DRY REFRACTORY MIXES IN LADLE AND LANCE DESIGNS FOR BLOWING GASES

Margarita A. Goncharova, Olga V. Karaseva, Konstantin A. Korneev

ABSTRACT

In order to increase the service life of lances, it was proposed to replace the lining from stopper tubes by a monolithic one of refractory concrete. Concrete compositions were selected on the basis of corundum and mullite-corundum refractory masses.

A significant economic effect was obtained due to the reduction of labor costs for the manufacture and repair of the lining of insulating ladle covers and lances, to the increase in their durability and to cost reduction.

Thus, as a result of the research and pilot tests, optimum compositions of dry refractory mixes with additives from metallurgical waste were determined, which increased the service life of linings and reduced labor costs for their manufacture.

Keywords: refractory concrete, dry refractory mixes, metallurgical waste, steelmaking.

INTRODUCTION

The low durability of reinforced concrete products used in the metallurgical industry (insulating ladle covers, rapid heating stands, lances for blowing oxygen and argon into molten steel) is explained by severe operating conditions of steel-making equipment.

The most important functional property of any structural construction material is its ability to resist damage. The achievable level of composite resistance to damage is used to assess the technical performance and the economic efficiency of products and structures as a whole.

The potential of damage resistance of composites as an integral category is assessed through assessing stress-strain behavior, strength, crack resistance and many other parameters. All the above properties of composites reflect the specificity of the mechanisms for the development of stresses and strains under both mechanical loading and other types of loading.

The change in the stress-strain behavior of composites as an integral system can be caused by any load on the material.

The properties of composites can only be controlled through understanding the structural and physical nature of the complex process of deformation and damage.

At modern metallurgical enterprises, large-tonnage waste is generated. The problem of this waste utilization is currently extremely urgent because a large area is required for its storage, the ecological situation deteriorates, storage organization and maintenance require vast expenses. At the same time, it has already undergone high-temperature treatment and does not contain organic impurities, therefore it can be an excellent raw material for the construction industry.

The operating conditions of steelmaking equipment (insulating ladle covers, rapid heating stands, lances for blowing oxygen and argon into molten steel in steelmaking) predetermine rapid disability. In this respect, increasing the life of steelmaking products together with the application of metallurgical waste for their manufacture is an urgent technological and economic problem [1 - 4].

The analysis of the existing technology for manufacturing steel-making equipment shows that it is
lined manually with the help of refractory small-piece products. Even though this implies the application of imported expensive refractory masses, the latter do not provide sufficient life cycle of these thermal units because of seams. Therefore, it is more appropriate to use refractory concrete of a monolithic structure as lining.

EXPERIMENTAL

The choice of raw materials for refractory concrete compositions was based on the analysis of refactoriness tests both in a pure form and in the form of mixes, as well as with account of their use in steelmaking. As to binders, it was decided to use M400 Portland cement and slag Portland cement (SPC) with a 20 % content of NLMK-produced granulated slags. For high working temperatures, VGMC-1 refractory high-alumina cement produced by the Podolsk cement plant and containing up to 90 % \( 2\text{CaO.Al}_2\text{O}_3 \) and small amounts of \( \text{CaO.Al}_2\text{O}_3 \) and \( \text{SiO}_2 \) was used.

The following metallurgical waste was used as fine ground additives (FGA): silicomanganese slag dust (an aspiration dust from the ferroalloy furnace degassing system of PJSC NLMK) and primary fireclay for ladle coating. Even at room temperature, these additives interact with cement components, which promotes the increase of the density and resistance to huge temperature swings, the reduction of the free lime content in the cement paste and its transition to more fire-resistant silicates and calcium aluminates.

During the production test of insulating ladle covers, cracking of the lining made from refractory concrete on slag aggregates was observed [7, 8]. The causes of cracking were determined after samples with cracks were cut out of the lining.

It was established that the main phase of slag inclusions is akermanite with clear crystallization and the presence of small amounts of merwinite. At high temperatures, merwinite melts to form magnesium metasilicate, which has four modifications – enstatite, two types of clinoenstatite, and protoenstatite. When heated to 900°C, monoclinic clinoenstatite changes into other modifications with a significant increase in volume. The volume of refractory concrete increases particularly intensely in an oxidizing environment, which leads to concrete cracking and to the reduction of its bearing capacity. Since the minerals form because of molten slag crushed stone, it was decided to limit its use. Therefore, crushed stone and sand from ladle brick scrap obtained while repairing the lining of ladles were used as aggregates. The grain composition of the aggregates after crushing and sieving is given in Table 1.

