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Influence of layer thickness on part quality in SLA process by TOPSIS method

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ABSTRACT

Stereolithography is one of the Rapid Prototyping technologies, useful for time-compression of the product development cycle. The part characteristics of SL product are essential for the intended functional applications. The parameters are layer thickness, orientation, Post curing, hatch spacing and over cure. The study is conducted on test samples of SL5530 which were built on SLA 5000 machines and tested under ASTM specified test conditions. This study is to investigate the influence of layer thickness on part quality by using the TOPSIS method. The results show that the optimal layer thickness which influences the part quality is 50 microns.

Introduction

In a customer driven market, every manufacturer wants to produce their products in a very short span of time. This is a prerequisite for survival in the global market. Decrease in product development cycle time and increase in product complexity require new ways to realize innovative ideas. In response to these challenges, a spectrum of new technologies has been evolved to develop new products and to broaden the number of product alternatives. One such technology is Layered Manufacturing, which produces parts by deposition of material, layer by layer. Today the key benefits of Layered Manufacturing are mostly derived from its ability to create physical models directly from CAD models, regardless of their shapes and complexities. Among the various layered manufacturing processes, SLA (Stereolithography) is being recognized as an innovative technology, it still cannot be fully utilized in tooling applications since it lacks in part quality characteristics (surface finish, dimensional accuracy, form feature accuracy in terms of parallelism / perpendicularity / included angle/out off roundness, curl and distortion) when compared to conventional processes. In this paper an attempt has been made to identify the influence of layer thickness on the parts made by SL, one of the processes used for rapid tooling. The figure 1 represents the overview of SLA process in which intricate parts of a plastic monomer are directly built by photo polymerization process with the model constructed using a computer Aided Design (CAD) package [1]. A Various process parameters affect the SLA process Part Quality Characteristics. Diana et. al [2] identified more than fifty process parameters that induce errors and affect part accuracy and surface finish. There are three kinds of parameters in SLA: Part Parameters, Support Parameters & Recoat parameters, among which part parameters are the most important ones that affect the part quality of built parts in SLA Process [3, 4]. Part quality in the rapid prototyping process is a function of the build parameters such as Layer thickness, Orientation, Post curing, hatch spacing / fill spacing, hatch over cure, hatch cure depth and Part Characteristics. The Part characteristics can be divided into part physical characteristics and Mechanical characteristics. The part physical characteristics are surface finish, dimensional accuracy and distortion. Whereas, Mechanical characteristics are Flexural Property, Ultimate Tensile strength and Impact strength [5]. The figure 2 shows the probable parameters (Causes) that influences the Part Quality Characteristics (effects) in the SLA Process.

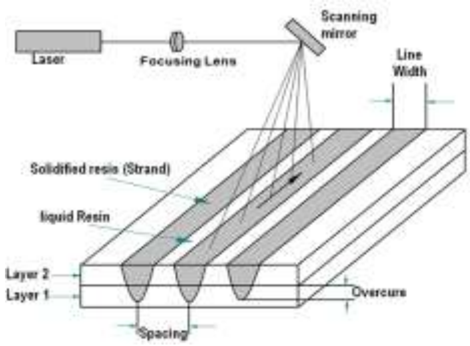

Fig 1: Detailed view of SLA process

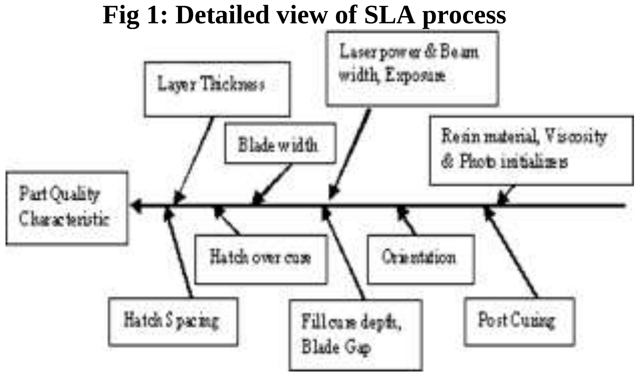

Fig 2. Cause and effect diagram for SLA process

Experimental Description

3D system's SLA 5000 is used in fabricating the SLA parts. The system has both hardware and software parameters, which can influence the mechanical strength. The Stereolithography material resin SL5510 is used to produce the ASTM standard

