Investigation on Parameter Optimization of Fused Deposition Modeling (FDM) for Better Mechanical Properties – A Review

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Abstract— Rapid prototyping (RP) refers to a modern technology that produces the tangible parts from available computer aided design (CAD) data directly. Fused deposition modeling (FDM) is one of the RP technologies that produced parts from plastic material by lying track of semi molten plastic filament on to a platform in a layer wise manner from bottom to top from plastic filament nozzle. The quality of FDM made parts is highly affected to various process parameters of FDM process. So optimization of FDM process parameters is essential in order to optimize the quality of parts. The purpose of this paper is to explore the reviews for various optimization methods used for process parameter optimization of FDM process given by researchers and application of full factorial method.

Key words: optimization, rapid prototyping, fused deposition modeling (FDM) process, full factorial and taguchi method

I. INTRODUCTION

In this modern time of manufacturing sectors, there is a throat cutting competition for getting the customers. So, it is very important for the new products to reach the market as early as possible to get big group of customers. Hence companies have started focusing on rapid prototyping on behalf of traditional product development methodology in order to save resources. The Fused deposition modeling is one of the RP technology by which physical products are created directly from CAD model data by tracking layer on layer deposition of extrusion material with help of extrusion nozzle. But, the part quality of FDM produced part is highly affected by various input process parameters used in fabrication of parts. So, this is the necessity to optimize FDM process parameters. Optimization of process parameters gives the correct adjustment of parameters which improve the quality of the parts being produced. The full factorial method is most widely used for design of experiments because it can be provide simplification of experimental plans and reduced the number of experiments compare to general single factor method. The Response Surface methodology is the powerful tool which may be used for exploring relationship between explanatory variables and one or more response variables.

II. PROBLEM FORMULATION

The cost, lead time and delivery time of the product is most affected factors to attract the customer. But as earlier discussion the product quality of FDM process is highly susceptible to various process parameters used while fabrication. So, this is the essential to carry out the optimization of FDM process parameters. Optimization will improve the quality of parts or models. There are so many methods available for optimization, design of experiments and prediction purpose. Without brief review it is difficult to say which one is better compare to other one. This paper helps to find out which method is better for its particular application and one can use best suited method to achieve their goals.

III. VARIOUS APPROCH FOR OPTIMIZATION OF FDM PROCESS PARAMETERS

Optimization of process parameters provides the correct adjustments of process parameters which gives best suited quality of parts or products. Review of various approaches which is used by other researchers for process parameters optimization of FDM process is discussed under this section.

A. K. Sood et al. [1] have studied with five important FDM machine process parameters such as air gap, raster angle, part build orientation, layer thickness and raster width on compressive strength of test specimens. They made the statistically valid predictive equation for finding out optimal process parameters setting for better parameters optimization. The experiments were conducted with use of central composite design (CCD) method. Using response surface plot the effect of various factors and their interactions are explained very well. They have concluded that fiber-fiber bond strength must be strong which can be achieving by controlling the distortions arising during part build stage. Optimization of process parameters of FDM process provides the optimum value of layer thickness, orientation, raster angle, raster width and air gap as 0.254 mm, 0.036 degree, 59.44 degree, 0.422 mm and 0.00026 mm respectively and the maximum compressive stress of 17.4751 MPa.

K. Thrimurthulu et al. [2] have investigated experiments for obtaining an optimum part deposition orientation of fused deposition modeling (FDM) process for enhancing part reducing built time and surface finish. They developed model for evolution of built time and average part surface finish. The effect of the support structure is considered in the evolution of the two objectives. The genetic algorithm was used to obtain the optimal solution of process parameters. Average part roughness and the built up time of the part are consider as two objectives. Hence, the support structure minimization is implicitly. The adaptive slicing is simultaneously used in the determination of optimum part deposition orientation.

