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# Rapid Tooling for Zinc Spin Casting Using Arc Metal Spray Technology

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**Abstract**
A research and development effort was made to investigate the feasibility of rapid tooling for zinc spin casting using stereolithography (SL) and arc metal spray technologies. The study is based on a specific practical case where intermediate tooling processes are required to make an intermediate tool from the SL pattern. The intermediate tool is then used in an arc metal spray process to form a metal master tool that is subsequently used to make spin casting moulds. Different materials and processes were studied to fabricate the intermediate tools. It shows that ceramics, used in investment casting and Shaw process, are suitable materials for the intermediate tools required to make the metal master tools. A preliminary analysis of the dimensional errors confirms the viability of the proposed tooling process chain.
Keywords: Rapid tooling; Arc metal spray; Spin casting

## 1. Introduction

In order to remain competitive and profitable, modern manufacturing enterprises must be able to cope with rapid changes to product designs and continually reduce product costs. Advanced manufacturing technologies, such as flexible manufacturing systems, have made it possible for manufacturers to switch from one product to another without the high costs of down time. However, design and manufacture of tooling for new products are the main contributors to product development period and cost. Technologies that can reduce time and cost of product development are essential in a globally competitive market.

Rapid prototyping (RP) technologies, such as Stereolithography (SL), Selective Laser Sintering (SLS) and Three Dimensional Printing (3DP) processes [1-3] that produce parts through building up in a layer by layer procedure directly from CAD models, have been mostly used to generate prototypes of new products that are not always fully functional. These technologies have also been used to create production prototype tools for various casting and moulding processes [4], and could be employed to make rubber moulds for the zinc spin casting process, which is often used to prototype parts that would be normally manufactured through high pressure die casting.

Zinc spin casting uses multi-cavity rubber moulds (several castings at once) that are made by a pressurised vulcanisation process at a temperature of about 168°C. This vulcanisation temperature is much higher than that both the stereolithography and wax patterns can withstand without distortion, making them unsuitable as materials for the master pattern or tool for making rubber spin casting moulds. Gypsum cement and other ceramics were

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assessed as materials for master patterns for the spin casting moulds [5] and were found to be unsuitable for this purpose.

This paper outlines a feasibility study of a tooling process for zinc spin casting using SL and arc metal spray technologies. Different intermediate processes are employed to convert the SL patterns into metal master tools or patterns suitable for making spin casting moulds. Preliminary results of the study are presented and analysed.

## 2. Experimental Work

The experimental work involves the design of a test part and a series of tooling processes (or process chain). Zinc spin casting processes utilise rubber moulds, which usually have a flat parting surface. Thus, depending on the shape of the component, the master tool used to form the cavities can also be made in two parts with parting surfaces mirroring the parting surfaces of the rubber mould. This fact makes it possible to use arc metal spray techniques to make the required master tools for complex castings, which could consist of two matching halves. For the purpose of this work a simple test part was designed and used so that there was no need for a composite master pattern. Fig. 1 shows the part developed for the tests. It fits into 95x30 mm envelope with maximum thickness of 20 mm. This model consists of various basic shapes and features including tapered and non-tapered grooves so that the process capability and dimensional accuracy could be evaluated.

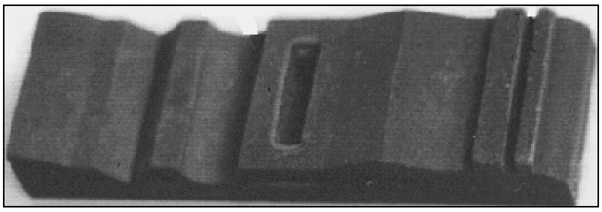


Fig. 1. Test part used in the study.

