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## 3DP Technology for the Manufacture of Molds for Pressure Casting

**G. Skorulski**

Faculty of Mechanical Engineering, Bialystok University of Technology  
ul. Wiejska 45C, 15-351 Białystok

\* Corresponding author. E-mail address: g.skorulski@pb.edu.pl

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### Abstract

The paper presents the use of rapid prototyping technology of three dimensional printing (3DP) to make a prototype shell casting mold. In the first step, for identification purposes, a mold was prepared to enable different alloys to be cast. All molds being cast were designed in a universal CAD environment and printed with the zp151 composite material (Calcium sulfate hemihydrate) with a zb63 binder (2-pyrrolidone). It is designated to be used to prepare colourful models presenting prototypes or casting models and molds. The usefulness of 3DP technology for use with copper alloys, aluminum and zinc was analyzed. The strength of the mold during casting was assumed as a characteristic comparative feature in the material resistance to high temperature, the quality of the resulting casting and its surface roughness. Casting tests were carried out in vacuum – pressure casting. The casting programs applied, significantly increased the quality of castings and enabled precise mold submergence. Significant improvement was noted in the quality compared to the same castings obtained by gravity casting.

**Keywords:** Innovative materials and casting technologies, Rapid prototyping, Ceramic mold, Vacuum - pressure casting

### 1. Introduction

Precise casting technologies are increasingly gaining in significance. They can be designed even for unit and small batch production in combination with the possibility of the rapid preparation of molds. Small-size castings are made using Rapid Prototyping (RP) technology systems using FDM technology [3]. The ease of making the molds allows to significantly reduce their preparation time. It is essential for the quality of the cast to have metal liquidity and metal and casting temperature [7, 9]. Numerical calculations are often used to accurately determine these parameters directly related to the arrests on the alloy cooling curves.[1, 2, 8]. RP casting technologies are mainly used to make casting models for the formation of sand or making shell molds by melting or burning models [3, 4].

The issues of plastics used on models made in RP methods are extensively described in the study [5]. Materials and printers enabling the construction of molds for direct casting can be found in the manufacturer's offer for 3DP devices [6]. However, these machines are not very popular and have many limitations when the aspect of presentation is considered. Powder denoted by the ZCast501 symbol is used for making molds for direct casting. Casting molds of the prototype rotor for direct casting expand the technological capabilities at relatively low cost. The use of modern, universal 3D printers and high-strength composite powder which made colourful presentation or casting models was proposed in order to carry out this mold.

## 2. Methods and results

On the basis of the preliminary analyzes undertaken, a split casting mold for casting copper alloy was designed in the SolidWorks environment (Fig. 1).

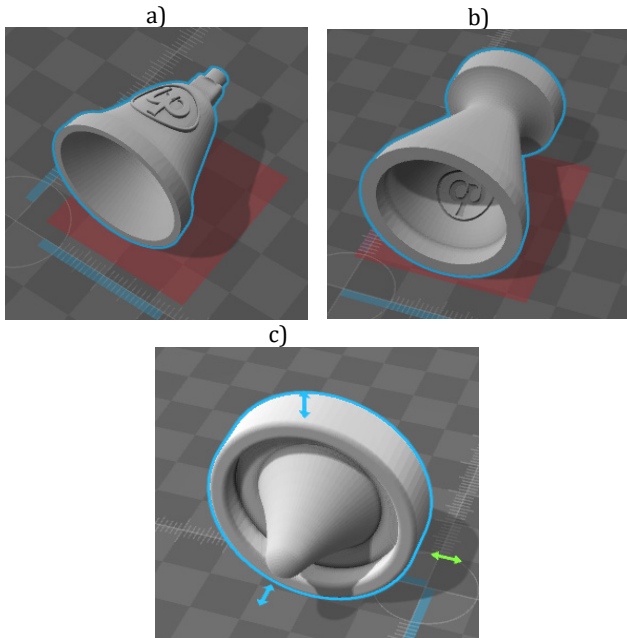


Fig. 1. Casting model prepared in the Solidworks program (a) and split mold (b, c)



Fig. 2. Model printed on a 3D printer

The printed model is shown in Fig. 2. Casting molds for making a comparison, were prepared from zp151 material with a zb63 binder which were printed on the 3DSYSTEMS ProJet 660 PRO machine device. The machine is shown in Fig. 3. Prepared and printed molds for casting zinc and aluminum alloys are shown in Fig. 4.



