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A Method to Upgrade Surface Finish of Parts Fabricated By Fused Deposition Modelling

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ABSTRACT: This paper describes Taguchi Design of Experiments for determining the optimum surface finish of a part built by the Fused Deposition Modelling (FDM) process. Surface finish of RP part is improved by performing acetone treatment. Experiments were conducted using Taguchi's design of experiments, with five levels and three parameters. From the result of the experiments, mathematical model have been developed to study the effect of parameters**.**

KEYWORDS: Layered manufacturing, rapid prototyping, fused deposition modelling, surface finish

I. INTRODUCTION

Rapid prototyping (RP) has emerged as an important technology as it supports design of the product and produces prototype to analyse it for customer specifications in a short span of time. Functionality of the RP parts is severely affected by poor surface finish primarily due to staircase effect resulting from layer-by-layer deposition. Surface roughness value which is a result of staircase on an RP component is also dependent on geometry of the enclosing surface.[1] . One of the most commonly used technologies is Fused Deposition Modelling (FDM). The main advantages of this technology include: a good variety of materials available, easy material change, low maintenance costs, quick production of thin parts, a tolerance equal to _0.1 mm overall, no need for supervision,
no toxic materials, very compact size, low temperature operation. The main disadvantages are that it leaves a seam line between layers, the material tends to bump up, supports are required, there is axial weakness perpendicularly, a larger area of slices requires longer building times, and temperature fluctuations during production could lead to delamination, and high surface roughness. [2] It is obvious that the surface finish is better if layer thickness is smaller and also influenced by the angle between vertical and surface tangent as shown in Fig. 1[1]

From the literature survey, it is observed that, several researches, analytical and design experiments have been carried out since a long time. These studies focused directly on the surface roughness of ABS parts of different shapes and orientations observed when using Layered Manufacturing (LM) technology in FDM. Pandey et al.[1] In this research, they have presented a semi-empirical model for evaluation of surface roughness of a layered manufacturing part by fused deposition modelling. An attempt is made to address this problem using a simple material removal method namely hot cutter machining (HCM). Pandey et al. [2]In their work, a virtual hybrid FDM system have proposed which uses the capabilities of material deposition and HCM of the staircase to enhance the surface finish of a typical FDM processed parts. L. M. Galantucci et al.[3]In this paper the roughness of FDM prototypes is analysed. Process parameters have been shown to affect the Ra. In particular the slice height and the raster width are important parameters while the tip diameter has little importance for surfaces running either parallel or perpendicular to the build direction. A chemical post-processing treatment has been analysed and yields a significant improvement of the Ra of the treated specimens. Nitish Kumar et al.[4] In this study, the effect of parameters on the part quality of SLS part graphically and visually identifying the factors, which appeared to be significant. This technique is used a statistical measure of performance called signal-to-noise (S/N) ratio. The change in the quality of a product under different levels and with different factors was the main preference of this experiment. The optimum level combination of the process parameters are: Laser power: 18.5kW (Level 1), Temperature: 171°C (Level 1), Part Orientation: 90° (Level 3) for the dimensional accuracy and micro hardness of the SLS prototype to enhance the quality of product. K. Thrimurthulu et al.[5] This paper presents an approach that determines the optimal part deposition orientation for

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FDM process. Two contradicting objectives, namely build time and average part surface roughness, are minimized by minimizing their weighted sum. The effect of support structure is considered in the evaluation of two objectives. Thus, the support structure minimization is also implicitly included in this work.

