REFRACTORY MATERIALS FOR STEEL-MAKING EQUIPMENT LINING

Margarita A. Goncharova, Olga V. Karaseva, Sergey V. Maklakov, Konstantin V. Bakhaev

Lipetsk State Technical University
30 Moskovskaya, Lipetsk 398055, Russian Federation
E-mail: kaf-st@stu.lipetsk.ru

ABSTRACT

The possibilities of using metal waste for the production of refractory concretes operating at the temperature of 1300°C are theoretically proved and practically confirmed in this paper. Solving the problem of using technogenic raw materials contributes to improving the environment of the metallurgical enterprise industrial zone.

The developed compositions may be used in the production of custom concretes and structures of thermal units exposed to prolonged high temperatures and their sudden changes. Designs of insulating caps of steel teeming ladles and lances for blowing gases are developed. The performance of these products under current production conditions is experimentally studied.

Keywords: refractory concrete, metallurgical waste, nano-additives, crushed refractories, reset strength after firing, heat resistance.

INTRODUCTION

The problem of developing heat-resistant materials using technogenic raw materials is becoming more urgent in regions with a developed metallurgical industry. Tons of wastes are formed at modern metallurgical enterprises. Nowadays the problem of using this waste is most relevant because a large territory is required to store it, the environmental conditions are violated, and money is allocated for storage organization and maintenance. Meanwhile, the waste has already been subjected to high temperature treatment and does not contain any organic impurities. Therefore it can be an excellent material for the construction industry.

At present, refractory concrete with a high Portland cement content is used in the construction of industrial facilities because of its increased initial strength (after drying). At the same time, hydrated Portland clinker minerals are known to contribute to sharp strength drop after firing at 800°C. This is in contradiction with modern normative documents, according which the residual strength after calcination at this temperature must not exceed 30 %. Otherwise, the bearing capacity of concrete structures is significantly reduced. Besides, a significant shrinkage of refractory concrete and susceptibility to cracking increase under such conditions.

The operating conditions of steelmaking equipment (insulating caps of steel teeming ladles, fast warm-up stands, lances for blowing molten steel with oxygen and argon in steel making) predetermine fast performance loss. In this regard, increasing the durability of steelmaking products with the simultaneous application of metal waste for their manufacture is a relevant technical and economic problem [1, 2]. Its solution treats simultaneously another important problem – that of creating waste-free production at any metallurgical enterprise [3].

The analysis of the existing technology of producing steel-making equipment shows that its lining is performed manually by means of refractory small-piece products. In this process, expensive imported refractory masses are used, which do not provide sufficient durability of these thermal units due to the presence of seams. That is, it is more expedient to use refractory concrete of a monolithic structure as lining.

Refractory concrete compositions based on fillers from crushed fireclay and high-alumina refractories cleaned from metal and slag impurities, as well as nano-additives made from fillers are developed at the Department of construction materials and road technologies of Lipetsk State Technical University. Crushed refractories obtained while repairing the linings of thermal units are cleaned of slag and metal impurities to become inexpen-
sive and widely available metallurgical wastes. In the application of fireclay aggregates and fillers, refractory concrete based on Portland cement can be used up to 1200°C, while in case of a reduced cement consumption – up to 1300°C. Such concrete can be used in the manufacture of refractory mixed concrete and structures of thermal units exposed to prolonged high temperatures and their sudden changes. Thus, the problem of using technogenic materials usage is solved. Furthermore, the environment of such productions industrial zone is improved.

The aim of this research is to increase the density, the residual strength after calcination at 800°C and the heat resistance of refractory concrete, while reducing the shrinkage and susceptibility to cracking. This is achieved by (i) decrease of the flow rate of Portland cement contained in the refractory concrete mix developed by us; (ii) elimination of the superplasticizer; (iii) introduction of a filler from a mixture of fine crushed fireclay and high-alumina refractories which are jointly wet-ground to obtain grain sizes from 30 nm to 200 nm. This provides an essential decrease of cement consumption and concrete mix cost and an improvement of the physical, mechanical and fire properties of refractory concrete mentioned above.

EXPERIMENTAL

It is well recognized that the introduction of sodium waterglass to the concrete increases the concrete mix mobility and workability at a lesser water consumption. Besides, it does not burn at concrete high temperatures and provides an increase in the density, strength and fire properties of the hardened concrete. Diluent was introduced to water for wet grinding to achieve a decrease of the water consumption to 15% of the dry materials mass without reducing the slurry flow. The optimal composition of refractory concrete mix [4] developed by us included the following component ratio, mass. %: Portland cement M400 – 8-15, a fine additive from a filler material of 30 nm - 200 nm particle size – 8-15, a fine additive from crushed high-alumina refractory of 30 nm - 200 nm particle size – 3, sand from crushed (fr. 0 mm - 5 mm) fireclay refractories – 24.5 - 26.4, stones of crushed (fr. 5 mm - 20 mm) fireclay refractories – 35 - 36.3, sodium waterglass – 0.2 - 0.35, water – to 100%.

