International Journal of Engineering & Technology, 7 (4.36) (2018) 1506-1509

International Journal of Engineering & Technology

Website: www.sciencepubco.com/index.php/IJET

Research paper

Optimization of the Position for the Support To Reduce Production Time on 3D Printers

Huu Nghi Huynh[1], Ha Nguyen Thanh[1], Huu Tho Nguyen[2], Thi Thu Ha Thai[1]

[1]Ho Chi Minh City University of Technology, VNU-HCM; 268 Ly Thuong Kiet St., Ward 14, Dist.10, Ho Chi Minh City, 700000, Vietnam

[2]Ho Chi Minh City University of Food Industry (HUFI); 140 Le Trong Tan St., Tay Thanh Ward, Tan Phu Dist., Ho Chi Minh City, 700000, Vietnam

Email:hhnghi@hcmut.edu.vn

Abstract

FDM (Fused Deposition Modeling) is the AM - Additive Manufacturing Technology or the fastest growing 3D printing technology has been paid more attention in Vietnam. Although this technology is being used in important fields such as industry, medicine, aerospace and education, etc. but product quality and manufacturing time are still the main limitation for its popularity. There are many factors which influence the fabrication time. In particular, the structure of the support part is one of the important factors. This paper examines the influence of technological parameters such as the direction of prototyping, the distance between the support and the material layer, and the location of support in order to reduce production time based on open source FDM devices. Besides, the study also uses the Taguchi method to design experiments and analyze the variance (ANOVA) to evaluate the effect of technological parameters on fabrication time. From obtained results, the optimal parameter values and the relationship function of the parameters have been figured out.

Keywords: *Support, FDM, ANOVA, Taguchi*

1. Introduction

FDM technology, also known as 3D printing technology in the world, and it has been paid attention to implement the advanced manufacturing technology in the small and medium enterprises in Vietnam. It is a technology that makes products directly from 3D design data on computer CAD (Computer Aided Design) by filling the material in the manner of layer by layer. The 3D printing technology is capable of making products quickly with a variety of materials (mainly plastic materials). The open source based FDM devices have been studied by the World Reprap community (founded by Dr. Adrian Bowyer, 2005). These devices use the open source will not be subject to copyright requirements as FDM devices are commercialized by businesses. It provides users with more opportunities to access 3D printing technology, making it easier to realize model design ideas, save costs and time. On open source FDM devices, the user can study the influence of the technological parameters of the fabrication process to produce the desired quality product. Similar to FDM devices in industry, FDM devices using open source also need the structure of support when making the complicated shape of products. At that time, the production time will be extended significantly. Moreover, it also affects the quality of the product. Thus, the machine parts or components are often completed through many various methods after fabrication such as chemical processing to achieve the desired quality [2].

Figure 1 illustrates the fabrication process on the FDM device using the support. It consists of two extruders, one head is used to extrude the main material, and the other extrudes the material for the structure of the support. The function of support is to create an auxiliary support structure, which can be considered as a scaffold to support another block of material above them, preventing them from falling off during the manufacture. When using support, the product development time will increase. Thus, there are two options: change the support structure and change the support's location. The change of support structure is to change the shape and configurability of the support and its types such as supported column and joints, etc. On the other hand, the change of the support position is to change its position from the default position on the software to the desired position or can be understood as re-positioning support.

In this article, the authors focused on the ability to change the support position (C) and two other parameters: the direction of prototyping (A), the distance between the support material and the main material (B). The parameters are selected based on the experience of the machine operators and the processing capabilities of the software that is designing the printing process. These parameters, apart from the impact on product manufacturing time, also affect its quality. Therefore, it is necessary to explore the influence of parameters affecting the time of making products, thereby finding the reasonable values among the parameters to create a good quality product.

There are many methods used in experimental design such as Complete Randomized Design (CRD), Randomized Complete Design (RCB), Latin squared layout (Latin Square design - LS), Split-plot plot plotting and experimental planning by Taguchi method. In particular, the Taguchi method is a widely used method due to the ability to shorten the number of experiments (the number of experiments is low but still ensures the desired goal). The Taguchi method is a statistical method developed by Genichi Taguchi to improve the quality and efficiency of a production line.