The refractoriness sample test above 1300°C was carried out in a kryptol furnace with an internal diameter of 60 mm. The rate of temperature rise in the range 1000°C - 1500°C was adopted at 15°C per minute, and over 1500°C - 5°C per minute. The production of samples, their tests and processing of results were carried out according to regulatory documents and recommendations for refractory concretes [5, 6].

It should be noted that according to all regulatory documents it is not recommended to add fine ground additives to concrete compositions on high alumina cement, because during this cement hydration a small amount of free calcium hydroxide is released [9 - 11]. However, in this research, the concrete strength and, hence, its bearing capacity increased due to concrete structure compaction.

It was established that the use of FGA together with high-alumina cement leads to a decrease in refactoriness

Table 1. The grain composition of aggregates of ladle brick scrap.

<table>
<thead>
<tr>
<th>Material</th>
<th>Sieve residue , %</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>10</td>
</tr>
<tr>
<td>Crushed fireclay</td>
<td>28.9</td>
</tr>
<tr>
<td></td>
<td>28.9</td>
</tr>
<tr>
<td>Fine fireclay</td>
<td>-</td>
</tr>
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<td></td>
<td>17.5</td>
</tr>
</tbody>
</table>
(Fig. 1). Only when 10% of fireclay was introduced into the matrix composition, did refractoriness increase slightly.

Refractory concrete compositions were optimized experimentally. The consumption of 5 - 10 mm ladle brick scrap was assumed to be constant for all compositions: on the basis of slag Portland cement - 380 kg per 1 m³ of concrete mix, on the basis of high-alumina cements - 860 kg per 1 m³. The research results showed that the compressive strength depends on the treatment temperature and the amount of the additive (see Fig. 2).

With an increase of the treatment temperature, a sharp decrease in the strength of all refractory concrete compositions was observed [12, 13]. The residual strength of concrete calcinated at 800°C is reduced to 30% depending on the amount and type of the fine ground additive, and at 1000°C - to 40%. The average density of concrete in treating by temperatures of up to 800°C does not practically change, and at a temperature of

![Fig. 1. The dependence of high-alumina cement refractoriness on the type and consumption of fine ground additives: 1 - silica manganese slag dust; 2 - fine ground fireclay.](image)

![Fig. 2. The dependence of the compressive strength of refractory concrete on slag Portland cement on the treatment temperature: 1 - with 40% of fine ground fireclay; 2 - with 20% of silica-manganese slag dust; 3 - with 30% of silico-manganese slag dust; 4 - with 40% of silica-manganese slag dust.](image)
of 800°C it decreases sharply. Moreover, the more fine ground additive is in the sample, the less the shrinkage strain in the concrete and the more it “blows out” due to lower density.

The lowest decrease in strength after calcination is achieved by using fireclay. But in order to increase the initial concrete strength, its consumption should be limited to 20%, since otherwise an undesirable increase in cement consumption is required.

The analysis of the current preparation and service of oxygen and argon lances in ladle treatment stands showed that they operate in particularly severe conditions. When gases are blown into steel, the lances are immersed almost half of their height in the metal and slag melt with a temperature of 1580°C - 1650°C. They are kept at this temperature for 1 - 18 minutes, after which they are removed and cool down sharply in air to a temperature of 50°C - 100°C.

In order to increase the service life of lances, it was proposed to replace the lining from stopper tubes by a monolithic one of refractory concrete. Concrete compositions were selected on the basis of corundum and mullite-corundum refractory masses of the Semiluky, Borovsky and St. Petersburg refractory plants. At the same time, MKN-94, SMN-61, SMN-91, SMN-94, SMK-72, MMKTS-72, SKNT-94 refractory masses were studied. The properties of refractory concretes based on refractory masses, as well as the durability of lances lined with the masses are given in Table 2.

The SMN-61 mass lining had the highest strength; dry refractory mix compositions were developed for it with fine ground additives. It was shown that additives from high alumina refractories or their mixes with fireclay had the highest efficiency.

**RESULTS AND DISCUSSION**

At PJSC NLMK, insulating ladle covers are used in basic oxygen steelmaking shops #1 and #2 (BOS-1 and BOS-2). In BOS-1 with a lower steelmaking capacity, the volumes of ladles are smaller and their covers have a diameter of 3,630 mm, therefore the volume of concrete for the manufacture of one cover is 1.5 m³. Ladle covers in BOS-2 have a diameter of 5,000 mm, so the concrete consumption for each of them is 4.65 m³. The lining is fixed to the metal frame of the cover with anchors to which the fittings in the form of a helix from a 30 mm wide steel plate are attached. The helix pitch is 150 mm, the height is 180 - 280 mm. The thickness of the lining is 350 mm. Such non-rigid reinforcement makes it possible to reduce the difference between the CTE of a steel cover and refractory concrete and to eliminate the possibility of cracking when temperatures change [14 - 16].

