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Innovative Technology of Manufacturing of Reusable Metallurgical Equipment with Increased Operational Resistance from the Blast Furnace Cast Iron of the First Melting

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Authors' contributions

This work was carried out in collaboration between all authors. Author LVV designed the study, performed the statistical analysis, wrote the protocol and wrote the first draft of the manuscript. Authors VVA and DAL managed the analyses of the study. Author LVV managed the literature searches. All authors read and approved the final manuscript.

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ABSTRACT

The parameters of complex non-furnace treatment of liquid blast furnace cast iron with pulsating inert gas injection are elaborated. The new technology makes possible a significant increase in the operational resistance of reusable metallurgical equipment (molds, pallets, slag chalices). The possibility of reuse of naturally alloyed cast iron in the form of broken molds under induction melting conditions for heat-resistant articles is shown. As a result, the additives dissolving and the cast iron refining accelerate and the time of the casting process reduces. It has been experimentally proven that using the ultrasonic testing method (UT) to determine the longitudinal wave velocity in the mold it is possible to find the limit value of pourings providing the operation of molds without emergency destruction with molten metal leakage. This provides the safety of the process of steel castings manufacturing, the reduce of loss in steel dissolution and the preservation of the optimal ecologic environment in the foundry workshop.

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Keywords: Blast furnace cast iron; non-furnace treatment; pulsating blowing; molds; pallet; material properties; operational resistance; longitudinal wave velocity; cast iron microstructure; thermal cracks; thermal cyclic impact; dimensions of graphite inclusions; limit number of pourings; operational resistance of molds.

1. INTRODUCTION

The new effective technology of the liquid blast furnace pig iron non-furnace treatment that includes supplementary alloying with ferroalloys in the casting ladle along with the inert gas injection in molten metal by pulsating resonance refining (PRR) is elaborated and mastered.

The essence of this method of refining lies in the impact on the molten metal in the casting ladle by pulsating blowing of inert gas coming from a submerged blowing lance. At the same time the gas flow outflowing from the blowing lance causes intensive mixing of metal along with the activation of vibrations in the whole volume of molten metal because of numerous little bubbles popping up, that wasn't carried out before. These factors help to speed up the processes of melting of additives ad blast furnace pig iron refining, that reduces the time of the casting process.

It happens rather often that during the operation molds suddenly break down because of generation of vertical through thermal cracks in the corners of a mold with the leakage of significant volume of molten steel, Fig. 1.

To prevent sudden breaks, it is recommended to monitor the cast iron structure condition in the mold during its operation. In this article it is shown that it is possible to bring into reality by means of ultrasonic testing (UT) because physical and mechanical characteristics of cast iron (its form and the size of spare graphite inclusions) define its acoustic characteristics for non-alloyed cast irons, [1,2].

The main acoustic parameter characterizing the structure and strength of cast iron is the velocity of acoustic oscillations [3-5]. But so far there wasn't carried out the research dedicated to the influence the structure changes of cast iron castings (expressed in the longitudinal wave velocity changes) on the potential destruction of the castings under thermal impact.

2. EXPERIMENT

When implementing the new method of blowing in a pouring ladle with a capacity of 60 tons a special installation with two blowing lances (Fig. 2) is used.

A blowing lance represents a steel tube with an inner diameter of 41 mm lined on the outside with a fireproof material. To obtain pulsating oscillations of the gas flow coming from a blowing lance cylindrical gas-dynamic pulsators with a diameter of 16 mm installed in the gas path of a lance at a distance of 150 mm from the bottom end and of 70 mm from the upper end of a blowing lance are used. In the gas flow these pulsators form vortexes coming down with a determined frequency that depends on gas flow velocity and on geometrical parameters of the installation.

By varying vortexes detachment frequency, we obtain the optimum gas flow pulsation frequency in liquid blast furnace pig iron. By vibrating the metal with low-frequency oscillations (~1Hz) by means of pulsating blowing the intensity of filler ferroalloys melting and cast iron refining processes significantly increases.

Liquid blast furnace cast iron preparation for large-tonnage castings production (metallurgical and forging molds, slag chalices, pallets and other reusable equipment) is organized according to the following technology system [6]:

- Transfer of naturally alloyed liquid blast furnace pig iron with a temperature not less than 1360°C from blast furnace department to the foundry in cast iron carry ladles;
- Adjustment of chemical composition of blast furnace pig iron in a pouring ladle with a capacity of 60 tons by means of injecting the appropriate ferroalloys during the transfer of metal from a carry ladle;
- Transfer of the pouring ladle on the transfer trolley inside the installation for nitrogen injection in molten cast iron;
- Nitrogen blowing of liquid blast furnace pig iron in the pouring ladle by pulsating resonance refining with the temperature of 1240…1260°C within the stationary installation through two blowing lances submerged in the molten metal during 12…15 minutes with the overall gas consumption of 0,3…0,4 m^3 per minute and the pressure of 2,5...3 ATM;

- Pouring of prepared cast iron in casting molds for reusable metallurgical equipment with the temperature of 1210…1240°C.

