-LITE® 26 LI has now been improved to meet the demands of severe furnace environments. Low iron content minimizes destructive CO disintegration attack by reducing furnace atmospheres. Its vastly improved strengths reduce cracking from mechanical abuse or steel shell flexing. Higher alumina content improves its maximum service temperature to 2,600°F (1,425°C). Lower water content for placement reduces internal steam pressure during initial heat up. It is ideal for boilers, reheat furnace floor backup, furnace stacks and flues, air heaters, aluminum furnace roof backup and petrochem oil heaters.

KAST-O-LITE® 26 LI G is a low iron content 2,600°F (1,425°C) maximum service temperature limit insulating gunning castable. Vastly improved strengths reduce cracking from mechanical abuse or steel shell flexing. It is ideal for boilers, furnace stacks and flues, air heaters and petrochem oil heaters.

KAST-O-LITE® 30 LI is a high-alumina, lightweight, 3,000°F (1,650°C) maximum service temperature, insulating castable. It exhibits moderate density, excellent strengths, low iron, and low thermal conductivity. Typical applications are aluminum furnace stacks, aluminum holding furnace doors, reheat furnace discharge doors, carbon black back-up linings, air heaters and reheat furnace backup linings.

KAST-O-LITE® 30 LI G is a high-alumina, lightweight, 3000°F (1650°C) maximum service temperature insulating gunning castable. It exhibits moderate density, excellent strengths, low iron, low thermal conductivity, and low rebound. Typical applications are aluminum furnace stacks, aluminum holding furnace doors, reheat furnace discharge doors, petrochem heaters, sulphur recovery unit back-up linings, air heaters, reheat furnace back-up linings, and catalytic reformer back-up lining behind stainless steel shroud.

Exclusively serving the glass, iron and steelmaking industries…

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Moon Township, PA 15108
Phone: (412) 375-6600 • 1-800-377-4497
Fax: (412) 375-6846

Cat. # HW139 (3/03) 1C

MAGSHOT®

For Cement & Lime Kilns

Harbison-Walker Refractories Company

Description: Magnesite-based chrome-free gunning mix

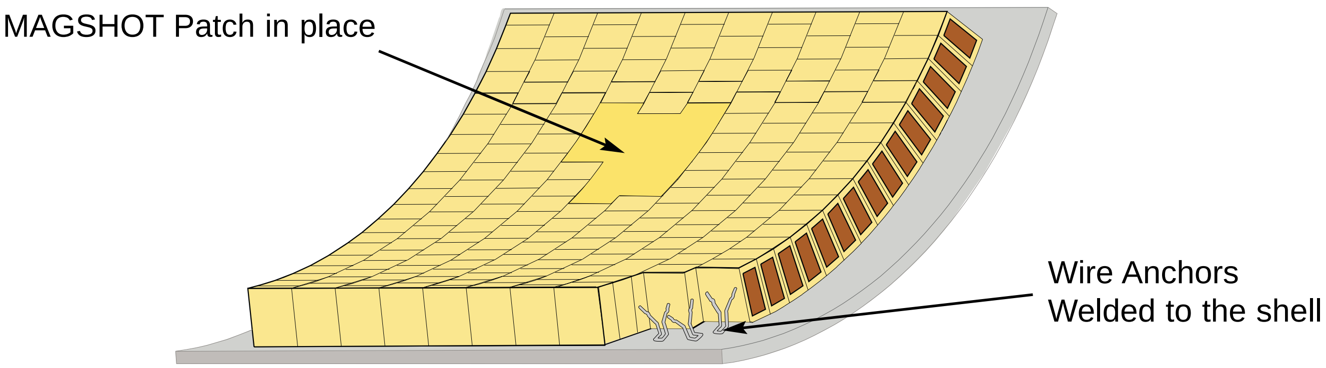
Features & Benefits:

- Chemistry similar to basic brick
- Ease of installation
- Quick turnaround for repairs
    - Heat-up can begin 2 hours after installation
    - Does not require lengthy cure times or slow heat-up schedules
- Low dust and rebounds
- Prolong existing lining until scheduled outage
- Castable variant (MAGSHOT® CASTABLE) for larger installations
- Proven track record

Uses:

- Burning zone patches in cement and lime rotary kilns
- Nose rings in lime kilns
- Flash coating basic brick in vertical lime shaft kilns
- Throat areas of cement coolers
- Patch where needed
- Manways or access doors

Packaging: Shipped in 55 pound - multi-wall moisture - resistant sacks



MAGSHOT®

TECHNICAL DATA

	MAGSHOT®	MAGSHOT® CASTABLE
Physical Properties; (Typical)		
Bulk Density, pcf		
After 230°F	160	179
Modulus of Rupture, psi		
After 230°F	1,690	1,510
After 1500°F	1,560	1,480
Cold Crushing Strength, psi		
After 230°F	5,870	10,100
After 1500°F	5,930	7,000
Chemical Analysis, % Approximate (Calcined Basis)		
Silica (SiO_2)	7.2	5.8
Alumina (Al_2O_3)	1.9	1.7
Titania (TiO_2)	0.1	0.1
Iron Oxide (Fe_2O_3)	5.8	10.0
Lime (CaO)	6.1	9.6
Magnesia (MgO)	76.7	68.7
Alkalies ($Na_2O + K_2O$)	0.7	1.2
Phosphorous Pentoxide (P_2O_5)	1.5	2.9

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Harbison-Walker Refractories Company
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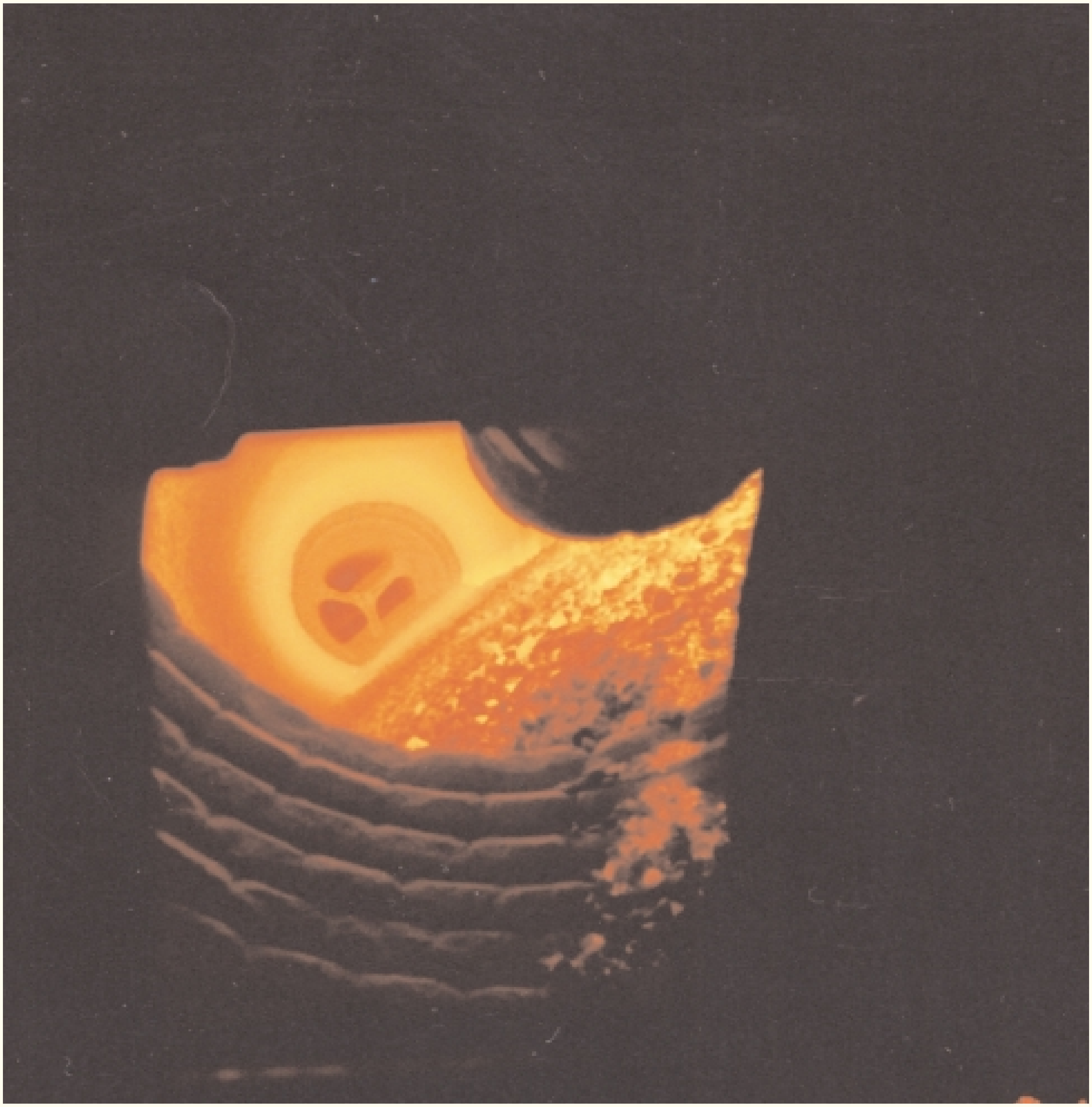
Moon Township, PA 15108
Phone: (412) 375-6600 ● 1-800-377-4497
Fax: (412) 375-6846

Refractories for the Lime Industry

Harbison-Walker Refractories Company



BASIC BRICK		MAGNEL® RS	MAGNEL® RSV	NOKROME® 87LK	NOKROME® 92LK
Bulk Density, lb/ft^3		182	187	180	182
Apparent Porosity, %		17.4	15.0	18.0	16.5
Crushing Strength, lb/in^2					
At 70°F (21°C)		4,000	7,100	5,100	7,800
Modulus of Rupture, lb/in^2					
At 70°F (21°C)		690	840	800	960
At 2300°F (1260°C)		920	1,100	1,200	1,500
Reheat Test					
Permanent Linear Change, %					
After Heating at 2910°F (1600°C)		0.0	0.0	—	—
Chemical Analysis: (Approximate)					
(Calcined Basis)					
Silica	(SiO_2)	0.4%	0.3%	0.5%	0.5%
Alumina	(Al_2O_3)	15.2	9.6	11.0	6.0
Titania	(TiO_2)	0.3	0.1	—	—
Iron Oxide	(Fe_2O_3)	0.2	0.2	0.25	0.4
Lime	(CaO)	1.5	1.4	1.6	1.5
Magnesia	(MgO)	82.4	88.4	86.5	91.4

ALUMINA BRICK		KRUZITE®-70	ALTEX® 75B	KALA®	UFALA®	ALADIN® 80
Bulk Density, lb/ft^3		165	175	152	157	170
Apparent Porosity, %		18.7	15.0	14.4	14.3	19.5
Crushing Strength, lb/in^2						
At 70°F (21°C)		8,500	13,000	7,400	8,410	9,610
Modulus of Rupture, lb/in^2						
At 70°F (21°C)		1,700	2,700	1,730	2,640	1,610
Reheat Test						
Permanent Linear Change, %						
After Heating at 2910°F (1600°C)		+4.5	+2.3	+0.6	-0.1	+1.2
Chemical Analysis: (Approximate)						
(Calcined Basis)						
Silica	(SiO_2)	23.0%	15.5%	46.6%	38.2%	15.2%
Alumina	(Al_2O_3)	71.0	76.0	49.6	58.1	78.6
Titania	(TiO_2)	3.4	3.2	2.2	2.2	3.4
Iron Oxide	(Fe_2O_3)	1.6	1.4	1.3	1.2	1.8
Lime	(CaO)	0.2	0.2	0.1	0.1	0.3
Magnesia	(MgO)	0.2	0.2	0.1	0.1	0.3
Alkalies	(Na_2O+K_2O)	0.6	0.5	0.1	0.1	0.4
Phosphorous Pentoxide	(P_2O_5)	—	3.0	—	—	—

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Harbison-Walker Refractories Company

PLASTIC		NARPHOS 55S	REDD RAMM	NARPHOS 80S
Maximum Service Temperature		3000°F (1649°C)	3100°F (1740°C)	3200°F (1760°C)
Approximate Amount Required				
As Rammed lb/ft^3 (kg/m^3)		156 (2,499)	166 (2,659)	184 (2,948)
Bulk Density, lb/ft^3				
After Drying at 230°F (110°C)		147	154	170
After Drying at 1500°F (816°C)		144	151	166
Modulus of Rupture, lb/in^2 (Mpa)				
At 230°F (110°C)		1,250 (8.6)	1,450 (10.0)	1,650 (11.4)
At 1500°F (816°C)		1,250 (8.6)	1,500 (10.3)	1,800 (12.4)
At 2700°F (1482°C)		1,500 (10.3)	2,000 (13.8)	1,500 (10.3)
Permanent Linear Change, %				
After Drying at 230°F (110°C)		-0.8	-0.8	-0.8
After Heating at 1500°F (816°C)		-0.8	-0.7	-0.8
After Heating at 3000°F (1649°C)		+0.5	+0.3	-0.2
Chemical Analysis: (Approximate)				
(Calcined Basis)				
Silica	(SiO_2)	35.98%	24.22%	9.22%
Alumina	(Al_2O_3)	55.86	68.00	83.31
Titania	(TiO_2)	1.08	1.26	1.91
Iron Oxide	(Fe_2O_3)	0.73	0.77	1.14
Lime	(CaO)	0.52	0.09	0.05
Magnesia	(MgO)	0.19	0.18	0.11
Alkalies	(Na_2O+K_2O)	0.59	0.11	1.91
Phosphorus Pentoxide	(P_2O_5)	3.61	3.59	2.86
L.O.I		1.03	1.59	1.33

CASTABLES

VERSAFLOW® CASTABLES - Dense, low cement castables exhibiting high mechanical strength and excellent abrasion resistance. Can be vibcast, conventionally cast or pump cast into place. Uses include preheater shelves, feed end linings, precast lifter sections, cast dams, and nose/tail rings. Products include VERSAFLOW® 45C, VERSAFLOW® 57A, VERSAFLOW® 60, VERSAFLOW® 70, and VERSAFLOW® 80C. VERSAFLOW products are also available in shotcrete versions (PNEUCRETE®).

NARCON CASTABLES - Dense, low cement castables exhibiting excellent mechanical strength and excellent abrasion resistance. Can be vibcast, conventionally cast or pump cast into place. Uses include preheater shelfs, feed end linings, precast lifter sections, cast dams, and nose/tail rings. Products include NARCON 60, NARCON 65. NARCON products are also available in shotcrete versions (SHOTKAST®).

HPV™ CASTABLES - Unique group of products that are light in weight yet exhibit physical properties approaching those of denser materials. Possible uses include precast lifter shapes and feed end linings. Products include HPV 3000, HPV CASTABLE and HPV GUN MIX.

LO-ABRADE® - Conventional, high strength 2600° F castable that exhibits good resistance to abrasion and erosion. Can be used for general-purpose repairs in all areas. Also available in a gunning version (LO-ABRADE® GR).

MAGSHOT® - Magnesia based gunning mix that is ideally suited for temporary repairs. Magnesia base makes it compatible for use in burning zone areas where conventional alumina products do not have enough refractoriness. Unique bonding mechanism does not require a 24-hour air cure therefore it can be heated immediately after placement to allow for quick turnaround.

EXPRESS® 27 C PLUS® is a 2700°F (1480°C) dense, free-flowing refractory castable. It has unique property that vibration is not required to remove air voids. It can be either cast or pumped. Its density together with very good abrasion resistance make it an ideal hot face lining material.

