Electroforming of 3D Digital Light Processing Printed Sculptures Used as a Low Cost Option for Microcasting

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Abstract—In this work, two ways of creating small-sized metal sculptures are proposed: the first by means of microcasting and the second by electroforming from models printed in 3D using an FDM (Fused Deposition Modeling) printer or using a DLP (Digital Light Processing) printer. It is viable to replace the wax in the processes of the artistic foundry with 3D printed objects. In this technique, the digital models are manufactured with resin using a low-cost 3D FDM printer in polylactic acid (PLA). This material is used, because its properties make it a viable substitute to wax, within the processes of artistic casting with the technique of lost wax through Ceramic Shell casting. This technique consists of covering a sculpture of wax or in this case PLA with several layers of thermoresistant material. This material is heated to melt the PLA, obtaining an empty mold that is later filled with the molten metal. It is verified that the PLA models reduce the cost and time compared with the hand modeling of the wax. In addition, you can manufacture parts with 3D printing that are not possible to create with manual techniques. However, the sculptures created with this technique have a size limit. The problem is that when printed pieces with PLA are very small, they lose detail, and the laminar texture hides the shape of the piece. DLP type printer allows obtaining more detailed and smaller pieces than the FDM. Such small models are quite difficult and complex to melt using the lost wax technique of Ceramic Shell casting. But, as an alternative, there are microcasting and electroforming, which are specialized in creating small metal pieces such as jewelry ones. The microcasting is a variant of the lost wax, that consists of introducing the model in a cylinder in which the refractory material is also poured. The molds are heated in an oven to melt the model and cook them. Finally, the metal is poured into the still hot cylinders that rotate in a machine at high speed to properly distribute all the metal. Because microcasting requires expensive material and machinery to melt a piece of metal, electroforming is an alternative for this process. The electroforming uses models in different materials; in this case, 3D printed microsculptures, which can be subjected to galvanic baths that cover the work of a very thin layer of metal. This work will investigate the recommended size to use 3D printers, both with PLA and resin. In this study, first tests are being done to validate use of microsculptures, printed on resin using a DLP printer, for electroforming with low-cost kits.

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I. Introduction

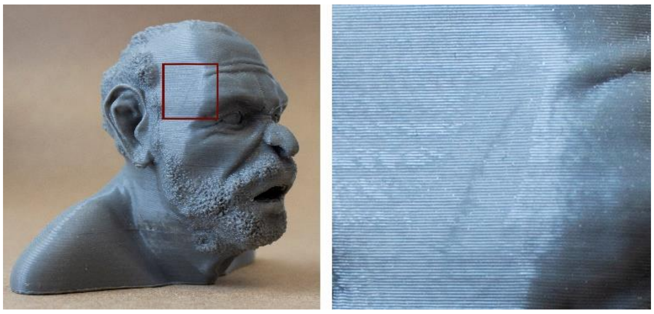
Foundry is defined as the process of forming objects of metal, casting it and pouring it into a mold creating complex objects in a single step and with a variety of shapes and sizes [1, 2]. There are other methods of shaping metal such as machining, forging, welding, stamping, hot working, etc. [3]. The different techniques are used according to the characteristics of the model to be built and usually several methods are combined at the same time to create a final object.

There are several casting procedures; Sand casting [4], casting with gasifiable moulds [5], die casting [6], lost wax casting technique [7], and finally microfusion [8], a variant of lost wax, which is used to make small detailed parts such as jewelry. On the other hand, a technique called electroforming is also commonly used in jewellery [9]. This technique does not melt the model to convert it into metal, but is a process that coats the pieces with a very thin metal layer through the use of an electric current.

With the appearance of additive manufacturing, the idea arose to replace the wax models used in lost wax casting with models manufactured using low-cost 3D printers in the material PLA (polylactic acid). This material is a biodegradable thermoplastic polyester from renewable resources such as corn starch, a non-toxic material that has a melting point similar to wax [10]. When the wax model is replaced by a PLA model in lost wax casting technique, it is called lost-PLA casting [11]. Computer-designed models allow for greater complexity than can be achieved with the use of traditional hand modeling techniques. The creation of hollow pieces, the variation of scales in the models and the realization of variants in pre-designed forms, suppose a minimum effort in digital models, if we compare them with those realized in a traditional way [12, 13].