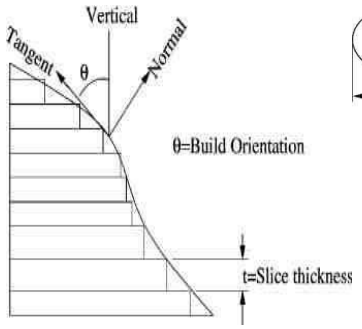

Fig.1 Staircase Effect in RP Part[1]

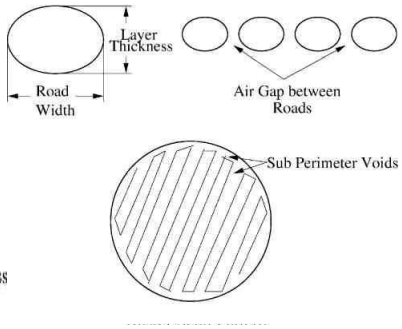

Fig.2Important Process Parameters[1]

II. RP MODEL

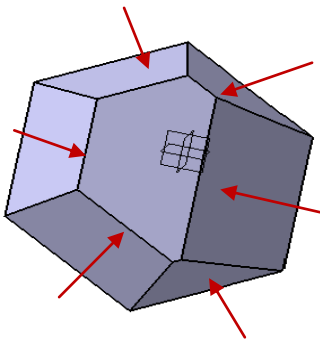

Fig.3 FDM Specimen

Fig. 4 MITUTOYO SJ-201 Machine

The literature survey presented in the previous section clearly indicates that layer thickness and build orientation are the two most significant process variables that affect surface finish. For the present study, FDM part (shown in fig.3) is fabricated with 0.254 mm layer thickness, 2700 C model temperature, 2650C support structure temperature, 0.511 mm road width and zero air gap. The designed part has six faces, which are inclined at 10°, 15°, 20°, 25°, 30° and 45° respectively, with the vertical. Gautham et al. [6] concluded that the rate of variation of surface roughness in the range of 40°-90° build orientation is less than that in 0°-40° region. Hence the inclinations are chosen between 0°- 45°. The surface roughness (Ra) value of the six faces before chemical treatment is measured using MITUTOYO SJ-201 machine (shown in fig. 4). The surface roughness is measured along the direction shown in fig. 3. Surface roughness is measured with the stylus attached to the detector at three points and surface roughness readings are noted from the measurement screen.

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III. EXPERIMENTATION

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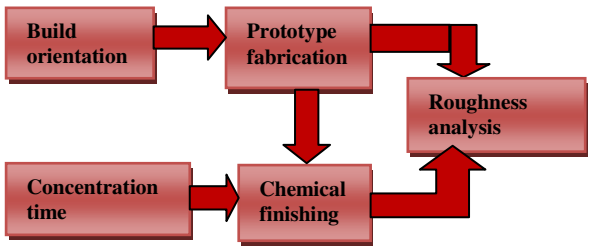

Fig. 5 Methodology

While studying the chemical properties of ABS material, it is observed that it can dissolve easily in acetone if treated for particular time. This method performs better because it needs marginal human intervention, the cost is very low and curing times are about few minutes after conducting experimentation. Hence three working parameters viz, build orientation, concentration of the Acetone and treatment time are selected with different levels. The process parameters like road width, layer thickness, raster scan pattern, air gap between roads are kept constant. Experiments are performed according to Taguchi design of experiments with three factors and five levels as shown in Table1. The L25 orthogonal array using MINITAB software is used for the experimentation.

Table1:Process Parameters to be Controlled

Factor	**Symbol**	**Unit**	**Level**				
			1	**2**	**3**	**4**	**5**
Build orientation	A	Degree	15	20	25	30	45
Concentration	B	%	80	85	90	95	100
Time	C	sec	30	60	90	120	150

According to L25 orthogonal array, 25 parts are to be manufactured on FDM machine. The material used for part fabrication is ABS P400. Each test part is to be chemically treated for different concentration of acetone and time.

- Chemical Finishing

The process resulted to be difficultly controlled using pure acetone hence the bath was added with water due to its very high mix ability with acetone. Surface roughness of treated specimens was measured.