PRECAST LIFTERS

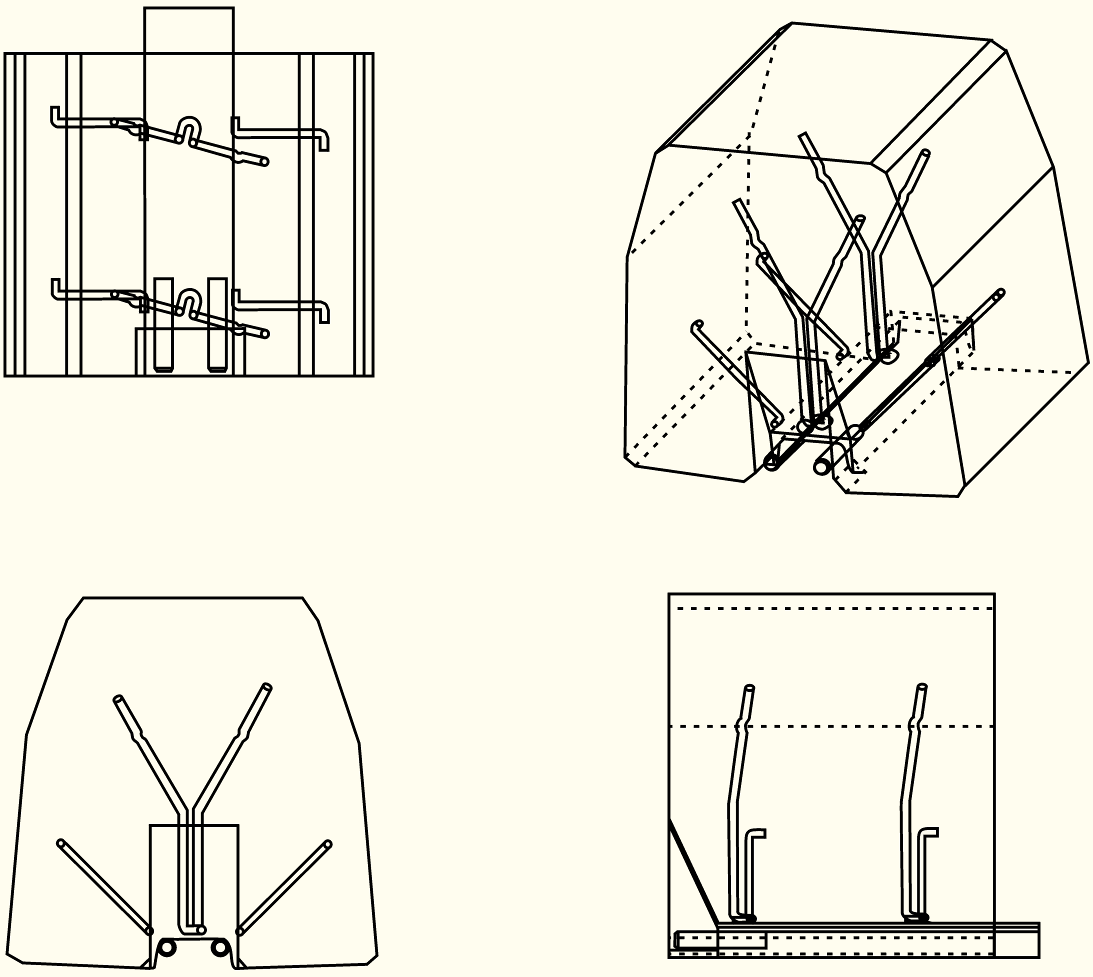
Precast lifters or tumblers are large kiln blocks made out of our castable refractories. When installed in a kiln section the lifters act to increase the tumbling efficiency of the kiln feed which exposes a larger percentage of feed to hot kiln gas and thereby reduces the heat consumption and improves fuel efficiency of the kiln system. Equipment manufacturers generally place the lifter section within the preheating zone of a rotary lime kiln.

Our precast lifters can be made to fit any kiln diameter and can be incorporated with any brick shape or castable lining. The lifters are typically designed to be 5” to 6” taller than the existing refractory lining. The sections generally consist of four (4) to six (6) rows running parallel with the kiln axis.

Installation requires welding a piece of carbon steel bar stock for each row to the kiln shell, again running parallel with the kiln axis. Lifters within the same row interlock together through a unique steel footing system which is also welded to the carbon steel bar. Once the lifters are in place the main lining can then be installed.

If you are interested in more information on increasing your kiln’s fuel efficiency contact your local HW representative.

PRECAST KILN TUMBLER BLOCK



Harbison-Walker Refractories Company.
400 Fairway Drive
Moon Township, PA 15108
Phone: (412) 375-6600 ● 1-800-377-4497
Fax: (412) 375-6846

Cover Photo Courtesy of Dravo Lime Inc.

Cat# HW135 (9/02) 2C

THOR AZSP ADTECH®

Pumpable Castable for Cement & Lime Kiln Systems

Harbison-Walker Refractories Company

THOR AZSP ADTECH® - a premium anti-buildup product

THOR AZSP ADTECH® is a pumpable special low-moisture fused zirconia-mullite castable with a silicon carbide addition that can also be shotcreted with GT activator. The zircon is tied up with the mullite and will not reduce. It is totally inert and will not react with alkalis, chlorides and sulfates. Like others in the THOR family, it has excellent abrasion and anti- buildup resistance, and high refractoriness. It is unique in that it is pumpable giving you a faster turnaround in tight outage situations.

TECHNICAL DATA		**THOR AZSP ADTECH$^{T®}$**
Physical Properties (Typical)		
Maximum Service Temperature, °F		2800
Material Required, lb/ft^3		177
Bulk Density, pcf		
After 230°F		178
After 1500°F		175
Water Required to Cast, weight - %		5.5
Modulus of Rupture, psi		
After 230°F		1,750
After 1500°F		2,050
Crushing Strength, psi		
After 230°F		8,600
After 1500°F		8,200
Abrasion Resstance		
After 1500°F		6.8 cc
Chemical Analysis, wt. %		
Zirconia	(ZrO_2)	23.7
Silica	(SiO_2)	21.4
Alumina	(Al_2O_3)	47.3
Iron Oxide	(Fe_2O_3)	0.2
Titania	(TiO_2)	0.2
Lime	(CaO)	1.9
Silicon Carbide	(SiC)	4.8
Alkalies	(Na_2O)	0.5

Exclusively serving the glass, iron and steelmaking industries…

North American Refractories Company (NARCO) is a leading supplier of refractory solutions to the iron and steel industries. The company makes high-performance products for BOFs, EAFs, LMFs, ladles, finishing, alternative ironmaking, casthouses, and blast furnaces. In addition to providing complete technical support services, NARCO also can design and implement a turnkey refractory management program to meet your facility's specialized requirements.

Exclusively serving the non-ferrous metals, ferrous foundry, hydrocarbon, incineration, minerals processing and other industries…

Harbison-Walker Refractories Company (H-W) provides high-performance refractory solutions to all non-steel-related industries. In addition to its own outstanding line of products, many of which have become industry standards, H-W is recognized worldwide for its technical support and expertise. Founded in 1875, the company is North America's oldest refractory maker.

Manufacturing products exclusively for NARCO and Harbison-Walker…

A.P. Green Refractories (APG) makes products for the iron and steel, aluminum, cement, copper, glass, and hydrocarbon and minerals processing industries. The company also has one of the world's top capabilities for customized pre-cast shapes, along with a full line of insulating ceramic fibers.

Products from all these companies are available through:

For Mineral Processing:

Harbison-Walker Refractories Company
400 Fairway Drive
Moon Township, PA 15108
Phone: 1-800-377-4497
Fax: (412) 375-6846

THOR AZS CASTABLE
THOR AZSP ADTECH®

For Cement Kiln Nose Rings

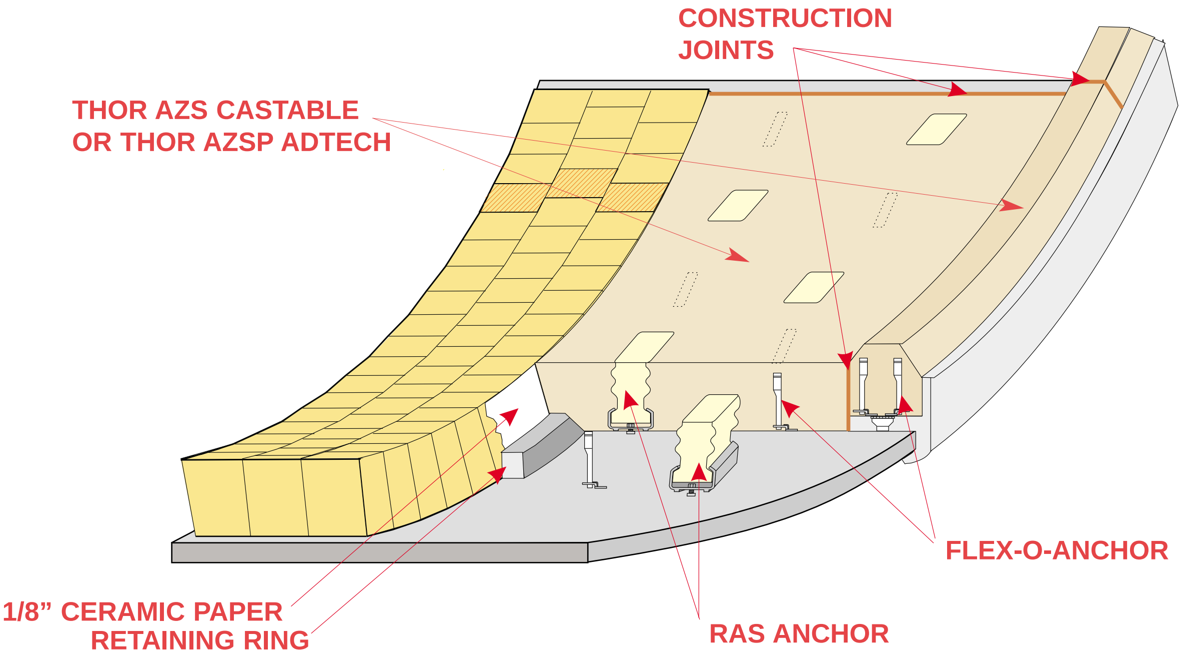
Harbison~Walker Refractories Company

Description: A Special Low-Moisture, Zirconia-Mullite Castable that can be conventionally cast or pumped

Features & Benefits:

- 2800°F Service Temperature
- High Hot Strength
- Excellent Thermal Shock Resistance
- Ease of Installation
- Conventional Casting or Pumping
- High Refractoriness
- Proven Track Record
- Unique Flex-O-Anchor design

Packaging: Shipped in 55 pound - multi-wall moisture - resistant sacks



TECHNICAL DATA

		THOR AZS CASTABLE	THOR AZSP ADTECH®
Physical Properties; (Typical)			
Bulk Density, pcf			
After 230°F		180	179
Hot Modulus of Rupture, psi			
After 1500°F		4,000	1,950
After 2000°F		5,100	--
After 2500°F		1,000	--
Cold Crushing Strength, psi			
After 230°F		12,300	11,600
After 1500°F		10,800	10,500
After 2200°F		15,200	--
Chemical Analysis, % Approximate (Calcined Basis)			
Silica	(SiO_2)	17.8%	18.4%
Alumina	(Al_2O_3)	55.2	53.3
Titania	(TiO_2)	0.2	0.2
Iron Oxide	(Fe_2O_3)	0.1	0.1
Lime	(CaO)	1.4	1.4
Silicon Carbide	(SiC)	5.0	5.0
Zirconia	(ZrO_2)	20.1	21.4
Alkalies	($Na_2O + K_2O$)	0.2	0.2

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Statements or suggestions concerning possible use of our products are made without representation or warranty that any such product is fit for such use or that such use is free of patent infringement of a third party. The suggested use assumes that all safety measures are taken by the user.

Warning: If proper procedures for preparation, application and heat-up of this material are not observed, steam spalling during heat-up may occur.

Harbison-Walker Refractories Company
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Moon Township, PA 15108
Phone: 1-800-377-4497 • Fax: (412) 375-6846

TZ 352 DRY MORTAR

Anti-Buildup For Existing Linings

Harbison~Walker Refractories Company

TZ 352 DRY MORTAR

TZ 352 DRY MORTAR is a heat-set Zircon-containing dry mortar that is an effective anti-buildup material for nonbasic refractory linings. It can be installed over monolithic or brick linings thereby saving time and money. The application method is either by trowel or spraying. TZ 352 DRY MORTAR is chemically inert and if a buildup does occur, it is easily removed.

TECHNICAL DATA		**TZ 352 DRY MORTAR**
Physical Properties (Typical)		
Maximum Service Temperature, °C - (°F)		1732 - (3150)
Cement Required, tons per 1000 ft^2		1
Required Installation Thickness, inches		0.125 - .25
Water Required:		
For trowelling add		12-15%
For spraying add		20-25%
Chemical Analysis, wt. %		
Zirconia	(ZrO_2)	60.0
Silica	(SiO_2)	32.0
Alumina	(Al_2O_3)	1.0
Phosphorous Pentoxide	(P_2O_5)	4.7
Alkalies	(Na_2O+K_2O)	1.6

Exclusively serving the glass, iron and steelmaking industries…

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Products from all these companies are available through:

For Mineral Processing:

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Fax: (412) 375-6846

Cat. # HW138 (11/02) 2C

VERSAFLOW® 70 ADTECH®

For Cement Kiln Nose Rings

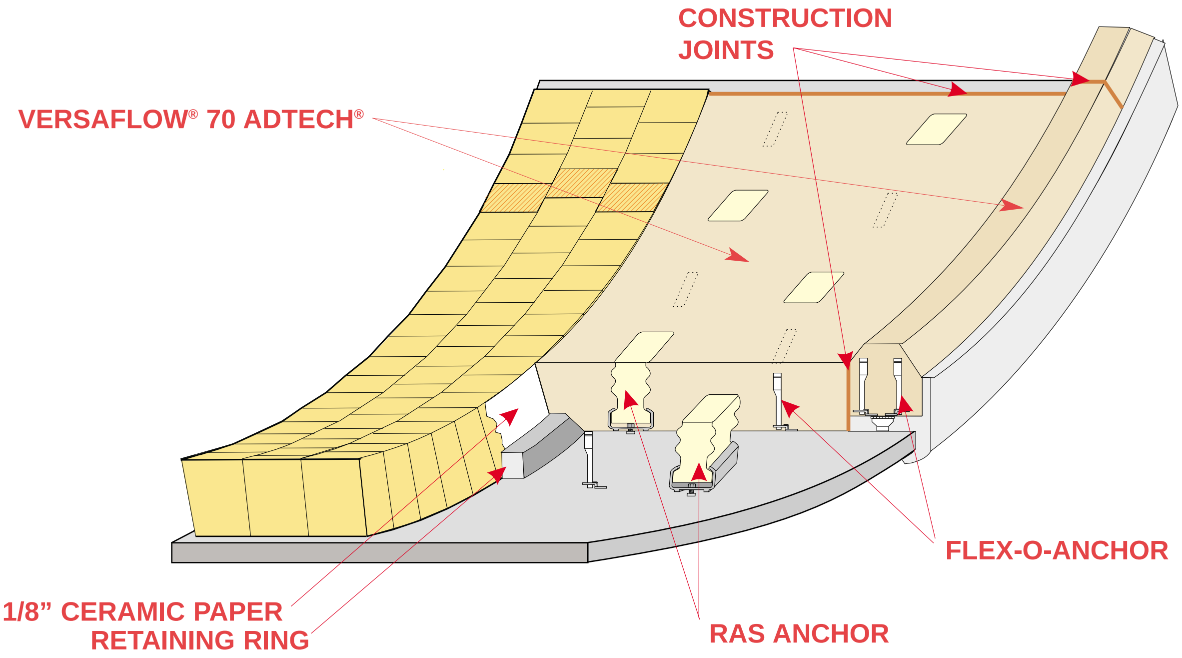
Harbison-Walker Refractories Company

Description: A 70% High Alumina Low Cement Castable

Features & Benefits:

- 3100°F Service Temperature
- High Hot Strength
- Excellent Abrasion Resistance
- Ease of Installation
    - Vibcasting
    - Conventional Casting
    - Pumping
- High Refractoriness
- Proven Track Record
- Unique Flex-O-Anchor Design

Packaging: Shipped in 55 pound - multi-wall moisture - resistant sacks



VERSAFLOW® 70 ADTECH®

TECHNICAL DATA

	VIBCASTING	CONV. CASTING/PUMPING
Physical Properties; (Typical)		
Bulk Density, pcf		
After 230°F	158	153
Modulus of Rupture, psi		
After Drying at 230°F	1,990	1,980
After Heating at 1500°F	3,300	2,500
At 2500 °F	750	--
Cold Crushing Strength, psi		
After 230°F	21,660	18,160
After 1500°F	15,000	14,770

Chemical Analysis, % Approximate (Calcined Basis)

Silica	(SiO_2)	27.0%
Alumina	(Al_2O_3)	67.3
Titania	(TiO_2)	2.4
Iron Oxide	(Fe_2O_3)	0.9
Lime	(CaO)	2.1
Magnesia	(MgO)	0.1
Alkalies	($Na_2O + K_2O$)	0.2

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Statements or suggestions concerning possible use of our products are made without representation or warranty that any such product is fit for such use or that such use is free of patent infringement of a third party. The suggested use assumes that all safety measures are taken by the user.

Warning: If prpoer procedures for prepration, application and Heat-up of this material are not observed, steam spalling during heat-up may occur.

This product is covered by Patent No. 4,430,439

Harbison-Walker Refractories Company
400 Fairway Drive
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AOD Refractories
for Industrial Foundries

Harbison-Walker Refractories Company

Mag-Chrome Brick Selections

SUPER NARMAG® FG: This product is a burned 100% fused Mg-Cr grain brick with chrome enhancement. This yields extremely low porosity, very high density, and excellent strength. SUPER NARMAG® FG is intended for the most extreme basic steel and iron containing conditions with regards to slag corrosiveness and temperature.

