An Experimental Investigation of Surface Roughness of FDM Build Parts by Chemical Misting

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An Experimental Investigation of surface roughness of FDM Build parts by Chemical Misting

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Abstract: Rapid Prototyping or additive manufacturing is a process of creating 3 dimensional objects by adding materials layer by layer. It is a modern manufacturing process of producing more complex shaped materials which might be difficult or impossible in traditional machining processes. This technique has application in all fields of life and many tools artefacts circuit boards etc. have been produced by this process. It also produces new bones to be replaced by older ones. In this treatise an experiment has been conducted to determine the surface roughness before and after chemical treatment thereby comparing both values. Design of Experiments was conducted in Minitab by Taguchi analysis and six parameters, three-part building parameters Raster Angle, Raster Width, Air Gap, and three-part smoothing parameters Temperature, Time, Cycle have been found out. Analysis of Variance (ANOVA)has been carried out to determine the relationship of each parameter along with regression equation. Also surface plots have been drawn to examine the effect of parameters on surface roughness.

Keywords: Rapid prototyping, layer by layer, Taguchi, Design of Experiments, ANOVA

1 Introduction

Rapid prototyping technologies are growing very rapidly and are in great demand due to cheap cost easy and quick manufacturing of large complex shaped parts [7,8,11,12]. There are numerous 3d printers and they differ in the way material is deposited or cured. Among them Fused Deposition Modelling is the most widely used technology. It uses Acrylonitrile Butadiene styrene(ABS) plastic to produce material. ABS is a widely used plastic, used for manufacturing of low cost end use parts having high strength and stiffness. The appraisal shows that ABS plastic is mainly used for production of prototypes due to its exceptional dimensional stability and for easy machinability. The powder is deposited on the model tray. The movement of build platform is over the z-axis (i.e. up and down) and the material extruder movement is over x and y axis. The head applies resin in shape of model. After 1st layer is formed model tray moves down distance of layer and another layer is deposited on model tray. The print head again applies resin in shape of model. this process continues until the total material is formed. Plastic components have major advantages over metal built up parts in terms of weight reduction, ease fabrication of complex geometry and design flexibilities. However, some of the major disadvantages of plastic parts are, its limited wear resistance and structural weakness. Also the surface roughness of parts manufactured by FDM process is one of the main concerns in the industries. The poor surface roughness is due to the stair-stepping effect resulting from the layer by layer deposition of 3D parts. Other factors like raster angle, raster width & air gap also affect surface roughness. Chemical misting is one of the post processing process by which the surface texture of the ABS-FDM 3D printing parts are enhanced.

2 Experimental approach

Our prime objective is to develop relationship between surface roughness and process parameters. In order to do this Taguchi method [3] is adopted in Minitab software by going to the Design of Experiment option. Using a design of experiment (DOE) approach (i.e. Taguchi L orthogonal array, L27) test specimens are fabricated by controlling the process parameters at their different levels. Taguchi design is adopted due to its easiness in data handling and low experimental run order as compared to other DOE approach. Specimens are fabricated using FDM Fortus 250mc in a controlled environment as recommended by ASTM D618 standards. (Layer Thickness: 0.254mm fixed). To obtain uniform result ASTM D618 standards is adopted since different results will be produced in different environment. The process parameters along with their values at different levels is presented in the table below.

Table 1. Process parameters and their levels

Name	Low Level	Centre Level	High level
Raster Angle (degree)	0	45	90
Raster Width (mm)	0.3556	0.5306	0.7306
Air Gap (mm)	0	0.05	0.1
Temperature (° C)	50	60	70
Time (Sec)	10	20	30
Cycle	1	2	3

In order to determine the surface roughness of ABS parts at first the parts are created using Fortus 250 mc (Stratasys Inc.) FDM machine. The material used for preparing the 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%). ABS is a widely used plastic, used for manufacturing of low cost end use parts having high strength and stiffness. The material is added one over another in a sequential manner as defined by the machine software (Insight 10.2). Since it is an additive manufacturing process material waste is minimum than other conventional manufacturing processes. The movement of build platform is over the z-axis (i.e. up and down) and the material extruder movement is over x and y axis. The post processing technique is most important step in rapid prototyping process as parts made have comparatively rough surface. To reduce the surface roughness chemical vapor treatment using acetone is carried out which is the simplest easiest and environment friendly technique. It has other advantages like enhancement of aesthic beauty.

