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MATERIALS FOR CONVEYOR POURING INGOT MOULDS OF NON-FERROUS ALLOYS

MATERIAŁY DO ODLEWANIA STOPÓW METALI NIEŻELAZNYCH DO WLEWNIC PRZY UŻYCIU PRZENOŚNIKÓW

Researches on increase of graphite steel mechanical properties and thermal stability were executed with the purpose of its application for conveyor pouring ingot moulds of non-ferrous alloys. Influence of copper on structure, shape of graphite inclusions and parameters of thermostability of steel are investigated. It is shown, that alloying by copper in quantity of 1.2−1.8% results in essential increase in strength and thermal stability, and also in decrease of graphite steel scale formation at temperatures 750-900°.

Keywords: ingot mould, graphite steel, non-ferrous alloys

Zbadano zmiany właściwości mechanicznych i stabilności termicznej stali grafitowej, w celu ich zastosowania przy odlewaniu stopów metali nieżelaznych do wlewnic. Przeanalizowano wpływ miedzi na strukturę i kształt wtrąceń grafitowych, a także parametry stabilności termicznej stali. Wykazano, że dodanie miedzi do stopów w ilości 1.2-1.8% powoduje znaczny wzrost wytrzymałości i stabilności termicznej a także ogranicza powstawanie zgorzeliny w temperaturach 750-900°C.

1. Introduction

In non-ferrous metallurgy and foundry practice metallic moulds are applied to get ingots and castings. The main feature of their work is the cyclic thermal influence resulting in a gradient of temperatures in a body of moulds and occurrence of thermal stresses, in oxidation, decarburization and erosion of working surfaces, in formation thermal erosion grids and thermal fatigue cracks on them. During conveyor pouring processes, mould destruction is accelerated due to the application of compulsory cooling by water.

The essential factor determining resistance of metallic moulds to crack formation and to destruction in conditions of thermal cycle loadings is the optimum combination of physicomechanical properties of a material they are made of. In the work [1] the generalized parameter of material stability at thermal cycle loading is presented. It is named parameter of thermal stresses

$$K = \frac{\lambda \cdot \sigma_u}{\alpha \cdot E},$$

where λ – heat conductivity, W/m·°C;
σ_u – ultimate strength,MPa;
α – thermal expansion coefficient, 1/°C;
E – elastic modulus of elasticity, MPa.

2. Statement of a problem

From the above mentioned formula follows that thermostability of a material raises with the increase in heat conductivity (as a result of reduction of a temperature gradient and, accordingly, value of thermal stresses in the wall of the mould), strength, with the increase of which, the initiation and growth of thermal fatigue cracks is braked, and also with reduction of the thermal expansion and the coefficient elastic modulus. Grey and high-strength cast irons, which besides are the cheapest foundry alloys, meet the requirements imposed to the materials for metal moulds.

According to [2], during conveyor pouring of the aluminium and copper alloys in ingots, weight 6 and 13.5 kg accordingly, the temperature of the working surface reached 870-900°C and 550-570°C. The difference of temperatures of interior and exterior surfaces reached 260-300°C and 80-100°C at practically identical to aluminium and copper alloys thickness of a wall metallic

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moulds equaled 20-25 mm. The life of moulds made from high-strength cast iron at 2.6-3.3 time was higher than the life of moulds made from grey cast iron; the consumption of moulds from high-strength cast iron was high enough and equaled 0.46 kg/t of aluminium and 2.7 kg/t of copper alloys. The principal causes of failure of grey cast iron moulds were: thermal erosion grid, erosion of the working surface, thermal fatigue cracks; from high-strength one – thermal fatigue cracks and warping. These data correspond to the results of the work [3], in which presented are the data on life and safety of the moulds made from low-carbon steel, grey and high-strength cast irons and intended for pouring the copper alloys. The moulds from steel failed owing to warping, the ones from grey cast iron – owing to cracking, the ones from high-strength iron – owing to warping and cracking. The warping of steel metallic moulds took place after 300-400 pourings. The life of moulds from steel and high-strength cast iron was approximately identical and essentially surpassed life of moulds from grey cast iron.

Thus, to avoid warping, the material of the metal mould should possess high heat conductivity; and to avoid cracking the one should possess high strength and plasticity. In terms of this, graphite steels, representing hypereutectoid iron – carbon alloys with inclusions of graphite, are very noteworthy. They possess higher strength and plasticity in comparison with high-strength cast irons and surpass heat conductivity of low-carbon steels, due to graphite inclusions.

