A Time, Cost and Accuracy Comparison of Soft Tooling for Investment Casting Produced Using Stereolithography Techniques

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Abstract

Investment casting is increasingly widely used in the production of metal prototypes in conjunction with rapid prototyping (RP) technologies. Some types of RP models can be used directly as sacrificial patterns in the casting process, but this can prove costly and time consuming where a number of castings are required.

Soft tooling such as resin tooling and silicon rubber tooling are used to produce a number of wax patterns for subsequent casting, using an RP model as the master. Stereolithography faced tools are starting to be used as in some circumstances they can offer time savings over other soft tooling methods. This paper aims to compare the costs and times taken to produce wax patterns for use in investment casting using the different soft tooling techniques and QuickCast™ build style for use as a casting pattern.

Introduction

Rapid prototyping allows several options for the investment casting process. The QuickCast™ build style that can be used with 3D Systems stereolithography (SL) machines can be used directly as patterns for investment casting. Some problems have been reported due to expansion during the burnout of the model. Patterns may also be produced by Selective Laser Sintering, Fused Deposition Modelling and Laminated Object Manufacture (Dickens *et al*). Producing the investment casting patterns by rapid prototyping can be very successful if only a few parts are needed. However, as the number of prototypes required increases, RP becomes increasingly expensive and time consuming. Soft tooling can then become useful because many wax patterns can be produced relatively quickly and cheaply once the tool is made.

The most common 'soft' methods of tooling are those of resin and silicon rubber. Recently, workers have started to experiment with SL faced tools backed with filled epoxy resin. Additionally, solid SL dies have been fitted to aluminium bolsters, and used as low pressure wax injection moulding tools.

The Direct Shell Production Casting (DSPC) technique can also be used to produce investment casting shells, but this also suffers from high costs when many castings are needed, but may also be used to make moulds directly (Sachs *et al*).

Two metal sintering processes have recently been reported which will enable the direct production of metal tools for wax injection moulding (Klocke *et al*).

Experimental Technique

A test part was chosen from a 'live' project which was suitable for the investment casting process and could not be moulded using a two part tool. It was decided that a four part tool would be required to release the part without the loss of any features. The design, consisting of a core, an 'L' shaped base/back, and two side plates was kept constant throughout the different types of tool made (see figure 4).

Resin Tool

Prior to construction, a sprue bush guide was fitted to the part. The resin tool sections are made by constructing a series of boxes around the SL part sequentially, that will define the split lines and outside edges of the first part of the tool. Location cones and studding to hold the tool together were embedded in the moulding box into each moulding box. Firstly, a metal filled epoxy gelcoat was applied to the surface, which was strengthened by applying six layers of glass fibre, laminated with epoxy resin. This shell was then filled with an epoxy resin/sand mix to create the solid tool section. This process takes 4-10 hours depending on the complexity of the part and moulding box. The resin is left to cure for 12 hours, until it is solid. The moulding box is removed, leaving the first part of the tool, with the SL model partially embedded in it. The next box is then constructed defining the next split lines and edges of the tool. This process then continues until all of the tool sections have been made.

The factors influencing the speed of manufacture of the tool are :

- The number of parts that will make up the tool
- The time taken for the resin to cure - about 12 hours.
- The time taken to construct the moulding box - a complex split line on a detailed part will require more time.
- The time taken to lay down the glass fibre matting - flat and gently curving parts are easily covered, where as bosses require more care, and therefore time.

Silicon Rubber Tool

Silicon rubber tools are widely used to make prototype and short run tools for use with gravity pour or low pressure injection if the mould is supported in a frame (Mueller), especially when polyurethane parts are required.

The tool is created by firstly making a moulding box that will define the outside edges of the tool. The split lines are then defined on the ACES SL part using scotch tape, coloured to make it easier to see in the silicon. The injection point is also defined and attached to the SL part at this point. The part is suspended in the moulding box, and silicon rubber is mixed, degassed, and poured around the part. The rubber is left to set for about 24 hours, which leaves the SL part encased in a solid rubber block. The rubber is cut down to the tape, with jagged lines, so that the tool will fit together well, and separated into its four parts.

The factors that control the speed of production of the tool are as follows:

- The time taken for the rubber to cure
- The complexity of the split line, which will increase the set-up time, and the time taken to cut the tool apart.

SL/Resin Tool

The SL/resin tool is made up from a SL mould face and mould box, which is then backfilled with a sand filled epoxy resin (Tsang *et al*).

