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SELECTION OF THE MATERIAL OF THE LINING OF INDUCTION FURNACES IN STEEL 20GL

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Abstract

This article is devoted to the study of the working conditions of the lining of the crucible of the induction crucible furnace in order to increase the service life of the lining and increase the number of melts, which will lead to a more stable operation of the furnace itself and an increase in the productivity of the furnace metal.

The article discusses the work of the lining in difficult conditions, such as thermal, corrosive and erosive effects of liquid metal, chemical corrosion of slag, ferrostatic pressure of the liquid metal column. The study was carried out at the 6 ton induction crucible furnace (ICF-6) in the conditions of the Tashkent foundry and mechanical plant.
To determine the intensity of the circulation of molten metal throughout the volume of the crucible, which leads to erosion and erosion of the working layer of the lining, the following were determined: electromagnetic force (1), and specific electromagnetic force (2) applied to a unit volume. [1,2]

Keywords: ICF lining, crucible service life, lining requirements, lining mass, thermal, corrosive, erosive, electromagnetic forces, 20GL.

1. Introduction

When operating induction crucible furnaces (ICF-6) in foundry mechanical plants, it is necessary to strictly monitor the temperature regime of melting, since even a slight (by 20 ~ 50 K) temperature increase against the lining allowable for a given material drastically reduces its service life. Meanwhile, the service life of the lining and, as a result, the operation of the furnace itself determines the productivity of metal and products. Based on this, increasing the service life of the lining and increasing the number of melts in induction furnaces is an urgent problem during its operation.
The working conditions of the lining layer of the crucible are subjected to severe conditions: thermal, corrosive and erosive effects of liquid metal, chemical corrosion of slag, ferrostatic pressure of the liquid metal column (70 kPa at a metal depth of 1 m in the ICF with a capacity of 6 tons), mechanical forces when loading the charge, and especially when upsetting the "bridges" formed during the melting process.
The value of the magnetic flux in the ICF depends on the distance of the metal from the inductor. Increasing the gap increases the reactive power. The smaller the thickness of the crucible wall, the lower the specific power consumption and the lower the capital costs for converters, as a result of the reduction in the thickness of the crucible, the economic indicators of the furnace increase. Therefore, the wall thickness of the crucible should be minimal. However, with a decrease in the thickness of the crucible, its service life is reduced and the reliability of the furnace operation decreases.
The inner surface of the crucible should have a high density and chemical-metallurgical resistance, i.e. resist chemical reactions between the lining and the melt (corrosive wear) and not form fusible eutectic mixtures with the lining.

2. Methods

In addition to the aggressiveness of the metal being smelted, the service life of the crucible depends on the degree of cooling of the lining, the difference between the temperature of the molten metal and the refractoriness of the lining, the value of the coefficient of thermal expansion of the lining material and its thermal resistance, the duration of holding the metal in the crucible, the thickness of the wall of the crucible, the intensity of hydrodynamic mixing, hydrostatic pressure metal pools on the crucible wall, from the fluidity of the metal, the rigidity of the structure of the furnace body, from the degree of vibration of the crucible, from the operating conditions of the furnace (continuous operation, two-shift operation, the regularity of cleaning the crucible), as well as from a number of quality indicators and the performance of lining works (stuffing, drying, heating and putting the oven into operation).

Based on the operating conditions and the increase in the service life of the lining, the main requirements for the lining of the ICF are determined.

a) Resistance to thermal stresses, since the relatively thin wall of the crucible must withstand large temperature differences (the temperature of the liquid metal during steel melting is 1800~1900 K; the temperature of the outer surface of the wall is approximately 450~500 K);

b) High mechanical strength, since the wall of the crucible with a small thickness must withstand a large load from the mass of liquid metal, when cleaning the crucible, as well as when loading a large charge;

c) Chemical resistance against the effects of slags;

d) The refractoriness of the lining must exceed the temperature of the melted metal by 150~200 K, since the wall of the crucible must resist the eroding action of the metal stirred by the magnetic field of the furnace. For the same reason, the lining must have a high density;

e) The lining should have a minimum thickness, since as the crucible thickens, the electrical and economic indicators of the furnace decrease;

f) The lining should not conduct current, otherwise a short circuit in the inductor is possible;

g) The lining should not have large volumetric changes (shrinkage or growth), since with large volumetric changes it may crack.

