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OPTIMIZATION OF FUSED DEPOSITION MODELING PARAMETERS FOR HIPS FLEXURAL STRENGTH WITH TAGUCHI METHOD

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Abstract. HIPS (High Impact Polystyrene) is one of the materials used in 3D printing. Research and application of the use of this material have not been done much, especially in the applications that require flexural strength. This study aims to find a combination of FDM (Fused Deposition Modelling) process parameter settings, that produce experiments with the highest flexural strength, with the optimization process using the experimental design of the Taguchi method with FDM parameters namely the orientation position of the specimen, fill pattern, fill density, and layer. The results showed the confirmation experiment produced the highest flexural strength (32.6753 MPa). In the experiment before confirmation, the highest flexural strength (31,3768 MPa) was shown in experiment number 5 (3rd orientation position, fill pattern lattice, 75% fill density, and 0.125 mm layer thickness).

Keywords: 3D printing, fused deposition modelling, flexural strength, high impact polystyrene, Taguchi

1. Introduction

In the current era, making products with good quality and evaluating various design alternatives is quickly needed to develop products with sustainable principles. Prototype making is one of the keys to success or failure of a product to be launched. One way to make prototypes is by using rapid prototyping (RP) technology. The advantages of RP technology include increasing product model variance, increasing quality of product complexity, increasing product durability and service life, and reducing product prototype processing time [1]. According to Shahrabi, the classification of RP technology can be divided into 4 groups based on the process of using basic materials to make prototypes. The classifications are liquid phase, powder, sheet form, and gas phase [2]. Fused Deposition Modelling (FDM) is the most used RP technology of various types of existing RP technology. Nearly half of the RP machines used by the market are FDM [3]. It is called FDM because its parts are formed by deposition of layers of fused material in the product making process. This RP technique is used both in making prototypes and in production applications. FDM was developed by S. Scott Crump in the late 1980s and was commercialized in 1990 by Stratasys [4]. The working principle of FDM is the material in the form of a solid polymer roll (such as ABS, PLA, HIPS, PETG, etc.) heated to liquid by a heated liquefier. Then, the liquid polymer is distributed through the nozzle. It produces a layer which then forms an object or part of arrangement of layers per layer. Heated liquid heater and nozzle are one component and can move three axes namely x, y, and z to form the produced object. The range of material properties needs to be carefully considered in the process of making a prototype because there are tradeoffs in cost, surface quality, and mechanical properties. [5].

Tanoto et al. had conducted several studies on setting of the printing process parameters in FDM to produce the best strength. The studied parameter was product orientation. The used materials were ABS and PLA, and the observed responses included tensile strength, processing speed, and dimensional accuracy of specimen products [6] [7] [8]. In this study, the best orientation position was obtained to produce the product or specimen that has the highest tensile strength and to compare the product quality and processing time between ABS and PLA material. Lee, et al (2004) examined the optimization of 3D printing parameters with FDM technology to produce flexible ABS materials. The parameters used are were air gap, raster angle, raster width, and layer thickness, each of which had 3 levels. Material testing was carried out using a catapult design to determine the level of flexibility of ABS, with each degree of slope 10°, 15°, and 20°. The result of this study is at a 10° slope position, the air gap parameter gives the maximum contribution to the performance of the product. Then, at a 15° slope position i.e., both the raster angle and layer thickness parameters contribute maximally. Last, at a 20 ° slop position, the layer thickness parameter gives the largest contribution on the product performance [9]. HIPS (High Impact Polystyrene) is a material other than ABS and PLA that is often used. This material offers advantages not possessed by other materials. Besides that, the application of the use and research on HIPS has not been done much. Therefore, this research chooses HIPS material as the main material that is tested by finding the most suitable print process parameters to produce the most optimal flexural strength response.

2. Research Methods

2.1 Printing Process

HIPS filament material used was white with the E-sun brand. The filament was 3 mm in diameter with print extrusion temperature of 220 - 260°C [10]. The dimensions of the specimen were 120 mm × 15 mm × 5 mm, where the shape followed the ASTM D 790-2010 standard for flexural testing. The specimen was drawn with 3D CAD software and converted to STL format. Axon V2 was used to slicing the STL [11]. Specimens were made using the Double Head 3D Touch BFB Machine. There were 4 process parameters used in this study where each parameter had 3 levels. The process parameters were orientation position, fill pattern, fill density, and layer thickness. Orientation position 1 (height of perpendicular bed), 2 (width of perpendicular bed), and 3 (length of perpendicular bed) was shown in Figure 1. Variations in the fill pattern parameters were linear, lattice, and hexagonal fill patterns. The fill density parameter was fill density with the level of 25%, 50%, and 75%. Finally, the layer thickness parameter used layer thickness with a level of 0.125 mm, 0.25 mm, and 0.5 mm. To set the fill density, fill pattern, and layer thickness parameters, Axon built setting menu was used as shown in Figure 2. The flexural test machine used was Shimadzu AGS Plus with a capacity of 50 kN type 3 points bend.

