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Comparative Evaluation of Additive Manufacturing Processes

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ABSTRACT

Rapid prototyping (RP) is an additive manufacturing process used for creating objects that are inconvenient or expensive to manufacture by conventional machining processes. Considering its growing popularity in today's world, it becomes necessary to quantify this technology to give its users a clear picture about how beneficial RP could be if it were made commonly available at cheaper rates. One of the most useful manufacturing technologies existing today, RP helps in the creation of miniature prototypes of large machines and structures, medical equipment, and even art forms. There are several different forms of this technology which employs different methods and different materials to print three-dimensional solid objects. This creates a dilemma to the user, as he has to make a choice between these forms of RP to use it for his needs. This paper emphasizes on the qualitative testing of identical specimens created by two of the most popular RP processes available today, namely, stereolithography apparatus (SLA) and selective laser sintering (SLS). The specimens will be evaluated on the parameters of dimensional accuracy, tensile strength, water absorption, shore hardness, surface roughness, density, and microscopic defect structure. The outcome of this study aims at helping people to understand SLS and SLA better in terms of the products they create so that it becomes easier for users to make a choice between the two. It also aims at highlighting the above-mentioned statistical information about SLA and SLS so that they may be improvised and enhanced in the future.

Key words: *Stereolithography, Selective laser sintering, Rapid prototyping, Additive manufacturing, Mechanical properties.*

1. INTRODUCTION

Since its inception, rapid prototyping (RP) processes have diversified in application [1]. What was initially devised as a method to create quick prototypes of components before investing in a full-scale working model, today finds application in industry, automobiles, aviation, medicine, architecture, cooking, and even as an art form [2,3]. Some examples of the above include the use of RP in wind tunnel modeling [4], medical prosthetics such as wrist implants and prosthetic legs [5], architectural prototypes and miniature construction models [6], in dentistry [7], the manufacture of injection molds [8] and the recreation of now obsolete technological specimens [9], nanotechnology among others.

Stereolithography apparatus (SLA) is one of the oldest but most commonly used RP processes. It involved raw material input in the liquid state. An ultraviolet laser is now focused on a container with photopolymer solution. The laser traces the path of the shape given by the computer aided design (CAD) file thereby hardening that portion of the liquid. One of the advantages of this process is quickness of manufacture. SLA is one of the fastest RP processes, considering the fact that process speed is proportional to the complexity of the part to be manufactured. Its downside is its cost. One gallon of photopolymer resin can cost up to 2500$. Furthermore, SLA is highly dependent on supports for manufacturing components. Selective laser sintering (SLS) is one of the most widely used prototyping processes available today. It was developed by Dr. Carl Deckard and Dr. Joe Beaman at the University of Texas at Austin. It involves sintering of raw material along predetermined paths to create the product as per the given CAD file. The difference is that SLS uses powdered raw material instead of liquid. A roller rolls a layer of powder onto the sintering bed, which is solidified by a laser. The advantage of this process is that the unsintered powder stacks up and suspends the sintered product between itself, this obviating the need for any support structure. It is thus very convenient to manufacture multiple parts in a single run. It is also cheaper than SLA.

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2. LITERATURE SURVEY

With the increasing importance of RP in today's industrial applications, it has become necessary to quantify all the aspects that govern the quality of solid free formed products. Nancharaiah *et al*. [10] conducted the analysis of energy utilization of the laser used in many RP applications, which is affected by the parameters of slice thickness and orientation of CAD model. A new approach to analysis of SLS using optical coherence tomography was discussed by Guan *et al*. [11]. Guan *et al*.'s work was purely virtual and did not involve actual testing of specimens. All the parameters tested in the above-mentioned works are process specific and not product specific. They elaborate on how to modify the process to get suitable changes in the final product.

Conley and Marcus [12] have briefly overviewed the concept and technicalities of various RP methods, SLS, and SLA among others. Determination of best choice of RP process using QFD has been highlighted by Pérés and Martin [13], which talk about the financial and business perspective of analyzing RP processes. Luo [14] have stated the environmental performance comparison of SLS, SLA and fused deposition modeling (FDM) in detail. Similarly, Chua Chee Kai has compared the processes of SLA, SLS, laminated object manufacturing and FDM-based on the material of use, their advantages and disadvantages, and their price [15]. Phatak and Pande [16] used the genetic algorithm to determine optimum part orientation in various RP processes. This again can be categorized as a preprocess parameter. Durham *et al*. [17] deduced that SLA undergoes lesser shrinkage than SLS during the process, and the shrinkage is easy to predict and correct. Finally, Antonio [18] has stressed upon the surface finish, its detection and its effect on parts manufactured by the FDM process. Although this does not pertain to the processes we are concerned with SLA, SLS, it provides useful insight on one of the most crucial parameters of RP.

