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A REVIEW ON VARIOUS APPROACH FOR PROCESS PARAMETER OPTIMIZATION OF FUSED DEPOSITION MODELING (FDM) PROCESS AND TAGUCHI APPROACH FOR OPTIMIZATION

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Abstract
The aim of this paper is review for different optimization methods used for process parameter optimization of FDM fabricated parts and Taguchi approach used for process parameter optimization for various processes. Reduction of product development cycle time is the major concern in industries for achieving competitive advantage. Thus the focus of industries has shifted from traditional product development methodology to rapid fabrication techniques. The Fused deposition modeling (FDM) is one of the rapid prototyping technologies by which physical objected are created directly from CAD data. The quality of FDM fabricated parts are significantly affected by various process parameter used in this process. So it is necessary to optimize the process parameter of FDM to improve the quality of the parts. This review of work can be helpful to the other researchers to carry out further work in the same era.

Key words: Fused deposition modeling (FDM), Optimization and Taguchi approach

Introduction
The competition in the world market for manufactured the product has intensified tremendously in recent years. It has become important the new product to reach the market as early as possible for achieving competitive advantage. So future is clear as rapid prototyping (RP) is now becoming the key technology that shorter product development cycle time for faster building of physical prototypes, tooling and models. Fused deposition modeling (FDM) is one of the RP systems that produced prototype from plastic materials by lying tracks of semi molten plastic filament on to a platform in a layer wise manner from bottom to top [4]. The quality of FDM manufactured parts is affected by various process parameter used in this process. There is a need for optimizing the process parameters both from technological and economic point of view. Optimization of process parameters helps to finding out the correct adjustment of parameter which improves the quality of the prototypes. Taguchi method is powerful tool for optimization of process design. The primary advantages for design of experiments using Taguchi's technique include simplification of experimental plan and feasibility of study of interaction between different parameters [1].

Problem formulation
In today's competitive market the quality of parts like surface finish, mechanical strength, dimensional accuracy etc. is most important things to satisfy and attract the customers. In the FDM machine the quality of the parts is highly depends upon the various process parameters of the process. For that, process parameter optimization of FDM process should be carried out. It will improve the quality of functional parts. There are different methods of optimization of process parameter like factorial design, Taguchi method, central composite design; response surface methodology etc. From these different methods of optimization, Taguchi approach is more powerful technique. Currently high quality of the parts with low cost and in shorter time period is the demands from the users. This is the big challenge so it is necessary to optimize the process parameter of respective machines.

Various Approach for optimization of FDM process
Optimization of process parameters helps to finding out the correct adjustments of parameters which improve the quality of prototypes. Review of various approaches which is used by other researchers for process parameter optimization of FDM process is discussed in this section.

R. Anitha et al., (2001) have performed the experiments to assess the influence of the parameters on the quality of the prototype. The Taguchi's design matrix L18 orthogonal array was selected for design of experiments. The factors and their levels selected for the study is shown in Table 1. They found that layer thickness is effective to 49.37% at 95%

level of significance, but on pooling, it was found that the layer thickness is effective to 51.57% at 99% level of significance. The other factors suggest road width and speed contribute to 15.57% & 15.83% at 99% level of significance respectively. According to the S/N analysis the layer thickness is most effective when it at level 3(0.3556mm), the road width at level 1 (0.537mm) & the speed of deposition at level 3(200 mm) [1].

Ahn et al., (2002) have characterized the properties of ABS parts fabricated by the FDM 1650. They have examined the process parameters of FDM such as raster orientation, air gap, bead width, color and model temperature by using design of experiments (DOE). Tensile strength and compressive strength of directionally fabricated specimens were measured and compare 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 greatly which is shown in the Fig.1. Bead width, model temperature and color have little effect. 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 [2].

K. Thrimurthulu et al., (2004) have tried to attempt towards obtaining an optimum part deposition orientation of fused deposition modeling process for enhancing part surface finish and reducing built time. They develop model for evolution of average part surface finish and built time. Fig. 2 represents the implementation of genetic algorithm which was used to obtain the optimal solution. Average part roughness and the built up time of the part are consider as two objectives. The effect of the support structure is considered in the evolution of the two objectives. Thus, the support structure minimization is also implicitly included in this work. The adaptive slicing is simultaneously used in the determination of optimum part deposition orientation. The predictions of the develop system are validated using the results published earlier [3].

Lee et al.,(2005) have perform the experiments for finding out the optimal process parameters of Fused deposition modeling rapid prototyping machine in order to achieve maximum flexibility of ABS prototype. They used Taguchi method for design of experiments. 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 layer thickness, raster angle and air gap significantly affect the elastic performance of the compliant ABS prototype [4].