NARMAG® FG: This product is a burned 100% fused Mg-Cr grain brick. This yields excellent porosity, density, and strength. NARMAG® FG is intended for extreme basic steel and iron containing conditions.

SUPER NARMAG® 142: This product is a burned 20% fused Mg-Cr grain brick. It offers very good porosity, density, and strength. This product is for normal basic steel and iron containing conditions.

NARMAG® 142: This product is a burned Mg-Cr brick containing no fused grain. Compared to the above products, NARMAG® 142 has slightly higher porosity along with lower density and strength. This product is for normal basic steel and iron containing conditions.

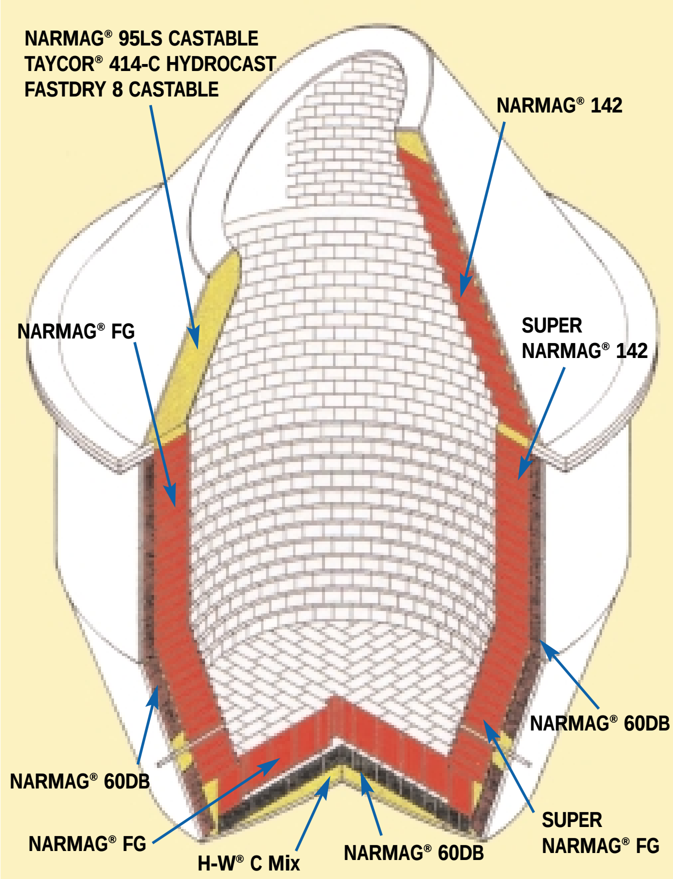
Problem Solvers: SUPER NARMAG®145 with 50% fused grain and TOMAHAWK® with improved thermal shock resistance.

Other Brands: NARMAG® 60DB and NARMAG® 60DBR can be considered as economical alternatives in zoned linings.

Other Selections

Mortars: Mag-Chrome brick should be laid with NARMAG® FG FINE MORTAR DRY.

Bottom Leveling: H-W® C Mix is a high purity, periclase ramming mix with chemical bonds.



Castable Selections

NARMAG® 95LS CASTABLE: This is a 96% magnesia castable with high density and outstanding hot strength. It is intended for basic steel and iron operations.

TAYCOR® 414-C HYDROCAST: This is a coarse grained, 96% alumina castable. The coarse grained structure provides for very good thermal shock resistance.

FASTDRY 8 CASTABLE: This is a high alumina, cement free castable with an alumina rich spinel matrix. It offers good resistance to steel and iron slags. The cement free formulation allows the dry out to begin sooner than for cement containing castables.

AOD Refractories	BRICK				CASTABLES		
Typical Test Data	**SUPER NARMAG® FG**	**NARMAG® FG**	**SUPER NARMAG® 142**	**NARMAG® 142**	**NARMAG® 95LS CASTABLE**	**TAYCOR® 414-C HYDROCAST**	**FASTDRY 8 CASTABLE**
Bulk Density, pcf							
After 230°F	210	207	205	204	178	182	195
Modulus of Rupture, psi							
At 70°F	1,700	1,500	700	600	500	1,800	1,900
At 2700°F	850	700	300	400	1,600	--	700
Apparent Porosity %	12	13	14	15	--	--	--
Chemical Analysis, % (Approximate)							
Silica (SiO_2)	0.5 %	0.6%	0.5%	0.3%	0.7%	0.2%	1.0%
Alumina (Al_2O_3)	6.1	6.3	6.8	6.9	0.2	96.5	90.8
Iron Oxide (Fe_2O_3)	12.0	12.0	12.0	13.0	0.2	0.1	0.1
Lime (CaO)	0.5	0.8	0.7	0.8	2.8	2.5	0.1
Magnesia (MgO)	58.0	62.0	61.0	59.0	96.0	--	7.8
Chromic Oxide (Cr_2O_3)	22.0	18.0	19.0	20.0	--	--	--
Alkalies ($Na_2O + K_2O$)	--	--	--	--	--	0.1	0.2

Photo shows AOD vessel with NARMAG® FG and SUPER NARMAG® 142 zoned by brand and thickness for optimal performance.

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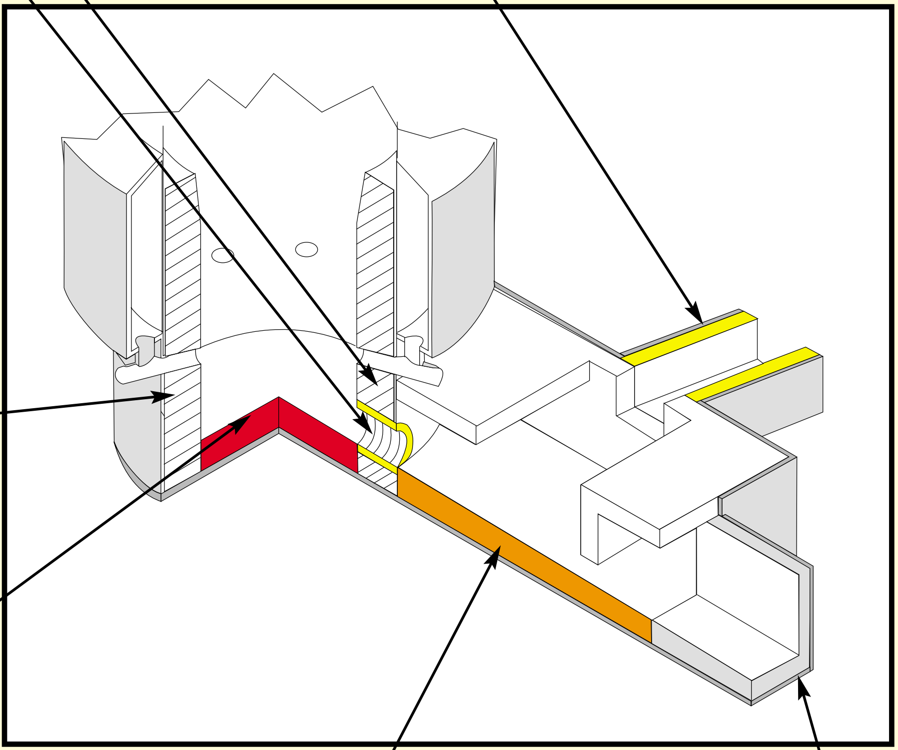
Cat# HW103R (01/03) 2C

CUPOLA Refractories

Breast Wall & Trough

Harbison-Walker Refractories Company

HW



Taphole Shapes

Precast Options
RUBY® SR/C
TUFLINE® 95 DM/C
TUFLINE® 90 DM/C
D-CAST TRC-SR
VERSAFLOW® 70/CU ADTECH®

Monolithic Options
SUPER NARCARB PLASTIC/RAM
NARCARB ZP PLASTIC
NARCARB XZR RAM
SUPER GRAPHPAK-85

Breast Wall

SUPER NARCARB PLASTIC
NARCARB ZP PLASTIC
SUPER GRAPHPAK-85

Slag Trough

D-CAST TRC-SR-CC
SUPER NARCARB PLASTIC/RAM
SUPER GRAPHPAK-85
RAMAL 85G

Well

D-CAST TRC 69
VERSAFLOW® 70/CU ADTECH®

Maintenance
SUPER NARCARB PLASTIC
NARCARB ZP PLASTIC

Bottom*

NARCARB ZP PLASTIC
RAMAL 85G
NARPHOS 55R (FINE)
*All used in combination with sand

Front Slagger & Dam

D-CAST TRC-SR-CC
SUPER NARCARB PLASTIC/RAM
SUPER GRAPHPAK-85
RAMAL 85G

Iron Runner

D-CAST TRC-SR-CC
RAMAL 85G
GREENPAK-85-MP

Service Conditions

- **Temperature (2000°F - 3000°F)**
- **Slag, Metal, Oxygen Reactions**
- **Metal Erosion and Velocity**

Cupola Brand Description
SiC / Graphite Plastic & Ram Selections:

SUPER NARCARB PLASTIC & RAM:	These products are based on fused alumina with SiC and oxidation inhibitors. This yields very low porosity for enhanced corrosion resistance to cupola slags. Both of these SUPER NARCARB materials are intended for extended cupola campaigns and the most severe service conditions. Both products offer the highest level of carbon containing, non-wetting components. These products offer a more environmentally friendly bond system than the phenolic resin bonded materials.
NARCARB XZR RAM:	This is a phenolic resin bonded ramming mix with the second highest amount of non-wetting components. This mix offers high density, low porosity and high hot strengths. NARCARB XZR RAM provides excellent performance in maintenance situations or as the original lining in Cupola bottoms and troughs.
NARCARB ZP PLASTIC:	This phenolic resin bonded plastic provides high strengths at iron producing temperatures. It contains SiC with oxidation inhibitors. NARCARB ZP provides excellent performance in extended cupola campaigns under severe conditions. This material is ideally suited for well zone and melt zone maintenance during bottom drops.
SUPER GRAPHPAK-85:	This air-setting, silicon carbide and graphite containing, oxidation resistance plastic contains no pitch or resins. As a result, it does not give off polluting emissions. This plastic possesses good resistance to hot metal and slag erosion and represents an economical alternative to NARCARB ZP and SUPER NARCARB in less severe conditions.
GRAPHPAK-85, GRAPHPAK-45 & RAMAL 85G:	These are high alumina and fireclay, graphite containing materials. They exhibit better corrosion resistance to molten iron and slag than conventional materials. These are workhorse type materials for cupolas. GRAPHPAK-45 and GRAPHAK-85 are plastics while RAMAL 85G is a wet ramming mix.

Taphole Material Selections:

VIBTECH® Shapes:	These are thixotropic-formed shapes which are fired to high temperatures to achieve properties equivalent to brick. Depending on the specific mix, VIBTECH shapes can provide longer service life, high hot strengths, low porosity, and excellent thermal shock resistance. Options for cupola taphole service include **TUFLINE® 90 DM/C, TUFLINE® 95 DM/C,** and **RUBY® SR/C.**
D-CAST TRC-SR:	This SiC and carbon containing castable can also be ordered as a precast shape. Either way, it provides exceptional properties such as 9% porosity, excellent hot strengths, and excellent thermal shock resistance. It is non-wetting to iron and slag, contains oxidation inhibitors, and exhibits slag resistance comparable to resin-bonded plastis. D-CAST TRC-SR is an excellent choice for taphole blocks, well blocks, or long iron runners.
VERSAFLOW® 70/CU ADTECH®:	This is a 70% alumina low cement castable containing SiC. It can be ordered as a castable or precast shape. The SiC provides enhanced corrosion resistance in taphole blocks, well blocks, or long iron runners.

Castables for Cupola Applications

D-CAST TRC-SR-CC	This is a low cement, SiC containing castable with improved slag resistance compared with other D-CAST materials. It features improved strengths above 1500°F, excellent thermal shock resistance, a modified matrix for enhanced slag resistance, and volume stability for negligible sintering cracks during service. These properties make D-CAST TRC-SR-CC an outstanding option for severe slag and metal contact applications.
D-CAST TRC 69	This a low cement, SiC and carbon containing castable. This product is a lower cost version of the other D-CAST products but is not as oxidation resistant. This product is used in applications where service demands are less severe.

Taphole Well and Bottom Materials

	VERSAFLOW® 70/CU ADTECH® Cast & Shapes	D-CAST TRC-SR-CC Cast & Shapes	TUFLINE® 90 DM/C VIBTECH® Shape	TUFLINE® 95 DM/C VIBTECH® Shape	RUBY® SR/C VIBTECH® Shape	D-CAST TRC 69 Castable	NARPHOS 55R (FINE) Ram
Max. Service Temp, °F	2850	3100	3300	3400	3300	3100	3000
Bulk Density, lb/ft^3							
After Heating to 230°F	173	194	197	200	204	185	156
Modulus of Rupture, lb/in^2							
At 70°F	--	--	1,710	1,720	1,360	--	--
After Heating to 230°F	1,890	1,900	--	--	--	1,800	1,100
After Heating to 1500°F	2,600	--	--	--	--	--	700
At 2500°F	700	600	--	--	--	1,100	650
At 2700°F	--	400	1,320	--	--	300	--
Apparent Porosity, %	--	--	14.6	15.8	15.5	--	--
Chemical Analysis: % (Approximate)							
Silica (SiO_2)	11.7	6.1	7.0	2.1	1.9	8.7	39.3
Alumina (Al_2O_3)	68.5	72.5	89.3	94.2	83.0	69.0	54.4
Titania (TiO_2)	2.2	1.6	--	--	0.1	2.4	1.5
Iron Oxide (Fe_2O_3)	1.0	0.1	0.1	0.1	0.1	0.9	1.0
Lime (CaO)	2.2	1.2	0.1	0.1	0.1	1.2	Trace
Magnesia (MgO)	0.2	0.1	--	--	Trace	0.1	0.1
Alkalies (Na_2O+K_2O)	0.2	0.1	--	--	0.2	0.2	0.3
Chromic Oxide (Cr_2O_3)	--	--	--	--	11.1	--	--
Silicon Carbide + Carbon ($SiC+C$)	14.0	18.0	--	--	--	17.5	--
Other Oxides	--	--	3.5	3.5	3.5	--	3.3

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Examples of VIBTECH® shapes. Such shapes can provide excellent performance in cupola well blocks and taphole applications.

Harbison~Walker Refractories Company

Breast Wall & Trough	Plastics						Ram Mixes		
	SUPER NARCARB PLASTIC	NARCARB ZP	SUPER GRAPHPAK -85	GRAPHPAK -85	GRAPHPAK -45	GREENPAK 85 MP	SUPER NARCARB RAM	NARCARB XZR	RAMAL 85G
Max. Service Temp, °F	3275	3275	3200	3100	2950	3000	3275	3275	3275
Material Required, lb/ft^3	184	178	185	166	142	178	184	188	160
Modulus of Rupture, lb/in^2									
After Heating to 300°F	1,300	800	900	350	250	750	1,300	2,600	200
After Heating to 1500°F	--	--	--	125	200	1,300	--	--	--
After Heating to 1800°F	700	900	--	--	--	--	1,200	640	--
At 2000°F	--	900	--	--	--	--	--	1,660	760
At 2500°F	1,100	--	--	--	--	--	1,300	--	--
Apparent Porosity, %									
After Heating to 1800°F	20	22.5	--	--	--	--	18	17	--
Chemical Analysis: % (Approximate)									
Silica (SiO_2)	8.7	7.8	13.5	11.4	46.7	11.0	6.6	6.5	9.1
Alumina (Al_2O_3)	61.8	70.0	62.7	72.1	39.6	80.0	64.0	68.9	76.1
Titania (TiO_2)	1.4	1.5	1.9	2.4	2.3	2.5	1.3	1.6	1.7
Iron Oxide (Fe_2O_3)	0.4	0.7	0.7	1.3	1.5	1.4	0.7	0.3	1.5
Lime (CaO)	0.1	0.2	0.1	0.2	0.5	0.1	0.1	0.1	0.6
Magnesia (MgO)	0.2	0.3	0.1	0.2	0.4	0.1	0.1	0.1	0.1
Alkalies (Na_2O+K_2O)	0.1	0.2	0.1	0.4	1.1	0.2	0.1	0.1	0.3
Phosphorus Pentoxide (P_2O_5)	--	--	--	--	--	4.0	--	--	--
Silicon Carbide + Carbon ($SiC+C$)	27.3	19.0	20.9	12.0	8.0	--	27.1	22.4	10.6

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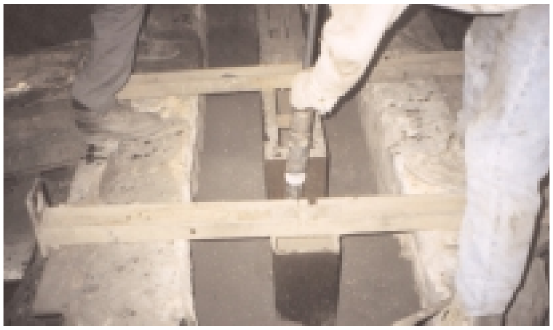

Installation of RAMAL 85 G in cupola trough application.

