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Research Article

EXPLORING CERAMIC REFRACTORY MATERIALS: CLASSIFICATION AND TECHNOLOGICAL INNOVATIONS

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ABSTRACT

The article explores the primary types of ceramic refractory materials, focusing on their properties and applications in high-temperature industrial processes. Key technological advancements in refractory manufacturing are discussed, with an emphasis on enhancing material strength, chemical resistance, and durability. The analysis highlights the specific characteristics of each refractory type, including fireclay, magnesite, corundum, and silicon carbide, and their utilization across various industries such as metallurgy, energy, and glass production. Modern production and modification methods for refractories are presented, aimed at improving thermal resistance and reducing the operational costs of equipment.

KEYWORDS

Dolomite, chromium, quartz or dinas, corundum, magnesia, exothermic synthesis, binder, fire resistance, heat resistance, mullite, fireclay brick.

INTRODUCTION

Modern science knows many outstanding scientists, physical chemists, metal physicists, and ceramists, whose fundamental works laid the foundation of modern materials science in the 20th century. These researchers include P.P. Budnikov, S.G. Tresvyatsky, A.S. Berezhnoy - the

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founders of the scientific school in the field of physical chemistry of oxide ceramics and silicate materials; Grozin, V.I. Trefilov, who developed the foundations of physical mechanics and physics of strength of materials; B.Ya. Pines, S.D. Hertzricken, Ya.E. Yaguzin, M.A. Krivoglaz, L.N. Larikov - the creators of modern concepts of defects and diffusion processes in solids. This is far from a complete list of outstanding scientists, whose contribution to modern materials science is invaluable [1-7].

The theoretical foundations of the production of refractory materials were first outlined by Academician A. A. Baikov, who considered the process of converting a powder mass into a solid crystalline aggregate as a process of recrystallization of refractory material in the liquid phase at a certain temperature [8,9].

In its basic features, this process is similar to the process of hardening cement mixed with water. Therefore, refractory materials can be called "high-temperature cements", and finished refractory products made from them - "high-temperature concretes" [10].

In the production of refractory products, a mass consisting of a refractory of a certain chemical composition and a binder is subjected to moulding, drying and firing [11].

During the moulding process, the product is given a given shape using special moulding presses.

During drying, excess moisture is removed and the product acquires some initial strength [12].

The firing process can be divided into three periods:

– During the first period, the temperature gradually rises to a certain fairly high level, determined by the chemical and mineralogical composition of the mass;

– in the second period, which is quite long, the temperature is maintained at a given level;

– In the third period, the temperature drops to normal, and the fired products cool.

The second period is of the greatest importance for the quality of the product. At the beginning, the fired product is a mass consisting of individual grains or granules of refractory material, impregnated and moistened with a small amount of melt. This liquid phase was formed by the interaction of the main oxide, which is a refractory material, with all the impurities present in the mass. The amount of melt formed depends on the temperature and the amount of impurities, and the higher the firing temperature in the second period and the more impurities, the more melt is formed. As a result of recrystallization in the melt at the end of the second period, solid particles form a dense crystalline intergrowth. In this case, the mass loses its friability and acquires mechanical strength. This transformation occurs at a constant temperature (which is lower than the melting point of the refractory) by recrystallization of the refractory material in a small amount of liquid phase [13, 14].

The degree of dissolution of the main oxide in the melt, and consequently the completeness of its recrystallization, depends on the degree of crushing of the original material, since with a decrease in grain size their solubility increases.

A solid with a regular crystal lattice has a lower solubility than a solid with a deformed lattice. Deformation of the crystal lattice can occur during firing either as a result of a polymorphic transformation accompanied by a significant change in volume or as a result of the decomposition of a chemical compound included in the composition of the original material [15].

The conditions that must be met to obtain high-quality refractory products are as follows:

– the presence in the batch of such impurities with which the refractory material can produce a melt and can dissolve in it;

– firing at a temperature that ensures the formation of the required amount of melt;

– holding at the firing temperature for a time sufficient to complete the recrystallization process.

The raw materials for the production of refractory types of brick products are mainly rocks with a fire resistance of at least 1580 °C, as well as finely ground defective products, unshaped materials, and waste returned to the technological process.

Various technologies and processes are used to manufacture refractories. The predominant technology includes preliminary, heat treatment and grinding of components, preparation of batches with the addition of plasticized components, moulding of products from them by pressing on mechanical and hydraulic presses or extrusion with subsequent additional pressing or casting, firing in the tunnel, less often in periodic and gas chamber furnaces to obtain the specified properties of the material [16].

The operational properties of refractory materials are determined by a complex of chemical, physicochemical and mechanical properties.