A. K. Sood et al., (2010) have investigated the effect of some important FDM process parameters for mechanical strength of test specimens shown in Fig.3. They adopted central composite design (CCD) for design of experiments. Optimal parameters setting for each response is determined using ANOVA. After the experimental works they have conclude that if the layer thickness increases, less number of the layer will be required and distortion effect will minimized, hence strength is increase. They also find out that the strength of prototype will decrease with increase in orientation because of the number of layer also increase with it [5].

A. K. Sood et al., (2011) have studied the effect of five important FDM machine process parameter such as layer thickness, part build orientation, raster angle, raster width and air gap on compressive strength of test specimens. The experiments were conducted using central composite design (CCD) method. Effect of various factors and their interactions are explained using response surface plot. Optimization of process parameters gives the maximum compressive stress of 17.4751 MPa and the optimum value of layer thickness, orientation, raster angle, raster width and air gap as 0.254 mm, 0.036 degree, 59.44degree, 0.422 mm and 0.00026 mm respectively given by statistically predictive equation [6].

Taguchi Approach for optimization

The Taguchi method is a well-known technique that provides systematic and efficient methodology for design optimization. Design of experiment using Taguchi's technique includes simplification of experimental plan with minimum experiments.

S. Shaji et al., (2003) have investigated the possibility of using graphite as lubricating medium to reduce the heat generated at the grinding zone in surface grinding. They have studied the effect of parameters such as speed, feed, in feed and mode of dressing on the performance characteristics of surface finish and force developed. Factors and their levels selected for the study is indicate in Table 3.Total nine experiments were carried out by using Taguchi's standard L9 orthogonal array design (Table 4) to find out the effects of parameters on force developed and surface quality. After the experimental work optimum condition has been found out and they observed that the result obtain in the conventional coolant grinding is in a good agreements with the results obtained graphite assisted grinding. It has been observed that with the graphite application, the tangential force and surface roughness are lower compare to those in conventional grinding [7].

Ulas et al., (2007) were developed, artificial neural network (ANN) and regression model to predict surface roughness in abrasive water jet machining (WAJM). They have consider machining parameters such as traverse speed, water jet pressure, standoff distance, abrasive grit size and abrasive flow rate. They have used Taguchi's design of experiments in order to collect the surface roughness values. Analysis of variance (ANOVA) was used to check the validity of regression model. At the end of the study, both the ANN and regression analysis results were comparing with experimental data. It can see from the Fig.4 that both the models ANN and regression presents a good agreement with the experimental data. Based on the ANOVA (Table 2), the most dominant parameter on the surface roughness was found as water jet pressure. Abrasive flow rate and standoff distance were less effective on surface roughness, while effect of abrasive grit size can be negligible [8].

D. Chakradhar et al., (2011), have investigated the effect and parametric optimization of process parameters for electrochemical machining of EN-31 steel. The process parameters consider are electrolyte concentration, feed rate and applied voltage and are optimize with considerations of multiple performance characteristics including material removal rate, over cut, cylindrical error and surface roughness. They used Taguchi's standard L9 orthogonal array design for performing experiments. They performed the ANOVA to get the contribution of each parameter on the performance characteristics. After the experimental works they found that the best combination of process parameters are electrolyte concentration at 15%, feed at 32 mm/min and voltage at 20 V. From the results they have conclude that the material removal rate can be maximize and the over cut, cylindercity error and surface roughness can be minimized through this method [9].

Anoop et al., (2008) have optimized the efficiency of pulsed ND: YAG laser for the laser surface structuring of porous alumina ceramic. The laser processing parameters like the pulse width, repetition rate and the scanning speed were evaluated. The Taguchi's standard L9 orthogonal arrays were used to identify the combination of process parameters for optimize physical attribute of the ceramic. ANOVA is carried out to identify the processing parameters that contributed the most to minimize the porosity and maximize the grain size. After the experimental work they have conclude that the pulse repetition rate was the most significant factor in minimizing the interdendritic porosity while the scanning speed played a vital role in increasing the grain size [10]

Fig.1 Plot of tensile strength (MPa) versus main effects

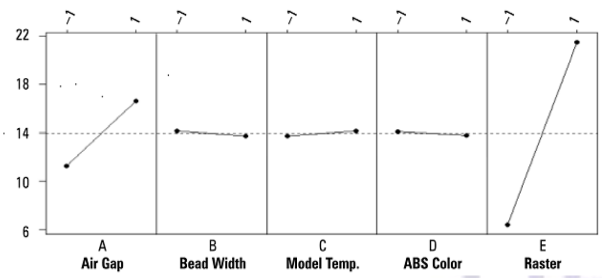


Fig.3 Test sample for mechanical strength(dimensions are in mm)

