Development of high-strength cast iron for back-up layer of bimetallic products

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Abstract. The article presents chemical composition of the charge and smelting regimes of the newly designed austenitic-bainitic high-strength cast iron with spheroidal graphite (ABHCSG), the analysis of research results of influence of isothermal hardening modes in pseudo-boiling layer on the mechanical properties and structure of cast iron.

In the modern world it is important to obtain new materials with special properties. A special role among new materials with special properties belongs to layered metal compositions. The use of bimetallic compositions in the production of die tools is also promising in order to save expensive materials and improve their durability [1, 2, 3]. Therefore, the design and study of materials for high resistance bimetallic dies is an urgent task.

Practicability of application of high-strength cast iron with spherical graphite for production of a basic layer is caused by its higher thermal conductivity that allows to improve at operation of stamps a heat sink from the warmed-up working surface of the tool on the weight or the refrigerator established in the basic part of a stamp. This significantly reduces the temperature gradient and the stress level in the contact zone of the die and, as a result, causes an increase in its performance. Working capacity of bimetallic dies increases at reception in a surface layer of the tool of dispersed structure. Namely, due to the lower heating temperature of cast iron than that of alloy steels, when filling the support layer there is an additional internal cooling-down of the top-doped layer. In this case, the grain size is reduced, the separation diffusion of alloying elements is slowed down, which leads to a decrease in dendritic liquation and an increase in the characteristics of heat resistance and thermal and mechanical fatigue of the surface layer of the dies.

There are high-strength cast irons with increased strength, ductility, toughness and heat resistance [4, 5]. However, to obtain them complex heat treatment technologies are used which lead to a high cost of production.

The aim of the work was to develop a method for producing aluminum high-strength cast iron with spherical graphite and austenitic-bainitic structure with a tensile strength $\sigma_B \geq 1200$ MPa by bainitic quenching from the cast state without additional heat treatment [6].

To obtain aluminum high-strength cast iron with spherical graphite and austenitic-bainitic structure in the cast state, the iron is smelted in an induction electric furnace, the liquid alloy when drained into the bucket is modified to obtain graphite inclusions in the castings of a globular shape, when poured into a metal form (chill mould), the liquid alloy in the bucket is further subjected to inoculating
modification, the castings after crystallization are removed from the mold at a temperature of 900-1000°C, moved to a furnace with a temperature of 950-1000°C, kept in the furnace for 10-30 minutes, then isothermal quenching is applied to the installation in a pseudo-boiling dispersed carborundum layer in the area of austenitic-bainitic transformation at a temperature of 300°C for 60 minutes, followed by air cooling, while using cast iron containing, wt. %: carbon (C) – 2.5 - 3.2; silicon (Si) – 1.5 - 2.5; aluminum (Al) – 7.2 - 9.0; manganese (Mn) – 0.7 - 0.75; magnesium (Mg) – 0.04 - 0.06; molybdenum (Mo) – 0.7 - 1.2; nickel (Ni) – 0.48 - 0.52; copper (Cu) – 0.49 - 0.52; sulfur (S) – 0.01 - 0.012; phosphorus (P) – 0.06 - 0.08; iron (Fe) – the rest.

Heating of high-strength cast iron is carried out, for example – in an induction furnace MGP – 52, with acidic lining on the charge, consisting of cast iron GOST 805-80, scrap steel and light graphitized electrodes. Alloying iron Si (silicon), Al (aluminum), Mn (manganese), Mo (molybdenum), Ni (nickel), Cu (copper) is carried out by the corresponding ferroalloys in the furnace for 10-15 minutes before the release of the metal (copper M2 (99.9 wt. % - copper (Cu), other impurities), GOST 859-78, Nickel, H3 (Nickel (Ni), wt. % more than 98.6%, the rest cobalt (Co) - 0.7; carbon (C) - 0.1; sulfur (S) - 0.03; copper (Cu) - 0.6;) GOST 849-70). Inoculating modification is carried out in the bucket modifier ZHKMK-4R at a temperature of 1450-1470°C the following chemical composition, wt. %: silicon (Si) – 49.6; calcium (Ca) – 9.5; magnesium (Mg) 8.6; rare earth metals (REM) – 4.7; iron (Fe) – the rest. As a flux cryolite was used K2 (GOST 10561-73). Gravitizing modification was performed by ferrosilicon FS – 75 (GOST 1415-78). Then in a ladle in a certain way [5], by means of quartz "bell", the modifier ZHKMK–4R is added. Obtaining castings is carried out in a metal form (casting mold), which is removed after crystallization from the mold at a temperature of 900 - 1000°C, then moved to a furnace with a temperature of 950 - 1000°C and kept in the furnace for 10-30 minutes. As a result, castings of cast iron with globular graphite and austenitic structure of the proposed chemical composition are obtained.

