Optimization of parameters in three-dimensional printing objects with fused deposition modeling technology against geometry accuracy

R Wilza, Iskandar, D Seprianto, EYT Adesta

Abstract--- Dimensional printing object to produce accurate geometry in accordance with the planned. The process parameters investigated are layer height, print speed, perimeter shells and polishing time. Test specimens made with polymaker polysmooth^{TM} material refer to ASTM D995-08 using 3D Printer type Fused Deposition Modelling (FDM). The measurement data were analyzed using ANOVA with design type 2 factorial level and design 4 factorial interactions (4FI) modelled by Design Expert® software. The result of ANOVA is known that the factors significantly (α = 0.05) have an effect on the geometry of 3D printing object and the optimum parameter combination that is height layer=0.14 mm, print speed=51.73 m s, perimeter shells=3 mm with polishing time=20 minutes.

Keywords: 2 level factorial; ANOVA; optimization; three-dimensional printing

1. INTRODUCTION

Additive manufacturing is a three-dimensional solid-manufacturing process of digital models (CAD). The 3D printing process creates a product using additive processes, which by adding basic materials gradually in accordance with the form of a pre-designed digital model. The use of additive manufacturing using 3D printing is more advantageous than the conventional method of manufacturing. Even NASA has broadly funded the research of 3D printing to feed astronauts in space [8]. The Center for European, governance and economic development research reports that the evolution of patents related to 3D printing technology in the US shows that the number of patents has skyrocketed over the past few years [1]. Two different methods are tested, cranial/intraoperative method and the injection molding method using polymethylmethacrylate/PMMA material and the result is concluded that injection molding method is better than cranial/intraoperative [6]. Based on the above situation, it can be concluded that the development of 3D printing object is very broad. This is accompanied by the development of materials used as a basic material forming object 3D printing results. The raw materials used for the manufacture of 3D objects with FDM technology are called filaments made of thermoplastics. There are many types of filaments with various properties that require different temperatures to be printed. In this research will be investigated the use of the latest filament type of polysmooth^{TM} which has superior properties can be done polishing process so as to produce a smooth product surface and cover the pathways that characterize the product of 3D printing and get the right combination of parameters and optimal. Prototyping, jigs, and fixtures, injection molding, patterns for casting and end-use parts are 5 things that should and can be done using 3D printers. 3D Printing is one of the world's newest printing technology, where 3D printing technology will be one of the future technology trends [5]. 3D Printing technology will produce solid objects, and not like printing a piece of paper on a commonly used printer. This 3D printer will complement the 2D printer technology that we have long used as a print tool that the output of a 2-dimensional sheet.

2. METHODOLOGY

In this research used 3D Printer with FDM technology. Where the object is generated from polysmooth^{TM} material, the reason for the use of such material can be done polishing with the aim to get the surface of 3D printing object better. Preparation of test specimens using ASTM standardization D995-08. Analyze the measurement data using analysis of variance (Two-Way ANOVA) with experimental 2 level factorial design and 4FI design model. To help data analysis used Design Expert software (trial version).

In the manufacture of test specimens, the controlled parameters and parameters are determined, the controlled parameters are shown in table 1.

Table 1: Controlled factors in the manufacture of test measurement specimens

No	Factors Controlled	Unit	*Level*	
			Min	Max
1	*Layer height*	mm	0.14	0.3
2	*Print speed*	m/s	50	80
3	*Perimeter shells*	mm	2	3
4	*Polishing time*	minute	0	30

The fixed factors used are:

- 3D printing technology used type FDM using polysmooth^{TM} material
- First layer height = 0.3 mm

Revised Manuscript Received on March 10, 2018.
R Wilza, Mechanical Engineering Department, Polytechnic State of Sriwijaya, Indonesia (dickyseprianto@gmail.com)
Iskandar, Mechanical Engineering Department, Polytechnic State of Sriwijaya, Indonesia
D Seprianto, Mechanical Engineering Department, Polytechnic State of Sriwijaya, Indonesia
EYT Adesta, Kulliyyah Of Engineering, International Islamic University Malaysia, Malaysia

- Top Solid and Bottom = 3 layers
- Fill density =15 %
- Fill Pattern = hexagon
- Temperature nozzle = 210oC
- Temperature platform = 50oC
- Nozzle diameter = 0.4 mm
- Filament diameter = 1.75 mm

3. RESULT AND DISCUSSION

3.1. Results and analysis of test specimen specimens

To know the effect of the factors on the response value of the test specimens, the analysis of the measurement data using the analysis of variance (Two-Way ANOVA) with the experimental method 2 level factorial design, using 4 (four factors). The measurements of the test specimen were randomized according to the measurement design matrix with 3 repetitions so that 48 specimens were produced. After the measurement of the test specimens, the measurement results obtained the minimum, maximum, mean, standard deviation and the ratio of each response and factor on the test, shown in table 2 The measurement of the test specimen was done without polishing process and by polishing process using alcohol 90%. The polishing process is performed using a polisher tool as shown in Figure 1.