The purpose is to adjust the parameters to the optimum level for the production process or experimental research.

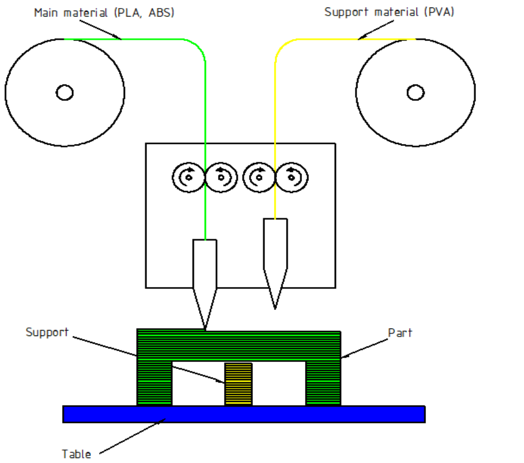


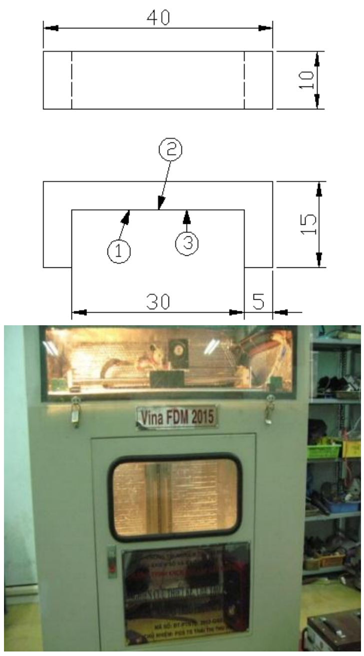
Figure 1: The principle of FDM device with two extrusion heads

2. Literature review

G. Pavan Kumar et al. [1] researched about the influence of 5 parameters: layer thickness, raster angle, orientation, contour width and part raster width on build time and support material volume. The result show that all parameters except raster angle have significant influence on build time and support material volume. Pandey et al. [3, 4] studied the effect of depositional direction during the production of the layer to the time of manufacture, support, dimensional accuracy and roughness. Using a multi-criteria genetic algorithm and developing a system to determine the optimum distribution orientation for FDM parts based on surface ruggedness and building time as objective functions. Neri Volpato et al. [5] studied the effect of the gap between support and support structure that affected the dimensional accuracy of Z axis, and optimized support for increased accuracy. Thrimurthulu et al. [6] showed that surface finishing and product manufacturing time are two important issues in the prototyping process and are conflict together. In order to neutralize these two factors, the study has optimized the deposition direction for FDM to improve surface quality and reduce product fabrication time. Models of average surface roughness and building time were developed. A real code algorithm is used to obtain the optimal solution. Vanek et al. [7] has researched and optimized support structures for FDM, which has built and optimized tree support structures on Autodesk Meshmixer. Eric Barnett et al. [8] researched support materials to reduce material and production time, built two geometric algorithms to optimize material support and ensure parts quality.
Through the literature review, it is easy to realize that all research aimed at reducing the time which is required to manufacture the product because this is an important factor in the production process. In the current competitive environment of production, the time is an important factor and brings more profit to the enterprise. Similarly, in the production of products by FDM technology, time should be considered firstly. So, this study is to determine the technology parameters based on open source FDM devices, especially the support location parameters to shorten product fabrication time.