After hardening in a chamber furnace of electrical resistance in the temperature ranging from 950 to 1000°C cast iron samples are transferred to the installation of "pseudo-boiling" layer. Isothermal hardening of cast irons was carried out at temperatures of 300°C, 350°C and 380°C for 30, 60 and 120 minutes. Heating of the working medium (carborundum) to these temperatures is carried out by pumping compressed air through the heating elements of electrical resistance (tubular furnace). The temperature in the working space is controlled, for example, by chromel-aluminum thermocouples.

The results of studies about the effect of the duration and temperature of isothermal exposure within 300 - 380°C on the mechanical properties of austenitic-bainitic cast irons are presented in table 1.

| Modes of isothermal hardening | Heat treatment parameters | Mechanical properties |
|------------------------------|---------------------------|-----------------------|
|                              | Austenitization | Isothermal hardening | σB, MPa |
|------------------------------|----------------|-------------------|--------|
| Mode № 1                    | 950°C          | 30                | 300°C  |
|                              | 60             |                   | 1220   |
| Mode № 2                    | 950°C          | 30                | 350°C  |
|                              | 60             |                   | 1084   |
| Mode № 3                    | 950°C          | 30                | 380°C  |
|                              | 60             |                   | 962    |
| Mode № 4                    | 950°C          | 30                | 300°C  |
|                              | 90             |                   | 1210   |
| Mode № 5                    | 950°C          | 30                | 350°C  |
|                              | 90             |                   | 1076   |
| Mode № 6                    | 950°C          | 30                | 380°C  |
|                              | 90             |                   | 954    |
| Mode № 7                    | 950°C          | 30                | 300°C  |
|                              | 120            |                   | 1210   |
| Mode № 8                    | 950°C          | 30                | 350°C  |
|                              | 120            |                   | 1070   |
| Mode № 9                    | 950°C          | 30                | 380°C  |
|                              | 120            |                   | 950    |
In the study of the influence of isothermal hardening modes of cast iron in a pseudo-boiling layer wedge-shaped samples with a thickness of 55mm (GOST 7293-85) were cast. It was found that the increase in the temperature of isothermal hardening in the range of 300 - 380°C during quenching of iron leads to a decrease in strength by 21%; plasticity by 3.5% and toughness by 20%. At the same time, the hardness in cast iron practically does not change (Table 1). The increase in isothermal hardening at the cooling in the pseudo-boiling layer over 60 min virtually has no effect on the hardness and other mechanical properties of aluminum austenitic-bainitic cast iron. The maximum strength characteristics \(\sigma_B, \sigma_{0,2}\) were obtained by isothermal hardening in a pseudo-boiling layer of austenitic-bainitic iron at an isothermal hardening at a temperature of 300°C for 60 minutes according to Mode №1 (Fig. 1).

Mechanical tests of cast irons under static loads were carried out on a universal breaking machine. Hardness (HB) was determined according to GOST 24805-81 on the Brinell device; impact strength was determined according to GOST 9454-78 on the pendulum.

The proposed method allows to obtain aluminum austenitic-bainitic cast iron with globular graphite maximum with the following mechanical characteristics: tensile strength \(\sigma_B = 1220\)MPa; yield strength \(\sigma_{0,2} = 960\)MPa; plasticity \(\delta = 4.6\%\); hardness HB 415; impact strength \(KC = 72\)J/cm².

The obtained high strength properties in the proposed austenitic-bainitic cast iron were achieved due to the rational content of graphite-forming elements: aluminum, silicon, nickel and copper, as well as carbide-forming molybdenum in combination with manganese. A positive role is also played by the proposed method of isothermal quenching of iron in a mobile "pseudo-boiling" layer, which provides uniform cooling of iron and as a result – obtaining a homogeneous structure.

References
[1] Golovanenko S A and Meandrov L V 1996 Production of bimetals M: Metallurgia 303 p
[2] Kolesnikov M S, Mukhametzyanova G F, Bikulov R A and Astashenko V I 2014 Bimetallic stamps of hot deformation of steel and suspension monoalloyed austenitic-bainitic cast iron. Foundry operation Number 3 pp 2 - 4
[3] Mukhametzyanova G F, Kolesnikov M S and Mukhametzyanov I R 2016 Molding bimetallic dies for liquid forging in the mold from the gas-tight molding sand *Foundry operation* Number 3 pp 26-28

[4] Patent of the Russian Federation 2449043 2012 IPC C22C37/10 and C21D 5/00 Method of heat treatment of spheroidal cast iron / K V Makarenko published 27.04.2012 Bulletin No 12

[5] Patent of the Russian Federation 2250268 2005 IPC C21C 1/10, C22C 37/04 and C21D 5/00 Method of producing castings of half cast iron with austenitic-bainitic structure / K V Makarenko published 20.04.2005 Bulletin No 11

[6] Patent of the Russian Federation 2605016 2016 IPC C21C1/10 and C22C37/04 Method of producing a ductile cast iron / M S Kolesnikov, G F Mukhametzyanova, V I Astashenko and Mukhametzyanov I R published 20.12.2016 Bulletin No 35