Increase of resistance of steel moulds using the complex modifier INSTEEL-7

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In this paper the authors examined the problem of insufficient operating resistance of moulds which are used for manufacture of steel ingots. Massive moulds, usually made from cast iron and sometimes from carbon steel, are used conventionally for production of steel ingots. Operating resistance of moulds depends of many factors and it can be maximized when three most important requirements are executed: structural strength; resistance to slopping of internal surface of mould walls during contact with liquid steel melt; ability of mould walls to hold thermal and mechanical effects. Satisfaction of the first two requirements is achieved via varying the mould wall thickness, while meeting the third requirement is determined by correct material choice. This choice, in its turn, is impossible without deep analysis of the problems occurring during mould operation and signs of their reject, such as cracks, erosion nets and burn-backs. Improvement of mould material parameters during their manufacture via casting seems to be the most prospective solution for increase of mould resistance. In this connection, the described research was aimed on formulating the scientifically substantiated choice of the initial material for moulds, which are used for manufacture of steel ingots in the conditions of the operating industrial production facilities (1), and the complex of experimental investigations in order to improve parameters of this material via technological methods of liquid phase treatment (2). The ingots made from carbon steel were chosen as initial material, while modifying and microalloying by the complex modifier INSTEEL-7 (produced by NPP "Tekhnologiya", Chelyabinsk) were used for liquid phase treatment of initial material for improvement of its properties. Based on the results of conducted pilot-experimental work, the following parameters were obtained: increase of impact toughness for modified metal almost by two times (in comparison with conventional metal), rise of tensile strength and yield strength by 8.5 % and 20 % respectively, decrease of relative elongation and area reduction by 27 % and by three times respectively, what provided increase of operating resistance of a mould more than by 2 times as a result.
Key words: mould, carbon steel, crack, erosion net, burn-back, operating resistance, steel ingot, liquid phase treatment, modifying, microalloying.
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Introduction

Massive cast iron or steel moulds are used at present time for manufacture of ingots. Usually moulds are fabricated from cast iron, and sometimes they are cast from carbon steel containing 0.20–0.45 % C.

Mould structure should be suitable for operation and has maximal possible strength. Operating resistance of a mould is characterized by number of cast-in ingots. Practically it depends on ingot weight and varies within the range 30–100 pieces.

The aim of this research is as follows: obtaining the increased physical-mechanical properties of modified metal in comparison with usually used metal, what finally provides increase of operating resistance of moulds.

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Resistance of moulds depends on composition and quality of steel (which is used for mould fabrication), on composition and temperature of cast-in steel, on operating conditions for moulds in the shop, on mould construction (for preset ingot mass) and on ingots holding time in moulds. Increase of ingots holding time in moulds leads to essential overheating of their walls, to growth of grain size and to rise of thermal stresses in mould walls. It finalizes in decrease of resistance of moulds [1–3].

For normal conditions of a mould operation, the main causes of moulds reject and removal from operation are forming of longitudinal and transversal cracks, origination of erosion nets on the internal surface, buckling of ingot walls etc. [4–8].

Respectively, the most important requirement to liquid meld during manufacture of high-quality moulds is provision of stable chemical composition, efficient microalloying and modifying.

Microalloying elements and modifiers provide obtaining of high-quality melts as well as creation of nucleation centers of crystallization, adjusting of crystal growth and diffusion processes in melt and solid phase, strengthening of metallic base, crystallization via the stable route [9–12].

The moulds from carbon steel were chosen as initial material for casting of forged and cylinder ingots from structural, tool, stainless steels and alloys with special properties in operating industrial conditions of Vyksa casting plant, in order to their consequent vacuum arc or electroslag remelting.

Experience of the authors of this paper displays, that it is quite sufficient to introduce one or two alloying components in liquid steel to provide increase of structural strength of cast products, while there should be essentially more such components to provide stable obtaining of the whole complex of properties. The complex modifiers (CM) [13] of three types are used for this purpose:

— refining CM, containing active elements (Mn, Si, Ca, Mg, Al, rare-earth metals (REM) etc.);

— strengthening CM, containing carbides, nitrides, which are forming as a result of interaction with corresponding elements and promote dispersion strengthening of metal base;

— refining-strengthening CM, which contain active elements and compounds [14–16].

