Development of optimal formulations of natural alloyed cast irons for metals and engineering, and thermal timing subjected to secondary treatment by the method of resonance-intermittent refining

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Abstract. This article presents the results of the introduction of resonant-pulsed refining technology in production, which made it possible to change the microstructure of blast-furnace irons and significantly increase the operational stability of molds and pallets.

1. Introduction

In [1], the preparation of the melt for obtaining products from heat-resistant cast irons was considered, as noted above, the molten iron was purified from sulfur, stabilized at a certain level in terms of oxygen, hydrogen, and nitrogen. Thermo-time treatment within the specified melt limits allowed melt to be obtained with the cast iron structure most favorable for a particular grade of cast iron [2]. Purging cast iron with argon or nitrogen made it possible to refine cast iron from gases and inclusions of mellow graphite, to grind graphite inclusions to the required sizes to increase the strength properties of cast iron (table 1) without additives of additional alloying additives.

| Type of processing                             | Tensile strength (MPa) |
|-----------------------------------------------|------------------------|
| Nitrogen purge by resonant pulsed refining method | 130..170               |
| No purge                                      | 91..105                |
2. Technology description
Titanium and vanadium, which fall into cast iron with charge materials, microalloy cast iron by the mechanism [3, 4], and can neutralize the harmful effect of phosphorus in heat-resistant cast irons as well. All this made it possible to proceed to the development of the chemical composition of economically alloyed cast irons for castings with enhanced operational properties.

The greatest effect of this technology is achieved when nitrogen is treated with natural blast furnace titanium and vanadium cast iron. With this technology, endogenous carbonitrides of titanium and vanadium are formed in the metal volume at the nanoscale, which serve as substrates for the formation of fine graphite. These inclusions are shown in Figure 1. Metal processing by this technology allowed, due to a significant change in the mechanical properties of the cast iron base, to reduce the amount of alloying additives and cast castings from economically alloyed cast iron. The application of this technology has significantly improved the microstructure of cast iron products, increase and stabilize the resistance of replaceable steel casting equipment from blast iron.

3. Results and discussion
In the shop of cast iron molds, continuous, deep-flow molds and molds weighing up to 42 tons are currently being cast for casting forging ingots (Figure 2). To increase the resistance of through molds that fail due to bottom erosion, it is necessary to increase the strength of cast iron by alloying with manganese and modified by ferrosilicon; to increase the resistance of through molds to cracks, it is necessary to increase the heat resistance of cast iron of molds, while reducing the amount of interdendritic graphite in the cast iron structure and eliminating cementite in the structure cast iron, for which it is necessary to reduce the alloying of cast iron with manganese. Molds, both through and deaf, are cast from one ladle with the same chemical composition (table 2).
Figure 2. Large mold for forging ingots of power engineering from blast furnace pig iron weighing 42 tons.

Table 2. Chemical composition of cast iron for casting molds and slag bowls.

| C, %  | Si, % | Mn, % | P, % | S, % | Cr, % | Ti, V, % |
|-------|-------|-------|------|------|-------|----------|
| No more |       |       |     |      |       |          |
| Not regulated | 0.6..1.3 (molds) | 0.45..1 | 0.3  | 0.05 | 0.1   | 0.03..0.20 (optimum 0.06..0.12) |
| 0.9..1.3 (slag bowls) |                   |       |      |      |       |          |

Therefore, when choosing the chemical composition of cast iron, they are guided by what type of molds prevails when casting molds and the economic effect of saving ferroalloys when preparing cast iron for casting molds. Due to the fact that through mold production at JSC “EVRAZ ZSMK”, through molds are predominantly cast, as well as taking into account the savings of ferrosilicon and silicomanganese, molds are tried to be cast from cast iron by the silicon and manganese content mainly with the lower values of these elements indicated in Table 2.