Technological Requirements for ICF Lining

The refractory lining is most often destroyed as a result of chemical interaction with slags and alloy components melted in the furnace. The degree of destruction of the lining depends on the chemical composition of the alloy, as well as on its melt temperature, the chemical composition of the lining and the porosity of the refractory. During the melting of steel, the wear of the lining generally occurs evenly in the form of erosion in accordance with the movement of the metal in the crucible. The aggressiveness of different steel grades determines the degree of wear (see table-1) [2]:

Table-1

Material	Aggressiveness index
Carbon steel 1,4~1,5 % C	0,9
Carbon steel, 0,8 % C	1,0
Chrome steel	1,2
HSS	1,7~2,5
High-alloy steels	2~3
Heat resistant steels	3~4

When melting steel in medium-frequency ICF, the movement of the metal is less intense, the wear of the lining is more uniform and, all other things being equal, the durability of the lining is higher than in industrial frequency furnaces.

The weak link in the crucible is the slag belt, where the lining is abundantly saturated with oxides from the slag, like SiO_2; CaO; MgO; R_2O. The mass fraction of MgO in the working zone of the slag belt is reduced to 21%, Fe_2O_3 increases to 8%, and the content of silicates increases by about 4 times, the refractory forsterite binder degenerates into a non-refractory one. At a melt temperature of 1850 –1900 K, with a constant supply of slag to the lining, destruction of aggregate accumulations, as well as individual grains of periclase and grains of the spinel formed during firing of the lining, is observed. As a result, a less stable structure is formed with corroded grains of periclase and spinel, separated by silicate interlayers, and with separate areas consisting of less refractory silicates. Such a structure is less wear-resistant in service and causes high wear in the slag belt of the crucible due to flashing.

When choosing the type of lining, it is necessary to take into account the tendency of some components in steels to exchange oxidation reactions with the oxides of the lining masses. This property depends on the heat of formation of oxides, which for the most common refractories is as follows (kJ/mol): MgO - 608, SiO_2 - 435, Al_2O_3 - 562, Cr_2O_3 - 381, ZrO_2- 540,1, Fe_2O_3 - 276,1, TiO_2 – 456 [1].

The reactions taking place at the “refractory–metal” phase boundary are of great importance both for the correct choice of the type of furnace lining and from the point of view of the quality of the steel being smelted. The tendency of molten metals and alloys to oxidize increases in the following sequence: chromium, nickel, iron, aluminum, silicon, titanium, zirconium, nichrome, magnesium, and the tendency of refractories to recover decreases in the series: Cr_2O_3; SiO_2; TiO_2; ZrO_2; Al_2O_3; MgO;

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$MgAl_2O_4$. The contact reaction between the steel melt and the acid lining can be represented by the following equation [1]:

$$2Fe + SiO_2 + O_2 = 2Fe^{2+} + SiO_4^{4-} \rightarrow (Fe_2 \cdot SiO_4)$$

Protective slag flooring prevents the oxidation of steel alloying components by air oxygen, accelerates refining, reduces the content of undesirable impurities and non-metallic inclusions in it. When melting steel in the main refractory crucibles, slags are formed little, therefore, additives that form slag are added to the main crucible: lime, fluorspar, periclase, lime glass, borax, aluminum oxide, quartz sand, fireclay powder, various salts, etc. [1,2].

3. Result and Discussion

Electrodynamic forces in metal

In the IHF, the molten metal circulates intensively throughout the volume of the crucible, and this leads to erosion and corrosion of the working layer of the lining, so it must be determined and taken into account.

As a result of the flow of an induced current in the metal, the electromagnetic force (1) is determined, and then the specific electromagnetic force (2) applied to a unit volume of the liquid (Fig. 1). The period-averaged value of the force acting on an elementary volume of liquid metal dV is determined by the formula [2].

$$dF = \frac{1}{2} \mathrm{Re}\{dI[dl\ B]\}, \qquad (1)$$

where Re – real part of a complex vector (reelle);
dI – elementary current flowing in a given conductor;
dl – elementary conductor length;
$B = \mu_{abs} H = \mu_0 \mu_r H$ - complex vector of magnetic induction;
μ_{abs} и μ_r – absolute and relative magnetic permeability;
$\mu_0 = 4\pi \cdot 10^{-7}$ - magnetic constant, H/m.