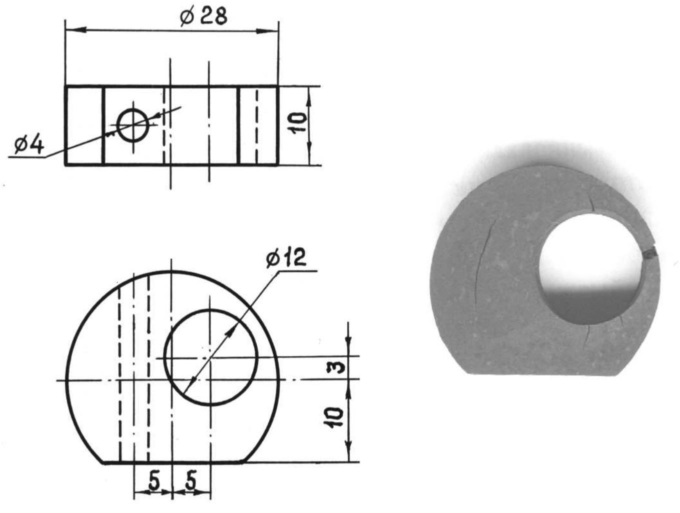
3. Technique of researches

In our work [4], devoted to optimization of chemical composition of graphite steel by the methods of mathematical planning of an experiment, it is shown, that the steel, containing 1.2-1.4% C and 1.4-1.6%Si, possesses optimum structure and mechanical properties. Also it has been established that copper in quantity about 1.5% renders positive influence on heat conductivity and mechanical properties of graphite steel.

That is why the possibility of graphite steel thermostability increase resulted from alloying by copper was studied. For this purpose in induction furnace IST-120 with the basic lining, the steel of the chemical composition structure: 1.24%C; 1.41%Si; 0.46%Mn; 0.028%S; 0.022%P with the maintenance of copper growing from 0.02 up to 3.08% was melted. Samples for tests have been made from received during fractional pouring ingots in weight of 20 kg after graphiting annealing (850°C during 4 h).

Strength and plasticity were defined on fivefold samples 5 mm in diameter and 25 mm long. To define the thermostability N applied a technique [5], having high enough efficiency and reliability. Tests were carried out on a sample (Fig. 1), which, due to the configuration, was simulating completely stressed state of the metal mould.

Samples heated up to temperature 900°C in muffle furnace which corresponds to the maximal temperature on an internal surface of moulds at their operation, carried out endurance during 5 minutes, then were cooled in water. Resistance of alloys to thermal cycle loadings estimated by the quantity of cycles before the first crack formation or before the full destruction of a sample (see Fig. 1b).



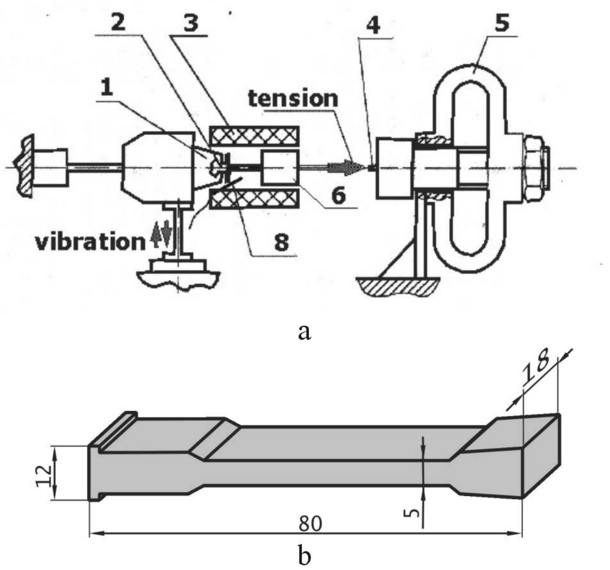
à b

Fig. 1. A sample for definition of thermostability N: a – the drawing; b – sample after tests

Thermal endurance σ^{t}_{-1} defined at temperature 750°C on the device ЛО2-727-00-00-СБ on a flat samples section 5×18 mm in conditions of a static tension with stresses σ_{st} = 25, 30, 35, 40 both 45 MPa and a dynamic bend with frequency 207...233 Hz at σ_{B} = 4 MPa (Fig. 2). Scale resistance tests carried out on a gas-dynamic installation in a stream of products of combustion of natural gas in oxygen on the flat ground samples in the sizes 50×10×2 mm. The samples fixed on a mobile platform were exposed to the cyclic heatings in a flame up to 900°C, during 1 minute, free cooling on air up to 600°C, to endurance in 1 minute and again heating up to 900°C. Duration of tests was 100 cycles. Scale resistance measured the weight of the sample was increasing.

