Causes of the Quartzite Lining Destruction during Operation of the IChT Furnace and Ways to Prevent Them

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Abstract. Causes of cracks formation in quartzite lining of induction crucible kiln with industrial frequency during iron smelting and events of insight of liquid metal into lining are considered in this article. Demonstrable presentation of these events, which was recognizing during research of causes of anticipated kilt out of its exploitation through a fault lining during its shake-out are considered. The main reasons for the formation of cracks in the lining during its operation, and ways to prevent them are given. The most difficult situations from the point of view of the correct operation of an industrial-frequency induction crucible furnace are described.

1. Introduction
Refractory materials and products ensure the functioning of the main technological units and machines in most industries. In many cases, the functioning and efficiency of entire technological systems is due to the quality and performance properties of refractories. This primarily relates to ferrous and nonferrous metallurgy, energy, chemical industry, mechanical engineering, etc.

The induction furnace (IChT) used in the foundry industry is one of the main production assets of the enterprise and is the main factor determining the development strategy of the enterprise as a whole. An increase in the reliability of the furnace operation is one of the main tasks for the reproduction of these funds. This is ensured by the versatility in the smelting of alloys, productivity, high durability of the lining, energy efficiency and optimization of maintenance costs.

In accordance with the passport of the IChT furnace, it is designed for the smelting of alloys at a melting temperature not higher than 1450 °C and using an acidic lining. The durability of such a lining with the correct operation of these furnaces and the smelting of synthetic cast iron with the use of casting or pig iron is 300-350 heats, and the temperature of conducting melting is no more than 1550 °C. When this temperature is exceeded, resistance starts to decrease.

2. Literature Review
The basis of the lining of the induction crucible furnace of industrial frequency is quartzite. The use of high melting temperatures leads to more intensive reactions of interaction of the lining with the melt and significantly reduces its resistance. The use of temperatures over 1550 °C is caused by the use of up to 90% of steel scrap in the metal smelter, both in Russia and abroad.
Correctly executed lining of the induction furnace crucible, which was also subjected to the correct mode of sintering, should have three zones in thickness, indicated in Figure 1.

**Figure 1.** The optimum thickness arrangement of layers in the wall of a quartzite crucible, b-thickness of the lining.

1. Monolithic - sintered zone, located in the immediate vicinity of the melt, which is obtained by sintering the powdered refractory material after the required temperature cycle. The powder binds, and a glass-like monolith is formed, which consists mainly of cristobalite grains, connected by a glassy phase - borosilicate. The material in this area has high mechanical strength. Low porosity contributes to resisting metal and slag due to the smaller quantity of the contact area;
2. Intermediate zone. In this zone, mainly quartz grains are bound by a vitreous body;
3. Buffer zone, which is a bulk material that prevents the penetration of metal to the inductor. Located on the cold side of the lining wall. Consists of unbound quartz grains. The porosity of this zone is maximum. The presence of a powdery zone is positive in terms of the possibility of solidification and, therefore, the cessation of metal that has penetrated through a crack in the two previous zones. In addition, this layer absorbs well the forces arising during thermal deformations.

It should be noted that the thickness of these zones is not constant in time. As the natural lining of corrosion during operation of the furnace, these areas must proportionally decrease in thickness, thus avoid the situation where one of the bands will disappear [18]. In addition, its role is played by the slagged layer, the thickness of which is usually 3-5 mm. Its absence leads to the rapid corroding of the sintered layer, and an increase in thickness to a decrease in furnace power.

In the operation of the furnace lining can occur cracks, sometimes can occur penetration of molten metal into it. The causes of these phenomena may be different.

3. Experimental Study and Discussion
In the present work, the causes of various defects in the lining of the IChT furnace during smelting of synthetic cast iron were studied. Studies were conducted on the basis of the analysis of samples taken
from an embossed lining (in the process of knocking out, the bulk layer on the sample is not preserved). One of them is shown in Figure 2.

**Figure 2.** A sample of the embossed lining, which withstood 149 heats: 1 - slaged layer, 2 - sintered layer, 3 - semi-sintered layer.

An enlarged sintered layer is visible on the sample (approximately 50-55 mm), the size of the semi-sintered layer was 25-30 mm. This led to the rapid formation of cracks in the lining and penetration of the melt through them.

### 3.1. Formation of Cracks

Cracking in the quartz lining of crucible furnaces during operation is almost inevitable. It is due to a number of factors (thermal and mechanical stresses, the structure and texture of the refractory lining, volumetric changes during polymorphic transformations of quartz and, finally, the culture of production).

The formation of a significant number of small shallow (hair) cracks reduces, due to the removal of internal stresses (relaxations) in the lining, the risk of one or two deep cracks and emergency passage of metal to the inductor. Furthermore, when, thermal (reversible) lining growth at the expense of quartz inversion occurs «closing» cracks. The formation of deep (through) cracks during the operation of the furnace is one of the most dangerous defects in the furnace lining, as it often leads to an emergency passage of metal to the outside with damage to the inductor and the furnace body.