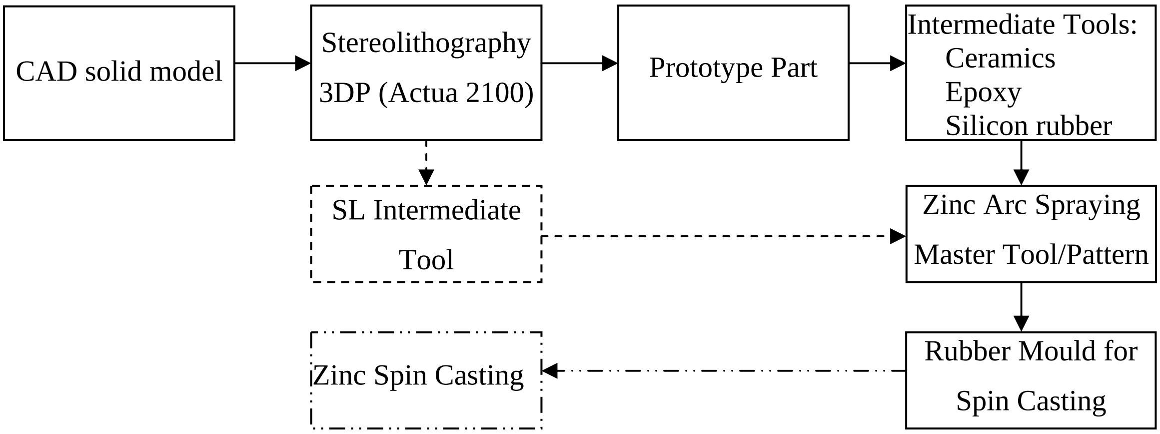
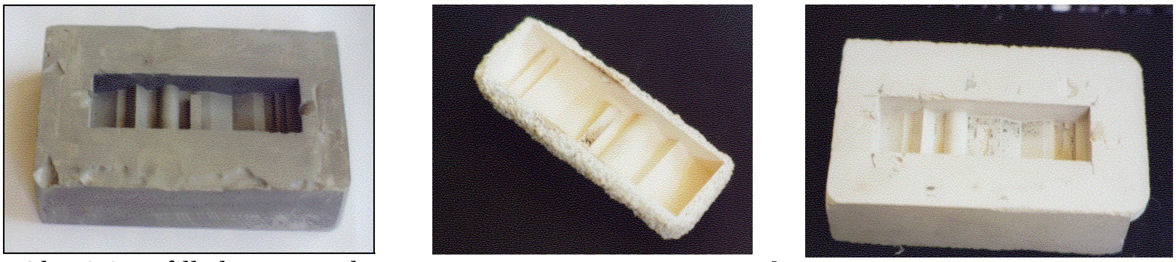



Fig. 2. Process chain for spin casting tooling.

The flowchart in Fig. 2 shows the tooling process chain implemented to manufacture the rubber mould from the SL and 3DP patterns and intermediate processes. The test part was designed as a CAD solid model using I-DEAS CAD software. The CAD file was then converted to the STL format that is required by most rapid prototyping machines. Two types of RP systems were used, the SLA-500 machine from 3D Systems using the CIBATOOL SL5220 epoxy resin and a 3DP machine, ACTUA-2100, also from 3D Systems that builds prototypes from wax type material. Similarly, the inverse solid model of the test part was designed and the SL intermediate tool (as shown in dashed lines in Fig. 2) was manufactured using the SLA 500 machine.

Two routes for master pattern making were tested. One route used directly reverse prototypes of the test part made by the SL process to fabricate the master pattern by metal arc spraying, as indicated by the dashed lines in Fig. 2, while the second route implemented an additional step converting the SL and 3DP prototypes of the test part into an intermediate tool (reverse of the test part in geometrical features) that is more functional than the prototype parts for arc metal spraying process.



Aluminium-filled epoxy tool | Investment casting ceramic tool | Shaw-mix ceramic tool

Fig. 3. Intermediate tools for making master patterns using arc metal spray technology.

**2.1 Fabrication of Intermediate Tools**

Intermediate tools (reverse of the test part) made from silicone rubber, aluminium filled epoxy and ceramics were fabricated as described below.

a) Silicone rubber tool

Silicone rubber is flexible and can withstand temperatures as high as 200°C. The tool made from silicone rubber using room temperature vulcanisation (RVT) process can accurately reproduce very fine features of the part being used to form the tool or mould. The SL prototype of the test part was placed in a box with the parting surface facing down. The box was then filled with liquid silicone (Elastosil M4644), which vulcanises at room temperature. Following the removal of the SL prototype, the silicone mould was post cured at 70°C, ready for arc metal spraying.

b) Aluminium-filled epoxy tool

The working temperature of Al-filled epoxy can be as high as 250°C depending on the aluminium content. It has good compression strength and is relatively inexpensive. This tool was manufactured using the SL prototype in a similar manner to the silicone rubber tool. Instead of using silicone, a liquid slurry of aluminium power and epoxy resin from CG Products in Brisbane, Australia was used. Unfortunately, for commercial reasons the company did not reveal the composition of the slurry. A sample of intermediate tools from this process is shown in Fig. 3.

c) Investment casting ceramic tool

Ceramic materials used to build investment casting ceramic shells seemed to be a good candidate for intermediate tool due to their physical properties, good surface finish, good ability to reproduce fine features and the fact that the existing shell building process, as can be found in [4], can be adopted to make these tools without any modifications.

