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Use of additive technologies for practical working with complex models for foundry technologies

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Abstract. The article presents the results of research of additive technology (3D printing) application for developing a geometrically complex model of castings parts. Investment casting is well known and widely used technology for the production of complex parts. The work proposes the use of a 3D printing technology for manufacturing models parts, which are removed by thermal destruction. Traditional methods of equipment production for investment casting involve the use of manual labor which has problems with dimensional accuracy, and CNC technology which is less used. Such scheme is low productive and demands considerable time. We have offered an alternative method which consists in printing the main knots using a 3D printer (PLA and ABS) with a subsequent production of castings models from them. In this article, the main technological methods are considered and their problems are discussed. The dimensional accuracy of models in comparison with investment casting technology is considered as the main aspect.

1. Introduction

Additive technology (AT) has been used in tasks aimed at creating material models in no time. At the same time, a distinctive feature of AT is that there is no need in using additional or special tools (equipment). Metal including steel details with complex geometry and surface shape are produced mainly by casting methods using investment casting or lost foam casting for burned-out models because traditional die casting with the use of sand mold has limited capabilities [1-2]. The major drawback of investment casting is high labor consumption due to use of manual work and low dimensional accuracy of castings, since the material of the model inherently has low durability and rigidity, especially taking into account the large number of technological operations it is subjected to [3].

The main objective of the work was to study the possibility of AT application for fast manufacture of high-precision models with the subsequent manufacture of metal castings. Development of die casting is complicated and cyclic process, where it is necessary to develop a large number of technological solutions, both for the whole casting and its separate parts. In practice this means the production of a large number of variants of the model and auxiliaries, which are die sets, cores, gating systems and risers. Obviously, special equipment, highly skilled personnel and considerable time expenditures are required for this reason. In this work, we have suggested to put aside intermediate industrial equipment at the stage of die casting development due to AT application, namely manufacture of models using a 3D printer.

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2. Materials and Methods

The main area of work was studying dimensional tolerance, quality of experimental castings surface and thermodestruction of modeling material, because the distinctive feature of the developed method is that the casting model is not preliminarily removed previously (unlike the Investment Casting method), but it is burned out by the melted metal. The defining feature of this research is the use of PLA and ABS material as the modeling material. The studies of properties of other materials for model production are presented in [2, 4-6]. Low melting temperature, biodegradability, stability during production of prepared models and easy machining completely meets the requirement to the produced models. PLA and ABS plastic has amorphous structure, which is an advantage for receiving smooth surface or surface of complex relief.

The experiments employed a typical example of 3 or 4 walls with different thickness combined into a single unit, model of a cast body of a stop valve (Figure 1a). Such object is the most difficult and widely spread at the stage of formulation of requirements for determining the thickness of walls depending on the feeding system and defining the design of radial blends between the walls. The design of such difficult unit, as a rule, is defined only by direct experiments, since the thickness of walls and radii of blend between them cannot be calculated both by analytical methods and by computer modeling methods.

The tasks of research included the development of computer parametrical model of casting (Figures 1a and 1b) with a capability of fast change of geometrical dimensions [7], printing of the model using a 3D printer, coating it by a refractory layer, study of burning properties of ABS and PLA for forecasting casting by molten metal. The models were printed using Makerbot Replicator 2 printer by Fused Deposition Modeling (FDM), i.e. layer-by-layer covering of the melted construction material by an extruder. According to ASTM International classification, this method belongs to Material Extrusion. Today it is the most affordable consumer technology, which is the basis for currently produced industrial and professional machines. ReplicatorG (open source 3D printing program) was used as the slicer (the software for converting of three-dimensional model into a set of movement commands for the printing head).

The desired result of printing was received with the following settings: layer height is 0.15 mm, object infill is 10%, printing temperature for PLA is 230 °C and printing temperature for ABS is 250 °C. Heating of table is 100 °C. Printing of a half of the model for both types of plastic took about 180 minutes.

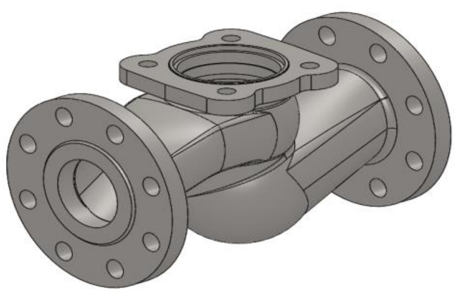

Figure 1. Initial design of cast valve body

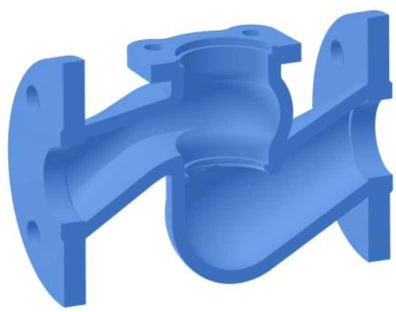

Figure 2. Design of cast valve body for 3D printing

In order to form an internal cavity, the body was divided into two parts (Figures. 2, 3 and 4) diametrically to the central plane of symmetry. Parting planes of half-models were subjected to machining by an emery paper P160 using the grinder.

The printed 3D model from PLA plastic was pre-treated by chloride methylene (dichloromethane) for the sake of high-quality surface; the model from ABS plastic was not chemically treated.