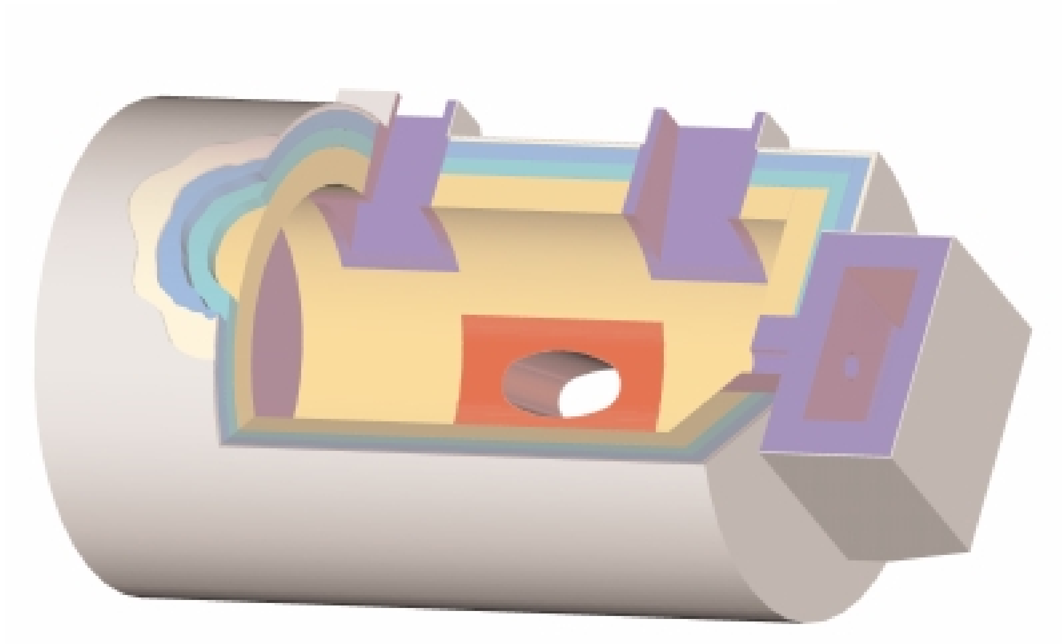

NARCARB ZP Plastic lining a cupola well zone

Harbison-Walker Refractories Company
400 Fairway Drive
Moon Township, PA 15108
Phone: (412) 375-6600 w Fax: (412) 375-6783

Channel Induction Refractories
For Industrial Foundries

Harbison-Walker Refractories Company

HORIZONTAL CHANNEL INDUCTION FURNACES



Service Conditions

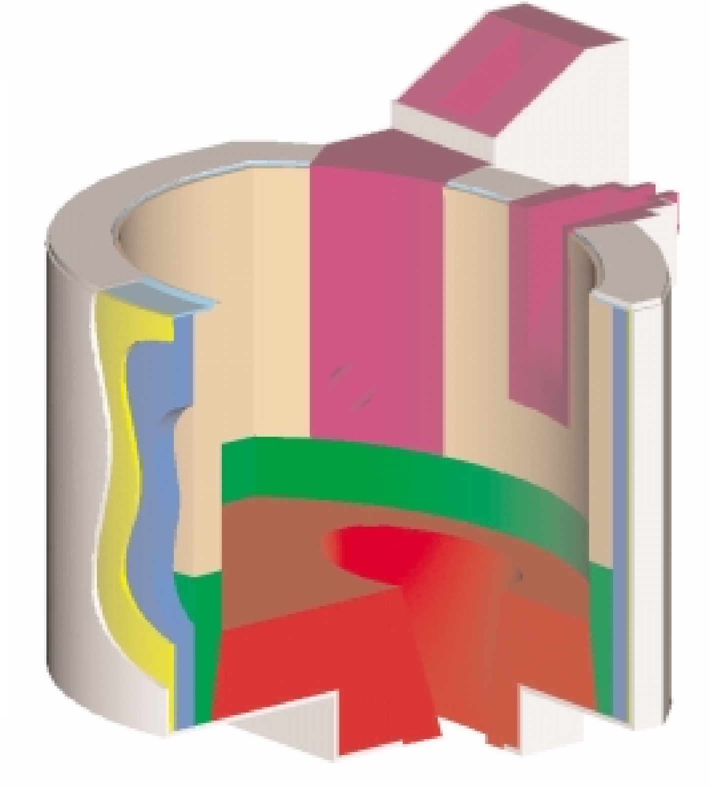
- Gray & Malleable Iron:
  - Temperatures of 2750°F +
  - Slag Buildup
- Ductile Iron:
  - Temperatures of 2800°F +
  - CaC_2 & MgO Attack
  - Slag Line Erosion
  - More Use of Chrome Containing Brick

Horizontal Channel Induction Furnace Refractory Selection

Operating Conditions	Slag & Metal Contact	Slag & Metal Backup	Crown	Receivers & Pour Spouts	Repair & Mainteance
Gray Iron	CORAL® BP KORUNDAL® XD	CLIPPER® DP	CORAL® BP	KORUNDAL® PLASTIC D-CAST 85TMCC GREENCAST®-94	KORUNDAL® PLASTIC
Malleable Iron	TUFLINE® 90 KORUNDAL® XD KORUNDAL XD® DM	KRUZITE® 70 CORAL® BP	CORAL® BP UFALA® XCR KORUNDAL XD®	KORUNDAL® PLASTIC D-CAST TRC-SR-CC FUSECRETE® C, C6, C10	GREENPAK-90-P
Ductile Iron	KORUNDAL XD® KORUNDAL XD® DM RUBY® RUBU® DM	KRUZITE®-70 DV-38	UFALA® XCR TUFLINE® 90 KORUNDAL XD®	RUBY® PLASTIC AMC RUBY® PLASTIC 10 FUSECRETE® C, C6, C10	RUBY® PLASTIC 10

VERTICAL CHANNEL INDUCTION FURNACES

Service Conditions

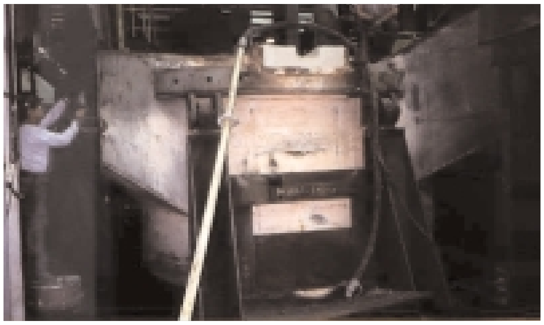


- Gray & Malleable Iron:
  - Temperatures of 2750°F +
  - Slag Buildup
- Ductile Iron:
  - Temperatures of 2800°F +
  - CaC_2 & MgO Attack
  - Slag Line Erosion
- Thermal Shock a Concern for Furnaces Without a Receiver.

Vertical Channel Induction Furnace Refractory Selection

Operating Conditions	Slag & Metal Contact Brick	Slag & Metal Contact Monolithic	Slag & Metal Backup	Roof	Receivers & Pour Spouts	Repair & Maintenance
Gray Iron	CORAL® BP KORUNDAL® XD	NARPHOS 85R RAM D-CAST 85TMCC	CLIPPER® DP	KAST-O-LITE® 97-L EXPRESS®-30 MIZZOU CASTABLE®	KORUNDAL® PLASTIC D-CAST 85TMCC GREENCAST®-94	KORUNDAL® PLASTIC GREFCOTE® 50
Malleable Iron	TUFLINE® 90 KORUNDAL XD® KORUNDAL XD® DM	HP CAST ULTRA D-CAST TRC-SR-CC	KRUZITE®-70 CORAL® BP	KAST-O-LITE® 97-L EXPRESS®-30 MIZZOU® CASTABLE®	KORUNDAL® PLASTIC D-CAST TRC-SR-CC FUSECRETE® C, C6, C10	GREENPAK-90-P GREFCOTE® 70
Ductile Iron	KORUNDAL XD® KORUNDAL XD® DM RUBY® RUBY® DM	RUBY® RAMMING MIX FUSECRETE C, C6, C10	KRUZITE®-70 DV-38	KAST-O-LITE® 97-L EXPRESS®-30 MIZZOU CASTABLE®	RUBY® PLASTIC AMC RUBY® PLASTIC 10 FUSECRETE® C, C6, C10	RUBY® PLASTIC 10 KORUNDAL® HOT GUN

RUBY® RAMMING MIX lining the upper case and KORUNDAL XD® forming the jack arch and floor.

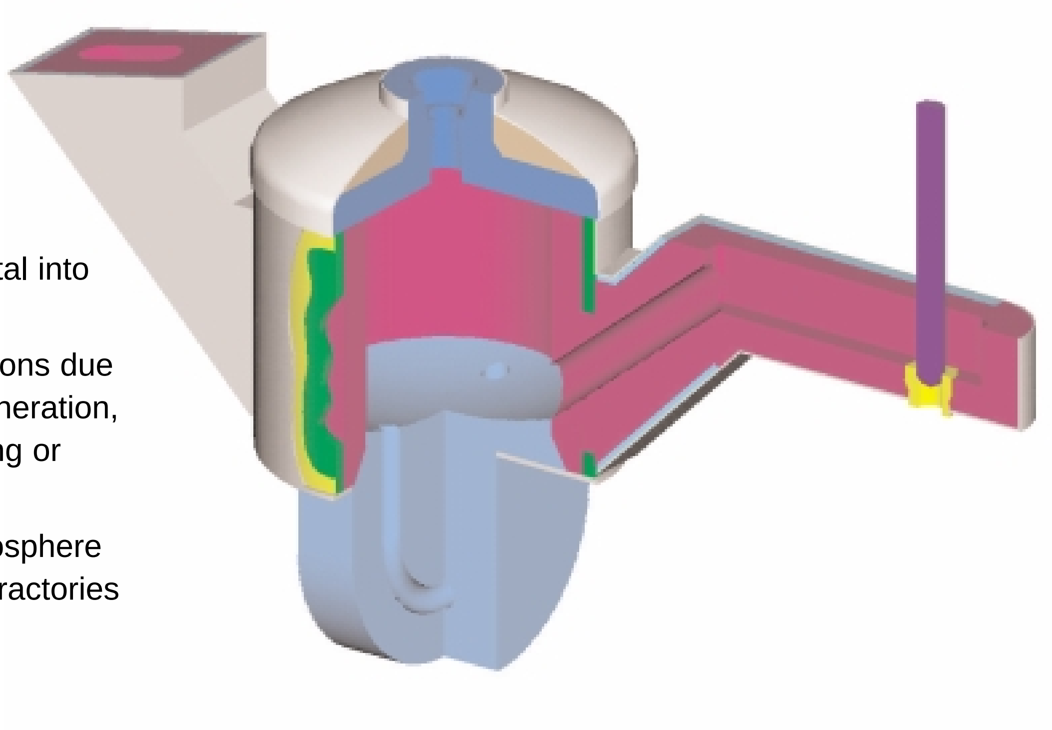


D-CAST TRC-SR-CC being pump cast into the pour spout and receiver.

PRESSURE POUR CHANNEL INDUCTION FURNACES

Service Conditions

- Narrow Inlet & Outlets Prone to Choking
- Pressure Can Force Metal into Open Cracks & Porosity
- Milder Operating Conditions due to Reduction in Slag Generation, and the Absence of Tilting or Rolling Movements
- Potential Reducing Atmosphere Can Reduce SiO_2 in Refractories



Pressure Pour Channel Induction Refractory Selection

Operating Conditions	Slag & Metal Contact	Slag & Metal Backup	Roof	Receivers & Pour Spouts	Repair & Mainteance
Gray Iron	NARPHOS 90R RAM D-CAST 85TMCC	KAST-O-LITE® 23 ES	KAST-O-LITE® 97-L	KORUNDAL® PLASTIC D-CAST 85TMCC GREENCAST®-94	KORUNDAL® PLASTIC
Malleable Iron	HP CAST ULTRA D-CAST TRC-SR-CC	KAST-O-LITE® 26 LI	KAST-O-LITE® 97-L	KORUNDAL® PLASTIC D-CAST TRC-SR-CC FUSECRETE® C, C6, C10	GREENPAK-90-P
Ductile Iron	RUBY® RAMMING MIX FUSECRETE® C, C6, C10	KAST-O-LITE® 26 LI	KAST-O-LITE® 97-L	RUBY® PLASTIC AMC RUBY® PLASTIC 10 FUSECRETE® C, C6, C10	RUBY® PLASTIC 10

D-CAST TRC-SR-CC showing little signs of wear after 1 plus years of service in a pouring arm.

Harbison~Walker • Refractories Company •

CHANNEL INDUCTION REFRACTORIES for Industrial Foundries

Technical Data Brick

Brand	KRUZITE® -70	DV-38	UFALA® XCR	TUFLINE® 90	KORUNDAL XD®	KORUNDAL XD® DM	RUBY®	RUBY® DM
Density, pcf	165	179	159	182	186	195	198	213
Apparent Porosity, %	18.7	14.0	14.1	17.6	16.1	12.4	17.8	12.6
Crushing Strength, psi								
At 70°F	8,500	18,000	7,400	11,500	11,350	16,000	12,500	19,450
Modulus of Rupture, psi								
At 70°F	1,700	3,400	2,200	1,730	2,330	3,840	4,500	7,150
At 2700°F	--	--	--	1,050	1,320	1,930	1,890	4,000
Chemical Analysis, % (Approximate)								
Alumina (Al_2O_3)	71.0	80.4	60.3	89.1	90.1	90.3	89.7	89.6
Silica (SiO_2)	23.0	11.0	36.8	9.7	9.5	9.2	0.5	0.3
Titania (TiO_2)	3.4	2.5	1.3	0.6	Trace	Trace	0.1	Trace
Iron Oxide (Fe_2O_3)	1.6	1.3	1.1	0.3	0.1	0.1	0.2	0.1
Lime (CaO)	0.2	0.1	0.1	0.1	0.1	0.1	0.3	0.1
Magnesia (MgO)	0.2	0.1	0.1	Trace	Trace	0.1	0.1	Trace
Alkalies (Na_2O+K_2O)	0.6	0.2	0.3	0.2	0.2	0.2	0.1	0.1
Chromic Oxide (Cr_2O_3)	--	--	--	--	--	--	9.0	9.8
Phosphorus Pentoxide (P_2O_5)	--	4.4	--	--	--	--	--	--

Technical Data Monolithic Products

Brand	KORUNDAL® PLASTIC	KORUNDAL® HOT GUN	GREENCAST® 94	HP-CAST ULTRA	D-CAST 85TMCC	RUBY® PLASTIC AMC	FUSECRETE® C10	D-CAST TRC-SR-CC	RUBY® RAM MIX
Density, pcf After Drying,	175	146	172	195	182	167	192	194	203
Crushing Strength, psi									
After 230°F	--	680	9,000	7,000	9,200	--	3,225	6,500	12,500
After 1500°F	--	980	9,500	9,500	13,200	--	2,580	--	14,800
Modulus of Rupture, psi						(500°F)			
After 230°F	--	340	1,700	2,000	1,400	1,160	1,040	1,900	3,000
After 1500°F	2,180	340	1,750	2,500	2,600	1,400	720	--	3,700
Chemical Analysis, % (Approximate)									
Alumina (Al_2O_3)	87.1	88.8	94.1	96.3	83.1	61.0	85.6	72.5	83.8
Silica (SiO_2)	8.5	8.4	0.2	0.1	11.0	18.1	0.6	6.1	1.8
Titania (TiO_2)	0.1	0.5	0.1	--	2.8	1.7	1.7	1.6	Trace
Iron Oxide (Fe_2O_3)	0.2	0.4	0.2	0.1	1.0	0.7	0.2	0.1	0.1
Lime (CaO)	0.1	1.6	5.1	2.5	1.4	0.1	1.7	1.2	0.1
Magnesia (MgO)	0.1	0.1	0.1	0.8	0.1	0.2	0.2	0.1	0.1
Alkalies (Na_2O+K_2O)	0.2	0.2	0.2	0.2	0.2	0.2	0.1	0.1	0.2
Phosphorous Pentoxide (P_2O_5)	3.7	--	--	--	--	3.7	--	--	3.8
Chromic Oxide (Cr_2O_3)	--	--	--	--	--	14.3	9.9	--	10.1
Silicon Carbide + Carbon ($SiC + C$)	--	--	--	--	--	--	--	18.0	--