Chemical composition of blast furnace pig iron before and after the nitrogen blowing is shown in the Table 1.

Fig. 1. A broken down mold with leaked alloy traces

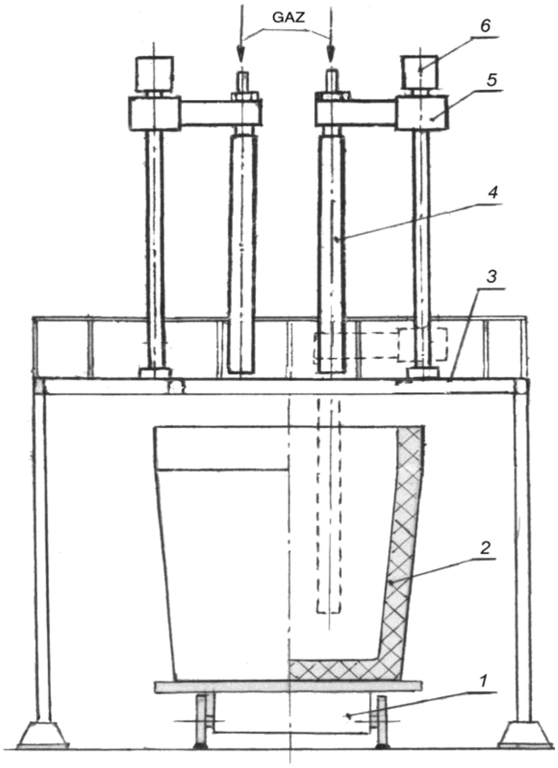


Fig. 2. Installation for nitrogen injection in the molten metal in pouring ladle

1 – transfer trolley, 2 – casting ladle, 3 – working area,
4 – blowing lance, 5 – mechanism for moving the blowing lance, 6 – drive unit for the mechanism

Table 1. Chemical composition of blast furnace cast irons

Cast iron type	**Mass fraction of elements, %**				
	C	**Si**	**Mn**	**V**	**Ti**
Original	4,4…4,6	0,35…0,65	0,35…0,40	0,10…0,15	0,10…0,15
After PRR	3,6…3,8	0,90…1,30	0,60…0,80	0,10…0,15	0,10…0,15

Technical Note: There are ≤0,15%P; ≤0,03%S and ≤0,1%Cr in both cast irons

The obtaining of blast furnace pig iron for reusable metallurgical equipment with the vanadium and titanium content of 0,12…0,15% is carried out with continuous functioning of blast furnace containing in its burden 10…12% of pellets from EVRAZ NTMK (Russian Federation). The technology providing periodical adding of pellets in the burden 9…10 hours before estimated release of cast iron for transferring it to the foundry is also elaborated. Hereby such chemical composition of burden is maintained during 2…3 hours. It is apparent from the analysis of the blast furnace functioning that episodic adding of pellets does not affect the quality of cast iron for metal production by converting.

Under nitrogen blowing of liquid blast furnace pig iron in pulsating resonance mode the content of carbon in the molten metal is reduced by 15…20%, and the carbon comes out in the form of graphite and is removed into slag or into the atmosphere with other gases. Concurrently, the effective assimilation of adding materials and even distribution of elements in metal through the whole volume of pouring ladle is occurring. This type of cast iron has higher strength characteristics that correspond to lamellar graphite cast iron of SCh15 standard model (R_m=150…170 Mpa).

The molds (Fig. 1) were casted from cast iron with lamellar graphite with the following chemical composition, %: 3,4-3,6 C; 1,9-2,1 Si; 0,6-0,8 Mn; 0,09-0,12 P; 0,05-0,06.

The steel temperature while releasing out of the furnace was 1500 – 1550°C. From one melting of 1000 kg there were casted two castings in two molds. Solidified castings withstanded 25-30 min in the molds. In the upper part mold walls were heated up to 650-700°C. Subsequently the ingots were drawn out by turning them by 180° and brought to the finished-products warehouse. The molds were cooled in a natural way until the inner surface temperature reached 200-300°C, then their inner surface was coated with fire-prevention coating and they were prepared for casting. The time of the operational cycle of molds until the next casting was 1,5-2 hours.

