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The effect of infill pattern, infill density, printing speed and temperature on the additive manufacturing process based on the FDM technology for the hook-shaped components

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Abstract

The additive manufacturing technology based on the principle of material addition is an important technology in product design, manufacturing, and development. In addition, the trend in the recent future of this technology will be a major step to develop in the rapid manufacturing industry. Among the rapid prototyping technologies, the most popular FDM (fused deposition modeling) technology has been widely applied in the practice. The quality of rapid prototyping technology in general as well as FDM technology in particular mainly depends on the parameters in the prototyping and operational process. In this paper, the optimum parameters of the prototyping process based on the FDM technology are identified to improve the tensile strength of 3D printing products with PLA and PLA-copper materials. The parameters are chosen in the process of doing the experiments such as infill pattern, fill density, print speed, and print temperature. Then, based on Taguchi analysis technique, the experimental planning method is employed for design and optimization, with the support of Analysis of Variance (ANOVA) to evaluate and identify the influence of parameters on the tensile strength of the printed hook-shaped product. The results highlighted that the maximum tensile force of the sample is printed with PLA-Copper material with the optimum parameters is infill density of 75%, printing speed of 65 mm/s, and temperature of 185°C.

Keywords: Additive manufacturing; FDM; PLA-copper; DOE; 3D printing.

1. Introduction

Rapid prototyping (additive manufacturing) technology has been considered to be a new step in product design and development. Compared with traditional prototyping methods, the results of this technology have been paid attention by many active researchers. In contrast to the tradition, instead of creating samples by cutting and removing materials, the rapid prototyping technology (additive manufacturing) is based on a completely new principle of accumulating materials in layers. In various manners, this technology brings about more benefits such as shortened sample time and reduced costs. Based on the principle of material accretion, it can save materials. In addition, shortening the prototyping time from which helps designers preview the sample quickly, improve the complex designs, increase creativity, and diversify products. In this latest technology, there are many different methods in which each owns advantages suitable for many various materials and properties. Typically, the SLA (Stereolithography) method uses liquid materials under the effect of a laser to harden materials and used for high-precision samples. The SLS (Selective laser sintering) method has the same principle as SLA; however, the material used is in powder form. In addition, there are other various methods such as LOM (Lominate Object Manufacturing), FDM (fused deposition modeling) and so on. Among the prototyping methods, FDM method (with the principle presented in Figure 1) is now very popular because of its low cost and the use of many easily accessible materials on the market compared with others. Based on the principle of accreting and addition, the fibrous materials are melted in layers. Products made by FDM technology that is besides being used as models can also be used immediately. The result of it is that this technology is becoming popular in the current state. However, the mechanical properties of the FDM sample or product is still an issue that needs to be improved. According to previous studies on this method, it can be seen that the process parameters are the main factors directly affecting the properties of the products. Following these results on new material PLA-copper as well as deep understanding on their tensile force, PLA-copper is a composite material made of PLA resin and copper powder. Their important process parameters such as infill pattern, infill density, print speed, and print temperature are selected in this research for improving the load capacity of the hook-shaped parts.

