Optimal selection of process parameters in FDM machine for surface roughness of PLA material

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Abstract **In today's growing market most emerging manufacturing technology is rapid prototyping and aim of this technology is to satisfy the customer with good surface quality and dimensional precision. Fused deposition modeling (FDM) is rapid prototyping technology, produces the 3D part from wax or plastic. But to attain the good surface quality and dimensional precision requires a good-skilled operator to set optimum input parameters. For modeling parts, printing head moves precisely overbuild platform according to layer by layer. However, determining the optimum parameters level is not an effortless task. This paper deals with the optimizing the i/p parameters to get minimum surface roughness of PLA manufactured parts by response surface methodology (RSM). The design of the experiment is based on a full factorial design by taking printing velocity, printing temperature and layer thickness as i/p parameters. Printing velocity 50 mm/s, printing temperature 205.01 ^{0}C, and layer thickness 0.2 mm is the optimum grouping of parameters for minimum surface roughness of 0.0510 micrometers.**

Keywords- Rapid prototyping, FDM, RSM, Surface roughness.

I. INTRODUCTION

In the current era of globalization main motto of industry or manufacturer is to build or provide the product with good quality, low cost, and mainly customer satisfaction. As the part complexity increases the cost of machining, time for production, inspection also increases. This increases the overall manufacturing cost. This leads to raising the new concept called Rapid Prototyping. RP technique models the product form 3D CAD design. For modeling, purpose materials use in solid, liquid or powder form. Depending upon the modeling material RP techniques are classified as SLS, Stereolithography, LOM, FDM, etc. Fused deposition modeling was introduced by STRATASYS INC, USA in 1990. FDM uses thermoplastic polymers like ABS, nylon, wood component, carbon fiber, etc. All these material uses in the type of wire as input to the machine for prototyping. Usually, FDM consists of 2 nozzles, one is for build material and other is for support material. For producing prototype or model STL format is required. STL is a slice file format of an existing 3D model. For this purpose, we use CURA software. As per the 2D slice format, the printing head travels above the build platform layer by layer and model the product. For heating, the filament in semi-molten state heater is provided. PLA is bioplastic which is used in FDM machine in the type of wire. The wire diameter is 1.75 mm for PLA filament. It is mainly manufactured by naturally available components such as corn starch or sugarcane. It is available in various colors. R. Anitha, S. Arunachalam and P. Radhakrishnan [1] apply the Taguchi method with ANOVA and S/N method to conclude the best possible level of input parameters. Results concluded that layer thickness is influential parameters for surface roughness. Pandey, Reddy, and Dhande [2] design the experiment with fractional factorial for ABS material with a layer thickness as well as build orientation as i/p parameters. ANOVA found out layer thickness as a significant parameter.

Masood et al [3] consider raster angle, build style, raster width as input parameters for the doe for improvement of the tensile strength of pc material. Best grouping of the i/p parameters gives maximum tensile strength. Kumar et al [4] improve mechanical properties by genetic algorithm and ANOVA method. ANOVA found out that raster angle is a significant parameter for tensile strength. Shenglon et al [5] performed laboratory experiments for polyetherimide mechanical properties of the material with nozzle temperature and build orientation as input parameters. Results into the enhancement of tensile strength with a modulus of elasticity. This research paper focused on the progress of the surface of PLA (Polylactic Acid) by RSM by considering printing temperature, layer thickness, and printing velocity as input parameters. This is for the reason that we know layer thickness is a significant parameter from the literature study.

II. Experimental Details and Measurement

The FDM machine used is Accucraft i250+, a single extruder machine. The printing head of this machine is traveling in X and Y direction according to the STL file format. Cura is software which makes the STL file and slices the 3D part. With the help of cura, we can set the value of input parameters. Specification of accucraft i250+ is as in TABLE I.

TABLE I. Specification of accucraft i250+

Specification	Value
Maximum printable area	300mm*250mm*200mm
Filament diameter	1.75 mm
Extruder diameter	0.4 mm
Number of extruders	1
Maximum print speed	200 mm/sec
Software's supported	Cura, Repetier, kislicer

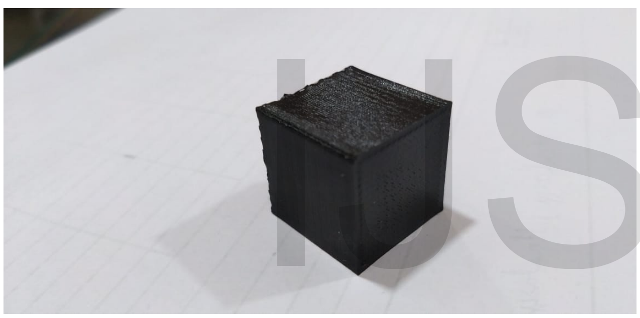

Fig. 1. PLA Specimen

PLA is a polylactide or polylactic acid is biodegradable thermoplastic.PLA serves better option for biocompatible products for the human body. Hence it is used for producing human body parts which necessitate being replaced due to permanent damage such as bones, skull, etc. PLA materials physical properties are as in TABLE II.

