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3D Printing for Glass Casting

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Abstract

This paper reports on research that investigates methods for streamlining the workflow for the production of small cast glass objects from 3D digital files, with a particular focus on how this workflow can be applied in jewellery manufacturing. The conventional method for lost wax casting, whilst effective, is lengthy and time consuming, could 3D printing provide a quicker and more efficient alternative? We will look at print material options for production of mould patterns together with the processes involved in converting these originals into usable moulds. The research also investigates the parameters of the casting and finishing process, in order to achieve a finished piece of acceptable quality. The study enables evaluation of viable options for processing a jewellery piece from a digitally designed model to fabrication in cast glass.

Introduction

This research project builds on knowledge gained from the Glass workshop hosted by Tavs Jorgensen at the University of West of England (UWE) in July 2018. The event was an interdisciplinary research workshop held at UWE, which involved a variety of practitioners, researchers and industry professionals, inviting them to create 3D objects, use them as a pattern and cast them in glass. The workshop and the following symposium (held in November 2018) highlighted the problems involved in the process, including, the importance of quality of the 3D printed patterns, the impact that the pattern material has on the quality of the mould and the time involved in the casting process itself.

In 2017 the 3D printing industry was estimated to be worth over £6bn worldwide (with an estimated 30% annual growth), of which only £300m was direct manufacturing [1]. 3D printing has great potential within the jewellery industry to create products, either through direct printing processes, or from the printing of a pattern which is then used for the making of a mould for investment casting. Direct printing processes are improving and developing but, are generally expensive and slow, so are currently only considered viable for highly complex shapes that cannot be cast [2]. When manufacturing in materials such as precious metals and glass, many 3D printing service providers use a process of printing a pattern, using it to make a mould, and then casting via conventional processes (rather than printing directly) [3].

Lost wax casting, is an established and effective method of casting glass objects which involves making a wax model, embedding it in a plaster mould, steaming out the wax and then pouring molten material into the mould [4]. To use this method for a 3D printed objects however involves an additional process, namely the making of a silicone mould, that is then used to make a wax pattern. This research investigates possibilities for omitting this part of the process to allow a direct route from a 3D printed object to a glass investment casting.

For the purpose of this research we will be aiming to create identical multiples of a single, small form. The shape that we will be using will be an oval link approximately 45mm long x 35mm wide x 15mm thick. Ultimately the links should be capable of being joined together to make a chain necklace, as shown in figure 1.

Figure 1. 3D printed resin links showing the form and how the links can be connected.

Process

The process of creating a cast glass object from a digital model (pattern) is a lengthy one with 7 basic steps as follows:
1 – Build the digital model using Computer Aided Design (CAD). In this case we used Rhino 3D and exported the file in stl format.
2 – Produce a pattern. There are a number of different materials that can be used to 3D print the pattern and this research investigates 4 commonly used materials.
3 – Embed the pattern in a plaster mould. The plaster is, reinforced and mixed with flint, to create a strong refractory mould.
4 – Remove the pattern from the mould. The method of removal will vary depending on the material used to make the pattern. In a conventional lost wax process the pattern is simply steamed out of the mould. A printed pattern must be burnt out in a kiln.
5 – Casting. Annealing schedules vary depending upon the specific type of glass being used and the shape and size of the object being cast. For consistency we have used transparent Gaffer Casting Crystal for all of our pieces and we have taken it up to a top temperature of 820ºC.
6 – Remove the piece from the mould*. This* is done by a process of soaking and excavating. The moulds are therefore single use.
7 – Finishing. Clean up the pieces, remove the sprue and undertake any coldwork necessary to achieve an acceptable quality of finish.

Pattern Materials

Figure 2 shows the 4 printing materials used and demonstrates the variation in print quality achieved by the various materials. The relevant material properties to consider for the casting process are:
Time required to make the pattern. Printing times vary depending upon material. Printing a pattern directly is quicker than making a silicone mould to produce wax patterns.
Amount of work required to produce a good quality pattern. The casting process picks up the finest of detail and therefore the quality of the pattern has a direct impact on the quality of the final piece.
Ease of removal of pattern from the mould. If burn out is required, the process often leads to cracking in the mould that will necessitate repair prior to moving on to the next stage.