Table 1. Parameter and level

Code	Parameter/Factor	Level		
		1	2	3
A	Orientation Position	Position 1	Position 2	Position 3
B	Fill Pattern	Linear	Lattice	Hexagonal
C	Fill Density	25%	50%	75%
D	Layer Thickness	0.125	0.25	0.5

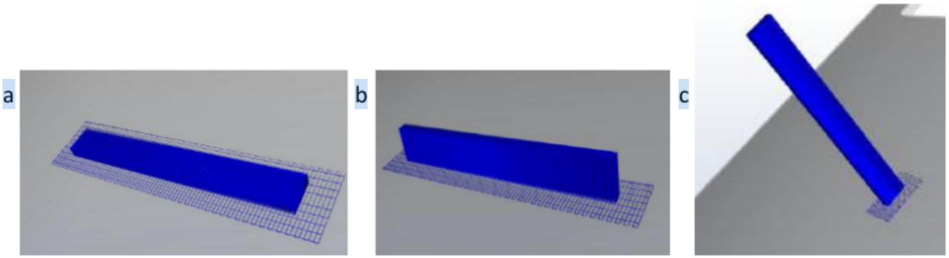
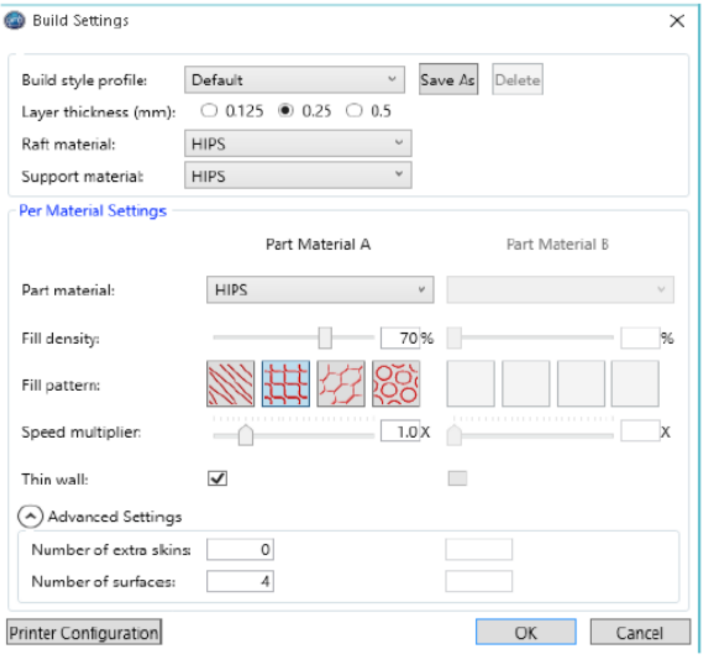


Figure 1. Orientation Position. a) Position 1, b) Position 2, c) Position 3



Build style profile: Default

Layer thickness (mm): ○ 0.125 ● 0.25 ○ 0.5

Raft material: HIPS

Support material: HIPS

	Part Material A	Part Material B
Part material:	HIPS	
Fill density:	70 %	%
Fill pattern:		
Speed multiplier:	1.0 X	X
Thin wall:	☑	☐
Number of extra skins:	0	
Number of surfaces:	4	

Figure 2. Axon built setting

2.2 Taguchi Method

The Taguchi method is a methodology in engineering that aims to improve product quality and reduce costs and resources to a minimum at the same time. The Taguchi method makes the product or process robust against noise factors therefore, this method is also called robust design. The advantage of the Taguchi method is that it makes the experiment more efficient because it is possible to conduct research that involves many factors and quantities. In addition, the Taguchi method can produce conclusions about the response of the factors and the level of control factors that produce the optimum response [12]. Taguchi method optimization was done by determining parameters and their levels, choosing orthogonal array, conducting experiments, analyzing experimental results with ANOVA, analyzing data and confirming experiments.