TABLE I. PHYSICAL along with THERMAL PROPERTIES OF PLA MATERIAL

Property	Value
Physical	
Density	1.24 g/cm^3
Melt mass flow rate	6 g/10min
Thermal	
Melting point	135^{0}C
Glass transition temperature	55-60 ^{0}C

Input parameters level for modeling is as in TABLE III.

TABLE III. INPUT PARAMETERS LEVEL

Level	Layer thickness (mm)	Printing velocity (mm/sec)	Printing temperature (^{0}C)
Level 1	0.1	50	190
Level 2	0.15	100	200
Level 3	0.2	150	220

DOE and their response are as in Table IV.

TABLE IV. DOE AND THEIR RESPONSE

Layer thickness (mm)	Printing velocity (mm/sec)	Printing temperature (^{0}C)	Surface roughness, R_a (micrometer)
1	1	1	4.765
1	1	2	4.824
1	2	3	5.064
2	2	1	12.12
2	3	2	6.938
2	3	3	6.3
3	1	1	9.052
3	2	2	9.052
3	3	3	8.852

MGW surface roughness tester works on the profilometer principle is used to measure the o/p. It consists of a diamond tip of radius 0.002 mm which measures the surface profile with the help of an electronic circuit. Usually, measured values are R_a, R_z, and R_q.

Fig. 2. MGW Surface Roughness Tester

III. RESPONSE SURFACE METHODOLOGY (RSM)

Response surface methodology would be defined as a methodology for constructing simple approximations of structural responses based on analysis of results. RSM adopts for both mathematical modeling and statistical techniques that are useful for the predicting results and analysis of problems. It also builds a relationship between measured responses and the important input parameters. The purpose of developing mathematical models is relating the responses and their factors for optimization of the machining process. By careful design of experiments, the objective is to optimize a response (output variable) which is influenced by several independent variables. An experiment is a series of tests, called runs, in which changes are made in the input variables in order to identify the reasons for changes in the output response.

IV. DEVELOPMENT OF REGRESSION MODEL

The relationship between the machining parameters such as Printing temperature, printing velocity, layer thickness for a third order response surface model is developed using Response surface methodology in coded units from the observed data which is given as follows.

Regression equation: 493.7+2719 Layer thickness- 6.265 Printing temperature-0.7163 Printing Velocity-1921 Layer thickness*Layer thickness+0.01923 Printing temperature* Printing temperature+0.000099 Printing Velocity*0.000099 Printing Velocity- 12.29 Layer thickness*Printing temperature + 4.731 Layer thickness*Printing Velocity

