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Parametric Optimization on fused deposition modeling

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Abstract

Rapid Prototyping (RP) or additive manufacturing uses layered manufacturing technique, in which layer by layer addition of the material is done under a controlled environment. The product manufacturing is done directly by using digital manufacturing where in CAD model of the product is used to process the file and then print the part using a 3D printer. In present work, Fused Deposition Modeling (FDM) was used to optimize the process parameters involved in the manufacturing the product. These parameters include build styles. The samples were further tested for their effect on the surface hardness, surface roughness and impact strength; then their significance during build was studied using paired t test; using Minitab and applied to a particular application. Upon conclusion, it has been seen that part build styles has no major effect on surface roughness. Minor variations were observed in the impact strength and surface hardness assessments.

Keywords: Rapid Prototyping, CATIA, Additive Manufacturing, FDM, Minitab.

I. INTRODUCTION

In modern era, using conventional methods for manufacturing products is time consuming and costly affair considering the recent scenario where interdependence has become the norm, not the exception, linking up countries with world class nations. The countries work for attaining the quality, developing new techniques to maintain the pace with the fellow competitors moving forward to upgrade their engineering and process capabilities [1, 2]. The competition on one product is such that you need to make changes in the aesthetic design as well as the functional aspect of the product; this is only possible when there are some new manufacturing methods [3]. Digital Manufacturing is employed to process directly three dimensional computer aided design (3D CAD) data and manufacture by using Additive Manufacturing (AM) [4, 5]. Layered Manufacturing (LM) or Additive Manufacturing is one in which material is added layer by layer till the height of the product is not reached [6]. The process time involved during the whole project may vary from few hours to few days as compared to the month's time in conventional methods. The accuracy achieved in this process is much higher and random errors are not included in final result as the machines or the 3D printers are calibrated to obtain the desired result; but still there is major difference seen in the mechanical properties of the products manufactured using various RP Technologies[7] Various technologies that cover the RP systems are stereo lithography (SL), selective laser sintering (SLS), laminated object manufacturing (LOM), fused deposition model (FDM), direct shell production (DSP), 3D Printing and a host of others already commercialized or in the developmental stage as discussed by onuh [8].

The aim of this paper is to compare the effect of part build orientation, build styles and rastor angle on mechanical Properties of the product i.e. surface hardness, surface roughness and impact strength. Additionally, a review has been presented on the effect of multi contouring and contour width on the mechanical properties for specimen under observation.

II. METHODOLOGY

The steps involved for conducting the above study are as mentioned below:

a. Sample Preparation
b. Converting 3D CAD data to standard triangulated language (STL) files
c. Processing the file using insight.
d. Connecting computer to the machine interface.
e. Printing the part in a Fused Deposition Modeling (FDM) Machine.
f. Post Processing of the build part.
g. Analysis of the Printed samples.
h. Analyzing the sample means using paired t test.

a. **Sample preparation:** The first stage of performing the analysis was to create a 3D CAD data which would be then processed further. Impact testing samples were designed using CATIA V5 r21, designing software. The samples were made in standards for plastics. ISO 180:1993 Plastics—Determination of izod impact strength of rigid materials were used to design the samples of given dimensions [5, 9]. Figure 1(a) and 1(b) shows the isometric view and design of the sample.

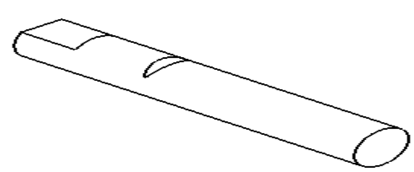

Figure 1 Isometric view of sample

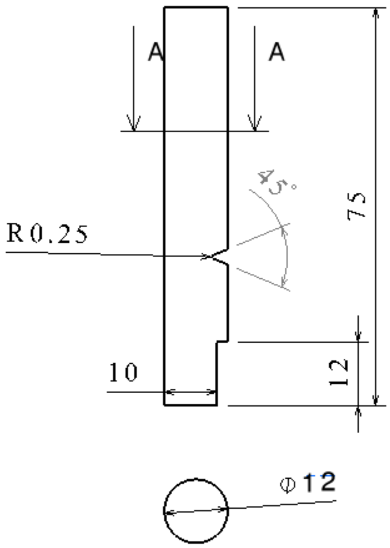

Figure 2 Design of sample for impact testing

b. Converting 3D CAD data to STL files: The CAD data created using modeling software is then converted to the STL files as FDM machine only uses STL files to process the data. Using the save as option in CATIA the 3D CAD data was converted to STL files.

c. Processing the file using Insight: The STL file fed to the Insight software is then processed. Insight here provides a common interface that combines FDM machine and the CAD Data. Relevant changes in the parameters are done here. The parameter which will be subjected to change here in this study was build styles.