4. Results of researches and their discussion

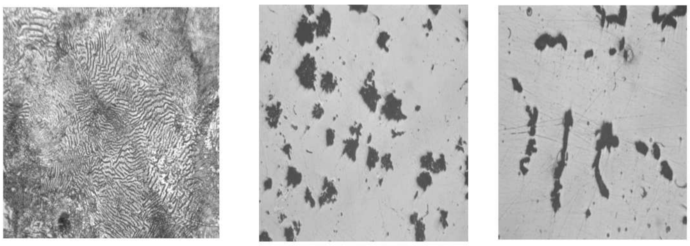
The structure of the initial steel metal matrix represented lamellar pearlite. In the process of copper content increase the quantity of ferrite grew approximately up to 25%, mainly around of graphite inclusions. With the growth of copper content up to 1.16% the inclusions of graphite had a compact, practically spherical shape; at the further increase in copper content the quantity vermicular graphite grew: at 1.82%Cu to 15%, at 2.33%Cu to 40% and at 3.08%Cu a share of inclusions vermicular graphite was about 80% from their total content (Fig. 3).



a

b

Fig. 2. The device (a) and a sample (b) for tests on thermal endurance: 1 – the left clamp; 2 – the sample; 3 – the heating device; 4 – a spring of a dynamometer; 5 – a dynamometer; 6 – the right clamp; 7 – the thermocouple; 8 – the vibration test-bed



a b c

Fig. 3. Typical structure (a, ×450) and the shape of graphite inclusions (×225) in steel with 0.02%Cu (b) and with 3.08%Cu (c)

With the increase in copper content from 0.02 up to 3.08% the parameter of the form of the graphite inclusions, representing the attitude of the maximal size to minimal, increased from 1.6 up to 6.9.

The increase in concentration of copper in the range, being studied, has led to the increase in strength on 45% (at 1.16%Cu) and on 35…40% of thermostability N at 1.16…1.82%Cu (Fig. 4) owing to solid solution hardening of a metal matrix of the steel. Decrease in parameters σ_u and N at higher concentration of copper speaks transformation of spherical graphite in vermicular.

At the content of copper of 0.58% some decrease in heat conductivity α, probably owing to distortions of a crystal lattice, took place at the solid solution hardening, complicating moving of conductivity electrons. At higher concentration of copper there was a growth of heat conductivity, due to allocation small copper containing phases on an interface “metal – graphite” and to increase in parameter of the shape of graphite inclusions. According to the literary data [2-4], solubility of copper in cast irons and graphite steels makes 0.6…0.7%, at its higher concentration on interphase surfaces the copper containing ε-phase, promoting increase of heat conductivity and resistance to oxidation at high temperatures is precipitated. As the results of our researches showed (see Fig. 4), 40% decrease in speed of steel oxidation (a gain of weight of a sample ΔP) took place at increase in the copper content up to 1.82%.

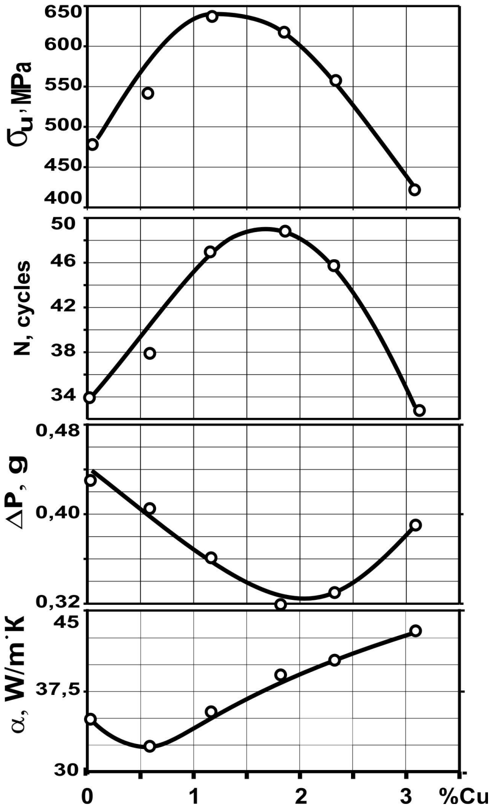


Fig. 4. The influence of copper on properties of graphite steel

The further alloying by copper resulted in growth ΔP, presumably, as a result of change of the graphite shape with spherical on vermicular and, there by, increases interfaces on which the processes of high-temperature oxidation have penetrated deep into metal.

