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EFFECT OF FABRICATION PARAMETERS AND MATERIAL FEATURES ON DIMENSIONAL ACCURACY OF FDM BUILD PARTS

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ABSTRACT

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This paper presents experimental investigations on influence of fabrication parameters viz., layer resolution, processing quality, fill mode and the processing material on dimensional accuracy of fused deposition modelling (FDM). The test specimen is designed and the levels of each factor are setup. Then Taguchi's parameter design is applied to find optimum parameters setting to minimize percentage change in direction of X, Y and Z of test specimen. As the percentages changes are obtained, the signal to noise ratio is defined to evaluate the influence and variation. Then main effect plot is drawn to find optimal level of fabrication parameters. The results indicate that optimal factor settings for each performance characteristic are different. Therefore, analysis of variance is performed to calculate the significance level of experiment factors affecting to the dimensional accuracy in each direction. Finally, the effect of fabrication parameters and material features on dimensional accuracy of FDM build parts is obtained.

KEYWORDS

Fused Deposition Modelling, Dimensional Accuracy, Taguchi's Parameter Design, Main Effect Plot, Analysis of Variance

1. INTRODUCTION

With the development of computer technology and the application of new material, additive manufacturing which commonly known as 3D printing has been used widely across the world due to its short productive cycle, and will surely play a more and more important part in people's lives [1]. According to 3D printing, 3D solid models are fabricated from CAD data automatically without special tools or moulds. As a result, 3D printing has several advantages especially in its ability to produce products with complex structure compared to traditional subtractive manufacturing [2]. The 3D printing includes technologies like fused deposition modeling (FDM), selective laser sintering (SLS), stereolithography apparatus (SLA), laminated object manufacturing (LOM), and so on. The FDM melts the filamentous material with the nozzle and makes the object by deposit the hot-melt materials, and features simple mechanical structure, easily operation and low material cost. As a result, the FDM developed rapidly and becomes the most popular technology. Nevertheless, it has been proposed that improvement of surface quality, part strength, build time, accuracy and repeatability are key issues to be addressed for successful implementation of 3D printing [3]. Several attempts have been made to carried out the effects of factors like data processing, build orientation, machine structure, fabrication parameters, material features on properties of 3D build parts [4,5]. However, the existing researches consider low number of factors and all the processes proceeding with different equipment have their own relative merits and demerits.

Therefore, the fabrication parameters and materials are selected and Taguchi's parameter design is applied to understand process parameters and their effects on response like dimensional accuracy of FDM build parts in this paper.

2. EXPERIMENTAL SETUPS

The UP Plus 2 produced by Beijing Tiertime Technology Co. Ltd is used as FDM printing equipment. The build volume is 140 x 140 x 135 mm and the

filament diameter is 1.75 mm. The fabrication parameters of the equipment include processing quality, layer resolution, fill mode, sealing surface setting, support setting, extruder temperature, platform temperature. The equipment can fabricate parts with extruded materials like ABS, ABS+, PLA, conductive and more.

A test specimen is designed to measure the dimensional accuracy of the FDM build parts and the detail drawing of which is shown in figure 1. Considering the support will surely reduce the quality of the bottom surface and result in great measurement errors, the test specimen is constructed with a pedestal. The nominal dimension of X, Y and Z of the body are set to 10 mm. 3D solid model of the test specimen is built in Pro/Engineer 5.0 software and exported as STL file.

Figure 1: Detail drawing of test specime

Considering not all the factors has a great effect on dimension accuracy of FDM build parts, the fabrication parameters like processing quality, layer resolution, fill mode and the processing material set to ABS or PLA are selected as the affecting factors in the experiment. Then the other fabrication parameters are set to defaults, which are value the same during the FDM printing of experiments besides the adaptation extruder temperature set by equipment system according to the processing material. Moreover, the affecting factors include layer resolution, processing quality, fill mode and the processing material are considered as factor A, B, C and D, respectively. And the values of each factors in the experiment are shown in Table 1. The processing quality as well as fill mode values 3 levels while the layer resolution values 6 levels.