Ladle insulating covers and rapid heating stands operating at huge temperature swings (from 50°C to 1300°C) were lined with refractory concrete of optimal composition. An important role in the manufacture and long-term operation of insulating covers and heating stands is played by the developed technology of their drying. An optimal selected mode is described below.

### Table 2. Properties of refractory concretes based on refractory masses.

<table>
<thead>
<tr>
<th>Properties</th>
<th>Refractory mass grade</th>
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</thead>
<tbody>
<tr>
<td></td>
<td>SMN-61</td>
</tr>
<tr>
<td>Average density, kg/m³:</td>
<td></td>
</tr>
<tr>
<td>- steam cured</td>
<td>2555-2635</td>
</tr>
<tr>
<td>- after drying</td>
<td>2490-2580</td>
</tr>
<tr>
<td>- after calcination at 800°C</td>
<td>2365-2475</td>
</tr>
<tr>
<td>Compressive strength, MPa:</td>
<td></td>
</tr>
<tr>
<td>- steam cured</td>
<td>9.2-9.6</td>
</tr>
<tr>
<td>- after drying</td>
<td>17.7-18.0</td>
</tr>
<tr>
<td>- after calcination at 800°C</td>
<td>14.0-14.2</td>
</tr>
<tr>
<td>Residual strength, %</td>
<td>78-79</td>
</tr>
<tr>
<td>Average number of treatments</td>
<td>6.6</td>
</tr>
<tr>
<td>FA-2 lances durability, min</td>
<td>88</td>
</tr>
</tbody>
</table>
The temperature was raised to 110°C at a speed of 10°C - 20°C, then held for 8 hours, after which the temperature was raised to 350°C at a speed of 20°C - 30°C, and then to a temperature of 550°C at a speed of 50°C. It was held at 550°C for 6 hours. This made it possible to soften the first heating of the covers and to minimize the formation of cracks in the products as a result of drying.

Rapid heating stand covers of BR P B15 112 refractory concrete were manufactured in a similar way, where the lining service temperature is lower, therefore the concretes contained Portland cement with fine ground refractory fireclay as a binder and with slag and pumice sand and crushed stone as aggregates, the operating temperature of which can amount to 1200°C, according to [5, 6]. The peculiarity of the covers was that they had a flat or slightly spherical rectangular shape. The lining of the covers was fixed to the metal frame with the help of anchors, to which wire fittings were welded.

In order to manufacture rapid heating covers to operate at temperatures not exceeding 1200°C, the following concrete composition was selected, kg per 1 m³ of concrete mix: cement M 400 - 550, aggregate - 150 and 0 - 5 mm - 1000 fireclay refractory sand, 5 - 10 mm - 450 crushed stone of the same materials, water - 200. Portland cement M 500 D0 or M 400 D 20 was used as a binder. After testing the concrete samples it was found that the average of the six simultaneously tested cubes had the following characteristics: compressive strength after steam curing - 18.5 MPa, after drying to constant mass - 22.7 MPa, after calcination at a temperature of 800°C - 9.9 MPa. The residual strength after calcination at 800°C was 43.6 %. Consequently, refractory concrete on Portland cement and aggregates from aluminosilicate refractory rubble met the requirements of GOST 20910-90 for BRP B15 112 refractory concrete, because the B15 class of concrete guarantees compressive strength of at least 20 MPa after drying, and the application temperature of not less than 1200°C. It should be noted that concretes on 500 D0 Portland cement have higher strength after drying but less residual strength than on 400 D 20 Portland cement. This is apparently caused by higher density of concrete on Portland cement with 20 % of aggregate from granulated blast-furnace slag consisting of calcium silicates which are similar in their chemical and mineralogical nature to Portland cement.

Portland cement was used to make rapid heating stand covers and ladle covers for BOS-2. The durability of rapid heating stand covers was 37.5 days, and that of ladle covers - 124 steel heats. The optimization of compositions for the manufacture of insulating covers and heating stands, as well as the developed mode of their drying made it possible to increase the resistance of the covers 15 times, and that of heating stands 2 times.

The developed compositions of MKN-94 and VGTS refractory masses with aggregates from aluminosilicate refractory rubble, as well as the optimal variant of fixing the lining served as the basis for manufacturing 77 experimental lances. They were tested in BOS-1 and BOS-2 in the ladle treatment stand while blowing the steel melt. The durability of the lances was 10 - 12 minutes, i.e. endured 2 - 3 treatments. The cost of such lining is lower than that from fireclay stopper tubes due to lower labor intensity and lower energy costs.

24 FA-2 lances were made on the basis of SMN-61, SMN-61f, SMK-72, MMKTS-2 refractory masses. They all were tested in real production conditions.