Most of the research done in the field of RP aim at modifying process variables to produce a more suitable product. The common customer, however, will rely on a more direct comparison to evaluate which process yields more favorable results. This study compares the specimens created by SLS and SLA and tested them for parameters of direct importance to the end-user. All our tests are experimental and rely less on virtual hypothesis, thus providing a clear picture of the pros and cons of SLS and SLS. This research will help customers get a clearer picture on which RP process is most suitable to their needs.

3. EXPERIMENTATION

The manufacture of components was done at Imaginarium (India) Pvt. Ltd. Table 1 shows the name and specifications of the machines used to print these components via SLA and SLS processes. The production was conducted at a temperature of around 32°C (72°F) under air conditioning. Laser power for SLA was 500 mW and laser intensity for SLS was 42 W.

3.1. Sample Preparation

The SLA specimens were made from 3D Systems Accura-60 Plastic, and the SLS specimens were made from 3D Systems DuraForm PA Plastic. The specimens were manufactured in the horizontal orientation for both processes. The machine used to manufacture the SLA specimens was the 3D Systems Viper Si^2 machine, and the one used to manufacture the SLS specimens was the 3D Systems Sinter Station HiQ + HQ machine. The shape and dimensions of the test specimens were decided according to the ASTM D638-10 standard (Type IV Specimen). The standard recommends at least five specimens for testing any particular process parameter. Our tests were conducted at a load rate of 1 mm/min and failure occurred in around 4-5 min. The dimensions of the specimen are shown in Figure 1.

3.2. Dimensional Accuracy (DA) Test

Five identical specimens of SLA and SLS each were taken to test their DA as compared to the dimensions of the CAD Model (Modeled after ASTM D638-10 Type IV specifications). The instrument used for measuring dimensions was the Mitutoyo Analog Vernier Caliper with a least count of 0.02 mm. The specimen was cleaned and tested for overall length (LO), overall width (WO), width of narrow section (W), and thickness (T) with the caliper. Radii and other dimensions were excluded in the testing for simplicity of operation.

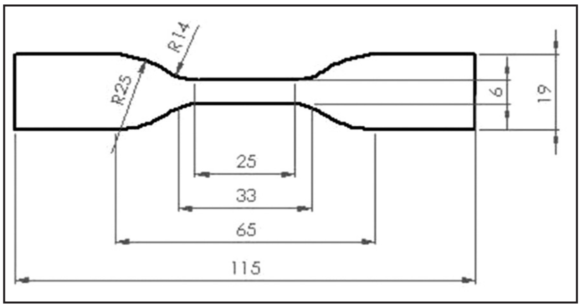

Figure 1: Graphical representation of ASTM D638-10 Type IV specimen with dimensions.

Table 1: Details of machines used for SLA and SLS specimen manufacture.

Type	Manufacturer	Model	Bed temperature
SLA	3D Systems	Viper Si^2	25°C
SLS	3D Systems	SinterStation HiQ+HS	172°C

SLA=Stereolithography apparatus, SLS=Selective laser sintering

3.3. Tensile Strength Test

This test comprised the tensile testing of five samples of SLA and SLS each, using the INSTRON 3366 testing machine, which has a 10 kN loading capacity. The gauge length was 25 mm and the specimens were loaded at a rate of 1 mm/min. The specimen was clamped in the jaws of the machine and it was pulled longitudinally to conduct the tensile test. The tensile stress, tensile strain and extension were recorded by increasing the load with time. The data obtained was recorded and was also plotted to obtain a stress-strain relationship.

4. RESULTS AND ANALYSIS

4.1. DA Test

To measure tensile properties of the SLA and SLS specimens, the specimens were first subjected to a DA test. The dimensions of the specimens of SLA and SLS each were calculated. Their dimensions were used to calculate the dimension change rate and DA using the following formulae:

Dimensional change rate (%) = [{Measured value (mm)/desired value (mm)} −1] × 100

DA (%) = | [{Measured value (mm)/desired value (mm)} −1] × 100 |

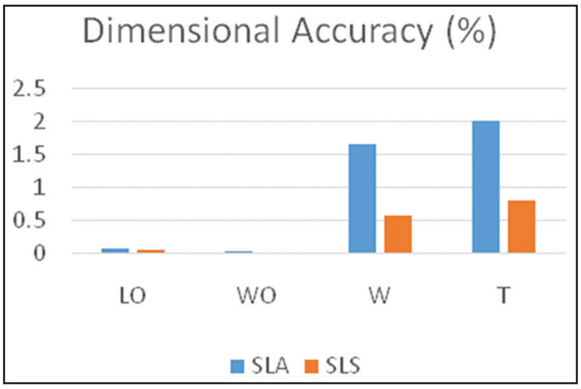

Figure 2: Dimensional accuracy of overall length (LO), overall width (WO), width of narrow section (W), and thickness (T) (stereolithography vs. selective laser sintering).