The starting point of the SL/resin tool is the creation of the three dimensional solid of the part using a suitable CAD package. Then by using appropriate Boolean operations, the tool faces are generated, and given a wall thickness of >2 mm, and the side walls of the mould faces are drawn to create a cavity for the resin/sand to be poured into. The four parts are then made on the SLA and backfilled with sand filled epoxy resin. Because the location cones and studding for clamping the tool were not included in the SL parts, these four parts had to be backfilled sequentially, which added to the build time considerably.

The factors controlling the speed of manufacture of the tool are as follows:

- CAD time to produce a 3D representation of the tool faces.
- SLA build times
- Resin cure times

Injection of tools and resulting patterns

A moving platen top injection machine was used (a Maymar MV30), which has a closing force of 20 tons applied through the nozzle, and ran at a pressure of 250 psi, with the wax injected at approximately 80 °C. The wax used was a filled Dussek Campbell type 489. The resin tool was successfully injected with 15 waxes. There was no visible wear on the tool. The resin tool needed to be heated up to about 40 °C for the tool to fill, with a cycle time of about 5 minutes. However, after about 5 shots, the tool started to get too hot, and needed 'cooling off' periods.

As the silicon rubber tool would be unable to take the injection pressures, without enclosing it in a box, it was attempted initially to gravity pour the wax into the tool. This did not create sufficient flow to fill the mould, so the wax was poured into a reservoir connected to the tool, and a vacuum of about 0.2bar applied to an outlet on the other side of the tool. Several waxes have been produced using this vacuum casting process.

Unfortunately, the SL/resin tool exploded during the injection process.

QuickCast™ patterns for investment casting

QuickCast™ is a build style that can be used on 3D Systems' stereolithography machines to build models that are used as sacrificial patterns for investment casting. Solid models built using the Ciba Geigy SL5170 and the ACES build style expand during the burnout part of the investment casting process, and can crack the shell of the mould.

Models using the QuickCast™ build style have an exterior skin encasing a honeycomb like internal structure, that should collapse in on itself when the pattern is burnt out (Jacobs).

Investment casting

Shell investment casting involves creating a ceramic shell around a pattern, which is then burned out, leaving a hollow shell. Metal can then be poured into the mould to give the finished part.

Investment casting of waxes is a widely used technique, but only about 85% of parts are successful. This is lower for direct investment casting of SL parts, even using the QuickCast™ build style (Hague *et al*). This reduction in the success rate is due to the stereolithography model not melting during the autoclave process, and expanding, to create stresses in the ceramic shell which may lead to cracking, even when the different build styles are used. Success in casting the SL patterns is also dependent on the experience of the foundry.

Results

The most time consuming tool made was the SL/resin mould. The four part tool took much longer than expected to generate as a 3D CAD file due to the complex split lines and design features incorporated to minimise the SL build time. The SL faces also took a long time to make as the parts took two builds on the SL, and were each close to the size limit of the machine, and so each build itself took a lot of time. Added to this was the time to back the faces with sand filled resin. As the same location and clamping system was used as the epoxy resin tool, the sand/resin backing of each piece also had to be done sequentially, adding more time to the process.

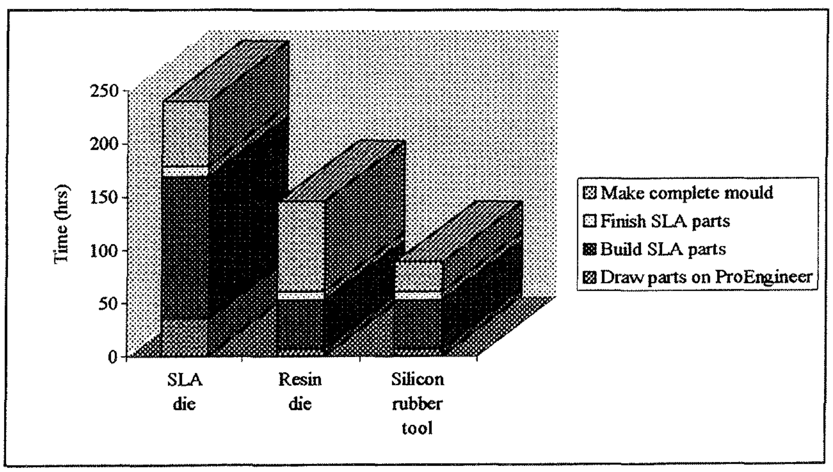

Figure 1. A comparison of the times to produce soft tooling from SL parts using silicon rubber, resin, and SL/resin tooling techniques.