Fig. 3. 3DSYSTEMS ProJet 660 PRO printer

CuSn10Pb10 alloy and ZnAl5 zinc alloy are used for casting a CuZn37 copper alloy. The primary chemical composition and temperature of casting alloy is contained in Tab. 1.

Table 1.  
The basic composition of the alloy and the casting temperature

Designation	Primary composition of alloys	Casting temp.
	%	°C
CuZn37	Cu 63, Zn 37	1050
CuSn10Pb10	Cu80, Sn10, Pb10	950
ZnAl5	Zn 95, Al 4, Cu 1	420

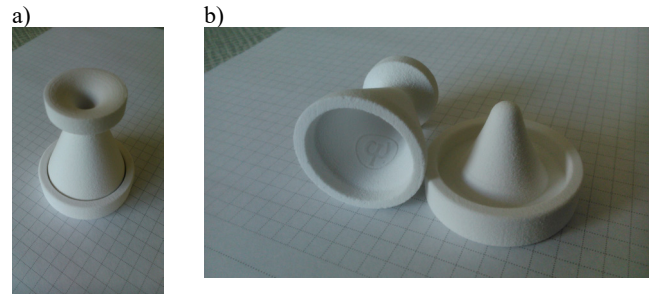


Fig. 4. Casting molds made in RP technology: a) split mold, b) components of split mold

After analyzing the obtained test results in the form of gravity casting and the possibility of using the model in the manufacture of prototype casting, subsequent molds were prepared, taking into account the technological and machining allowances in accordance with (Fig. 4.) from zp 151 powder with the zb63 binder. No account was taken of the inlet tank made as an additional element in Fig. 4.

The casting process was carried out using Nautilus T vacuum - pressure casting. This device allows vacuum - pressure casting with a split melting pot and has integrated cooling. Casting is conducted here manually (no pyrometer), following the visual inspection of the molten metal alloy. Commencement of casting occurs by pressing the corresponding button. Under the settings option, the appropriate program for casting can be selected. There is the possibility of entering your own program for casting. All available programs are described in the device manual [10]. Casting molds must be pre-prepared and basked in an induction furnace to the desired temperature. After visual inspection and

determining that the alloy is suitable for casting, the heated pre-mold is placed into the chamber under a melting pot which is supplied with the device. The casting process occurs automatically. Pressure parameters are set according to the selected casting program. The view of pressure castings used to carry out the test is shown in Fig. 5 and Fig. 6.



Fig 5. NAUTILUS T pressure casting

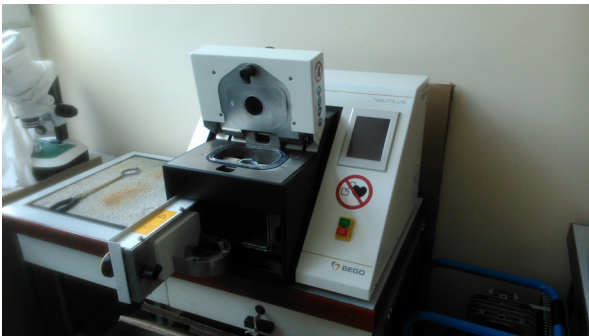


Fig. 6. Pressure casting: open melting pot chamber - above, and a ring for fixing molds – below

### 3. Description of the results obtained

After submerging and cooling the molds, preliminary inspection of the shell mold and then the broken cast was undertaken. In the cases described, it was initially found that the ceramic material used in the construction of molds allows for a satisfactory quality cast at a temperature not exceeding 700 °C to be obtained.

#### 3.1. The influence of temperature

On the basis of the inspection, it was found that the ceramic material used can be applied to molds for direct casting of zinc and aluminum alloys. In the case of casting at lower temperatures (about 400°C) the mold material retains its compactness and hardness. The influence of temperature is reflected to a depth of approximately 1 mm without significantly affecting the casting process. A change of the colour of the mold material and degradation of its structure occurs with increasing temperature. Coloration indicates a decrease in the strength of molds. There is

also strong gassing and smoke from the binder burn-up. The printed ceramic material is heated to a temperature of 700 °C and is deprived of binder but still maintains consistency at low hardness.



