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Optimization of Production Process Parameters of DLP Type 3D Printer Design for Product Roughness Value

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ABSTRACT
Additive Manufacturing (AM) is a breakthrough in manufacturing technology based on a layer by the layer printing process through various raw material input techniques. Objects to be printed using a 3D model design by adding raw materials to a 3D printing machine are opposite to subtractive manufacturing types, such as in a CNC milling machine. The purpose of this study was to obtain optimal parameters on the DLP type 3D printing machine for product roughness values using methods that include literature, design, and experimental studies. The specimens tested were 30x15x4 mm in size, with ultraviolet resin material. The test results were analyzed based on the 2-level factorial experimental design type and the 3FI design model, which was processed using the Anova method. The analysis results show that the optimal parameter for the DLP type 3D printing machine for the product surface roughness is the layer height; 0.035 mm, exposure time; 19.542 s, and bottom exposure; 60.679 s with a roughness value of 0.469 µm.

Keywords: *additive manufacturing, 3D printer, DLP, anova, resin, surface roughness*

1. INTRODUCTION

An object fabrication method using additive manufacturing (AM) based 3D printing machines have been developed. This method can overcome the weakness in the complexity of 3D structures that still rely on the traditional way by hand. This prefabrication method involves integrating computer-aided design (CAD) and computer-aided manufacturing (CAM) based designs to make objects or products with complex structures. Object dimensions can be made accurately. One of AM's main advantages depends on its ability to handle 3D structures' complexities because the AM method can be developed from solid, liquid, and powder materials. Objects are produced directly from a three-dimensional digital model by gradually adding raw materials.

Currently, AM is increasingly being used for applications in the health sector. While it is impractical to produce large-scale objects, AM can be a perfect fit for all applications that require a high degree of individual customization. For example, in the health sector, doctors use it to make samples of human organs as a pre-operative planning tool to help them visualize and plan the work of organs before the actual operation.

Apart from advances in AM technology, there are still many challenges, especially regarding raw materials, resolution, tolerance, and surface roughness. Among the AM technologies, digital light processing (DLP) is one of the most promising technologies and is partially used in anthropotomy. DLP is a process in which a liquid photopolymer in vat resin is selectively solidified by polymerization exposed to ultraviolet (UV) light. This technology is characterized by a high level of surface quality and accurate dimensions.

Surface roughness is an essential factor of a product's surface because it determines whether the machine elements can adequately measure a product's quality. A lousy surface roughness level will cause various problems such as wear and cracks, so it is necessary to know the effect of machining parameters to get a good surface roughness value. There are two basic parameters of DLP type 3D printing machines, that is recoat and scanning parameters. This fundamental parameter is further divided into several parts, that is layer height, exposure time, bottom exposure, the light of the delay, bottom layers count, lift distance, lift speed, and retract speed. Selection is a very influential part of each layer's accuracy and surface roughness during the printing process.

This study aims to obtain a good roughness value for 3D printing machine products by getting optimal parameters on the DLP type 3D printing machine for the product roughness value using methods that include literature, design, and experimental studies.

2. LITERATURE REVIEW

Computer-aided design (CAD) uses computers to help create, modify, analyze, or optimize related designs. CAD software is used to increase productivity, improve the quality of designs, and improve communication through documentation. In mechanical design, it is known as mechanical design automation (MDA) or computer-aided drafting (CAD), which includes the process of making engineering drawings using computer software such as Autodesk Inventor, Pro/ENGINEER, SolidWorks, and SketchUp Pro [1].

3D Printing Machine is a form of additive manufacturing in which a three-dimensional object is formed by adding raw materials layer by layer [2]. The first step of a 3D printing machine is to create a digital model of the object printed [3-5].

