Improving the Performance of FDM Machine Objects by using Optimization Techniques

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Abstract— Fused deposition modeling (FDM) is one of the rapid prototyping processes that use the plastics materials such as ABS (Acrylonitrile – butadiene – styrene) in the semi molten state to produce the goods directly from CAD model. FDM is an additive manufacturing method and the prototypes is completed by layer by layer addition of semi-molten synthetic material onto the platform from bottom to top. The design investigates the effect of the process parameter layer thickness, raster width, raster angle and air gap that influences the surface roughness of the piece produced by the process of Fused Deposition Modeling. Hence, the Optimization of these process parameters of FDM is gifted to make the system more specific and repeatable and such progression can direct to use of FDM in rapid manufacturing application to a certain extent than only producing prototypes. The novel ABS- M30 biomedical matter was used in this investigates work to build parts. The experimentation has been completed with the help of Taguchi. Taguchi grey relational analysis is used to optimize the process parameters on multiple performance distinctiveness such as length, diameter, width and surface finish. The experimental result investigation showed that the combination of Layer thickness(A), Orientation(B), Raster angle(C), Raster width(D) and Air gap(E) is essential to achieve minimization of surface roughness and maximum of dimensional accuracy.

Key words: FDM, Optimization Techniques

I. Introduction

The term rapid prototyping (RP) refers to a class of technologies that can involuntarily construct physical models from Computer-Aided Design (CAD) data. These "3-D printers" permit designers to quickly create physical prototypes of their designs, to a certain extent than just two dimensional pictures. Such models have copious uses. They make excellent visual aids for communicating dreams with co-workers or consumers.

In addition, prototypes can be used for design testing. For example, an aerospace engineer may mount a model airfoil in a wind tunnel to gauge lift and lug forces. Designers have always utilized prototypes; RP allows them to be made faster and less expensively. In addition to prototypes, RP techniques can also be used to make tooling (referred to as rapid tooling) and even production-quality parts (rapid manufacturing). For tiny production runs and complex objects, rapid prototyping is often the best manufacturing process available. Of course, "rapid" is a relative term.. These impressive time savings allow manufacturers to bring products to market faster and more cheaply. In 1994, Pratt & Whitney achieved "an order of magnitude [cost] reduction [along with] . . . time savings of 70 to 90 percent" by incorporating rapid prototyping into their investment casting process.

Although several rapid prototyping techniques exist, following is the most popular basic five-step process. The steps are:

1) Create a CAD model of the design
2) Convert the CAD model to STL format
3) Slice the STL file into thin cross-sectional layers
4) Construct the model one layer atop another
5) Clean and finish the model

FDM is one of the RP technology developed by Stratasys, USA . But unlike other RP systems which involve an collection of lasers, powders, resins, this process use heated thermoplastic filaments which be extruded from the tip of nozzle in a temperature controlled surroundings. For this there is a material deposition subsystem known as head which consist of two liquefier tips. One tip intended for model material and other tip intended for support material deposition both of which works alternatively. The piece forming material is supplied to the head in the form of a flexible strand of solid material from a supply source (reel). One pair of pulleys or rollers have a nip in flanked by are utilize as material advance mechanism to grip a flexible filament of modeling material and advance it into a heated dispensing or liquefier head. The material is heated above its solidification heat by a heater on the dispensing head and extruded in a semi molten state on a previously deposited material onto the build stage following the designed tool path.

The head is attached to the coaches that move along the X-Y plane. The build platform moves along the Z direction. The drive motion are provide to selectively move the build platform and dispensing head relative to each other in a predetermined pattern through constrain signals input to the drive motors from CAD/CAM system. The fabricated part takes the form of a laminate composite with vertically stack layers, each of which consists of contiguous material fibres or raster width interstitial voids. Fibre-to-fibre bonding within and among layers occurs by a thermally-driven diffusion bonding process during solidification of the semi-liquid extruded fibre.

