FEASIBILITY STUDY ON STEREOLITHOGRAPHY APPARATUS (SLA) AND SELECTIVE LASER SINTERING (SLS)

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ABSTRACT

The study on Stereolithography Apparatus (SLA) and Selective Laser Sintering (SLS) technologies deals with experimentation and finding out the material which is having the good mechanical properties irrespective of their layer manufacturing techniques. The material which was selected for the experimentation was Accura 60 material to build on SLA system and Duraform PA/Nylon material to build on SLS system. The prototypes which were built using Accura 60 and Duraform PA/Nylon were then subjected to various experiments like tension test, compression test, and hardness test. The SEM images were taken on the fractured surface of the test specimens to study the internal structural bonding and the cause for the fracture to occur on that surface. The result of experimentation displays the material which is having the good mechanical property compared to other.

Keywords: Layer Manufacturing or Rapid Prototyping or Additive Manufacturing, SLA, SLS, Accura 60, Duraform PA/Nylon, SEM analysis.

I. INTRODUCTION

In recent years, opening up local markets for worldwide competition has led to a fundamental change in new product development. In order to stay competitive, manufacturers should be able to attain and sustain themselves as "World Class Manufacturers". The manufacturers should be capable of delivering the products in fulfilling the total satisfaction of customers. The products developed by the manufacturers should be of higher quality within short delivery time with a reasonable cost and must fulfill all the safety requirements [1].

In many application or functional fields, the designer faces the problems with their new designs. The designers have to check out their new design, whether it suits and fits into functional area without wasting the lead time of the production. Hence a prototype is often used as part of the
product design process to allow engineers and designers the ability to explore their new design for various test conditions and theories, there by confirming the performance of design prior to start of the production. Engineers and the designers use their experience to design the prototype according to the specific unknowns still present in the intended design. Additive Manufacturing technologies employ various engineering techniques like laser, optical scanning, photosensitive polymers, material extrusion, material deposition, powder metallurgy, computer control programming, etc. to directly produce a physical model layer by layer (Layer Manufacturing) in accordance with the geometrical data derived from a 3D CAD model. Layer manufacturing had a ability to prepare working prototype at the early design stage of the new product development cycle. Thus the manufacturers can use the working prototypes in bridging a multi-disciplined team composed of the designers, engineers, manufacturer and marketing people to design right at the first instance in fulfilling the customer needs.

Rapid prototyping is rapid creation of a physical, fit and functional model. However, rapid prototyping is spread to all the braches of engineering, and it is slowly growing to include other areas like medical applications, aerospace research and etc.[2]. Also, Rapid Prototyping, Tooling and Manufacturing (RP&M) can be used to include the utilization of the prototype as a master pattern for tooling and manufacturing.

![Figure 1: General layer by layer building concept of AM](image)

Rapid prototyping is called by different names such as

1. 3D printing
2. Layer Manufacturing
3. Advanced Manufacturing
4. Direct Digital Manufacturing
5. Additive Manufacturing as per ASTM and ISO standards.

A. **Stereo lithography Apparatus**

A computer controlled laser fires its beam into a tank containing a special form of plastic resin (called a Photo-polymer). When the beam hits the plastic resin it makes the resin set into a solid. The beam travels in two dimensions across the surface of the resin (x axis and y axis), and ‘draws’ a layer of the model. The base layer is formed on the surface of a table within the vat. The table can be lowered (z axis), allowing another layer of resin to be formed above it. The adjacent layers bond to each other in the setting process, thus beginning the creation of a solid object [3].

Upon completion of the formation of the model, it is fully submerged in the tank, and so the table must be raised up. The model must then be cleaned of the uncured resin that its surface is wet with It is then ready for use, although some machining may be necessary.
B. **Selective Laser Sintering**

A layer of metal powder is spread on the machine’s table. The laser then fires in the X–Y axes and bonds the powder together in the desired shape for that layer. The process repeats until the whole prototype is completely built. The end product can be porous, and therefore may require infiltration to give strength and improve surface finish [4].
II. TEST SPECIMEN OR PROTOTYPE BUILDING

A. Designing the Test Specimen in Solidedge V18 Software

The preliminary step was to design the test specimens which were to be built on additive manufacturing technologies like SLA and SLS and the draft is as shown in figure 4 and 5.

