Lecture Notes in Networks and Systems 733

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Fundamental and Applied Scientific Research in the Development of Agriculture in the Far East (AFE-2022)

Agricultural Cyber-Physical Systems, Volume 1

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Contents

Transportation of Liquid Slag in Cast Iron Slag Bowls

Dmitriy Lubyanoi, Evgeniy Kuzin, Evgeniy Zvarych, Dmitriy Malyshkin, and Olga Semenova

Abstract The paper considers the transportation of liquid blast furnace slag in slag bowls made of blast furnace, cast iron. The cast-iron slag bowls are made to have high operational resistance. The article proposes technologies for modifying cast iron by pulsating purging and micro alloying with titanium and vanadium. The research proposes new time limits for modeling of the rail transportation of molten slag. The authors offer a model describing the maximum length of movement of molten slag. They also introduce a new model to determine the optimization criterion. The paper also considers the applicability of different types of lubricants for the operation of slag trucks. It has found that it is possible to apply blast furnace cast iron, which is for casting the slag bowls. It is advisable to use purging of cast iron with nitrogen and micro alloying of cast iron with titanium and vanadium in order to improve its properties. Mathematical modeling makes it possible to evaluate the optimal operating mode of slag bowls. The existing lubricants provide regular operation of the bowls.

Keywords Transportation · Slag · Cast Iron · Lubrication

1 Introduction

This article discusses the industrial experience of using cast iron slag bowls at a metallurgical enterprise. The purpose of this study was to evaluate the possibility of using blast furnace cast iron for casting slag bowls of slag trucks. It is also to evaluate the possibility of improving the properties of blast furnace cast iron in various ways.

Transportation of liquid slag from blast furnaces to slag heaps is currently carried out by rail slag trucks (Fig. 1).

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Fig. 1 A cast-iron bowl of a slag carrier on a railway carriage

2 Materials and Methods

The research was carried out at the metallurgical enterprise JSC "EVRAZ-ZSMK" [1]. The research methods were described in detail in previously published papers [2–5].

The main content of the research methodology is based on the methods of alloying cast iron, leading to obtaining the required properties. Practical methods of alloying cast iron with vanadium, ferrophosphorus, manganese, titanium and silicon additives are proposed. By methods of mathematical statistics, regression models were obtained that take into account both the percentage of alloying elements and the technological modes of producing cast iron. The temperature regime at all stages of the technological process has a significant influence on the properties of the cast iron obtained.

3 Results

When transporting molten slag in blast furnace production, railway transport is used. When using a cast-iron slag bowl on a slag truck instead of steel, the temperature regime should have an important influence on operation of the slag bowl and the properties of cast iron. Therefore, the slag bowl of the slag truck should not transport the weight for a long time (1).

$$t_{tr1} \leq t_{body1} \quad (1)$$

t_{tr1}—is the time of transportation of molten slag, min;
t_{body1}—the heating time of the slag bowl to the limit state, min.

On the other hand, when the slag is drained, the slag bowl gradually begins to cool down, which leads to stresses and cracks. Therefore, the slag bowls should not stand idle for a long time (2).

$$t_{tr2} \leq t_{body2} \quad (2)$$

t_{tr2}—the time of finding the bowl of the slag truck in an empty state, min;
t_{body2}—the cooling time of the slag carrier bowl to the limit state, min.

The forward transport time includes the time of slag release from the blast furnace travel t_{fill}, time with slag t_{traf1}, and the time of draining the slag into the dump t_{dev} (3).

$$t_{tr1} = t_{fill} + t_{traf1} + t_{dev} \quad (3)$$

The time of movement of an empty slag truck includes the time of movement in the opposite direction t_{traf2}, time of waiting $t_{\exp}$.

$$t_{tr2} = t_{traf2} + t_{\exp} \quad (4)$$

It is possible to determine the heating time of the transport bowl to the limit state using the following dependencies (5) and (6).

$$t_{body1} = t(T; V) \quad (5)$$

$$t_{body2} = t(T) \quad (6)$$

T—the temperature of carried slag, K;
V—the volume of carried slag, m^3.

Then the travel time will be limited by the following conditions (7), (8).

$$\mathrm{t_{traf1}} \leq \mathrm{t(T; V)} - \mathrm{t_{fill}} - \mathrm{t_{dev}} \quad (7)$$

$$t_{traf2} \leq t(T) - t_{\exp} \quad (8)$$

The length of the trip will be limited

$$\begin{cases} L_{ij} \leq v \cdot \left(t(T; V) - t_{fill} - t_{dev}\right) \\ L_{ij} \leq v \cdot \left(t(T) - t_{\exp}\right) \end{cases} \quad (9)$$

In case when the bowl should not get very hot when moving in the forward direction, and cool down strongly when moving in the opposite direction, it leads to the need to develop a new optimization model that depends on time parameters. To determine the optimal distance between the objects of loading and objects for unloading, it is necessary to select a criterion. When solving a transport problem, it is proposed to take the minimum cost of transporting the entire cargo as an optimal criterion. Then the solution of the problem will be reduced to determining the minimum value of the following function (10)

$$F(t) = \sum_{i=1}^{m} \sum_{j=1}^{n} C_{ij}(t_{tr1}; t_{tr2}) \cdot V_{ij} \quad (10)$$

$C_{ij}(t_{tr1}; t_{tr2})$—cost of transportation of a unit volume of slag from the point of departure i to the destination j;
V_{ij}—volume of slag transported from the point of departure *i* to the point of destination *j*.