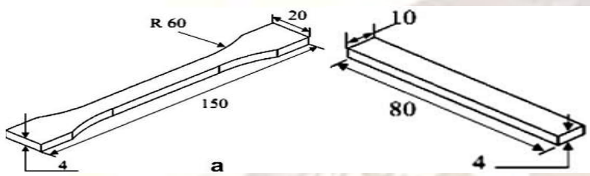
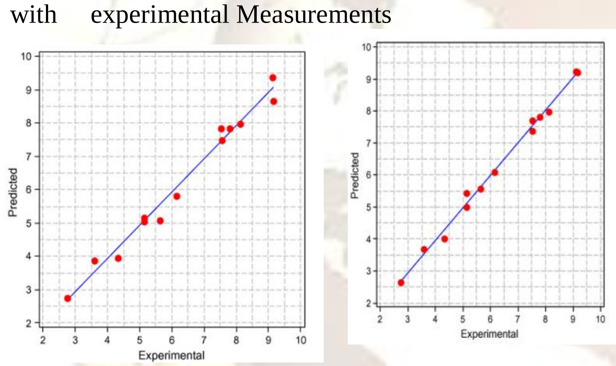


Fig.4 Comparison of (A) ANN and (B) regression results with experimental Measurements



(A) (B)

Table 1 List of process variable and their level

Factors	Level 1	Level 2	Level 3
Layer thickness (mm)	0.1778	0.254	0.3556
Road width (mm)	0.537	0.622	0.706
Speed deposition (mm)	100	150	200

Table 3 Factors and their level selected for the study

Factor	Label	Level-1	Level-2	Level-3
Speed (m/s)	*S*	22	27	32
Feed (m/min)	*F*	5	10	15
Infeed (μm)	IF	10	20	30
Mode of dressing	DR	Fine[a]	Medium[b]	Coarse[c]

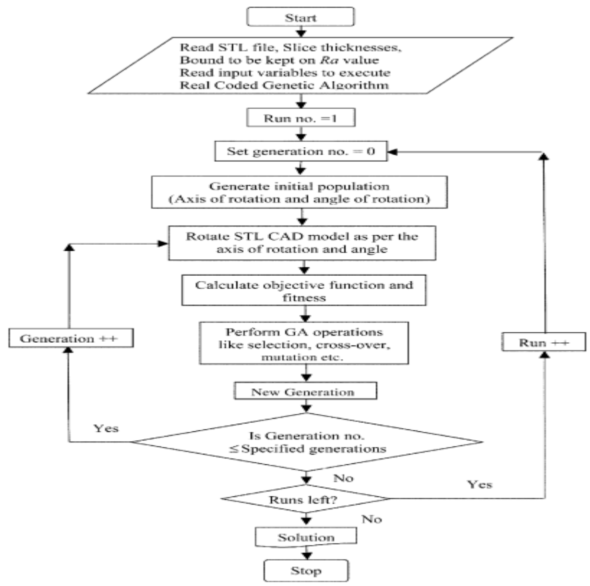


Fig.2 Implementation procedure of genetic algorithm

Table 2 Result of the ANOVA for the surface roughness

Machining parameter	Degree of freedom (f)	Sum of squares (SS_A)	Variance (V_A)	F_{A0}	Contribution (%)
Traverse speed	2	22.21	11.11	2.60	17.81
Waterjet pressure	2	88.39	44.20	29.23	70.89
Standoff distance	2	2.84	1.42	0.28	2.28
Abrasive grit size	2	0.89	0.44	0.09	0.71
Abrasive flow rate	2	9.08	4.54	0.94	7.28
Error	24	4.39	2.195		1.03
Total	34	127.8			100

Table 4 Standard L_9 OA with factors and levels

Trial no.	Factors and their levels			
	S	*F*	IF	DR
1	1	1	1	1
2	1	2	2	2
3	1	3	3	3
4	2	1	2	3
5	2	2	3	1
6	2	3	1	2
7	3	1	3	2
8	3	2	1	3
9	3	3	2	1

Conclusion

From the above reviews we can conclude that Taguchi's approach is versatile tool for process design optimization. The Taguchi's tool such as orthogonal array, signal to noise ratio, factor effect analysis (ANOVA) is most effective to get the contribution of each parameter and to determine significant parameters which affect the performance characteristic respectively. There are different optimization methods but as shown in above reviews researchers got better results with Taguchi's approach because of it can be provide systematic, efficient and simplification of experimental plan with minimum experiments so the time and cost are reduced concerned with manufacturing.

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