The introduction of a nano-sized filler from crushed high-alumina refractories eliminated the use of scarce and expensive imported alumina hydrate and at the same time increased the content of alumina component which in turn increased the concrete fire and heat resistance. In this case, it was advisable to obtain fine materials by joint wet grinding to achieve mixing uniformity. During wet grinding to a given particle size, the fillers acquired an amorphous structure and an ability to self-harden. It was enough to introduce small amounts of hardening catalyst as Portland cement.

Nanoscale fillers of crushed fireclay and high-alumina refractories mixed with cement had an increased activity creating a filled binder. They did not move apart the grains of the coarse aggregate, but filled the surface pores in it and improved the adhesion between the binder and the fillers. Besides, such fillers improved the ductility and workability of the concrete mix, which provided to exclude the use of expensive and scarce burnable superplasticizer C-3 [5].

The dimensions of filler nanoparticles were determined using the Solver NT-MDT scanning probe microscope produced by Zelenograd Physics and Technology Institute of Nanotechnical and Microscopic Studies. The shape and dimensions of the filler particles after joint wet grinding under the microscope are shown in the Fig. 1. The analysis of these figures leads to the conclusion that...
slurry grains after wet grinding of a mixture of fireclay and high-alumina refractories have a size of less than 200 nm. Neither do the surface of the particles and the height of the relief exceeded the specified sizes [6].

The 1.5-2 times decrease in cement consumption due to active nanoscale fillers provided a decrease of the strength drop of concrete, its shrinkage at high temperatures and, consequently, its susceptibility to cracking at prolonged exposure to such temperatures. The refractory concrete temperature resistance to sudden temperature changes increased.

These benefits were also determined by the fact that both nanoscale fillers and aggregates had an identical coefficient of thermal expansion (CTE). Therefore, the expansion and contraction of the concrete components occurred equally during the processes of heating and cooling of the concrete structures in absence of any thermal stresses which typically contributed to microcracking.

The low sand content in the composition suggested provided the filling of coarse aggregate voids without moving apart the grains of crushed stone when compared to known refractory concrete compositions based on fireclay aggregates. This helped to ensure a maximum dense packing of the grains of the mineral mixture and increase the hardened concrete density. Besides, this did not require high cement consumption in enveloping small sand grains [7, 8].

The studied concrete compositions in correspondence with the present invention are shown in Table 1. It is evident that the cement consumption is 1.5 - 2 times lower than that of the known compositions of refractory concretes.

It was necessary to determine the properties of the proposed refractory concrete, so preliminary crushing and sieving of crushed purified fireclay refractories was carried out to obtain predetermined fraction sizes of sand and crushed stone. The joint wet grinding of the sifted crushed fireclay and the high-alumina refractories was performed in the ratio specified in Table 1. It aimed at obtaining fillers of nanoscale particles of up to 200 nm. The slurry was drained after grinding through a sieve with a mesh size of 0.063 mm. This provided the separation of particles larger than 200 nm, and their re-grinding.

<table>
<thead>
<tr>
<th>Raw materials</th>
<th>Material consumption, kg/m³ of concrete mix</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>In the proposed compositions</td>
</tr>
<tr>
<td></td>
<td>1</td>
</tr>
<tr>
<td>Portland cement</td>
<td>176</td>
</tr>
<tr>
<td>Fine ground fireclay additive, 30-120 nm</td>
<td>330</td>
</tr>
<tr>
<td>Fine ground additive of crushed high alumina refractories fr. 30-120 nm</td>
<td>80</td>
</tr>
<tr>
<td>Fireclay sand, fr. 0-5 mm</td>
<td>581</td>
</tr>
<tr>
<td>Crushed stone fr.5-20 mm of crushed fireclay refractories</td>
<td>800</td>
</tr>
<tr>
<td>Plasticizer C-3</td>
<td>5.5</td>
</tr>
<tr>
<td>Sodium waterglass</td>
<td>0.2</td>
</tr>
<tr>
<td>Water</td>
<td>234</td>
</tr>
</tbody>
</table>
It was possible to reduce the concrete workability with less water consumption due to the increased slurry flow. 

