AN INVESTIGATION INTO THE EFFECT OF THE SHELL ON SALM PROCESSED PARTS

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Abstract

Shell Assisted Layer Manufacturing (SALM) is a novel process for rapid prototyping/ tooling/ manufacture (RP/RT/RM) which is presently undergoing feasibility studies. SALM is based on layered manufacturing technology (LMT). Initially it develops the shell (boundaries) of a selected layer using a technique similar to fused deposition modelling (FDM). The developed shell is filled with a UV curable resin and is exposed to UV radiation for curing. This procedure is repeated until the complete part is built. This paper compares and contrasts properties of parts made using two options available with the SALM technique: building the part using a soluble shell (FDM support structure material, finally dissolved to recover the part); or using a polymer material such as ABS that is bonded with the resin whilst making the part.

1.0 Introduction

The modern approach towards Quality, Cost, Competitiveness, Product varieties and especially the time factor have made the integration of rapid processes (Rapid Prototyping/ Rapid Tooling/ Rapid Manufacturing (RP/RT/RM) within present industries. The use of RP processes as RT and RM applications has become the major focus for industry and researchers alike. Yet, the majority of rapid processes are having many limitations such as material, cost of material, accuracy, production speed, machine cost and build envelope [1]. One of the major drawbacks of RP processes has become the speed of the process due to material addition in a layered manner. Build speed of rapid processes has increased by a factor of 10 during recent years, still these processes are very much slower compared to conventional process such as injection moulding and die-casting [2].

Investigation of the SALM process is focused on developing productivity and a quality improved process with a larger build envelope, faster process and comparatively low machine cost. This paper discusses the effect of the shell on the parts made using SALM technology. Therefore, for the purpose of investigations, parts have built with sacrificial shell (water soluble FDM support structure material) that can be easily removed when the part is built. Other parts have been built with a shell material such as ABS plastics. In this option, the shell material is bonded with the model material and this eliminates additional requirements for the removal of the shell when the part is built.

2.0 The SALM Process

The SALM process is based on layer manufacturing technology [3, 4]. The key steps of the SALM process are (Figure 1); development of the shell (boundaries) of a particular layer of the part using the Fused Deposition Modelling (FDM) technique; then the shell is filled with UV (Ultraviolet) curable resin and is then cured using a UV light source. This procedure is repeated until the complete part is built. The support structure is introduced when building the geometries with overhangs and undercuts. SALM produces parts using two different methods; (1) Developing the shell using a water soluble plastic (Acrylic copolymer thermoplastic, FDM water soluble support structure material) [5] and finally dissolving the shell in a special water bath to recover the finished part. (2) Developing the shell using high quality thermoplastic (for example ABS plastics and making the part with a bonded shell) [6]. This option results in stronger parts but it loses the transparent property of the product even though transparent resin is used.

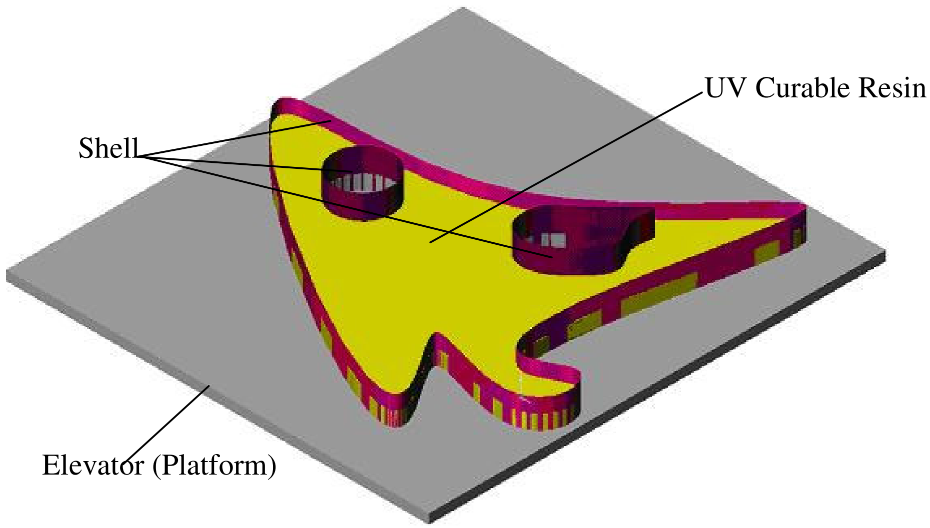
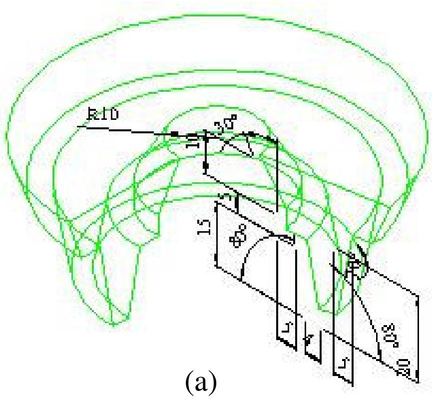
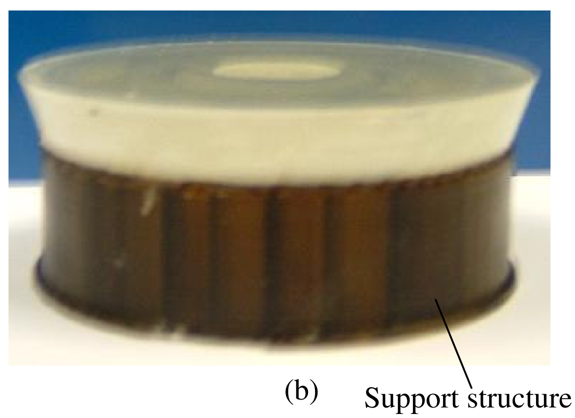


