Development of cast dispersion-hardening ferrite-carbide steel

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Abstract. A method is proposed for producing cast dispersion-hardening ferrite-carbide steel for manufacture of cast molds of hot deformation, molds for die casting under pressure and forging dies for solid-liquid forming, providing production of steel with fine-grain structure and uniform distribution of carbides in a ferrite matrix without formation of casting cracks. In the process of steel production waste carbide ceramic-metal inserts of a cutting tool from alloys are used, they are of the following types: T5K6, T15K6, T5K10, T21K8, TT7K12, TT8K6, TT10K9, TT20K9 and T30K4 containing titanium carbides (TiC), tantalum carbides (TaC), tungsten carbides (WC).

Steel for hot deformation dies and die casting molds should have high heat resistance, wear resistance, thermal stability and resistance to interaction with melts. For the tool group under consideration, martensitic class steels are mainly used: 4Χ5МФС, 3Χ2В8Φ, 4Χ4ВМФС (ДΙ – 22), 5Χ3В3МФС (ДΙ – 23), 5Χ2МНФ (ДИ – 32), etc. [1 - 7].

Dies and die casting molds, as a rule, are made of forged blanks, which are associated with high costs in the manufacture of complex engraving of the press tool. The experience of using cast dies from 35Χ5НМФСЛ steel for hot deformation at PJSC “KamAZ-Metallurgy” conditions showed that slow cooling during crystallization of die castings in zircon forms leads to the formation of a “rough” cast structure, which leads to low operational performance in comparison with the press – a tool from forged blanks.

A promising direction in the manufacture of a molded press tool for hot deformation is the use of directional crystallization, which provides dispersed structure during accelerated cooling during casting in a cooled chill mold [1]. However, the low plastic characteristics and the high coefficient of thermal expansion of martensitic steels do not allow their use in accelerated cooling due to the formation of casting cracks. This problem can be solved by using types of steel with an isomorphic structure.

In addition, during the operation of a heavily loaded press tool, the temperature of which on the engraving reaches values higher than polymorphic transformations (800 - 900°C) [2], the structural-phase hardening in steels with an isomorphic structure is eliminated due to $\alpha \leftrightarrow \gamma$ transformations during each loading cycle and as a result, the tendency of steels to crack of thermomechanical fatigue decreases.
For the manufacture of cast press tools (hot deformation dies, solid-liquid stamping (SLS), die casting molds of aluminum-based alloys, etc.), cast dispersion hardening ferrite-carbide steel without polymorphic $\alpha \leftrightarrow \gamma$ transformations was developed [8].

To obtain the developed cast dispersion hardening ferrite-carbide steel after the melting of 35Л steel, ferrotitanium and ferronickel are introduced into the melt to ensure the chemical composition of the steel containing, by weight (%): carbon (C) 0.27 - 0.32; nickel (Ni) 0.7-0.9 and titanium (Ti) 5.8-6.2. Then, waste carbide ceramic-metal inserts of a cutting tool from alloys of the following type are introduced: T5K6, T15K6, T5K10, T21K8, TT7K12, TT8K6, TT10K9, TT20K9, and T30K4, containing titanium carbides (TiC), tantalum (TaC), tungsten (WC). They are introduced into the melt at temperature of 1500 - 1520 °C followed by exposure at given temperature for 30 min, which ensures the dissolution of the cobalt binder entering the carbide inserts and uniform distribution in the carbide melt. Then the casting of the melt into a chill mold is carried out, followed by cooling to obtain steel castings, while the steel castings has the following chemical composition, wt. %: carbon (C) 0.27 - 0.32; titanium (Ti) 5.8-6.2; nickel (Ni) 0.7-0.9; cobalt (Co) 0.02; carbides: titanium (TiC), tantalum (TaC), tungsten (WC) 0.5-1.5%; ferrum (Fe) and the rest.

In this case, the cobalt binder dissolves, and the carbides (TiC, TaC, WC) in the carbide compositions are evenly distributed in the melt in the form of inoculators.