There are 3D printers that produce more detailed objects directly in wax, these machines are integrated into the industrial foundry and specialized in the processes of creating jewelry, where they have revolutionized production [14], aunque although they are high cost. One 3D printing technology established at industrial levels is "selective laser sintering" (SLS), which builds objects directly on metal. The metal objects created by this type of printer have approximately 99.99 percent density, and can therefore be used instead of traditional metal parts in the vast majority of applications [15]. But the cost of the printed model is high, so they are not a viable alternative in artistic casting.

PLA is a material that due to its properties is presented as a viable substitute for wax, within the processes of lost wax casting. However, 3D printers that use PLA are FDM (Fused deposed modeling) type. This is an additive process, where the successive layers of material are placed adapting to the required shapes, predefined in a 3D digital file [16]. This form of construction produces a laminar texture in the objects (Fig. 1). To eliminate the laminar texture, the pieces can be subjected to procedures to soften the surface [13].



(a) (b)

Figure 1a: 10 cm figure printed on an FDM printer with PLA.
Figure 1a: Detail of the laminar texture on the model printed on PLA.

The laminate texture together with the surface softening treatment presents acceptable results in pieces with low detail of about 10 cm. However, these procedures are not feasible for very small parts, as they degrade surface details and can deform the parts. In order to obtain smaller and more detailed pieces, as well as to minimize the texture of the printed pieces, the use of 3D DLP (Digital Light Processing) printing is investigated, which allows obtaining more detailed and smaller pieces than those printed with FDM, in addition, it presents less texture. Among these printers, you can find low cost models with prices similar to FDM printers.

The resolution of FDM printers is conditioned by the way objects are manufactured, using stacked layers of molten material. The molten PLA comes out of a nozzle that is normally 0.4 mm in diameter, allowing a resolution on the x, y (width and length) axes of 0.4 mm (400 microns). The resolution of the z-axis (height) depends on the motors and sleeves used to move the nozzle on the z-axis. Typically, in these printers, the accuracy can range from a maximum of 0.05 mm to a minimum of 0.3 mm. This gives the height of each layer that is built, so the layers have a resolution of between 50-300 microns.

DLP printers do not deposit a thread, but produce by means of a light that passes through an LCD screen and hardens a photosensitive resin. In this case the resolution of the x, y depends on the resolution of the screen. Low-cost 3D printers of this type usually have a screen resolution of 2560 x 1440 pixels for a 5.5-inch screen (often referred to as 2K screens). This gives a detail of x, y of 40 microns. The resolution of the z-axis, as in PLA printers, depends on the motors and screws used to move the printing table on the z-axis. In most low cost printers they are typically between 35 - 50 microns.

TABLE I
FDM AND DLP PRINTER RESOLUTION COMPARISON

Resolution	FDM Low Cost Printers	DLP Low Cost Printers
Resolution X, Y	400 microns	40 microns
Resolution Z	50 – 300 microns	35 – 50 microns

DLP parts are so small in size that it is not feasible to cast them using the lost wax ceramic technique. In order to convert small pieces into metal, two alternative techniques are considered in this work. On the one hand the microfusion, a variant of the lost wax that is used for small pieces and on the other hand the method of electroforming where the object is covered by a layer of metal by electric current.

II. MATERIALS AND METHODS

A. Creation and 3D printing of the models

To print a model with a 3D printer, you need a digital model. These are obtained through specialized 3D modeling software or through 3D digitalization through scanners or photogrammetry [17]. There are many 3D modeling programs to suit specific disciplines. In the field of artistic modeling there is software whose operation reproduces, to a large extent, the processes of real modeling in clay, although it also allows geometric modeling. Currently there are different programs, some of them free, that allow this mode of work, such as ZBrush, Sculptris, Mudbox, Meshmixer, 3D Coat, Blender, etc.