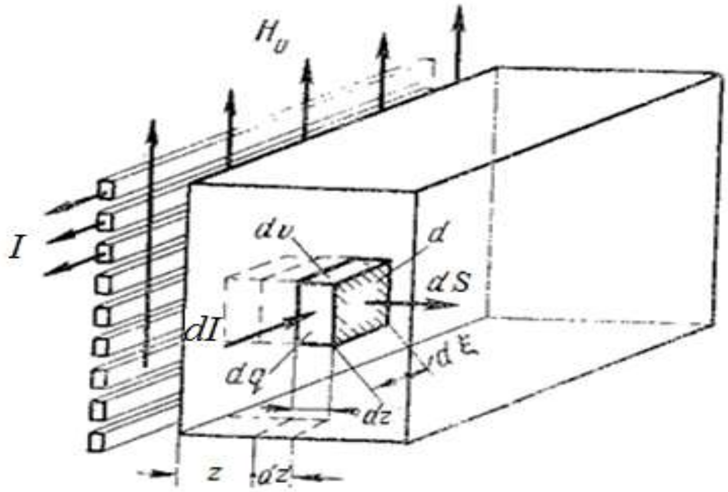

Figure 1. Electromagnetic forces in the "inductor - metal" system

The specific electromagnetic force applied to a unit volume of liquid metal [1] is, N/m³

$$F_{sp} = \frac{dF}{dV} = \frac{\mu_{abs}\tilde{S}}{\rho}, \qquad (2)$$

where $\tilde{S}$ – Poynting vector, W/m²;
ρ – electrical resistivity, Ohm·m.

From formula (2) it follows that the direction of electromagnetic forces corresponds to the direction of the energy flow $\tilde{S}$ at a given point. Electromagnetic forces create at each point of the metal an infinitesimal pressure $dp_{с.ж}$ created by this force, equal to its ratio to the area dS (see Fig. 1):

$$dp_{l.s} = \frac{dF}{dS} = \frac{F_{sp}dV}{dS}. \qquad (3)$$

The pressure at a given point is summed from the elemental pressures created in all elements dV lying between the considered point and the metal surface (Fig. 2).
In ICF, the current in the inductor can reach several thousand amperes, and the magnetic field strength created by the inductor has a value of the order 10^4~10^6A/m. As a result, the electromagnetic forces arising in the inductor and the straightened metal can reach a significant value. For a mechanically strong inductor, these efforts do not pose any danger, but in the liquid metal in the crucible, these efforts cause movement, which takes the form of electrodynamic circulation, as a result of which the metal in the bath is vigorously mixed.

With current strength $I \approx 1 \dots 10$ kA ICF inductor creates a magnetic field strength $H = IN_1 \approx 10 \dots 100$ kA/m, so that the maximum pressure $p_{l.s}$ in liquid steel ($\mu_r = 1$) at $D_m/\delta_{eqv} \geq 9$ ($k_{MP} \to 1$) achieves 0,1~10 kPa [2]:

$$dp_{l.s} = q_M \cdot \sqrt{\mu_0/(4\pi \cdot \rho_M \cdot f)} \approx 6{,}28 \cdot 10^{-7}(IN_1)^2, \quad (4)$$

where q_M – active power flux density, kW/m²;

$\rho_M = 1{,}4 \cdot 10^{-6}$ Ohm · m – specific electrical resistance (SER) liquid steel grade 20GL.

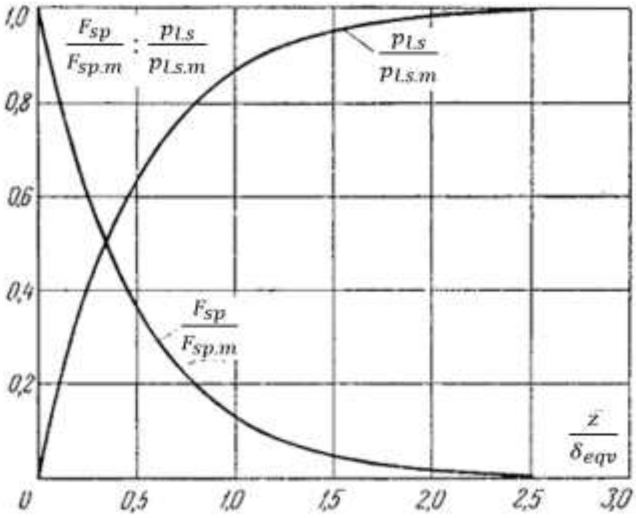

Figure 2. Graphs of the relative values of electromagnetic specific forces and pressures in a semi-infinite metal body

Due to electrodynamic mixing in the entire volume of the bath, the temperature and, most importantly, the chemical composition are equalized, which contributes to faster melting and obtaining a homogeneous metal composition. On the other hand, electromagnetic forces and the electrodynamic circulation of the metal caused by them deform the surface of the bath, which acquires a convex meniscus with a height h_{ed} (see Fig. 3). As a result, the slag that covers the surface of the metal flows down to the walls of the crucible, and in order for the entire mirror of the bath to be covered with slag, more slag-forming agents have to be added. The slag accumulating at the wall of the crucible and chemically interacting with the lining corrodes it to a greater extent than with a flat metal surface. In addition, during the circulation of the metal, there is an increase in exogenous slag particles in the volume of the metal.