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specimen models. The three values of layer thickness i.e., 50µ, 100µ & 150µ where build for each mechanical property. The models were modeled by using 3D CAD software - CATIA, which is then converted into the STL file which is a generalized input format for the RP Machines. The built in software of RP machines - 3D light year software is used for STL verification, Orientation, generation of support structure & slicing. A fine / Curtain point support is used to construct the models which impose the high surface finish. After processing the sequential steps in the 3D light year software, the models were fabricated by varying the layer thickness by placing them horizontally in XY direction for high strength [6]. The layer thickness of the material is varied and the test parts are built. Post curing duration is kept constant to 60 minutes.

Tensile Test

The tensile test is carried out on the universal testing machine. The three values of layer thickness (50,100 and 150 micron) were chosen and the tensile test specimens build as per ASTM D638 – 03 specification of Type –I.

Flexural Test

The flexural property of the test piece of 9.6x13x191 mm which was build with L/d ratio 16 to 1 as per ASTM D 790, was subjected to a point load by means of a loading nose mid way between the supports which were kept away between 160 mm apart. The flexural test is carried out on the universal testing machine, the three values of layer thickness (50,100 and 150 microns) are chosen and the flexural strength at fracture was calculated for the simply supported beam with concentrated load at the centre by the equation 1.

$$S = 3PL/2bd^2 \quad (1)$$

Impact Test

The notched specimen for pendulum impact resistance test was built as per the ASTM standard D256 - 04 for the izode impact tester. Thus the impact strength per unit width is then calculated by dividing the energy absorbed by the specimen during the breaking across the cross section by the width of the specimen

Crystallographic orientation (Density Anlaysis)

The easiest way to know the discrepancy of the crystallographic orientation is density method and this discrepancy is the major factor for the variation in the mechanical property. The density of a component can be found from the formula given below

Density of a component = {Weight of the component in air / (weight of component in air – weight of component in water)}

The influence of Layer thickness over the Tensile, Flexural and Impact strength with its crystallographic orientation is tabulated as shown in table 1.

Table 1: Test results with varying Layer thickness

Layer Thickness	TEST RESULTS			
	Tensile strength (N/mm^2)	Flexural Strength (N/mm^2)	Impact Strength (J/m)	Density Analysis
50µ	75.013	206.85	29.4	1.2295
100µ	72.326	149.84	34.2	1.2186
150µ	70.559	174.12	25.25	1.2324

Topsis Method

TOPSIS (Technique for order preference by similarity to an ideal solution) method is presented in Chen and Hwang [7], with reference to Hwang and Yoon [8]. TOPSIS is a multiple criteria method to identify solutions from a finite set of alternatives. The basic principle is that the chosen alternative should have the shortest distance from the positive ideal solution and the farthest distance from the negative ideal solution [9]. A positive ideal solution maximizes the benefits criteria or attributes and minimizes the cost criteria or attributes, whereas a negative ideal solution maximizes the cost criteria or attributes and minimizes the benefit criteria or attributes [11]. The TOPSIS method is expressed in a succession of six steps as follows:

Step 1: Calculate the normalized decision matrix. The normalized value r_{ij} is calculated as follows:

$$r_{ij} = \frac{x_{ij}}{\sqrt{\sum_{i=1}^{m} x_{ij}^2}} \quad i = 1, 2, \ldots m \text{ and } j = 1, 2, \ldots \ldots n. \quad (2)$$

Step 2: Calculate the weighted normalized decision matrix. The weighted normalized value V_{ij} is calculated as follows:

$$V_{ij} = r_{ij} * W_j \quad i = 1, 2, \ldots m \text{ and } j = 1, 2, \ldots n \quad (3)$$

Where W_j is the weight of the j^{th} criterion or attribute and $\sum_{j=1}^{n} W_j = 1$.