A comparative analysis of cast iron specimens cut from the upper side of the wall of a new mold and a mold after operation (near locations of the most probable destruction) has shown significant differences in cast iron microstructure.

The graphite in the microstructure of the new mold (Fig. 3) is lamellar, its distribution is uneven, its quantity is 5...8%, it is small and the length of inclusions is 30...60 µm.

Metal base (Fig. 4) of the cast iron is pearlitic, the pearlite is lamellar, the pearlite dispersity with the distance between the cementite layers is 0,...0,8 µm.

In the cast iron structure of a mold that has undergone operation and numerous thermal cycle impacts (Fig. 5) there is thicker and larger (120...250 µm) lamellar graphite in the amount of ≈12% of even distribution as well as numerous small graphite inclusions that result of partial graphitization of cementite layers of pearlite.

In this, the cast iron metal base (Fig. 6) is pearlite-ferritic with ferrite borders being formed around graphite inclusions. The pearlite is medium-lamellar.

The cast iron microstructure after thermal impact (Fig. 6) is characterized by large (rough) inclusions, increased lamellar graphite volume fraction and by presence of considerable (≈30%) ferrite fraction in mainly pearlytic metal base.

3. RESULTS AND DISCUSSION

It is apparent from microstructural analysis that after non-furnace treatment of blast furnace pig iron the size of lamellar graphite inclusions (their length and thickness) decreases and mainly perlite metal base is formed.

From treated blast furnace cast iron there are cast: metallurgical (12N1 and P8N) and forging (deaf-mute and through) molds for castings with the weight of 7 to 40 tons (Figs. 7, 8), and also cast iron slag transporters chalices with the weight of 32 tons (Fig. 9).

Mean operational resistance of metallurgical molds (with the weight of 10…12 tons and wall thickness of 160...200 mm) from the blast furnace pig iron of the first melting constitutes 90 pourings that provides the lowest mold consumption per 1 ton of steel in the industry.

Forging molds from blast furnace pig iron that underwent non-furnace treatment also have high operational resistance:

- That of molds for castings of the weight of 7…10 tons (wall thickness of 180...190 мм) is not less than 60 pourings,

- That of molds for castings of the weight of 30…40 tons (wall thickness of 300...350 мм) is not less than 40 pourings,

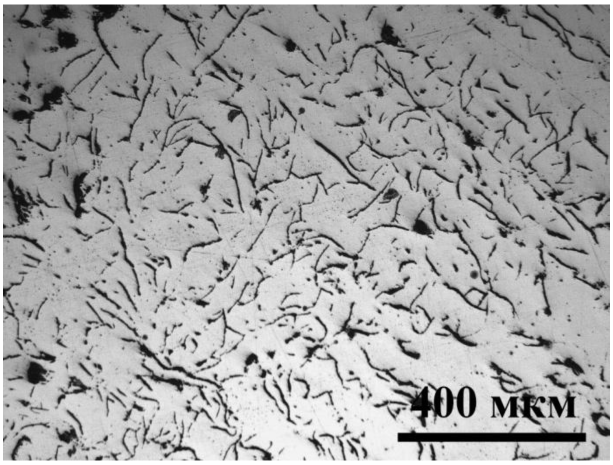
Hereby the cost price of molds is ~1,5 times lower because of using of the blast furnace pig iron of the first melting for their production.

Cast iron slag chalices are far less expensive to make in comparison with the ones made of steel and they have shown high working capacity that has constituted 1350…1400 cycles of loading and unloading of liquid blast furnace slag.

The longitudinal ultrasonic wave velocity in the mold was identified on the wall (thickness about 50 mm) with echo method by the time of the bottom echo arrival. The signal was distinguished from white and structural noise using special equipment with the system of optimal filtration of echo-signal which was developped in Moscow Power Engineering Institute [7-10]. The ultrasonic frequency was 1 MHz.

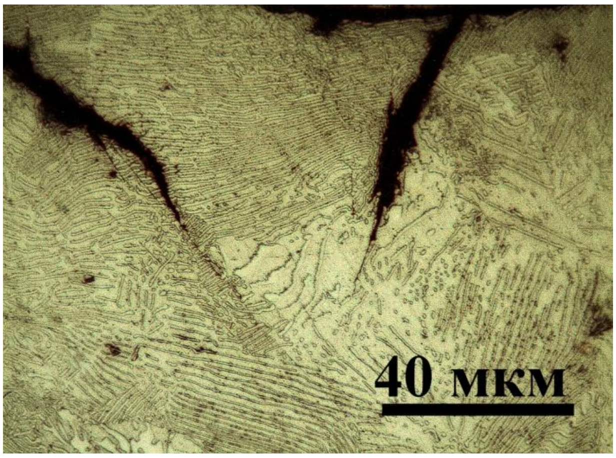
It is apparent from the test results (Table 2) that during the operation in consequence of changes having occurred in cast iron structure under influence of high temperatures and thermal cycle loads the longitudinal ultrasonic wave velocity in molds naturally decreasesт [11,12].