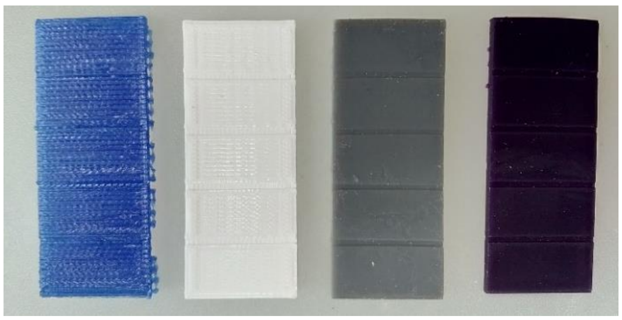

Figure 2. 5cm x 1cm Test strips, left to right, ABS, PLA, Printable Resin, Printable wax

For this research we have used the following materials for making the pattern, they have been chosen because they are all commonly used and readily available.

ABS - using Fused Deposition Modeling (FDM)
Produces a quick and economic pattern, however the quality of print is poor, with rough edges and uneven surfaces necessitating lengthy work to the pattern to create a smooth and even finish prior to embedding in the mould [5].

PLA - using Fused Deposition Modeling (FDM)
Produces a quick and economic print with a smooth finish. The quality is better than with ABS, however the layers created by the printing process are typically still visible. If this layering can be incorporated into the design of the piece PLA would be a good option, otherwise work is required to get a smooth finish [5].

Printable resin -using steriolythography (SLA)
Produces a good quality print, reasonably quickly with very little work required to achieve a very good surface finish. The resin in not designed for burn out [6].

Printable wax / resin - using steriolythography (SLA)
Designed for casting, primarily in metal (rather than glass), this product gives a very good quality finish and a high definition of fine detail and is specifically designed to be burnt out in a kiln with little or no ash residue remaining. Although described as printable wax, this material only contains 20% wax [7].

We have looked at the implications of making the original patterns solid or hollow and how this affects printing times, burn out and residue quantity.

Casting Tests

16 castings were made and in each case one parameter was changed within the process. The first cast was a control piece made using the lost wax method, this piece set a bench march for the quality of finish that we were aiming for. Figure 3 below shows the finished lost wax piece.

Figure 3. Lost wax cast control piece

Subsequent castings involved using the 4 different materials for making the pattern either solid or hollow and including (or not) a sprue and / or a reservoir. The variables and outcomes were all recorded on a spreadsheet. Table 2 below is an extract form this recorded data.
During the pattern making process the time taken for printing, and finishing the patterns was recorded together with the amount of material used to print.
Moulds were made using a plaster: flint: water: mix in a ratio of 1:1:1 and using a variety of building methods including pouring, painting and hand raising. Records were kept of the firing schedule for both the burn out and cast firings. Where available the manufacturer's recommendations were followed for the burn out, typically the duration of the burn out schedule was estimated to be 19 hours. The casting schedule was altered to experiment with reducing the soak time to streamline the process. The optimum casting schedule for this particular shape, was found to be as outlined in table 1 below. The full time taken to complete this schedule will vary depending upon the efficiency of the kiln, however it was calculated to be approximately 40 hours.

Table 1 - Casting Schedule

Step		Speed (ºC/min)	Temp (ºC)	Time (mins)
1	Drying	50	95	300
2	Stabilise Mould	50	250	25
3	Chemical burn out	100	450	120
4	Rapid heat	125	820	120
5	Anti-Sucker soak	1000	515	120
6	Anneal cool	50	430	240
7	Anneal cool	20	360	15
8	Cooling	30	80	15

