MANUFACTURING THE POLYMERIC METALLIC CONNECTORS BY THE INVESTMENT CASTING METHOD

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Abstract— In this article, the problems that arise in the procedure of molding by the investment casting method are considered. Information about polymeric metallic materials, their application features is described. The important aspects of the quality of molding manufactures be investment casting method are considered. Some methods for improving the quality of products are proposed. The optimal technological process, to choose the size and number of ingredients of the molding mixture to recycle the shell forms as raw materials, has been found by field experiments and the obtained technological process was resource-saving, highly productive, with a lower cost of the produced details.

Keywords: Manufacturing, Polymeric Metallic Connectors, Investment Casting.

1. Introduction
The connectors of two details or parts of any constructions, depending on their purpose and working conditions, are made of various materials - metals, rubber, plastics, etc. Recently, connectors made of metal-polymer material have become popular.

Metal polymer material is a semi-finished product consisting of polymers and metals forming a single structure due to the bonding between them by atomic molecular forces or mechanically. Polymers which are the main component of plastics, are made mainly from natural and associated gases.

Polymers as a structural material have a number of properties that limit its use. To improve consumer properties, polymers are combined with metals (in the form of powders or fibers). Metal powders in the polymer perform not only the role of fillers, but also structure-forming agents, special additives, etc. The smaller the particle size of the metal, the more physically and chemically active it is. As a result, extremely homogeneous two-phase aggregately stable metal-polymer matrix materials (colloidal metal-polymers) are formed [1].

The main direction of modern mechanical engineering development is the desire to use such methods of obtaining products, in which metal cutting is minimized in the production. To do this, it is required to obtain blanks (billets) in size and shape that are closest to the finished products. The technological processes that most satisfy these requirements are plastic deformation of dimensional billets from long products by forging or hot-volume stamping, as well as casting methods for billets production [2].

One of the main methods of forming billets, and more recently, structural products in finished form which do not require additional mechanical processing, is precision investment casting method (i.e., models with a low melting temperature). Another name is precision casting on soluble or burnable models. This method of casting is used in all types of production, from single to large mass production.

The technological process includes five operations, each of which can be performed in various ways and methods: obtaining models in a releasable press-form from the melted material (paraffin, stearin, rosin, etc.), forming a refractory ceramic shell on the surface of the resulting model, removing models from the shell form, calcining the ceramic shell mold, pouring the resulting mold with a metal-polymer material. All technological operations are widely covered in the literature, but here some of the important features and new items in this area are considered.
Here we consider a way to improve the quality of castings obtained by the investment casting method by the use of a combined shell form [3]. The disadvantages of traditional technologies for producing castings in combined ethyl silicate-liquid-glass shell forms are:

- The penetration of liquid glass particles on the working melted surface, where they induce a chemical reaction with the cast alloy, which reduces the quality of the surface layer of castings;
- The appearance of cracks in the shell when it is heated above 200 °C;
- The instability of the ethyl silicate layer of the shell due to the evaporation of its ethyl alcohol;
- The negative environmental impact on production;
- The complexity of shell form removal due to its over-hardening when pouring an alloy into it;
- The possibility of heterogeneous structure presence of the shell form due to the low speed and depth of impregnation of the coating layers.

To eliminate them, it is proposed to use aqueous solutions of an alumina-borophosphate concentrate. Its advantage is a double efficiency of application: for creation of an intermediate barrier layer between liquid glass and ethyl silicate layers, and also as a chemical fixative of liquid glass layers. To reduce the effect of high temperature on the shell, it is proposed to replace the pulverized quartz of silicon dioxide with tridymite.

Applying an alumina-borophosphate concentrate for each new layer of the liquid-glass coating contributes to the acceleration of the binder gelation, an increase in the thermal strength of the ceramic forms in the process of calcination due to the formation of refractory products. As a tridymite material, it is recommended to use ground silica refractory material of two fractions: the small fraction (up to 100 μm) for use as a filler and the large fraction (from 100 to 400 μm) for dusting. The positive effect is achieved due to the match of the expansion of the tridimite filler liquid-glass layers in the temperature range 115 ... 180 °C with shrinkage processes in the bonding liquid-glass layer.

Thus, both undesirable processes mutually compensate each other, the outer liquid-glass layers do not shrink, and therefore do not affect the internal ethyl silicate layers. Studies have shown that the use of this technology reduces by 1.5 times the scrap of the shells in the process of their formation, reduces by 2-3 times the waste of castings due to the shape and 1.5-2 times reduces the deviation of casting sizes from nominal.