Jaimin Patel et al. [3] have investigated the effect of three important FDM process parameters like raster width, orientation angle and layer thickness on flexural strength and tensile strength of FDM produced test specimens. They have taken three FDM process parameters each of at three levels for experiments. Taguchi method was selected for design of experiments (DOE). Analysis of variance (ANOVA) and signal to noise ratio were used to find out which parameter was significant over output response. After the experimental work and ANOVA analysis used for conclusion that the orientation angle and layer thickness is highly significant to response characteristics whereas raster width have a little effect on it which is shown in figure 1 and figure 2.

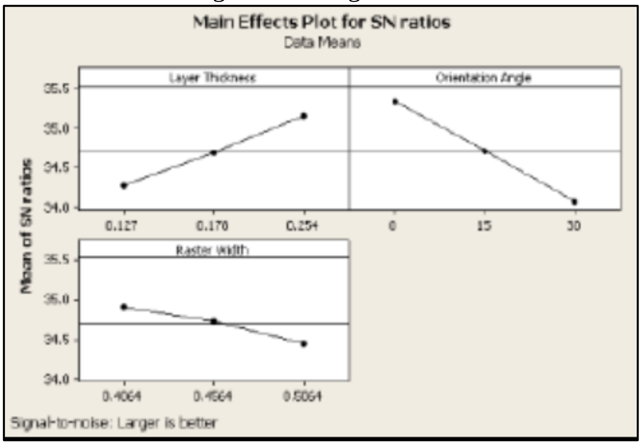

Fig. 1: Effects of FDM parameters on Tensile strength of test specimen

Anoop Kumar et al. [4] have investigated the effect of important process parameters such as raster width, part orientation, raster angle, layer thickness and air gap along with their interaction on dimensional accuracy of fused deposition modeling (FDM) process on ABS material parts. They have studied that the shrinkage is dominant along with the length and width direction of built parts. But the positive deviation from the required value is observed in the thickness direction. Optimum parameter settings to minimize percentage change in length, width and thickness of standard test specimen have been found out using Taguchi's parameter design method. Artificial neural network (ANN) was used for prediction purpose. Finally, they have concluded that for minimizing percentage change in length higher layer thickness (0.254 mm), orientation (0), maximum raster angle (60), medium raster width and 0.004 air gap will give optimum results. On the other hand lower value of layer thickness (0.127mm), orientation (0), raster angle (0) and higher value of raster width and minimum value of air gap (0.004mm) will minimize percentage change in thickness of test specimen. They used grey Taguchi method to produce the part in such a manner that all the 3 dimensional shows minimum deviation from actual value. Finally layer thickness (0.178 mm), part orientation (0 degree), raster angle (0 degree), road width (0.4564 mm) and air gap (0.008 mm) will produced overall improvement in part dimensions.

R.anitha et al. [5] have observed the effect of various process parameters of fused deposition modeling (FDM) fabricated part quality. Taguchi method was used for implementation of optimization of both product design and process design. They have used three important FDM process parameters such as speed deposition, road width and layer thickness and each of at three levels. For design the experiments Taguchi's L18 orthogonal array was used and signal to noise ratio was applied to find out most significant factor on the response characteristics, at last regression analysis was used in order to predict the experimental data. After the experimental work they have found that road width and speed contribute 15.57% and 15.83% at 99% level of significance according to s/n ratio. Layer thickness is affected 49.37% without pooling and with pooling it is affected 51.57% at 99% level of significant. They have concluded that the layer thickness is the most effective FDM parameter among three, which affect the output response widely.