In this case, a wax like prototype test part made by the 3DP process was covered with a ceramic shell (~10mm thick). This shell was built up by applying 12 separate coats [4] including 1 coat of Primcote with zircon sand stucco, 2 coats of Fascote slurry with an intermediate aluminosilicate stucco and 9 coats of Fascote slurry with a coarse aluminosilicate stucco. In the next step the bottom, flat side of the shell was ground down to expose the prototype that was then removed. The ceramic shell was finally sintered at a temperature of about 950°C for one hour.

d) Shaw-mix ceramic tool

Shaw technology is a precision casting process that utilises a ceramic mixture in the form of slurry that is poured over the pattern. The slurry hardens at room temperature allowing pattern removal before subsequent sintering at high temperatures. This process offers advantages similar to that of investment casting techniques and thus was deemed worthy of comparison.

The ceramic slurry was made by mixing certain amount of Shaw-mix powders with a Shaw-mix slurry to achieve a suitable viscosity for coating on the patterns. The composition of the Shaw-mix powders, in weight units, used in this work was as follows: 1 part of zircon sand + 1 part of zircon flour + 1 part of alumina silica with a grain size of 0.7-1.2 μm + 0.5 part of alumina silica with a grain size of 0.2-0.7 μm. The Shaw-mix slurry was produced by mixing 100 parts of Ethol silica binder with 3 parts of 25% Ammonia solution. The ceramic slurry was poured into a box with the prototype test part in a similar manner to that used in the silicone rubber tool making process.

Two prototypes were used, one SL prototype and one wax prototype produced by the 3DP process. The SL prototype was removed from the ceramic casting prior to sintering, while the wax pattern remained inside and was melted out in the sintering process.

### 2.2 Fabrication of Metal Master Tools

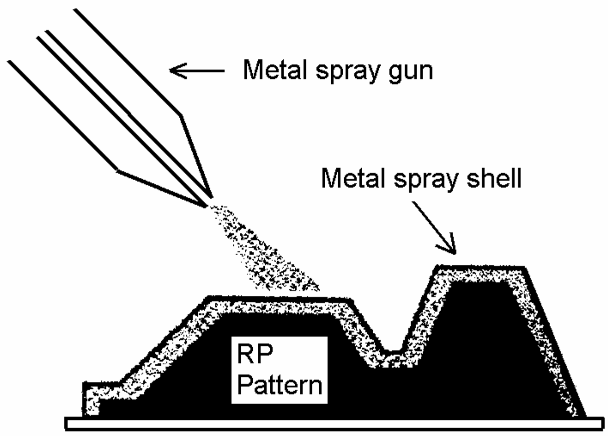
The intermediate tools were cleaned using pressurised air. The ceramic tools, prior to metal spraying, were held at a temperature of 100°C for 60 minutes to remove potentially absorbed moisture, and were sprayed while their temperature was at about 40 to 50°C in order to reduce the temperature gradient during spraying and avoid possible cracking. The silicone rubber tool was sand blasted to modify its surface in an attempt to improve adhesion of the sprayed metal.

A Sultzer-Metco electric arc metal spray system was used to spray 99% pure zinc wire (2mm in diameter). The spraying system used a push wire delivery technique to feed a zinc wire through the nozzle while the electric arc from a separate power supplier melted the wire before it left the nozzle. Pressurised air was used to blow the metal droplets onto the target surface (the intermediate tool cavities). Fig. 4 shows the process of arc metal spray on an RP pattern to produce a metal tool. In this study, the RP pattern is replaced by the intermediate tools shown in Fig. 3. The arc spraying process can coat metals on many different substrates according to the specific engineering needs. Used in rapid tooling, this process can reduce the lead time by as much as 90% when compared to the traditional tooling process [6]. Residual stress in the metal tools produced as a result of shrinkage during cooling is a problem in metal spray.