The modifiers containing rare-earth metals, Ca, Ba are considered as efficient remedy for varying the nature and shape of non-metallic inclusions and for obtaining the most preferential kind of oxide inclusions in the shell of sulfides [17].

Materials and methods

The grade range of complex modifiers, which are manufactured in Russia, is presented rather widely. In particular, NPP “Tekhnologiya” (Chelyabinsk) fabricates different Fe–Si-based modifiers practically for all iron making and steelmaking production facilities. Overwhelming majority of products is manufactured as thin plates via quenching from liquid state. Advantages of such kind of modifiers are presented by high homogeneity of modifiers, increase of absorption ability at low temperatures, decrease of modifier consumption for obtaining the required results, reducing of pyro-effect during ladle treatment by modifiers containing rare-earth metals, improvement of reproducibility of modifying effect.

Charge composition is shown in the **Table 1**.

Table 1. **Charge composition**

Charge components	Mass, kg
Steel scrap	5,100
Return of carbon steel	500
Ferromanganese FMn78 GOST 4755-91	45
Ferrosilicon FS45 GOST 1415-93	130
Aluminium AV91 GOST 295-98	7
Silicocalcium SK25 GOST 4762-71	—
Slag-forming additives	225
Liquid metal in a ladle — 5,260 kg	

Technological parameters of a mould: mass 1.5 t, wall thickness 100 ± 3 mm, top diameter 710 ± 3 mm, bottom diameter 570 ± 3 mm.

When conducting the researches, the main grounds of the modern theory of steelmaking processes are used, as well as standard methods and techniques if investigation of chemical composition and mechanical properties of steel, pilot-industrial melts in the operating electric arc furnace.

Results and discussion

The complex modifier INSTEEL-7, manufactured by NPP “Tekhnologiya” (Chelyabinsk), was used during pilot-experimental research in the conditions of operating production facilities at Vyksa casting plant for fabrication of “Mould” castings from 20L steel, in order to increase mould resistance via modifying and microalloying. Actual content of chemical elements in this modifier is presented in the **Table 2**.

The complex modifier INSTEEL-7 contains the following elements: alkaline-earth elements, Si, Ti, Al, REM, which provide carbonitride strengthening, improvement of hardness, impact strength, heat resistance and scale resistance (from one side) and determine the type, shape, number and uniformity of distribution of forming non-metallic inclusions (from other side).

The pilot melt from 20L steel was conducted in the electric arc furnace DSP-6.0 with basic lining. Charge was

Table 2. **Chemical composition of the complex modifier INSTEEL–7 TU 082-002-72684889-2015, fraction 1.0–10 mm**

	Mass part [1], %					
Elements	Ca	Ba	Al	REM	Ti	Si
Actual content	12.0	5.6	0.4	5.1	8.1	48.2

[1] The rest is Fe.

loaded in the furnace and molten. Steel chemical composition was controlled by sampling step-by-step during melting: I – just after melting; II – after slag pouring; III – after final processing before melt tapping; IV – in ladle.

The results are presented in the **Table 3**.

Table 3. **The results of control of pilot steel chemical composition during melting**

Element	I	II	III	IV
C	0.608	0.278	0.182	0.230
Si	0.09	0.001	0.312	0.478
Mn	0.431	0.189	0.615	0.715
P	0.015	0.015	0.015	0.016
S	0.012	0.01	0.008	0.007
Mg	0.002	0.009	0.002	0.006
Cr	0.076	0.049	0.074	0.083
Ni	0.154	0.164	0.165	0.167
Mo	0.091	0.080	0.083	0.083
A1	0.414	0.067	0.088	0.089
Ti	0.001	<0.001	0.001	0.014
V	0.005	0.001	0.003	0.005
W	<0.003	<0.003	<0.003	<0.003
Co	0.034	0.032	0.032	0.033
Sn	0.002	<0.001	0.001	0.002
Pb	0.004	<0.001	0.003	0.004
As	<0.002	<0.001	<0.001	<0.002