The cost of transportation of a weight item includes the cost of servicing a slag truck, which directly depends on its wear due to overheating. The establishment of dependencies between the cost of transportation and the temperature parameters of the slag carrier would make it possible to determine more accurately the optimal condition of the object of study. Although you can use the boundaries described in formulas (1) and (2) for a rough assessment of the state of the object.

In this research:

(1) new time limits were proposed for modeling the rail transportation of molten slag;
(2) a model was proposed describing the maximum length of movement of molten slag;
(3) a new model was proposed to determine the optimization criterion.

Measures have also been developed to improve the properties of cast iron used for casting slag bowls. Nano powders are used for effective modification of cast iron. The technology of manufacturing these powders is very complex and energy-intensive, requires the presence of planetary mills. However, the formation of titanium nitrides can also be carried out by endogenous methods, in particular due to the formation of titanium nitrides, first considered in [1]. It was found that during prolonged purging, nonmetallic inclusions—titanium nitrides—are generated in sufficient quantities in the melt. They serve as substrates for the formation of graphite (Fig. 2).

As the photo shows (Fig. 2) the size of non-metallic inclusions on the order of 0.05–0.1 of the division scale of the microscope (when the microscope is magnified

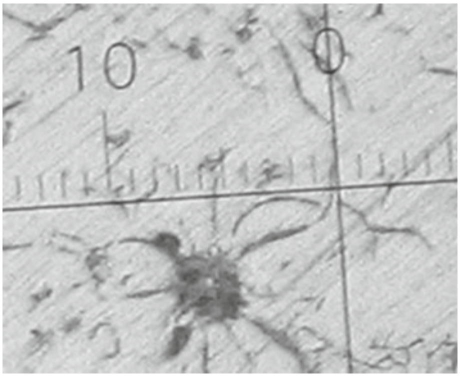

Fig. 2 Graphite nascent on a non-metallic inclusion

250, the division price is 0.004 mm). Consequently, the size of inclusions is 0.0002–0.0004 mm = (2–4) × 1077 m = 200–400 nm., which corresponds to nanoparticles. For a uniform distribution of particles in the bucket volume in the mill shop, we combine the treatment of cast iron with nitrogen with low and high-frequency melt treatment [1]. The production of blast furnace cast iron for casting bowls with a vanadium and titanium content of 0.10–0.12% is carried out during the operation of blast furnaces with a charge content of 10–12% of pellets of Kachkanarsky mining and processing plant. The technology [1] has also been tested, which provides for the periodic addition of pellets to the charge 9–10 h before the expected release of cast iron for the foundry. At the same time, this composition of the charge is maintained for 2–3 h [1]. The analysis of the blast furnace stroke showed that the episodic addition of pellets does not affect the quality of cast iron for converter production.

Resonantly pulsating nitrogen supply to liquid blast furnace cast iron leads to the release of carbon in the form of large inclusions of lamellar graphite and its removal with slag and exhaust gases. In addition, there is a uniform distribution by volume and effective assignment of alloying additives in cast iron. Such metal has higher strength characteristics corresponding to cast iron of the standard grade SCH15 (Tensile strength = 150–170 MPa).

Microstructure analysis (Fig. 3) showed that after out-of-furnace treatment of blast furnace cast iron, the size (length and thickness) of plate graphite inclusions decreases and a predominantly pearlite metal base is formed (Figs. 4, 5 and 6).

Evaluation of the quality of the microstructure (Fig. 7) showed that a significant amount of titanium nitrides is formed after purging (Fig. 7), which ensures a uniform distribution of graphite in the structure of cast iron (Fig. 6).

These technologies [3–5] provide high operational durability of products. Metal treatment with titanium and vanadium compounds, as presented in the literature [6–20], significantly improves the properties and quality of various products.

