Increase of grinding balls service durability in the inoculation of cast iron primitive liquid by briquette nanomodifiers

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Abstract
Research of the influence of cast iron processing by nanodisperse high-melting compounds on quality of cast balls is carried out and their choice for cast iron melts processing is proved. Optimum quantity of modifying agent is 0.030…0.035% of TiCN. The technology of nanomaterials putting into cast iron in the form of briquettes is developed and passed experimental-industrial test. Tests of balks industrial party showed the increase of their service durability - from 22 up to 27% and reduction of their consumption from 0.5...0.8% to 0.13…0.3% from the mass of processed ore.
Key words: CAST IRON, GRINDING BALLS, CHILL MOLD, NANODISPERSE MODIFICATOR, BRIQUETTES, HARDNESS, IMPULSE RESISTANCE, SERVICE DURABILITY

Issue status and problem formulation

Cast iron grinding balls are used in drum mills for ore, clinker, coal and other materials degradation. The balls quality determines the efficiency of material grinding [1-3].

In Ukraine, the main method of the balls production is chilling in ball-casting machines [4-6]; at PJSC “ArcelorMittal Kryvyi Rih” the balls of Ø60 mm - on the conveyor-chill mould utility installation of KKU-1 type [7].

Cast iron grinding balls, having sufficient hardness, have lower impulse resistance compared with steel balls. However, steel balls are relatively expensive and have non-uniform hardness in volume (from 45...50 HRC on the surface up to 15...20 HRC in the center), which causes their low service durability. Therefore, the present study aimed at improving the resistance of grinding balls of iron, obtained by disperse and nanodisperse (less than 0.1 mkm or 100 nm) materials modifying is important.

Purpose of the study

The aim of the study is to improve the quality and working properties of cast iron grinding balls by liquid-alloy modifying by nanodisperse materials, as well as the development of recommendations for the implementation of technological process of high quality balls casting.

Main results

The most promising direction in the modification of cast iron is the use of nanodisperse modifiers, which effectively influence the crystallization of graphite phase, primary grain and non-metallic inclusions, activating the latter as more heterogeneous graphitization centers [8].

Research of the influence of cast iron processing by nanodisperse high-melting compounds on quality of cast balls is carried out and their choice for cast iron melts processing is proved. Theoretical evaluation of the influence of chemical composition of modifier material on modification mechanism and crystallization processes in cast iron.

Considering the modifying process with position of modifying additions interaction with cast iron liquid, all applicable materials can be divided into three groups: soluble, hard-melting and destruct. Soluble additions include known modifiers of graphitizing and spheroidizing effects (Si, Al, C, Ti, Sr, Mg, P3M, Y etc.), as well as metal powders and granules, which have inoculazing effect on liquid-alloy. Modifiers, degradable in liquid-alloy are: SiC, Ca2C, Si3N4, AlN of graphitizing effect and Mg2Si, Mg3N2, MgC2 of spheroidizing effect.

To improve the impulse- and wear-resistance of iron grinding balls it is most appropriate to apply the inoculating modification. The main criteria for the modifying efficiency of high-melting compounds evaluation are: melting temperature, formation enthalpy change, conductivity type and solubility in liquid-alloy. The higher the thermodynamic stability of compound, the greater the difference between compound melting temperatures and liquid-alloy, the less the solubility and existence of modifier electron affinity with liquid-alloy are, the higher its efficiency is. Comparative analysis of thermodynamic parameters of high-melting slightly-soluble compounds allowed to arrange them in the descending by modifying efficiency range:

$$TiCN \rightarrow TiC \rightarrow ZrC \rightarrow TiN \rightarrow ZrN \rightarrow VC \rightarrow WC \rightarrow B_4C \rightarrow SiC.$$

Based on the analysis 4 nanomodifiers - TiCN, TiC, B4C and SiC are selected for the research and experimental smeltings on cast iron modification for grinding balls casting are carried out.

Calculation and experimental data showed that nanomaterials in liquid-alloy have sufficiently high kinetic stability, substantially uniformly distributed throughout the liquid-alloy height in ladle. It was found that titanium compounds with carbon and nitrogen - titanium carbonitride (TiCN) - completely meet the requirements for hard-melting inoculating modifiers.