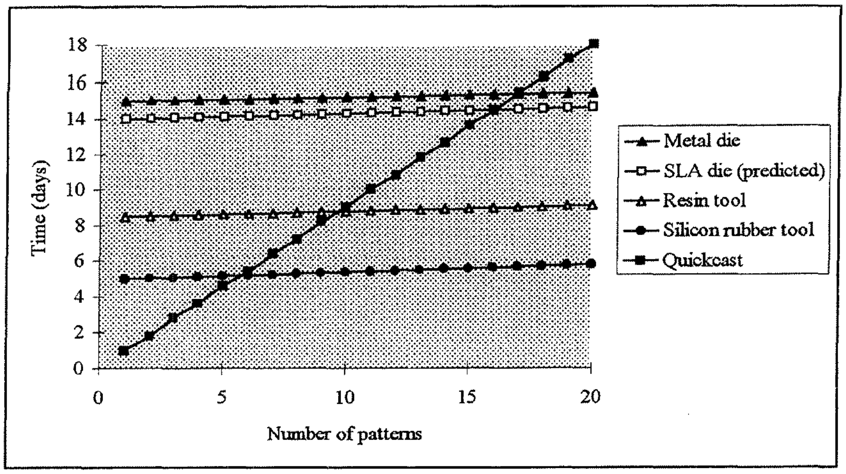

Figure 2. Plot of the time taken to produce casting patterns by the different tooling routes.

During injection of the SL faced tool, the tool failed, meaning that no wax pieces were produced using it. This was due to either the pressure of the moulding machine holding it clamping the tool together, or due to the pressure of the wax injection.

The resin tool took approximately half the time to build than the hybrid tool, but also took almost twice the time of the silicon rubber tool.. The reduction in time over the hybrid tool is due to eliminating the lengthy CAD and SL work involved. However, the increase in time needed over the silicon rubber tool is due to the fact that each part of the tool has to be made sequentially. Therefore, the increase in time is primarily due to the part needing a four part tool. The epoxy resin tool was injected successfully and gave a number of wax patterns.

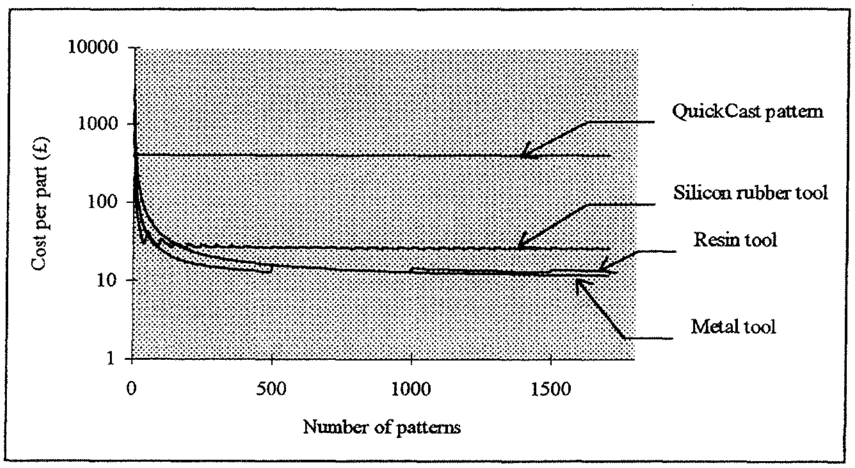

Figure 3. Plot of costs to produce casting patterns by the different tooling routes.

It can be seen that the times involved in producing a casting pattern in the QuickCast build style are significantly faster than producing a mould up to about ten patterns. Above this number, time savings can be made by making a soft tool and injecting or vacuum casting wax into them. The SL build times may be faster than this on larger machines using different recoating techniques, which cut down on the recoating time for each layer.

The soft tools were cost effective when more than about five patterns were required. This is due to the relatively high costs of producing a part by stereolithography.

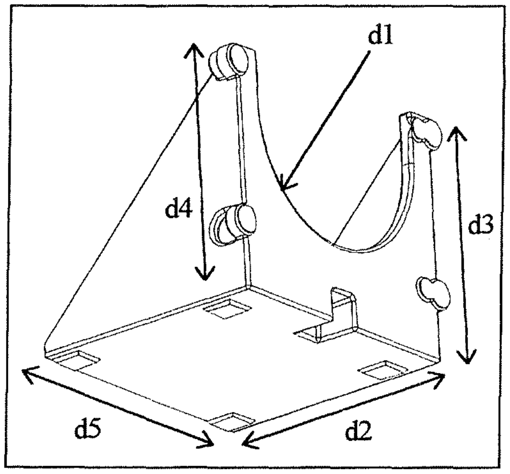

Figure 4. 3D CAD model of part used in this investigation, showing dimensions used over.