Molds of different types can be cast from one bucket, therefore, the chemical composition of cast iron depends on the prevailing type. To improve the microstructure of cast iron, nitrogen purging is used by the method of resonant pulsating refining [4]. The essence of such refining consists in applying vibrations to the metal by pulsating blasting, in the spectrum of which there is a low-frequency component, which coincides with the natural frequency of the metal oscillations in the bucket. The use of this relatively simple technology, as shown by many years of experience in its practical use, can significantly improve the quality of casting. These works allowed to significantly improve the quality of products, to develop compositions of economically alloyed cast irons (table 2), which provide a significant reduction in the consumption of ferroalloys. After operation, cast iron molds are broken in combat pits, and the resulting mold battle is used as a charge in induction furnaces.
Figure 3. Dynamics of reducing the consumption of pallets for through molds at JSC “EVRAZ ZSMK”: 1 - cupola (ferritic iron); 2 - induction furnace, remelting of foundry and pig iron, without thermal treatment (ferritic-pearlite cast iron); 3 - induction furnace, with thermal treatment (perlite-ferritic cast iron); 4 - induction furnace, with thermal treatment, purging with argon (pearlitic low manganese cast iron); 5 - induction furnace, with thermal treatment, economically alloyed cast iron (structure - perlite).

Induction melting pig iron is used to obtain pallets, molds and covers for intermediate ladles of continuous casting machines. So, depending on the chemical composition and structure of cast iron, the operational durability of pallets of through molds is increased and their consumption is reduced (Fig. 3), the operational durability of the covers of intermediate ladles of casting continuous casting machines made of economically alloyed cast iron is increased, and the resistance of ingot molds for forging ingots is increased. The chemical composition of cast iron products is shown in table 3.

Table 3. The chemical composition of cast iron for the production of heat-resistant castings at JSC “EVRAZ ZSMK”.

| Alloy group                     | Grade of the alloy (or purpose) | C %  | Si %  | Mn %  | Cr %  | Ti %  | V %  | S, % no more | P, % |
|--------------------------------|---------------------------------|------|-------|-------|-------|-------|------|--------------|------|
| Gray heat resistant cast iron  | Pallets for molds and for casting ferroalloys | 3.6.. | 1.8.. | 0.4..0.8 | 0.03.. | 0.05 | 0.03.. | 0.05 | before 0.27 |
|                                | 3.8                             | 2.0  |       | 0.4..0.75 | 0.06.. | 0.15 | 0.06.. | 0.15 |            |
|                                | Economically alloyed cast iron for pallets, ladle covers of continuous casting machines | 3.85.. | 0.9.. | 0.4.. | 0.02.. | 0.05 | 0.02.. | 0.05 | 0.14.. 0.27 |
|                                | 4.0                             | 1.05 | 0.7   | no more 0.15 | 0.05 | 0.05 | 0.05 | 0.27 |
|                                | 3.85.. | 1.05.. | 0.4.. | 0.0.15 | 0.0.15 | before 0.27 |            |

After the introduction of steel frames installed in the form for the pallet, the durability of the pallets increased, and in 2019 their consumption reached 2.7 kg per ton of steel. Thus, the introduction of scientific methods allowed to reduce the consumption of pallets by 2.66 times.
Due to the fact that through-casting molds are mainly cast at the plant, as well as taking into account the saving of ferroalloys, molds for forging ingots and similar equipment are tried to be made of cast iron with a low content of manganese (0.45 - 0.8 %) and silicon (0.6 - 1.3 %), while carbon is not regulated, ≤ 0.3 % P, ≤ 0.05 % S, ≤ 0.1 % Cr, the optimal content of Ti and V is 0.06 - 0.12 %. In this regard, to obtain molds of maximum resistance, the content of titanium and vanadium was limited to 0.06-0.12 %.

A decrease in the content of titanium and vanadium below this limit adversely affects the resistance of molds to heat. The average operational stability of the blacksmith molds in this treatment reaches 50 bulk. The resistance of through molds at the plant reached 90 bulk (in 2007-2016 it was at the lowest level in the CIS of 11.98-12.05 kg per ton of steel) - this is the lowest consumption of molds in the industry [5]. In fact, the enterprise has reached the technological limit on the resistance of molds for gray cast iron. However, the use of cast iron molds with a given titanium and vanadium content is not limited to this. After operation, the molds are broken up in the pile shop and the battle is used as a charge in the induction furnaces of the foundry.

4. Conclusion
The developed technologies [1-5] allowed the plant to master the production of almost all types of blacksmith molds weighing up to 42 tons, allowing casting forge ingots for power engineering weighing up to 70 tons. The developed technologies made it possible to almost completely change the microstructure of blast-iron irons, to significantly increase the operational stability of molds, pallets, and their total consumption was reduced to the level of the best world indicators [5].

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