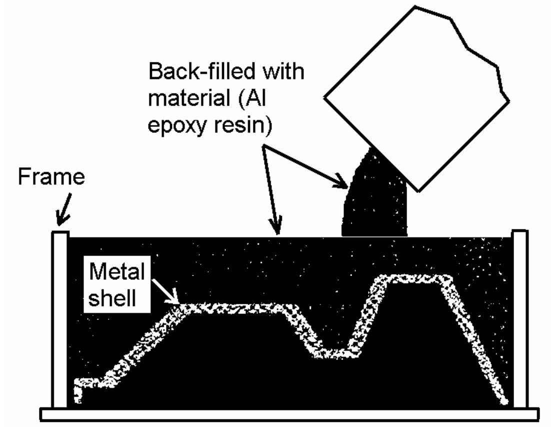
A preliminary experiment using a statistical procedure was conducted to determine the parameters for the metal spraying process [7]. This experiment covered different air pressures, electric voltages and currents, and the other parameters. The best combination of the parameters as determined by the sprayed surface quality, form error and microstructure was finally used in this work. Thus, the major process parameters used were: air pressure = 0.276 MPa (or 40 psi); voltage = 21V; and current = 100A.

The spraying was carried out manually, maintaining a stand-off of the spraying gun of about 100-150mm from the target. In each case a minimum coating of 4 mm thickness coating was produced. The developed zinc shells were separated from the intermediate tools, back-filled with gypsum cement, and machined to form the flat parting surface. In total, eight master patterns were produced, two from each type of intermediate tools described above.

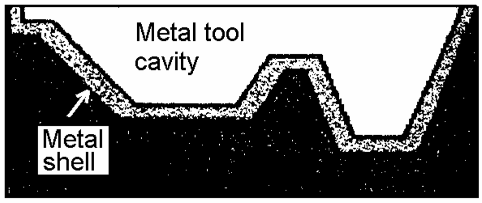
(a) RP pattern for spraying.



(b) Arc spray of metal on the RP pattern.



(c) Metal shell back-filled with Al epoxy.



(d) Metal tool after the removal of RP pattern.

Fig. 4. The tool making process using arc metal spraying.

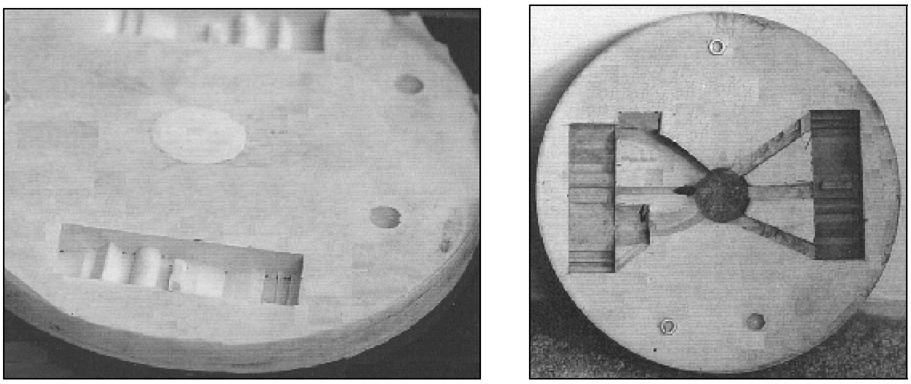


Fig. 5. Bottom halves of the spin casting rubber moulds (without and with runners).

**2.3 Fabrication of Spin Casting Mould**

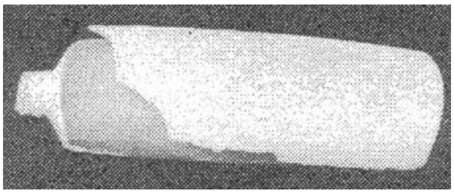
TEKSIL (HT) silicone rubber discs (228.6 mm diameter and 25.4 mm thick) were used to make the rubber mould for spin casting. The top half of the mould (top disc) was simply a flat disc with the in-gate and venting holes, while the cavities of the test part were impressed in the bottom half as shown in Fig. 5.

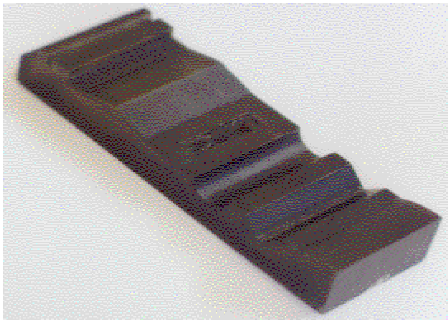
Detailed process of making the spin casting moulds can be found in [6], while only the major process parameters are given here. The rough cavities were carved in the bottom disc, which accommodate the metal master patterns and locating pins. Then the disc together with the master patterns and locating pins were assembled into a vulcanising frame and vulcanised for 90 minutes at about 20 MPa (or 3,000 psi) and 168°C temperature. When the disc cooled down, a 12.7 mm thick un-vulcanised rubber disc (with release agent) was placed on the top of it and the whole mould was vulcanized for 45 minutes before being removed from the vulcanizing frame. The mould was then separated and the master patterns removed. Finally, runners, reservoirs and venting holes were prepared for the casting of zinc alloy parts. Fig. 5 shows the bottom half of the mould without and with runners. As this study is limited to the tooling process, the work on the casting and casting parameters can be found from [5,7].

