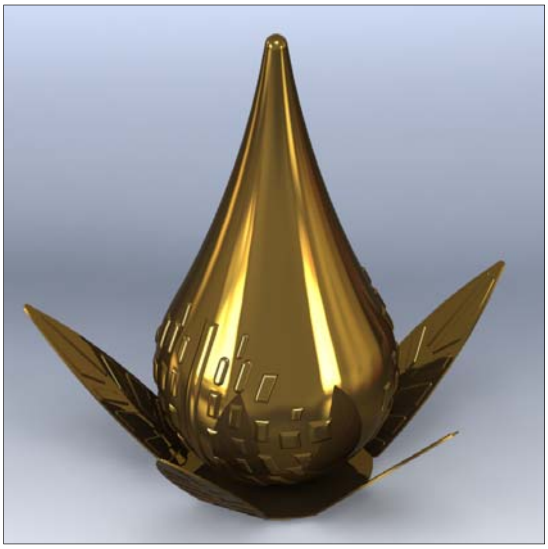
ME3263 TERM ASSIGNMENT

DESIGN AND FABRICATION USING ADDITIVE MANUFACTURING PROCESS

SELECTIVE LASER SINTERING (SLS)



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1. INTRODUCTION

This report highlights the decision-making process and important parameters involved in fabrication of a rapid prototype. Firstly, an overview of the prototype CAD model is presented. Following this, based on certain key factors, it is noted why Selective Laser Sintering (SLS) is chosen as the appropriate RP process for fabrication of the model. Lastly, the report addresses three key parameters that affect the fabricated part – build orientation of the model, build time and estimated cost of building the prototype.

2. 3D MODEL OF ‘KALASH’

The 3D model being analyzed in this report is ‘Kalash’. This CAD model was designed using SolidWorks software. Detailed views and designs of the CAD model are illustrated in Appendix A.

‘Kalash’ is used as a decorative motif in Indian art. It is usually made of metals like bronze, copper, silver and gold. It comes in various designs, sizes, patterns and finishes. In this report, the prototype of ‘Kalash’ to be fabricated using RP process needs to adhere to the following properties and objectives –

- The RP prototype will be further used as pattern for investment casting.
- The prototype has a smooth surface finish.
- The size of the prototype is such that it fits in a 20 cm by 20 cm cuboid.

3. RP PROCESS SELECTION

The main objective is to create a pattern for investment (metal) casting. The RP processes which can be used to create such patterns include Stereolithography (SLA), Selective Laser Sintering (SLS), Fused Deposition Modeling (FDM), 3D Printing (3DP) and Multi-jet Modeling (MJM).

From the above-mentioned processes, SLS process is chosen to build the prototype of 'Kalash'. The factors that were considered and evaluated in reaching the decision are as follows –

a) Speed of process: High speed is not necessary since a small quantity of parts are needed as patterns for the secondary casting process. Large quantity of product will be created from the patterns through investment casting.

b) Accuracy: A good accuracy is desired since it is important that the patterns produced have tighter tolerances and hence, are consistent in their design. Parts made by 3DP have low accuracy and might be unable to develop the small feature design patterns as illustrated in the figures in Appendix A.

c) Support structures: The part being produced has a complex geometry and requires many support structures when orientated in any direction. FDM, SLA and MJM processes requires support structures to support the overhanging parts and features. As observed from the CAD model figures in Appendix A, more than half of the model will require support structures in any of the orientations illustrated. Moreover, due to its internal geometrical features, it would be difficult to remove the support structures. Although, with MJM, the support structures can be easily removed or 'washed' away using a water jet, the surface finish will be affected due to the presence of many support structures or polishing will be required after the support structures have been washed away. With SLS process, the part can be built without the need for support structures as each layer or the part is supported by the powder material used in its fabrication. As for the surface finish, the part can be polished or painted to obtain a smooth surface.

d) Cost: While 3DP and MJM machines are priced low, they are unable to satisfy the requirements for the part fabrication. SLS systems are expensive; however, casting companies can outsource the fabrication of prototypes via RP service bureaus since large quantity of prototype are not required.