In 3D modeling programs it is easy to change the size to 3D models. Once obtained our digital model, and to be able to be printed in 3D, we will need the help of a program that translates the geometry to a file that can be interpreted by a 3D printer. There are numerous programs, some of them free, like Cura, Slic3R, Repetier, Octoprint, Creation Wokshop, etc. By means of this type of programs, all the parameters that affect the 3D printing process are edited. In this study, two printers are going to be used, one with PLA and another with resin.

In the following image it can be verified that when preparing the figures for its 3D impression with PLA by means of a printer of FDM type, so much the figure of 3 cm as the one of 2 cm, they can be made. But when calculating the figures of 1 cm and 0,5 cm, the machine is not able to construct the model (Fig. 2).

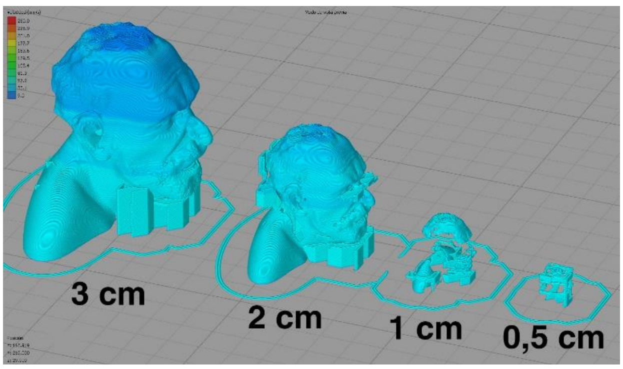


Figure 2: Preparing the 4 models in different sizes in the Simplify program for PLA printing in the Witbox Ultimaker

In the following image you can see that when preparing the figures in the Creation Workshop program for resin printing, none of the figures presents problems for printing (Fig. 3).

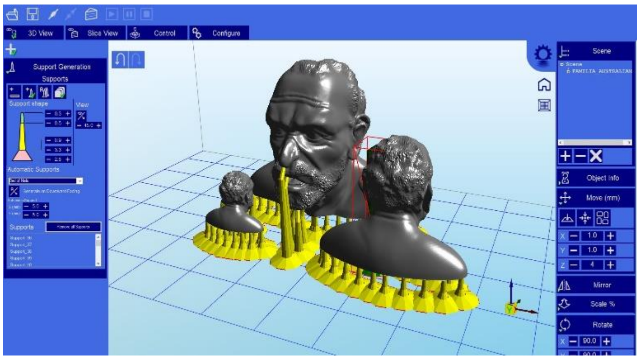


Figure 3: Preparation in the Creation Workshop program of the 4 models in different sizes for printing in resin using the WANHAO Duplicator 7 printer.

In this case, with the DLP type 3D printer, all four models could be made in resin without problems. The following image shows that the construction of the pieces is perfect (Fig. 4) and many more details are shown than in the parts printed using PLA However, the smaller the piece, the more details are lost, leaving the 0.5 cm piece almost unrecognizable.

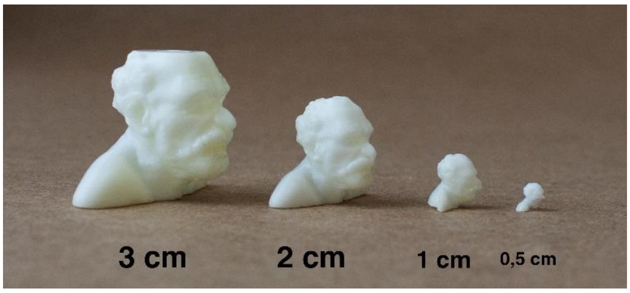


Figure 4: Pieces printed in resin using a DLP printer

On the other hand, the figures printed in PLA in the sizes of 3 and 2 cm, have been printed with many defects and laminar texture, since these sizes are very close to the limit in which the printer works. Also, when you want to print hollow pieces, these defects are accentuated and almost make the details disappear. In figure 5 you can see a comparison of the result in PLA and resin for the size of 2 cm. The resin figure has far fewer defects and texture than PLA, so for small parts, the use of PLA can be discarded.