![Sketch of ASTM standard tensile test specimen](image1)

**Figure 4:** Sketch of ASTM standard tensile test specimen

![Sketch of cylindrical shape specimen](image2)

**Figure 5:** Sketch of cylindrical shape specimen

B. Design of Test Specimen for Tensile Testing

A standard dog bone shape specimen as per the ASTM standards which are preferably used in the testing centre was designed as 3D sketch on Solid Edge V18 software. The test specimen has a gripping head so that the test specimen can be easily fixed on the work holding jaws of the UTM on both the ends. These gripping head has a length of 50mm and a diameter of 16mm. The test specimen has a gauge length of 196mm and a gauge diameter of 12mm where actually the properties of the polymers can be found subjected to the respective test as shown in the figure 6.

![Tensile Test Specimen](image3)

**Figure 6:** Tensile Test Specimen

C. Design of Test Specimens for Compression and Hardness Test

A standard cylindrical shape specimen as per the ASTM was designed on a Solid Edge V18 software for compression and to determine the hardness of the polymer materials.

The test specimen designed is of a solid cylindrical shape having a length of 50mm and a diameter of 16mm as shown in the figure 7.
D. Converting the Cad File into Standard Triangulation Language (STL) Format

Once the CAD model was generated in CAD software it was stored in STL file [5], the STL files were transferred to the respective build techniques like SLA and SLS systems. Slicing of the STL file was done at the respective systems. The thickness of the layers ranges from 0.01 to 0.7mm depending on the build technique.

For SLA process the minimum layer thickness ranges from 0.05mm to 0.15mm. Therefore as per the requirement of the project the layer thickness of 0.05mm is considered to build a part in horizontal orientation for a part thickness of 16mm, hence to total number of slices made from the STL file will be 320.

Similarly in SLS process the minimum layer thickness should be 0.076mm. Therefore the numbers of slices required to build a part in horizontal orientation for a part thickness of 16 mm will be 211 slices.

E. Build Orientation

A build orientation of 00 was considered for both the SLA and SLS parts, the part was built layer by layer on the vat with a horizontal orientation as shown in figure 8 and 9.

F. Support Systems

The SLA system need supports to build the parts and liquid soluble supports were used. These supports were removed at post process through immersion in the liquid container or through hand breaking techniques.
G. Building the Prototypes in SLA and SLS Systems

Two test specimens were built for each test in Viper Si2 SLA station with Accura 60 polymer and it is as shown in figure 11.

Similarly two test specimens were built for each test in SinterstationHiQ HS SLS station with Duraform PA polymer and it is as shown in Figure 12

H. Mechanical Properties of the Materials

The theoretical mechanical properties of the materials Accura 60 and Duraform PA/Nylon is shown in table 1.

<table>
<thead>
<tr>
<th>Test Type</th>
<th>Mechanical Properties</th>
<th>Accura 60</th>
<th>Duraform PA</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tension Test</td>
<td>Failure Load N</td>
<td>6000 – 7000</td>
<td>2500-3700</td>
</tr>
<tr>
<td></td>
<td>Tensile stress N/mm²</td>
<td>58 – 68</td>
<td>40</td>
</tr>
<tr>
<td></td>
<td>Yield stress N/mm²</td>
<td>N/A</td>
<td>N/A</td>
</tr>
<tr>
<td></td>
<td>Ultimate Stress N/mm²</td>
<td>N/A</td>
<td>N/A</td>
</tr>
<tr>
<td>Compression Test</td>
<td>Breaking Stress N/mm²</td>
<td>N/A</td>
<td>N/A</td>
</tr>
<tr>
<td></td>
<td>% Elongation</td>
<td>5-13%</td>
<td>20%</td>
</tr>
<tr>
<td></td>
<td>Failure Load N</td>
<td>N/A</td>
<td>N/A</td>
</tr>
<tr>
<td></td>
<td>Compressive stress N/mm²</td>
<td>N/A</td>
<td>N/A</td>
</tr>
<tr>
<td></td>
<td>Peak Stress N/mm²</td>
<td>N/A</td>
<td>N/A</td>
</tr>
<tr>
<td>Hardness Test</td>
<td>BHN</td>
<td>80</td>
<td>70</td>
</tr>
</tbody>
</table>
III. RESULTS AND DISCUSSIONS