Based on the experimental design and simplex studies, the chemical composition of the cast tool steel was optimized for hot deformation dies and die casting molds. Based on the results of resistance to thermomechanical fatigue cracking, the optimum ratios of the components in ferrite-carbide were determined by the content of carbon, titanium, nickel and titanium carbides introduced into the melt during suspension casting [9].

Figure 1 shows the microstructure of the developed 30T6HTiC – 1.5 steel with the optimum content of all components.

Dies for hot deformation and other types of press tooling are obtained by pouring the obtained molten steel into a chill mold. Due to the accelerated cooling of castings when pouring the obtained steel melt into a chill mold, a fine-grained structure is formed with a uniform distribution of carbides in the ferrite matrix without the formation of foundry cracks. The presence of Ni in the alloy allows the use of dispersion hardening regimes with the formation of fine particles of the Ni$_3$Ti type, which provide an additional increase in hardness and resistance to abrasive wear of the press tool.

![Fig. 1 - The microstructure of dispersion-hardening ferrite-carbide steel 30T6HTiC - 1.5, x500.](image-url)
The combined effect of all components within the specified limits provides an increase in working capacity, which is confirmed by the test results of the developed steel for thermomechanical fatigue. Physical and mechanical properties of the developed steel (30T6NTiC - 1.5) are presented in table 1.

Table 1. Physical and mechanical properties of steel.

| Steel grades | Thermal conductivity, $\lambda$, J/m·°C | Temperature coefficient of linear expansion, $\alpha \times 10^{-6}$/degree | Mechanical properties |
|--------------|----------------------------------------|-------------------------------------------------|-----------------------|
|              |                                        |                                                 | $\sigma_B$, MPa | $\sigma_{0.2}$, MPa | $\delta$, % |
| 4X5MФС      | 41.4 - 42.6                            | 12.3 - 13.6                                     | 1840 - 1900       | 1730                 | 6.8 – 7.2 |
| 30T6HTiC-1.5| 28.6 - 32.8                            | 10.4 – 11.8                                     | 1826 - 1828       | 1716 - 1732          | 8.0 – 8.6 |

The test for thermomechanical fatigue (TMF) was carried out according to the procedure [10]. The number of loading cycles of the samples before the appearance of cracks of TMF with dimensions of 0.1 mm in depth of the sample was estimated. The test mode corresponded to the operational loading of the “Autoforge” dies during brass dyeing: $T_{max} = 780 ^\circ C$ on the surface of the sample, $T_{min} = 460 ^\circ C$, contact time of the sample with the stamped material $\tau = 3$ with a pause of $\tau_p = 2$ s. Sample dimensions: height $h = 12$ mm, thickness $b = 2$ mm, sample length $l = 80$ mm. As can be seen from table 1, the proposed ferrite-carbide steel in terms of thermophysical characteristics differs little from the known austenitic-carbide steel. The resistance to crack development of TMF of the proposed steel is 9–10% higher than that of the known austenitic-carbide steel.

The use of a cast press tool made of ferrite-carbide steel, instead of traditionally manufactured by mechanical and electrophysical methods from forged blanks of martensitic steels, can drastically reduce the manufacturing time and production costs by eliminating mechanical operations to produce complex engraving tools.

Replacing complex alloyed austenitic-carbide steel with economically alloyed ferrite-carbide steel simplifies the steelmaking process and also reduces production costs by reducing the content of alloying elements. High hardness of steel castings (46-48HRC) is achieved due to precipitation hardening during aging as a result of precipitation of a dispersed $\gamma$ phase of the Ni$_3$Ti type from ferrite, as well as due to the presence of titanium carbides.

The developed steel can be used for the production of hot-formed cast dies, injection molds, forging dies for solid-liquid dyeing (“Autoforge” dies) of copper-based alloys, etc., while solving the environmental problem of recycling carbide cermet cutting tool inserts.

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