Steel tapping in a ladle was implemented at the temperature 1570 °C, ladle temperature was 630 °C (based on the results of the control by an optical pyrometer). Melt processing by the modifier INSTEEL-7 was conducted in the ladle. This modifier was introduced to ladle bottom during its filling, consumption of the modifier was 2.5 kg per 1 t of steel (25 % per ton).

Ladle treatment of steel allows to provide the preset chemical composition of this steel, to optimize the melt temperature, to decrease sulfur content and contamination by non-metallic inclusions. Mechanical properties of the pilot steel were controlled on the samples (5 samples for each parameter). The results of testing are presented in the **Table 4**.

The data about chemical composition and mechanical properties of 20L steel in correspondence with the requirements of GOST 977-88 are displayed for comparison in the **Tables 5** and **6**.

As a result, the average resistance until appearance of the signs of moulds reject (5 moulds), which sere manufactured with melt ladle treatment by alloying composition, made 47 pourings, while average resistance of the moulds manufactured without additional treatment was 20 pourings (**Table 7**).

Actually, the less is sulfur content, the less is content of non-metallic inclusions and, respectively, the higher are metal quality and mechanical properties. The complex modifier includes active desulfurizers Ca, Ba, REM (see Table 2) and desulfurization occurs as a result of interaction (see Table 3).

Conclusions

Modifying of initial carbon steel by the complex modifier INSTEEL-7 has led to decrease of sulfur content from 0.012 to 0.007 % in finished metal of mould material. It is connected with forming of complex compounds with sulfur via metal processing by REM modifier. Obtained complex compounds can be effectively removed out of the melt.

Increase of impact strength for modified metal (in comparison with usual metal) was obtained in average from 49.1 to 87.0 J/cm²; tensile strength and yield strength increased from 412 to 450 MPa and from 216 to 355 MPa respectively, while relative elongation and relative area reduction decreased from 22 to 16 % and from 35 to 11 % respectively. As a result, it provided rise of operating resistance of moulds more than by 2 times.

Table 4. **The results of mechanical testing of the pilot steel**

Tensile strength $\sigma_в$, MPa	Yield strength $\sigma_т$, MPa	Relative elongation after bursting δ, %	Area reduction ψ, %	Impact strength J/cm²
450	355	11	16	87

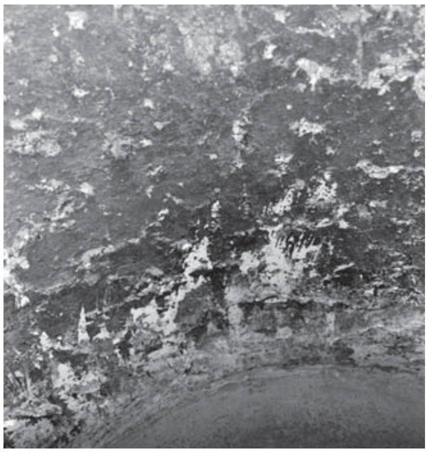
Table 5. **Chemical composition of the steel 20L (GOST - 977-88)**

Mass part, %							
C	Si	Mn	P	S	Cr	Ni	Cu
0.20	0.17–0.37	0.35–0.60	0.035	0.04	0.20	0.30	0.30

Table 6. **Mechanical properties of the steel 20L at the temperature T=20 °C (GOST – 977-88)**

State	Tensile strength $\sigma_в$, MPa	Yield strength $\sigma_т$, MPa	Relative elongation after bursting δ, %	Area reduction ψ, %	Impact strength J/cm²
Normalization 880–900 °C, Tempering 630–650 °C	412	216	22	35	49.1

Table 7. **State of moulds during their operation**

40 pourings, mould with modifying		
20 pourings, mould without modifying		

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