An Experimental Investigation on the Coating of Fused Deposition Build Parts

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Abstract

Among all Additive manufacturing (AM) technologies, the Fused Deposition Modelling (FDM) is one of the advantageous technology due to its ease in handling of 3D complex jobs with less material waste and time. Now-a-days, metallisation of FDM build parts are deeply necessary to meet challenges in the fabrication of complex electrical discharge machining (EDM) tools, preservation of artefacts, manufacturing of circuit boards etc. Therefore, experiments are conducted adopting design of experiment (DOE) technique to minimise experimental runs and to get maximum data for analysis purpose. Two FDM build parameters i.e. raster angle and air gap and two coating parameters i.e plating time and voltage are selected to investigate their effects on the surface texture of the copper metallised FDM build parts. Analysis of variance (ANOVA) has been performed to check the significance of each process parameters and their interactions. One regression equation is developed relating process parameters with the surface texture of the metallised FDM build parts. Using surface plots, effect of process parameters on the surface texture are studied and analysed. One recently developed, nature inspired firefly algorithm is adopted to get an optimum parameter setting in order to improve the performance characteristic.

Keywords: Additive manufacturing; fused deposition modelling; Design of experiment; Analysis of variance; Firefly algorithm

1. INTRODUCTION

RP technologies are growing rapidly due to its easiness in product design, modelling, manufacturing of complex shapes efficiently with less material waste and time. FDM technology one of the RP technologies, has been widely appreciated worldwide due to its ability to manufacture complex designs shape without any human interventions. The FDM modelling process is one of the wide appreciated technology that produces prototypes from acrylonitrile butadiene styrene (ABS) plastic materials by putting semi molten filaments one over another. The heated filament is extruded from the extrusion nozzle as defined by the machine software (Insight 10. 2) in a layer by layer wise manner. The semi melted plastic material rapidly solidify to chamber temperature, which develops thermo residual stress inside the build part and make some adverse effect on the performance of FDM build parts . FDM manufacturing process is a parametric dependant process. Some process parameters have large influence over the mechanical properties as well as on the surface texture of the build parts. Therefore, present research paper is devoted to study the effect of some important controllable machine process parameters (raster angle and air gap) on the surface roughness and surface texture of metallised FDM build parts. Other supplementary parameters such as part contour number, layer thickness, part orientation, interior style, shrinkage factor, perimeter to raster gap etc. are kept at default levels. Raster angle is the angle of raster with respect to x axis of in the raster fill pattern. The term air gap represents the distance between two nearby rasters in a layer.

2. EXPERIMENTATION

In order to establish relations between FDM process parameters and the surface roughness again with process parameters with plating thickness, face centred central composite design (FCCCD) design is adopted. The advantage of FCCCD is that the points are presented on the face of the cube and the axial distance (α) between the points is one. FCCCD has the capability in handling of curved profile in the system. To decrease the experimental runs, half factorial (2k–1 where k is number of factor) with single block design is selected for experimentation [1]. Two levels along with a zero level are considered for experimental purpose. In the design layout 21 experimental run order which includes 5 centre pints are considered. All values of the input parameter values are converted inti coded from using the equation (1)

$$\xi_{ij} = \left(\frac{x_{ij} - \bar{x}_i}{\Delta x_i} \right) \times 2 \qquad (1)$$

$$\bar{x}_i = \frac{\sum_{j=1}^{2} x_{ij}}{2} \qquad (2)$$

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and $\Delta x_i = x_{i1} - x_{i2}$ $1 \le i \le k$; $1 \le j \le 2$,

where ξ_{ij} and x_{ij} are the coded and actual value of j_{th} level of i_{th} parameter respectively. All process parameters along with their respective levels are listed below in Table 1.

Table 1. Factors and their levels

Factors (Units)	Low Level (-1)	Zero Level (0)	High Level (1)
Raster Angle (degree) (A)	0	45	90
Air gap (mm) (B)	0	0.05	0.1
Voltage (volt) (C)	6	9	12
Time (min) (D)	5	10	15

To study the surface texture of metallised ABS parts, specimens are fabricated using Fortus 250 mc (Stratysis inc.) FDM machine (Fig. 2). The material used for fabrication of test specimen is acrylonitrile butadiene styrene (ABS M30) as it is a combination of monomeric chemical acrylonitrile butadiene and the styrene in presence of carbon hydrogen and nitrogen. ABS is a carbon chain copolymer and belongs to styrene ter-polymer chemical family. It is made by dissolving butadiene-styrene copolymer in a mixture of acrylonitrile and styrene monomers and then polymerizing the monomers with free-radical initiators. It contains 90-100% acrylonitrile/butadiene/ styrene resin and may also contain mineral oil (0-2%), tallow (0-2%) and wax (0-2%). Its three structural units provide a balance of properties with the acrylonitrile providing heat resistance, butadiene imparting good impact strength and the styrene gives the copolymer its rigidity [16].

The coating of a non-metallic object with a metal is known as metallization. Metallisation is usually done to improve certain characteristics of the substrate so that it can be used for various other applications like increasing conductivity [2, 4, 5, 7] corrosion resistance, for aesthetic purposes, etc. In this research, a number of metallisation processes have been studied that can be used to metallize ABS plastic and the most feasible of all i.e. electroplating, has been chosen keeping in mind the cost and complexity of the process [3, 5]. From the exhaustive literature review it has been noted that very few research work has been performed considering the FDM parameters with the coating parameters [8-15].

The substrates have been electroplated with and without pre-treatment processes to study the differences in the adhesion of metallised FDM build parts (Fig. 1). A number of substrates have also been electroplated in varying current densities to see the variation in the surface roughness of the metallised FDM build parts.