3 Fabrication of specimens

To study surface roughness of ABS parts, specimens are manufacture using Fortus 250 mc (Stratasys Inc.) FDM machine (Fig. 1). The part specifications are 50×20×15 mm (Fig. 2). The parameters set are raster angle (0º, 45º and 90º), raster width (0.3556, 0.5306 and 0.7306) and Air gap (0, .05 and 0.1mm). The numbers of experimental runs are 27, for each experiment two specimens are fabricated. Hence, a total of 54 numbers of specimens are fabricated.

Fig. 1. FDM 250mc (Stratasys Inc.) with a specimen

The material used for fabrication of test specimen is acrylonitrile butadiene styrene (ABS M30). ABS 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.

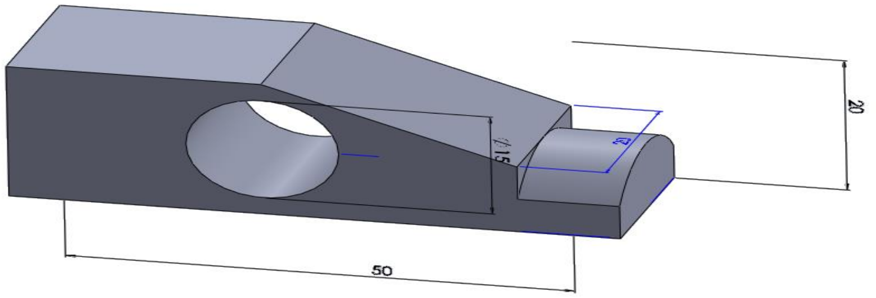

Fig. 2. CAD Model of Specimen

4 Smoothening of abs plastics

For enhancing the surface roughness of ABS plastics, a chemical post processing has been conducted [1,2,4,5,9]. As it is well known that ABS plastics are soluble in acetone liquid. Therefore, in this method, Acetone in vaporized form is used to enhance the surface of the ABS specimen [10]. In order to know the effect of chemical process on the specimen, the specimen is so selected that it contains all the three surface, i.e., flat surface, inclined surface and curved surface [9,10]. First of all, an electrical hot plate with temperature control is taken. A tin container with a glass lid is kept on it. There are two slots on the lid of the container. One for digital thermometer and another for hanging the specimen inside the container. The container is heated to various temperatures such as 50, 60 and 70 degrees Celsius with the help of the temperature controller provided on the hot plate. Then 20-25 ml of acetone is poured inside the container. The acetone now becomes in a vaporous state. At this time, the specimen, tied with a thread is introduced inside the container for various time period like 10, 20 and 30 seconds. The samples are also exposed to the acetone vapour for one, two or three cycles. In one cycle, the specimen is exposed only once. In the two cycle method, the specimen is exposed for certain period of time at a particular temperature. Then it is kept outside for a period of 10 minutes to cool. Again it is exposed to the acetone vapour with the same constraint. Similarly, for three cycle experiment, the specimen is cooled in air for two times in between three exposures. The smoothening process is shown in the following figure (Fig. 3.)