In this case of sample preparation for impact testing, part build orientation showed only the variations in time required to build the sample as its effect is insignificant on the mechanical properties of the sample. Impact of build style was observed in the response parameters.

d. **Connecting computer to the machine interface:** Control center is the software that performs the virtual placement of the product on the worktable and analyzes the feasibility of the build. It shows you the amount of material which will be consumed in both model tip and support tip and the time required for the part to build. It connects the digital data to the FDM interface. Once the file is ready to be printed is sent to the machine, you can print the part. You can't change any previously defined parameter here in control center.

e. **Printing the part in a Fused Deposition Modeling Machine:** Once the file is received on the machine interface the build process can be manually initiated. Bounding box is defined where in which the part will be build. The job on the machine is started manually. The time taken by the machine to build is same as defined in Control Center.

f. **Post Processing of the build part:** the post processing of the sample involved washing the sample in an Agitation Tank where in a solvent dissolved the dissolvable Support material. The time required for post processing is majorly affected by the size of the sample, intricate shapes if any. After the post processing sample is dried and analysis was done on the sample

g. **Analysis of the Printed samples:** Analysis of the samples is done using the Vickers' Surface Hardness tester to check the micro surface hardness; surface roughness tester is used to test the surface roughness of the sample. And Izod test was performed to test the Impact strength.

h. **Analyzing the sample means using paired t test:** The data obtained from samples is checked for its significance using paired t test for each of the response parameters. If the p value came less than the confidence level, the test is significant otherwise not. Also, if the p value is greater than confidence level, null hypothesis is chosen in which sample means are considered equal.
If p value is less than confidence level then alternate hypothesis is selected in which sample are considered different.

Similarly, for multi contouring the testing of the sample is done on the surface roughness tester and micro hardness tester. Hardness was tested on Vickers scale (Hv).

III. RESULTS:

The data obtained from the samples is discussed below. Following trends were observed when testing of the samples is done.

3.1 Analysis of the surface roughness:

In the case of build styles; solid, sparse and sparse double dense were taken as three levels. The results are then analyzed for p value to check the type of hypothesis to be applied; null or alternate hypothesis. Upon changing the build style the variations obtained in the surface roughness are as mentioned in table 1. The interaction of build styles is studied in a paired t test in form of groups; table 2 defines the group interactions and p value for surface roughness obtained from Minitab.

Table 1 – Values for surface roughness

	Surface roughness (µm)					
Solid	0.28	0.38	0.44	0.39	0.27	0.28
Sparse	0.3	0.32	0.22	0.26	0.24	0.21
sparse - double dense	0.22	0.37	0.23	0.26	0.18	0.25

Table 2 – p values of interaction for surface roughness

S. No.	Interaction of build materials	p values of interaction for surface roughness
Group 1	solid-sparse	0.046
Group 2	sparse- sparse double dense	0.839
Group 3	Sparse double dense-solid	0.049

In this case, p values for group interaction for groups 1 and 3 come under the confidence level, so it can be concluded that the sample means are different and the factors are considered to be significant. Group 2 had its p value greater than confidence level; so, alternate hypothesis is rejected and factor interaction is considered to be insignificant.

3.2 Analysis of the surface hardness:

The hardness values for the material ABS M30i varies from 5.0 to 16.2 on the Vickers scale. In this case, readings were concentrated more on the lower part. Testing was done under the weight of 10 Kgf. Dwell time for the process varied from 12-16 seconds. When samples were tested for surface hardness, following readings were obtained. Table 3 defines the values obtained. Table 4 describes the p value for group interactions to check the mean of the samples.