Table 1: Values of each factors

Factors Levels	A	B	C	D
1	0.15 mm	fast	Completely Filled	PLA
2	0.20 mm	normal	Incompletely Filled	ABS
3	0.25 mm	fine	Shell	
4	0.30 mm			
5	0.35 mm			
6	0.40 mm			

After that, an experiment plan is designed based on orthogonal test design (OTD) with mixed levels according to Taguchi's parameter design. The OTD can not only improve the uniformity of factors' value during tests, but also reduce the test time which referring to experiment time cost. The number of tests in designed experiment plan is 27 and expressed by N . Each test in experiment is operated n times and n is set to 5. The FDM printing of test specimen and the axes of the FMD printing equipment is shown in Figure 2.

Figure 2: The FDM printing of test specimen

3. RESULT ANALYSIS AND DISCUSSION

Three readings of X, Y and Z are taken per sample and percentage change in dimension is calculated by

$$\Delta D_i = \frac{|D_i - D_0|}{D_0} \times 100 \quad (1)$$

where D_i represents the measurement value of X or Y or Z while i is the operation index of each test and valued $1 \sim n$. D_0 represents the nominal dimension of the test specimen and ΔD_i stands for percentage change in D_i . According to Taguchi's parameter design, signal to noise (S/N) ratio is applied to evaluate the influence and variation caused by each factor to the total variation observed in the result. Since the objective of experiment plan is to reduce the percentage change in X, Y and Z, smaller the better quality characteristic is considered. Consequently, S/N ratio expressed as η can be determined by

$$\eta = -10 \log_{10} \left(\frac{\sum_{i=1}^n \Delta D_i^2}{n} \right) \quad (2)$$

Experimental data on percentage change in dimensions of each test is convert to S/N ratio and shown in Table 2. The range of S/N ratio is [-13.74, 12.64] for ΔX , [-9.92, 7.96] for ΔY , [-4.78, 13.98] for ΔZ . Main effect plot for S/N ratio shown in Figure 3 is used to predict optimum factor level with significant factors. The results indicate that optimal factor settings for each direction of the FDM build part are different. According to main effect plot, the optimum factor levels for ΔX , ΔY , ΔZ are $A_1B_3C_1D_2$, $A_1B_3C_1D_1$ and $A_4B_3C_1D_1$, respectively. Table 2 shows the delta values stand for response of ratio. The values show that the influence of the factors follows the sequence as $B > A > C > D$ for ΔX , $A > B > C > D$ for ΔY , $A > B > C > D$ for ΔZ . And then the relative influence of each factor is determined by analysis of variance (ANOVA). Parameters of ANOVA like degree of freedom (DOF), sum of square deviation (SS), mean square (MS), F-ratio (F) and p-value (P) is calculated and shown in table 3-5. As the significance level is set to 0.05, it is considered that the factor has obvious influence on the dimensional accuracy when $P < 0.05$ and vice versa. It is observed that significant factors are A and B for ΔX , B for ΔY , A, B and C for ΔZ .