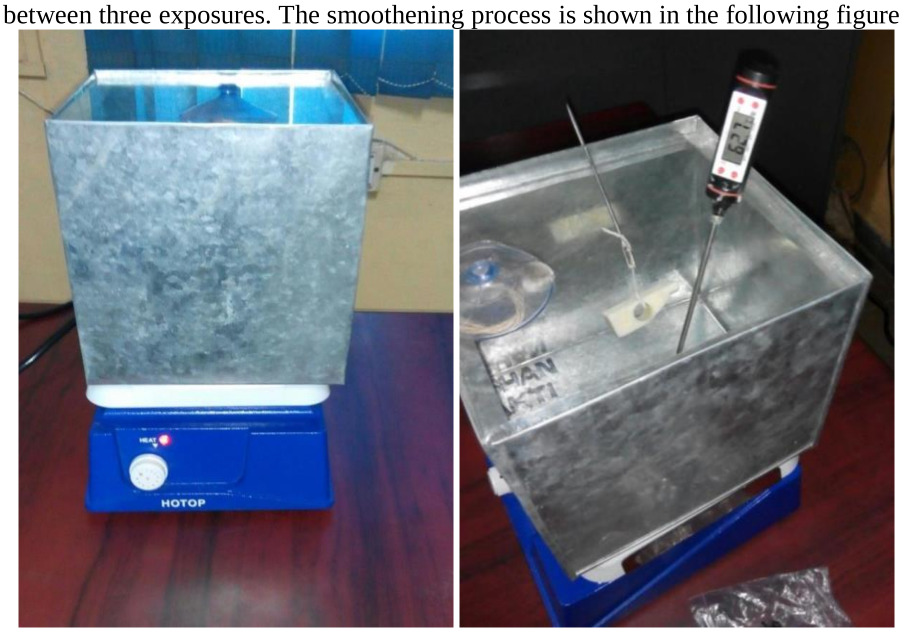

Fig. 3. Smoothening Process of ABS Specimen

5 Surface roughness photographs

The photos of surface texture [5,6,9] of ABS-FDM parts were taken using metallurgical microscope OLYMPUS STM6 measuring microscope (Fig. 4.1) for curved surface before and after chemical treatment. The specimen was kept on the base of microscope and image was seen alongside the computer attached to the microscope by focusing the microscope metallurgical controller. When the relevant image was formed, snapshot of it was immediately captured on the attached computer.

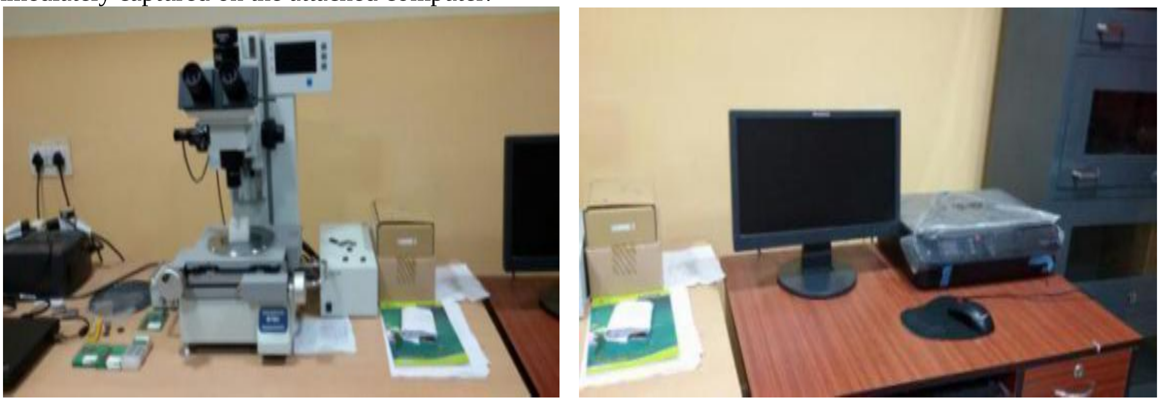

Fig. 4.1. Metallurgical microscope (OLYMPUS STM6)

Fig. 4.2. Curved surface before (left) and after (right) Smoothing

The Fig. 4.2. shows surface textures curved surface before and after smoothing. In the before smoothing sections of curved surface the rasters are clearly visible and they are in oblique direction. Inside the raster of curved surface some marks or globules are spotted. The small spots are also visible in before smoothing section of curved surface. Those spots indicate that those areas are rough. In the after smoothing section small spots are seen which are uniformly scattered in straight line path which shows the surface roughness is reduced after chemical treatment by acetone and the surface has been smoothed. There is also a small hole like image is observed which indicates that particular area has been over smoothened.