The main reasons for the formation of cracks in the lining during its operation, and ways to prevent them are given in Table 1.

| Types of cracks | Probable cause of education | Ways to prevent |
|-----------------|-------------------------------|-----------------|
| The formation of cracks in the form of «grid». | Thermal and mechanical stresses in the lining due to temperature fluctuations, high temperature gradient over the thickness of the lining, volume changes during quartz inversion. | The least dangerous type of cracks for industrial frequency furnaces. To ensure maximum lining life, chips and small scrap should be loaded into the molten metal, preventing them from entering these cracks with further melting and passage to the inductor. |
| Formation of vertical cracks of considerable thickness and depth. | Shrinkage of the lining during rapid cooling. | After sintering the lining, the first 3-4 melts should be performed at a high temperature, pouring only no more than 1/3 of the metal volume, thus ensuring the formation of a sufficiently powerful sintered |
3.2. Formation of Growths

In addition to cracks, in the smelting process, slag build-ups may form on the lining, worsening the smelting mode. It is much easier to prevent the formation of slag outgrowths (crusts) than to remove them, since the methods for eliminating them create the risk of destruction of other areas of the lining.

The formation of growths is due to chemical reactions of molten metal and slag with lining, as well as physical processes of sticking (adhesion) of slag to the walls of the crucible. Slag inclusions are formed due to impurities introduced with the charge (sand, clay, etc.), due to the oxidation process and the interaction of metal components with the lining [19].

The composition of the slag, its activity and viscosity depend on the composition of the charge and are divided into two groups:

1. Materials giving a liquid (low-viscosity) low-melting active slag. These include oxidized scrap, crude chips and small steel scrap.

2. Materials giving thick (viscous) refractory inactive slag. This crude residue and metal penetration of the moldable mixture refund scrap steel with a high content of silicon and aluminum.

Thus, the optimal viscosity of the slag can be achieved by appropriate selection of the charge. Otherwise, the following situations may occur:

1. The formation of growths of low-melting slag at the level of the metal surface and below. This can be eliminated either by periodically cleaning it from the walls of the lining mechanically, or by increasing the level of the metal in the crucible with a simultaneous increase in temperature and scrape the molten slag. This operation is accompanied by active mixing and can lead to the release of liquid metal due to the formation of a large meniscus, and therefore requires great care.

2. The formation of growths of refractory viscous slag in the upper and middle parts of the crucible. The removal of such growths is extremely difficult, mechanical cleaning from slag after each discharge is inefficient, some effect is obtained by carrying out smelting with the addition of cryolite, but it must be borne in mind that it is very actively eroding the lining. The most reliable method is to conduct smelting on sufficiently clean, charge materials.
3.3. Emergency Situations

Especially dangerous are situations of penetration of the molten metal through the entire layer of lining. The most difficult situations from the point of view of the correct operation of an industrial-frequency induction crucible furnace are the following:

1. The decrease in insulation resistance in the initial period of operation, and when switching to lower levels of power, the insulation resistance continues to fall. The reason is, as a rule, the formation of moisture on the coil of inductor and, as a result, in the lining of the furnace due to the depressurization of the coil itself. If you do not eliminate the cause of the formation of moisture, then there may come a moment when the metal through the cracks reaches the lining layer of high humidity and an explosion occurs. To avoid this situation, it is necessary to stop the furnace, drain the metal and eliminate the cause of the appearance of moisture. The most unpleasant thing is that this leads to the relining of the furnace.

2. Emergency exit of the furnace out of operation, accompanied by an explosion with the release of liquid metal and the formation of a hole in the lining, through which the metal passed to the inductor and the furnace body. The lining of the crucible retained good condition. The cause may be the appearance of micro cracks in the coil of inductor due to a short circuit due to insulation failure, leading to the appearance of water leaks from the inside of the coils of inductor. As a certain amount of lining wear or cracks occurs, the metal comes into contact with the raw lining, resulting in an explosion. Measures to prevent such a situation are: cleaning and inspecting the inductor after each campaign and if damage is detected in the inductor insulation, carrying out the necessary repairs; when assembling an inductor, it is necessary to well bind the coils in the axial direction; in order to reduce vibration during the campaign, to tighten the fastening studs; prevent damage to the inductor during lining knockout.

3. The passage of liquid metal through the lining at the level of junction of the inductor with the upper concrete ring of the furnace or with refractory masonry, and the metal penetrates from the side opposite the drain tip of the furnace. The reason for this is itself constructive execution of the lining and the subsequent mode of sintering it, even in the case of performing these processes with strict observance of the generally accepted technology for induction crucible furnaces of industrial frequency. The explanation is as follows: based on the design features of the furnace, the lining is performed above the upper turns of the inductor and during sintering the lining layer, which is above these turns, does not acquire the necessary strength. The lining layer, located in the area of the drain toe, gradually reaches the necessary strength because in this place the metal with the high temperature constantly merges. When metal penetrates, the hoses ignite and the inductor is damaged and, therefore, the furnace fails for a long time. For this reason, the operational documentation specifies the requirement at which top level the melt can be kept in the furnace. Therefore, for the IChT-2.5 furnace, the upper level of the melt in the furnace should be 300 mm below the working platform. A measure to prevent this phenomenon is only strict compliance with the above conditions. Above this level can only be slag.

4. The passage of liquid metal down through the hearth of the furnace. The reason may be insufficient quality lining of the bottom (low packing density), work with the “swamp” of less than 1/3 of the crucible volume and long-term exposure of a small amount of metal at high temperature. Especially dangerous is the creation of conditions for the formation of a “bridge” of unmelted charge with simultaneous supply of high power [20].

4. Conclusions

As a result of the research, the following was established:

1. Ways to prevent the formation of cracks in the form of “grid”; vertical cracks of considerable thickness and depth; horizontal cracks of considerable thickness and depth; horizontal or vertical cracks through the entire thickness of the lining to the inductor and loosening and peeling the lining in the initial period of operation.

2. Methods of eliminating the resulting slag growths.
3. Ways to eliminate emergency situations of failure of the lining, arising from violations of operating rules when working on a smelting furnace.

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