Figure 1: Concept illustration of SALM process

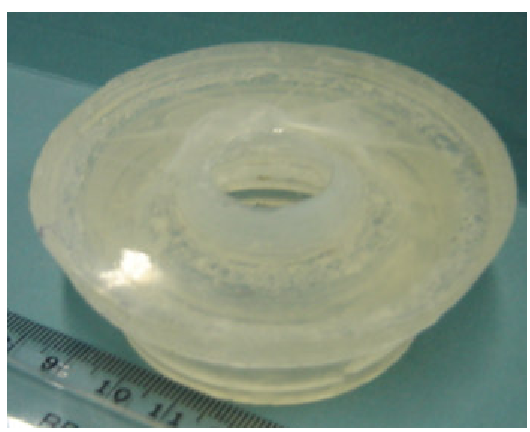


(a)



(b)

Figure 2: A part made with a support structure (a) Detailed dimensions of the built part; (b) part with the support structure (built using, P400 SR, FDM support structure material) and the shell; (c) finished part after removing the shell and support structure.



(c)

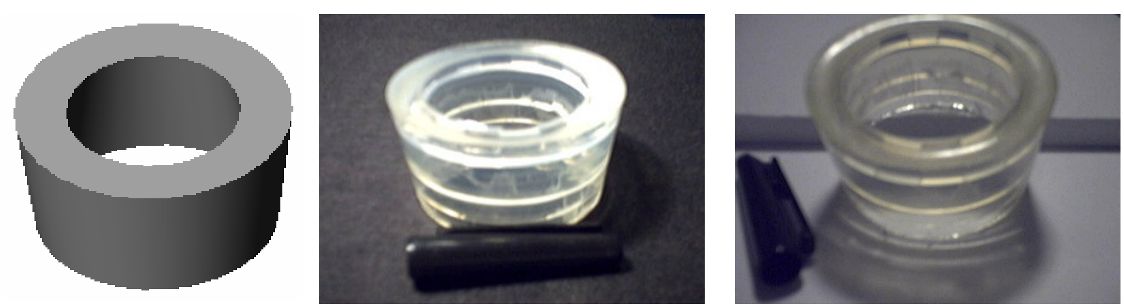
3.0 Experiments

The fundamental experiments were carried out using a FDM 3000 machine with a few added elements for UV curing and material feeding. The waterclear Somos® 10120 resin was used for the model material. The FDM support structure development material and the procedure were used without any modifications to build support structures for the geometries with undercuts and overhangs. Experiments were carried out with relatively simple geometrical parts.

3.1 Parts without the shell

Some selected geometries were built via SALM technology, in order to investigate the properties and strength of the parts built without the shell. An STL file of the CAD modelled geometry was fed to the FDM machine. Having done the slicing and support structure generation, the part was built layer by layer using sacrificial shell material. When the complete part is built, the part with the shell was put in the FDM waterworks solution in order to remove the shell.

Figure 3: A simple spanner (upper) made (with the shell removed) using the SALM method. A shell for the spanner is shown below.