After weighing the dosing of all components for the refractory concrete mixes, sample cubes 100 mm ×100 mm ×100 mm and 70 mm ×70 mm ×70 mm were molded. The moisture contained in the wet grinding fillers was taken into account at dosing the water added to the concrete mix for each composition. The waterglass consumption of a density of 1.23 g/cm³ was calculated as percentage by weight of the dry materials fed to the grinding machine. The slurry flow was sufficient for it to be transferred by pumps and fed through the pipeline.

The compaction of the sample cubes was performed on a shaking table with a frequency of 3,000 rev / min and an amplitude of 0.3 mm up to the conjoint state (for 1 min - 1.5 min). The samples were hardened in the 3 h + 6 h + 3 h steaming mode, followed by drying to a constant weight. The refractory concretes obtained under such conditions of hardening gained 100% of strength.

**RESULTS AND DISCUSSION**

The test results of the studied compositions are summarized in Table 2. The analysis of the results of this table leads to the following conclusions.

Despite a decrease of the cement consumption which is more than 2 times than that of the known compositions, the proposed refractory concrete compositions are not inferior and are even superior to the former in compressive strength, both in a dry and a burnt state at the temperature of 800°C. It should be noted that with cement consumption decrease the residual concrete strength increases 1.5 - 2 times after firing at a temperature of 800°C. The average density of the proposed compositions is significantly higher than that of the usual composition based on fireclay fillers, which indicates a more compact grain packing that helps to reduce shrinkage during firing and to increase spalling resistance. Almost the same density of the known composition based on slag aggregates is achieved only due to heavier slag aggregates and cannot serve as a proof of the most compact grain packing.

After firing at a temperature of 800°C, the residual strength of the proposed compositions is 1.5 - 2 times higher than that of the known compositions. This results in a longer concrete life after prolonged exposure to high temperatures.

The spalling resistance of the proposed compositions is also more than 1.5 - 2 times higher than that of the usual composition on fireclay fillers. This determines a greater stability to sudden temperature changes. Almost the same spalling resistance of the concretes based on slag aggregates is explained with the higher coefficient of thermal expansion (CTE) of the slag aggregates as compared to that of fireclay one and the fact that the maximum compact packing of the grains in the concrete is not reached.

Thus, the developed refractory concrete compositions of aggregates from crushed fireclay refractories with nanoscale fillers from aggregate materials demonstrate more economy and quality in all property parameters and can be used for the manufacture of load-bearing structures of thermal units with service temperatures of up to 1300°C. They can also be used for lining the kiln cars hearth in the ceramic industry.

**Table 2. Refractory concrete properties.**

<table>
<thead>
<tr>
<th>Properties</th>
<th>Property values in compositions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Average density of dry concretes, kg/m³</td>
<td>2050  2070  2085  2100</td>
</tr>
<tr>
<td>Average density of burned concretes, at 800°C, kg/m³</td>
<td>1990  2000  2010  2025</td>
</tr>
<tr>
<td>Compressive strength of dry concretes, MPa</td>
<td>41.4  42.0  43.2  45.8</td>
</tr>
<tr>
<td>Compressive strength of burned concretes, at 800°C, MPa</td>
<td>30.6  30.7  30.7  31.1</td>
</tr>
<tr>
<td>Residual strength, %</td>
<td>73.9  73.1  71.1  67.9</td>
</tr>
<tr>
<td>Heat resistance, number of water thermal cycles</td>
<td>27    25    24    22</td>
</tr>
</tbody>
</table>
CONCLUSIONS

The developed optimal compositions of refractory concretes based on aggregates made from metallurgical waste were introduced at Novolipetsk Steel (NLMK) during the reconstruction and major repairs of the thermal units [9, 10]. Refractory concretes based on fireclay aggregates (made from crushed fireclay refractories) and high alumina cement (HAC) were used to produce the linings of insulating caps of steel teeming ladles with an operating temperature of 1300°C. The concretes based on these aggregates and Portland cement were used for the manufacture of cast house hanging screens, for thermal insulation covers and for rapid heating stands of steel teeming ladles working at sharp temperature changes (from 50°C to 1300°C) lined with refractory concrete of an optimal composition.

The curing at a temperature of 550°C lasted for 6 h. It allowed to soften the first warm-up caps and to minimize the formation of cracks during the product drying.

The developed technology of drying thermal insulation caps and drying-in stands played an important role in their manufacture and long life. The optimal drying mode was determined in an industrial environment. The temperature was increased to 110°C at a speed of 10°C - 20°C. Then they were cured for 8 h. After that, the temperature was increased to 350°C at a speed of 20°C-30°C, and then to 550°C at a speed of 50°C. The curing at 550°C was 6 h. This helped to moderate the first heating of the caps and to minimize the products cracking.

REFERENCES