Production of the steel casting with improved dimensional and geometrical accuracy using complex models

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Abstract. Modern conditions of functioning of mechanical-engineering enterprises are determined by the need to develop and to use the technologies for casting products manufacturing with minimal costs for processing. Such requirements are met by the technology of precise casting manufacturing made by complex models. There have been developed technological variants of forming of complex casting models based on the pressing of powder made from the wax-like composition on a metal or aluminothermic unit with subsequent creating of the single-piece ceramic shell. The use of such technological solutions allows to minimize the processing of cast products, to obtain bimetallic castings with high dimensional and geometric accuracy, and realizes the possibility to use the waste of metallurgy (scale and metal chips).

Reduction of the product life cycle and increase of the competition in the mechanical engineering sector are the most significant problems for enterprises focused on the manufacturing of cast blanks. In this regard, the most preferred are new technologies, the use of which allows to obtain a wide range of products, approximate in their characteristics to the final product. Traditional technologies of casting manufacturing, first of all, are used to produce the cast blank made by the metal melt with subsequent processing consisting of fettling of gating and feeding system elements and allowance correction. The need for such operations increases the complexity of production and leads to the overrun of materials. Among the methods of casting manufacturing with minimal allowances for processing, and in some cases with a surface that does not require subsequent processing, the lost wax investment casting has become the most wide-spread one [1, 2]. Using this method it is possible to produce castings of complex geometry in the range of sizes from 1 to 500 mm, the accuracy of which corresponds to 11 to 12 quality grade with tolerances on the dimensions of the working cavity of the press-mold, not exceeding 8 to 9 quality grade (GOST 25347-82) [1]. However, usage of some kinds of technological methods for lost wax investment casting [1, 3] does not allow to obtain a bimetallic product with a high dimensional and geometric accuracy.

The traditional sequence of casting manufacturing using lost wax investment process includes the following stages: creating of the investment model from the investment compound melt in press-molds; assembly of the investment model on the model unit; layering and drying of the fire-proof ceramic shell on the model unit; melting of the investment compound out of the shell; fusion of the investment compound out of the shell; quenching of the shell in the basic filler material and pouring of the shell with the molten metal. A significant number of the process stages and a wide range of
materials used cause inadmissibility of costs connected with the defects removing. Defects in the investment model and the shell, as a rule, occur as a result of thermophysical effects on the investment compound which lead to the shrinkage phenomenon inside the investment model, and also to the destruction of the shell because of the investment compound expansion during its fusion [4, 5]. The amount of shrinkage, in some cases, reaches 14%. The final product obtained as a result of pouring metal into defective shell forms leads to additional energy costs associated with melting of the metal. To eliminate the temperature defects of the investment model, there has been used the technology based on the compaction of the investment model powder in the press-mold to a density value lower than the density of the model material by the amount of shrinkage [6].

Such approach makes it possible to obtain distributed porosity in the structure of the investment model and, therefore, to prevent the creation of temperature defects in it. The quality of the surface and the accuracy of geometry of the casting manufactured by such investment model are limited by the quality of the molding cavity. The problem of increased consumption of the molten metal can be solved by using the inserts made from compacted aluminothermic charge or iron-carbon melt into the investment unit. In the first case, the operation of pouring the melt is removed, in the second case, the volume of the required melt is significantly reduced compared to the traditional method of casting manufacturing.

The process of creating a wax-like finish layer on such model units, which determines the final configuration of a casting and provides the improved dimensional and geometric performances of a casting, seems to be understudied. The problem, in this case, is the elastic response of the wax-like material that appears while its compaction. The experiment has proved that the value of the elastic response is 0.4–0.6% of the size of the molding cavity. To reduce the negative impact of the elastic response seems possible in considering this phenomenon while drafting the press- molds or using the pressing modes (as particular, pressing speed and dwelling time of the material under load) which allow to throw away the elastic response. In the world practice, there is a lot of information about the polymer material relaxation after compaction, or its adhesion to the base material [7, 8, 9]. However, due to the fact that wax-like materials have structure similar to polymers, they are not considered as structural materials, and the combination of their performances (Young's modulus E ~ 80 hPa and Poisson's ratio μ ~ 0.5) is unique, it is still difficult to adapt well-known calculation methods for them.

Having regard to the abovementioned, the development of technological variants aimed at reducing production costs associated with the increased consumption of liquid metal, the elimination of defects due to temperature effects, seems to be an urgent task.

The aim of the research is to develop a technological process for the production of steel castings with improved dimensional geometric accuracy using complex models.

To achieve the aim of the research, the following tasks have been carried out:
- To form the frame of the investment unit by compaction of aluminothermic compound in the press-mold, or to make the investment unit from iron-carbon alloy;
- To study the effect of the movement rate of the molding elements on the elastic response value of the wax-like material pressed on the investment unit;
- To study the effect of the dwelling time of the wax-like material under load (when all movable elements are closed and are not moving) on the elastic response value of the wax-like material pressed on the investment unit.