3. Result and Discussion

The factors and levels considered in this study are shown in Table 1. Experiments were conducted with four factors. Each at three levels and hence a three-level orthogonal array (OA) was chosen. Degrees of freedom (Dof) required for the design were eight. The OA, which satisfied the required Dof was L9. Figure 3 shows the results of the printing process from a different orientation. This product was tested for flexural strength. Before being tested, the specimen was first finished to fit the test standard. The specimen then flattened the surface and the sides by rubbing using sandpaper and miserly paper until the specimen dimension result was suitable for testing. The sandpaper used was grade 180, and the file used was a small file size, 7 mm. The experiments were conducted using L9 OA. The response values of flexural strength obtained are given in Table 2. Each experiment was carried out five times to obtain five flexural test results.

Table 2. Parameter and level

Experiment No	Factor/Parameter				Flexural Strength Average (MPa)
	A	B	C	D	
1	1	1	1	1	10.666
2	1	2	2	2	18.2719
3	1	3	3	3	21.5722
4	2	1	2	3	17.7125
5	2	2	3	1	31.3768
6	2	3	1	2	18.1126
7	3	1	3	2	27.1102
8	3	2	1	3	18.8914
9	3	3	2	1	25.6361

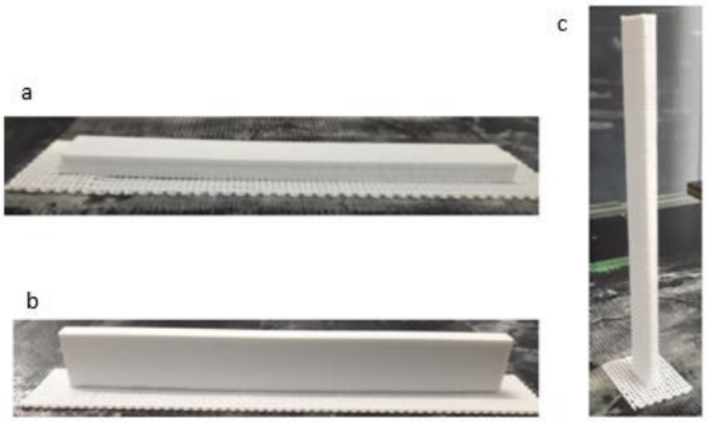


Figure 3. Printing result for each orientation. a) Position 1, b) Position 2, c) Position 3

Figure 3 shows the results of the printing process from a different orientation. This product would be tested for flexural strength. Before being tested, the specimen was first finished to fit the test standard. The specimen then flattened the surface and the sides by rubbing using sandpaper and miserly paper until a dimension result of the specimen was suitable for testing. The sandpaper used was grade 180, and the file used was a small file size, 7 mm. The results of the response table and response graph can be seen in Table 3 and Figure 2. These tables and graphs are assisted with Minitab software. On the response graph, it is shown that the optimum parameter setting combination is orientation position 3 (A = 3), fill pattern lattice (B = 2), fill density 75% (C = 3), and layer thickness 0.125 (D = 1). The resulting settings are the 3rd orientation position, fill pattern lattice, 75% fill density, and layer thickness 0.125 mm where the combination produces the highest flexural strength.

Figure 4. Response graphic

Table 2. Table response

Level	A	B	C	D
1	16.84	18.5	15.89	**22.56**
2	22.4	**22.85**	20.54	21.16
3	**23.88**	21.77	**26.69**	19.39
Max-Min	7.04	4.35	10.8	3.17
Rank	2	3	1	4

Analysis of variance (ANOVA) was carried out to determine the contribution of each parameter. Following ANOVA can be seen in Table 4. Looking at the ANOVA results, it is known that the orientation position (A) 26.19% and fill density (C) 56.55% contribute greatly to flexural strength.

Table 3. ANOVA

Source	Sq	vq	Mq	F-*ratio*	Sq’	*ρ*%
A	414.37	2	207.185	162.625	411.822	26.19
B	154.697	2	77.34	60.706	152.149	9.67
C	881.001	2	440.5	345.761	878.453	56.55
D	76.2	2	38.1	29.905	73.652	4.68
e	45.882	36	1.274	1	56.074	2.91

St	1572.15	44	35.73	-	1516.09	100
Sm	19916.88	1	-	-	4	
ST	21489.03	45	-	-	-	

The next step was to carry out a confirmation experiment to verify or prove that the combination of parameter settings from the response table could produce the optimum/highest flexural strength. Test specimens were prepared according to a combination of response tables (A3, B2, C3, D1). In the confirmation experiment, an experiment of five replications was carried out. Confirmation experiment data for average flexural strength were 32.6753 MPa. The flexural strength of the confirmation experiment was then compared with the flexural strength of the Taguchi experiment (experiments 1 through 9). Comparisons were made by calculating the µ and the confidence interval (CI). Calculations are shown as follows:

