Using of additive technologies in fabrication of casting models

D Besnea¹, C Rizescu¹, E Moraru¹, I Panait¹, D Rizescu¹ and E Dinu¹

¹University Politehnica of Bucharest, Department of Mechatronics and Precision Mechanics, Splaiul Independenţei Street No. 313, Romania

Email: d_bes@yahoo.com

Abstract. The paper presents a comparative study of the technological process of obtaining casting moulds by means of additive technologies (fused deposition modelling and vat photopolymerisation) from a wide range of materials (thermoplastics and industrial photocurable resin). The obtained results of the researches in the study highlight the advantages and disadvantages of these methods for the realization of metallic and polymeric parts with unique character or very small series.

1. Introduction
Applying to unconventional technologies, modern equipment, design and control software solutions, the paper introduces a new possibility of using additive technologies to realize functional prototypes in small series of models or products. Rapid prototyping is a new technology with wider spread in engineering by streamlining the design process.

FDM (Fused Deposition Modelling) technology is the most widely used additive manufacturing technology due to its simplicity and affordability. It is used in modelling, prototyping, but also in production applications due to the continuous improvement of equipment and new materials. As applications, it can be mentioned parts and resistant subassemblies for functional testing, conceptual design, presentation and marketing models, details pieces for food or medical applications, casting moulds.

Another additive technology with a spectacular development lately is DLP (Digital Light Processing) based on the photopolymerization process, with liquid raw material. It is a superior technology compared to FDM, which can be used to obtain fine and precise prints applied to the jewellery industry, electronics and dental technology. There is a wide range of photosensitive materials, including certified materials for medical use.

Considering that serial and mass production requires specialized machines and moulds whose costs may be quite high, 3D printing has become a useful tool to avoid substantial investment when it comes to getting small lots of pieces (100-300 units). The 3D print products are not finished, with a light texture from the layers of bonded material, while casting the objects have a much better finish, the material being injected and cooled homogeneously [1, 2, 3, 4, 5].

In this paper the authors want to highlight the possibility of obtaining small series of moulds realized by additive technologies, making a comparative study between two different additive technologies - FDM and DLP. In order to evaluate the manufacturing accuracy for each semi-mould, the linear dimensional parameters were taken into consideration and the designed nominal size to the manufactured one was compared.
2. Material and methods

The process comprises three main stages, namely: the pre-processing phase, the proper construction phase of the piece and the postprocessing stage. The first step is to load the CAD model of the part into a specialized program that will generate the FDM machine code. The used software for FDM technology was Replicator G (figure 4a). With the help of the software, the piece is oriented correctly on the work platform and is scaled accordingly. After fully reading of the CAD model, it is oriented into the working space of the machine so that the construction of the workpiece is optimal in terms of working time and material consumption. The construction step is made layer by layer and the last stage of the postprocessing consists of separating the workpiece from the building platform and removing the supports or sacrificial layers. Figure 2 shows the thermal image of the semi-mould obtained with an infrared camera. It can be seen that the highest temperature values are found on the work platform (110°C), which should be heated when the ABS (Butadiene styrene acrylonitrile) is used as building material, so that the depositing layers adhere to the work platform.

DLP Printing Technology (Digital Light Processing) is an additive manufacturing process based on the use of UV light for the solidification of liquid polymer resins. This fabrication technique has as its principal element the DMD (Digital Micromirror Device) chip - a micro-mirror matrix used for fast spatial light modulation. Initially, the 3D CAD model is converted by the software of the 3D printer into the cross sections (slices) of the object, then the information is sent to the printer and the DMD chip. For each cross section of the 3D CAD model, the UV light emitted by a projector is modulated and projected by means of the chip on the surface of the polymer resin in the construction vat. Each individual micro-mirror of the DMD chip projects pixels from the cross-section of the 3D model.