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Moon Township, PA 15108

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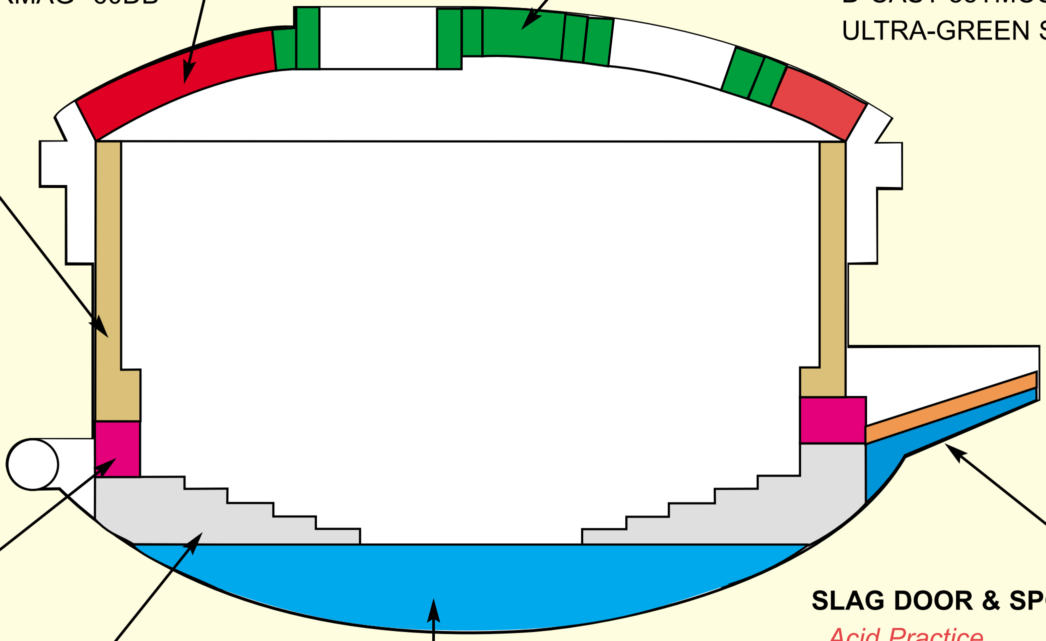
Cat# HW 122R (2/03) 3C

Electric Arc Furnace Refractories

For Industrial Foundries

Harbison-Walker Refractories Company



UPPER SIDE WALL

Acid Practice

ALADIN® 80

KRUZITE®-70

Basic Practice

NARMAG® 80DB

NARMAG® 60DB

ROOF

Acid & Basic Practice

ALADIN® 80

KRUZITE®-70

DELTA/ELECTRODE RINGS

Acid & Basic Practice

GREENPAK-85-MP

SUPER HYBOND 80

Precast

NOVACON® 65

D-CAST 85TMCC

ULTRA-GREEN SR

SLAG LINE

Acid Practice

ALADIN® 80

KRUZITE®-70

Basic Practice

SUPER NARMAG® B

NARMAG® 142

NARMAG® FG

LOWER SIDE WALL

Acid Practice

ALADIN® 80

KRUZITE®-70

Basic Practice

SUPER NARMAG® B

NARTAR 7

BOTTOM/HEARTH

Acid Practice

GANNISTER MIX

SLAG DOOR & SPOUT

Acid Practice

GREENPAK-85-MP

RUBY® PLASTIC AMC

FUSECRETE® C10

Basic Practice

SUPER NARMAG® B

NARTAR 7

NARMAG® FG RAM MIX

MAINTENANCE

Acid Practice

GREFCOTE® 70

ACID PRACTICE BRICK & MONOLITHICS

BRAND	ALADIN® 80	KRUZITE®-70	D-CAST 85TMCC	GREENPAK-85-MP	NOVACON® 65	RUBY® PLASTIC AMC	FUSECRETE® C10	GREFCOTE® 70
Density, lb/ft^3	170	165	182	178	155	180	189	130
Modulus of Rupture, lb/in^2 At 70°F/After 230°F	1,610	1,700	1,400	750	1,490	(500°F) 1,160	1,040	600
Crushing Strength, lb/in^2 At 70°F/After 230°F	9,610	8,500	9,200	--	7,950	--	3,225	2,000
Apparent Porosity, %	19.5	18.7	13.5	--	--	--	--	--
Chemical Analysis, % (Approximate)								
Silica (SiO_2)	15.2%	23.0%	11.0%	11.0%	31.1%	18.1%	0.6%	22.0%
Alumina (Al_2O_3)	78.6	71.0	83.1	80.0	64.8	61.0	85.6	70.5
Titania (TiO_2)	3.4	3.4	2.8	2.5	2.2	1.7	1.7	3.3
Iron Oxide (Fe_2O_3)	1.8	1.6	1.0	1.4	0.9	0.7	0.2	1.4
Lime (CaO)	0.3	0.2	1.4	0.1	0.1	0.1	1.7	2.0
Magnesia (MgO)	0.3	0.2	0.1	0.1	0.1	0.2	0.2	0.2
Alkalies (Na_2O+K_2O)	0.4	0.6	0.2	0.2	0.4	0.2	0.1	0.6
Chromic Oxide (Cr_2O_3)	--	--	--	--	--	14.3	9.9	--
Phosphorous Pentoxide (P_2O_5)	--	--	--	4.0	0.4	3.7	--	--

BASIC PRACTICE BRICK & MONOLITHICS

BRAND	NARMAG® FG	NARMAG® 142	SUPER NARMAG® B	NARTAR 7	NARMAG® 80DB	NARMAG® 60DB	NARMAG®FG RAM MIX
Density, lb/ft^3	207	204	185	197	191	191	195
Modulus of Rupture, lb/in^2 At 70°F	1,500	600	2,500	3,000	750	650	1,000
AT 2700°F	700	400	--	--	160	220	--
At 2800°F	--	--	1,700	1,400	--	--	--
Crushing Strength, lb/in^2, At 70°F	12,000	--	8,700	14,000	--	5,800	--
Apparent Porosity, %	13.0	15.0	14.0	15.0	16.0	18.0	21.0
Chemical Analysis, % (Approximate)							
Silica (SiO_2)	0.6%	0.3%	0.9%	1.0%	1.3%	2.5%	0.7%
Alumina (Al_2O_3)	6.3	6.9	0.2	0.1	3.6	7.3	6.8
Iron Oxide (Fe_2O_3)	12.0	13.0	0.3	0.3	6.1	10.0	12.0
Lime (CaO)	0.8	0.8	2.1	2.4	0.9	1.4	0.5
Magnesia (MgO)	62.0	59.0	96.5	96.2	78.8	62.0	59.0
Chromic Oxide (Cr_2O_3)	18.0	20.0	--	--	9.3	16.0	21.0

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Harbison-Walker Refractories Company
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Moon Township, PA 15108

Phone: (412) 375-6600 w Fax: (412) 375-6783

LADLE REFRACTORIES

For Industrial Foundries

Performance Factors

- Dimensional Stability
- Resistance to Slags, Molten Iron & Steel
- Thermal Shock Resistance
- High Strength
- Ease of Installation
- Proven Performance Record
- Fast Turn-around

Iron & Steel Ladle Refractory Selections

Application	Brick	Castables	Vibratables	Plastics & Rams
Steel & Alloy	COMANCHE® ALADIN® 85 ALADIN® 80	FASTDRY 8 HP-CAST ULTRA D-CAST 85TMCC	GREFVIBE® 850	GREENPAK-90-P
Iron Transfer & Inoculation	ALADIN® 80 KRUZITE®-70	D-CAST 85TMCC ULTRA-GREEN 70 KRUZITE® CASTABLE	GREFVIBE® 850 TASIL® 570 LM GREFVIBE 700	GREENPAK-85-MP RAMAL 80
Iron Pouring	KRUZITE®-70	EXPRESS®-30 PLUS ULTRA-GREEN 45 MIZZOU CASTABLE	GREFVIBE® 700	H-W® BULL RAM PLASTIC

Harbison-Walker Refractories Company
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Moon Township, PA 15108
Phone: (412) 375-6600 w Fax: (412) 375-6783

H-W LADLE REFRACTORIES For Industrial Foundries

BRICK	COMANCHE®	ALADIN® 85	ALADIN® 80	KRUZITE®-70
Density, lb/ft^3	189	172	170	165
Porosity, %	7.0	20.0	19.5	18.7
Modulus of Rupture, lb/in^2	3,100	1,700	1,610	1,700
Chemical Analysis: (Approximate)				
Silica (SiO_2)	3.9%	12.9%	15.2%	23.0%
Alumina (Al_2O_3)	82.4	81.4	78.6	71.0
Titania (TiO_2)	--	3.3	3.4	3.4
Iron Oxide (Fe_2O_3)	--	1.6	1.8	1.6
Lime (CaO)	--	0.3	0.3	0.2
Magnesia (MgO)	8.5	0.2	0.3	0.2
Carbon (C)	5.0	--	--	--
Alkalies (Na_2O+K_2O)	--	0.3	0.4	0.6

PLASTIC & RAMMING MIXES	GREENPAK-90-P	RAMAL 80	GREENPAK-85-MP	H-W® BULL RAM
Maximum Service Temperature	3200°F	3200°F	3000°F	3000°F
Quantity Required - Net, lb/ft^3	195	160	178	168
Modulus of Rupture, lb/in^2 After1500°F (816°C)	2,600	500	1,300	1,070
Chemical Analysis: (Approximate)				
Silica (SiO_2)	3.5%	13.6%	11.0%	21.7%
Alumina (Al_2O_3)	91.0	80.0	80.0	71.5
Titania (TiO_2)	0.1	2.7	2.5	1.8
Iron Oxide (Fe_2O_3)	0.2	1.4	1.4	1.1
Lime (CaO)	0.1	0.4	0.1	0.2
Magnesia (MgO)	0.1	0.2	0.1	0.3
Alkalies (Na_2O+K_2O)	0.2	0.2	0.2	0.2
Phosphorus Pentoxide (P_2O_5)	4.8	--	4.0	3.2

CASTABLES	FASTDRY 8 CASTABLE	HP-CAST ULTRA	D-CAST 85TMCC	ULTRA-GREEN 70	KRUZITE® CASTABLE	EXPRESS®-30 PLUS	ULTRA-GREEN 45	MIZZOU CASTABLE
Maximum Service Temperature	3300°F	3400°F	3200°F	3100°F	3200°F	3000°F	3000°F	3000°F
Quantity Required - Net, lb/ft^3	195	195	182	166	155	154	146	139
Modulus of Rupture, lb/in^2								
After 230°F (110°C)	1,700	2,000	1,400	1,550	550	2,500	1,750	1,080
After 1500°F (816°C)	1,100	2,500	2,600	2,700	400	3,000	2,500	700
Crushing Strength, lb/in^2								
After 230°F (110°C)	--	7,000	9,200	8,700	3,500	20,000	9,400	5,000
After 1500°F (816°C)	5,300	9,500	13,200	11,500	2,500	20,000	14,000	3,000
Chemical Analysis: (Approximate)								
Silica (SiO_2)	1.0%	0.1%	11.0%	24.0%	17.0%	32.7%	46.0%	32.5%
Alumina (Al_2O_3)	90.8	96.3	83.1	71.0	76.0	60.0	48.3	60.0
Titania (TiO_2)	--	--	2.8	2.5	2.8	2.3	2.4	2.5
Iron Oxide (Fe_2O_3)	0.1	0.1	1.0	1.0	1.4	1.0	1.2	1.5
Lime (CaO)	0.1	2.5	1.4	0.8	1.7	3.1	1.2	2.5
Magnesia (MgO)	7.8	0.8	0.1	0.1	0.2	0.2	0.1	0.4
Alkalies (Na_2O+K_2O)	0.2	0.2	0.2	0.3	0.5	0.7	0.6	0.6

VIBRATABLES & PLASTICS	Vibratable Plastics			Patching Materials	
	GREFVIBE® 850	GREFVIBE® 700 WET	TASIL® 570 LM	GREFPATCH 85	NARCOLINE C & M MORTAR
Maximum Service Temperature	3200°F	3100°F	3200°F	3100°F	3000°F
Quantity Required - Net, lb/ft^3	175	174	176	165	--
Modulus of Rupture, lb/in^2					
After 2500°F (1371°C)	1,500	2,080	4,600	1,800	--
Crushing Strength, lb/in^2					
After 1500°F (816°C)	5,600	7,500	--	--	--
After 2550°F (1400°C)	--	5,850	--	15,000	--
Chemical Analysis: (Approximate)					
Silica (SiO_2)	9.5%	23.3%	28.0%	10.2%	52.6%
Alumina (Al_2O_3)	82.8	69.8	68.8	83.7	29.4
Titania (TiO_2)	2.8	1.9	2.0	1.9	1.7
Iron Oxide (Fe_2O_3)	1.1	1.4	1.1	1.0	2.1
Lime (CaO)	0.2	<0.1	0.1	<0.1	0.4
Magnesia (MgO)	0.2	<0.1	0.3	<0.1	0.3
Alkalies (Na_2O+K_2O)	0.3	0.4	0.5	0.4	1.5
Phosphorus Pentoxide (P_2O_5)	3.1	3.1	--	2.8	--
Carbon (C)	--	--	--	--	12.0

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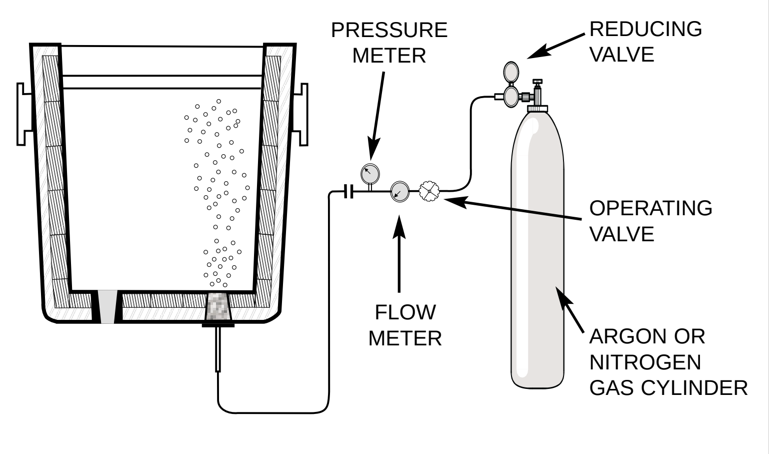
NARGON® Porous Plugs

For Industrial Foundries

Harbison-Walker Refractories Company

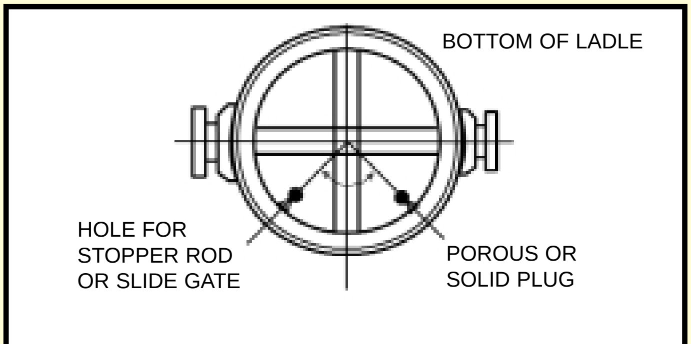
NARGON® Porous Ladle Plugs allow the introduction of inert gases via one or more permeable plugs in the ladle bottom. The gas bubbles rise and produce the following effects:

- Dispersion & Stirring of Additives
- Temperature Adjustments for Optimum Teeming & Homogeneity
- Removal of Non-Metallic Inclusions
- Degassing



Typical arrangement

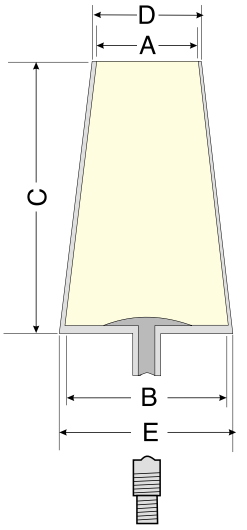
These illustrations show typical porous plug arrangements and piping used for ferrous foundry ladle applications.



Recommended location of NARGON® Porous Plug.

Available NARGON® Porous Plug Sizes (Dimension in Inches)

	Plug Dimensions			Sleeve Dimensions	
	(A) Top Dia	(B) Bottom Dia	(C) Height	(D) Top Dia	(E) Bottom Dia
NP-3	2.9	3.2	3.1		
NP-5	3.38	4.9	5		
NP-8	3.38	5.8	8.3		
NP-11 & NPG-11	3.8	4.5	10.8		
NP-11S*	3.8	4.5	10.8	5.2	6.9
NPG-11S	3.8	4.5	10.8	5.8	9.2
NP-15 & NPG-15	3.8	6.1	15.1		
NPG-15S	3.0	6.1	15.1	4.3	9.2



*S-Castable sleeve between plug and can.