## 3. Results and Discussion

In the zinc spraying process, the SL reverse prototype of the test part distorted as might be expected. This is possibly due to the high temperature and the large temperature gradients that developed during the process. This tendency to unpredictable distortion rendered this path useless, and hence was excluded from further consideration.

It was found that all the intermediate tools were of reasonably good quality. The silicon rubber tool from the RTV process showed better quality than the other three types. A detailed analysis of dimensional errors for the intermediate tools can be found in Ref [7]. Fig. 6 shows some samples of the metal shells produced when using different intermediate tools presented in section 2.1; the respective results are discussed below.


(a) Excessive peeling of sprayed metal when spraying on silicon tools.


(b) Metal shell distorted when spraying on Al-epoxy resin.

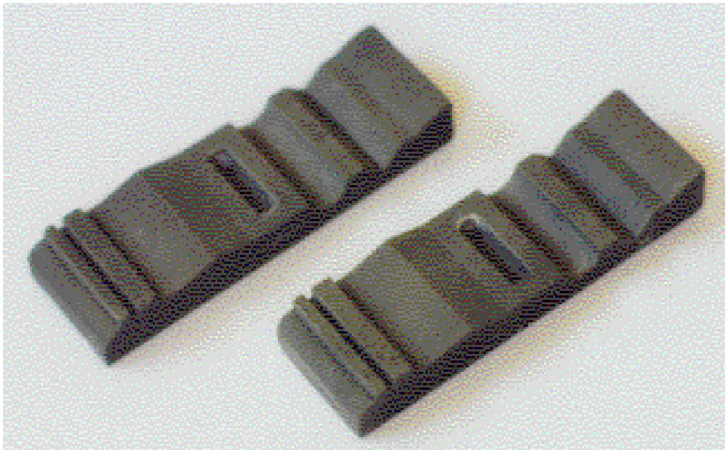

(c) Good metal shells produced from investment casting ceramic tool (top), and Shaw-mix ceramic tool (bottom).

Fig. 6. Photographs of metal shells produced using different intermediate tools.

- During zinc alloy spraying, silicon rubber tools remained in good condition without any apparent damage to the tool. However, the metal coating created in this process did not adhere well to tool surfaces. Sand blasting the silicone tool did not change its metal adherence. Excessive peeling and warping of the coating could not be avoided despite using a large range of spraying conditions (Fig. 6(a)). The peeling in turn blocked the air way for spraying so that some design features could not be achieved.

- Al-filled epoxy tools did not show any problems with adherence of the coating to the tool's surface. Zinc coatings reproduced all design features including the recesses, spigots and deep sharp sections. The sprayed shells were easily removed from the negative tool cavities. However, due to the large temperature gradients the tool suffered from severe distortion and warping pushing the geometrical accuracy of the sprayed metal patterns beyond the acceptable tolerance level (Fig. 6(b)). Thus, this material was considered unsuitable for this process.

- For the tools made from ceramic material used in the investment casting process, the adhesion of the coating to the surface was so strong that in order to separate the ceramic shell from the zinc coating a sand blasting process was used to destroy the ceramic shell. Excellent zinc replicas were produced without any obvious distortion or warping, as shown in Fig. 6(c), although some dents due to sand blasting were noticed on the metal surface. These dents were believed not to significantly affect the quality of spin cast parts.

- Shaw-mix ceramic tools produced metal shells that were generally fine with no distortion or warping and free of porosity (Fig. 6(c)). There was no difficulty in removing the metal pattern from the ceramic shell. However, in some cases the ceramic cracked under the thermal impact resulting in coating peeling off at the edges and corners. Preheating the tools to about 80°C before spraying yielded good metal replicas without cracking the tools.

Consequently, the shells made from investment casting and Shaw-mix ceramics are suitable for arc metal spraying to form the master patterns. The metal master patterns produced using these two types of ceramics were successfully used to make rubber moulds for spin casting. In some cases, the non-tapered grooves or slots of the master pattern caused difficulty in separating the pattern from the mould. Clearly, further studies to determine the limits of the geometrical features in terms of rubber mould making process are required.