A. Tensile Testing of SLA Accura 60 Materials

Most of the AM/RP materials are polymers, the parts built on RP processes cannot be subjected into tensile test under a high capacity UTM. So, here to conduct a tensile test of SLA built Accura 60 part an Electronic Tensometer, Model Pc-2000 was used.

Calculations of specimen 1:

Initial gauge dia \( (D_0) \) = 12mm
Initial gauge length \( (L_0) \) = 196 mm
Initial gauge area \( (A_0) \) = 113.04 mm\(^2\)
Initial overall length \( (L_1) \) = 300mm
Final gauge dia \( (D_u) \) = 11.23 mm
Final gauge length \( (L_u) \) = 208.5 mm
Final gauge area \( (A_u) \) = 99.048 mm\(^2\)
Final overall length \( (L_2) \) = 312.5 mm

Area \( A \) = \( \frac{\pi D^2}{4} \) mm\(^2\)
Stress \( \sigma \) = \( \frac{F}{A} \) N/mm\(^2\)
Strain \( \epsilon \) = \( \frac{\Delta L}{L_0} \)
Yield Stress \( \sigma_y \) = \( \frac{F_y}{A_0} \) N/mm\(^2\) = \( \frac{1768}{113.04} \) = 15.82 N/mm\(^2\)
Ultimate Stress \( \sigma_u \) = \( \frac{F_u}{A_0} \) N/mm\(^2\) = \( \frac{6805}{113.04} \) = 60.23 N/mm\(^2\)
Nominal Breaking Stress \( \sigma_v \) = \( \frac{F_b}{A_0} \) N/mm\(^2\) = \( \frac{60376}{113.04} \) = 60.376 N/mm\(^2\)
True Breaking stress \( \sigma_{bt} \) = \( \frac{F_b}{A_u} \) N/mm\(^2\) = \( \frac{60376}{99.048} \) = 68.9 N/mm\(^2\)

The Stress vs Strain graph of Accura 60

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**Figure 13:** Stress vs Strain graph of Specimen 1 of Accura 60
The observed yield load was 1789 N, the yield stress was 15.82 N/mm$^2$. The ultimate load was 6809 N, the ultimate stress was 60.23 N/mm$^2$ and the breaking load was 6825 N with a nominal breaking stress of 68.9 N/mm$^2$.

The Load v/s Displacement graph of Accura 60

The maximum displacement observed was 12.5mm at the load of 6825 N

![Load v/s Displacement graph of Specimen 1 of Accura 60](image)

**Figure 14**: Load v/s Displacement graph of Specimen 1 of Accura 60

**Calculations of specimen 2:**
- Initial gauge dia ($D_0$) = 12mm
- Initial gauge length ($L_0$) = 196 mm
- Initial gauge area ($A_0$) = 113.04 mm$^2$
- Initial overall length ($L_1$) = 300mm
- Final gauge dia ($D_u$) = 11.21 mm
- Final gauge length ($L_u$) = 208.7 mm
- Final gauge area ($A_u$) = 98.69 mm$^2$
- Final overall length ($L_2$) = 312.7 mm

Area $A$ = $\frac{\pi D^2}{4}$ mm$^2$

Stress $\sigma$ = $\frac{P}{A}$ N/mm$^2$

Strain $\varepsilon$ = $\frac{L - L_0}{L_0} \frac{L}{L}$

Yield Stress $\sigma_y$ = $\frac{F_y}{A_0}$ N/mm$^2$ = $\frac{1789}{113.04}$ = 15.79 N/mm$^2$

Ultimate Stress $\sigma_u$ = $\frac{F_u}{A_0}$ N/mm$^2$ = $\frac{6809}{113.04}$ = 60.23 N/mm$^2$