NARGON® Porous Plugs are available with a variety of options. This information gives the specific details for these parts. Please contact your H-W sales representative or Technical Marketing for further details.

NP - G - 11(3.8) - 6 .5 - 5 - M

- CAN MATERIAL
- PIPE LENGTH
- PIPE DIAMETER
- OPTION NUMBER
- NARGON PLUG SIZE
- GEOMETRIC SHAPE CHANGE
- NARGON PLUG

Porous Plug Typical Test Data

	NARGON® A-90	NARGON® A-94
Bulk Density, lbs/ft^3	165	184
Apparent Porosity, %	24	23
Permeability, Centidarcy	570	950
Mean Pore Diam., microns	55-70	50-70
Chemical Analysis, %		
Alumina (Al_2O_3)	90.0%	95.0%
Silica (SiO_2)	7.6	2.4
Chromic Oxide (Cr_2O_3)	--	1.5

NARGON® A-90

This permeable composition is based on high-purity sintered alumina. It is designed for applications where erosion and thermal shock are severe. This plug is best suited for shops requiring periods of gentle bubbling with small bubbles.

NARGON® A-94

This permeable composition is based on high-purity fused alumina. It is designed for applications where erosion and metal penetration are more severe.

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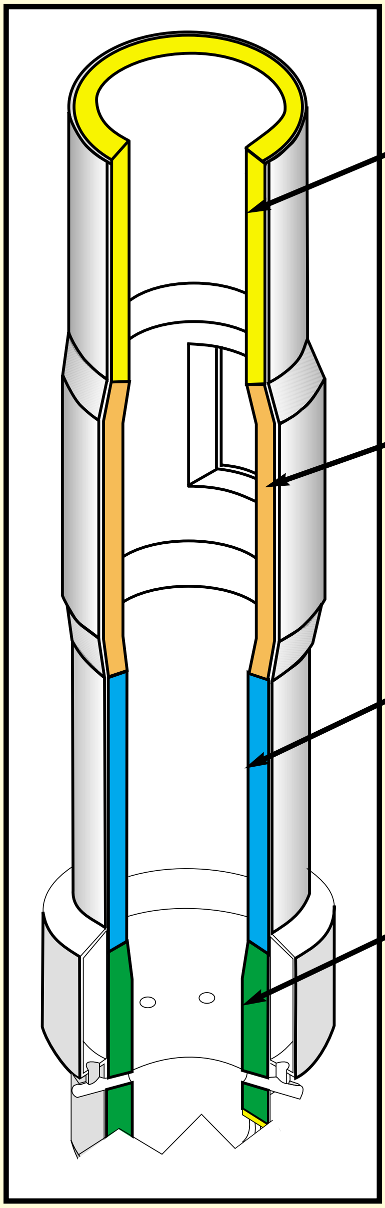
Cat# HW121R (1/03) 2C

CUPOLA Refractories

Upper Stack to Melt Zone

Harbison-Walker Refractories Company



UPPER STACK

Premium	*Work Horse & Maintenance*
UFALA®	**TUFSHOT® LI/OT**
KRUZITE®-70	**VERSAGUN® 50 ADTECH®**
CLIPPER® DP	**NARCO GUNCRETE AR**
VERSAGUN® 60, 70 ADTECH®	**KS-4V® GR PLUS**

CHARGE ZONE

Premium	*Work Horse & Maintenance*
TUFLINE® 90	**ALADIN® 80**
UFALA® XCR	**KRUZITE®-70**
UFALA®	**KX-99®**
	VERSAGUN® 50, 60, 70 ADTECH®

PREHEAT ZONE

Premium	*Work Horse & Maintenance*
TUFLINE® 90	**ALADIN® 80**
GREENAL®-80	**KRUZITE®-70**
ALADIN® 85	**KX-99®**
	VERSAGUN® 50, 60, 70 ADTECH®

MELT ZONE

Premium	*Work Horse & Maintenance*
KORUNDAL XD®	**ALADIN® 85/80**
TUFLINE® 90	**KRUZITE®-70**
DV-38	**NARCARB ZP PLASTIC**
	NARCOGUN BSC-DS

Service Conditions

CHARGE ZONE	*PREHEAT ZONE*	*MELT ZONE*
• Abrasion from Charging	• Abrasion from Charge Movement	• Slag Attack
• Thermal Shock	• Thermal Shock Reduced	• Metal Corrosion
• 600 - 2000 °F Temperature	• 2000 - 2400 °F Temperature	• 2000 - 3200 °F Temperature

BRICK

	KORUNDAL XD®	TUFLINE® 90	DV-38	ALADIN® 80	ALADIN® 85	UFALA® XCR	KRUZITE®-70	KX-99®	UFALA®
Bulk Density, lb/ft^3	186	182	179	170	172	159	165	143	157
Modulus of Rupture, lb/in^2									
At 70°F	2,330	1,730	3,400	1,610	1,700	2,200	1,700	2,200	2,640
At 2700°F	1,320	1,050	--	--	--	--	--	--	--
Apparent Porosity, %	16.1	17.6	14.0	19.5	20.0	14.1	18.7	12.0	14.3
Chemical Analysis: % (Approximate)									
Silica (SiO_2)	9.5	9.7	11.0	15.2	12.9	36.8	23.0	52.6	38.2
Alumina (Al_2O_3)	90.1	89.1	80.4	78.6	81.4	60.3	71.0	42.2	58.1
Titania (TiO_2)	Trace	0.6	2.5	3.4	3.3	1.3	3.4	2.3	2.2
Iron Oxide (Fe_2O_3)	0.1	0.3	1.3	1.8	1.6	1.1	1.6	1.4	1.2
Lime (CaO)	0.1	0.1	0.1	0.3	0.3	0.1	0.2	0.2	0.1
Magnesia (MgO)	Trace	Trace	0.1	0.3	0.2	0.1	0.2	0.3	0.1
Alkalies (Na_2O+K_2O)	0.2	0.2	0.2	0.4	0.3	0.3	0.6	0.9	0.1
Phosphorus Pentoxide (P_2O_5)	--	--	4.4	--	--	--	--	--	--

MONOLITHICS

	KS-4V® GR PLUS	NARCARB ZP PLASTIC	VERSAGUN® 50 ADTECH®	VERSAGUN® 60 ADTECH®	VERSAGUN® 70 ADTECH®	TUFSHOT® LT/OT	NARCO GUNCRETE AR	NARCOGUN BSC-DS
Bulk Density, lb/ft^3	120	169	143	151	153	127	132	146
Crushing Strength, lb/in^2, After 1500°F	1,500	--	7,720	7,670	7,700	3,340	7,300	2,600
Chemical Analysis: % (Approximate)								
Silica (SiO_2)	40.0	7.8	40.8	30.6	23.1	40.7	37.4	10.7
Alumina (Al_2O_3)	46.0	70.0	53.1	63.6	70.1	45.9	48.3	66.4
Titania (TiO_2)	3.2	1.5	1.8	1.7	2.0	2.4	1.3	0.4
Iron Oxide (Fe_2O_3)	1.5	0.7	0.6	0.7	0.9	0.9	1.2	1.1
Lime (CaO)	8.0	0.2	3.0	3.1	3.5	9.3	9.5	2.3
Magnesia (MgO)	0.4	0.3	0.2	0.2	0.2	0.4	0.4	0.1
Alkalies (Na_2O+K_2O)	0.9	0.3	0.5	0.1	0.2	0.4	0.3	0.1
Silicon Carbide + Carbon ($SiC+C$)	--	19.0	--	--	--	--	--	18.5

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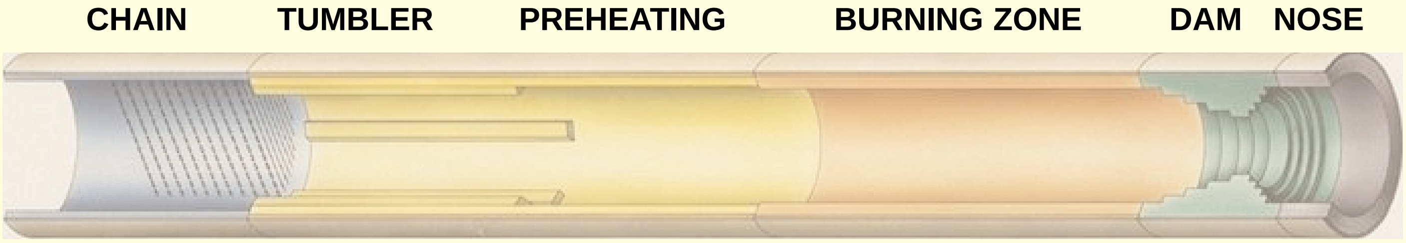
Cat# HW 117R (2/03) 3C

LIME
RECOVERY KILN

SECTIONS



	REFRACTORY ISSUES	SOLUTIONS	
CHAIN	Abrasion & Impact	LO-ABRADE GR MC-25® PLUS PNEUCRETE® BF ADTECH®	Gun Mix Castables Spray Mix
TUMBLER	Strength & Lining Stability	VERSAFLOW® 45 C ADTECH®	Precast
PREHEATING	Alkali & Insulation	GREENLITE® HS CLIPPER® DP	
BURNING ZONE	Temperature & Alkali	UFALA® KRUZITE® 70 MAGNEL® N/XT NOKROME® 92 LK MAGNEL® RS & RSV	
DAM	Strength & Abrasion	UFALA® VERSAFLOW® 60 PLUS	
NOSE	Volume Stability & Strength	NARPHOS 85P PLASTIC VERSAFLOW® 60 PLUS	

Three H-W burning zone refractories: (from left) UFALA, KRUZITE 70 and MAGNEL N/XT.

Harbison-Walker Refractories Company manufactures both high alumina and basic brick for burning zones of lime recovery kiln. UFALA is the industry standard for 60% alumina brick. It offers superior hot strength and alkali resistance compare to 70% alumina and other 60% alumina products. For kilns requiring basic brick, H-W has proven performance with the MAGNEL and NOKROME families of products.

BRICK	**MAGNEL® N/XT**	**NOKROME® 92 LK**	**MAGNEL® RS**	**MAGNEL® RSV**	**KRUZITE® -70**	**UFALA®**	**CLIPPER® DP**	**GREENLITE® -HS**
Bulk Densit,y lb/ft^3	183	182	186	187	165	157	142	75
Apparent Porosity, %	17.0	16.5	15.5	15.0	18.7	14.3	15.2	-
Crushing Strength, lb/in^2								
At 70°F	7,100	7,800	6,000	7,100	8,500	8,410	5,750	2,800
Modulus of Rupture, lb/in^2								
At 70°F	930	950	710	840	1,700	2,640	1,250	950
At 2300°F	870	1,500	920	1,100	--	2,135	--	--
Chemical Analysis: (Approximate) %								
(Calcined Basis)								
Silica (SiO_2)	2.3%	0.8%	0.4%	0.2%	23.0%	38.2%	52.6%	57.2
Alumina (Al_2O_3)	9.7	6.0	14.4	4.6	71.0	58.1	42.2	36.8
Titania (TiO_2)	0.2	--	0.3	0.1	3.3	2.2	2.3	1.8
Iron Oxide (Fe_2O_3)	0.9	0.4	0.3	0.2	1.6	1.2	1.4	1.6
Lime (CaO)	1.8	1.5	1.4	1.4	0.2	0.1	0.2	0.8
Magnesia (MgO)	85.1	91.4	83.2	88.4	0.2	0.1	0.3	0.4
Alkalies (Na_2O+K_2O)	--	--	--	--	0.6	0.1	0.9	1.4

MONOLITHIC	**LO-ABRADE GR**	**NARPHOS 85P PLASTIC**	**VERSAFLOW® 45C ADTECH®**	**PNEUCRETE® BF ADTECH®**	**MC-25 PLUS**
Maximum Service Temperature	2600°F	3150°F	2700°F	2800°F	2550°F
Approximate Amount Required As Installed (No Allowance for Rebound Loss) lb/ft^3	1127	171	132	133	125
Bulk Density lb/ft^3					
After Drying at 230°F	136	--	135	135	130
After Drying at 500°F	--	164	--	--	--
Modulus of Rupture lb/in^2 After 1500°F	1,150	980	1,410	1,310	350
Permanent Linear Change, % After Heating at 1500°F -0.2	-0.8	-0.3	-0.3	-0.2	
Chemical Analysis: (Approximate)%					
(Calcined Basis)					
Silica (SiO_2)	40.3%	11.0%	49.4%	50.8%	42.5%
Alumina (Al_2O_3)	49.0	80.0	44.6	43.6	42.5
Titania (TiO_2)	2.5	2.1	2.2	2.0	2.5
Iron Oxide (Fe_2O_3)	1.3	1.1	0.7	0.5	1.3
Lime (CaO)	6.0	0.1	2.4	2.1	6.0
Magnesia (MgO)	0.2	0.1	0.2	0.2	0.3
Alkalies (Na_2O+K_2O)	0.7	0.4	0.5	0.7	1.0
Phosphorous Pentoxide (P_2O_5)	--	2.7	--	--	--

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Cat# HW 104R (11/02) 3C

MAGSHOT®

Harbison-Walker Refractories Company

MAGSHOT® GUN MIX

Magnesite-based chrome-free gun mix, proven to give superior life in recovery boiler systems in pulp and paper mills.

- **Superior Smelt Resistance**
- **Chrome-Free Composition**
- **Good Thermal Conductivity**
- **Ease of Installation**
- **Proven Track Record**

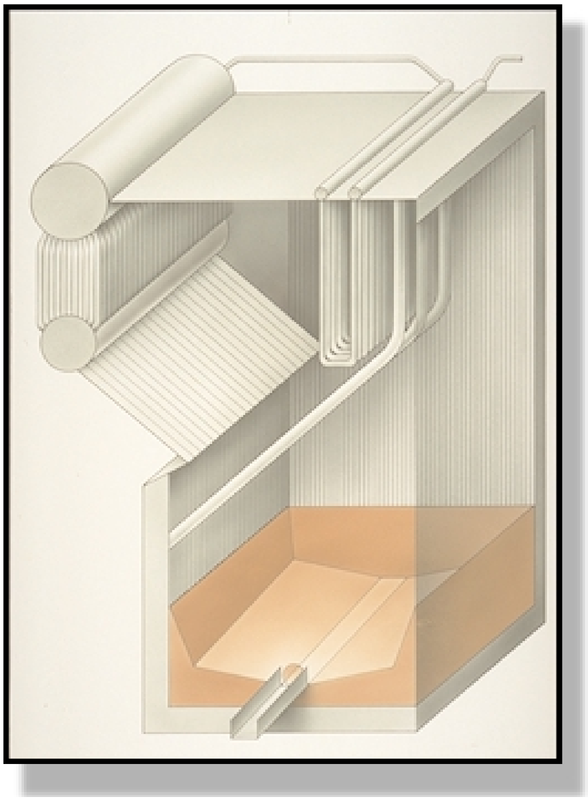
MAGSHOT was developed to help meet the environmental and performance needs of the pulp and paper industry. Its chrome-free composition eliminates concerns about disposal of possibly hazardous chrome-containing refractory waste. As for performance, laboratory tests have shown that this unique dicalcium silicate bonded magnesite product provides an exceptional level of chemical resistance to molten smelt.

A long record of success in numerous recovery boiler systems throughout the industry testifies to the durability of MAGSHOT where it matters most – under demanding field conditions.

Superior Smelt Resistance Demonstrated in Drip Slag Tests

Samples After Drip Test:

MAGSHOT Remarks: No Erosion, No Alteration, No Build-up	
Typical 80% Alumina-Phosphate Bonded Plastic Remarks: Eroded, Cracked, Bloated Slag Build-up	



MAGSHOT installed in the lower section of a recovery boiler.