Dimensional errors at each stage and their accumulations through the tooling process for all major geometrical features of the design have been determined. In general, these errors are within a reasonable and acceptable range [7].

Fig. 7 shows the error propagation from the 3D solid model to the wax pattern, then to ceramic pattern (interim tool) and finally to metal tool (master pattern). For the Shaw-mix ceramic interim tools, the longitudinal dimensions show increases while decreasing trends are associated with the width when compared with the wax prototype of the part. This is possibly due to a prolongation of the tools during the fabrication process. By contrast, the errors in investment casting ceramic tools increase for both length and width with respect to the wax prototype. The results when using the SL patterns to produce the Shaw-mix ceramic tools show similar trends [7].

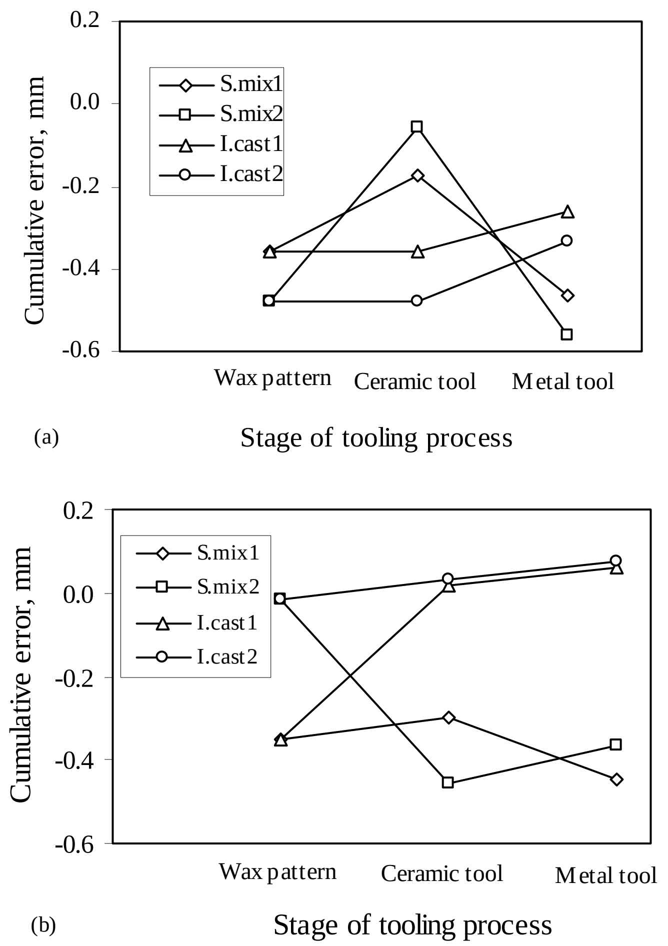



Fig. 7. Cumulative errors for major dimensions, (a) length 95 mm and (b) width 30 mm.

The findings for dimensional errors for the length of the master pattern are interesting, as shown in Fig. 7(a). Clearly, the sizes of the metal tools were reduced with regard to the interim tools made from the Shaw-mix ceramic, while the reverse applies to the intermediate tools of investment casting ceramic. A similar trend was also found for the width although these are in a smaller scale, as shown in Fig. 7(b). This may be attributed to the difference in thermal expansion coefficients of the two ceramics as well as the shrinkage of the metal tools. In the first case, the expansion of the Shaw-mix ceramic tool due to heating in the spraying process could not compensate the shrinking of the metal shell, while in the latter case the shrinking was overcompensated and the master pattern size increased.

This analysis again shows that the process chain presented can be used in tooling for spin casting and possibly other manufacturing processes. The findings indicates that the final dimensions of the master pattern seem to be repeatable, however a larger sample of data is required for meaningful statistical analysis.

## 4. Conclusions

A study of tooling for zinc spin casting process using streolithography and arc metal spray techniques has been presented. It has been shown that the SL pattern is not suitable for metal arc spraying, necessitating the use of intermediate tools. Intermediate tools made from the silicone rubber and aluminium-filled epoxy were found unsuitable for zinc arc metal spraying.

By contrast, intermediate ceramic tools made of materials used in metal casting were successfully used to make the master metal patterns, which were subsequently used to fabricate moulds for spin casting. More work is required to study the dimensional and geometrical accuracy of the tools produced from the proposed process as well as strategies to reduce and compensate for the errors.

## 5. Acknowledgements

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