Table 2 – Extract form recording spreadsheet

Original Model material	Print time	Hand Finishing time	Model Type	Image of model	Burn Out time	Finishing Time	Photo of Final Cast piece	Comments
Resin. Printed on FormLab	2hr 15 mins	20 mins	Hollow - 1mm wall thickness, with integral reservoir		18.9hr	30 mins		Reservoir too small, size to be increase with a clay base. No real benefit from printing the reservoir. It increases the print time and produces more material to be burnt out.
Resin. Printed on FormLab	2hrs	20 mins	Hollow - 0.75mm wall thickness, with integral sprue but no		18.9hr	30 mins		Mould cracked during burn out and had to be reinforced prior to casting.
ABS Printed on Makerbot	37mins	90mins	solid with integral sprue but no reservoir		18.9hr	30 mins		Hollow model failed. On finishing holes appeared in the mould. Solid mould needed some working before casting and still the finished piece had an uneven finish.
PLA Printed on Makerbot	37mins	60mins	Hollow - 2mm wall thickness, with integral sprue but no reservoir		18.9hr	30 mins		Despite all of the time spent on finishing the model / pattern it was still not enough. The link has cast well, but there are still marks visible from the layers of the 3D printing.
Printable Wax solid	72mins	10 mins	Solid link finish as printed		18hr	30 mins		Unfortunately I made a mistake with the firing schedule and only held at top temperature for 1hr, consequently, the mould did not fill completely. The variation in finish is only visible under a microscope therefore it seems that there is potentially little benefit to spending time polishing, pre casting.
Printable wax hollow	69mins	5mins	Hollow link as printed		17hr	45 mins		Mould made with 2 poured layers second one reinforced. Some air trapped in mould - resulting in bobbles on the surface of the final piece.
PLA Printed on Makerbot	37mins	60mins	Hollow - 2mm wall thickness, with integral sprue but no reservoir		30 mins + 17	45 mins		Mould made with 2 poured layers with no reinforcement. No cracking post burn out. Layering in the model left on to investigate the amount of detail that the mould picks up. Level of detail very good. All of the layers from printing are clearly visible.

Removing the pattern via burn out in a kiln is inevitably more time consuming and expensive than steaming out a wax pattern and therefore we wanted to look at options for reducing or omitting this stage all together.

Tests were therefore undertaken to investigate the possibility of combining the burn out and the casting firing into a single process, therefore potentially reducing the time in the kiln by 19 hours.

These tests were unsuccessful with ash residue being trapped in the final piece. With further testing it may be possible to determine the location of these residue build ups and incorporate a reservoir or escape route to allow them to be removed post casting with cold working. Figure 4 below shows this residue build up.
These tests were done using a printable wax pattern. Further future tests would look at a similar procedure using other pattern materials. In order to establish which pattern material is likely to perform best in this process, it is necessary to understand exactly how the various materials respond to the burn out process.

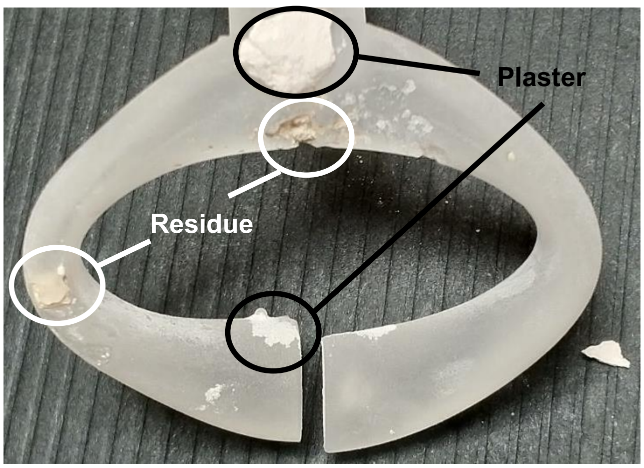

Figure 3. Photographs of test link burn out and cast in one, showing trapped residue.

Investigating the Effect of Heat on 3D Printing Materials

The test castings led us to question what was happening to the various materials during the burn out process. In order to better understand how the materials responded to heat we took a sample of each, printed in 1cm x 5cm strips and heated them to various temperatures, recording and documenting the outcomes. Figure 5 shows photographs of some of the tests. The tests were carried out using purpose made ceramic trays. The trays were weighed before and after the test in an attempt to establish the extent of ash residue remaining. Unfortunately this was inconclusive because the trays themselves lost weight during the process, presumably due to moisture loss during firing. The primary results were therefore based on visual observations.