Nominal Breaking Stress $\sigma_v$ = $\frac{F_v}{A_0}$ N/mm$^2$ = $\frac{6825}{113.04}$ = 60.438 N/mm$^2$

True Breaking stress $\sigma_{Bt}$ = $\frac{F_{Bt}}{A_u}$ N/mm$^2$ = $\frac{6825}{98.69}$ = 69.22 N/mm$^2$
The Stress v/s Strain graph of Accura 60

![Stress v/s Strain graph of Specimen 2 of Accura 60](image)

**Figure 15:** Stress v/s Strain graph of Specimen 2 of Accura 60

The observed yield load was 1785 N, the yield stress was 15.79 N/mm². The ultimate load was 6809 N, the ultimate stress was 60.23 N/mm² and the breaking load was 6832 N with a nominal breaking stress of 69.22 N/mm².

The load v/s displacement graph of Accura 60

The maximum displacement observed was 12.7mm at the load of 6832 N

![Load v/s Displacement graph of Specimen 2 of Accura 60](image)

**Figure 16:** Load v/s Displacement graph of Specimen 2 of Accura 60

The image of the materials after fracture during tensile test

![Accura 60 material after Break](image)

**Figure 17:** Accura 60 material after Break

The SEM analysis of the accura 60 specimen which was subjected to tension test was done on the part where actually the fracture occurred due to breaking load and is as shown in figure 18.
Figure 18: SEM image taken on the fractured surface at 495x magnification

From the SEM images it was seen that the fracture occurred on the weak bonded surface of the Accura Tensile test specimen and the internals stresses causing the shrinkage of the material can be observed at a magnification of 495x.

B. Tensile Testing of SLS Built Duraform PA/Nylon Material

Calculations of Specimen 1:

- Initial gauge dia (D₀) = 11.33mm
- Initial gauge length (L₀) = 196 mm
- Initial gauge area (A₀) = 100.82 mm²
- Initial overall length (L₁) = 300mm
- Final gauge dia (Dᵤ) = 10.98 mm
- Final gauge length (Lᵤ) = 224.5 mm
- Final gauge area (Aᵤ) = 94.68 mm²
- Final overall length (L₂) = 328.5 mm

Area A = \( \frac{\pi D^2}{4} \) mm²

Stress \( \sigma \) = \( \frac{F}{A} \) N/mm²

Strain \( \varepsilon \) = \( \frac{L - L₀}{L₀} \)

Yield Stress \( \sigma_y \) = \( \frac{F_y}{A₀} \) N/mm² = \( \frac{1445}{100.82} \) = 14.33 N/mm²

Ultimate Stress \( \sigma_u \) = \( \frac{F_u}{A₀} \) N/mm² = \( \frac{3098}{100.82} \) = 30.7 N/mm²

Nominal Breaking Stress \( \sigma_v \) = \( \frac{F_B}{A₀} \) N/mm² = \( \frac{3182}{100.82} \) = 31.82 N/mm²

True Breaking stress \( \sigma_{Bt} \) = \( \frac{F_{Bt}}{Aₜ} \) N/mm² = \( \frac{3389}{95.00} \) = 33.89 N/mm²
Stress Strain graph of Duraform PA specimen 1.

![Stress v/s Strain graph of Specimen 1 of Duraform PA/Nylon](image)

**Figure 19:** Stress v/s Strain graph of Specimen 1 of Duraform PA/Nylon

The observed yield load was 1445 N, the yield stress was 14.33 N/mm$^2$. The ultimate load was 3096 N, the ultimate stress was 30.7 N/mm$^2$ and the breaking load was 3209 N with a nominal breaking stress of 31.82 N/mm$^2$.

Load v/s Deformation graph of Duraform PA specimen 1.