FDM Vantage uses insight software to import STL file automatically slice the file, generate necessary support structure and material extrusion path.

- Power required - 230 V, AC
- Motor - 50/60 Hz, 3Φ
- Max. Room temperature- 29.3^{o}C
- Size of the system - 1277mm wide * 874 mm deep * 1950 mm height

Earlier studies (Mahapatra, et al, 2009), (Ahn, et al, 2002) have reported that FDM parameters such as layer thickness, air gap, raster width, and raster orientation were significantly impacting the quality characteristics of build parts. The FDM systems available in the market are different in their build speed, build volume, range of parameter settings and build materials (Masood, et al, 2010).

In relevant empirical studies, parametric optimization was used to develop the quality characteristics of FDM parts or the process performance, where the number of FDM process parameters were studied and optimized. For instance, (Lee, et al, 2005) and (Laeng, et al, 2006) investigated the elasticity performance of ABS material. Similarly, (Anitha, et al, 2001) optimized the FDM process parameters improving the surface roughness of build parts, while (Gregorian, et al., 2001), (Sood, et al., 2010) have looked into the dimensional accuracy of FDM parts

The material used for the present investigation is ABS M30 plastic

II. Experimental Plan

A trial run was performed in which a series of samples were built on the FDM machine using ABS M30 material. The machine is equipped with Insight software that assists the user to adjust the variable parameters in building part specification. Principally, the FDM variables are considered as four groups of operating parameters, as follows; FDM build specification, FDM environment/machine, and material specification. The full factor experiment was obtained to develop the experimentation plan for five parameters and three levels, considering the highest number of experimentation runs for the specified number of runs and levels in order to optimize the maximum parameters combinations. In this study, Full factor experiment, Box-Behnken design (three levels-five factors) has been selected initially according to the number of FDM variable parameters and number of settings or levels. Four parts per experiment are fabricated by the use of FDM Vantage SE machine. ABS m30 is the material used for fabricating the designed part. The surface roughness is taken to be the representative value respectively. Mitutoyo Talysurf is used to measure the surface roughness

CONTROL FACTORS				
Factor	Symbol	Levels		
		1	2	3
Layer thickness (mm)	A	0.127	0.178*	0.254
Orientation (°)	B	0	15	30
Raster angle (°)	C	0	30	60
Raster width (°)	D	0.4064	0.4564	0.5064
Air gap (mm)	E	0	0.004	0.008
*modified centre level value				

Table 1: Control Factors

S.NO	A	B	C	D	E	LENGTH	DIAMETER	THICKNESS	ROUGHNESS
1.	1	1	1	1	1	0.025833	0.9903	4.6667	2.1058
2.	1	1	1	1	2	0.0125	0.9938	2.6667	2.8062
3.	1	1	1	1	3	0.0475	0.9918	3.667	6.9003
4.	1	2	2	2	1	0.071667	0.9899	3.5833	6.372233
5.	1	2	2	2	2	0.06333	0.911	2.5833	2.544867
6.	1	2	2	2	3	0.057	0.9892	2.9167	2.180467
7.	1	3	3	3	1	0.12	0.9899	3.9167	3.611833
8.	1	3	3	3	2	0.106	0.9897	2.5833	3.606433
9.	1	3	3	3	3	0.048	0.9885	2.6667	1.917867
10	2	1	2	3	1	0.19	0.9914	3.83	3.130267
11	2	1	2	3	2	0.17	0.9897	2.6667	6.346833
12	2	1	2	3	3	0.02	0.991	3.1667	4.028567
13	2	2	3	1	1	0.137	0.9897	4	2.9945
14	2	2	3	1	2	0.117	0.9894	3.75	2.1671
15	2	2	3	1	3	0.012	0.9913	2.667	7.254867
16	2	3	1	2	1	0.0333	0.9925	4.3333	5.599933
17	2	3	1	2	2	0.07	0.9911	4.5	4.084567
18	2	3	1	2	3	0.09	0.9922	3.6667	3.707867
19	3	1	3	2	1	0.14	0.9979	4.833	1.9162
20	3	1	3	2	2	0.13	0.9929	4.5	2.097433
21	3	1	3	2	3	0.07	0.9888	3	3.0828
22	3	2	1	3	1	0.04	0.9968	3.6667	3.638867
23	3	2	1	3	2	0.06	0.9943	4.5833	3.092767
24	3	2	1	3	3	0.025	0.9901	2.5883	2.657233
25	3	3	2	1	1	0.137	0.9936	4	2.646733
26	3	3	2	1	2	0.117	0.9969	3.75	2.917867
27	3	3	2	1	3	0.121	0.9889	3.4167	3.0783