The American Society for Testing and Materials (ASTM) publishes classification standards for the Additive Manufacturing process into seven categories. This classification standard aims to clarify and differentiate between one type of processing technique and another. The seven categories are; (1) Binder Jetting, (2) Directed Energy Deposition (DED), (3) Material Extrusion, (a) Fused Deposition Modeling (FDM), (b) Fused Filament Fabrication (FFF), (c) Contour Crafting. (4) Jetting Materials, (5) Fusion Powder Bed; (a) Selective Laser Sintering (SLS), (b) Direct Metal Laser Sintering (DMLS), (6) Sheet Lamination, and (7) Vat Photopolymerization; (a) Stereo Lithography (SLA), (b) Continuous Liquid Interface Production (CLIP), (c) Digital Light Processing (DLP) [5].

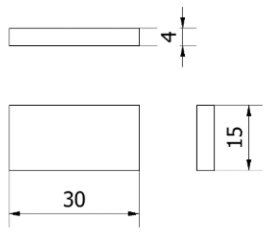
The quality of a product that is considered acceptable is usually characterized by good surface quality. The level of surface roughness significantly affects the quality of the 3D printed product in the Digital Light Processing (DLP) method, mostly when the printed components are used in the assembly that requires high accuracy, in testing mechanical properties, and in joining components that require component dimensional accuracy [6].

From various previous studies on the product surface roughness value on a 3D printing machine, the conclusions were obtained is the roughness value obtained from the best results with a roughness value of 8.55 μm from the first experiment on the 4th side and the average roughness obtained on each side is 11 μm [7]. The more extensive the layer used, the value The surface roughness is also getting bigger, and vice versa, with the conclusion that ABS polymer with horizontal orientation is the best result for the surface roughness test [8].

3. MATERIALS AND METHOD

The method used in this research includes literature, design, and experimental studies of the DLP-type 3D printing machine. In this study, a DLP type 3D printing machine that uses resin raw materials is used; using resin raw materials is due to the complex structure, object detail, and roughness level of the 3D printing machine. The test is carried out by making a test specimen measuring 30x15x4 (see Figure 1). This test aims to obtain parameter optimization in the DLP type 3D printing machine production process on the product surface roughness value to produce the product according to the design. Also, the resulting data will be analyzed using Anova. In making the DLP type 3D printing machine test specimen, there are three stages: designing a 3D model using CAD software, slice and export 3D models using Chitubox software, and making a 3D model object of a test specimen printed with a DLP-type 3D printing machine.

In making test specimens, fixed-parameter factors (see Table 1) and control parameters (see Table 2) were determined.



Information :

Length : 30 ± 0.04 mm

Width : 4 ± 0.04 mm

Height : 15 ± 0.04 mm

Figure 1 Test specimen

Table 1 Fixed parameter factors

No.	Parameter	Value	Unit
1	Light-off (Delay)	0	(s)
2	Bottom Layers Count	3	-
3	Lift Distance	5	(mm)
4	Lift Speed	65	(mm/min)
5	Retract Speed	150	(mm/min)

Table 2 Controlled parameter factors

Parameter	Lower	Upper	Unit
Layer Height	0.035	0.05	(mm)
Exposure Time	14	20	(s)
Bottom Exposure	60	90	(s)

Next, the data obtained from the test results were analyzed by Anova, which analyzes the differences between the group means in the sample and test the hypothesis (Ho) that the average of two or more populations is the same. The Anova concept is based on the F distribution concept and can be applied to analyze the relationship between various observed variables [9].

In this research, the tools and materials used are; Autodesk Inventor Pro 2020 student version, Chitubox software version 1.6.5 as a central control and slicer system, Design of expert trial version software, DLP type 3D printing machine, Laptop, Surface Roughness Testers, and Resin.

4. RESULTS AND DISCUSSION

After the testing process is carried out on the test specimens, the data from the measurement results are analyzed to determine the factors that affect the layer height, exposure time, and bottom exposure. The parameter combination can be determined to obtain the optimal parametric roughness value using a DLP type 3D printing machine.

