

The Application of Aluminum Fiber in Refractories



The application of aluminum fibers in refractory materials primarily serves as a reinforcement and toughening agent. Through unique physical and chemical interactions, it significantly enhances the performance of traditional refractory materials, particularly in terms of thermal shock resistance, spalling resistance, mechanical strength, and erosion resistance. Below is a detailed explanation of its core mechanisms, application methods, and specific advantages:

1. Core Mechanism of Action

Physical toughening (fiber reinforcement mechanism)

Bridge connection and crack deflection:

When microcracks occur inside refractory materials, uniformly dispersed aluminum fibers can span both sides of the crack, acting as a "bridge" to prevent further crack propagation. At the same time, cracks will deflect when encountering fibers, consuming more energy, thereby improving the material's fracture toughness and impact resistance.



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Pull out effect:

Even if the crack propagation causes the fiber to detach from the matrix, pulling the fiber out of the matrix requires additional energy, which further enhances the toughness of the material.

Chemical strengthening (in-situ reaction to generate new phase):

This is the most distinctive advantage of aluminum fiber. In high-temperature environments (usually above 500°C), metal aluminum fibers will react with oxygen in the air to generate high melting point alpha alumina (Al_2O_3) in situ.

This reaction process is accompanied by slight volume expansion, which helps to bridge the micropores and microcracks generated during sintering or use of the material, making the material structure denser.

The newly generated alumina microcrystals or networks are firmly combined with the original refractory matrix (such as corundum, mullite, etc.) to form an "embedded" ceramic reinforcement network, greatly improving the high-temperature strength, wear resistance, and corrosion resistance of the material.

2. Typical application areas include:

Steel and metallurgical industry:

Steel ladle and intermediate ladle impact zone: withstand severe erosion and thermal shock of molten steel, aluminum fiber reinforcement can significantly improve the anti-stripping life of the lining. Blast furnace tapping groove and torpedo tank: resistant to molten iron, slag erosion, and thermal shock. Heating furnace and homogenization furnace lining: especially for parts that require frequent start stop or sudden temperature changes.

Cement industry:

High wear and high heat impact areas such as kiln mouth protection iron, coal injection pipe, grate cooler, etc.

Petrochemical industry:

The cyclone separator and regenerator lining of the catalytic cracking unit (FCC) resist high-speed flushing and thermal cycling of catalyst particles.

Ceramic industry:



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Components such as kiln car bricks and kiln furniture that require good thermal shock resistance.

3. Summary of Key Advantages:

Excellent thermal shock resistance:

The fiber toughening mechanism can effectively suppress the generation and propagation of cracks, making the material less prone to cracking and peeling under rapid cooling and heating conditions.

Excellent high-temperature strength:

The in-situ generated alumina network provides long-lasting high-temperature structural support.

Improving corrosion resistance:

The compacted structure after reaction can better resist the infiltration and erosion of slag and molten metal.

Improving the integrity of the construction body:

The addition of fibers can improve the plasticity of the construction body before sintering, reducing the occurrence of cracks during construction and baking processes.

Extending service life:

The improvement of comprehensive performance directly leads to the extension of the service life of refractory lining, reducing the number of kiln shutdowns and maintenance, and improving the operation rate of industrial furnaces.

4. Precautions for use

Uniformity of dispersion:

It is crucial to ensure that aluminum fibers are evenly dispersed in the mixture, otherwise weak points may occur. It is usually necessary to use a forced mixer and mix it with appropriate dispersants.

Oxidation control:

During the material baking stage, it is necessary to control the heating rate to ensure smooth oxidation of aluminum fibers and avoid structural damage caused by intense oxidation heat release.

Cost considerations:

Aluminum fiber is a high value-added additive, and an optimal addition amount (commonly ranging from 0.5% to 3% according to weight of refractories) is usually determined based on the performance requirements of the specific usage site to balance performance and cost.

5. Summary



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Metal aluminum fibers play the role of "intelligent strengthening phase" in refractory materials. It not only physically toughens the material through fiber morphology, but also permanently strengthens the material matrix through in-situ chemical reactions in high-temperature service environments, both chemically and microscopically. This dual enhancement mechanism makes it an effective and advanced technological means to improve the performance of refractory materials used in key high-temperature equipment, especially to solve the industry problem of thermal shock resistance.