The practical result of present investigations is the establishment of the limit value of the longitudinal ultrasonic oscillations velocity (≈4040 m/s) in cast iron of the molds of the present construction to determine by ultrasonic testing (UT) the limit value of pourings providing the operation of molds without emergency destruction with molten metal leakage. Further decision about operation prolongation of such molds can be taken with supplementary measures for safe operation (for example, mold banding can be used).



Not etched, x100

Fig. 3. Graphite form in the cast iron of the new mold

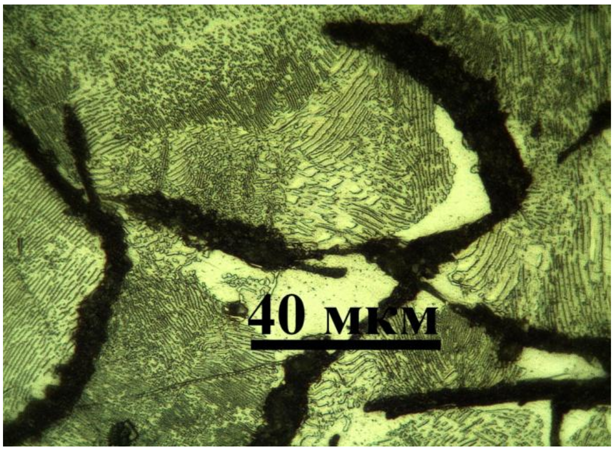


Etched, x500

Fig. 4. Metal base of the cast iron in the new mold

Not etched, x100

Fig. 5. Graphite form in the cast iron of the mold after operation



Etched, x500

Fig. 6. Cast iron metal base of the mold after operation

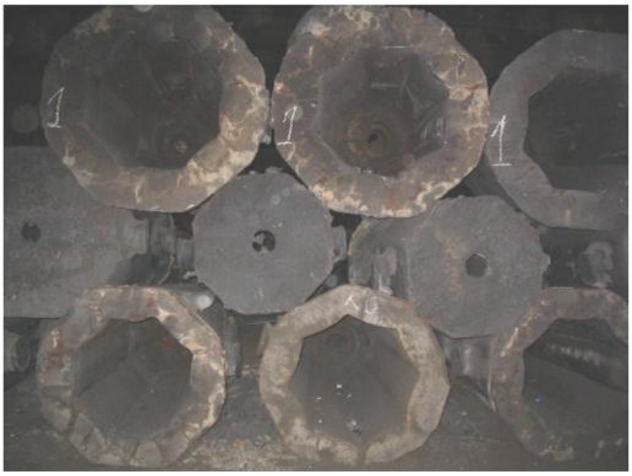


Fig. 7. Deaf-mute molds for forging castings with the weight of 7…10 tons

Fig. 8. A through mold for a forging casting (the weight is 42 tons, the wall thickness is 350 mm)

Fig. 9. Slag chalice on a slag-transfer platform (the volume is 15m3, the height is 3240 mm, the diameter is 3740 mm)

Table 2. Ultrasonic wave velocity in the examined molds

Mold characteristics	US wave velocity, m/s	Relative change
Molds that were destroyed with the opening of deep through cracks and with the leakage of metal	3740 3750	0,86
Molds that underwent the operation before the appearance of small cracks in corners	4020 4040	0,93
New molds	4280 4340	1,0

4. CONCLUSION

High operational resistance of articles from the blast furnace pig iron of the first melting is provided by the effective non-furnace treatment with nitrogen injection in molten metal in pulsating resonance mode. As a result of the suggested technology the time required for the casting process is reduced which reduces the cost of the casting.

Knowing the level of decrease of US oscillations velocity in cast iron of the mold during the operation from the original value (in the new mold) it is possible to confidently predict the emergency failure probability of the mold during its further operation. Structure changes in the casting under thermal impact provided the velocity decrease of the longitudinal ultrasonic wave by ≈14% by the end of the operation of the mold. The influence of graphite inclusion dimensions [13] and lamellar graphite proportion [14] on the velocity of the longitudinal ultrasonic wave in cast iron was explored on the probes. In this article the overall dependency of longitudinal ultrasonic wave velocity on size and content of the lamellar graphite was obtained not on cast iron probes but on real cast iron castings.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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