Ease of Installation

Ease of installation makes **MAGSHOT®** the product of choice for quick-turnaround repairs. It can be gunned, hand-packed, or cast. For larger cast installations this product is available as **MAGSHOT® CASTABLE**. Both products require minimal curing time – heat-up (100°F/hr.) can begin two hours after installation. Other features include:

- **Low dust and rebounds**
- **Quick dry-out schedule**
- **Up to one year shelf life**

MAGSHOT

TECHNICAL DATA

	MAGSHOT®	MAGSHOT® CASTABLE
Physical Properties; (Typical)		
Maximum Service Temperature, ˚F	2700°F	2700°F
Bulk Density, pcf		
After 230°F	160	179
Modulus of Rupture, psi		
After 230°F	1,690	1,510
After 1500°F	1,560	1,480
Crushing Strength, psi		
After 230°F	5,870	10,100
After 1500°F	5,930	7,000
Chemical Analysis, % Approximate (Calcined Basis)		
Silica (SiO_2)	7.2	5.8
Alumina (Al_2O_3)	1.9	1.7
Titania (TiO_2)	0.1	0.1
Iron Oxide (Fe_2O_3)	5.8	10.0
Lime (CaO)	6.1	9.5
Magnesia (MgO)	76.7	68.7
Alkalies ($Na_2O + K_2O$)	0.7	1.2
Phosphorous Pentoxide (P_2O_5)	1.5	2.9

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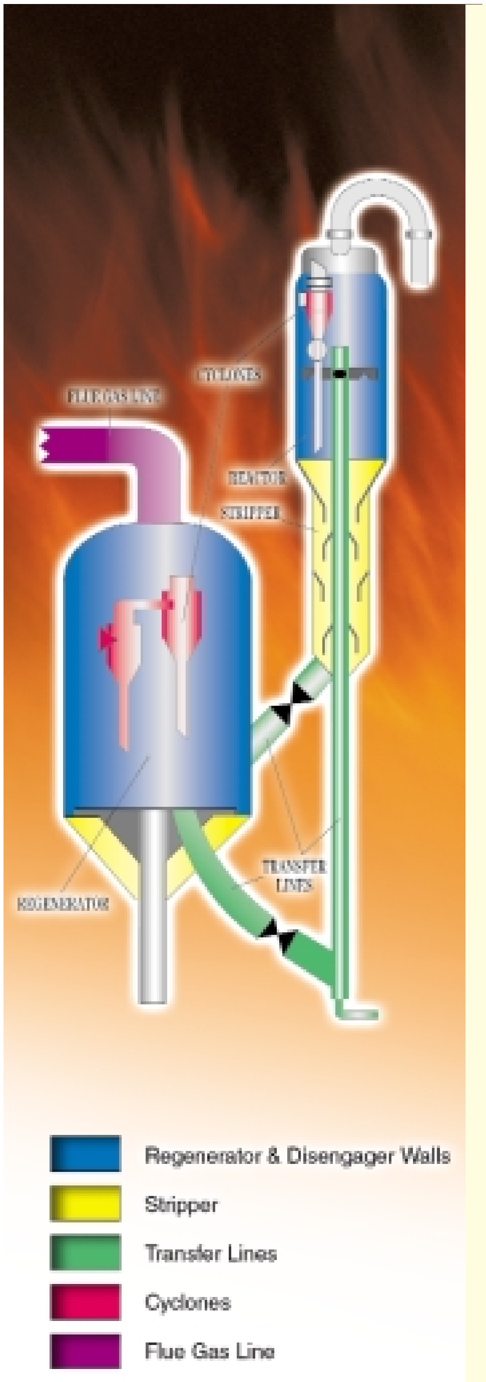
FLUID CATALYTIC CRACKING UNIT

Harbison-Walker Refractories Company

HW



REGENERATOR & REACTOR WALLS

Service Conditions:

- Relatively mild
- Reducing environment
- Coking

Solutions: Highest strength to density ratio with use of GREENLITE® aggregate for superior service with:

- Gun Mix – GREENLITE®-45L GR, KAST-O-LITE® 26 LI G, KAST-O-LITE® 23 ES, HPV GUN MIX
- Spraying – PNEULITE SPRAY 26

TRANSFER LINES

Service Conditions:

- Severe erosion and abrasion
- Coke penetration

Solutions:

High strength, low porosity castable with superior erosion and thermal shock resistance:

- Vibracast – GREENKLEEN-60 PLUS, VERSAFLOW® THERMAX® PLUS,
- Self Leveling Pumpable – EXPRESS®-27 Plus, COREX EXPRESS®, EXPRESS® THERMAX®
- Gun Mix – VERSAGUN® THERMAX®, HPV GUN MIX

STRIPPER

Service Conditions:

- Mild to moderate erosion

Solutions: Medium weight castables with superior strength:

- Gun Mix – GREENLITE®-45-L GR, LO-ABRADE® GR, KAST-O-LITE® 26 LI G, COREX GUN MIX, KAST-O-LITE® 23 ES, HPV GUN MIX
- Spraying – PNEULITE® SPRAY 26

CYCLONES

Service Conditions:

- Severe erosion and impingement

Solutions: High strength, phosphate bonded plastics or castables with excellent installation characteristics.

- CORAL PLASTIC® (28-82)
- GREENPAK-85-P
- EXCELERATE ABR PLUS

FLUE GAS LINES AND SEAL PO

Service Conditions:

- Thermal shock
- Chemical reaction
- Mild to moderate erosion

Solutions: Low iron, high strength castable providing volume stability with resistance to chemical attack:

- Self Leveling Pumpable – EXPRESS®-27 PLUS, EXPRESS® THERMAX®
- Gun Mix – LO-ABRADE® GR, GREENLITE®-45-L GR, COREX GUN MIX, VERSAGUN® THERMAX®, HPV GUN MIX

FLUID CATALYTIC CRACKING UNIT

TYPICAL DATA After 1500°F

	CORAL PLASTIC® (28-82)	GREENPAK 85-P	VERSAFLOW® THERMAX® PLUS	EXECELERATE ABR PLUS	VERSAGUN THERMAX® ADTECH™	COREX GUN MIX	COREX EXPRESS®	LO-ABRADE® GR	HPV GUN MIX
Type	Dense Severe Erosion Plastic	Dense Severe Erosion Plastic	Dense Mod. to Sev. Erosion Castable	Dense Mod. Erosion Gun/Castable	Med. Weight Mod. Erosion	Med. Weight Mod. Erosion Gun Mix	Med. Weight Mod. Erosion Self Leveling	Dense Mod. Erosion Gun Mix	Med. Weight Erosion Gun Mix
Density, pcf	169	183	126	172	120	100	116	127	110
Modulus of Rupture, psi	1,980	1,500	1,000	2,200	820	750	1,300	1,150	1,000
Crushing Strength, psi	8,000	–	11,800	14,950	5,190	4,100	8,900	6,500	6,200
Permanent Linear Change, %	-0.1	-0.2	-0.1	-0.3	-0.1	-0.3	0.2	-0.2	-0.3
C-704 Abrasion, cc:	3.1	5.1	7.8	4.0	15.0	19.0	12.0	12.0	12.0

	EXPRESS® 27-PLUS	PNEULITE™ SPRAY 26	KAST-O-LITE® 23 ES	KAST-O-LITE® 26 LI G	GREENLITE® 45-L GR	GREENKLEEN -60 PLUS	EXPRESS® THERMAX®
Type	Dense Mod. to Sev. Erosion Self-Leveling	Med. Wt. Insulation Spray	Med. Wt. Insulation Cast./Gun	Med. Wt. Insulation Gun Mix	Med. Wt. Insulation Gun Mix	Dense Severe Erosion Castable	Dense Mod. to Sev. Erosion Self-Leveling
Density, pcf	135	92	78/91	105	71	157	124
Modulus of Rupture, psi	1,200	–	300/480	500	350	2,000	1,000
Crushing Strength, psi	11,500	1,480	1,370/2,630	1,580	2,500	10,000	8,000
Permanent Linear Change, %	-0.2	-0.4	-0.2/-0.3	-0.2	-0.2	-0.2	-0.1
C-704 Abrasion, cc:	12.0	–	–	–	–	6.0	8.3

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Statements or suggestions concerning possible use of our products are made without representation or warranty that any such product is fit for such use or that such use is free of patent infringement of a third party. The suggested use assumes that all safety measures are taken by the user.

Names: KAST-O-LITE 23 ES (formerly H-W LIGHTWEIGHT ES REFRACTORY)
KAST-O-LITE 26 LI G (formerly H-W LIGHTWEIGHT GUN MIX 26)
GREENLITE 45 L GR (formerly GREENCAST 45-L-GR)

Harbison-Walker Refractories Company
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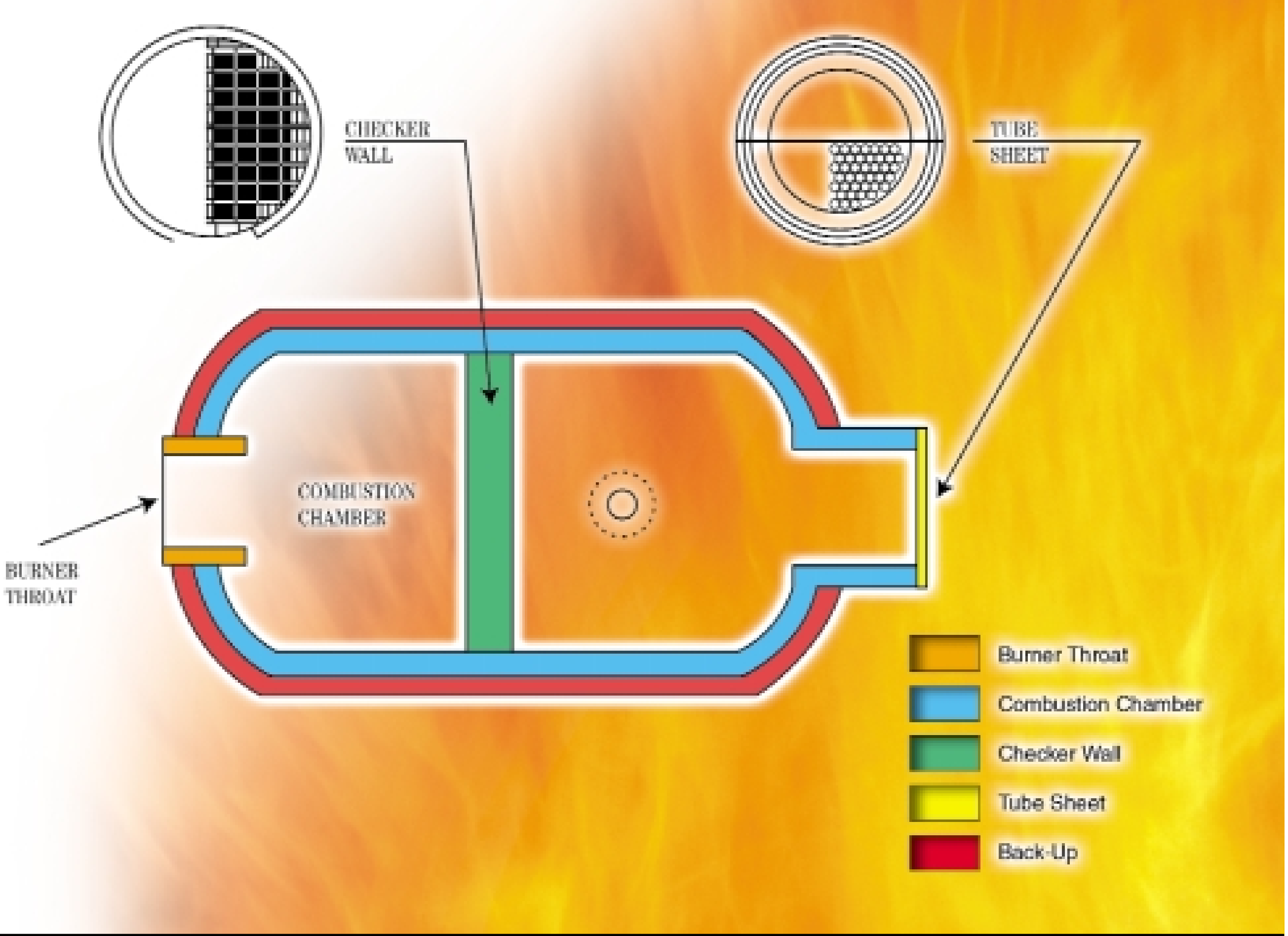
Cat# HW94R (11/02) 2C

THERMAL REACTOR

SULFUR RECOVERY UNIT

Harbison~Walker Refractories Company



		BURNER THROAT		COMBUSTION CHAMBER		CHECKER WALL	TUBE SHEET
SERVICE	**LOCATION**	**BRICK**	**MONOLITH**	**BRICK**	**MONOLITH**	**BRICK**	**MONOLITH**
Most Severe	**Hot-Face**	TUFLINE® 98 DM	NOVACON® 95	KORUNDAL XD®		KORUNDAL XD® DM H-W® CORUNDUM DM	NOVACON® 95
	Back-Up			G-3000 LI	KAST-O-LITE® 30 LI G		
Severe	**Hot-Face**	KORUNDAL® XD GREENAL-90	GREENPAK-90-P GREENCAST® 94 PLUS	KORUNDAL XD® GREENAL-90		KORUNDAL XD® GREENAL-90	GREENCAST®-94 PLUS
	Back-Up			G-28 LI G-3000 LI	KAST-O-LITE® 30 LI G		
Less Severe	**Hot-Face**	UFALA® UCR	GREENCAST®-94 PLUS GREENPAK-90-P	KRUZITE®-70	NOVACON® 95 GREENCAST®-94- GR PLUS	UFALA® UCR	GREENCAST®-94 PLUS GREENCAST®-94-GR PLUS
	Back-Up			G-28 LI	KAST-O-LITE® 26 LI G		

Notes:

1) Mortar for laying brick linings with KORUNDAL®, GREENAL and TUFLINE® SERIES BRICK, use KORUNDAL® BOND.
2) Most Severe = Oxygen Enrichment (up to 3,000˚F)
Severe = Higher Temperatures (2,400-2,700˚F)
Less Severe = Lower Temperatures (2,000-2,400˚F)

SULFUR RECOVERY UNIT THERMAL REACTOR

BRICK DATA

	TUFLINE® 98 DM	KORUNDAL XD® DM	KORUNDAL XD®	H-W CORUNDUM DM®	KRUZITE®-70
Bulk Density, lb/ft^3	210	195	186	208	165
Apparent Porosity, %	12.0	12.4	16.1	12.9	18.7
Modulus of Rupture, lb/in^2 — At 70˚F	2,760	3,840	2,330	4,500	1,700
Modulus of Rupture, lb/in2 **— At 2,700˚F**	1,080	1,930	1,320	–	–
Chemical Analysis % (Calcined Basis)					
Silica (SiO$_2$)	0.12	9.2	9.5	0.2	23.0
Alumina (Al$_2$O$_3$)	97.6	90.3	90.1	99.7	71.0
Titania (TiO$_2$)	0.05	Trace	Trace	Trace	3.4
Iron Oxide (Fe$_2$O$_3$)	0.09	0.1	0.1	0.1	1.6
Lime (CaO)	0.04	0.1	0.1	Trace	0.2
Magnesia (MgO)	0.16	0.1	Trace	Trace	0.2
Alkalies (Na$_2$O + K$_2$O)	-	0.2	0.2	–	0.6
Other Oxides	1.94	–	–	–	–

	GREENAL-90	UFALA® UCR	G-3000 LI	G-28 LI
Bulk Density, lb/ft^3	189	160	62	51
Apparent Porosity, %	13.0	14.1	-	-
Modulus of Rupture, lb/in^2 — At 70˚F	4,000	2,150	284	210
Modulus of Rupture, lb/in**2 — At 2,700˚F**	2,500	620	-	-
Chemical Analysis % (Calcined Basis)				
Silica (SiO$_2$)	7.7	36.1	25.1	51.3
Alumina (Al$_2$O$_3$)	90.0	62.3	73.4	45.0
Titania (TiO$_2$)	Trace	0.2	0.1	2.0
Iron Oxide (Fe$_2$O$_3$)	0.1	0.8	0.1	1.0
Lime (CaO)	0.1	0.1	Trace	0.3
Magnesia (MgO)	Trace	0.1	Trace	0.1
Alkalies (Na$_2$O + K$_2$O)	0.2	0.4	0.6	0.3
Phosphorus Pentoxide (P$_2$O$_5$)	1.9	–	–	–

MONOLITH DATA

	NOVACON® 95	GREENCAST®-94 GR	KAST-O-LITE® 26 LI G	KAST-O-LITE® 30 LI G	GREENCAST®-94	GREENPAK-90-P
Bulk Density, lb/ft^3 After Heating to 1,500˚F	185	158	105	99	163	195
Modulus of Rupture, lb/in^2 After Heating at 1,500˚F	2,630	1,000	500	375	1,750	2,600
Crushing Strength, lb/in^2 After Heating at 1,500˚F	9,280	6,070	1,580	1,750	9,500	10,000
Permanent Linear Change After Heating at 1,500˚F	0.0	0.0	-0.2	-0.1	0.0	–
Chemical Analysis % (Calcined Basis)						
Silica (SiO$_2$)	5.1	Trace	44.6	35.0	0.2	3.5
Alumina (Al$_2$O$_3$)	93.9	93.2	44.5	57.0	94.1	91.0
Titania (TiO$_2$)	<0.1	Trace	2.3	1.5	0.1	0.1
Iron Oxide (Fe$_2$O$_3$)	0.1	0.2	1.0	0.9	0.2	0.2
Lime (CaO)	0.1	6.4	6.4	4.7	5.1	0.1
Magnesia (MgO)	–	Trace	0.3	0.2	0.1	0.1
Alkalies (Na$_2$O + K$_2$O)	0.5	0.2	0.9	0.8	0.2	0.
Phosphorus Pentoxide (P$_2$O$_5$)	0.3	–	–	–	–	4.8

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Cat# HW170 (11/02) 2C

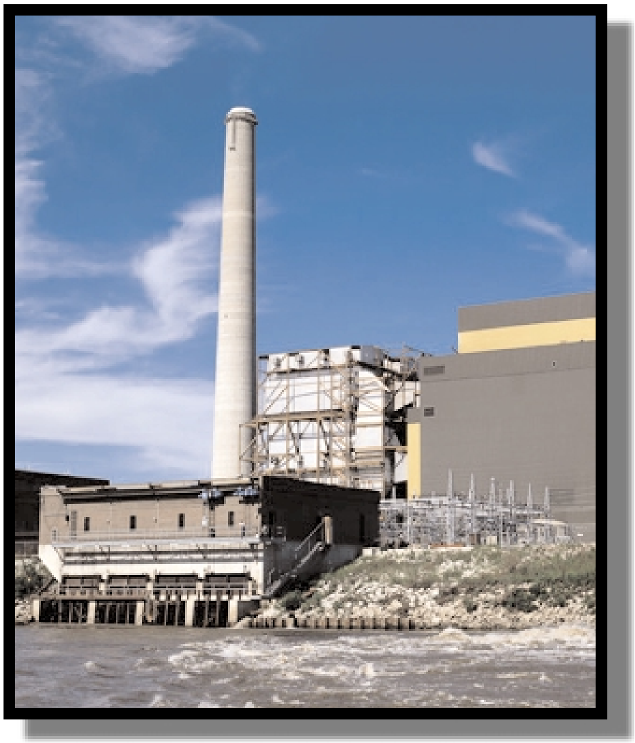
ASH HOPPER REFRACTORIES

Harbison-Walker Refractories Company

Ash-Hopper Service

Ash hopper service includes a number of conditions, which can be detrimental to a refractory lining. Refractories used in this service must show good resistance to a variety of destructive conditions.