V. RESULTS AND ANALYSIS

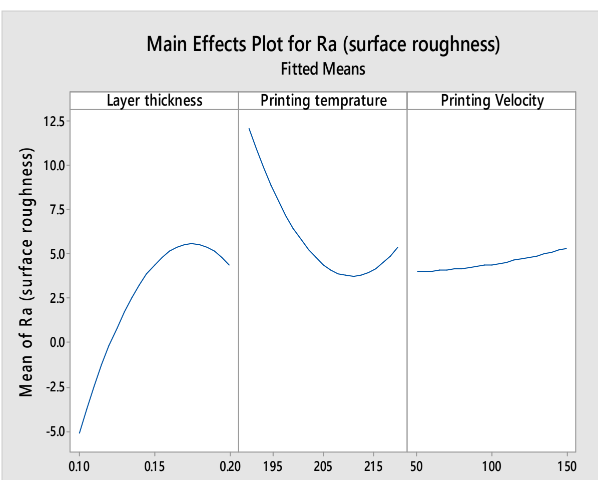

Fig. 3. Main Effect Plot

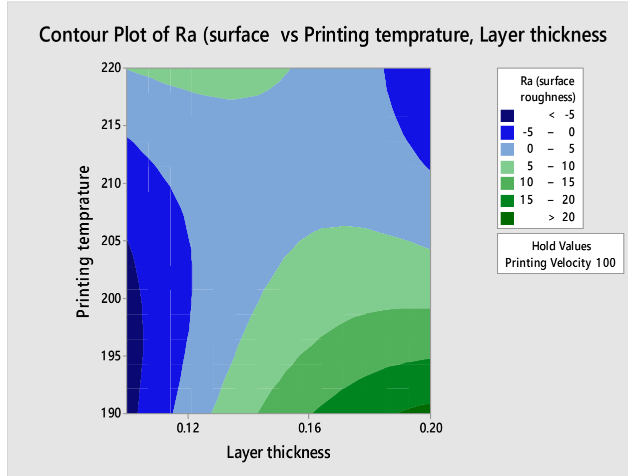

Fig. 4. Contour Plot

Main effect plot shows the effect of individual input parameters on surface roughness, it reveals that printing velocity has a negligible effect on surface roughness. In a contour plot considering printing temperature and layer thickness, a feasible region is shown with minimum surface roughness. Figure 3 and figure 4 shows the main effect plot and counterplot and for our experiment.

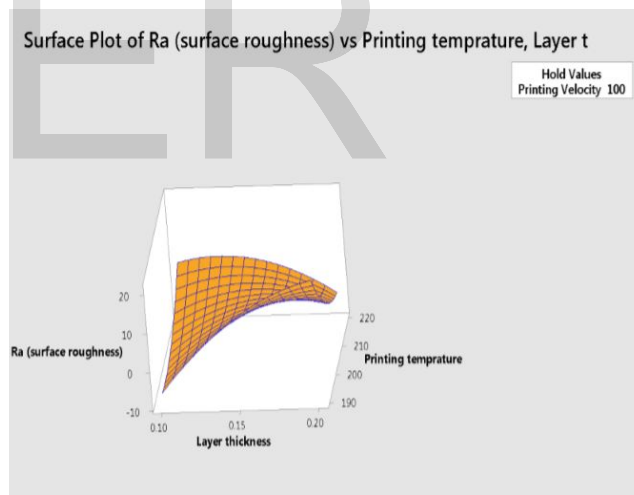

Fig. 5. Surface Plot

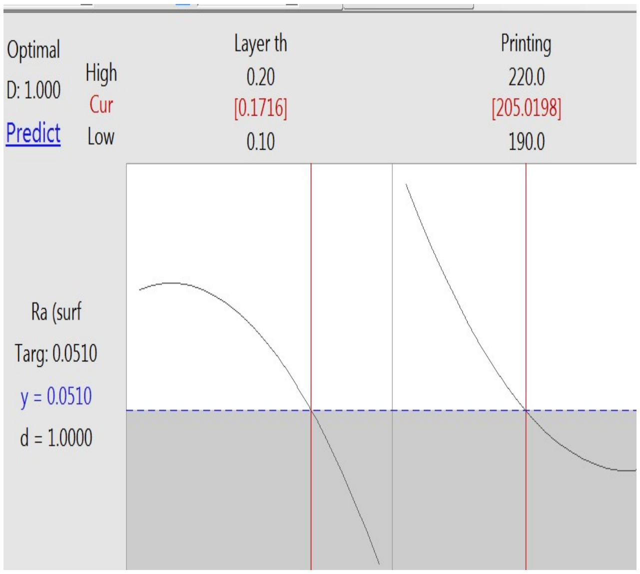

Fig. 6. Optimization Plot

Optimization plot is shown in figure 6.optimization plot shows optimum values of all three input parameters i.e.
Printing temperature, printing velocity, layer thickness so that output parameter i.e. surface roughness is optimized accordingly. The surface plot reveals the values of printing temperature, printing velocity layer thickness at which surface roughness is minimum.
Optimal machining parameters obtained are – printing temperature of 205.01^{0}C, printing velocity 50m/sec, layer thickness 0.2mm. The optimized surface roughness obtained is 0.0510 micrometer.

IV.CONCLUSION

This paper presented the following conclusions of an experimental investigation of the effect of input process parameters on the surface roughness of PLA material.
1. The effect of process parameters on the surface roughness has been evaluated with the help of response surface methodology. The optimum process parameters are obtained to minimize the surface roughness is determined.
2. The third-order response surface model for surface roughness is developed from the observed data.
3. From all the plots significant factors that mainly affects surface roughness has been found. Hence, the RSM model developed is significant and adequate.
4. The optimal parametric combination - printing temperature of 205.01^{0}C, printing velocity 50m/sec, layer thickness 0.2mm.
5. Minimum surface roughness found by RSM is 0.0510 micrometer which is very close the value we get after confirmation test

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