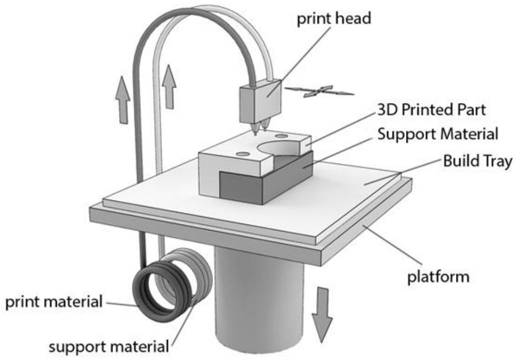

Figure 1. Basic FDM process

2. Related works

Dat [1] has applied rapid prototyping technology for fabricating flowing samples which have achieved certain success. By analyzing the advantages and disadvantages of the rapid prototyping methods, this study selected the SLA method to create flowing samples. The device is a SLA250 stylist based on photochemical polymer material. The application of rapid prototyping technology helps to reduce the time of making the flowing samples, reduce the cost of making molds and make complex patterns in a short time to increase the competitiveness. Tho et al. [2] focused on improving the compressive strength of products created by FDM technology by optimizing the parameters of the modeling process with the following factors including infill pattern, fill density, wall line count, layer height, raster angle and three levels on PLA materials. Based on the Taguchi method with the same five parameters selected and printed by 3D printers (REPMARBOX), the results were measured in accordance with ISO 604-2003 on JTM tech Model TM-UTC compressors. Through analytical research, the team concluded that the most influencing factor for the compressive strength of a product is the fill density and the least influence on the raster angle. Truong Hai Group [3] has also pioneered the application of rapid prototyping technology in the manufacturing process. The Group has used MJM prototyping technology on Project 5000 equipment with Acrylic materials, which has successfully applied in design and manufacturing of the support/fixture with the product that has been put into use in reality as the BRT fast bus. In the near future, the group also aims to use rapid prototyping technology for research and development of double-decker buses or a further vision to localize the design and manufacture of its products. Upadhyay Kshitiz et al. [4] presented the experiment with a layer height of 0.254 mm and two directions of sample construction including horizontal X and vertical Z for the purpose of improving mechanical properties through adjusting the parameters of the prototyping process. The above parameter was used by the research team on SST – 768 and a rapid prototyping device of FDM technology with ABS P400 material. Based on the results of ASTM D638 procedure with Instron 3382 instrumentation, conclusions have been drawn. The horizontal construction direction gives the best tensile and impact strength while the vertical construction gives the highest compressive results. Mahdi Kaveh et al. [5] concluded the accuracy and internal structure with a minimum deviation of 0.0514 mm for size and 0.129 mm for hole size. The team selected the parameters of the FDM prototyping process such as temperature, print speed, and line width as factors to study the extent of their influence. To conclude, the study used RapMan 3.0 device and HIPS material to make the sample. Fuda Ning et al. [6] with carbon fiber-reinforced plastic (CFRP) with the help of FE-SEM electron microscope concluded the construction angle (0; 90), the prototyping speed of 25 mm/s, the temperature of 220°C and the layer height of 0.15 mm give the best tensile strength on this material.

3. Research methodology.

In order to reach the conclusion of the study, a rapid prototyping device based on FDM technology with Proin model (Figure 2) is employed to print the product with a minimum layer thickness of 0.1 mm. The material selected in this study is PLA – Copper that is a combination of eco-friendly PLA resins and copper powders. In addition, PLA materials can also be used to compare the results of tensile strength of these two materials.

Figure 2. Proin 3D printing machine

The test samples (Figure 3) were designed in CAD with support from Solidworks and exported into files with *.STL format. The *.STL file is handled by MeshLab software before being scanned and parameterized using CURA 4.0 tool. Finally, the G-code file exported by CURA software was used for Proin 3D printers for prototyping.

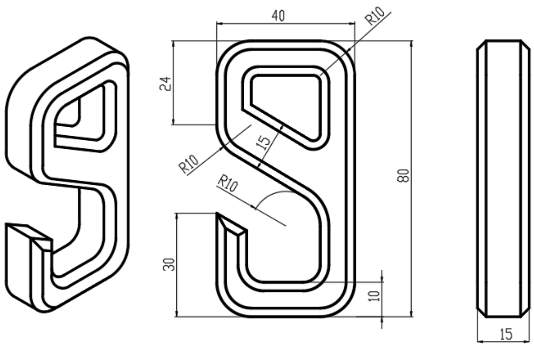

Figure 3. Experimental sample

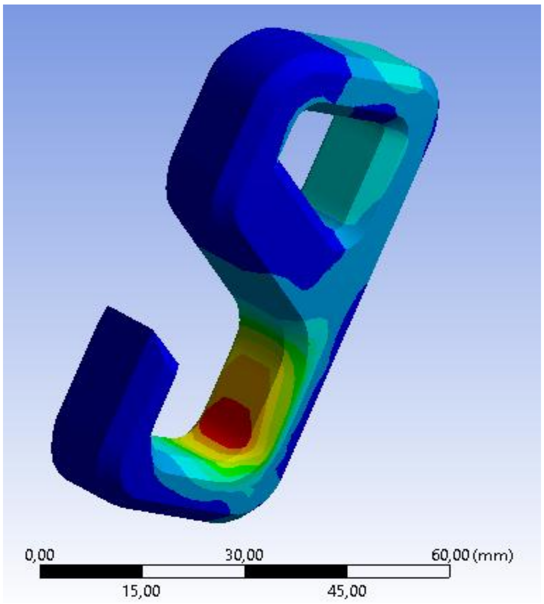

Figure 4. CAE analysis

In addition, the sample was also analyzed for CAE by finite element method (FEM) (Figure 4) using ANSYS Workbench software to predict stress concentration points and high risk of destruction.

Inheriting from the relevant studies to identify the important parameters that affect this technology, the levels of factors are selected based on the suggestions from experienced technician and manufacturers or suppliers shown in Table 1. To measure the research parameters, we have used the SHIMADZU equipment (Figure 5) with the method of increasing the force until the sample is destroyed and then stop operating.