To determine the effect of factors on the specimen's response value, analysis of the roughness test results using Anova with the experimental method two level factorial design, using three factors and one response. The specimen testing was carried out randomly according to the measurement design matrix in Table 3 and Table 4, with two replications resulting in 16 test specimens. After the testing process is carried out on the test specimen (see Figure 2), the test results obtained the average value and standard deviation of each response (see Table 5), and the factors on the test are shown in Table 4.

a) before testing process b) during testing process c) after testing process

Figure 2 The specimen testing process

Table 3 Randomized test result data

Std	Run	Factor 1 A:Layer Height	Factor 2 B:Exposure Time	Factor 3 C:Bottom Exposure	Response 1 Surface Roughness
		mm	s	s	µm
1	1	0.035	14	60	0.556
12	2	0.05	14	90	0.484
9	3	0.035	14	90	0.546
15	4	0.05	20	90	0.481
10	5	0.035	14	90	0.549
7	6	0.05	20	60	0.476
16	7	0.05	20	90	0.429
2	8	0.035	14	60	0.489
6	9	0.035	20	60	0.501
11	10	0.05	14	90	0.397
4	11	0.05	14	60	0.382
13	12	0.035	20	90	0.542
8	13	0.05	20	60	0.412
14	14	0.035	20	90	0.533
5	15	0.035	20	60	0.425
3	16	0.05	14	60	0.398

Table 4 Mean and standard deviation of test results

Name	Min	Max	-1 (Code)	+1 (Code)	Mean	Std. Dev
Layer Height (mm)	0.35	0.05	0.035	0.05	0.0425	0.00774597
Exp Time (s)	14	20	14	20	17	3.09839
Bottom Exp (s)	60	90	60	90	75	15.4919

Table 5 Response testing with the 3FI model design

Name	Min	Max	Mean	Std. Dev	Ratio
Surface Roughness (µm)	0.382	0.556	0.475	0.0606454	1.4555

To identify the effect of layer height, exposure time, and bottom exposure factors and determine the optimal combination of values for the test specimens' surface roughness, analysis of the test results data was carried out using Anova. It is known that the hypothesis (Ho) tested is that there is an influence of factors on the roughness of the test specimen, as shown in Table 6.

Table 6 Anova test results

Source	Sum of Squares	df	Mean Square	F Value	F Tabel (α=0.05)	
Model	0.043	7	0.006096	3.91	0.0375	**Signi-cant**
A-Layer Height	0.029	1	0.029	18.62	0.0026	
B-Exp Time	0.00000025	1	0.000000249	0.0001 60	0.9902	
C-Bottom Exp	0.00648025	1	0.006480	0.79	0.0760	
AB	0.004761	1	0.004761	4.15	0.1189	
AC	0.000361	1	0.000361	3.05	0.6435	
BC	0.000025	1	0.0000249	0.23	0.9024	
ABC	0.001980	1	0.001980	0.016	0.2927	
Pure Error	0.012	8	0.001561	1.27		
Cor Total	0.055	15				

From the results of the analysis shown in Table 6, it is known that the value of F Value > F Table so that Ho is rejected. The most significant F value is the layer height factor, which indicates that this factor significantly affects the roughness test on the product surface.

After the testing and data processing have been carried out, optimization is carried out to determine the optimal value conditions for the layer height, exposure time, and bottom exposure. Specimens were made using a DLP type 3D printing machine, the minimum, maximum, and target levels of each factor and the specified response. The solution to getting the desired optimal value from the response with the factors determined based on the two factorial levels experimental method and the 3FI design model processed using the Anova method can be seen in Table 8 with the factor conditions shown in Table 7. The selected parameters' combination is layer height; 0.035 mm, exposure time; 19.542 s, and bottom exposure; 60.679 s. Option number 3 is made due to the size accuracy of the layer height parameter.