Another way to eliminate the above-described disadvantages of the ethyl silicate forming system is to use an alternative technology, namely the technology of making ceramic corundum forms on an alumina-borophosphate concentrate (ABPC) [4]. The expensive and at the same time environmentally harmful ethyl silicate is replaced by a suspension consisting of ABPC and electrocorundum, granulated periclase is used as a dusting, which is also a hardener to the binder (Table 1).

Tab.1. Dependence of parameters of ceramic corundum forms on different binders

| Parameter                          | Forms on hydrolyzed ethyl silicate solution | Forms on ABPC |
|-----------------------------------|-------------------------------------------|---------------|
| Gas permeability of the ceramic shell, units | 1 ... 2                                       | 5 ... 7       |
| The duration of the shell manufacturing, h.     | 20 ... 24                                    | 4 ... 6       |
| The flexural strength of samples at 20 °C , MPa              | 5.0 ... 6.5                                 | 6.5 ... 7.0   |
| The flexural strength of samples at 900 °C , MPa            | 5.5 ... 7.0                                 | 8.0 ... 9.5   |
| Residual strength (knocking-out ability) of samples, MPa     | 3.5 ... 4.5                                 | 1.5 ... 1.8   |

The carried out experiments recorded that when using these materials, the sprinkling is embedded in the suspension layer and begins to interact with the alumina-borophosphate concentrator. As a result, a three-dimensional framework structure is formed with centers at the points of solidification. Its composition is double-substituted magnesium phosphate, prone to polymerization with the acceleration of formation (Fig. 1). This technology allows to achieve several improvements. Firstly, the manufacturing time of shell molds is reduced by 4-6 times, which significantly increases the efficiency of casting molding.
Secondly, the cost of the casting itself is becoming cheaper, since the cost of ABPC is much less than ethyl silicate, moreover, is not a deficient material. Thirdly, when heated to 1000 °C ceramic corundum form expands by only 0.015%, and smoothly, without spikes, which significantly increases the accuracy of castings. The derivatogram of a corundum ceramic sample on ABPC is shown in Fig. 2.
Another problem is to increase and stabilize the dimensional accuracy of castings. When manufacturing the structural parts, such as connectors, this issue is particularly relevant, since the accuracy required from castings is often increased. In this case, dimensional accuracy just affects the quality of the resulting billets. Increasing the accuracy of castings is traditionally solved by selecting (experimenting) the composition model, refractory suspension, etc., which is very inconvenient in production, as it contains a lot of technological information, often of an individual character for a particular casting. An alternative is the method for predicting the dimensional accuracy of castings [5]. To calculate the size of the casting from its nominal value, formula (1) was applied.

\[
\Delta_i = l_{OH}^i \left[ \frac{2(100-\alpha_M^{MIN})(100+\alpha_M^{MAX})(100-\alpha_O^{MIN})}{100+\alpha_KO^{MAX}} \right] - 2 \tag{1}
\]

where \( l_{OH}^i \) - nominal size of the i-th casting size according to the working drawings, m;
\( \alpha_M^{MIN} \) and \( \alpha_M^{MAX} \) - coefficient of minimum and maximum shrinkage of the casting model according to i-th size;
\( \alpha_KO^{MAX} \) and \( \alpha_KO^{MIN} \) coefficient of maximum and minimum expansion of the ceramic shell form i-th size;
\( \alpha_O^{MIN} \) и \( \alpha_O^{MAX} \) - the coefficient of minimum and maximum shrinkage of the casting material by i-th size.

The coefficients of expansion and shrinkage included in formula (1) are calculated using empirical formulas, presented in [5]. The coefficients are calculated individually for various forms and types of castings, materials used and ambient temperature. The repeatability of coefficients for the model composition from batch to batch is proved. The dependence of the absolute value of the interval of deviations of the casting size on the ratio of the maximum and minimum values of the ceramic casting is revealed. The implementation of this method for determining dimensional accuracy of castings has shown that it is preferable to make casting models from model compositions with a coefficient of thermal linear expansion equal to or close to zero.