The following section evaluates key parameters involved in the fabrication of the part by SLS.

4. KEY PARAMETERS

In SLS, four major parameters affect quality of the part – part orientation, powder properties, laser beam and the machine operation. In this report, the focus is on optimal part orientation. The aforementioned parameters affect other secondary parameters such as the build time and the related cost of producing the part. It is important to estimate these secondary parameters for scheduling reasons and for evaluating the optimal RP process for part fabrication.

4.1. BUILD ORIENTATION

The main objectives for optimal part orientation considered in this report are minimum build height and hence, minimum build time, and, minimum surface roughness for the diamond-shaped feature in the center.

Firstly, the minimum height is obtained by rotating the prototype model at regular angles of about 5 degrees about x- and y-axis. The minimum height for the 'Kalash' model was obtained as depicted in figure 3 of Appendix A.

Secondly, based on experiments conducted on a diamond-shaped model using various algorithms[1], it is inferred that the orientation giving the minimum surface roughness for the conical feature in 'Kalash' satisfies the orientation shown in the figure above, that is, the orientation determined for achieving minimum height. Figure 4 in Appendix A shows the optimal orientations obtained using the algorithms for minimum build time and minimum surface roughness for diamond-shaped prototype.

4.2. BUILD TIME

One possible estimation for the build time can be formulated based on the steps involved in SLS process[2] –

$$T_i = T_p + \frac{A_i}{v_{laser} D}$$

where T_i = time to build *i*th layer

T_p = powder spreading time,

A_i = cross-sectional area of *i*th layer

v_{laser} = x-y speed of the laser

D = diameter of the laser beam

Therefore, the time to build the entire prototype is[2]:

$$T_b = \sum_{i=1}^{i=n} T_i$$

$where\ n = number\ of\ layers$

The build time for 'Kalash' prototype is estimated to be 7 hours. The detailed calculation for the build time is shown in Appendix B.

4.3. ESTIMATED COST

The fabrication cost consists of four parameters[3] –

a) **Material Cost**: $C_{mat} = P_{mp}V_{part}$, where P_{mp} is unit cost of material and V_{part} is the volume of part.
b) **Machine Running Cost**: $C_b = r_b T_b$, where r_b is the machine running rate
c) **Cost in Data Preparation Stage**: $C_{pre} = (w_0 + w_{cp})T_{pre}$, where T_{pre} is the preparation time, w_0 is the hourly operator wage and w_{cp} is the computation cost rate
d) **Cost in Post Processing Stage**:

$$C_{post} = T_{cleaning}\gamma_1 + T_{post\_cure}\gamma_2 + T_{polishing}\gamma_3 + T_{post}w_0$$

$$T_{post} = T_{cleaning} + T_{post\_cure} + T_{polishing}$$

where γ_1, γ_2 and γ_3 are the hourly charge rates for cleaning, post curing and polishing tasks respectively.