**CONCLUSIONS**

The results of observing the lances with lining from the researched masses and their durability under the operating conditions are given in Table 2. The analysis of the results makes it possible to conclude that the greatest number of treatments (heats) – 7 - 8 – was endured by lances lined with refractory concrete from SMN-61 mass without fiber. The average life of this lining was 88 min, which is ten times longer than that of the lining from stopper tubes and of MKN-94 high-alumina mass. SMN-61 mass lining with fiber endured only 4 - 5 heats, despite a slight increase in concrete strength when the fiber was added to the mass composition. Its durability averaged 64 minutes. From this it can be concluded that if fiber is added to medium-alumina mass compositions, it does not increase lining durability. These results, however, require further elaboration because the number of lances made from SMN-61 mass without adding fiber - 3 pieces per each shop - is clearly not sufficient for final conclusions. FA-2 lances made for BOS-2 with lining from this mass without adding fiber endured an average of 6.6 heats with a total duration of 93 minutes. Lances with lining from the same mass with fiber endured an average of 6.8 heats with a total duration of 75 minutes. Thus, these results also confirm the conclusion that it is inexpedient to add fiber to compositions of these masses.
The reason for it may be that metal fiber’s melting point is significantly lower than that of refractory concretes from refractory masses.

The main reason for the failure of pilot lances lined with all masses is the wear of the lance bottom at the height of 500 - 600 mm in the slag belt. This indicates an insufficient resistance of the lining to the action of slag melts. The residual lance thickness in BOS-1 in the slag belt was 140 - 150 mm and 160 - 170 mm in the molten metal zone with the initial lining diameter of 200 mm. In BOS-2, when steel was treated with oxygen and argon at temperatures of 1580°C - 1665°C for 10 - 20 minutes, the reason for the lance failure was chipping of the lower part of concrete lining at the height of 200 - 350 mm, which led to the loss of the metal rod of the lance. Therefore, the lance tip reinforcement and fixing were also designed.

Following the test results, a pilot batch of 90 - 100 lances with monolithic refractory concrete lining was produced on the basis of SMN-61 mass. 8 FA-1 lances and 19 FA-2 lances were manufactured on the basis of SMN-91 refractory mass.

The greatest resistance was typical for concrete lances with water consumption of 4.77 %, which endured 13 heats (133 minutes) in BOS-1, and 16 heats with a total duration of 175 minutes in BOS-2. According to this indicator, this water consumption is optimum. The other compositions endured significantly fewer heats, although they were more resistant than concretes from MKN-94 and even SMN-61 masses. In manufacturing linings from SMN-91 mass with the optimum water consumption recommended in this research, the average durability of lances was 12 heats 112 minutes long. Thus, the use of SMN-91f mass for the manufacture of lance lining made it possible to increase their durability 4 times at high service temperatures and their huge swings.

When fiber is added to concrete compositions with low water consumption, mixing is impeded and the mixer blades wear rapidly. Therefore, its load factor has to be reduced almost 2 times compared with concretes where fiber is not added. Fiber, however, is supposed to increase the bending strength of hardened concrete and reduce the brittleness of lining, as well as to reduce the difference in the CTE of steel and concrete and, consequently, to improve heat resistance.

As a result, it was concluded that the addition of fiber has a positive effect only on high-alumina masses containing at least 94 % Al₂O₃. For masses containing 90 % of this oxide, the addition of fiber does not have practically any effect on lance resistance. Comparing the obtained results with the data on the durability of lining from SMN-91 masses, it can be concluded that Riokast masses are less resistant to high temperatures even when the alumina oxide content in their composition is within 95 - 96 %. Therefore, pilot tests of 20 - 25 lance linings made from Riokast-95f and SMN-91f masses were performed.

While observing the lances lined with refractory fiber-reinforced concrete, it was established that the lining first bakes, then after each heat the outer layer sweats and peels off. During the next heat, the next layer bakes, sweats and peels off too. These processes mostly occur in the middle of the lance height, as well as along cracks, if there are any. When argon is blown, lances sweat stronger along the existing cracks and quickly break down, although the concrete remains undamaged. Lances reinforced with a sprocket with spirally wound thin steel wire are much more resistant both to cracking during drying and to other defects, including sweating at high operating temperatures. Lances with such reinforcement endured 13 - 15 heats. It should also be noted that sprocket-reinforced lances sweat in the middle of the tube length, and this occurs gradually from the outer layers to the inner ones until the rod itself.

A significant economic effect was obtained due to the reduction of labor costs for the manufacture and repair of the lining of insulating ladle covers and lances, to the increase in their durability and to cost reduction. Thus, as a result of the research and pilot tests, optimum compositions of dry refractory mixes with additives from metallurgical waste were determined, which increased the service life of linings and reduced labor costs for their manufacture.

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