The maximum displacement observed was 28.5 mm at the load of 3209 N

![Load v/s Displacement graph of Specimen 1 of Duraform PA/Nylon](image)

**Figure 20:** Load v/s Displacement graph of Specimen 1 of Duraform PA/Nylon

**Calculations of Specimen 2:**

- Initial gauge dia ($D_0$) = 11.33mm
- Initial gauge length ($L_0$) = 196 mm
- Initial gauge area ($A_0$) = 100.82 mm$^2$
- Initial overall length ($L_1$) = 300mm
- Final gauge dia ($D_u$) = 11.03 mm
- Final gauge length ($L_u$) = 224.6 mm
- Final gauge area ($A_u$) = 95.55 mm$^2$
- Final overall length ($L_2$) = 328.6 mm

Area $A = \frac{\pi D_u^2}{4}$ mm$^2$

Stress $\sigma = \frac{F}{A}$ N/mm$^2$
Strain \( \epsilon \)  
\[ \epsilon = \frac{L - L_0}{L_0} \]

Yield Stress \( \sigma_y \) 
\[ \sigma_y = \frac{F_y}{A} \text{N/mm}^2 = \frac{1536}{100} = 15.23 \text{ N/mm}^2 \]

Ultimate Stress \( \sigma_u \) 
\[ \sigma_u = \frac{F_u}{A} \text{N/mm}^2 = \frac{3088}{100} = 30.62 \text{ N/mm}^2 \]

Nominal Breaking Stress \( \sigma_v \) 
\[ \sigma_v = \frac{F_v}{A} \text{N/mm}^2 = \frac{3111}{100} = 31.86 \text{N/mm}^2 \]

True Breaking stress \( \sigma_{Bt} \) 
\[ \sigma_{Bt} = \frac{F_{Bt}}{A} \text{N/mm}^2 = \frac{336}{100} = 33.6 \text{ N/mm}^2 \]

Stress v/s Strain graph of Duraform PA specimen 2

![Stress v/s Strain graph of Duraform PA](Image)

**Figure 21:** Stress v/s Strain graph of Specimen 2 of Duraform PA

The observed yield load was 1536 N, the yield stress was 15.23 N/mm\(^2\). The ultimate load was 3088 N, the ultimate stress was 30.62 N/mm\(^2\) and the breaking load was 3211 N with a nominal breaking stress of 31.86 N/mm\(^2\).

Load v/s deformation graph of Duraform PA specimen 2

The maximum displacement observed was 28.6 mm at the load of 3211 N

![Load v/s deformation graph of Duraform PA](Image)

**Figure 22:** Stress v/s Strain graph of Specimen 2 of Duraform PA
Fractured tensile test specimen of duraform PA/Nylon part

![Figure 23: Nylon material after break](image)

The SEM analysis of the accura 60 specimen subjected to tension test was done on the part where actually the fracture occurred due to breaking load and as shown in figure 24.

![Figure 24: SEM image taken on the fractured surface at 1180x magnification](image)

From the SEM analysis on the fractured surface of the Nylon tensile test specimen, the fracture of bonding between the sintered powder parts was seen at a magnification of 1180x.

The table 2 gives the detail tensile properties of the test materials.

**Table 2: Comparison of tensile properties of Accura 60 v/s Duraform PA/Nylon powder**

<table>
<thead>
<tr>
<th>Material</th>
<th>Specimen no.</th>
<th>Tensile Test values of Accura 60 and Nylon</th>
<th>Experimental Values</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Failure Load N</td>
<td>Yield Stress N/mm²</td>
</tr>
<tr>
<td>Accura 60</td>
<td>1</td>
<td>6825</td>
<td>15.82</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>6832</td>
<td>15.79</td>
</tr>
<tr>
<td>Duraform PA/Nylon</td>
<td>1</td>
<td>3209</td>
<td>14.33</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>3211</td>
<td>15.23</td>
</tr>
</tbody>
</table>
C. **Compression Test of SLA Accura and SLS Nylon Materials**

The compression testing of the materials are carried out on an Aimil Mu CTM to find out the failure load, failure stress and peak stresses of the SLA and SLS built materials.