The total fabrication cost is thus given by

$$C_f = C_{mat} + C_b + C_{pre} + C_{post}$$

APPENDIX A

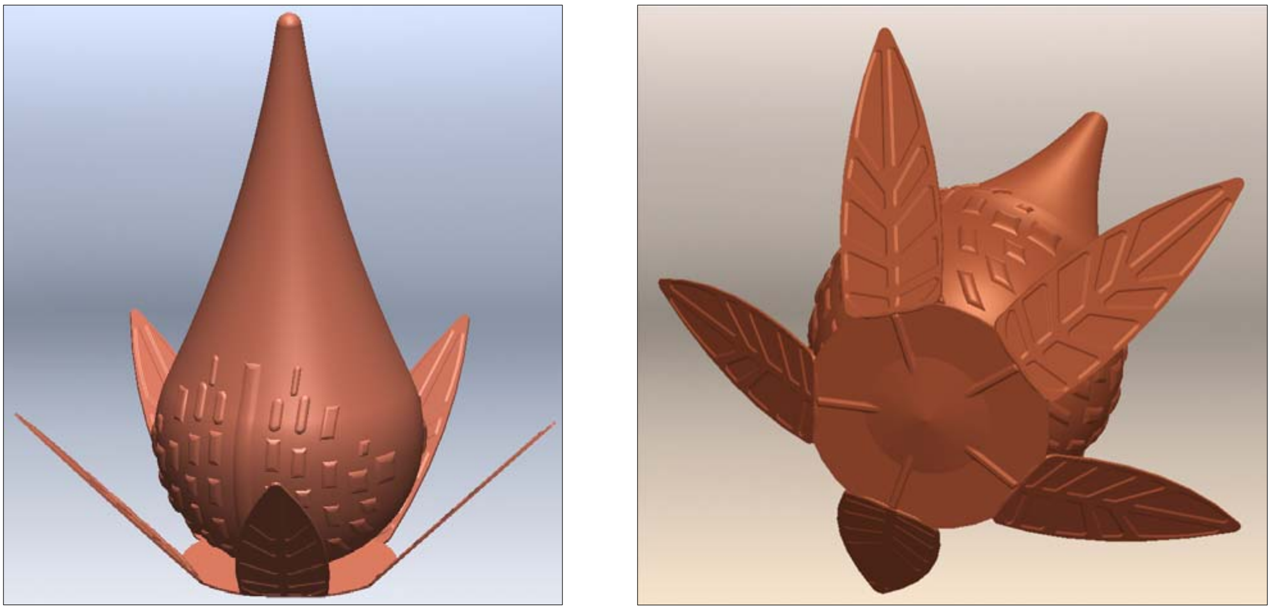

Figure 1: ‘Kalash’ model designed using SolidWorks

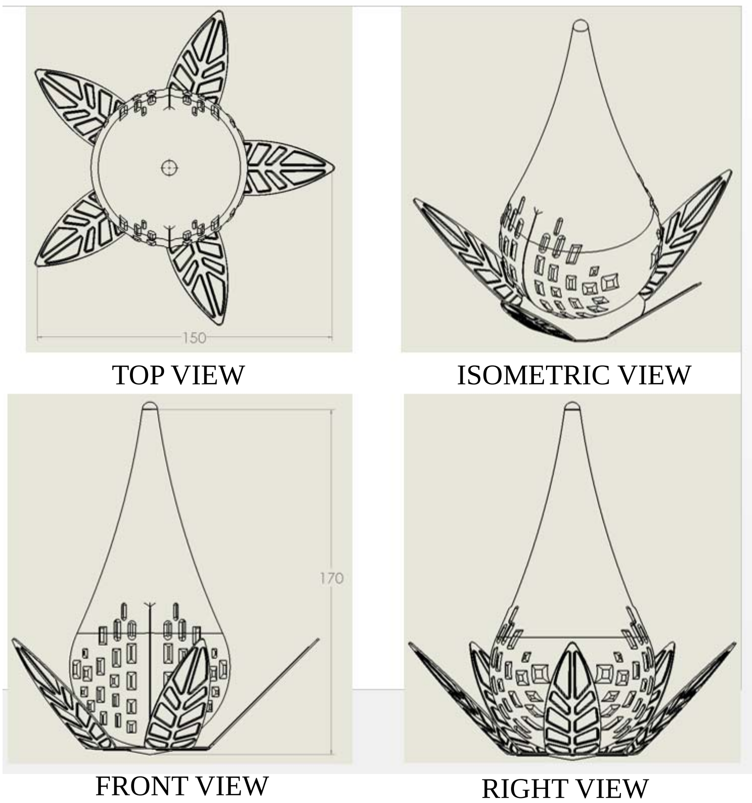

Figure 2: Drawing of the ‘Kalash’ model depicting the four major views

(All dimensions in mm)