Test results on termal endurance σ^t_{-1} in of completely stressed conditions have shown, that microcracks were initiated, basically, at graphite inclusions. As a rule, they were distributed from one inclusion to an-other (Fig. 5). Thus, inclusions of the extended shape in the greater measure promoted cracking, than compact, spherical one. In process of loading of samples there was a disclosing of microcracks, oxidation of their surfaces and formation of the main macrocrack.

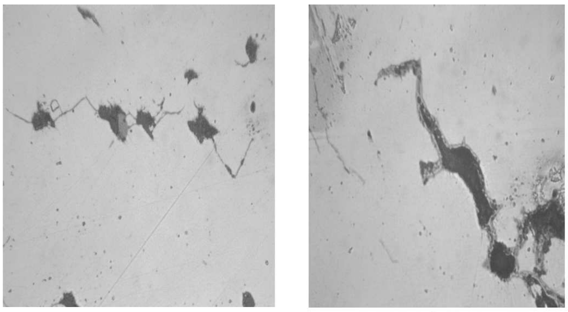

a b

Fig. 5. Initiation and development of thermal fatigue cracks ×400

Data, submitted on Fig. 6, show that σ_{-1}^{t} of the steel alloyed by copper in the range from 1.16 up to 1.82% possessed maximal thermal endurance. At all values σ_{st} alloying by copper in the specified limits resulted in increase of a parameter σ_{-1}^{t} in 2,5…5 times.

It is possible to explain the received results high enough strength (about 650 MPa) and heat conductivity (about 40 W/m·K), and also the favorable form of graphite inclusions. Owing to the specified factors a parameter σ_{-1}^{t} of the graphite steel alloyed by copper, essentially surpassed the parameter of high-strength cast iron (see Fig. 6). That does graphite steels perspective material for ingot moulds and for other types of metallic moulds.

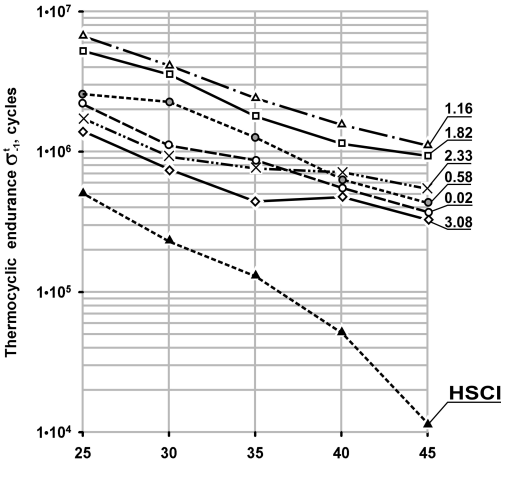


Fig. 6. Thermocyclic endurance of graphite steel. Figures at curves – the contents of copper, %; HSCI – high-strength cast iron

5. Conclusions

During the conveyor pouring of non-ferrous color alloys the basic materials for ingots are grey and high-strength cast irons, less often low-carbon steel. Cast irons incline to cracking, steel to warping. That is why the attempt to suggest for metallic moulds a material having on structure and properties intermediate position between low-carbon steels and cast iron – hypereutectoid graphite steel – is made.

Aiming to increase heat conductivity and thermostability steel of chemical composition 1.24%C and 1.41%Si was alloyed growing additives of copper.

It has been established that with increase in the copper content up to 3.08%, the increase of a ferrite component approximately up to 25% occurred, and the growth of the average sizes and parameters of the graphite inclusions shape and change in their shape from spherical on vermicular occurred. Owing to solid solution hardening and changes in the shape of graphite inclusions, the dependence of strength and parameters of thermostability looked like curves with maximum at 1.2-1.8% of copper. With the growth of copper concentration, the heat conductivity of steel grew; scale formation was minimal at 1.82%Cu. As a whole, results of the researches, which have shown the possibility of essential increase of graphite steel thermostability at temperatures 750…900°C as a result of alloying by copper in quantity 1.2…1.8%, allow to draw a conclusion on expediency of its application for moulds for pouring of non-ferrous alloys.

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