3. Experimental design

The test sample (Figure 2a) was designed to assess the change in the support position. The samples recommended by the machine operator and were designed on Solidworks CAD modelling software. Then, they are exported to STL format files. Currently, this is the format in which all of the cutting software (software available for 3D printing) is readable. The software also allows us to adjust the parameters including the change of support position, and the sample was fabricated on an open source FDM device, as shown in Figure 2b.
The equipment used for the fabrication process is open source FDM (Figure 2b) developed by the research team at the Faculty of Mechanical Engineering, Polytechnic University. The machine uses a pair of extrusion heads, an extrusion support material (PVA resin) and a print head material (plastic PLA). PLA resins are one of the plastics used in FDM machines. PLA is synthesized from starch (maize, potato, etc) that is biodegradable so it is safe for the environment when using the required average temperature (from 190°C to 220°C) and does not require heat table and easy to use in FDM equipment. PVA plastics are water-soluble plastics (especially warm water). So, this plastic is used to making the support for 3D printing technology. The temperature of PVA resin is very similar to PLA, so it is easy to use. Experimental design using the Taguchi method is using an orthogonal array in experimental planning, optimizing experiments to study the effect of input parameters on the selected outputs. The experimental design by method Taguchi to evaluate the impact of three parameters at three different levels based on three parameters (see Table 1). Experimentally designed samples of Taguchi L9 (three factors with three levels) are shown in Table 3. The samples were generated using a 3D printer, and the completion time was recorded based on the time displayed on the cut software. The parameters fixed during the operation of the device are shown in Table 2. The data after the recording will be processed and evaluated by the method of ANOVA to find the degree of influence of the parameters. Taguchi Experimental Planning and Analysis of ANOVA Variance were implemented based on Minitab statistical software and presented in Table 3.



(a) Experimented samples (b) FDM device with two extruders
Figure 2: Experimented samples and FDM device

Table 1: Minimum values of spacing and edge and end distances

Parameters	Symbol	Level Low (1)	Level Medium (2)	Level High (3)	Unit
Orientation	A	0^0	15^0	30^0	Degree (^{0})
Distance between the support layer and main	B	0	0.2	0.4	mm

Material layer					
The position placing the support	C	2	1,3	1,2,3	position

A – Orientation: is the direction of the horizontal plane of the parts compared to the table
B – The distance between the support layer (PVA) and the main material (PLA, ABS): is the distance between the final support layer and the main material. This parameter is measured according to the displayed value on the slicing software
C – The support location: is where the support is used on the parts. The support location can be set by the user or set as default by the software.

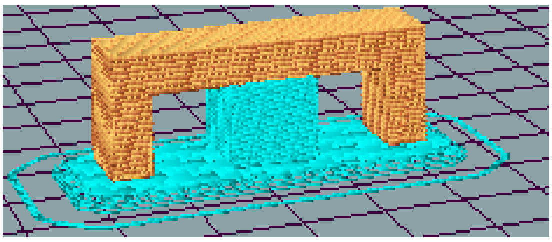
Table 2: Parameters are fixed in the FDM device used in the experiment.

Table size of machine	Printing speed	Layer thickness	Filling density	Number of substrates	Temperature of extrusion head (extruder)
200x200x250 (mm)	60 mm/s	0.2 mm	20%	3	200^0C

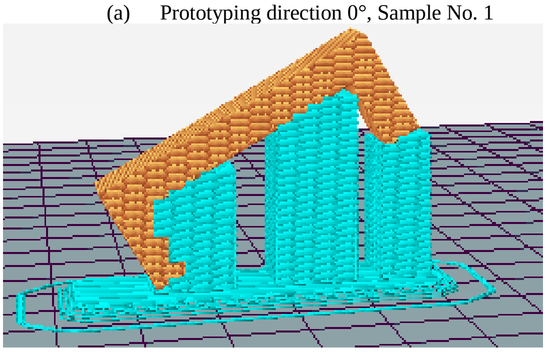
Table 3: Orthogonal design and S / N ratio

No.	A	B	C	Result (Time-second)	S/N
1	1	1	1	1588	-64.0170
2	1	2	2	1636	-64.2757
3	1	3	3	1620	-64.1903
4	2	1	2	2438	-67.7407
5	2	2	3	2412	-67.6475
6	2	3	1	2343	-67.3954
7	3	1	3	3102	-69.8328
8	3	2	1	3007	-69.5627
9	3	3	2	3120	-69.8831

4. Results and discussion



(a) Prototyping direction 0°, Sample No. 1



(b) Prototyping direction 30°,Sample No. 9
Figure 3: The Prototyping direction of printing parts

Figure 3. shows the details of simulation process. From Table 3, we have realized that there were many factors affecting the time of manufacturing the product such as layer thickness, filling density, other factors. The results show that when changing the design direction of printed parts, the time of making the product also changes (when increasing from 0° to 30°, the time increases by). The reason of the increased time is due to the inappropriate change in the direction of the design, so it leads to the use of many of the support structures. Figure 3a shows the location of the 0° design direction, the amount of support material needed, the shortened product manufacturing time. But with Figure 3b, the direction of the model is 30°, the amount of support materials needs more and leads to increased production time.