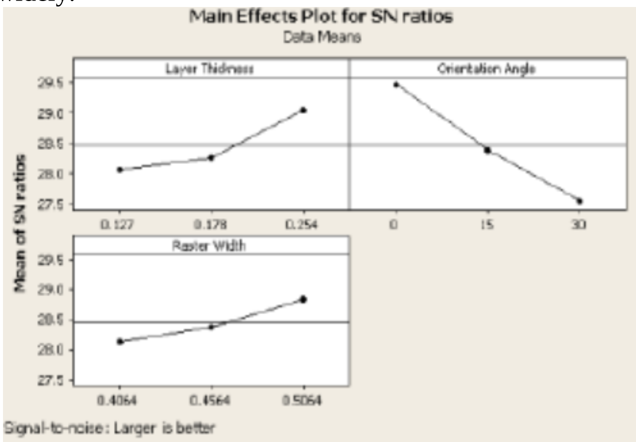

Fig. 2: Effects of FDM parameters on Flexural strength of test specimen

S. kannan and D. senthilkumaran et al. [6] have observed the effect of electroplating on the impact and hardness properties of ABS plastics produced from Fused Deposition Modeling (FDM) process. The impact test was carried out on a specifically designed 'drop impact tester'. The drop weight impact tests are carried on the normal and electroplated specimens with different depth level: 60 μm, 70 μm and 80 μm and at different drop weights: 0.89 kg, 1.395 kg and 2.33 kgs. A drop height was 400 mm. The hardness of the electroplated specimens has improved by 6.3%, 7.7 % and 11.2% with 60, 70 and 80 μm specimens respectively, as compared with non plated ABS specimens. Impact dimension as per earlier discussion is that the electroplated specimens (70 μm and 80 μm) indicate that the electroplating gives considerable increment in the impact strength of the ABS. The 60 μm impact test specimens showed a decrease of 25% in strength.70 μm specimens showed an increase of 147 % and 80 μm specimens showed an increase of 243%. Hence one can say that the higher coating thickness has increased the impact resistance of FDM-ABS materials.

Es.Said et al. [7] have studied the effect of different layer orientation on mechanical properties of ABS used parts. The parts were produced by a 'Stratasys rapid prototyping machine' with five different layer orientations. They studied impact test on ABS parts and found that (0 degree) orientation where layer were deposited along the length of the sample displayed impact resistance and superior strength overall the other orientations. It is also observed that the anisotropic properties were probably causes by weak interlayer inter-layer porosity and bonding.

Rajal bansal et al. [8] have observed the effect of dominant process parameters of FDM process such as part orientation, raster angle and layer thickness on the dimensional accuracy of the parts fabricated using ABS material. Due to shrinkage of the filament, the dimension of the CAD model does not match with the FDM process part the shrinkage dominates along length and width of the build part where as positive deviation is observed along thickness direction. Effect of each parameter response such as percentage change in length, width and thickness of build part are studied using response surface methodology. The optimization of process factors is made by genetic algorithm (GA) and finally they get optimum value of process parameter so the dimensional accuracy is improved. After the experimental work, they give the optimum setting of process parameters to get the improvement in dimensional accuracy.

B. H. Lee et al. [9] have carried out the experiments for finding out the optimal process parameters of fused deposition modeling rapid prototyping machine in order to achieve maximum flexibility of ABS material parts. They have taken help of Taguchi method for design of experiments (DOE). They also employed signal-to-noise (S/N) ratio and analysis of variance (ANOVA) to investigate the process parameters in order to achieve the optimum elastic performance of ABS prototype. From the results it was found that FDM parameters raster angle, layer thickness and air gap significantly affect the elastic performance of the compliant ABS prototype.

Ahn et al. [10] have investigated the characteristic properties of ABS parts fabricated by the FDM 1650 machine. They have examined the process parameters of FDM such as air gap, bead width, raster orientation, and color and model temperature by using design of experiments (DOE). Compressive strength and tensile strength of fabricated parts were measured and compared with injection molded ABS P400 material. After the experiments they have found that the air gap and raster orientation affect the tensile strength of an FDM parts. Bead width, model temperature and color have little effect on response properties. The measure tensile strength of the ABS material with optimum FDM parameter were between 65 to 72 % of the measured of injection molded ABS and the compressive strength ranged from 80 to 90 % of the injection molded ABS respectively.

L. M. Galantucci et al. [11] have studied the effect of FDM machine process parameters on acrylonitrile butadiene styrene (ABS) part surface finish. The surface finish of prototype after the modification of extrusion parameters has been measured and processed through designed experiment. They have investigated the chemical method to improve surface finish of the prototype. Finally they have concluded that the slice height and raster width are important parameters while the tip diameter has a little important for surface running either parallel or perpendicular to the build direction. A chemical post processing treatment has been analyzed and yields a significant improvement of the R_a of the treated specimen the proposed chemical treatment is economical, fast and easy to use. While varying the tip dimension, the response variable R_a remains the same and the raster width affects the top surface, also the slice height is major factor.