Under the action of ultraviolet light, the photocurable liquid (sensitive to UV light) solidifies in successive layers. Since the entire cross-section is projected into a single exposure, the construction speed of a layer is constant regardless of the complexity of the geometry. Three-dimensional pieces with more complex geometries are made using sacrificial layers that are later removed. The material left in the vat can be used for future fabrications. As a material, a photosensitive industrial resin has been used which has found its place in many applications in different fields and has adequate mechanical properties [6, 7, 8].

The production starts from a CAD model saved in .stl format, which will then be processed by the software of the installation. The "Creation Workshop" (figure 1b) software of the machine allows to view and positioning the piece on the work plane as well as the mirroring operations, scaling, rotating and the possibility to simulate the deposition of the layers during the fabrication of the object. After the slicing operation, the work platform is submerged in the photocurable liquid and printing starts.

![Figure 1](image_url). Orientation of the piece on the workplace: a – Replicator G software for FDM process; b – Creation Workshop for DLP process.
After the completion of the process, the obtained DLP part is inserted into the water to complete the photopolymerization process. After the two semi-moulds are completed, they are assembled for the casting operation (figure 4). As casting material was used Zhermack Industrial ZA 22 Mould [9], which is obtained by mixing the base with the catalyst (ratio 1:1). These silicon rubbers guarantee impressive accuracy in the reproduction of details and an extended working life, due to excellent dimensional stability and broad-spectrum chemical compatibility. In addition, Zhermack Industrial ZA 22 Mould material has very good mechanical properties (flexibility, tear resistance), resistance to extreme temperatures (-40°C/210°C), compatibility with a wide range of materials and biocompatibility. After casting, the object is left for at least 4 hours for drying and solidification. The resulted pieces is presented in the figure 5.
Figure 4. a – Obtaining of the bicomponent casting mixture; b – Casting process

It was realized two sets of moulds by two different additive technologies – FDM and DLP. The first set was obtained with 100% scale factor and second set was reduced in size with 25%.

Figure 5. Obtained pieces after casting

Figure 6. Microscopical captures of obtained semi-moulds: a – Semi-mould realized by FDM technology; b – Semi – mould realized by DLP technology

In order to choose the right variant for casting moulds, realized semi-moulds by the two technologies have been compared in terms of surface condition and dimensional precision, using an electron microscope, images showing the superiority of the DLP process in comparation with FDM due to the smaller thickness and uniformity of the deposited layers (figure 6). In order to evaluate the manufacturing accuracy for each semi-mould, the dimensional parameters presented in figure 7 were
taken into account. Dimensions A, B, C, and E were measured by means of a digital caliper with a precision of 0.01 mm and the D dimension with the help of a digital micrometer with a precision of 0.001 mm. The results (Table 1) highlight the possibility of using the FDM process in casting operations that do not require dimensional accuracy and high surface quality, resulting in relative errors below 2%. Instead, the error grows at small internal dimensions in both processes, especially at FDM. If high conditions are required for dimensional precision and surface quality of the final object, DLP is more recommended, which is a more precise technique, with errors of less than 1% being obtained in most cases.

![Defining of the investigated measurement surfaces](image)

**Figure 7.** Defining of the investigated measurement surfaces

**Table 1.** Results of measurements of semi-moulds

| Process | Nominal dimension [mm] | Upper mould | Lower mould |
|---------|------------------------|-------------|-------------|
|         |                        | Measured value [mm] | Error [mm] [%] | Measured value [mm] | Error [mm] [%] |
| FDM     | A 40                   | 39.84       | -0.16 -0.4  | 39.81 -0.19 -0.47  |
|         | B 50                   | 49.82       | -0.18 -0.36 | 49.78 -0.22 -0.44  |
|         | C 4                    | 3.81        | -0.19 -4.75 | 3.8 -0.2 -5        |
|         | D 10                   | 10.14       | 0.14 1.4    | 10.16 0.16 1.6     |
|         | E 10                   | 9.77        | -0.23 -2.3  | 9.76 -0.24 -2.4    |
|         | A 40                   | 40.09       | 0.09 0.22   | 40.11 0.11 0.27    |
|         | B 50                   | 50.11       | 0.11 0.22   | 50.1 0.1 0.2       |
| DLP     | C 4                    | 4.05        | 0.05 1.25   | 4.05 0.05 1.25     |
|         | D 10                   | 10.04       | 0.04 0.4    | 10.11 0.11 1.1     |
|         | E 10                   | 10.12       | 0.12 1.2    | 10.09 0.09 0.9     |
4. Conclusions