Another problem addressed by the research in the field of investment casting method is the increase in the crack resistance of shell molds. Micro cracks lead to the formation of such defects as blockages, burrs on casting molds. Larger cracks can completely destroy the shell form. The most characteristic causes of increased cracking have been revealed [6]:

- Application in the first layer, adjacent to the internal cavity, a refractory filler of the same fraction as for the other layers;
- An excess of shell molds in the calcined flasks, which leads to an increase in thermal stress, which increases the cracking;
- Irrational arrangement of shell molds in a flask with supporting filler.

The list of measures to combat these causes are: first, the manufacture and pouring of the shell mold using refractory dusting of calcined foundry sand, which reduces the amount of evaporated moisture from the model, which favorably affects the mass loss during calcination (Fig. 3). Also eliminated repeated polymorphic transformations during calcination of the finished shells in a thermal furnace [10, 11].
Fig. 3. The use of calcined molding sand in the composition of the refractory dusting

The calcined molding sand is obtained by calcining quartz sand in a heat furnace at a temperature of 900 ... 950 °C for 1 ... 1.5 hours. Secondly, the introduction of boric acid powder into the refractory suspension in a volume of 2 ... 3% by mass. When calcining the form, boric acid melts and, acting as a binder, strengthens the shell. Thirdly, the harmful effects of organic substances contained in marshallite used as a refractory material of the suspension and molding sand were revealed. The introduction of input control for this material, its verification for compliance with the requirements of standard (GOST), showed a positive result. As a result, the proposed three measures reduced the number of shell defects by cracking by an average of 2.75 times, which is a good result.

Relevant is the issue of reuse of spent shell form. Studies have shown that the most promising from the point of view of recycling is the use of technology based on handling self-hardening mixtures on cement binder for volume investment casting forms. The possibility of reuse was proven by experiments using X-ray phase analysis on a Dron-3M diffractometer (Fig. 4) [7-9].

Fig. 4. Diffractometer « Dron -3M»

Analysis of material heated to 1100 °C and then cooled showed the following. Moisture from the material evaporated. The main chemical composition: third calcium silicate 3CaO · SiO 2 and dicalcium silicate β-2CaO · Si O 2. Additional chemical composition is the remains of hydrated cement. The study of the composition led to the conclusion about the possibility of basic elements to interact with water, and additional - to perform the role of micro inclusions in the matrix frame, providing the necessary strength.

The most difficult moment in the creation of the technology of recycling was to choose the size and number of ingredients of the molding mixture, using the used forms as raw materials. Field experiments showed the optimal composition consisting of 28.9 ... 44.1% fine silica sand, 11.0 ... 32.4% recycled cement mix, 10.8 ... 18.2% Portland cement, 0.6-1.5 % aluminum nitrate nine, the rest is water. The obtained technological process is resource-saving, highly productive, with a lower cost of the produced details.

With the increasing of castings complexity, and consequently of molding forms, the complexity and knowledge-intensiveness of the technological process of casting production increases. In modern market conditions, industrial enterprises have to increase their efficiency, increase the profitability of production [12,13]. One of the measures is cost reduction, which is a set of measures to find and analyze the causes of additional costs, control them and make changes to the current process to reduce
them. To assist in carrying out these activities, the SADT methodology has been developed, which allows simulate data and objects (functional modeling).

This model vividly shows all the mechanisms and principles of the interconnection of various subsystems within one project. The introduction of this system allows you to break the complex process of pre-production into several more simple activities:

- Determination of the required functional responsibilities of the system;
- Division of the system into subsystems and their design;
- Implementation of subsystems after their design;
- Creation of a unified system from implemented subsystems;
- Testing the overall system for performance;
- Adjusting the functioning of the system;
- System start-up.

The advantage of the system is a simple intuitive interface that does not require programming knowledge, which greatly simplifies the use of this system. The result of the system is the construction of the SADT diagrams (Fig. 5).

![Requirements of normative-technical documentation (NTD) to the control](image)

Fig. 5. SADT – Diagram of investment casting method

The system contains the following elements: on the left is the input, on the right is the output, from the bottom is the mechanism, from the top is the control.

2. Conclusions

The carried out experiments showed the technology of using alumina-borophosphate concentrate reduced the time of shell molds manufacturing by 4-6 times, which significantly increases the efficiency of casting molding, reduced the cost since alumina-borophosphate cheaper than ethyl silicate, and significantly increased the accuracy of castings.

The analysis showed that SADT -diagram allows structuring the process of pre-production, to upbuild a system with input, output and internal transformations. This makes the process more understandable for the designer, and therefore allows to identify and prevent errors in the initial stages of the production process, to reduce the low-quality castings results.
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