Figure 5. Photographs of test trays from heat testing on materials

Figure 6. Photographs of finished pieces

Results

Pattern Making

During the pattern making process the following results were noted:

- Incorporating a sprue into the CAD model (and therefore the print) was useful to give a consistency in diameter, position and angle. Further investigation would be necessary to establish the optimum potion, size and distribution of sprue (s)
- Incorporating a reservoir into the CAD model (and therefore the print) was of little benefit because it increased the print time and the amount of print material required. Forming a reservoir by hand from clay is a quick and easy process.
- Making the CAD model hollow decreased the amount of print material and reduced the print time for the FDM printed models, however there was no reduction in print time for the SLA printed models.
- The printable wax gave a good quality of finish to the pattern with very little work required to the pattern post printing.
- Using Microcrystalline / Paraffin wax, gives good results and if making numerous copies of the same pattern the time spent making a silicone mould would be worthwhile and would be quickly recouped in time and cost savings during the pattern removal stage.

Mould Making

- The quickest way to make the moulds is to use a former to surround the pattern and pour the plaster. This method however is prone to bubbles forming and therefore the moulds need to be vibrated immediately to remove air bubbles before the plaster sets.
- 2 layers of plaster were sufficient for the walls of the mould. There was no benefit in adding a third layer.

Burn Out

- All of the moulds made with a printable wax pattern cracked during burn out necessitating repair prior to casting. Based on the visual observations during the heat tests it is likely that this is due to the expansion of the material during the burn out process.
- None of the moulds made with PLA patterns cracked during burn out.

Further Research

This research has focused on a single piece of a specific shape and size and results may not be applicable to larger or more complex shapes. Despite the experimentation we did not find a method of making that produced better results than the conventional lost wax method, however if we could find a way of combining the burn out and cast firing, this would have the potential to deliver a very effective workflow. Looking at the results from the heat tests, this is most likely to be achievable with PLA patterns, perhaps with designs that utilize the layering which is characteristic of the 3D printing process.

References

[1] Additive Manufacturing UK (2018) *National Strategy 2018 - 2025* [online]. Available from: http://am-uk.org/wp-content/uploads/2017/11/AM-UK_Strategy_Publication_Amends_Novermber_Digital.pdf.

[2] Cooksons (June 19) *Cooksongold E-manufacturing | Direct Metal 3D Printing*. Available from: https://www.cooksongold-emanufacturing.com/ [Accessed 13 May 2019].

[3] Shapeways (2019) *Gold 3D Printing Material Information - Shapeways*. Available from: /materials/gold [Accessed 20 March 2019].

[4] Bullseye Glass (2014) *TipSheet 8: Basic Lost Wax Kilncasting | Kilncasting*. Available from: http://www.bullseyeglass.com/methods-ideas/tipsheet-8-basic-lost-wax-kilncasting.html [Accessed 4 July 2019].

[5] MalerBot (no date) *MakerBot Method - 3D Printing Materials - Rapid Prototyping Materials*. Available from: https://www.makerbot.com/3d-printers/materials/method/ [Accessed 5 July 2019].

[6] FormLabs (2018b) *3D Printing Materials for Professionals*. Available from: https://formlabs.com/materials/standard/ [Accessed 5 July 2019].

[7] FormLabs (2018a) *3D Print High Detail Jewelry with New Castable Wax Resin*. Available from: https://formlabs.com/blog/introducing-castable-wax-resin-jewelry-3d-printing/ [Accessed 5 July 2019].

Author Biography

Dr Susanne Klein FInstP is an EPSRC Manufacturing Fellowship and Associate Professor at the Centre for Fine Print Research. She holds a diploma in theoretical physics and a PhD in medical physics. She is a Fellow of the Institute of Physics. She was a German Telecom Research Fellow and a Royal Society Research Associate. She is the chair elect of the British Liquid Crystal Society, a member of the Society for Imaging Science and Technology and the conference committee of 'Measuring, Modeling, and Reproducing Material Appearance'.

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Ryan Brown is a member of UWE fabrication staff. He describes himself as a "failed artist and a terrible designer."