- Airborne particulate generated during combustion can cause severely abrasive conditions.
- Slag can fall into the hopper in large chunks called "clinker". The impact of this clinker upon the refractory can be quite severe.
- In the case of wet-bottom ash hoppers, the splash generated by falling clinker can introduce severe thermal shock.
- Products installed in ash hoppers can be cast, gunned or sprayed.



	SERVICE CLASSIFICATION	INSTALLATION METHOD	IMPACT RESISTANCE	THERMAL SHOCK RESISTANCE	ABRASION RESISTANCE
TUFSHOT® LI/OT	Less Severe	Gun	Good	Fair	Fair
NARCO® GUNCRETE AR	Less Severe	Gun	Excellent	Good	Good
LO-ABRADE® GR PLUS	Severe	Gun	Excellent	Good	Good
VERSAFLOW® 45	Severe	Cast	Excellent	Fair	Good
PNEUCRETE® 45	Severe	Spray	Excellent	Fair	Good
VERSAFLOW® THERMAX®	Most Severe	Cast	Excellent	Excellent	Excellent
VERSAGUN® THERMAX®	Most Severe	Gun	Excellent	Excellent	Good
PNEUCRETE® THERMAX®	Most Severe	Spray	Excellent	Excellent	Good

Less Severe: Low impact, mild abrasion, and minimal thermal shock.
Severe: High impact, moderate abrasion and thermal shock.
Most Severe: High impact, severe abrasion and thermal shock.

ASH HOPPER REFRACTORIES

TECHNICAL DATA

	LESS SEVERE SERVICE		SEVERE SERVICE			MOST SEVERE SERVICE		
	TUFSHOT® LI/OT	NARCO® GUNCRETE AR	LO-ABRADE® GR PLUS	VERSAFLOW® 45	PNEUCRETE® 45	VERSAFLOW® THERMAX®	VERSAGUN® THERMAX®	PNEUCRETE® THERMAX®
Maximum Service Temperature,˚F	2600	2500	2600	2700	2700	2000	2000	2000
Density, pcf								
After Drying at 230˚F	127	132	136	136	131	126	126	125
Modulus of Rupture, psi								
After Drying at 230˚F	770	1,500	1,700	1,050	1,270	1,350	1,520	1,030
After Heating at 1500˚F	480	1,400	1,150	1,200	540	1,000	820	840
Crushing Strength, psi								
After Drying at 230˚F	3,620	8,600	10,000	8,500	6,260	10,500	6,180	5,560
After Heating at 1500˚F	3,340	7,300	6,500	5,000	4,800	7,600	5,190	5,620
C-704 Abrasion Test								
CC Loss After 1500˚F	–	12.0	12.0	–	16.0	7.8	15.0	10.0
Chemical Analysis, % (Approximate)								
Silica (SiO_2)	40.7	37.4	40.3	49.2	51.3	75.1	73.4	76.0
Alumina (Al_2O_3)	45.9	48.3	49.0	44.6	43.0	21.6	23.1	21.3
Titania (TiO_2)	2.4	1.3	2.5	2.2	2.0	0.5	0.2	0.5
Iron (Fe_2O_3)	0.9	1.2	1.3	0.7	0.8	0.3	0.1	0.1
Lime (CaO)	9.3	9.5	6.0	2.4	2.1	2.1	3.1	1.9
Magnesia (MgO)	0.4	0.4	0.2	0.2	0.2	0.1	–	0.1
Alkalies (Na_2O & K_2O)	0.4	0.3	0.7	0.5	0.6	0.3	0.1	0.1

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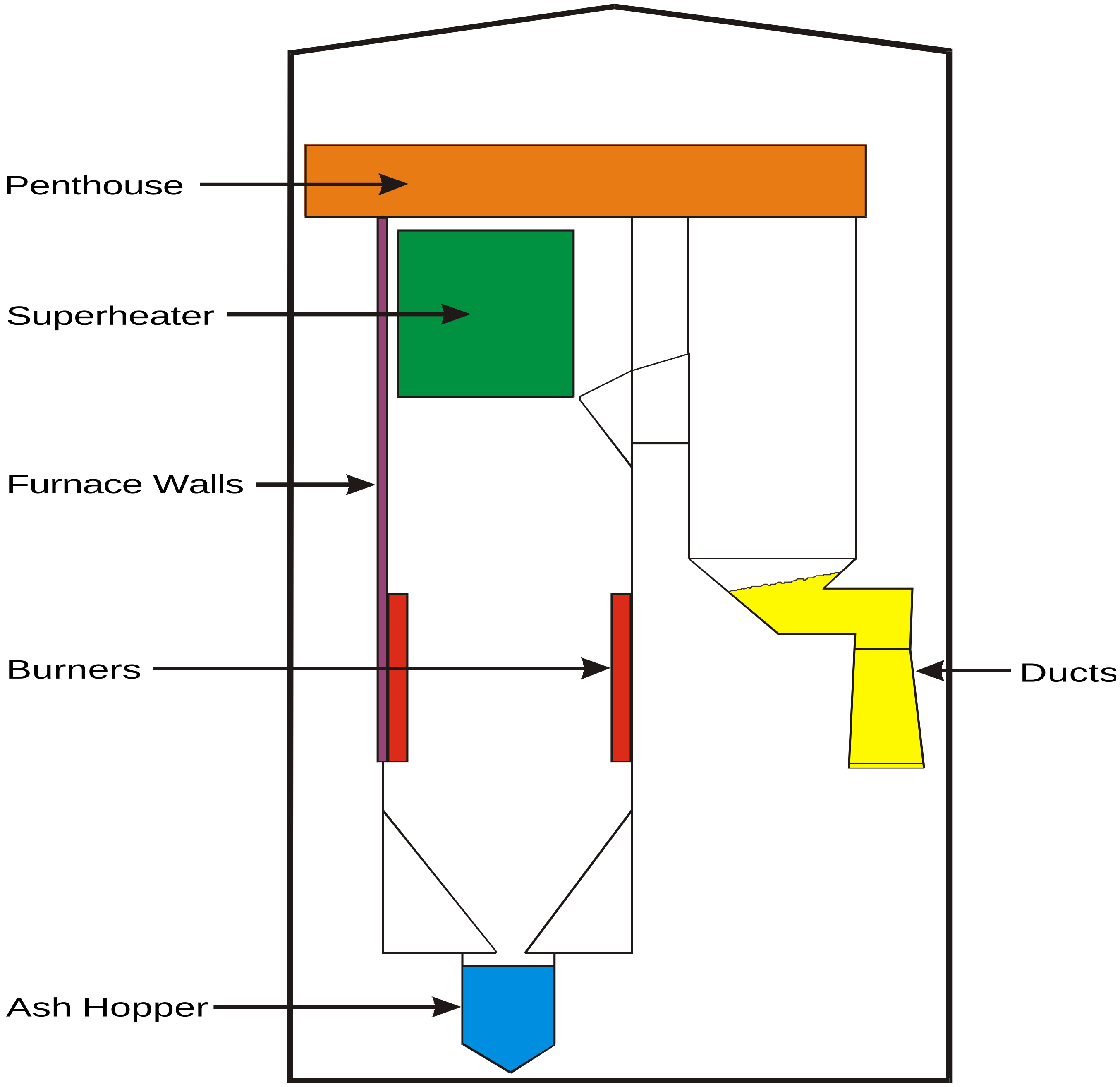
Cat# HW75R (12/03) 2C

Product / Application Update

Boiler Refractory Applications



Boiler Application Guide

		KAST-O-LITE 19-L	KAST-O-LITE 22	GREENLITE 22	GREENLITE 45 L GR	VERSAFLOW THERMAX	VERSAGUN THERMAX	PNEUCRETE THERMAX	COREX GUN MIX	NARCO GUNCRETE AR	LO-ABRADE	KS-4	TUFSHOT LI/OT	GREENCAST 94	THOR 80 ADTECH	NARCOGUN SiC-80 AR	MAGSHOT	GREENPAK 50-P	H-W BULL RAM PLASTIC	GREENPAK-90-P	ECLIPSE 60-P	ECLIPSE 70-P	ECLIPSE 80-P	GREENGUN ECLIPSE 73-P	RUBY PLASTIC	INSWOOL PUMPABLE	INSBOARD 2300	INSWOOL HP BLANKET	GREENPATCH 421	INSULATING CEMENT
Furnace Walls	Inside Casing & Tangent Wall Outside Casing	✓									✓	✓	✓													✓	✓	✓		✓
	Tangent Wall Inside Casing	✓	✓	✓	✓						✓	✓	✓					✓	✓									✓	✓	✓
	Opening Patch and Access Doors				✓						✓	✓	✓	✓				✓	✓								✓			
Penthouse	Floor	✓	✓	✓	✓																					✓				
	Headers, Tubes, Nipples																									✓		✓		✓
	Drum Head Insulation																									✓	✓	✓		✓
Ash Hopper	Lining					✓	✓	✓	✓	✓	✓	✓	✓					✓												
Ducts	Inside Lining	✓			✓	✓					✓	✓	✓						✓										✓	
	Outside Lining and Piping Insulation																										✓	✓		✓
Burners	Tangential and Front Fired													✓	✓	✓		✓	✓	✓	✓	✓	✓	✓	✓					
Special Applications	Slagging Bottom Boiler														✓	✓				✓	✓	✓	✓	✓	✓					
	Cyclone Boiler Studded Tubes														✓	✓				✓	✓	✓	✓	✓	✓					
	Baffles and Boiler Seals										✓	✓							✓							✓				
	Floors (Industrial Boilers)					✓											✓													
	Stoker Pier (Industrial Boilers)										✓	✓						✓	✓											
	Hearth (Recovery Boilers)																✓			✓										

CIRCULATING FLUIDIZED BED COMBUSTOR

CFB OPERATION

- Fuel to be burned is injected into the fluidized bed of inert media
- Efficient combustion at relatively low temperatures, avoiding the formation of harmful pollutants.
- Partly burned fuel and ash flow through the system to a cyclone separator
- Paticulates separate from the gas stream in the cyclone and re-circulate to the fluid-bed
- Hot gases escape from the cyclone and move down stream to various boilers, economizers, super-heaters, and other heat exchange equipment to create steam and electricity.
- The solids that return to the fluid-bed enjoy an effectively long residence time in the combust

CROSS-OVER DUCT

Service Conditions:

- thermal cycling potential
- zoning may be required

Solutions: volume stable, abrasion resistant gun mixes and phosphate bonded plastics
LO-ABRADE GR PLUS, VERSAGUN 60 ADTECH, NARMUL P

COMBUSTOR

Service Conditions:

- abrasion
- thermal cycling

Solutions: silicon carbide, high alumina phosphate bonded plastics
ECLIPSE PLASTICS, NARPHOS 85 P, NARCOGUN SIC 80AR

LOOP SEAL

Service Conditions:

- most severe abrasion
- media collection and return

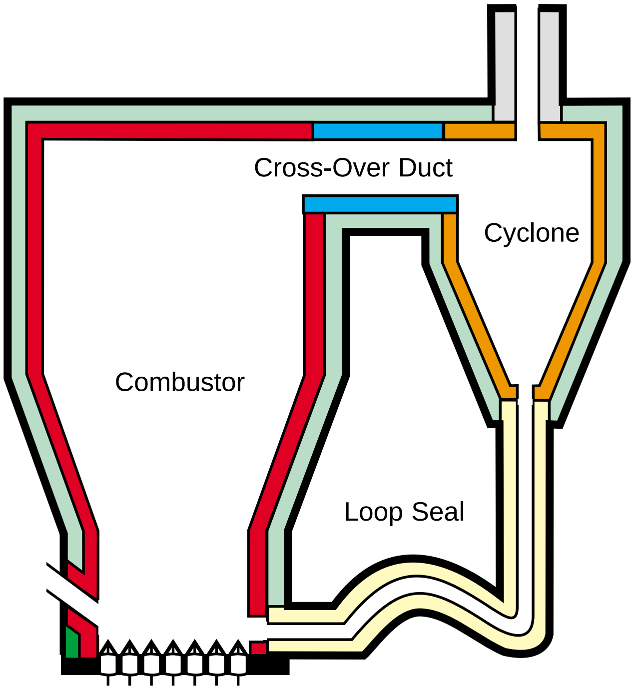
Solutions: vitreous silica to minimize thermal shock and withstand abrasion
THERMAX PRODUCTS

CYCLONE

Service Conditions:

- particulate removed from gas
- severe abrasion
- thermal shock

Solutions: volume stable, abrasion resistant brick and gun mixes
KX-99 BF, KALA, NIKE 60AR, VERSAGUN 60, GREFCON 70GR



REFRACTORY BLOCK
SLAG DAM

Harbison~Walker Refractories Company

RUBY® SR/C

Refractory Block Slag Dam.

In a continued effort to improve the life of their refractory around the slag tap of their boiler floors, Exelon Generation (formerly Commonwealth Edison) has designed and patented their "Refractory Block Slag Dam*."

Harbison Walker has been given the rights to make, manufacture and sell the dams.

Features:

- Improved slag flow characteristics and floor sintering
- Reduced floor repairs by extending floor life
- Reduce repairs of frozen slag taps
- Unit output increased based on reduction of planned unit outages, thus eliminating lost generation capacity

Slag Dams are made of RUBY® SR/C.

- High Density
- Low Porosity
- Shock Resistant
- Slag Resistant

The dams are made of 8 pieces that come together to form an Octagon.

The dams protect the tubes around the slag tap.

*The design is covered by U.S. Patent No. 5,800,775

RUBY® SR/C

Classification: Spall Resistant Chrome - Alumina Vib-Cast/Fired Shapes

Bulk Density:	204 /b/ft^3
Apparent Porosity, %:	15.5
Modulus of Rupture:	
At 70°F (21°C)	12,900 lb/in^2
Crushing Strength:	
At 70°F (21°C)	1,360 lb/in^2

Chemical Analysis: (Approximate)
(Calcined Basis)

Silica	(SiO_2)	1.9%
Alumina	(Al_2O_3)	83.1
Titania	(TiO_2)	0.1
Iron Oxide	(Fe_2O_3)	0.1
Lime	(CaO)	0.1
Magnesia	(MgO)	Trace
Chromic Oxide	(Cr_2O_3)	11.1
Alkalies	(Na_2O+K_2O)	0.2
Other Oxides		3.5

This design is covered by U.S. Patent No. 5,800,775

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The **ANH** Refractories Family of Compaines

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