3.2. Analysis of influential variables against length response

To identify the effect of layer height, print speed, perimeter shells and polishing factors and to determine the optimum combination of length measurement values of test specimens, analysis of measurement data with ANOVA was performed. The hypothesis (H_0) tested that there is no influence of the factor on the length of the test specimen. The results of ANOVA with the help of design-expert software are shown in table 3.

Fig. 1: Measurement of test specimens, polishing tools, and 3D printers

Table 2: Mean, Standard Deviation, and The Ratio of Test Specimen Measurement Results

Design Model: 4FI Design Type: 2 Level Factorial Runs: 48								
	Factor					Response		
	A	B	C	D		Y_1	Y_2	Y_3
Name	Layer height	Print speed	Perimeter shells	Polishing	Name	Length	Width	Height
Units	mm	mm/s	mm	minute	Units	mm	mm	mm
Minimum	0.14	50	2	0	Observes	48	48	48
Maximum	0.3	80	3	30	Analysis	factorial	factorial	factorial
Mean	0.22	65	2.5	15	Minimum	127.04	12.64	3.27
-1 (code)	0.14	50	2	0	Maximum	127.44	13.03	3.48
+1 (code)	0.3	80	3	30	Mean	127.269	12.8154	3.375
Std. Dev	0.08	15	0.5	15	Std. Dev	0.104156	0.0952479	0.0375868
					Ratio	1.00315	1.03085	1.06422

Table 3. Analysis of variance (ANOVA) for response length

Response 1 LENGHT						
ANOVA for selected factorial model						
Analysis of variance table						
Source	Sum of Squares	df	Mean Square	F Value	F* (α=0.05)	
Model	0.481614583	15	0.032107639	36.34827044	1.99	significant
A-LAYER HEIGHT	0.133352083	1	0.133352083	150.9646226	4.15	
B-PRINT SPEED	0.009352083	1	0.009352083	10.58726415	4.15	
C-PERIMETER SHELLS	0.011102083	1	0.011102083	12.56839623	4.15	
D-POLISHING	0.174002083	1	0.174002083	196.9834906	4.15	
AB	0.062352083	1	0.062352083	70.58726415	4.15	
AC	0.02566875	1	0.02566875	29.05896226	4.15	

AD	0.004602083	1	0.004602083	5.20990566	4.15	
BC	0.017252083	1	0.017252083	19.53066038	4.15	
BD	0.00991875	1	0.00991875	11.22877358	4.15	
CD	0.00421875	1	0.00421875	4.775943396	4.15	
ABC	0.015052083	1	0.015052083	17.04009434	4.15	
ABD	0.002552083	1	0.002552083	2.889150943	4.15	
ACD	0.005852083	1	0.005852083	6.625	4.15	
BCD	0.00091875	1	0.00091875	1.04009434	4.15	
ABCD	0.00541875	1	0.00541875	6.134433962	4.15	
Pure Error	0.028266667	32	0.000883333			
Cor Total	0.50988125	47				

From the calculation result of software design expert design shown in table 3, it can be seen that the biggest F_{Value} is polishing factor indicating that this factor has the biggest influence to length response. From table 3 it is known that the value of F_{Value}> F * (F_{Table} obtained from the distribution table F with α = 0.05), so H_0 is rejected, means with 95% confidence level (α = 0.05) there is an influence of layer height factor, print speed, perimeter shells and polishing against length values of test specimens. From the calculation results using software design-expert obtained model of linear regression equation in the form of factor code:

LENGTH = 127.27 + 0.053*A - 0.014*B - 0.015*C + 0.060*D + 0.036*A*B +.023*A*C - 9.792E-003*A*D + 0.019*B*C + 0.014*B*D - 9.375E-003*C*D - 0.018*A*B*C - 7.292E-003*A*B*D - 0.011*A*C*D - 4.375E-003*B*C*D + 0.011*A*B*C*D (1)

To determine whether the data used to meet the assumptions of identical, independent and normal distribution, residual data from the result of measurement of test specimens with predictive measurement values, as shown in figure 2. While figure 3 shows the actual length of the actual test specimens made using 3D printing and prediction length values based on the calculation results of equation (1). Figure 3 can be seen the results of experiments conducted close to and direction with a diagonal line. This indicates that the equation of the linear regression model generated from the statistical analysis with the help of expert design software can be used to predict the length of the test specimen.