Table 3 – Values for Micro Surface Hardness

Micro surface hardness (Hv)								
Solid	8.2	8.2	6.2	5.6	7.8	10.2	8.4	5.6
Sparse	6.5	6.8	7.1	5.4	6.7	6.1	5.3	6.2
Sparse-Double Dense	9.8	6.2	7.5	8.2	7.8	6.4	6.3	5.8

Table 4 – p values of interactions for surface hardness

S. no.	Group interactions	p values of interactions for surface hardness
Group 1	solid-sparse	0.185
Group 2	sparse-double dense	0.291
Group 3	double dense-solid	0.618

Considering the p value group interactions in table 4, it was seen that the table's values exceeded the confidence level for all the groups. This suggests that alternate hypothesis is rejected and the interactions have insignificant effect on the output response of hardness value. Thus build styles had no major impact on the hardness of the component.

3.3 Analysis of the impact strength:

Impact strength of the samples was tested using izod impact test. For this material (ABS M30i) the average impact strength is 124J/m. Variations in this case are justified by the material density. Build style is defined as the part filling style during the build; solid, sparse and sparse double dense. The values for impact testing are shown in table 5 while table 6 defines the p values of group interactions in Impact strength.

Table 5 – Values for Impact Strength

	Solid	Sparse	Sparse double dense
Impact strength (J/m)	132	112	122
	126	108	115
	120	113	118
	118	109	119
	120	110	123

Table 6 – P values of interactions for impact strength

S. No.	Group interactions	p values for interaction for impact strength
Group 1	solid-sparse	0.001
Group 2	sparse-double dense	0.006
Group 3	double dense-solid	0.188

P values of group 3 from the table exceeded the confidence level of 95% i.e. .05; so, alternate hypothesis was rejected. It could be concluded that sample means were same for group 3 and its effect was insignificant. For groups, 1 and 2, p values were less than the confidence levels so, alternate hypothesis was accepted i.e. the sample means were different and the factor was found significant and its relation can be explored further.

3.4 Analysis of effect of multi-contouring on surface roughness

In this case, it was interesting to consider the effect of surface roughness as numbers of contours were increased in multi-contouring. This was because the effect of change of material density on the outer layer on the surface. Table 7 shows the values of surface roughness in multi-contouring.

Table 7- values obtained from samples

S. No.	1	2	3	4	5	6
Sample 1	11.78	11.84	13.3	10.66	11.55	12.54
Sample 2	13.25	11.89	12.78	12.56	13.25	13.1
Sample 3	10.8	13.55	14.2	12.87	13.22	13.54

Table 8 showed various p value obtained from the data to analyze the effect of contour width on surface roughness.

Table 8- p values of contour width for surface roughness

S. no.	contour width	p value of surface roughness
1	0.4064	0.081
2	0.6064	0.708
3	0.8314	0.06

In this case, p values from 1, 2 and 3 were exceeding the confidence level of 95% i.e. alternate hypothesis is rejected and all the sample means are same. So, contour width of 0.4064, 0.5064 and 0.8314 had no impact on the surface roughness.

3.5 Analysis of effect of multi-contouring on surface hardness

For the case of surface hardness, increasing the number of contours definitely adds on to the surface hardness of the part. Following data was obtained from the multi-contouring samples is shown in table 9 given below. Table 10 defines the p values of surface hardness.

Table 9- values for surface hardness

Micro surface hardness							
Sample 1	8.2	10.5	10.1	11.2	11.8	10.5	10.8333
Sample 2	9.5	8.9	9.1	8.7	9.3	7.8	8.88333
Sample 3	8	7.6	8.3	6.2	7.1	6.9	7.35

Table 10 – p value of contour width for surface hardness

S. no.	contour width	p value of surface hardness
1	0.4064	0.045
2	0.6064	0.003
3	0.8314	0.009

From table 10, it was seen that the all the p values came under the confidence level i.e. sample means for all the samples is different. So, it was concluded that contour width was a significant parameter for surface hardness.

IV. CONCLUSIONS:

This study was conducted to analyze the effect of various build styles in FDM Machine on the mechanical properties of the material used. In this case, material used is ABS M30i, which is a grade of plastic. Following conclusions were made.

- Effect of build style on the surface roughness is insignificant.
- Build style shows no variation in hardness values.
- Impact strength of part is varied due to change in material density which is due to change in build styles. Solid and sparse styles vary the impact strength of part and considered.
- The trends observed in case of multi-contouring show that Surface roughness was unaffected by the increasing contour width or number of contours.
- Hardness is majorly affected by the effect of multi-contouring. It would be interesting to know the clear relationship between surface hardness and number of contours.

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