Figure 5: Comparison between PLA printing (left) and resin printing (right)

Once we have checked the minimum sizes that each of these printers allows us to obtain, we can begin to carry out tests to obtain metal models from these printed figures. As it has been commented, in this work it is proposed, on the one hand, the microfusion, a variant of the lost wax that is used for small pieces and on the other hand the electroforming method where the object is covered by a layer of metal by electric current.

B. Microfusion and electroforming techniques

Microfusion is commonly used in jewellery to create small, detailed pieces. In this technique, a wax model is usually used first and then inserted into a cylinder into which the refractory material is also poured. The moulds are heated in an oven to remove the wax and bake them. Finally, the metal is poured into the still hot cylinders. But when the molten metal is poured into the cylinder, it rotates at high speed to facilitate the correct distribution of the metal in each hole. The high rotation speed causes centrifugal forces to cause the metal to take the shape of the mold cavity. This technique requires a complete foundry workshop and a machine that rotate the cylinders [17].

Another variant of microfusion is to use machines with integrated vacuum metal casting system. These machines start with the heating of the metals, then the cylinder is placed in one of the two vacuum chambers with gasket. When the vacuum/pressure values are reached in both chambers, the gap between the two opens and the metal flows into the cylinder. Immediately afterwards, a strong compression takes place, forcing the metal to be perfectly introduced into the mould [18].

Microfusion techniques work in a similar way to lost wax casting, so it is possible to replace the wax models with 3D printed models, on the one hand printed on an FDM printer using PLA at the smallest possible size and the best resolution that can be obtained. On the other hand, a model manufactured by means of a DLP printer, also with the minimum possible size and the best viable resolution. The definition, the detail obtained as well as the perfection of the surface of various sizes printed with both machines are checked. However, it must be taken into account that the usual resin used in DLP printers is not meltable and therefore it is not possible to introduce these parts into the microfusion process. But there is castable resin for this type of machines, specially designed to be used in casting processes.

The second technique is electroforming. This technique consists of the production or reproduction of articles by electroplating on an object, which is introduced into an electrolytic bath that is composed of a solution (ion) of salt and the metal to be coated. A continuous current of electricity passes through the solution, transferring metal ions to a cathodic surface, coating the metal on the object. As the current passes between the two electrodes, the metal ions in solution become atoms on the surface of the object and accumulate layer after layer, micron after micron to produce a continuous deposit [19].

It is an extremely versatile process, used to produce microelements for the medical and electronic industry and large components for the aeronautical and aerospace industries, in the artistic field is a technique used in the production of jewelry. Although this technique is used in large machines in the industry and in the production of elements with expensive metals such as gold, there are low-cost electroforming kits that can be purchased from 50€ and are useful for small tests.

Electroforming can be used to manufacture many thin, small and detailed products more economically than by normal metallurgical procedures such as casting. A base model of a wide range of materials such as metals, plastics, glass, wood, fabrics etc. is used for electroforming. These materials are divided into electrical and nonelectrical conductors, so the procedures required to prepare them for electroforming vary. Conductive materials such as metal do not require additional treatment. However non-conductors have the disadvantage of having to become conductive to allow the electroplating process. This is done by applying a thin metallic film, using conductive paint [20]. This means that parts printed in 3D with both machines must first be coated with conductive paint. Unlike microfusion, small-scale electroforming does not require specific machinery or an authorised workshop. In this case, a conductive metal paint, an electrical power supply and the conductive electrolyte solution are required.

C. Pilot testing of the proposed techniques

In order to carry out the microfusion pilot test, meltable resin is required, which so far has not been able to be tested. Analyses are expected to be carried out shortly, once the specific material is available. Due to the fact that the sculptures printed by PLA in the size of the proofs present too many faults and a very marked laminar texture, it was decided not to take them to the micro-casting process nor to carry out an electroforming process with them.