Table 1. Parameters and levels

Factors	**Symbols**	**1**	**2**	**3**
Infill pattern	A	Linear	Grid	Tri-hexagonal
Infill density %	B	20	50	75
Speed mm/s	C	50	65	80
Temperature °C	D	175	185	205

- Infill pattern: is the internal network structure.
- Infill density: is the internal infill density that creates the porosity of the sample.
- Speed: the movement speed of the print head.
- Temperature: the temperature of the printhead (nozzle) melted the material.

Experimental design was done by Taguchi method [7] on Minitab software v.17 on Windows 7 with three levels and four elements as described in Table 1. We have Table 2 with nine experiments.

Table 2. Experimental planning and empirical data.

Exp Run No.	**Factors**				**Loads (N)**	
	A	**B**	**C**	**D**	**PLA**	**PLA - Copper**
1	1	1	1	1	332.03	198.49
2	1	2	2	2	463.31	387.14
3	1	3	3	3	798.61	547.76
4	2	1	2	3	430.32	279.69
5	2	2	3	1	622.9	387.43
6	2	3	1	2	656.67	501.55
7	3	1	3	2	357.5	223.78
8	3	2	1	3	469.58	401.33
9	3	3	2	1	531.86	575.08

Figure 5. Load-bearing capacity test on SHIMADZU

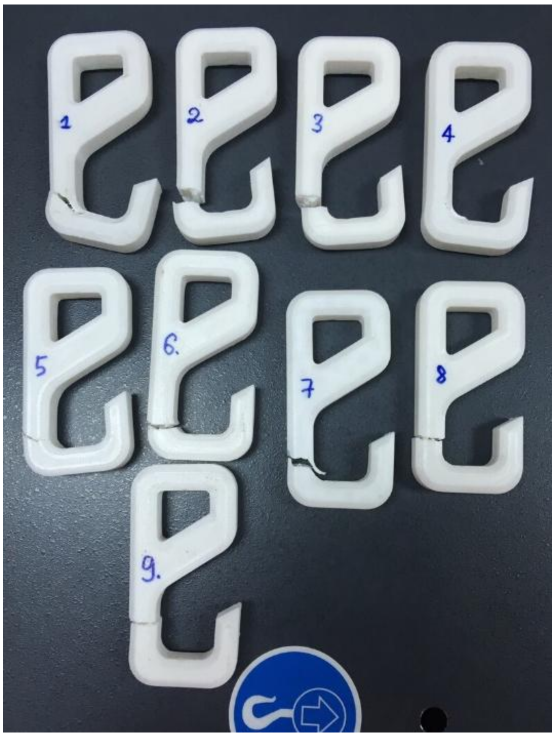

Figure 6 (a). PLA samples

Taking advantage of the results (marked with the “*”) of the experimental planning from Table 2 for PLA-Copper, the Taguchi method is utilized to determine the optimal process parameters for tensile load capacity. The experimental design for the PLA-Copper materials is implemented to study the three factors that are the infill density, print speed and temperature along with the three levels as shown in Table 1 and their results are presented in Table 3.

Figure 6 (b). PLA-copper samples
Figure 6. Samples destroyed after testing.

Table 3. Planning and empirical data of three elements on PLA – Copper.

Exp Run No.	Factors			Loads (N)
	B Infill Density(%)	C Speed (mm/s)	D Temperature (°C)	
1*	20	50	175	198,49
2	20	65	185	250,55
3	20	80	205	225
4	50	50	185	395,5
5	50	65	205	430
6*	50	80	175	387,43
7	75	50	205	530
8*	75	65	175	575,08
9	75	80	185	550

4. Results and discussion.

Taguchi method analyzed the deviation between the experimental value and the desired value. To calculate the noise, the function offered for calculation is S/N (signal/noise). There are usually three types of ratings concluding smaller-the-better, the-larger-the-better and the nominal-the-best. The purpose of this study is to optimize the tensile strength. Hence, we choose the-larger-the-better which is represented by the equation (1).

$$n_c = 10\lg\left(\frac{1}{n}\sum_{i-1}^{n} y_i^2\right) \qquad (1)$$

where, y_i is the data obtained from i^{th} experiment and n is the number of experiments.