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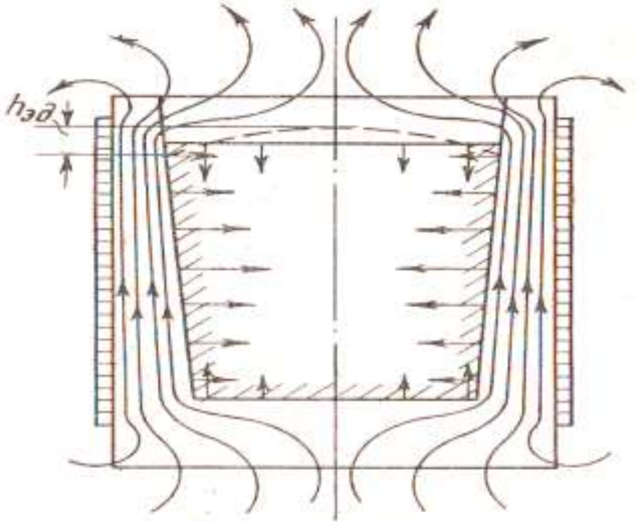

Figure 3. Magnetic field and electromagnetic forces in the crucible [1].

Electromagnetic forces in a metal cylinder placed in a cylindrical inductor are directed radially to the axis of the cylinder (in the direction of the energy flow), and the maximum pressure is created by these forces on the axis of the cylinder.

Due to the fact that the electromagnetic forces acting on the metal surface at the bottom of the crucible and on the bath mirror are very small, the electromagnetic pressure on the axis of the crucible will squeeze the metal into places with reduced pressure, i.e. up and down (see Fig. 3) , this metal will flow from the crucible axis to the wall at the top and bottom. The movement of the metal at the bath mirror and at the bottom is not quite the same due to the unequal ferrostatic pressures and friction forces in these places.

Vertical forces at the metal surface (see Fig. 4) enhance circulation. The resulting circulation is called double-circuit.

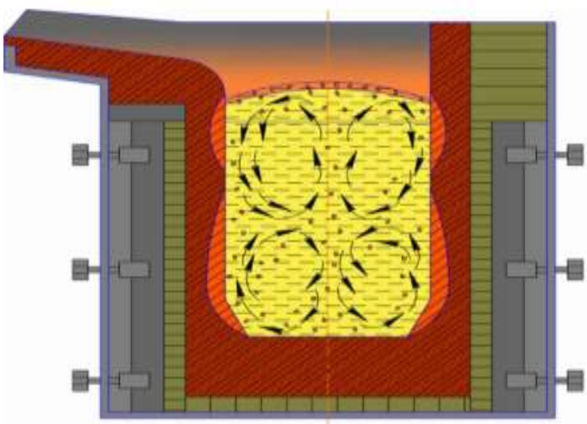

Figure 4. Electrodynamic circulation of metal in the ICF crucible [1].

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- metall - slag - crucibal - most washed out areas

Sufficiently high speed (0.5~1.5 m/s) of the turbulent movement of the metal enhances the erosive wear of the crucible lining, especially in the lower zone of rotation of the liquid metal flow at high ferrostatic pressure (up to 70 kPa). With the developed turbulent motion of liquid metal in the ICF, the Reynolds number exceeds 20000, (according to the Scientific Research Institute of Electrothermal Equipment).

4. Conclusion

Based on the study of accounting for erosion and some metals, it is proposed to use the exchange reaction of oxidation with oxides that are part of the lining masses, as well as the high speed of the turbulent movement of the metal:

ICF lining with a capacity of 3~10 tons of spinel composition based on MgO and Al_2O_3. The durability of such linings is 50~150 heats, depending on the range of steel being smelted and the composition of the refractory. 20~30% of fused corundum is introduced into the periclase. The optimal composition of spinel masses: 45% coarse, 10% medium and 45% finely ground component. The upper limit of the grain size is usually 4 mm, the finely ground component is cooked to a full pass through the sieve ≤0.074 mm. Grain size Al_2O_3<0,15 mm. Boric acid, borax or B_2O_3 in the amount of 1~2%, clay, phosphates or chromites are introduced into periclase-corundum mixtures as additives. The mass of periclase-corundum composition based on calcined and fused periclase in ICF with a capacity of 5.5~10 tons had satisfactory durability. At the same time, for ICF with a capacity of 6~10 tons, a combined lining can be used. The thickness of the brick layer is 75~130mm, the buffer layer is 20~30mm. The lining is made of dry charge from fired basic materials.

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