APPENDIX A

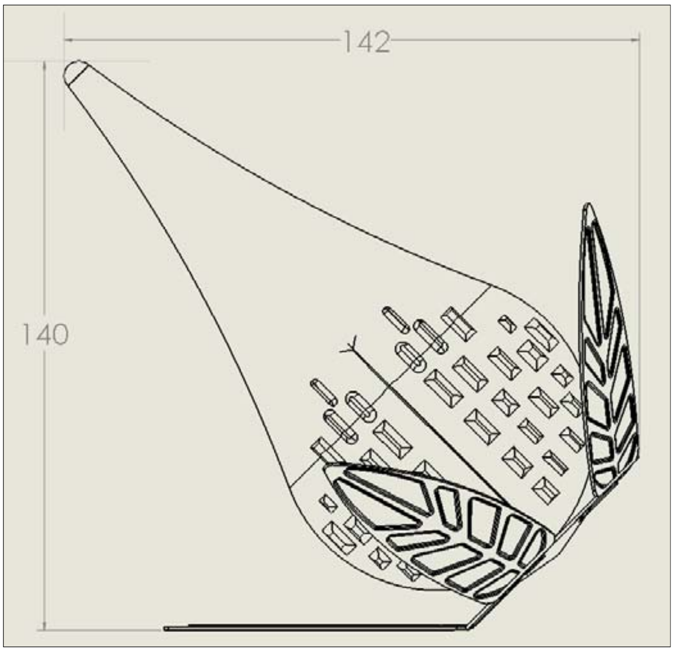

Figure 3: Drawing depicting the minimum build height orientation

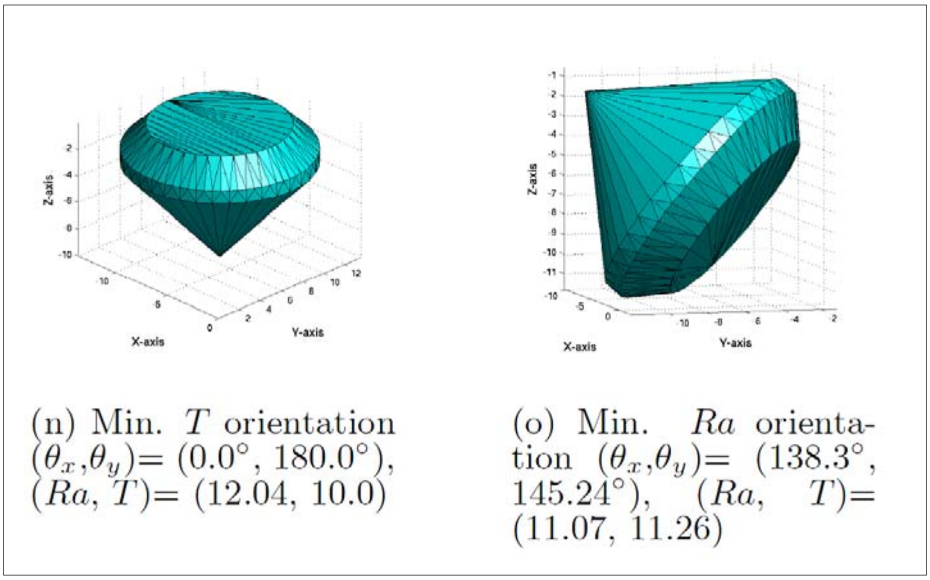

Figure 4: Optimal orientations for a diamond-shaped model; *Left:* Minimum build time orientation; *Right:* Minimum surface roughness orientation[1]

APPENDIX B

Parameter	Value
Powder Spreading time, T_p	10 s
Approximate cross-sectional area of i^{th} layer, A_i	142 X 150 X 0.5 mm^2
Laser/scan speed, v_{laser}	7500 mm/s
Lease beam diameter, D	0.47 mm
Build height, h	140 mm
Layer thickness, t	0.076 mm

Table 1: Various parameters and their values [a]

Time to build one layer is given as follows:

$$T_i = T_p + \frac{A_i}{v_{laser}D}$$

$$= 10 + \frac{142 \times \frac{1}{2}(150)}{(7500)(0.47)}$$

$$= \ 13.02\ s$$

Hence, the total build time is given as

$$T_b = \sum_{i=1}^{i=n} T_i$$

$$\therefore \quad T_b \approx n(T_i)$$

$$= \frac{h}{t}(T_i)$$

$$= \frac{140}{0.076}(13.02)$$

$$= 2.4\ \times 10^4\ s$$

$$\approx 7\ hrs$$

[a] The values for the various parameters were obtained based on 3D Systems Vanguard™ si2™ SLS® System[4].

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