3D printing is cost-effective as long as it does not exceed the costs of moulds made by traditional methods, providing prototypes of low-cost moulds to meet customer requirements. Among the factors that influence the accuracy of execution of the piece can be highlighted: the orientation of the model in the work space, which is important from the point of view of the manufacturing precision of the piece, because during the process the elements that are made by contouring will result more precisely than the elements made by construction; the diameter of the extrusion nozzle of the material influences the workpiece precision by the fact that depending on this will result the dimensions of the section of the deposited yarn as the diameter of the extrusion nozzle is larger, the wider section of the thread of the deposited material will increase, which leads limiting the possibilities to achieve fine detail of the piece and at a lower precision. Experimental research has shown that the FDM process quality of the casting surface is lower with some irregularities on the surface compared to the molded parts in the DLP process.

ABS semi-moulds obtained by the FDM process can also be used directly as casting molds, unless strict conditions are imposed on the quality of castings surfaces and dimensional precision. It was found that dimensional deviations did not exceed 0.19 mm in absolute value, which means relative errors below 5%. If high conditions are required for dimensional precision and surface quality of the parts, the post-processing operations of FDM semimould is required. Due to the complexity of the cavity shape, finishing is usually done manually, which can lead to uncontrolled changes in the dimensions, respectively the shapes of the active surfaces and the time of manufacture of the semimould. In order to obtain more precise casting parts, DLP technology can be used with the superior quality of the obtained surfaces and dimensional precision compared to the FDM process, the dimensional deviations did not exceed 0.12 mm in absolute value, the relative error being 1.2%, but with a higher cost of consumable materials and rapid prototyping equipment. However, it was observed an increase in errors in the case of small internal dimensions for both technologies.

The experimental researches have shown that the fabrication of the moulds by additive technologies presents some advantages in terms of manufacturing preparation time which is not influenced by the complexity of the parts, the use of special tools and devices is not necessary, the mechanical characteristics of the printed object correspond to the use for the realization of small series of conceptual models, being a much faster and cheaper version compared to conventional material processing technologies (turning, milling) and unconventional (electroerosion, ultrasound).

References

[1] Berce P, Balc N, Pacurar R, Bratean S, Caizar C, Radu A and Fodorean I 2014 Tehnologii de fabricatie prin adaugare de material si aplicatiile lor (Bucuresti: Editura Academiei Romane)
[2] Spanu A R, Constantin V, 2017 Int J Mech Appl. Mech.2 7-11
[3] Dontu O G, Barbilian A, Florea C, Lascar I, Dobrescu L, Sebe I, Scarlat R, Mihaila C, Moldovan C, Pantazica M, Besnea D, Gramezu B, Dobrescu D, Lazo V, Firtat B and Edu A 2018 Rom J Inf Sci Tech 21 (2) 139-150
[4] Moraru E, Dontu O, Petre A, Vaireanu D, Constantinescu F and Besnea D 2018 J Optoelectron Adv Mat. 20 (3-4) 208-213
[5] Moraru E, Besnea D, Dontu O, Gheorghe I G and Constantin V 2018 Int J Mech Appl. Mech 3 67-71
[6] Pandey R 2014 Photopolymers in 3D printing applications Degree Thesis Plastics Technology
[7] Shkuro A E, Krivonogov P S 2017 Technologies and materials for 3D printing (Ural State Forest Engineering University)
[8] Ko D H, Gyak KW, Kim D 2017 J. Flow Chem. 7(3-4) 72-81
[9] https://www.zhermack.com/en/