Fig. 7. Castings after knocking out and cleaning: a) ZnAl5, b) CuSn10Pb10, c) CuZn37

The mold for casting brass was similar to others dried and heated to a temperature of 100 °C. As a result of liquid metal activity, the binder bonding the ceramic powder was partially burned out (Fig. 8). Discoloration caused by high temperature is shown here, the dark layers are part of the inner walls of the mold. The characteristic layered structure of the walls formed during the execution of molds using the 3DP method can also be observed here.

Powerful gassing of the mold effectively hinders its proper filling. The quality of the cast made was very low. It is worth recalling that the forms were not specially prepared for the process of casting. They were not soaked or additionally reinforced with anything.

Whilst casting the alloys of non-ferrous alloys, it is necessary to treat the mold thermally by burning it at 700 °C until a uniform white hue is obtained, after which it should be soaked with a formulation increasing its strength and simultaneously resistant to temperature.

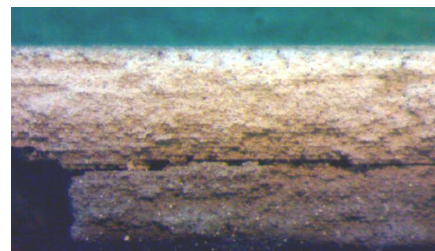


Fig. 8. Thermal degradation of the ceramic mold wall (submerged in alloy at a temperature of 1050 °C)

### 3.2. The quality of the resultant casting

RP 3DP technology is an incremental application of successive layers of material, in the case of ceramic powder under consideration. Applied layers of grain are visible on the completed forms. This is not demonstrated on the perpendicular planes to the incremental axis (Z-axis machinery). "Stepping" is more or less visible on the other faces. The surfaces are readily available and can be further smoothed mechanically but this cannot be done for areas which are difficult to access. The resultant casts obtained copy the casting surface of the mold, thus the surface smoothness obtained is related to their arrangement with respect to the axis of mold growth. The results of roughness measurements are presented in Tab. 2. The maximum measured values on a few selected measurement sections of the  $R_a$  roughness parameter is summarized in it.

Table 2.  
Surface roughness of castings

Alloy	Maximum roughness of $R_a$ surface [um]
ZnAl	11.9
CuZn	12.1
CuSn	16.3

Printing closed molds also creates additional difficulty in removing loose, binder-free building material from the inside. This is important in the case of channels and ribs on the small sections and difficult to reach areas. In order to facilitate the removal of unbound building material and the possibility of providing the opportunity to smooth interior surfaces, split molds are used and are mounted directly before casting. In this way misrun casting is avoided.

### 4. Conclusions

The obtained results allow concluding about the possibility of using 3DP techniques for making direct casting molds using zp151 powder with a zb63 binder. This solution is remarkable in the case of casting alloys in which the casting temperature is not high, for example, zinc alloys. When designing and printing molds, it is necessary to pay attention to the arrangement of the surface of the casting. Surfaces which require high smoothness should be perpendicular or parallel to the axis of growth. The "stepping" of the surface is characterized by another position, which is copied by casting. Split molds can be used to facilitate removing material from the interior of the mold or to allow additional mechanical smoothing of the inner surfaces. In case of casting aluminum alloy or copper mold, it is desirable to remove the binder burning at a temperature of about 700 °C and then recapture the material resistant to high temperatures. The burning zb53 binder is heavily gassed preventing the accurate mold filling

with metal. It is necessary to prepare a ceramic mold with a temperature of approx. 950 °C (CuSn10Pb10 alloy) during casting. This can be done by pre-burning the binder and saturating it with a concentrated solution of sodium metasilicate  $Na_2SiO_3$ . The next step is to re-burn the mold. Another proposed solution is to use another mold material (e.g. Deguvest GF), which is recommended by the pressure - vacuum casting manufacturer. It is bonded investment material designed to perform a particularly precise casting technique of dental crowns and bridges from precious and base metal alloys for creating a mold. Here, however, the mold must be made with a different technology. The lost wax method seems to be the most accurate. The construction of the mold is another factor affecting the accuracy of casting. It is recommended to use split molds in the production technology using a 3DP printer. Before carrying out casting, slight print defects (possible access to and inspection of the interior of the mold) should be already rectified in the process of preparing the mold.

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