The main property of refractory products is fire resistance, i.e. the ability of the product to withstand high temperatures without melting. Fire resistance is characterized by the temperature at which a standard sample of the material in the form of a triangular truncated pyramid 30 mm high and with base sides of 8 and 2 mm (Zeiger cone) softens and deforms so that its apex touches the base [17]. The temperature determined in this way is usually higher than the maximum permissible operating temperature of refractory materials.

A distinction is made between:

– refractory materials proper (refractory 1580-1770 °C);

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– highly refractory (1770-2000 °C);

– materials with high fire resistance (above 2000 °C).

Refractories can be of general purpose and for the determination of thermal units and devices, for example, blast furnaces, high-temperature furnaces, etc., which is indicated in the regulatory and technical documentation.

Classification by shape:

- straight.

- trapezoidal, wedge-shaped, arched– used for laying out arched openings and vaults).

- shaped– found application in finishing works.

- suspended– also go to internal vaults, but already in powerful industrial furnaces.

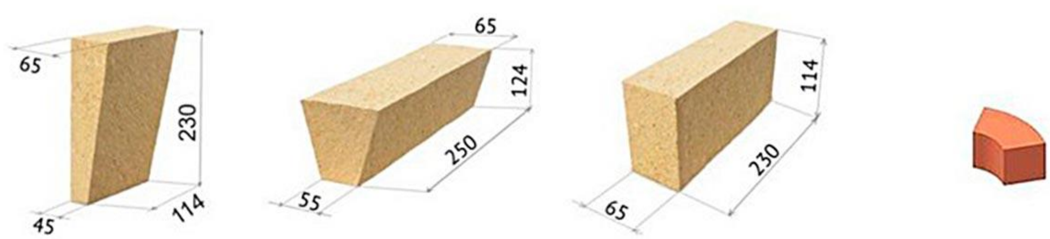

Fig. 1.

Average operating temperature is an important characteristic when choosing a brick for devices with a long operating cycle.

Thermal inertia is the ability to heat up quickly and cool down slowly.

Heat capacity is the ability to accumulate thermal energy for subsequent transfer.

Their main technical characteristics include:

Heat resistance, heat resistance, as this important parameter determines the range of application of a particular type of firebrick. For example, for laying a domestic heating stove or constructing a steel-making unit with oxygen blasting, different types of bricks will be required.

Low thermal conductivity coefficient, which prevents the outer surfaces of heating equipment from heating up to critical temperatures.

Resistance to sudden strong heating, low coefficient of linear, volumetric expansion, which ensures the strength and integrity of the masonry made of fireproof bricks.

Resistance to aggressive environments - from acids to alkalis, as well as to radiation, which allows the use of brick refractories not only in the construction of furnaces - from household to thermal power plant boilers, but also in the

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creation of apparatus, chemical industry installations, and nuclear power plant reactors.

Refractories for glass furnaces. Glass furnaces operate at critical temperatures, according to technical standards, special grades of refractory materials are used for laying instead of bricks, and the glass industry also uses ceramic products. Such materials withstand critical heating and retain strength, providing the frame with the necessary rigidity. The lining is used as a facing, which protects the walls from mechanical and chemical damage.

Features of refractories for glass furnaces. The following types of refractories are used for glass melting:

– Dinas - suitable for constructing furnace vaults and decorating upper segments;

– magnesite;

– aluminosilicate;

– baddeleyite-corundum.

To produce quality glass, reliable furnaces are required, in which a constant melting temperature can be maintained. Under such conditions, the mass will completely melt and form a homogeneous substance without inclusions. Such furnaces must be hermetically sealed, reliable and made of heat-resistant materials. The choice of refractories is the most important factor in creating a glass furnace since the service life of the furnace directly depends on the quality of the refractory. While refractory selection, important factors should be taken into account:

- heat resistance;

- stability at high temperatures;

- thermal resistance;

- thermal expansion;

- thermal conductivity;

- mechanical strength;

- corrosion resistance.

Aluminium oxide, zirconium dioxide, and silicon dioxide are the main structural refractory materials for glass furnaces primarily because it is not so easily wetted by molten glass, and because of their low reaction with them. Fused alumina jargal, zirconium oxide, zirconium oxide-mullite, silicon dioxide, magnesium oxide, sillimanite, fireclay refractory brick, refractory mortar, rammed refractory mixtures and many other refractory products are used for glass furnaces. Zirconium-containing products are also used, which are used to separate dissimilar materials to eliminate the reaction between them. A furnace designed on this principle will work for a long time without breakdowns and provide the plant with high-quality products.

Refractory materials– products based on mineral raw materials, distinguished by their ability to retain their properties under operating conditions at high temperatures, and which serve as structural materials and protective coatings.