Table 2: Plan

III. Analysis and Discussion of Experimental Results

In the grey relation analysis, experiment data, i.e., measured responses are first normalized in the range of 0 to 1. This process is called normalization or grey relation generation. There are three different types of data normalization according to the requirement of Lower the Better (LB), Higher the Better (HB), or Nominal the Best (NB) criteria.

S.No	S/N Ratio Of Length	S/N Ratio of Diameter	S/N Ratio Of Thickness	S/N Ratio Of Surface Roughness
1	31.7565	0.084664	-13.3802	-6.4683
2	38.0618	0.05402	-8.51948	-8.9624
3	26.46613	0.071518	-11.2862	-16.7774
4	22.89362	0.088174	-11.0857	-16.0858
5	23.96781	0.07765	-8.2435	-8.1133
6	24.8825	0.094318	-9.29784	-6.7710
7	18.41638	0.088174	-11.8584	-11.1546
8	19.49388	0.089929	-8.2435	-11.1416
9	26.37518	0.100467	-8.51948	-5.6564
10	14.42493	0.075022	-11.664	-9.9116
11	15.39102	0.089929	-8.51948	-16.0511
12	33.9794	0.078527	-10.0121	-12.1030
13	17.26559	0.089929	-12.0412	-9.5265
14	18.63628	0.092562	-11.4806	-6.7176
15	38.41638	0.075898	-8.52046	-17.2126
16	29.55112	0.06539	-12.7358	-14.9637
17	23.09804	0.07765	-13.0643	-12.2229
18	20.91515	0.068016	-11.2855	-11.3825
19	17.07744	0.01826	-13.6843	-5.6488
20	17.72113	0.06189	-13.0643	-6.4338
21	23.09804	0.097831	-9.54243	-9.7789
22	27.9588	0.027839	-11.2855	-11.2193
23	24.43697	0.049651	-13.2236	-9.8069
24	32.0412	0.086419	-8.2435	-8.4886
25	17.26559	0.055768	-12.0412	-8.4542
26	18.63628	0.026968	-11.4806	-9.3013
27	18.34429	0.096952	-10.6721	-9.7662

A. *Normalization*

Normalization of the signal to noise ratio is performed to prepare raw data for the analysis where the original sequence is transformed to a comparable sequence. Linear normalization is usually required since the range and unit in one data sequence may differ from the others.

There are three different types of data normalization according to the requirement of Lower the Better (LB), Higher the Better (HB), or Nominal the Best (NB) criteria.

If the target value of original sequence is infinite, then it has a characteristic of the "higher is better". The original sequence can be normalized as follows:

$$x_i^* = \frac{x_i^o(\mathrm{k}) - \min x_i^o(\mathrm{k})}{\max x_i^o(\mathrm{k}) - \min x_i^o(\mathrm{k})} \quad (1)$$

When the "Smaller is better" is a characteristic of the original sequence, then the original sequence should be normalized as follows:

$$x_i^* = \frac{\max x_i^o(\mathrm{k}) - x_i^o(\mathrm{k})}{\max x_i^o(\mathrm{k}) - \min x_i^o(\mathrm{k})} \quad (2)$$