µ Predicted.

$$\mu_{prediction} = \sum \bar{x}_i - n\,.\,\bar{y}$$
$$\mu_{Predicted} = \bar{A}_3 + \bar{B}_2 + \bar{C}_3 + \bar{D}_1 - 3\,.\,\bar{y}$$
$$\mu_{Predicted} = 23.88 + 22.85 + 26.69 + 22.56 - (3 \times 21.038)$$
$$\mu_{predicted} = 32.866$$

Confident Interval (CI) for *mean Predicted* (µ predicted).

$$n_{eff} = \frac{\text{number of experiment}}{\text{number of DOF in Predicted}}$$

$$n_{eff} = \frac{45}{3} = 15$$

α = 0.05 for v1 = 2 dan ve = 36 are 3,2653 (interpolation from F *distribution table*).

$$CI = \sqrt{F_{\propto,v1,ve} \times Me \times \left(\frac{1}{n_{eff}}\right)}$$

$$CI = \sqrt{F_{0.05,2,36} \times 1{,}274 \times \left(\frac{1}{15}\right)}$$

$$CI = \sqrt{3{,}2653 \times 1{,}274 \times \left(\frac{1}{15}\right)}$$

$$CI = \pm 0{,}526$$

So, the upper and lower limits for the µ :

$$\mu_{prediksi} - CI \leq \mu_{prediksi} \leq \mu_{prediksi} + CI$$
$$32{,}866 - 0{,}526 \leq \mu_{prediksi} \leq 32{,}866 + 0{,}526$$
$$32{,}34 \leq \mu_{prediksi} \leq 33{,}392$$

Confident interval (CI) for experiment confirmation

$$CI = \sqrt{F_{\propto,v1,v2} \times Me \times \left(\frac{1}{n_{eff}} + \frac{1}{r}\right)}$$

$$\mathrm{CI} = \sqrt{\mathrm{F}_{0.05,2,36} \times 1{,}274 \times \left(\frac{1}{15} + \frac{1}{5}\right)}$$

$$\mathrm{CI} = \sqrt{3{,}2653 \times 1{,}274 \times \left(\frac{1}{15} + \frac{1}{5}\right)}$$

$$\mathrm{CI} = \pm 1{,}053$$

So, the upper and lower limits for the experiment confirmation:

$$\mu_{\mathrm{confrimation}} - \mathrm{CI} \leq \mu_{\mathrm{confrimation}} \leq \mu_{\mathrm{confrimation}} + \mathrm{CI}$$
$$32{,}6753 - 1{,}053 \leq \mu_{\mathrm{confrimation}} \leq 32{,}6753 + 1{,}053$$
$$31{,}6223 \leq \mu_{\mathrm{confrimation}} \leq 34{,}7283$$

A comparative interpretation of the two confidence intervals is shown in Figure 5.

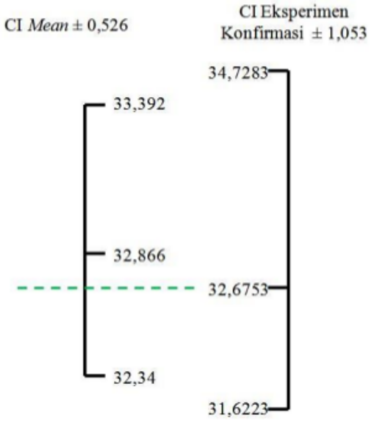


Figure 5. Comparison of confident interval

Figure 5 shows the confidence interval of the flexural strength of the average confirmation experiment within the range of the Taguchi experiment confidence interval (predicted μ). Thus, it can be concluded that the combination of factor level settings at the optimum conditions that have been obtained is valid.

Orientation position 1 has the best flexural strength because the results of surface area comparison with the specimens fill volume explain that the 3rd orientation position produces a large number of wall layers. Thus, it has an important effect on flexural strength. At the layer thickness, the smaller the value of the thickness, the more layers are produced to form a product This causes the flexural strength to be as high as possible. Whereas in fill density, of course, the denser a product is, the greater its strength.

4. Conclusion

Based on the results of optimization of the flexural test that has been done the right parameter settings according to the response graphs are Orientation position 3, lattice fill pattern lattice, 75% fill density, and 0.125 mm for layer thickness. Fill density parameter has the biggest contribution to affect the result of flexural strength.

5. 6Acknowledgement

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