On the other hand, the pieces printed with resin in the DLP machine have come out with an acceptable resolution (40 microns in X, Y and 35 microns in Z) for which the first tests with these models are carried out. For this purpose, a low-cost electroforming kit called "Plug N' Plate® Bronze Plating Kit" from Caswell Inc. will be used (Fig. 6). In this case a bronze electroforming kit is used because it is the usual metal in artistic casting, but any other could be used depending on the final destination of the pieces (silver or gold should be used for jewellery). These kits can be obtained from 50€, in addition to the conductive paint is easy to use and does not need any additional machinery or specific knowledge to perform the process. The kit used in this test is designed for the coating of small parts and comes with a suitable power supply, which supplies the right amount of energy. It is ideal for small workshops performing prototype work. The bronze set of the Plug N plate contains:

- 1 x Plug N' Plate® 4.5V Power Supply
- 1 x 8oz Bronze solution
- 1 x Stainless Steel Casing Rod
- 1 x Rod bandage
- 1 x instruction manual
- Free Technical Support

Figure 6: Plug N' Plate® Bronze Plating Kit

In order to use the kit described above, the resin pieces obtained in the previous section are first transformed into conductive pieces in which the electric current can pass and allow the formation of a metal layer that covers them To achieve this, a paint based on graphite powder and acetone is used. Both materials are mixed at 50% until a pasty paint is obtained. This paint transforms non-conductive items such as plastics, resins, leather, ceramics, cardboard, flowers, leaves, roses, etc. into conductors so that they can be electroformed. Care should be taken when applying the mixture to PLA figures as it can dissolve if you insist too much on a surface. But they can be applied without problem to pieces printed on resin. The paint dries in a few minutes and then the excess must be removed with a brush or a towel. The graphite powder paint leaves a very thin layer and accentuates the details of the printed parts.

To begin, the electrolytic liquid is poured into a container large enough to introduce the pieces. Then plug in the power supply and insert one end into the liquid. On the other hand, the clamps at the other end of the power supply unit are used and the piece printed in 3D and painted with conductive paint is adhered to. This is also introduced into the electrolytic bath and left to act for a few minutes (Fig. 7). Then the sculpture can then be removed with the bronze layer.

Figure 7: Electroforming process

III. Results

Low-cost DLP printers significantly improve the resolution of micro-sculptures with FDM printers. DLP printers, increase the resolution X, Y from 400 microns to 40 microns.

Sculptures printed at less than 3 cm in PLA have too much laminar texture due to their construction form, accentuated also by being hollow pieces, so they are considered unviable for use in microfusion or electroforming processes. The pieces printed in resin by means of machines DLP have an acceptable resolution until the size of 2 cm, to smaller size, they begin to lose detail of the surface. On the other hand, parts made of PLA are feasible to lead to the processes of microfusion and electroforming, however resin parts can not be taken to microfusion because the standard resin used is not meltable, but are ideal for electroforming.

Electroforming can be done with low cost kits (Fig. 8). At the time of writing this article the first tests are being done to validate use of the kits with parts printed on resin using a DLP printer.

Figure 8: Results of the electroforming process

IV. CONCLUSIONS

To create micro-sculptures of less than 3 cm, PLA printers do not show sufficient results, however, low-cost DLP printers can be used to create smaller pieces, up to a minimum of 1 cm. For parts smaller than 1 cm, more detailed printers would be required.

Parts printed using the resin are ideal for electroforming, however they cannot be carried to microfusion as the resin does not melt. But there is special casting resin that is compatible with the low cost printers available. Castable resin can therefore be a good choice for micro-sculpture by casting and eletroforming.

The low-cost kit works for preliminary testing, but a more expert method should be sought for the final microsculptures in order to achieve more professional metal finished parts.

V.FUTURE WORK

As future work, more detailed tests of the processes proposed in this article are intended to determine the costs, the effect of texture on the final product and the minimum sizes that can be used with 3D resin printers. On the other hand, it is proposed to design a 3D printer of the DLP type that improves the resolution of the existing ones, keeping the characteristics of low cost and that is open source.

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