Raw materials for refractory materials are simple and complex oxides (e.g. SiO_2, Al_2O_3, MgO, ZrO_2, MgO-SiO_2), oxygen-free compounds (e.g. graphite, nitrides, carbides, borides, silicides), as well as oxynitrides, oxycarbides, sialons.

Dinas, operating at maximum operating temperatures of up to 1730 °C.Dinas is a refractory material made from quartzite or quartz rocks and containing at least 93% SiO_2. They are used for lining industrial heating units.

Fig. 2. Dinas refractory brick

Corundum (silicon carbide - obtained by calcining in an electric furnace a mixture of pure quartz sand with petroleum coke or anthracite and table salt, fire resistance up to 2000°C) - used in installations designed to produce sulfuric acid, furnaces with an oxidizing environment.

Fig. 3. Corundum-zirconium-mullite

Magnesite, (The raw material for the production of magnesite refractories is the mineral magnesite $MgCO_3$, which contains 90% or more MgO)withstands long-term heating up to 1900°C, has high mechanical strength, including abrasion resistance, therefore it is widely used in metallurgy.

Fig. 4. Magnesite refractory brick

Zirconium - made from the mineral baddeleyite (containing 80-99% ZrO_2 and up to 20% other impurities), with fire resistance up to 2500 °C.

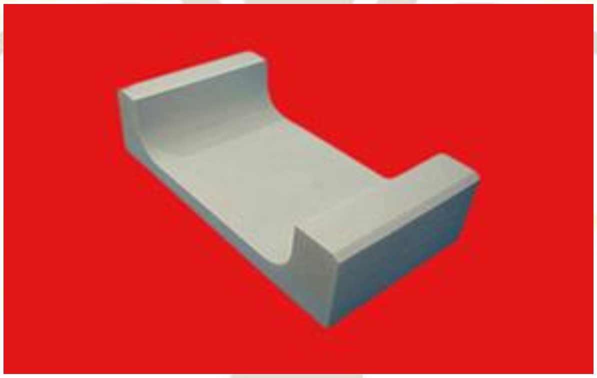

Fig. 5. Zirconium refractory brick

Carbon or graphite, is created based on free carbon. The fire resistance of such individual products, obtained by firing up to 2000 °C of a charge of coal tar with graphite, is simply enormous - up to 3500 °C, so it is not surprising that they are in demand for lining smelting furnaces in metallurgy, at energy enterprises, including nuclear power plants.

Dolomite refractories are made from the mineral dolomite, which in its pure form is a double carbonate of magnesium and calcium ($MgCO_3 \bullet CaCO_3$). They have a fairly high fire resistance up to 1780-1800 °C.

Chromium is made from chromite rock. It is inert to acidic and alkaline environments, including the effects of slags formed during the welding of metal alloys. The maximum operating temperature is 1850 °C.

The main, as alumina fireclay brick is often called, as it is the longest-produced, proven type of individual refractory product. An important factor is also the cost of its acquisition, which costs customers less than other types of this refractory. Fireclay brick is the main furnace material in civil engineering, and municipal infrastructure of populated areas, including boiler houses, and thermal power plants.

The purpose of fireclay bricks is determined by their markings:

SHA, SHB, SHAK - universal material, used most often for laying fireplaces and stoves. Products of this type are characterized by an optimal price-quality ratio.

ШКУ - kosher brick, used for lining cast iron ladles. The most famous brands are ШКУ-32, 37, 39.

SHUS, SHV - has the highest heat capacity, due to which it is used mainly for lining the walls of convection shafts and steam generator flues.

SHAV - purpose: the lining of cupola furnaces.

ShPD - necessary for laying blast furnaces and kilns.

ШК - used mainly in coke production.

ШЛ is a lightweight material for lining furnaces operating at temperatures not exceeding 1300 °C.

ШЦУ - end double-sided products intended for laying rotary kilns.

PV and PB are intended mainly for the construction of chimneys, barbecues and grills.

The values following the letter are necessary for dividing the products by size. For example, the straight product Ш-5 has dimensions of 230x114x65, the end product Ш-22 - 230x114x55, and the ribbed product Ш-45 - 220x114x45 mm.

Brand	Dimensions, mm	Brand	Dimensions, mm
SHA-5	230x114x65	ШБ-22	230x114x65/55
SHA-6	230x114x40	ШБ-23	230x114x65/45
SHA-8	250x124x65	ШБ-25	250x114x65/55
ШБ-5	230x114x65	SB-29, 30	300x150x65/55 (65/45)
ШБ-8	250x124x65	SHA-22	230x114x65/55
SL-5	230x114x65	SHA-23	230x114x65/45
ШЛ-8	250x124x65	SHA-25	230x114x65/45
PB-5	230x114x65	SHA-29. SHA-30	300x150x65/55

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