6 Results

For better understanding of relationship between surface roughness and process parameters, S/N Plot regression equations and ANOVA table has been presented. The S/N plot shows maximum and minimum values of process parameters. The regression equation gives relationship of process parameters with surface roughness. The ANOVA table shows significant influence of parameters over surface roughness when significant level is less than 0.05. The coefficient of determination (R2), 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.

Table 2. Result Table

Sl. No.	FDM Parameters (Part Building)			Smoothing Parameters (Part Testing)			Surface Roughness of Curved Surface		
	Raster Angle	Raster width	Air Gap	Temp	Time	Cycle	Before Smoothening	After Smoothening	% Error
1	0	0.3556	0	50	10	1	3.207	2.992	6.70
2	0	0.3556	0	50	20	2	3.104	3.043	1.96
3	0	0.3556	0	50	30	3	2.335	2.147	8.05
4	0	0.5306	0.05	60	10	1	2.571	2.242	12.79
5	0	0.5306	0.05	60	20	2	2.922	2.557	12.19
6	0	0.5306	0.05	60	30	3	2.701	2.455	9.10
7	0	0.7306	0.1	70	10	1	1.927	1.662	13.7
8	0	0.7306	0.1	70	20	2	2.994	2.713	9.38
9	0	0.7306	0.1	70	30	3	2.475	2.360	4.64
10	45	0.3556	0.05	70	10	2	2.456	2.295	6.55
11	45	0.3556	0.05	70	20	3	2.485	2.264	8.89
12	45	0.3556	0.05	70	30	1	2.242	1.997	10.92
13	45	0.5306	0.1	50	10	2	2.263	2.109	6.80
14	45	0.5306	0.1	50	20	3	1.551	1.352	12.83
15	45	0.5306	0.1	50	30	1	2.183	2.041	6.50
16	45	0.7306	0	60	10	2	2.180	2.310	5.6
17	45	0.7306	0	60	20	3	2.111	1.835	13.07
18	45	0.7306	0	60	30	1	1.743	1.503	13.76
19	90	0.3556	0.1	60	10	3	2.231	2.154	3.45
20	90	0.3556	0.1	60	20	1	2.562	2.241	12.52
21	90	0.3556	0.1	60	30	2	1.666	1.455	12.66
22	90	0.5306	0	70	10	3	2.325	2.134	8.21
23	90	0.5306	0	70	20	1	1.712	1.489	13.02
24	90	0.5306	0	70	30	2	2.191	1.996	8.90
25	90	0.7306	0.05	50	10	3	1.650	1.488	9.81
26	90	0.7306	0.05	50	20	1	2.036	1.851	9.08
27	90	0.7306	0.05	50	30	2	1.776	1.617	8.95

ROUGHNESS REGRESSION EQUATION =-2.30567 + 1.87407A + 0.80375B + 0.165028C - 0.183444D + 0.773742E + 0.269687F - 0.559833A×B - 0.34616A×C - 0.0166429A×E + 0.00169048A×F + 0.181417B×C - 0.0483889B×E - 0.0349444B×F - 0.0164444C×E + 0.135944C×F - 0.0791667D×E - 0.233083E×F.