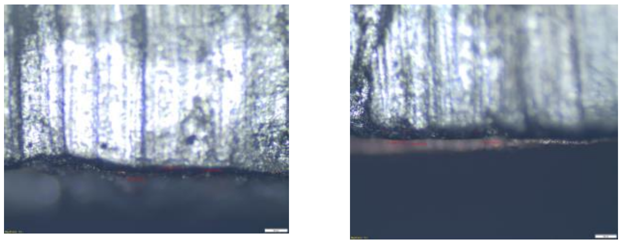

Fig. 1 Coating thickness measured through electron microscope

Fig. 2 Fused deposition modelling machine

3. RESULTS

Due to the complexity of the problem, a full quadratic model is attempted for suitably explaining the performance measures like surface roughness. In this present context, experimental data obtained using FCCCD design runs are fitted with following empirical model (Equation 3):

$$y = \beta_0 + \sum_{i=1}^{k} \beta_i x_i + \sum_{i=1}^{k} \beta_{ii} x_i^2 + \sum_{i<j} \sum \beta_{ii} x_i x_j \quad \ldots\ldots \quad (3)$$

where y is the performance measure and x_i and x_j are i_{th} and j_{th} factor respectively, k is the total number of factors. In the analysis of variance (ANOVA) table, the terms which have the P value less than 0.05 are considered as the significance parameters with 95% confidence level.

In the analysis of variance (ANOVA) table shown in Table 3, the significant terms influencing the surface roughness of Copper plated FDM built parts can be identified at significance level of 0.05. However, time (D) is not a significant parameters but its interaction with other parameters exhibits significant influence. The coefficient of determination (R^2), which indicates the percentage of variation explained by the terms in the model to the total variation in the response is 0.9818 for Surface roughness of Copper plated FDM Parts. It is to be noted from the table that lack of fit is not significant. Residual analysis has been carried out and found that residuals are normally distributed. The model for surface roughness involving important terms is shown in equation 4.

$$\text{Surface Roughness} = 2.858 + 0.0089 \times A - 16.856 \times B - 0.2016 \times C + 0.0249 \times D - 0.0045 \times A \times B + 0.002 \times A \times C - 0.0013 \times A \times D + 0.52 \times B \times C + 1.01 \times B \times D - 0.0024 \times C \times D - 4.44e\text{-}005 \times A^2 + 2.051 \times B^2 + 0.008 \times C^2 - 0.0002 \times D^2. \quad \ldots (4)$$

S. No.	(A)	(B)	(C)	(D)	Copper Plated ABS	
					Surface Roughness (µm)	Plating Thickness (µm)
1	90	0.1	12	5	2.45	55.65
2	90	0.1	6	5	1.78	56.38
3	90	0	12	15	1.85	45.01
4	0	0.1	6	15	2.21	47.87
5	90	0	6	15	1.63	43.24
6	0	0	12	5	1.53	46.1
7	0	0.1	12	15	1.93	45.96
8	0	0	6	5	1.98	55.12
9	0	0.05	9	10	1.61	73.21
10	90	0.05	9	10	2.13	45.31
11	45	0	9	10	2.07	43.26
12	45	0.1	9	10	1.86	49.43
13	45	0.05	6	10	1.98	48.72
14	45	0.05	12	10	2.08	47.64
15	45	0.05	9	5	1.98	45.61
16	45	0.05	9	15	1.93	46.58
17	45	0.05	9	10	1.93	44.32
18	45	0.05	9	10	1.91	42.89
19	45	0.05	9	10	1.92	43.12
20	45	0.05	9	10	1.93	44.31
21	45	0.05	9	10	1.93	44.35

4. CONCLUSIONS

Since FDM process is a parametric dependent process, the performance characteristics are largely influenced by the selection and variation of process parameters. To examine the effects of each individual process parameters on the performance characteristic experiments are conducted adopting design of experiment approach. From the experimental result it has been seen that raster angle and air gap have more significant effects on the plating of copper upon FDM build parts. On the other hand time has less influence than coating voltage. From the combine effects, it is observed raster angle has more significant influence over the performance measures.

Table 3.ANOVA Table for Surface roughness of Copper plated FDM Parts

Source	Sum of Squares	df	Mean Square	F Value	p-value Prob > F
Model	0.82	14	0.058	59.13	< 0.1051
A	0.14	1	0.14	136.70	< 0.0001
B	0.022	1	0.022	22.29	0.0033
C	6.760E-003	1	6.760E-003	6.83	0.0399
D	1.250E-003	1	1.250E-003	1.26	0.3039
AB	1.600E-004	1	1.600E-004	0.16	0.7015
AC	0.33	1	0.33	331.68	< 0.0001
AD	0.12	1	0.12	124.57	< 0.0001
BC	0.048	1	0.048	48.58	0.0004
BD	0.10	1	0.10	103.14	< 0.0001
CD	9.800E-003	1	9.800E-003	9.91	0.0199
A^2	0.021	1	0.021	20.85	0.0038
B^2	6.711E-005	1	6.711E-005	0.068	0.8032
C^2	0.013	1	0.013	12.69	0.0119
D^2	6.061E-005	1	6.061E-005	0.061	0.8127
Residual	5.934E-003	6	9.890E-004		
Lack of Fit	5.614E-003	2	2.807E-003	35.09	0.0029
Pure Error	3.200E-004	4	8.000E-005		
Cor Total	0.82	20			

Optimal Parameter Setting to minimize the Surface roughness of Copper plated FDM abs parts using one nature inspired metaheuristic algorithm known as firefly approach.

Table 4. Optimal Parameter setting to minimize the Surface roughness of Copper Plated ABS.

Raster Angle	Air gap	Voltage	Time	Ra
30.705	0.058	8.618	6.099	1.414

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