Experimental Evaluation of the best Orientation of Taper Plug to Minimize Support Material Required in 3D printing (FDM)

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Abstract - In the process of completing the Design of any machine Component, Prototyping or realistic Model Making is very important step. This process is useful to develop and improve the concept of a design. It is general procedure to fabricate a prototype and to test it, before the starting of the actual manufacturing. 3D printing or Rapid Prototyping is a generative or Additive Manufacturing method. This process is unlike metal machining, forming or subtractive processes such as turning, milling, grinding, or press work, etc., in which removal of excess material or metal deformation in the plastic state, is responsible for the shaping of the form of the work piece. In 3D printing process, a component is produced by adding of material by layers. This 3D printing technology is practically applied in various sectors such as Automobiles, Defense, Aero space technology, Ship Building, Bio-Medical applications, etc., The component is constructed by the material deposition in the form of layers which is shaped in a (x-y) plane two dimensionally in Fused Deposition Modeling process. FDM is one process in 3D printing Technology. Also, (z), third dimension is resulted from single layers being stacked up on the top of one by one. In the present experimental work, V 5 CATIA R 20 software is used to generate the 3D - CAD model for Taper Plug component, which consists of a base plate and taper plug. A number of components are produced by conducting several experiments on 3D printing FDM machine. Also, by changing the orientation of the component with respect to the X- axis, the actual components are produced. Every time, the requirement of the support material is noted. In order to fabricate the Taper Plug component with the condition of minimum requirement of support material, the Optimum or Best Orientation is experimentally evaluated.

Keywords: 3D Printing; FDM; Layer Resolution; Catalyst Software; CATIA V 5; Support Material

1. INTRODUCTION

In the recent times, many manufacturing organizations are widely using digital prototyping in different areas for product development. After the
addition, the component also has to undergo various operations on milling machine, under many orientations of the component, to get the square shape and aero gels [4].

1.1 Scope for Silicon di-Oxide as reinforcement

In this research work, Silicon di-Oxide has been chosen as reinforcement. The so chosen Silicon di-Oxide is measured to be of 53 µm in its average size. Whilst imaging under Scanning Electron Microscope, the Silicon di-Oxide exhibits from Cuboids to Sub-round in geometrical appearance. This geometry is very vital in occupying the lobules in-between the reinforcement material, here in this case Aluminum. The final structure after the Metal Matrix formed would give a viable material for applications which demands greater mechanical properties, automotive parts for instance. The Fig. 1 below shows the structure of SiO$_2$ particles captured under Scanning Electron Microscope, that being taken under a Magnification of 500x. The Fig. 1 shows the Scanning Electron Microscope utilized for this work which could produce an output resolution of 3 nm at 30 kV HV mode, 10 nm at 3k V HV model.

![Fig. 1 Pictorial view of SEM](image)

In the present experimental work, a large number of experiments are performed under different orientations of the taper plug component on the work table; to reduce or minimize the quantity of the support material.

2. 3D PRINTING PROCESS

2.1 Principle

A number of methods are available in 3D printing process. FDM is the abbreviation for Fused Deposition Modeling. After Stereo Lithography, this is the important technology extensively used practically. The product in FDM is built up in several thin layers. These layers are comprised with thermo plastic wire like filaments. Here, we do not use liquid photo polymers, powders and lasers.

2.2 Process Description

In FDM process, thermo plastic filament wire is electrically heated in a nozzle and it is extruded from a tip that moves in the x- y plane. To deposit the first layer on to the build platform, very thin beads of material are deposited by the controlled extrusion head. In order to achieve quick hardening of the thermo plastic material, low temperature is maintained at the platform.

As shown in Fig. 2, the extrusion head deposits a second layer upon the first layer, after the platform lowers. Supports are built along the way, fastened to the part. This is done either with a second weaker material or with a perforated junction. Many types of build materials are available viz., A B S (Acrylonitrile Butadiene Styrene), Elastomer (96 durometer), P L A (Poly Lactic Acid), Poly carbonate, Polyphenol sulfone and Investment casting wax. A B S offers good strength. More recently Poly carbonate and Poly (phenyl) sulfone materials have been introduced which extends to the improved capabilities of the method further in terms of strength and temperature range. Support material is same as the above materials, but with a lesser grade, which will melt at a lesser temperature, and which will react chemically with some type of liquids. Support structures are fabricated for overhanging geometries. These are removed by breaking them away from the object at the end. Also, water soluble materials are available to remove the support materials.

![Fig. 2 Working Principle of FDM](image)

As the nozzle of the 3D printing machine is moved over the work table in the specified geometry under computer control, a thin bed of extruded plastic is deposited to from every layer. Immediately, the plastic is hardened after being released from the nozzle and sticks to the layer below. The total process is contained within a chamber which is maintained at a temperature just below the melting point of the plastic.

2.3 Fused Deposition Modeling Process

FDM method is very simple and operator friendly and the working of the machine are very less noisy and accurate. In order to produce small components, FDM machine operation is quick. Also, for the parts that have tall and thin sections, FDM is very useful. For the components with wide cross sections, FDM process may be slow.

2.4 Advantages of FDM Process

The advantages of FDM process are furnished below: uneconomical and quick fabrication of the Components ii.Various Colors are available iii. Safe
working environment in FDM; and toxic chemicals, lasers or liquid polymer bath are eliminated iv. Material is not wasted during or after production of the model v. Materials can be changed at a faster rate.