S.no	Normalization of length	Normalization of diameter	Normalization of thickness	Normalization of surface roughness
1	0.2775	0.1922	0.9441	0.0709
2	0.0147	0.5650	0.0507	0.2865
3	0.4980	0.3521	0.5592	0.9624
4	0.6470	0.1495	0.5224	0.9026
5	0.6022	0.2775	0.0000	0.2131
6	0.5641	0.0748	0.1938	0.0970
7	0.8336	0.1495	0.6644	0.4761
8	0.7887	0.1282	0.0000	0.4750
9	0.5018	0.0000	0.0507	0.0007
10	1.0000	0.3095	0.6287	0.3686
11	0.9597	0.1282	0.0507	0.8996
12	0.1848	0.2669	0.3251	0.5581
13	0.8816	0.1282	0.6980	0.3353
14	0.8244	0.0962	0.5950	0.0924
15	-0.0001	0.2989	0.0509	1.0000
16	0.3694	0.4267	0.8257	0.8055
17	0.6385	0.2775	0.8860	0.5685
18	0.7294	0.3948	0.5591	0.4958
19	0.8894	1.0000	1.0000	0.0000
20	0.8626	0.4693	0.8860	0.0679
21	0.6385	0.0321	0.2387	0.3572
22	0.4358	0.8835	0.5591	0.4817
23	0.5826	0.6181	0.9153	0.3596
24	0.2656	0.1709	0.0000	0.2456
25	0.8816	0.5437	0.6980	0.2426
26	0.8244	0.8941	0.5950	0.3159
27	0.8366	0.0428	0.4464	0.3561

B. *Calculation of Grey Relational Coefficient (GRC)*

GRC for all the sequences expresses the relationship between the ideal (best) and actual normalized S/N ratio. If the two sequences agree at all points, then their grey relational coefficient is 1. The grey relational coefficient ξi(k) for the kth performance characteristics in the ith experiment can be expressed as :

$$\xi_i(k) = \frac{x_i^o(\mathrm{k}\Delta\min + \zeta\Delta\max)}{\Delta O_i(k) + \zeta\Delta\max}$$

s.no	Length GRC	Diameter GRC	Surface roughness GRC	Thickness GRC
1	0.4090	0.3823	0.349863	0.8995
2	0.3366	0.5348	0.412047	0.3450

3	0.4990	0.4356	0.929995	0.5315
4	0.5861	0.3702	0.836906	0.5114
5	0.5569	0.4090	0.388537	0.3333
6	0.5342	0.3508	0.35639	0.3828
7	0.7503	0.3702	0.488338	0.5984
8	0.7029	0.3645	0.487803	0.3333
9	0.5009	0.3333	0.333479	0.3450
10	1.0000	0.4200	0.441944	0.5738
11	0.9255	0.3645	0.832725	0.3450
12	0.3802	0.4055	0.530864	0.4256
13	0.8085	0.3645	0.429306	0.6234
14	0.7401	0.3562	0.35522	0.5525
15	0.3333	0.4163	1	0.3450
16	0.4423	0.4659	0.719962	0.7415
17	0.5803	0.4090	0.536774	0.8144
18	0.6489	0.4524	0.497924	0.5314
19	0.8189	1.0000	0.333333	1.0000
20	0.7844	0.4851	0.349133	0.8144
21	0.5803	0.3406	0.437506	0.3964
22	0.4698	0.8110	0.491024	0.5314
23	0.5450	0.5670	0.438436	0.8552
24	0.4051	0.3762	0.398589	0.3333
25	0.8085	0.5229	0.397646	0.6234
26	0.7401	0.8252	0.422246	0.5525
27	0.7537	0.3431	0.437086	0.4746

Table 3: Calculations

The overall quality characteristics of the multi-response process depend on the calculated grey relation grade. After the grey relational coefficient is derived, it is usual to take the average value of the grey relational coefficients as the grey relational grade. The grey relational grade is defined as follows:

$$\gamma_{i=1/n}\sum_{k=1}^{n}\xi i(k)$$

The grey relational grade γ_i represents the level of correlation between the reference sequence and the comparability sequence.