T.Nancharaiah et al. [12] have carried the experiments to determine the optimum dimensional accuracy and surface finish of a part built by the Fused Deposition Modeling (FDM) process. They have found that effect of the process parameters air gap, road width, raster angle and layer thickness on the dimensional accuracy and surface finish. Experiments were conducted using Taguchi's design of experiments with three levels for each factor. From the ANOVA analysis, it was found that the layer thickness and road width affect the surface quality and part accuracy greatly. Raster angle has little effect. But air gap has more effect on dimensional accuracy and little effect on surface quality.

IV. FULL FACTORIAL APPROCH FOR OPTIMIZATION OF FDM PROCESS PARAMETERS

D. Njoya and M. hajjaji et al. [13] have studied the changes in microstructure and technical properties of vitrified ceramic samples, made of kaolin tic-clay and feldspar-rich raw materials from Cameroon, against feldspar content, firing temperature and soaking time were studied by X-ray diffraction and scanning electron microscope, and with use of full factorial design. Mullite, glassy phase and spinal were formed. The results of the full factorial design showed that temperature was the most influential factor, and its increase had a positive effect on ceramic properties. The effects of the flux content and soaking time were somewhat comparable and their impacts were same to that of temperature. The effects of interactions between the factors were relatively less important and their weights differed for properties.

The full factorial design was very useful method for evaluating the effects of feldspar content, temperature and soaking time on vitreous ceramic properties. In that respect, one can conclude that the increase in temperature had a marked and positive effect on them ensured properties. Positive effects also were due to the increase of the flux content and soaking time. The weights of interactions between the factors were less affecting and varied for properties.

Alhubail Mohammad et al. [14] they have observed the effect of main FDM process variable parameters. Five important FDM process parameters like air gap, raster width, contour width, layer thickness and raster orientation are on their effect quality of dimensional accuracy, tensile strength and surface roughness. They have selected the new ABS M30, bio medical material in order to manufacture the parts, full factorial method was used for design of experiments (DOE) a number of analytical methods such as regression analysis, analysis of variance (ANOVA) were used to determine the influence of the variable FDM process parameter settings. After the experimental work they have found that not all FDM parameter have impact on the proposed response characteristics, they have also conclude that air gap parameters has been proved statistically to influence the surface finish of FDM built parts, building parts with thinner layer may reduce the surface roughness they have also find that negative air gap increase the tensile strength, layer thickness and raster width may prove better dimensional accuracy.

Shiba Narayan sahu et al. [15] have studied that that glass fiber reinforced plastics (GFRP) are having good weight to strength ratio, so they have wide range of application for many purposes. Micro drilling of GFRP produces de-lamination in it. So it is always needed to optimize the process parameters by minimizing torque and thrust force. The process parameters and response parameters values are used here for analyzing and optimizing the micro drilling of GFRP. The introduction of peck micro drilling in lieu of direct micro drilling was found to be responsible for lower value of torque and thrust force.

The optimized result of thrust force and torque was found to be 40000 and 5 of rpm and feed respectively for both direct and peck type of micro drilling. The main effect plot of full factorial methodology, one can conclude that feed is directly proportional to both torque and thrust force. Feed is also having maximum percentage of contribution towards torque and thrust force. With the decrease in speed the development of thrust force and torque is reducing.

V. CONCLUSION

From the above reviews one can conclude that the rapid prototyping technology is very promising modern technology. Among all RP techniques FDM is one of the techniques that give fast production of products. So the optimization of process parameters is very essential for achieving high part quality from FDM process. Full factorial method is much well suited approach for experimental design. ANOVA analysis is helpful to determine most significant factor which affect performance characteristics. The Response Surface methodology is the well suited tool for exploring relationship between explanatory variables and one or more response variables for creating better ideas.

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