Table 7 The desired factor condition

Name	Goal	Lower Limit	Upper Limit
A:Layer Height	is in range	0.035	0.05
B:Exposure Time	is in range	14	20
C:Bottom Exposure	is in range	60	90
Surface Roughness	is target = 0.469	0.382	0.556

Table 8 The combination of the parameter optimization factor against the roughness value

No.	Layer Height	Exp. Time	Bottom Exp.	Surface Roughness	Desirabillity	
1	0.044	15.480	76.832	0.469	1.000	
2	0.047	19.915	89.220	0.469	1.000	
3	**0.035**	**19.542**	**60.679**	**0.469**	**1.000**	**Select-ed**
4	0.040	19.730	67.189	0.469	1.000	
5	0.041	14.160	60.812	0.469	1.000	
6	0.044	15.854	80.064	0.469	1.000	
7	0.046	14.258	89.445	0.469	1.000	
8	0.043	15.852	70.612	0.469	1.000	

5. CONCLUSIONS

In this study, it can be concluded that:

1) The combination of optimization factors is obtained: layer height; 0.035 mm, exposure time; 19.542 s, and bottom exposure; 60.679 s with a roughness value of 0.469 µm.
2) The DLP type 3D printing machine can make a product with a high degree of accuracy and precision with detailed complex structure and smooth surface.

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REFERENCES

[1] S. Dicky, Iskandar, W. Romi, Adesta. YET, 2019, “Influence of Internal Fill Pattern, Polishing Time and Z-Axis Orientation on the Tensile Strength of the 3D Printed Part”, International Journal of Recent Technology and Engineering (IJRTE). Volume 7.

[2] Rayna, Thierry and Striukova, Ludmila, 2014, The Impact of 3D Printing Technologies on Business Model Innovation. Benghozi, P.-J., Krob, D., Lonjon, A., and Panetto, H., editors, Digital Enterprise Design & Management, Chapter 11, pages 119-13. *Springer International Publishing*, January 2014, Available at SSRN: https://ssrn.com/abstract=2412841

[3] Romli, D. Seprianto, D.P Putra, Zamheri, Rasyid. “Effect of Object Making Process Parameters with Digital Light Processing Rapid Prototyping Technology on Bending Stress”, Journal of Physics: Conference Series, 2020.

[4] D. Seprianto, R. Sugiantoro, Siproni, Yahya, M. Erwin. “The Effect of Rectangular Parallel Key Manufacturing Process Parameters Made with Stereolithography DLP 3D Printer Technology Against Impact Strength”, Journal of Physics: Conference Series, 2020.

[5] Sandy. Bobby, 2019, The Effects of Layer Thickness and Exposure Time on Surface Roughness of Gear that made from 3D Printer Digital Light Processing, Other thesis, Politenik Negeri Sriwijaya.

[6] Sugiantoro. Bambang, Rusnaldy, Widyanto. Adi Susilo, 2014, Optimization of Milling Process Parameters on the Quality of Aluminum Machining Results with the Taguchi Method, TRAKSI Vol. 14 No. 1 Juni 2014.

[7] Setiawan. Andik Aris, Karuniawan. Bayu Wiro, Arumsari. Nurvita, 2018, Optimization of 3D Printing Parameters for Dimensional Accuracy and Surface Roughness of Products

Using the Taguchi Gray Relational Analysis Method, Proceedings Conference on Design Manufacture Engineering and its Application, Politeknik Perkapalan Negeri Surabaya.

[8] Waluyo. Bambang, Febriantoko, Riyanto. Rachman Rio, 2017, Coating of 3-Dimensional Printer Products Using Paints and Resin Coatings, Prosiding SNST ke - 8 Tahun 2017 Fakultas Teknik Universitas Wahid Hasyim Semarang.

[9] S. Dicky, W. Romi, Iskandar, 2017, Optimization Parameters in the Process of Making 3D Printing Objects with FDM Technology on Geometry Accuracy, Seminar Nasional Teknik Industri Universitas Gadjah Mada.