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What refractories are used for the impact zones of steel ladles and tundish?

The impact zone of the ladle and tundish is one of the most demanding service conditions for refractory materials in metallurgical processes, which is subjected to severe erosion, thermal shock, and chemical corrosion of high-temperature molten steel (about 1550-1650°C) and slag. Therefore, the refractory materials used in these areas must have extremely high corrosion resistance, thermal shock resistance, and high temperature strength.

The following are the commonly used types of refractory materials and their characteristics in these two regions:

1. Steel Ladle Impact Zone

The impact zone of the ladle directly bears the violent impact of the steel water column and the prolonged immersion of high-temperature molten steel during the steelmaking process.

Mainstream materials:

aluminum magnesium (carbon) castables/prefabricated blocks

Material: High purity fused alumina ($Al_2O_3 \geq 90\%$) or special grade alumina clinker is used as aggregate, and magnesium sand (MgO) fine powder and micro powder are added. Sometimes a small amount of graphite (C) is added to improve slag resistance.

Key mechanism:

At high temperatures, Al_2O_3 reacts in situ with MgO to form magnesium aluminum spinel ($MgAl_2O_4$). This reaction is accompanied by moderate volume expansion, which can make the lining structure denser at high temperatures and effectively resist the infiltration of molten steel and slag.

Form: Mostly cast as a whole or using prefabricated impact blocks. Prefabricated blocks are pre baked, with stable performance and quick installation, which can effectively reduce the baking risk caused by on-site construction moisture.

Enhancement technology:

Stainless steel fibers or the aforementioned metal aluminum fibers are often added to the casting material to further improve thermal shock resistance and peel resistance.

High performance material:

magnesia carbon brick



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Material: Made mainly of high-purity fused magnesia (MgO) and high-quality flake graphite (C), combined with phenolic resin.

Advantages:

Graphite has excellent thermal conductivity (facilitating uniform heat distribution and reducing thermal stress) and is not easily wetted by slag, making it highly resistant to slag erosion and infiltration.

Application scenario:

Commonly used in steel ladles with high requirements for clean steel and particularly severe slag line erosion, or as an integrated lining material for the impact zone and slag line zone of the ladle. Usually used in conjunction with antioxidants (such as metal powders of Al, Si, Mg, etc.) to inhibit the oxidation of graphite at high temperatures.

Other materials:

Spiny stone castable/brick:

using pre synthesized magnesium aluminum spinel ($MgAl_2O_4$) as raw material. Due to the pre formation of spinel, volume changes caused by in-situ reactions during use are avoided, resulting in better high-temperature volume stability and good slag erosion resistance, but the cost is relatively high.

2. Tundish Impact Zone

The impact zone of the tundish is subjected to the impact of molten steel flowing out from the long water outlet of the ladle, and its thermal shock conditions are more severe (temperature difference of molten steel, intermittent pouring), but the slag erosion is relatively lighter than that of the ladle. The core requirements are thermal shock resistance, erosion resistance, and ease of cleaning and maintenance.

Mainstream materials:

high-strength magnesia or magnesia calcium refractory materials

Magnesium impact plate:

The main component is sintered magnesia (MgO), which has excellent resistance to steel erosion and alkaline slag erosion. It is currently the most widely used impact zone refractory material.



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Magnesium calcium impact plate:

Introducing calcium oxide (CaO) on the basis of magnesium material, it has the function of purifying molten steel (adsorbing impurities such as Al_2O_3 , S, P, etc. in molten steel), especially suitable for producing clean steel and high-quality special steel

Form: Usually prefabricated into standardized sized impact plates (or slag barriers), installed inside the intermediate package. The service life is one or several times of pouring and needs to be replaced regularly.

High performance/special requirements materials:

Zirconium (ZrO_2) impact plate:

It has extremely high high-temperature strength and excellent corrosion resistance, especially strong resistance to acidic slag. Commonly used for harsh conditions such as continuous casting of special steel and high oxygen steel, but the cost is very expensive.

Integral casting material:

Some intermediate packages use integral working lining, and the impact zone also uses corundum spinel or magnesium casting material with good thermal shock resistance for integral casting, and adds thermal shock resistant fiber reinforcement.

Magnesium olivine stone:

It has certain thermal shock resistance and cost advantages, and is also used in some occasions.

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