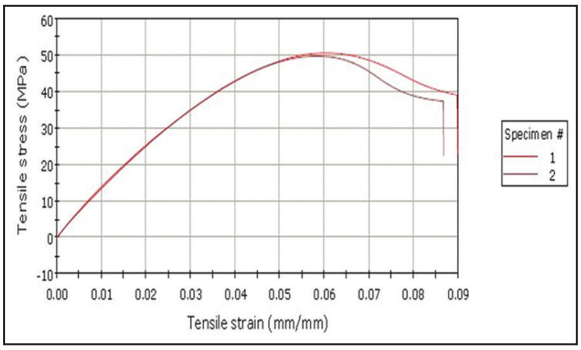

Figure 3: Stress-strain curve (stereolithography apparatus).

4.1.1. DA of SLA specimens

The dimensions of overall length (LO), overall width (WO), width of narrow section (W) and thickness (T) of the SLA specimens were measured. The average of these readings was determined and used to calculate the standard deviation, dimensional change rate (DCR) and DA of each dimension as shown in Table 2.

4.1.2. DA of SLS specimens

Similarly, the standard deviation, DCR and DA of each dimension are as shown in Table 3.

4.1.3. Graphical interpretation

The statistical and graphical data in Figure 2 show that the DA of SLS (0.23) is better than that of SLA (0.94). It is also observed that both SLS and SLA specimens exhibit greater dimensional error in the smaller dimensions W (width of smaller section) and T (thickness). This could be due to warping of the product due to the post-production curing process, or due to the machines inability to maintain its accuracy while printing smaller dimensions. However, even in these, the SLS specimens prove to be more accurate.

4.2. Tensile Strength Test

Parameter	SLA	SLS
Average elongation (mm)	2.206175	5.84455
Average maximum tensile stress (MPa)	50.244585	42.643595
Average load at maximum tensile stress (N)	1296.3103	1100.2049
Tensile extension (mm)	1.503325	5.122585
Average elasticity modulus (MPa)	1330.609	679.58693

SLA=Stereo lithography apparatus, SLS=Selective laser sintering

4.2.1. Inference

It is observed that the average elongation of SLA specimens (2.206175 mm) is less than that of SLS specimens (5.84455 mm). Tensile stress of SLA specimens (50.24458 MPa) is greater than that of SLS specimens (42.64359 MPa). It can thus be concluded that SLA specimens outperform the SLS specimens in the tensile strength test. It was also observed that the experimentally obtained values of tensile stress and elongation conform to the expected values in both, the Accura-60 plastic used for SLA and the DuraForm PA plastic used for SLS. It must be noted that there was a large elongation in the SLS specimens (5.122585 mm) as compared to the SLA specimens (1.503325 mm), which is quite undesirable in terms of dimensional stability under loading.

5. CONCLUSIONS

It was observed that the DA of SLS specimens was better than that of SLA specimens. On the other

Table 2: Standard deviation, DCR and DA (SLA).

	Standard deviation (mm)	DCR (%)	DA (%)
L	0.103978	0.0835	0.0835
WO	0.021112	−0.042	0.042
W	0.062549	−1.644	1.644
T	0.053984	−2.0	2.0

Average DA for SLA (%) = 0.94. DCR=Dimensional change rate, DA=Dimensional accuracy, L=Overall length, WO=Overall width, W=Width of N.S., T=Thickness, SLA: Stereolithography apparatus

Table 3: Standard deviation, DCR and DA (SLS).

	Standard deviation (mm)	DCR (%)	DA (%)
LO	0.227968	0.0533	0.0533
WO	0.078631	−0.232	0.0232
W	0.042404	−0.578	0.0578
T	0.048873	0.8	0.8

Average DA for SLS (%)=0.23. DCR=Dimensional change rate, DA=Dimensional accuracy, L=Overall length, WO=Overall width, W=Width of N.S., T=Thickness, SLS=Selective laser sintering

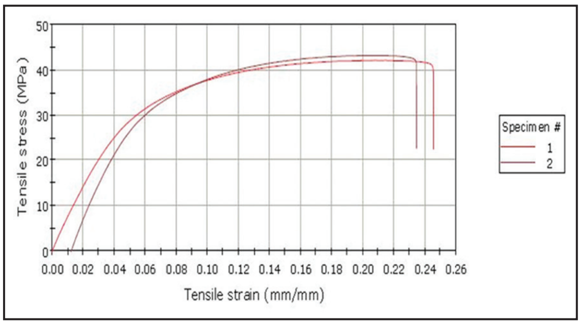

Figure 4: Stress-strain curve (selective laser sintering)

hand, the SLA specimens were better in the tensile test as compared to the SLS specimens. It is difficult to comment on the nature of the two processes until they are completely tested in all respects. The tests mentioned above aim at completing this analysis to determine a realistic qualitative assessment of SLA and SLS in all respects.