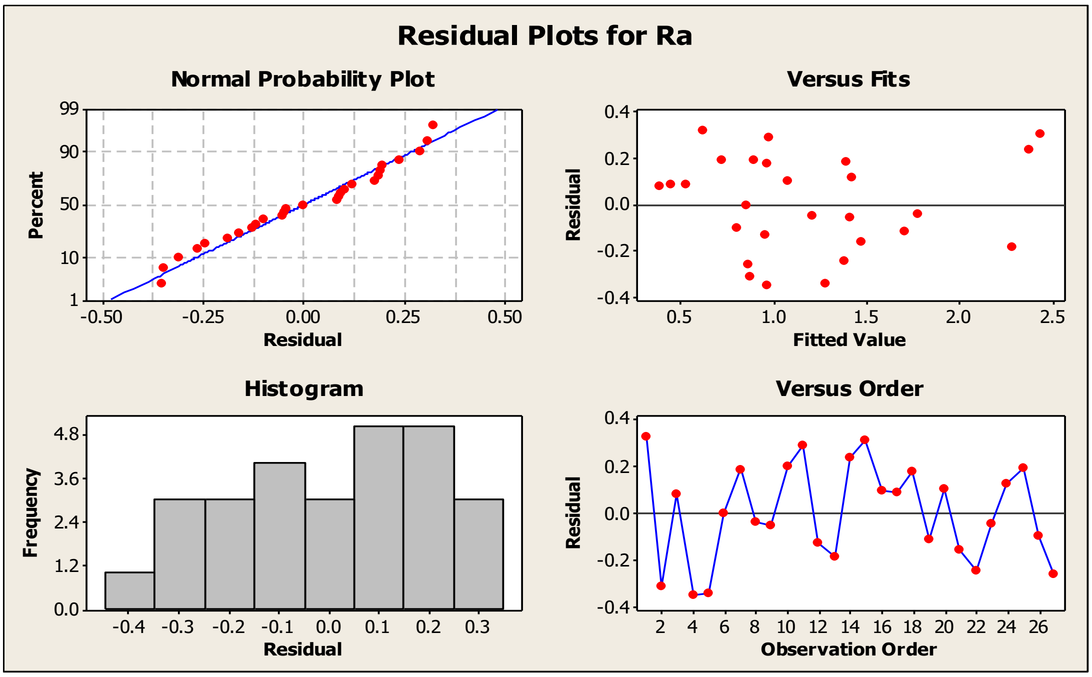

Fig. 5. Residual Plot for Surface roughness

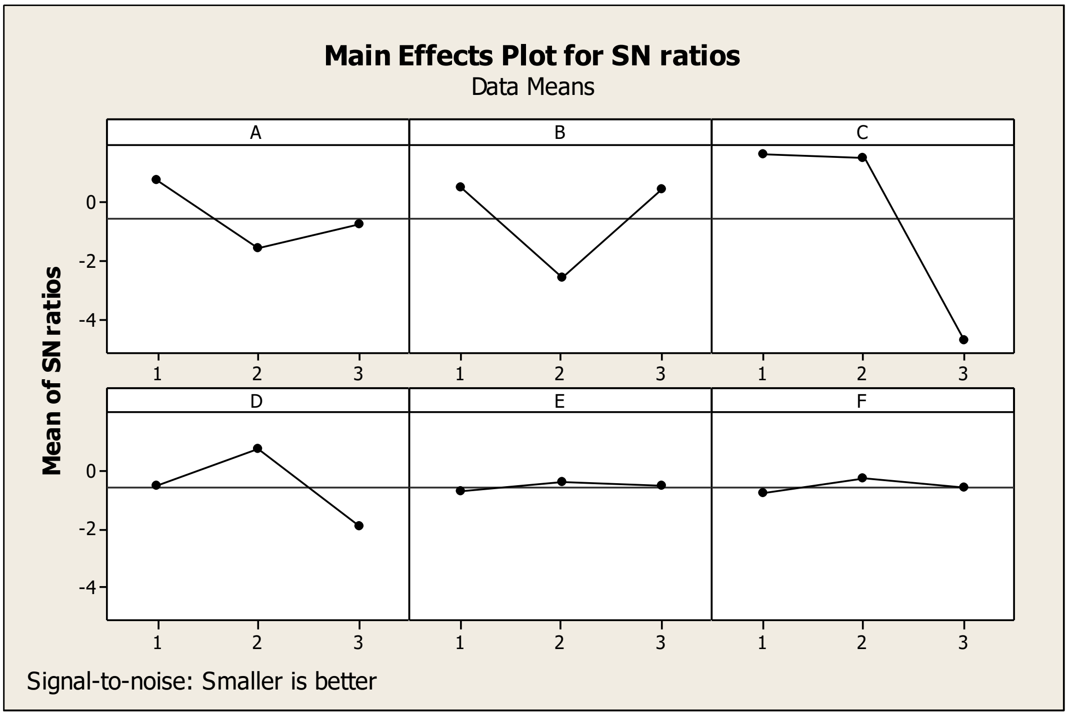

Fig. 6. Main Effect plot for S/N ratios

Table 3. ANOVA Table

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Regression	17	3.82069	3.82069	0.224747	8.8951	0.001083
A	1	0.06055	0.56187	0.561872	22.2379	0.001096
B	1	0.05120	0.25445	0.254448	10.0706	0.011304
C	1	2.26136	0.00378	0.003780	0.1496	0.707913
D	1	0.22267	0.02423	0.024229	0.9590	0.353038
E	1	0.00381	0.13121	0.131211	5.1931	0.048655
F	1	0.00534	0.00884	0.008838	0.3498	0.568787
A×B	1	0.12649	0.52236	0.522356	20.6739	0.001392
A×C	1	0.49093	0.19972	0.199719	7.9045	0.020327
A×E	1	0.08943	0.00088	0.000881	0.0349	0.855988
A×F	1	0.15545	0.00001	0.000009	0.0004	0.985279
B×C	1	0.02326	0.09403	0.094034	3.7217	0.085786
B×E	1	0.00460	0.01686	0.016859	0.6672	0.435105
B×F	1	0.08217	0.00550	0.005495	0.2175	0.652046
C×E	1	0.00089	0.00195	0.001947	0.0771	0.787594
C×F	1	0.06225	0.08316	0.083164	3.2915	0.103039
D×E	1	0.02507	0.02507	0.025069	0.9922	0.345230
E×F	1	0.15522	0.15522	0.155222	6.1434	0.035072
Error	9	0.22740	0.22740	0.025266		
Total	26	4.04809				

Optimum parameter to reduce surface roughness of ABS-FDM parts is given below. This optimum parameter is obtained by firefly algorithm which is based on movement of fireflies in the atmosphere.

Table 4. Optimum Parameter Setting for Curved Surface

Raster Angle (A) (Degree)	Raster Width (B) (mm)	Air Gap (C) (mm)	Temperature (D) (^{0}C)	Time Period (E) (Sec)	Cycle No. (F) (Magnitude)	Surface Roughness (µm)
37	0.5102	0.02	53	18	1	5.74

7 Conclusion

It has been observed that surface roughness is largely influenced by the air-gap and less influenced by other process parameters. Comparison of surface roughness before and after chemical treatment was successfully carried out and it has been noted that surface roughness is reduced after chemical vapour smoothing and surface textures of part are enhanced. From Analysis of Variance (ANOVA), the significance as well as the influence of each process parameters have been checked. Regression equations has been generated considering all process parameters and with the performance characteristics. Since FDM is a process dependent on parameters so the performance characteristics are largely influenced by the selection of parameters. To understand the effect of individual parametric effect on process characteristics design of experiments were conducted based on Taguchi L 27 orthogonal array. In this research, vapour smoothing with acetone has been considered for post processing of ABS printed parts. The reason being, it is cheaper, quicker and gives better finish. Also, all the three smoothing parameters such as temperature, time and number of cycle have substantial influence on the surface roughness of ABS build parts. The optimal parameter settings have been calculated using these regression equations.

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