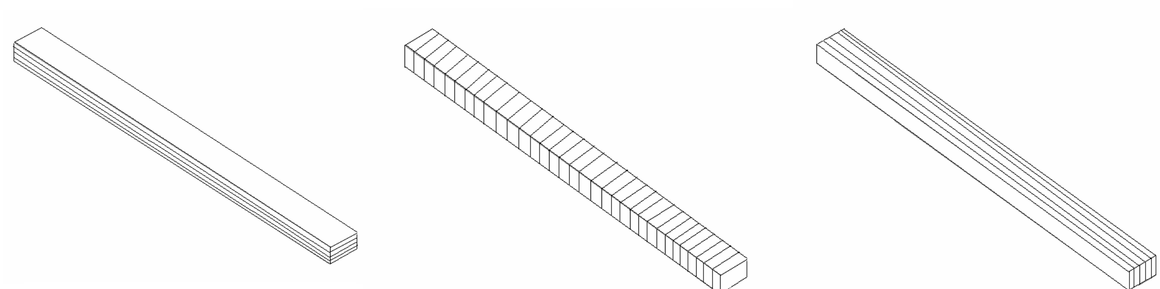


(a) CAD Geometry (b) Built part in one orientation (c) View in another orientation

Figure 4: CAD and Physical views of a built part

3.1.1 Strength of the parts built with the soluble shell

Investigations on the part strength for the parts made with the soluble shell were carried out. The specimens were made based on SALM technology using waterclear Somos® 10120 [7] resin according to the 3 possible layering directions (Figure 5). Testing was carried out using an INSTRON 2716 machine in all individual directions (X,Y,Z) to understand the anisotropic [8] nature of parts made based on the layered manner. The results obtained are shown in table 1. The experiments were repeated for 3 specimens from each orientation in order to minimise possible errors etc.



(a) Specimen on X-Layer (b) Specimen on Y-Layer (c) Specimen on Z-Layer

Figure 5: Illustration of parts with three layering orientations (a), (b) and (c) as explained.

Specimen	Tensile Strength (kN)	0.2% Yield Stress (MPa)	Young's Modulus (MPa)	Percentage elongation at yield
Specimen –X 1	1.294	13.57	1115	1.91%
Specimen –X 2	1.702	17.64	1237	2.24%
Specimen –X 3	2.001	14.88	1195	3.12%
Specimen –Y 1	12.350	6.63	369	2.23%
Specimen –Y 2	14.288	7.75	381	2.25%
Specimen –Y 3	13.285	5.75	450	1.97%
Specimen –Z 1	0.995	8.53	614.9	2.83%
Specimen –Z 2	1.324	10.70	854.7	2.83%
Specimen –Z 3	1.197	10.36	758.9	2.71%

Table 1: Summary of the test results for the specimens with different layering orientations.

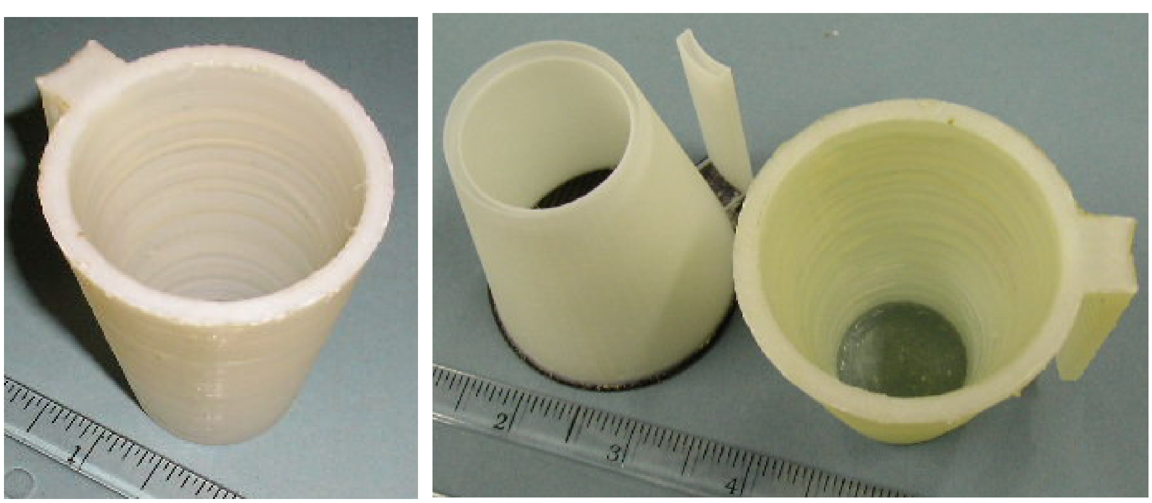
3.1.2 Environmental resistance of SALM parts

The change of properties with time in photopolymer resin based parts is a common problem [9] in the present RP applications. Modern RP applications have achieved significant level of improvement during the last few years and still they are under research and experiment to achieve a high level of resistance against change of properties with time. The properties regarding ageing on SALM process parts have not undergone any detailed investigation to date. Similar to most of the RP processes based on photopolymer resins, it is observed that in the SALM processed parts there is no significant change in dimensions and properties even after 3 months from manufacture.