3.3. Analysis of influential variables against width response

Hypothesis (H_0) to be tested that there is no influence of the factors on the response width of test specimens. From the calculation result using design expert software it can be seen that the largest F_{Value} is the print speed factor which indicates that this factor has the greatest influence on the Width response and it is known that the value of F_{Value}> F * (F_{Table} obtained from table Distribution F with α = 0.05), so H_0 is rejected, meaning with 95% confidence level (α = 0.05) there is influence of layer height factor, print speed, perimeter shells and polishing to width value of test specimen and based on calculation result obtained model of regression equation linear in the form of factor code.

WIDTH = 12.82 + 0.016*A - 0.054*B - 0.017*C - 0.019*D + 0.03*A*B + 0.039*A*C - 1.67E-03*A*D + 0.02*B*C - 0.01*B*D – 0.03*C*D - 0.014*A*B*C + 3.75E-03*A*B*D - 2.08E-03*A*C*D + 0.019*B*C*D – 3.33E-03*A*B*C*D (2)

Figure 4 shows that the faster print speed by using a small height layer will result in a smaller width value and closer to the dimension of the design of the planned test sample. While based on ANOVA interaction factors that have a large contribution percentage is the interaction factor AB, AC factor and factor C-D.

3.4. Analysis of influential variables against height response

The step of identification of the influence of the factors on the height of the test specimen height response is done similarly to the response length and width using analysis of variance (ANOVA). The hypothesis (H_0) tested that there is no influence of factors on the height of the test specimen. The results of ANOVA are shown in table 5 and it can be seen that the largest F_{Value} is the print speed factor with a contribution percentage of 20%, this indicates that this factor has the greatest effect on the height response. From the table, it is known that the value of F_{Value}> F *, so H_0 is rejected, which means that there is the influence of the factor on the test specimen height response value. Final equation in terms of coded factors:

HEIGHT = 3.37 + 0.014*A + 0.017*B - 5.000E-003*C - 9.583E-003*D - 2.917E-003*A*B + 0.012*A*C - 5.000E-003*A*D + 0.014*B*C - 7.917E-003*B*D +2.917E - 003*C*D - 5.417E-003*A*B*C - 6.667E-003*A*B*D - 5.833E-003*A*C*D - 250E-003*B*C*D +5.000E-003*A*B*C*D (3)

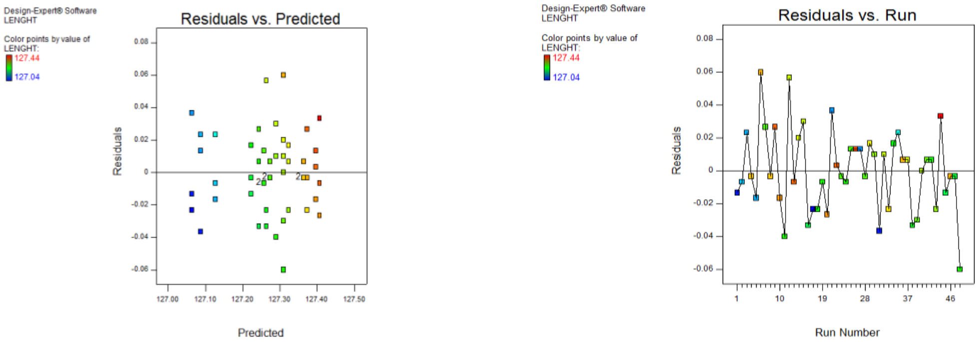

Fig. 2: Residual graphs are identical and independent of the response length

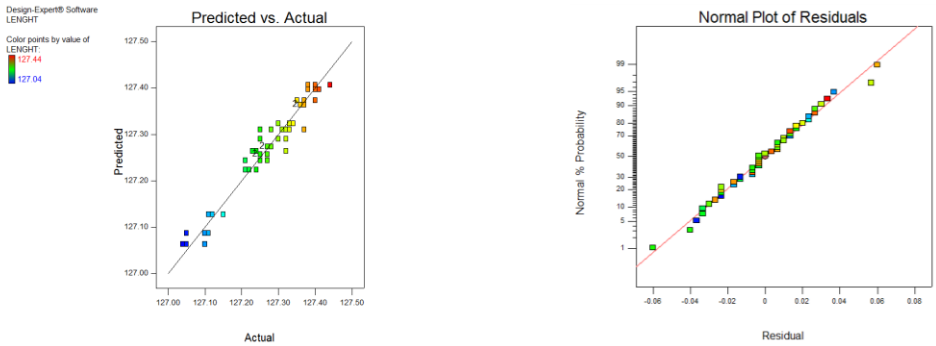

Fig. 3: Prediction vs actual and residual distribution of normal values of length