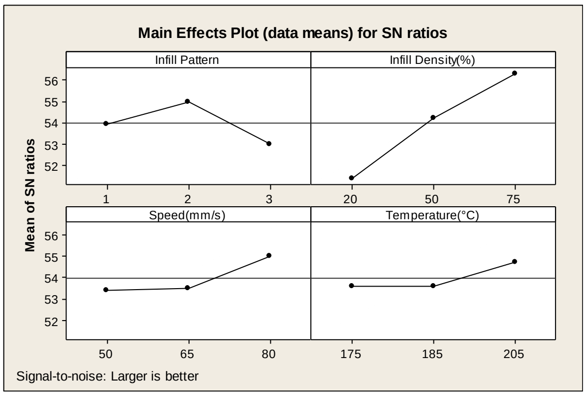

Figure 7. Effect of parameters on load capacity.

Figure 7 shows the influence of the factors over the slope of the graph and the parameters that affect the most and the least. The results of Figure 7 are derived from the S/N disturbance analysis by Minitab thereby evaluating the influence of the optimal parameters for tensile strength as Table 4. The infill pattern and its density have the most influence on the tensile capacity of the hook-shaped FDM product. Next, the printing speed is the third factor to have the impact on the tension capacity.

Table 4. Signal response table of S/N ratio to PLA – Copper

Level	Factors			
	A Infill Pattern	**B Infill Density (%)**	**C Speed (mm/s)**	**D Temperature (°C)**
1	50,83	47,29	50,68	50,97
2	51,57	51,86	51,96	50,92
3	51,42	54,66	51,18	51,93
Delta	0,74	7,36	1,28	1,01
Rank	4	1	2	3

In Table 4 of S/N analysis, it can be seen that factor A with the lowest influence on tensile strength will be eliminated. This study uses Analysis of Variance (ANOVA) for three factors B, C, D with a three-factor table as Table 3 to obtain the Analysis of Variance (ANOVA) results as shown in Table 5.

In Table 5, it can be seen that the factors B, C have the p-value <0.05 and the F value of factor B has the highest value so that B has the highest level of influence on the tensile load capacity of the sample.

Regression analysis is used for modeling and analyzing a number of variables when there is a relationship between a dependent variable and one or more independent variables in which the input variables being three elements and the output variable being towing ability. The forecast equations obtained by first-order linear regression model of towing capacity are as follows.

S = 24.8911; R-sq = 98.11% ; R-sq (adj) = 93.40%

Regression:

Ability to load pull = 40 + 5.947B + 0.427C + 0.202D

From the three factors selected as planned in Table 3 with the greatest tensile strength, we conducted the analysis to find the most optimal parameter set. The Minitab software has achieved maximum traction of 581.79 (N) with the following parameters (Figure 8):

Infill Density: 75%

Speed: 65 mm/s

Temperature:185(°C).

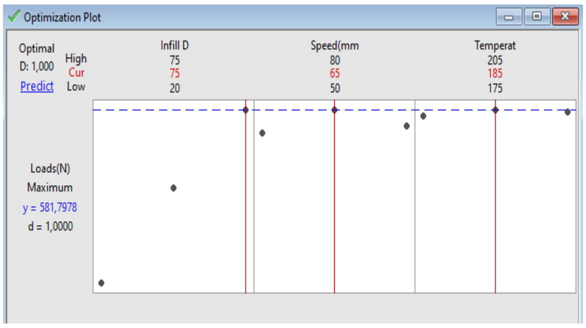

Figure 8. Optimum parameters for PLA-Copper material

5. Conclusions

First, PLA has better tensile strength than PLA-Copper. It means in each of the same parameters, the tension load capacity of PLA is higher than PLA-Copper. Second, the main factors affecting the load capacity of PLA-copper samples according to their rating are infill density, printing speed, and temperature. The infill pattern has very little influence. Thus, it should be ignored in the process of evaluating optimal parameters. Third, the maximum tensile force of the sample that is printed with PLA-Copper material with the optimum parameters is infill density of 75%, printing speed of 65 mm/s, and temperature of 185°C. And finally, the recommended optimum set of parameters is compatible with the machine operating in the range set by the manufacturer. The results of the test are on the fracture of the sample. Furthermore, the location of the destroyed completely are consistent with the results of prediction analysis by on ANSYS tool.

Table 5. Results of Analysis of Variance (ANOVA)

Variance source	Degree of freedom (DoF)	Sum of squares (SS)	Mean square (MS)	F ratio	p-value	Contribution rate (%)
B	2	160927	80463,3	1243,97	0,001	97,93
C	2	3055	1527,4	23,61	0,041	1,86
D	2	214	107,0	1,65	0,37	0,13
Error	2	129	64,7	-		0,08
Total	8	164325	-	-		100

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