Table 1: S/N ratio of percentage change in experiment plan

Exp. No.	Factors				S/N ratio		
	A	B	C	D	% ΔX	% ΔY	% ΔZ
1	1	1	1	1	-1.82	0.29	1.24
2	1	1	2	1	-0.56	2.31	0.60
3	1	2	1	2	4.44	0.29	1.94
4	1	2	3	1	5.46	3.52	-1.58
5	1	3	2	2	11.48	3.52	2.69
6	1	3	3	1	12.64	6.02	1.24
7	2	1	2	1	-6.58	-2.28	-2.50
8	2	1	3	1	-6.02	-1.82	-2.92
9	2	2	1	1	4.44	0.00	1.94
10	2	2	2	2	4.44	0.92	3.52
11	2	3	1	1	7.26	7.96	4.44
12	2	3	3	2	7.96	0.00	2.69
13	3	1	1	1	-11.05	-5.11	-0.56
14	3	1	3	1	-8.30	-7.60	0.00
15	3	2	2	1	-2.28	-0.83	0.60
16	3	2	3	2	-4.94	0.00	1.94
17	3	3	1	2	9.54	-0.28	2.69
18	3	3	2	1	6.62	7.26	6.62
19	4	1	3	2	-11.13	-7.36	1.24
20	4	2	2	1	-8.94	-3.90	5.46
21	4	3	1	1	-1.34	6.02	13.98
22	5	1	1	2	-2.05	1.58	-1.09
23	5	2	3	1	-9.45	-4.78	-2.05
24	5	3	2	1	8.71	1.58	0.00
25	6	1	2	2	-13.74	-9.92	-4.78
26	6	2	1	1	0.92	-7.60	-0.56
27	6	3	3	1	-3.52	3.52	-1.58

Figure 3: Main effect plot (a) ΔX , (b) ΔY and (c) ΔZ for S/N ratio

Table 3: Response of S/N ratio

Factor	Delta		
	X	Y	Z
A	12.4087	7.3277	9.2014
B	13.40135	7.2789	4.6154
C	3.07035	1.2951	2.7829
D	1.43243	1.504	0.1466

Table 4: ANOVA table for S/N ratio of ΔX

Source	DOF	SS	MS	F	P
A	5	449.08	89.82	7.35	0.001
B	2	810.02	405.01	33.13	0
C	2	42.93	21.47	1.76	0.204
D	1	12.31	12.31	1.01	0.331
Error	16	195.63	12.23		
Total	26	1509.97			

Table 5: ANOVA table for S/N ratio of ΔY

Source	DOF	SS	MS	F	P
A	5	127.145	25.429	2.35	0.088
B	2	255.598	127.799	11.81	0.001
C	2	7.68	3.84	0.35	0.707
D	1	13.573	13.573	1.25	0.279
Error	16	173.109	10.819		
Total	26	577.105			

Table 6: ANOVA table for S/N ratio of ΔZ

Source	DOF	SS	MS	F	P
A	5	152.002	30.4004	8.2	0.001
B	2	95.909	47.9545	12.93	0
C	2	34.89	17.4448	4.7	0.025
D	1	0.129	0.129	0.03	0.854
Error	16	59.339	3.7087		
Total	26	342.269			

Therefore, based on the above analysis, the significant factors and levels of dimensional accuracy vary from direction of FDM build parts. Factor of layer resolution mainly influences ΔX and ΔZ , and it affects ΔY with significance level on 0.10. Factor of processing quality influences all direction of the FDM build parts at a significance level. Factor of fill mode have great influence on ΔZ and little influence on ΔX and ΔY . Factor of processing material had no prominent influence on dimensional accuracy of FDM build parts.

4. CONCLUSION

In the present work, effect of four factors of fabrication parameters viz., layer resolution, processing quality, fill mode and the processing material with different levels is studied on the dimensional accuracy of FDM build parts. Taguchi's design of experiment is applied to find the significance of factors. The main effect plot for S/N ratio is obtained and ANOVA is performed for S/N ratio. It is found that the optimum factor levels for ΔX , ΔY , ΔZ are $A_1B_3C_1D_2$, $A_1B_3C_1D_1$ and $A_4B_3C_1D_1$, respectively. Furthermore, factor of layer resolution mainly influences the dimensional accuracy on the direction of X and Z. Factor of processing quality influences the dimensional accuracy on all direction of the FDM build parts. Factor of fill mode have great influence the dimensional accuracy on the direction of Z. And factor of processing material had no prominent influence on dimensional accuracy on all direction of the FDM build parts. In future, the proposed methodology may be tested for studying influence on mechanical properties of FDM build parts and make a greater contribution to optimum fabrication parameters for FDM build parts with complex structure.

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