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PRODUCTION OF INVESTMENT CASTING MODELS BY ADDITIVE MANUFACTURING

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Abstract

Investment casting is a well-established process to produce complex or thin-walled shapes metal castings. The goal of this test was to review the possibility of the use of two different 3D printers and materials for investment casting model production for educational and training purposes; the application of the two desktop-size 3D printers to produce models (from PLA and resign) is presented as a fast and low-cost method. The quality of the casting was reviewed regarding mentioned two different additive manufacturing processes and different model materials as well as model orientation in the mold.

Keywords: investment casting, additive manufacturing, 3D printing models

1. Introduction

The investment casting process is often considered the most appropriate process for the production of precise cast parts; even though models and molds are used one time only and are destroyed during the process. This casting process has several stages (Figure 1); in principle, the molten metal is poured into molds that are produced around models typically made from wax.

So, even considering the costly and time-consuming process of model and mold production, the investment casting process allows the production of complicated shape parts when production with some other manufacturing processes would be difficult and non-cost effective. Castings produced by this process have precise dimensions and good surface appearance so usually, final processing requires only small-scale operations for the final dimension achievements (i.e. just sawing off or grinding of the gating system). This is very important to produce complex shapes castings as machining those parts would be almost impossible. [1, 2]

Casting size and weights are defined by model and/or ceramic shell production limitations. Larger castings are usually produced as one-off parts in individual production. Although this process is typically used for quantities from 10 – 1000 products [2] it is considered cost-effective for the series of at least 50 castings in industrial applications [1]. Figure 1. shows the investment casting process.

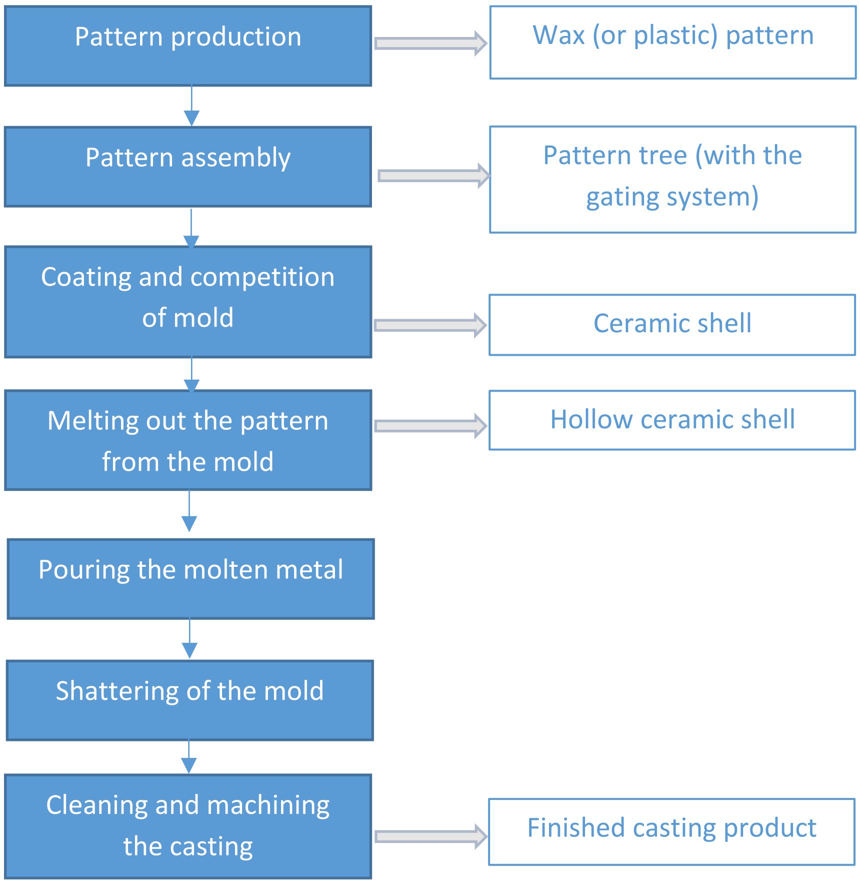


Figure 1. Investment casting process steps

Wax is considered the oldest thermoplastic material and today the majority of investment casting models are still produced from wax. Wax models can be produced from wax blocks or cylinders manually (with saws, shredders, grinding machines, carving tools, or tools that use heat). However, that method is slow and demands a high level of workers' skills, and the production of precise parts with dimensional consistency across the parts is not possible. Manual production of wax models is not utilized for industrial production and its application is generally for one-of-a-kind jewelry production, production of wax master models, and i.e., applications in dental laboratories [1].
Industrial production usually includes the application of metal dies into which wax is injected [2]. This allows higher productivity and dimensional and shape consistency (with narrow tolerances).