Fig.6 Procedure of Acetone treatment

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IV. EXPERIMENTAL RESULT

4.1 Roughness before chemical treatment

Table 2:Roughness Readings

Sr. No.	Angles With Vertical	Roughness(µm)			Average Roughness
		1	2	3	
1	10º	42.242	36.839	41.099	40.06µm
2	15º	34.670	37.545	35.236	35.817µm
3	20º	16.814	17.090	17.764	17.222µm
4	25º	40.542	34.526	29.615	34.894µm
5	30º	27.095	28.819	28.262	28.058µm
6	45º	19.426	16.571	17.462	17.819µm

4.2 Roughness after chemical treatment

Table 2: Orthogonal Array Matrix And Average Roughness Value

Exp.	Build Orientation(Degree)	Concentration	Time(s)	Roughness(µm)
1	15	80	30	11.809
2	15	85	60	3.147
3	15	90	90	3.117
4	15	95	120	3.588
5	15	100	150	2.219
6	20	80	60	1.798
7	20	85	90	1.979
8	20	90	120	1.628
9	20	95	150	3.628
10	20	100	30	3.426
11	25	80	90	12.015
12	25	85	120	14.8
13	25	90	150	7.72

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14	25	95	30	2.12
15	25	100	60	0.414
16	30	80	120	7.750
17	30	85	150	0.794
18	30	90	30	3.803
19	30	95	60	0.489
20	30	100	90	1.214
21	45	80	150	9.267
22	45	85	30	29.769
23	45	90	60	1.035
24	45	95	90	2.311
25	45	100	120	0.584

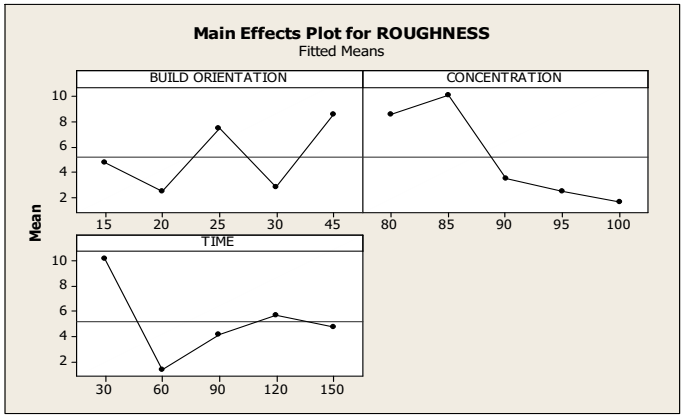

Fig. 6 Main effect plot

From Fig. 6 the optimum level for each factor as the level that has the lowest value of roughness. Thus best build orientation setting is A4 (30º), the best concentration setting is B5 (100%), the best time is C2(60 sec). Based on the matrix experiment, the setting A4B5C2 (30º,100%,60 sec) would give the lowest surface roughness value. The predicted best settings need not correspond to one of the rows in the matrix experiment.

- Mathematical modelling

Proposed mathematical model for roughness will be

Roughness = 38.1 + 0.472 A - 0.377 B - 0.0833C

Where, A = Build orientation

B = Concentration

C = Time

Predicted Valueof roughness is the roughness under the optimum conditions would be 0.752.

- Verification Experiment:An experiment with optimum parameter settings (30º,100%,60 sec) is carried out and compare the observed value with the predicted value.

Observed value is 1.023 micron.

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V. CONCLUSIONS

In this study the surface roughness of FDM prototypes which is the main issue is analysed. Different process parameters have been studied in particular the build orientation is an important parameter. A post-processing treatment with different concentrations of acetone has been performed and results in significant upgradation of the Ra of the treated specimens. The proposed chemical treatment is economic, fast and easy to use. Based on the analysis results following conclusions are drawn:

- Surface roughness value increases as build orientation (angle with vertical) decreases.
- Surface roughness value is minimum at 90º build orientation.
- It is observed that there is significant improvement in the surface finish of FDM made ABS part by considering build orientation, concentration and time as a process parameters.
- The predicted best setting 30º,100%, 60sec is better than the best among the rows of the matrix experiment.
- A mathematical model is developed to get surface roughness for three different parameters namely build
- Orientation , concentration and time. It is found that the two process parameters, viz., concentration and time have significant effect on roughness.
- Model validation is carried out on five specimens for different concentration and time.

Further studies need to be conducted on freeform products, also using other dimethylketone solvents such as ethylene.

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