Experiment number	Weighted grey relational grade
1.	0.510162
2.	0.407108
3.	0.599026
4.	0.576186
5.	0.421949
6.	0.406057
7.	0.551818
8.	0.472138
9.	0.378184
10.	0.608945
11.	0.616917
12.	0.435521
13.	0.556437
14.	0.500997
15.	0.523656
16.	0.592386
17.	0.58513
18.	0.532652
19.	0.788065
20.	0.608259
21.	0.438725
22.	0.575819
23.	0.601407
24.	0.378296
25.	0.588118
26.	0.635007
27.	0.502116

Table 4: Results

The weighted grey relational grade calculated for each sequence is taken as a response for the further analysis. The larger-the-better quality characteristic was used for analyzing the GRG, since a larger value indicates the better performance of the process. The number of repeated test is one, since only one relational grade was acquired in each group for this particular calculation of S/N.

The grey relation grades are now analyzed with Taguchi in Minitab17 software. This result shows that the best processing condition is the (A3, B1, C1, D2, and E1).

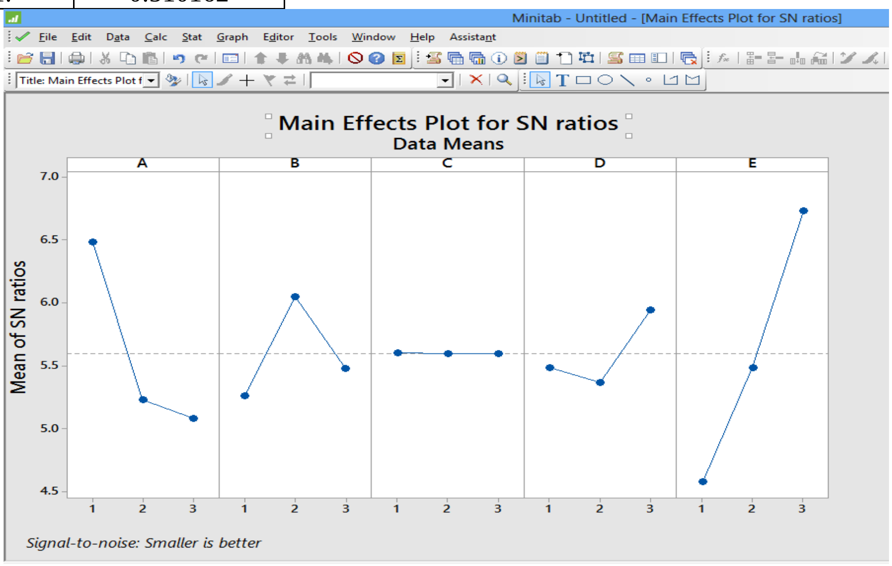

Fig. 1: Optimum results in Minitab

C. Optimum Conditions

	Layer thickness	Part orientation	Raster angle	Raster width	Air gap
Level	A3	B1	C1	D2	E1
Values	0.254	0	0	0.4564	0.000

Table 5: Optimum conditions

After determining the optimum conditions, confirmation test is to be done to check the responses obtained from the optimum conditions. The obtained optimum values are

- Length - 139.76 mm,
- Thickness - 3.43 mm,
- Diameter - 49.5mm and
- Surface roughness -4.059 microns.

IV. CONCLUSION

The selection of right combination of input parameters in FDM is difficult as the process involves a large number of control variables. The effects of input layer thickness, raster width, raster angle and air gap on surface roughness, length, diameter, while machining the ABS M30 material were analyzed with the experimental data obtained after conducting the experiments as per the Design of Experiments.

Grey Relational Analysis (GRA), to determine the optimal parameters affecting Surface Roughness is 4.059 microns are found at A3, B1, C1, D2 and E1. Further study Artificial intelligent system such as the fuzzy logic system, simulated annealing, genetic algorithms might be used to enhance the ability of the prediction system.

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