Besides the above-mentioned, models can also be produced by machining wax material on wood or metal processing machines or by the application of additive manufacturing technologies.

2. Application of additive manufacturing technologies

With the additive manufacturing group of technologies, objects are usually produced by computer-controlled machines from CAD models. Typically, the material is added in layers to form the chosen object and with this technological approach, it is possible to produce a tridimensional object almost without shape limitations (usual limitations are related to the material type and/or size of the object). Among several available additive manufacturing technologies, material extrusion (Figure 2.) or photo-polymerization process (Figure 3.) can be considered to produce casting models.

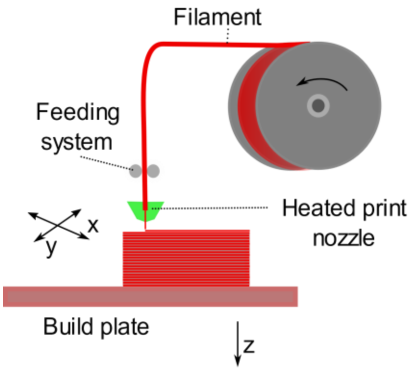


Figure 2. Material Extrusion Additive Manufacturing principle

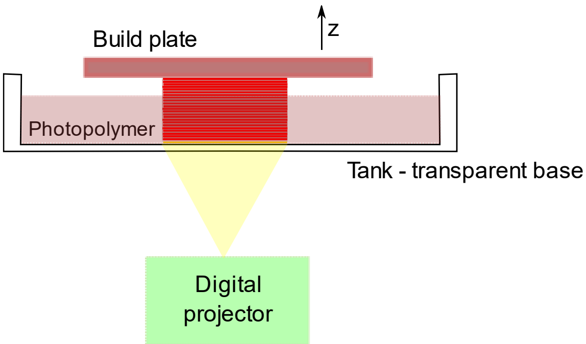


Figure 3. Digital Light Processing Additive manufacturing principle

Material Extrusion also known as Fused Deposition Modeling (FDM) is the additive manufacturing process in which an object is created by melting filament through a heated print nozzle. The product is printed layer by layer on a movable build plate (Figure 2). A filament (usually plastic wire) is fed through a feeding system of rollers to a heated nozzle and then extruded through the nozzle to build a layer (cross-section) of the object. After the layer is finished, the build plate is moved, and the next layer is printed [5].

Digital Light Processing (DLP) is an additive manufacturing process in which liquid polymer (photopolymer) is solidified layer by layer by a light from the digital projector to create a required object (Figure 3). Objects are printed in a tank with a transparent base filled with photopolymer. At the start of the process, the build plate is initially placed in its lowest position and the digital projector starts projecting through the transparent base of the tank creating the first layer of the object. The build plate is lifted and the projection process is repeated building the next layer until the entire 3D object is printed. Then treatment of the object in a UV oven can occur. [6]

3. Printing of models

As mentioned above, model production is a very important phase in investment casting; model defects can influence the final quality of the product. Some of the model defects causes are poor model design, incorrect model production parameters, incorrect handling/storage of models, or handling of models by unskilled staff. Due to this, every step of the model production process needs to be controlled to minimize the possibility of defects.
Wax is a sensitive material and demands careful handling, and as wax model defects cause casting defects, the quality of wax models is very important.
For example, the application of desktop-size 3D printers for the production of wax models is described in the paper [7] as a fast and low-cost method of model production. (The Duinotech printer used in this experiment was a relatively low-price desktop printer (around 150 €)). In order to produce wax models for the tests described in the paper [7] a Duinotech Mini 3D Printer L4076 with MachinableWax 1.75 mm Print2Cat Wax Filament was used.
After printing with certain parameters, it was evident that printing parameters play important role in the production of the model as well as that specific types of defects can appear on wax models. Those defects can be categorized as:

- Gas porosity – gas inclusions
- Excessive shrinkage
- Deformations - warping.

The goal of this trial was to avoid model defects and test the possibility of the production of models with different 3D printers and materials.

Building on the experience of the above-mentioned trial, in order to produce models for the tests described in this paper, two 3D printers were used:

1. FDM 3D Printer - Creality Ender 2 Pro (Figure 4.) with PLA Ø 1,75mm White Filament
2. DLP 3D Printer - Creality LD-006 Resin (Figure 5.) with PrimaCreator Resin -Light Grey (1,1 g/ml resin density).