The complex casting models considered in this work are two-layer constructions, inside of which the base (frame) of the investment unit is placed [10]. Thus, the present work presents two technological methods to manufacture castings with the improved dimensional and geometry accuracy, a characteristic feature of which is the need to take into consideration the pressing mode of a porous wax-like material when forming the finish layer on a porous rigid investment unit made from compacted aluminothermic material (see Fig. 1, a, b, c, d, e – to the left of the axis of symmetry), and also on a solid rigid investment unit made from iron-carbon alloy, e.g.: steel (see Fig. 1, a, b, c, d, f – to the right of the axis of symmetry). The use of the second variant allows to obtain bimetallic castings.
with an external layer from any melt, the temperature of which is lower than the melting point of the iron-carbon frame of the investment unit.

To form the base of the investment unit, a frame made from compacted aluminothermic compound, consisting of iron cinder, ferroalloy impurities [11], a reducing agent and a plasticizer is used. As a plasticizer, wax-like material is used that is similar to that applied to the unit base [1].

The stages of a casting manufacturing according to the first variant shown schematically in Fig. 1 are the following: aluminothermic frame 3-1 is placed into press-mold 1 equipped with movable pressing elements 2 (Fig. 1, a – the left side); wax-like compound powder of the model is delivered into the gap between frame 3-1 and press-mold 1; by compaction of wax-like material during the travel of movable elements 2, pressed layer 4 is obtained (Fig. 1, b – the left side); the obtained investment unit is ejected from press-mold 1; ceramic shell 5 is formed by layers on the investment unit (Fig. 1, c – the left side); the investment compound is removed from shell 5 by fusion; shell 5 is quenched. The metal melt is resulted in the exothermic reaction on an open surface of the investment unit activated by ignition. The melt resulted from exothermic reaction moves frontally down the shell form filling it gradually, forms a body of casting, and slag is displaced to the upper part of the shell (Fig. 1, d – the left side). As the exothermic reaction occurs under high temperatures, high-refractory compounds as a component of fire-proof material is required to use during the ceramic shell creating. The advantage of this casting production method is the possibility to obtain the metal melt without using a foundry mold and traditional melting units. It allows to make a significant reduction in the work intensity of the process.

The stages of a casting manufacturing according to the second variant shown schematically in Fig. 1 are the following: steel frame 3-2 is placed into press-mold 1 equipped with movable pressing elements 2 (Fig. 1, a – the right side); wax-like compound powder of the model is delivered into the gap between frame 3-2 and press-mold 1; by compaction of wax-like material during the travel of movable elements 2, pressed layer 4 is obtained (Fig. 1, b – the right side); the obtained investment

Figure 1. The diagram of sequence of casting formation produced by the combined patterns: 1 – press-mold; 2 – movable die; 3-1 – aluminothermic frame; 3-2 – steel insert; 3-3 – casting made from aluminothermic alloy; 4 – wax-like pressed layer; 5 – ceramic shell; 6 – bimetallic casting.
unit is ejected from pre-mold 1; ceramic shell 5 is created by layers on the investment unit (Fig. 1, c –
the right side); the investment compound is removed from shell 5 by fusion; shell 5 is quenched, the
gap between the investment unit and the shell is filled with metal melt 6, its temperature is
significantly lower than the melting point of frame 3-2 (Fig. 1, d – the right side).

In both cases, the surface quality of the final product is limited by the characteristics of the forming
cavity of the press-mold. The experiment has proved that when such approach to create the pressing
on the frame of the investment unit is used and the gap between the walls of the press-mold and the
frame does not exceed 10% of the cross-sectional area of the frame, the travel rate of movable
elements of the press-mold should not exceed 2 mm/sec. Increase of the travel rate leads to uneven
compaction of wax-like material. Therefore, the dispersed composition of the wax-like investment
compound fraction is determined by the linear size of the gaps between the forming cavity of the
press-mold and the base frame.

The ways to control the elastic time effect value of the compacted wax-like material during the
usage of these two technological variants for casting production are different. With the application of
the first technological variant, relaxation of pressed wax-like material 4 by dwelling it under pressure
is not required because part of the material damps through open pores on the surface of frame 3-1 (Fig.
1, c). With the application of the second technological variant, relaxation of stresses in the pressed
material is required. The experiment has proved that relaxation of stresses able to effect the geometry
of a casting product, for a number of wax-like materials related to the first group of the classification
[1], is achieved by dwelling the material for 8 minutes under load (when all elements of the press-
mold are in the closed position). This method allows to eliminate the elastic response of wax-like
material with uniform distributed density by controlling its volume dosing into the press-mold.

The abovementioned advantages of the approach to create casting products with improved
dimensional and geometric accuracy allows to minimize (and in some cases to eliminate) machining
process. The application of such technological solutions makes it possible to obtain bimetallic castings
with high dimensional and geometric accuracy, the metal melt from wastes (e.g., iron oxides, metal
chips) without using traditional melting units.

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