In the harsh conditions of metallurgical production, there is a tendency to increase the volume of transported goods, which means an increase in the loads on the supporting elements of the rolling stock. The axle boxes should attract a special attention, as they are the main supporting element of railway cars. In recent years,

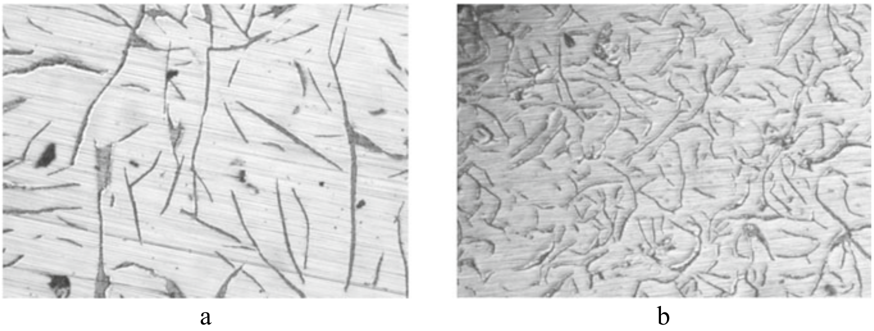

Fig. 3 Microstructure of blast furnace cast iron **a**—the original, **b**—after out-of-furnace treatment (magnification × 100)

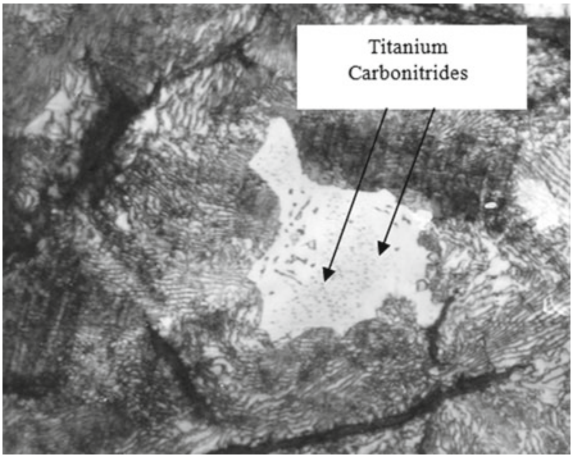

Fig. 4 Small titanium carbonitrides in phosphide eutectic P = 0.30% before purging (magnification × 800)

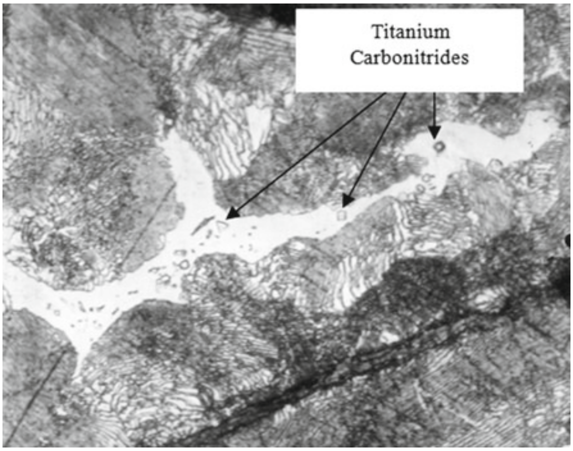

Fig. 5 Large titanium carbonitrides in phosphide eutectic P = 0.30% before purging (magnification × 800)

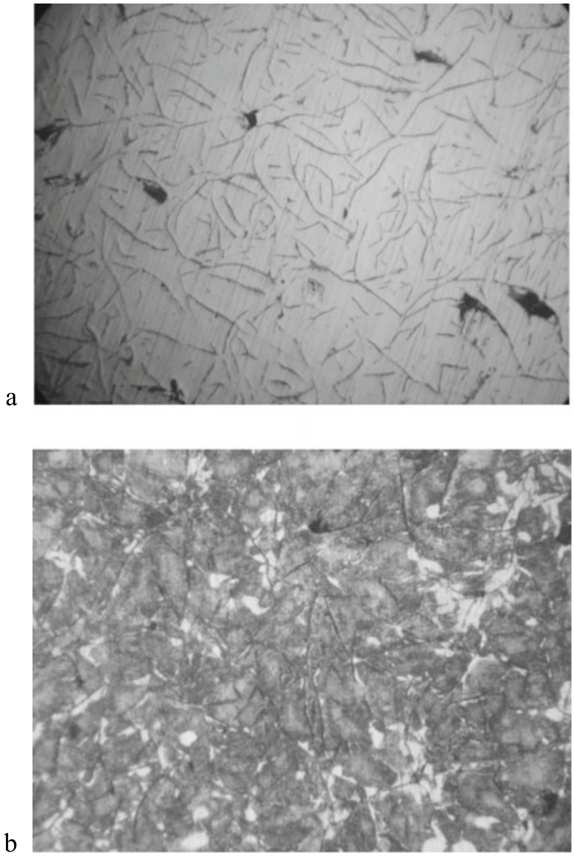

Fig. 6 Microstructure of cast iron of slag bowl No. 10907 (15 × 3) (increase × 100): Si = 1.03%, Mn = 0.70%, P = 0.18%,V = 0.06; (≈ 800 pours) **a**—not etched; **b**—etched