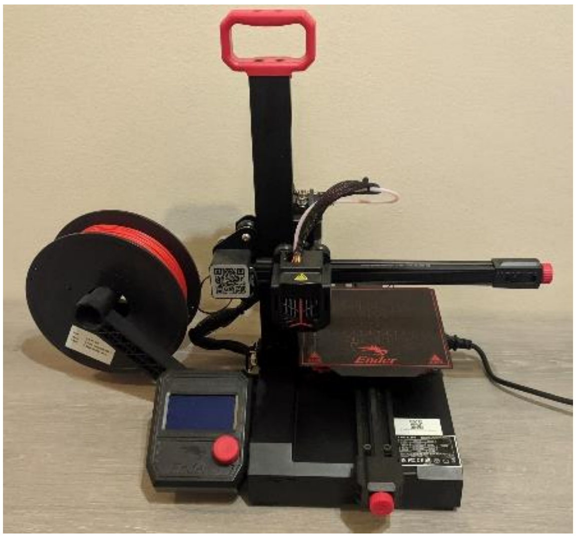


Figure 4. Creality Ender 2 Pro

Figure 5. Creality LD-006

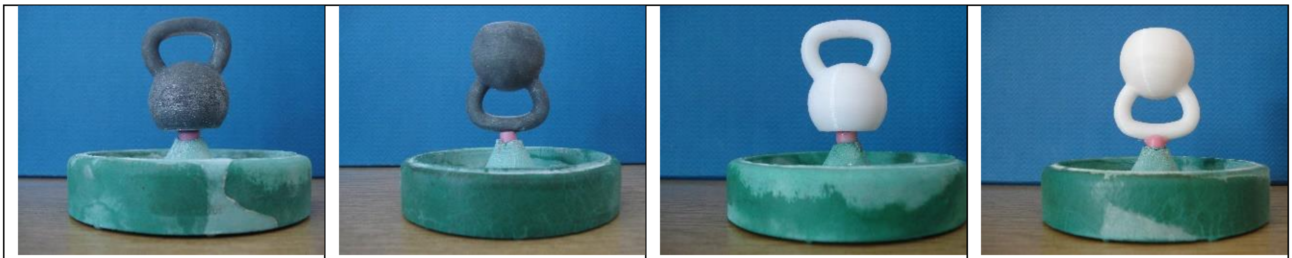
The model for printing was shaped like a kettlebell (35 mm in diameter). Printing parameters for PLA models (Figure 6.): Layer Height: 0,16 mm, Infill density: 10%, and for Resin model (Figure 7.) were: Layer Height: 0,01 mm, Infill density: 100%.

Figure 6. PLA model

Figure 7. Resin model

4. Investment casting

The investment casting was done in the Laboratory for casting at University of Slavonski Brod. 3D models were in the single mold with different positions of casting sprue (Figure 8.).



1) Resin model Bottom pouring	2) Resin model Top pouring	3) PLA model Bottom pouring	4) PLA model Top pouring

Figure 8. 3D Models before investment casting

Dimensions of molds were Ø 75 x 90 mm. Mold material was SRS Investment powders – Classic. Table 1. shows recommended burnout cycle of molds before metal casting [8].

Table 1. Burnout Cycle of molds [8]

Step	Time in hours	Heating process
1	1.5	Heating from room temperature to 230°C
2	3	Holding on 230°C
3	3.5	Heating from 230°C to 730°C (150°C/h)
4	4	Holding on 730°C
5	1	Cooling from 730°C to ~600°C

The casting material was Brass Ms58 (CuZn39Pb3) and the casting temperature was 1050 °C and casting was performed under a vacuum. Figure 9. show castings after cooling and cleaning.

Figure 9. Castings after cooling and cleaning

After casting and cleaning, on castings 1 and 2 larger defects were observed on the surfaces. Castings 3 and 4 had small surface defects caused by residual air bubbles in the plaster that were successfully removed by grinding. Figure 10 shows the castings after cutting the and grinding.

1) 2) 3) 4)

Figure 10. Castings after cutting and grinding

5. Conclusions

Model production is a significant step in the investment casting procedure. Model defects result in casting defects, so the quality of models is very important. The goal of this paper was to trial the possibility of production of models for investment casting with different 3D printers and materials (PLA and resin). The influence of the different model materials (resin and PLA) and the use of the low-cost 3D printing equipment and casting parameters (model orientation), on casting quality, is reviewed. After 3D printing, both models had satisfactory quality, but after cooling and cleaning of castings, it was observed that the use of resin models resulted in castings with defects (possibly caused by incomplete burning of the resin). So for the selected object and casting setup, FDM 3D Printer with PLA Filament was presented as a better option to use for pattern manufacturing for needed educational and training purposes.

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