6. REFERENCES

1. S. Upcraft, R. Fletcher, (1980), The rapid prototyping technologies, ***Assembly Automation***, **23(4):** 318-330.
2. S. K. Tiwari, S. Pande, S. Agarwal, S. M. Bobade, (1995) Selection of selective laser sintering materials for different applications, ***Rapid Prototyping Journal***, **21(6):** 630-648.
3. A. Kochan, (1980) Rapid developments in rapid prototyping, ***Assembly Automation***, **15(4):** 18-19.
4. R. N. Chuk, V. J. Thomson, (1995) A comparison of rapid prototyping techniques used for wind tunnel model fabrication, ***Rapid Prototyping Journal***, **4(4):** 185-196.
5. A. M. Patterson, R. Bibb, R. I. Campbell, G. Bingham, (1995) Comparing additive manufacturing technologies for customised wrist splints, ***Rapid Prototyping Journal,*** **21(3):** 230-243.
6. I. Gibson, T. Kvan, L. W. Ming, (1995) Rapid prototyping for architectural models, ***Rapid Prototyping Journal***, **8(2):** 91-99.
7. A. Azari, S. Nikzad, (1995) The evolution of rapid prototyping in dentistry: A review, ***Rapid Prototyping Journal***, **15(3):** 216-225.
8. S. Rahmati, P. Dickens, (1995) Stereo lithography for injection mould tooling, ***Rapid Prototyping Journal***, **3(2):** 53-60.
9. H. Lipson, F. C. Moon, J. Hai, C. Paventi, (2005), 3-D printing the history of mechanisms, ***ASME Journal of Mechanical Design***, **127:** 1029.
10. T. Nancharaiah, M. Nagabhushanam, B. A. Nagendram, (2013) Process parameters optimization in SLS process using design of experiments, ***International Journal of Mechanical Engineering and Technology***, **4(2):** 162-171.
11. G. Guan, M. Hirsch, Z. H. Lu, T. D. David, S. J. Matcher, R. Goodridge, K. M. Groom, A. T. Clare, (2015) Evaluation of selective laser sintering process by optical coherence tomography, ***Materials and Design***, **88:** 837-846.
12. J. G. Conley, H. L. Marcus, (1997) Rapid prototyping and solid freeform fabrication, ***ASME Journal of Manufacturing Science and Engineering***, **119:** 811.
13. F. Pérés, C. Martin, (1999) Design methods applied to the selection of a rapid prototyping resource. emerging technologies and factory automation. Vol. 1. ***Proceedings ETFA***. 7th ***IEEE International Conference***.
14. Y. Luo, (1999) Environmental performance analysis of solid freeform fabrication processes. ***Electronics and the Environment***, New Jersey: ISEE.
15. C. K. Chua, K. F. Leong, C. S. Lim, (2010) ***Rapid Prototyping: Principles and Applications***, 3rd ed. Singapore: World Scientific.
16. M. A. Phatak, S. S. Pande, (2012), Optimum part orientation in rapid prototyping using genetic algorithm, ***IEEE Journal of Manufacturing Systems***, **31:** 395-402.
17. M. Durham, T. Grimm, J. Rollins, (1996) SLS, SLA: Different technologies for different applications. ***Promotional Literature***, Austin, TX: Accelerated Technologies Inc.
18. A. Antonio, (2006) Assessment of surface quality on textured FDM prototypes, ***Rapid Prototyping Journal***, **12(1):** 35-41.

***Bibliographical Sketch**

Mukund Joshi is a final year student studying Mechanical and Manufacturing from Manipal Institute of Technology, Karnataka, India. He is an ambitious budding engineer with a penchant towards the fields of Computer Aided Design (CAD), and Design and Control Systems. He has previously published an international paper on Cost Effective Refrigeration using Phase Change Materials and Thermoelectric Effect, and is currently working with a team of biomedical engineers to design innovative products that will be of use in the medical profession. His research over the term of his undergraduate course includes the topics of Cost Effective Refrigeration, Rapid Prototyping, Biomedicine and Computer Aided Design.