Ratio analysis

The lower is the production time and the lower is the cost of production. That's what every manufacturer wants to achieve. Taguchi planning to use to measure the control of input parameters using high signal S / N ratios. The "lower-the-better" equation is used to analyze the S / N ratio. The S / N feedback results are shown in Table 4. The level values of the control parameters in Table 4 are shown graphically in Figure 4. The best level for the parameters found is the highest S / N ratio at that parameter. According to table 4, the best level for parameter A is level 1 (S / N = -64.16), parameter B is level 2 and level 3 (S / N = -67.16) N = -66.99)
From Figure 4, we can predict that the order of the effects of the parameters to the time value of making the product. On the graphs A and C, the high tilt graphs show the high influence of the A and C parameters on the value of the product's production time. In the B-parameter graph, the linear curve is near horizontal. On the other hand, we realized that the B parameter has little effect on the results.

Table 4: S / N feedback table

Level	A	B	C
1	-64.16	-67.20	-66.99
2	-67.59	-67.16	-67.30
3	-69.76	-67.16	-67.22
Delta	5.6	0.04	0.31
Rank	1	3	2

ANOVA analysis

ANOVA is a statistical method for determining the interaction between factors. Analysis of ANOVA was carried out with a mean of 5% confidence level of 95%. The importance of the factors in the ANOVA analysis is determined by the P value of the factors. The results of the analysis are shown in Table 5. It can be seen that the B parameters were not significant (PB = 0.371). Meanwhile factor A and factor C have the greatest influence on the outcome.
From the results of the analysis, the regression equation (with a confidence level of 99.6%) can be drawn. Fabrication time = 851 + 731 * A - 7.5 * B + 32.7 * C (analyzed from Minitab 2016 software). It is possible to see the greatest impact on product development time as parameters A and C. When changing the value of the parameter A, it is necessary to add the support. With the A value at 0°, the value of production time is small because the amount of support is low and the height for completion is low in this position. But increasing this value to 30° is that means the journey height is changed. With a layer thickness of 0.2mm and when increasing the height, each layer will increase with increasing time. Parameter B reduces the material support layer leading to time to be shortened. For parameter C, when changing certain positions, the time varied. When positioning at number 2, the number of support columns to print only one column so the time is shortened. But when the change is placed in 3 positions, the number of columns was increased to 3, so the time was increased. From table 4, it can be seen that the appropriate support position is position 2 (in the center of printing part) where appropriate printing time reduced. Factor C also affects the product's quality. If the position of the support is not suitable, it will cause "plastic tarp" phenomenon, and the plastic will flow down into the areas without the material of the support.
All three parameters directly affect the time of making the product. In addition, they affect the product's quality (size accuracy, surface roughness, etc.). In future research, it is essential to consider the placement position of auxiliary materials and the structure of the support as well as the distance between support columns. The final

aim of the research is to reduce the time required to manufacture the product and improve the quality of the product.