Table 4. Result measurement of confirmation test specimen

No.	*Layer height*	*Print speed*	*Perimeter shells*	*Polishing*	*Length*	*Width*	*Height*
1	0.14	51.73	3.00	20.00	127.18	12.76	3.3
2					127.20	12.70	3.28
3					127.20	12.75	3.32

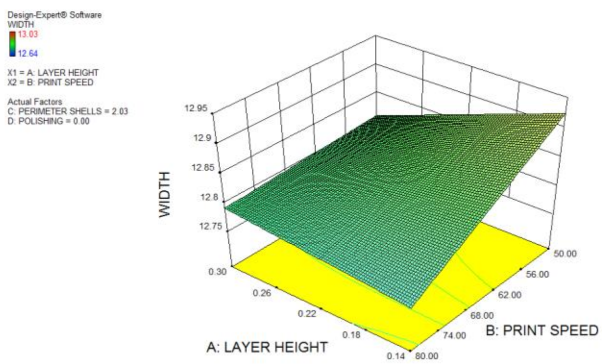

Fig. 4: 3D graph of the influence of factors on the response width value

3.5. Design optimization

After testing with various responses, the design optimization is done to determine the optimum condition of the height layer, print speed, perimeter shells and polishing time. Specimens made using additive manufacturing technology based on the minimum, maximum and target levels of each factor and the specified response. The optimum solution to obtain the desired value of the response by a factor determined by the experimental 2 level factorial design type and the 4FI design model using ANOVA created with the help of design-expert software. The combination of parameters selected layer height = 0.14 mm, print speed = 51.73 mm / s, perimeter shells = 3 mm and polishing time = 20 minutes. Option number 3 is done due to the timing accuracy of the polishing tool.

3.6. Test confirmation

After determining the optimum factor combinations based on statistical analysis using ANOVA, confirmation testing was performed by making test specimens using selected parameters. The result of measurement and process of making specimen for confirmation test is shown table 4.

4. CONCLUSIONS

Based on the research, it can be concluded that the factorial interaction type 2 factorial design with 4 factorial interaction (4FI) modelled by design-expert software has been successfully constructed to predict the influence of factors on the accuracy of the geometry of 3D printing objects with FDM technology. From the linear regression equation to the length response, the width and height produced using ANOVA and confirmation test can be determined the optimum condition of the combination of factors i.e. height layer = 0.14 mm, print speed = 51.73 mm / s, perimeter shells = 3 mm and polishing time = 20 minutes.

ACKNOWLEDGEMENT

The authors acknowledge funding support from the Directorate of Research and Community Service of the Ministry of Research, Technology and Higher Education of the Republic of Indonesia through a National Strategic Research grant (Institution). The authors also regard thanks to all civitas academic State Polytechnic of Sriwijaya for motivation and help.

REFERENCES

1. Ana L A, Imnaculada M Z and Klaus P (2015), *The impact of 3d printing on trade and FDI, a center for European, governance and economic development research* No **262,** Georg August Universitat Gottingen.
2. Delfi C (2016), *Mass Customization Pengertian Dan Pendekatan*, Universitas Gadjah Mada, Indonesia
3. H W Kang *et al* (2016), A 3D bioprinting system to produce human-scale tissue constructs with structural integrity, *Nature Biotechnology* 34, 312–319.
4. Johan T S W (2002), *Introduction to the Statistical Experiment Design*, University of Queensland Australia.
5. Kenny H (2016), *Top 5 Things You Should Be Doing With a 3D Printer*, R&D Technologies Inc, North Kingstown.
6. Kuswanto D and Tontowi AE (2017), Analisa Akurasi Geometri Penggunaan Metode Injection Moulding berbasis Printer 3D Untuk Produksi Implan Pada Bedah Cranioplasty, *J. Iptek desain,* Vol 16, pp 28-32.
7. Roger N (2014), *Rapid Prototyping of Biomaterials Principles and Application, Woodhead* Publishing Limited 80 High Street Sawston Cambridge CB22 3HJ UK.
8. Siddharth B (2014), 3D Printing and Its Applications, *Int. J. of Computer Science and Information Technology Research,* Vol 2, pp 378-380.
9. William E M (2007), *Using Design-Expert for Enhancing Engineering Experimentation Labs*, ASEE Southeast Section Conference University of Kentucky.
10. Gridlogics Tech (2014), Technology Insight Report 2014