The dimensions of the final parts should be as follows:
d1 = rad 55 mm   d2 = 120 mm d3 = 120 mm d4 = 120 mm d5 = 140 mm

Model	shrinkage (%)	d1	d2	d3	d4	d3
'Perfect' master	1.6	55.88	121.92	121.92	121.92	142.24
SLA master	1.6	55.79	122.06	122.26	122.24	142.16
Error (actual /percentage)	1.6	-0.09 0.16	+0.14 0.11	+0.34 0.28	+0.32 0.26	-0.08 0.06
'Perfect' casting pattern	1	55.55	121.2	121.2	121.2	141.4
Wax from silicon tool	1	55.73	121.39	121.24	121.14	141.37
Error (actual /percentage)	1	+0.18 0.32	+0.19 0.16	+0.04 0.03	-0.06 0.05	-0.03 0.02
QuickCast pattern	1	55.54	121.91	122.04	122.2	141.47
Error (actual /percentage)	1	-0.01 0.02	+0.71 0.59	+0.84 0.69	+1.00 0.83	+0.07 0.05
'Perfect' finished metal	0	55	120	120	120	140
QuickCast metal	0	55.75	120.4	120.57	120.48	141.57
Error (actual /percentage)	0	+0.75 1.36	+0.4 0.33	+0.57 0.48	+0.48 0.4	+1.57 1.12
Predicted investment casting tolerances		±0.28	±0.45	±0.45	±0.45	±0.53

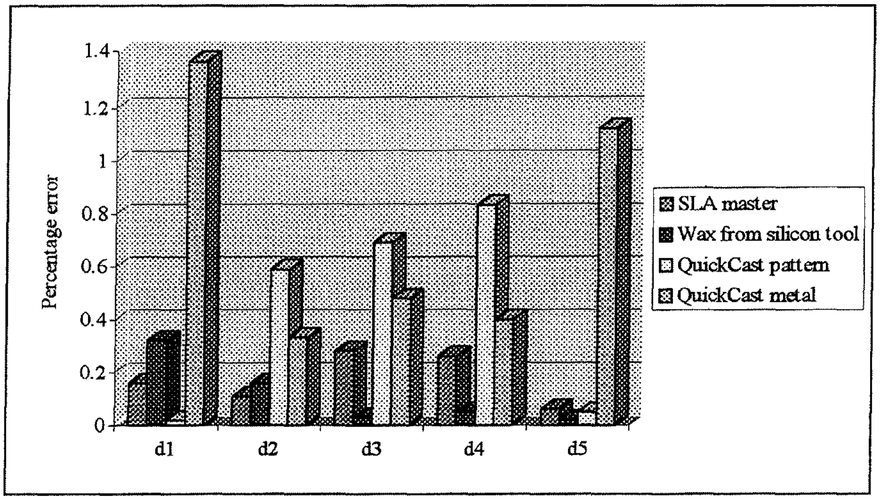

Figure 5. Plot of the percentage dimensional error in the patterns and casting produced.

The casting patterns produced were measured on a co-ordinate measuring machine to give an indication of the accuracy's of the different routes. The wax pattern measured was shown to be very accurate, although flash on the part was more evident than the waxes produced by the resin tool. The wax from the silicon tool also showed markings from where the tape that defined the split lines had been. The metal part produced from the QuickCast pattern showed the largest errors as the measurements also included the variations caused by investment casting. The results from the waxes produced from the resin tools were not available.

The accuracy's obtained have to be considered with relation to the tolerances quoted for the investment casting process, and also the fact that most castings have some kind of machining done on them before use.

Conclusions and Summary

The results show that the hybrid SL/epoxy mould is not effective in reducing times and costs for this test part. This is due to the size of the part, which made building the pieces in SL time consuming. Also, the four part construction with locators and clamps added separately mean that the backing with resin also takes longer than may be possible. The time taken to make the tool could also be minimised in further projects by utilising the flexibility of the combination of 3D CAD and SL.

The resin tool was successful in producing waxes for use in investment casting. The tool was robust enough for the wax injection process with no visible damage to the tool. However, as with the other soft tools, they cannot easily be modified as a metal tool can, and so it is perhaps more important that the design is checked as much as possible before the tool is made.

The silicon rubber mould was the fastest mould to make and the number of parts of the tool does not significantly increase the time required. The disadvantage of the silicon tooling means that the wax cannot easily be injected without mounting the silicon in a box. Also, the means that the wax cannot easily be injected without mounting the silicon in a box. Also, the life of the tool may be limited to about 50 mouldings.

Method	Total cost of tool (£)	Total time to build tool (days)	Expected total number of patterns	Average error on patterns produced (%)
Resin tooling	1500	8.5	500	N/A
Silicon rubber tooling	800	5	50	0.12
SL/resin tooling	6000	14	0	N/A
QuickCast patterns	400	1	1	0.44
Metal tool	3000	15	5000	N/A

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