Step 3: Determine the positive ideal solution and negative ideal solution

$$A^+ = \{V_1^+, \ldots, V_n^+\} = \left\{\left(\max_j V_{ij} / i \in I\right), \left(\min_j V_{ij} / i \in j\right)\right\} (4)$$

$$A^- = \{V_1^-, \ldots, V_n^-\} = \left\{\left(\min_j V_{ij} / i \in I\right), \left(\max_j V_{ij} / i \in j\right)\right\} (5)$$

Step 4: Calculate the separation measures using the n-dimensional Euclidean distance. The separation measures of each alternative from the positive ideal solution and the negative ideal solution, respectively, are as follows:

$$S_i^* = \sqrt{\sum_{j=1}^{m} \left(V_{ij} - V_j^+\right)^2}, \quad j = 1, 2, 3, \ldots\ldots m \quad (6)$$

$$S_i^- = \sqrt{\sum_{j=1}^{m} \left(V_{ij} - V_j^-\right)^2} \quad (7)$$

Step 5: Calculate the relative closeness to the ideal solution. The relative closeness of the alternative A_j with respect to A^* is defined as follows:

$$RC_i^* = \frac{S_i^-}{S_i^+ + S_i^-}, i = 1, 2, \ldots \ldots m \quad (8)$$

Step 6: Rank the preference order .

Results

The study tests the relationship between the layer thickness and part characteristics in the stereolithography process. The layer thickness was identified as 50µ, 100µ and 150µ with four criteria which were established through test facilities: Tensile strength, Flexural Strength, Impact strength and Crystallographic orientation (Density Analysis) as shown in Table 1. Then the procedure of TOPSIS for interval number can be expressed in the following steps. We normalized the test results as shown in Table 2by using equation (2). All the above criteria have the same importance. In this study, we adopt the suggestion of Jahanshahloo et al. [10] and all the criteria are given a weighting of 0.25 for normalization. We used equation (3) to find the weighted normalized decision matrix shown in table 3.

Table 2: Normalized Matrix with layer thickness and evaluation criteria (Characterization of part)

Layer Thickness	Tensile strength (N/mm^2)	Flexural Strength (N/mm^2)	Impact Strength (J/m)	Density Analysis
50µ	0.5961	0.6692	0.5688	0.5551
100µ	0.5747	0.4847	0.6617	0.5501
150µ	0.5607	0.5633	0.4885	0.5564

The positive ideal (A^+) and negative ideal (A^-) solutions are determined using equation (4) and (5). The results are tabulated in the Table 4. The separation of each alternative solution is calculated using equations (6) and (7) and results are shown in table 5.

Table 3: Criteria weighting with 0.25

Layer Thickness	Tensile strength (N/mm^2)	Flexural Strength (N/mm^2)	Impact Strength (J/m)	Density Analysis
50μ	0.1490	0.1673	0.1422	0.1387
100μ	0.1437	0.1212	0.1654	0.1375
150μ	0.1402	0.1408	0.1221	0.1391

Table 4: Positive and negative ideal idea solution

Solution	Tensile strength (N/mm^2)	Flexural Strength (N/mm^2)	Impact Strength (J/m)	Density Analysis
Positive ideal	0.1490	0.1673	0.1654	0.1391
Negative ideal	0.1402	0.1212	0.1221	0.1375

Table 5: Measures of separation of each alternative solutions

S_{i1}^{*}	0.0232	S_{i1}^{-}	0.0510
S_{i2}^{*}	0.0464	S_{i2}^{-}	0.0434
S_{i3}^{*}	0.0515	S_{i3}^{-}	0.0196

The results of the ranking of approaches (Different Layer thickness) are derived using equations (8) and as shown in the table 6. The first alternative is considered as the best maximization of expected benefits for the manufacturer to obtain higher strength of the prototypes built through stereolithography process.

Table 6: Results of closeness coefficient and rank

Layer Thickness	RC_i^{*}	Rank
50μ	0.6873	**1**
100μ	0.4832	**2**
150μ	0.1369	**3**

Conclusions

This study found that the influence of layer thickness on the processing of prototypes by additive manufacturing which enhance the mechanical and physical characterization of the part quality. The ranking results by the TOPSIS method pointed out that the first alternative (50μ) is strategically optimum for the selection of layer thickness. The best options for the Tensile, Flexural, Impact and Density analysis is found to be with 50μ Layer thickness for processing the prototypes. The following study can strengthen the link between the rapid prototyping user and the rapid prototyping manufacturer through other approaches similar to the TOPSIS method.

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