**Table 3: Comparison of Compressive properties of Accura 60 and Duraform PA/Nylon**

<table>
<thead>
<tr>
<th>Material</th>
<th>Specimen no.</th>
<th>Experimental Values</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Failure Load N</td>
<td>Failure Stress N/mm²</td>
<td>Peak Stress N/mm²</td>
<td></td>
</tr>
<tr>
<td>Accura 60</td>
<td>1</td>
<td>18550</td>
<td>92.28</td>
<td>199.2</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>18558</td>
<td>92.94</td>
<td>199.7</td>
</tr>
<tr>
<td>Duraform PA/Nylon</td>
<td>1</td>
<td>10141</td>
<td>50.44</td>
<td>309.6</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>10146</td>
<td>51.06</td>
<td>308.9</td>
</tr>
</tbody>
</table>

The compression test Accura 60 material gave the record that for specimen 1 it was having a failure load of 18550 N and a failure stress of 92.28 N/mm². Similarly for specimen 2 of Accura material was having a failure load of 18558 N and failure stress of 92.94 N/mm².

The compression test Duraform PA/Nylon material gave the record that for specimen 1 it was having a failure load of 10141 N and a failure stress of 50.44 N/mm². Similarly for specimen 2 of Accura material was having a failure load of 10146 N and failure stress of 51.06 N/mm².

The load distributions of the specimens were shown in figure 25.

![Figure 25: Compressive load](image-url)
The test specimen photographs were taken after the failure occurred and is as shown in figure 26.

![Figure 26: Specimens after Test](image)

The SEM Image analysis was done on the parts of both Accura 60 and Duraform PA/Nylon where actually the buckling occurred.

![Figure 27: SEM image of Accura 60 compressed material](image)

![Figure 28: SEM image of compressed Nylon material](image)

D. Hardness Test

Most preferable Hardness testing equipment for polymeric materials is the Brinell’s Hardness Testing Machine; hence both the materials were subjected to hardness test on Brinell’s Hardness testing machine.
TABLE 4: Hardness test

<table>
<thead>
<tr>
<th>Material</th>
<th>Specimen no.</th>
<th>Hardness BHN</th>
</tr>
</thead>
<tbody>
<tr>
<td>Accura 60</td>
<td>1</td>
<td>86</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>85</td>
</tr>
<tr>
<td>Duraform PA/Nylon</td>
<td>1</td>
<td>73</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>75</td>
</tr>
</tbody>
</table>

The chart of hardness in BHN of the materials are shown in the figure 29

**Figure 29:** Hardness in BHN

**IV. CONCLUSION**

Though, the process of fabrication is different in both SLA and SLS i.e., SLA is of liquid form fabrication process and the SLS is of powder form fabrication process, the technique here was to compare the mechanical properties of the materials fabricated through these processes. During the tests both the materials displayed an anisotropic behavior and the results are concluded as follows.

(a) Tension tests indicate that the ultimate and yield strengths are the largest for the SLA built accura 60 material.

(b) The compression test data indicates that the SLA built accura 60 specimens are stronger than the SLS built Duraform PA/Nylon specimens, and it can be observed from the Figure 5.19 that even though both the specimens undergone buckling the degree of buckling was higher in SLS built nylon specimen.

(c) The BHN hardness shows that the hardness of SLS built Duraform PA/Nylon specimen is significantly weaker than the SLA built accura 60 specimen.

(d) From all the above mechanical property testing concluded that the results obtained were approximately equal to the theoretical values in the Table and SLA accura 60 specimen is having good mechanical properties than the SLS Duraform PA/Nylon specimen even though they have some similar physical properties like brittleness and toughness.

The results of this project was useful in defining the most appropriate material irrespective of their fabricating process that can be used in industrial application or in any fit and functional AM/RP components on the basis of their service requirement. Results are also useful to benchmark future analytical or computational models of SLA and SLS using strength or stiffness as a function of varying density.
V. REFERENCE


VI. BIOGRAPHY

Vikas C M is currently working as a Asst. Professor in Srinivasa Institute of Technology, Mangalore. He pursued his M.Tech graduation in the stream of Computer Integrated Manufacturing from PES College of Engineering, Mandya (An autonomous institute affiliated to VTU Belgaum). He had received his Bachelors of degree in Mechanical Engineering from Adichunchanagiri Institute of Technology, Chikmagalur, Karnataka, India. His area of interest includes Rapid Prototyping, Robotics, CAD/CAM, Automation, FMS, Manufacturing Process, Metrology, etc.