3.2 Parts with the shell

As described before, the alternative method of making RP parts based on SALM process is building the shell using some engineering plastics such as ABS (Acrylonitle Butadiene Styrene) [10]. In this approach, the shell is bonded with the model material and eliminates additional work required for shell removal. For the concept realisation experiments, some parts have been built based on SALM technology. The shell is built using the ABS plastic used in the FDM process. Figure 6 and 7 show some parts built based on the SALM technique with an ABS plastic shell.

Figure 6: Two views of a cup made for the experiment with the ABS plastic shell.



(a) (b)

Figure 7: (a) The cup with the ABS shell and (b) The ABS shell made for experiments (left) and the cup with the ABS shell (right)

3.2.1 Surface finish and staircase effect.

Since, when a part is made via SALM technology, the resin layer is retained within the shell, the final part reproduces the surface finish of that of the shell and as the shell is built using the FDM technology the surface finish of the SALM processed part is very similar to that of FDM parts. In the SALM process, the shell retains the resin while it is cured under a UV lamp. Therefore, the staircase effect of the SALM processed parts are independent of the individual thicknesses of the resin layers cured (Figure 8). The staircase effect is similar to that of the shell. This is the staircase effect of the FDM technology used to build the shell.

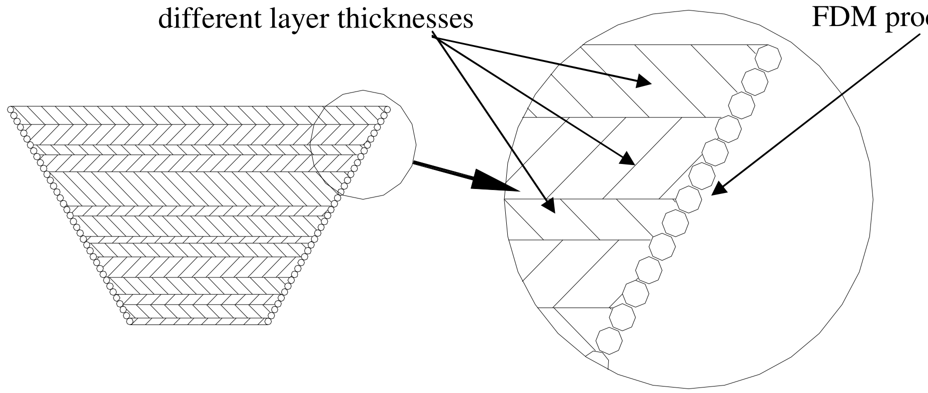


Figure 8: An illustration showing the "staircase effect" of the SALM parts is independent from the thickness of the cured material layer.

4.0 Discussion

The SALM process has been investigated by making parts with and without a shell. A general concern, when a part is produced without the shell, the shell is built with a sacrificing material. Also the removal of the shell involves some extra work. The experiments were carried out with the FDM waterworks setup for shell removal. When the shell is built using ABS plastics, the shell is bonded with the model material. This result in the saving of the extra work required for the shell removal and an improvement in part strength. To investigate the real effect of the shell on strength issues, further investigations are required. When the part is covered with the plastic shell, it prevents exposure of surfaces (except top facing and bottom surfaces) to the atmosphere. This can result in better resistance of the material against changes of environmental conditions with time. The strength analysis was carried out for the parts without the shell under 3 different layering orientations. The specimens with x-direction layers show the highest yield strength and the Z-direction layered part shows the next level of yield strength. The lowest yield strength can be finding in the Y-direction layered specimens and this value is equivalent to the bond strength between two consecutive layers of the part. The yield strength values for the parts with the shell are yet to be investigated. The experiments were carried out with waterclear Somos® 10120 resin which is specially developed for the Stereolithograpy (SLA) process with solid state laser curing. Therefore, it is expected that with the identification of the right material for the SALM process this would further improve the part properties.

5.0 Conclusions and future work

Based on the fundamental experiments carried out, two basic different options for producing RP parts using SALM technology have been established. They are parts with and without the shell in the final product. The experiments show promising results to strengthen the scope of commercialising the SALM technology based on the above mentioned options. The strength properties of the parts without the shell show properties of the same order of SLA products. Strength properties of the part with the shell are yet to be investigated.

The following key areas are focused for further research and experimental work.

- Investigation into the strength and environmental resistance of the part built with the shell.
- Identifying/ producing alternative materials
- Specific adaptive slicing techniques [11]
- Possible modifications to improve SALM as a RT/RM system
- Improvement of product surface finish by improving shell finish through the FDM process

Acknowledgement

The authors acknowledge the assistance given by Mr. Paul Keenan and Mr. Ryan McWhinnie through carrying out experiments and making specimens.

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