Macrostructure of cast balls (Fig. 1) confirms the selection correctness as an effective nanodisperse modifier - titanium carbonitride (Fig. 1d). Balls molded from modified TiCN iron have slight shrinkage defects that are located in the middle of casting, which practically excludes their split during use. The macrostructure of balls from unmodified (Fig. 1a) and the modified SiC (Fig. 1b), TiC (Fig. 1c) and B4C (Fig. 1e) iron has a coarse columnar structure with more shrinkage defects that cause their low service durability.

Analysis of the research results showed that the optimum amount of modifying agent is 0.030...0.035% TiCN. The most effective balls structure is the presence of chill up to 10.0 mm in depth in the surface layer, the transition zone and perlite-ferrite matrix with finely-divided graphite in core. It is found that balls hardness after modification increases in average from 45 to 50 HRC in surface layer, and impulse resistance, defined on drop-testing machine of K01 type, increases from 25 to 28 impulses.

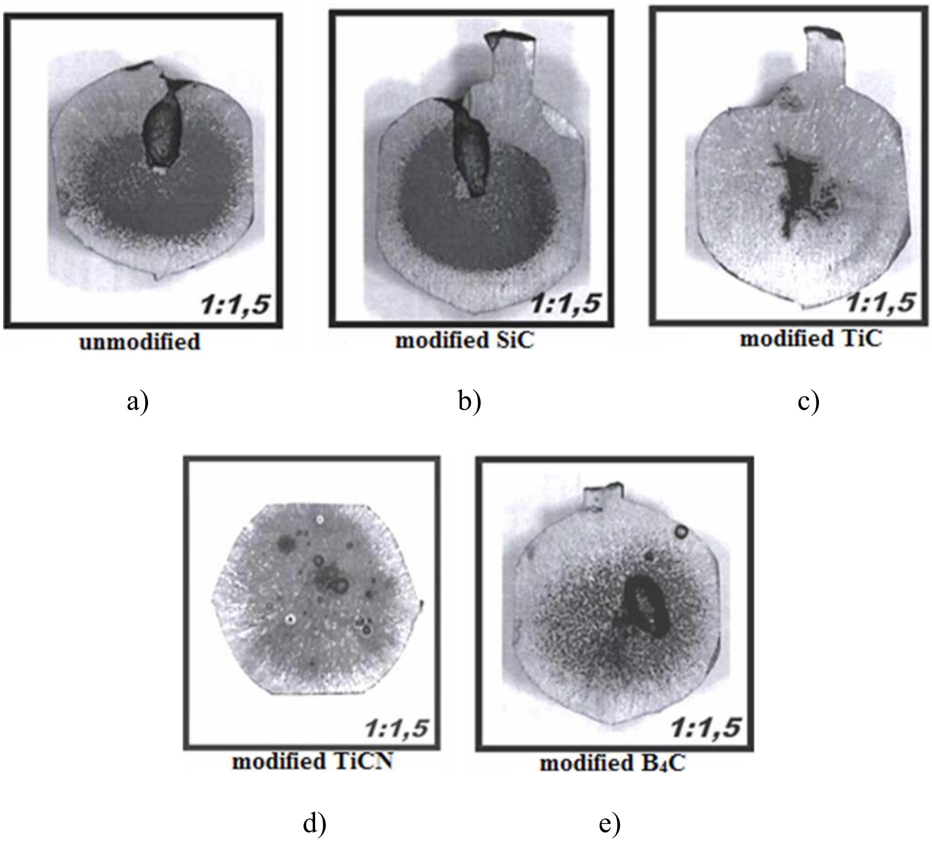

Figure 1. The macrostructure balls, cast from unmodified (a) and modified SiC (b), TiC (c), TiCN (d), B_4C (e) iron

Using nanodisperse materials the most effective is their putting into the ladle in the form of briquettes. The requirements for modifying briquettes are formed and the technology of their production with dimensions Ø 30...50 and a height of 15...20 mm by means of their pressing [9-10] is developed.

Experimental-industrial research to determine the rational composition of briquettes is carried out. Liquid-alloy processing was held in a 1-ton ladle with partition according to the "sandwich process" technology and subsequent casting on conveyor-chill casting machine at nanodisperse titanium carbonitride (TiCN) consumption in amount of 0.030...0.035% from metal weight.

It was found that optimal is the following composition of briquette: 65...70% of nanodisperse powder TiCN, which particles are additional crystallization centers, grinding dendritic structure austenite, and 30...35% of the organic binder in the form of flour production waste.