Figure 3. Inner surface of ABS-model after removing the pattern-supporting layer

Figure 4. Model after machining the parting plane

3. Application of the refractory layer

The refractory layer was applied in two stages. The first stage was the filling of the internal space; the second stage was the creation of the shell. The internal cavity was filled with mix on the basis of fine quartz sand and plaster binding in equal proportions, water was added for ensuring plasticity of the mix. The resulting solution was pressed through one hole before complete filling, which allowed reducing the probability of emergence of air cavities to minimum (Figure 5). In 24 hours the model was disassembled, the core was completely hardened. Then, the two halves of the model were put together and bound with a special thread.

The external refractory layer was deposited by method of dipping into the solution on the basis of quartz sand and organic binding in two layers with intermediate drying of 12 hours. Drying of the refractory layer was carried out in a vacuum oven with blowing by warm air (35-40°C). PLA plastic has good adhesion with the refractory layer; there was no peeling or destruction of the refractory layer (Figure 6).

Figure 5. Rammed core in the model

Figure 6. Model with the deposited refractory coating after 12 hours

4. Studying thermodestruction of model material (ABS and PLA) and its properties

Important feature of the developed technology is the possibility of direct removal of ABS and PLA model due to impact of high temperature of the melted metal. The initial burning temperature of both plastics is ~395 °C; at the same time, the process has the maximum intensity at the temperature of more than 425 °C, and it is accompanied by release of gases. Products of thermodestruction of PLA plastic are considered harmless; ABS plastic partially emits toxic agents. In this work, the rates of model material burning were investigated, because slow gasification can result in unsatisfactory filling of a form by liquid metal and, as a result, to the formation of gas sinks or gas porosity in future casting due to dissolution of gas in metal. The technique of experiment consisted in intense temperature impact on ABS and PLA plastic with the measurement of burning rate and identification of residual products. The standard wire for printing with the diameter of 1.75 mm was used. Thermodestruction rate was investigated by kinetic movement of the burning edge under conditions of steady burning of the material. Speed of burning of the PLA thread was 2.25 mm/sec, and for the ABS thread it was 3.33 mm/sec. With the increase in temperature, the speed of burning will proportionally increase, but from the received measurements, it is possible to make a conclusion about low speed of thermodestruction of plastics.

5. Visual and instrumental assessment of chosen parameters

Layer-by-layer material deposition causes uneven cooling of layers, which leads to distortion of parts. When the printing of models ended, the edges of PLA model were detached from the table (the shape distortion is obvious), and the ABS model completely adhered to the table. ABS plastic turned out to have better adhesion. The deformation of substrate layers was noticed, which indicated the distortion. This was confirmed at the interface of model parts. Both plastics required machining of the parting plane.

The linear dimensions of parts increased without obvious regularity, probably, according to the settings of the software (slicer) when converting 3D-drawing into the commands for the printer (Table 1). The holes are not straight and are out of plane. The printed holes are often oval. Visual control showed that the holes printed on the axis of a circle mainly deviate from planeness, and the holes printed perpendicularly to the axis deviate from straightness.

Table 1. Deviations of the actual sizes of model from sizes given in the drawing in percent

	drawing	model (PLA)	model (ABS)
Length	100	+1.010	+1.016
Flange thickness	100	+1.048	+1.086
Flange diameter	100	+1,004	+1.013
Thickness of the cover flange	100	+1.119	+1.048

According to the standard “Geometrical Product Specifications (GPS) — Dimensional and geometrical tolerances for moulded parts — Part 3: General dimensional and geometrical tolerances and machining allowances for castings (ISO 8062-3:2007)”, the parts from PLA and ABS had dimensional casting tolerance grades DCTG7. According to the INTERNATIONAL STANDARD ISO 8062 Second edition 1994-04-01 Castings — System of dimensional tolerances and machining allowances] casting tolerances — the grade was CT7, and CT8 for the ABS detail.

6. Conclusion

In this research, it was established that application of additive technologies can be used for fast production of castings models, including those with irregular shape with a sufficient accuracy.

When using PLA plastic, the model has bigger tendency to distortion of initial layers, as compared with ABS. It is possible to prevent such effect by choosing optimal parameters of table heating, to keep the printer working chamber warm, to improve adhesion by applying special structures to the table before the printing.

When placing the part on the table, it is important to consider that support will be necessary for all protruding elements. Therefore, it is recommended to place the part on the table with the wide element facing down. The larger the interface surface between the part and the table, the lesser the probability of separation.

If there are requirements to dimensional accuracy, the manufactured models should be checked for deviations of the size and shape from set values. Special attention should be paid to the geometrical sizes of holes and their relative arrangement.

The use of different software (slicers) can lead to the different sizes of the model.

Too dense refractory solution can crack when drying. Obviously, it is connected with adhesive properties of PLA plastic.

The problem of low thermodestruction speed of plastics can be solved by increase in temperature of filling by 10-15 °C, use of an open sprue channel of increased diameter (up to 20%) in cross-sectional area, increase of form filling time, application of open risers for removal of burn products.

It is necessary to perform works in well aired rooms. PLA combustion occurs rather slowly, plastic transforms into liquid, it is not fully burned out without release of acrid substances. ABS burns rather actively, transits into liquid phase and burns, emitting acrid substances and particles of soot in air.

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