Table 5: Analysis results of ANOVA

Source	DF	Seq SS	Adj SS	Adj MS	F	P
A	2	3210147	3210147	1605073	6016.52	0.000
B	2	904	904	452	1.69	0.371
C	2	11950	11950	5975	22.4	0.043
Error	2	534	534	267		
Total	8	3223535				
S = 16.3333 R-Sq = 99.98% R-Sq(adj) = 99.93%						

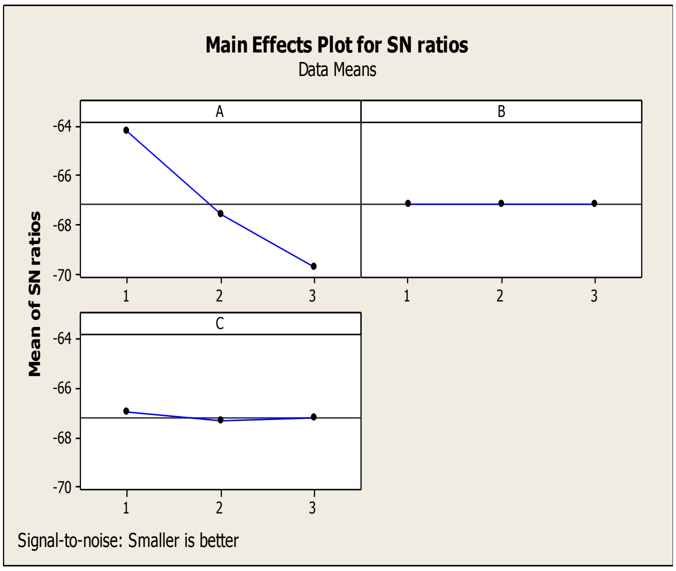


Figure 4: Impact of S / N ratios

5. Conclusions

Nowadays, FDM technology is increasingly developed and widely used. Optimization and improvement of product's quality by selecting and adjusting the technological parameters are the issues most concerned about today. The direction of the prototype and the position of the supporting material are two elements having the greatest impact on the time of making or manufacturing the product. For prototyping directions, the position of the product parallel to the Z axis (ie forming the angle of 0°) when fabricated is the appropriate position to optimize the fabrication time. For the position, the support should be in position 2 (central location of the sample). This is a competitive place to reduce the production time, but cause the product deflection in the absence of support as analyzed. The optimal parameter values ensure the time of fabrication of the product is (based on the S / N ratio analysis): A = 0°, B = 0.2 mm, and C is the center of printed parts/components. Although time was optimized, product quality was used to be the opposite of time, so the trade-off solution is recommended for the benefits of time and quality.

References

[1] G. Pavan Kumar, Srinivasa Prakash Regalla, (2012) "Optimization Of Support Material And Build Time In Fused Deposition Modeling (FDM)", Applied Mechanics and Materials, Vols. 110-116 (2012) pp 2245-2251

[2] L.M. Galantucci, F. Lavecchia, G. Percoco, (2009) “Experimental study aiming to enhance the surface finish of fused deposition modeled parts”, CIRP Annals - Manufacturing Technology, Volume 58, Issue 1, 2009, Pages 189-192.

[3] P.M. Pandey, N. Venkata Reddy, S.G. Dhande, (2007) “Part deposition orientation studies in layered manufacturing”, Journal of Materials Processing Technology Volume 185, Issues 1–3, 30 April 2007, Pages 125-131.

[4] P. M. Pandey, K. Thrimurthulu , N. Venkata Reddy, (2004) “Optimal part deposition orientation in FDM by using a multicriteria genetic algorithm”, International Journal of Production Research, Volume 42, 2004- Issue 19.

[5] Neri Volpato, José Aguiomar Foggiatto, Daniel Coradini Schwarz, (2014) "The influence of support base on FDM accuracy in Z", Rapid Prototyping Journal, Vol. 20 Issue: 3, pp.182-191.

[6] K. Thrimurthulu, Pulak M. Pandey, N. Venkata Reddy, (2003) “Optimum part deposition orientation in fused deposition modeling”, International Journal of Machine Tools and Manufacture Volume 44, Issue 6, May 2004, Pages 585-594.

[7] J. Vanek, J. A. G. Galicia, B. Benes, (2014) “Clever Support: Efficient Support Structure Generation for Digital Fabrication”, Eurographics Symposium on Geometry Processing 2014, Volume 33 (2014), Number 5.

[8] Eric Barnett, Cl´ement Gosselin, (2015) “Weak Support Material Techniques For Alternative Additive Manufacturing Materials”, AdditiveManufacturing, Volume 8, October 2015, Pages 95-104