In addition, the organic binder effect on briquette destruction and the associated time of its dissolution in liquid-alloy were investigated. Organic binder is a natural polymer, which is composed of nitric-acid and acetic acid aethers with extremely high reactivity. Intensive gasification of the briquettes allowed to combine the process of modifier dissolving in liquid-alloy with processes of temperature raising at the briquette surface contact with liquid-alloy and, thereby, significantly reduce its dissolution time.

The results analysis of briquettes gasification studies showed that their destruction process is connected with rupture of briquette body under the action of internal pressure due to gas release during binder decomposition, leading to briquette gradual decrease in size, formation of pores and cracks. In this regard, due to metal penetration into these pores the briquette dissolution time decreases from 8...10 to 4...5 min. with modifier consumption increasing up to 95...97%.

To determine the casting temperature effect on shrinkage defects value the computer simulations of casting and crystallization processes of cast iron in chill of conveyor-chill mould utility installation were carried out. Chemical composition of grinding balls for simulation is shown in Table. Composition №3 is selected as a result of technical literature analysis for comparative characteristics, since it is the most durable.

Table. Chemical composition of grinding balls

Cast iron	Chemical composition, %							
	C	Mn	Si	S	P	Cr	Ni	Ti
№1 corresponding TT090-008:2008	3.2-3.6	0.3-0.5	0.8-1.5	to 0.1	to 0.12	0.3-0.6	0.4-1.2	-
№2 modified TiCN	3.86	0.33	1.05	0.017	0.074	0.105	0.01	0.015
№3 ICHKH28N2	2.9	0.6	1	0.1	0.1	29	2.5	-

Given the statistical analysis of balls casting temperatures on conveyor-chill mould utility installation the following temperatures: 1280°C, 1320°C, 1350°C and 1380°C were chosen for simulation. The results of sinkholes formation prediction are shown in Fig. 2.

The analysis of simulation results showed that pouring temperature rise to 1380°C increases the amount of sinkholes. Based on these results, casting temperature in the range of 1280 - 1320°C is recommended.

The results of experimental-industrial batch cast balls mechanical properties test showed that the hardness of modified cast iron balls compared with serial technology balls rose in average from 45 to 60 HRC, the impulse resistance - from 25 to 32 impulses.

Operational tests of balls modified by briquetted nanodisperse materials showed that their service durability is 22-27% higher compared to serial production balls and ball consumption was reduced from 0.5...0.8% to 0.13...0.3 % from processed ore weight.

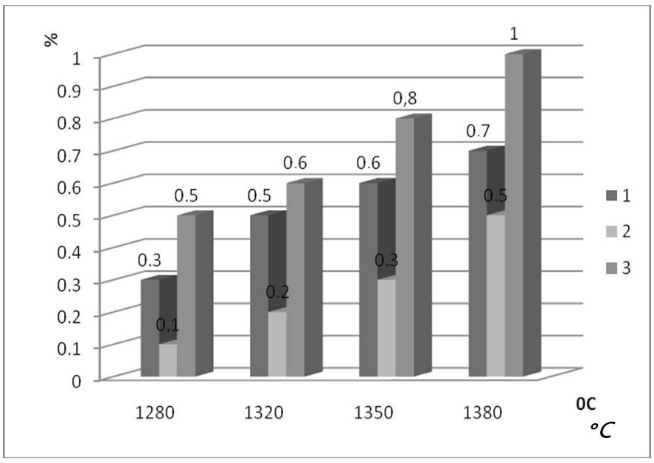

Figure 2. Prediction of sinkholes volume at different pouring temperatures: 1, 2, 3 – for chemical composition of balls№1, №2 and №3 respectively

Conclusions

1. Analysis of the experiments results allowed to reveal that the most effective modifier is titanium carbonitride (TiCN), putting which into liquid-alloy the experimental balls hardness rose in average from 45 to 50 HRC, and the impulse resistance - from 25 to 28 impulses.

2. The input technology of nanomaterials in the form of briquettes, in which the dissolution time of briquette is reduced from 8...10 to 4...5 min. and modifier consumption increases up to 95...97% was developed and passed experimental-industrial test.

3. The pilot batch of balls from cast iron, modified by briquettes based on nanodisperse TiCN is poured, and their comparative test with balls, poured according to current technology of PJSC "ArcelorMittal Kryvyi Rih" is carried out. The analysis of research results showed that balls hardness increased in average from 45 to 60 HRC, service durability increased from 22 to 27% and balls consumption decreased from 0.5...0.8% to 0.13 ... 0.3% from processed ore weight.

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