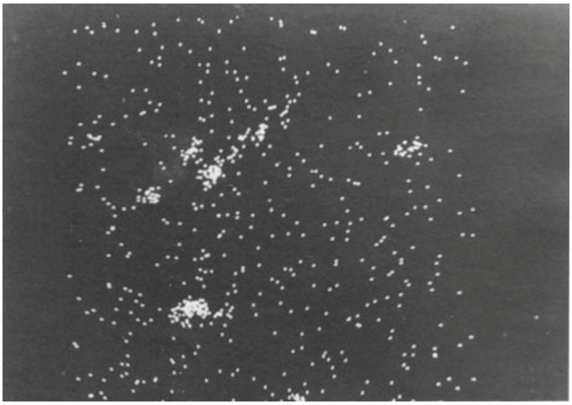

Fig. 7 Fine nitrides and carbonitrides in phosphide eutectic P = 0.30% after purging in resonance mode (magnification × 1200)

almost all modern railway transport has been equipped with axle boxes with rolling bearings. Moreover this type of bearings allows you to operate railway transport at higher travel speeds and withstand significant axial loads (especially roller bearings). During the operation of railway transport, bearings are subjected to significant alternating loads and thermal influences, which can result in fatigue failure. It also can lead to an abrasive wear of the working surfaces of bearing assembly elements, bullying, corrosion formation inside a particular unit, etc. Therefore, it is relevant to choose the appropriate lubricants that reduce the degree of influence of these factors.

Analysis of existing lubricants of bearing assemblies has shown that recent basis of the domestic assortment is 44.4%. Parameters of lubricants significantly affect the operation and the rate of wear of mechanical equipment [21]. It is outdated hydrated calcium lubricants (Solidols), the share of which is already small in developed countries. The production of sodium and sodium-calcium lubricants in Russia amounts 31% of the total volume, or up to 12.5 thousand tons/year. These materials have good characteristics and used at temperatures from −30 to + 100 °C. The share of other soap lubricants in Russia is small—0.3%, or 89 tons/year. These are products based on aluminum, zinc, mixed soaps (lithium-calcium, lithium-zinc, lithium-zinc-lead, barium-lead, etc.), as well as obtained by mixing the finished lubricant with metal powder. At sufficiently high loads and speeds, there is a significant heating of the elements of the bearing assemblies, as a result, these lubricants practically lose their properties. That happens since they contain soap additives that break down while being used at high temperatures.

At present, Buxol and Litol 24 lubricants have turned the most effective. The special additives included in the lubricant with extreme pressure and antioxidant properties allow this lubricant to reduce the formation of bullying, corrosion during intensive operation of the axle box. These types of lubricants contribute to the smooth operation of the bearing assemblies of wagons during the entire service life until the next revision.

Comparison of the operational properties of these materials showed that Buxol and Litol 24 are the most effective materials, due to the fact that:

Buxol consists of mineral oil thickened with the use of lithium soaps and a whole package of additives capable of not losing its operational properties when the ambient temperature changes from −60 °C to +60 °C and up to +120 °C directly in the friction unit itself. The axle box assembly of the rolling stock, equipped with a towbar, can operate at speeds of up to 200 km/h.

Litol-24 is made by thickening the base oil with lithium soaps. The composition of the lubricant includes additives that effectively improve the quality of Litol. They use lubricant for the treatment of rolling and sliding bearings operating under conditions of temperature change from −40 °C to +120 °C. The material retains its working properties with a short-term temperature increase up to +130 °C. Litol is stable in contact with water even when it boils.

If the temperature of the bearing assembly exceeds 200 °C, it is possible to use thickeners based on copper or boron nitride. The temperature stability of ceramic thickened greases is very high, reaching up to 1100 °C in some grades. The thickening additive creates a cellular structure that holds lubricant components and releases them when heated or mechanically deformed. At the same time, high-temperature lubricants are more expensive, the higher the temperature. For axle boxes of slag carriers, the temperature range is from 60 °C to 160 °C.

Mentioning all the above, we can conclude that the use of lubricants "Buksol" and "Litol 24" in modern metallurgical production is actual.

4 Discussion

The work stated that the transportation of liquid blast furnace slag in slag bowls from blast furnace cast iron is quite possible. The cast-iron slag bowls have been found to have a high operational resistance (800 pours or more). The article proposed technologies for modifying cast iron by pulsating purging and microalloying with titanium and vanadium. This treatment ensures that the cast iron structure is of acceptable quality. The work proposed a mathematical model that allows optimizing the operation of slag bowls. The paper also considers the applicability of different types of lubricants for the operation of slag trucks. The existing lubricants ensure the normal operation of the bowls.

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