2.5 Disadvantages of FDM process

The disadvantages of FDM process are listed below: i. Restricted accuracy due to the shape of the material used. ii. Supports may be required iii. Strength of the part is weak perpendicular to the build axis iv. If there are differences or changes in the temperature during production, they will result in delaminating.

2.6 Applications of FDM Process

3D Printing process (FDM) or Additive Manufacturing finds wide application in Defense, Research Organizations, Machine Tools Industry, Aerospace Technology, Automotive Companies, Biomedical applications such as bone and teeth making, etc., FDM process has wide range of engineering applications: i. Model for operation and functional part testing ii. Design model for assessing the final appearance and geometry of complex parts iii. After assembling all the individual components in a machine, the correctness in the working can be found. iv. FDM process finds application in Injection Molding and Investment Casting.

3. STATEMENT OF THE PROBLEM

To investigate experimentally and evaluate the minimum support material requirement for the component of Taper Plug, to fabricate in different build orientation angles such as $0^\circ$, $30^\circ$, $60^\circ$ and $90^\circ$ with respect to the x-axis. Other FDM process factors such as Layer Thickness (0.01") Support material Fill type (Smart), Model Interior (Sparse High Density) are kept constant for the entire experimental work and fabrication of the Taper Plug component. Due to the increasing complexity of the components and types of the build materials and support materials; that is being used for the FDM process, there occurs the problem of the cost of the materials. This directly relates to the increase in the overall operational costs. If the support material is more, it results in excess electrical power consumption. Also, it leads to thermal wear on the machine. In addition, the time taken for the post processing operations of the complex components is increases. This support material concept has direct relation to the manufacturing cost, maintenance cost and also results in more time consumption.

4. RESULTS AND DISCUSSION

The Taper Plug component is designed using CATIA V 5, as shown in Fig. 3. The CAD model of the Taper Plug component is converted into .stl file format. It is loaded into CATALYST V 4.2 interface software of STRATASYS Dimension 1200 ES 3D Printing (FDM) machine, USA make, as shown in Fig. 4.

![Fig. 3 CAD model of Taper Plug.](image)

CATALYST software does interface work and it transfers CAD data into the printer readable language by slicing the CAD model into thin slices as per the defined layer thickness. Experiments are conducted on this FDM machine with different orientation angles of the Taper Plug component, for the estimation of minimum requirement of the Support Material.

![Fig. 4 STRATASYS Dimension 1200 ES 3D Printing machine (FDM).](image)

The Taper Plug component is shown in different build orientation angles as mentioned below:

$0^\circ$, $30^\circ$, $60^\circ$, $90^\circ$

The CAD model of the Taper Plug component in $0^\circ$ is shown in Fig. 5.

![Fig. 5 CAD model of the Taper Plug in $0^\circ$.](image)

The CAD model after slicing for the Taper Plug in $0^\circ$ is shown in Fig. 6.
Fig. 6 CAD model after slicing in $0^\circ$ orientation

Here, red colour indicates model or build material. Blue colour indicates the support material. The CAD model of the Taper Plug component in $30^\circ$ is shown in Fig. 7.

Fig. 7 CAD model of the Taper Plug in $30^\circ$ orientation

The CAD model after slicing for the Taper Plug in $30^\circ$ is shown in Fig. 8.

Fig. 8 CAD model after slicing in $30^\circ$

The CAD model of the Taper Plug component in $60^\circ$ is shown in Fig. 9.

Fig. 9 CAD model of the Taper Plug in $60^\circ$ orientation

The CAD model after slicing for the Taper Plug in $60^\circ$ is shown in Fig. 10.

Fig. 10 CAD model after slicing in $60^\circ$

The CAD model of the Taper Plug component in $90^\circ$ is shown in Fig. 11.

Fig. 11 CAD model of the Taper Plug in $90^\circ$ orientation

The CAD model after slicing for the Taper Plug in $90^\circ$ is shown in Fig. 12.

Fig. 12 CAD model after slicing in $90^\circ$

In each experiment, the support material is obtained after fabrication of the Taper Plug component. The results are shown in Table 1.

Table 1 Variation of Support material with different build orientation angles for Taper Plug

<table>
<thead>
<tr>
<th>S. No.</th>
<th>Build Orientation Angle (degree)</th>
<th>Vol. of Support Material (in$^3$)</th>
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<tbody>
<tr>
<td>1</td>
<td>0</td>
<td>0.10</td>
</tr>
<tr>
<td>2</td>
<td>30</td>
<td>0.32</td>
</tr>
<tr>
<td>3</td>
<td>60</td>
<td>0.75</td>
</tr>
<tr>
<td>4</td>
<td>90</td>
<td>0.29</td>
</tr>
</tbody>
</table>
A graph is drawn to show the variation of Support material with different build orientation angles for Taper Plug, as shown in Fig. 13.

Fig. 13 Graph between volume of the Support Material versus the build Orientation Angle for Taper Plug.

5. CONCLUSION

From the experimental investigation after the fabrication of the Taper Plug component, it is concluded that Zero degree build orientation angle yields the minimum Support Material requirement when compared to the other angles. The observed Support Material requirement in the Zero degree build orientation angle for the Taper Plug component fabricated by Fused Deposition Modeling technology is 0.10 inch$^3$.

REFERENCES


