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A Response Surface Methodology Approach for The Optimisation of Energy and Waste Manufactured by Portable 3D Printing

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Abstract — *Additive manufacturing (AM) processes such as fused deposition modeling (FDM) give a material-efficient effect to minimize material waste better than the subtractive machining process. The application of AM could also save energy, but the research on energy consumption of the process is not explored critically. Besides, the fabricated parts that suffer badly from low part quality require extra time and cost to improve their quality. Therefore, in this study, the optimization of built parameters was identified and analyzed to consider material waste and energy consumption using Response Surface Methodology (RSM). An optimal solution for material waste and energy consumption was determined by using the Minitab Response Optimizer tool. The result for optimal settings was; a number of shells = 3, slice orientation = 0º, layer height = 0.4 mm, and infill percentage = 100%, and the parameters gave the lowest values of waste and energy consumption. The confirmation test has shown that the percentages of error for response variables were within 11% to 26%, which are considered low due to some external sources of errors as the R-squared was not perfect as 100%.*

Keywords — *Material Waste, Energy Consumption, Optimal Build Parameters, Minitab Optimizer Tool*

I. INTRODUCTION

Nowadays, environmental sustainability is one of the global concerns as it is an appearance of the increasing public mandate which the development strategy was depends on the enduring economic growth whether it is sufficient to compensate for the environmental impact of production or it will cause the environmental degradation from the process [13]. Malaysia has a higher prevalence of such problems where economic growth, environmental sustainability and energy security are simultaneously important to overcome the problems [1]. Fused deposition modeling (FDM) is one application AM that has drawn increasing attention from the industry world to fabricate a 3D object [7]. The FDM process works by utilizing a molten thermoplastic filament deposited in a layer by layer fashion onto a substrate [6]. Typically, these layers of process occupy a substantial portion of production time, which causes increasing material waste and increasing energy consumption. To improve the sustainability of AM, it requires reduced material and energy consumption [5]. However, studies on waste and energy consumption are relatively low because of the FDM process's simple energy behavior. Therefore, this study aims to identify the significant portable 3D printing build parameter setting for energy consumption and waste and analyze optimum functionality against environmental impact and part quality. In practice, the number of shells, infill percentage, and layer height are the key process parameters that significantly impacted society and the environment. In addition, to achieve the aim of this study, Response Surface Methodology (RSM) approach was used for part optimization with a consideration of scrap weight, and energy consumption as RSM is a collector of statistical techniques for solving the problems which also analyzed the investigation between input parameters and responses to identify the design parameters that great influence on the product [8].

II. LITERATURE REVIEW

Additive manufacturing provides the capability of freeform fabrication. It removes traditional manufacturing such as CNC machined parts and injection folded parts restrictions and gives design freedom of product innovation. Then, AM also enhances the profit space for manufacturers and reduces the fabrication process's supply chain. A huge potential to reduce environmental impact is the most important thing provided by AM technologies than the normal manufacturing process [10]. FDM is one of the AM processes contributing to material efficiency, minimizing material waste better than the subtractive mechanical machining process. However, the research for the AM process's energy consumption is critically unexplored [2]-[5]. In FDM, the selection for build-up orientation of the model is one of the crucial factors where it affects the different areas of the model such as main material, support material, built-up time, and total cost per part [4]. In determining optimum built orientation, the main material's minimization, support material, and slicing were used. This means that the use of optimum built orientation affected the optimization wastes produced during the manufacturing process. Besides, the built time values and the number of layers required are determined for various built orientations. In addition, to optimize the manufacturing process cost, selecting the best build orientation of the part, and creating optimal process planning were helped the manufacturer [3]. The part orientation and settings of the printing were influenced by the quantity of support material and increased time consumption.

III. METHODOLOGY

This section covers the brief introduction about the specimen selection for (Acrylonitrile Butadiene Styrene) ABS material, and the detailed dimensions of CAD drawing are shown. The parameter selection with its three-level settings and other constant FDM process parameter settings are discussed, and the parameters are set by using Cura software. For design optimization, the Minitab software was used for RSM preparation and generated experimental runs based on FDM parameters. The slicing STL format method into a thin layer and the parameter and its levels of setting also used Cura Software and printed by the New Dual Extruder 3D Printer. In addition, all response variable measurement devices and methods were discussed. After the response variables were completed, the data collected were analyzed using ANOVA and contour plot to finalize the optimum FDM parameter.

A. Test Specimen and Material

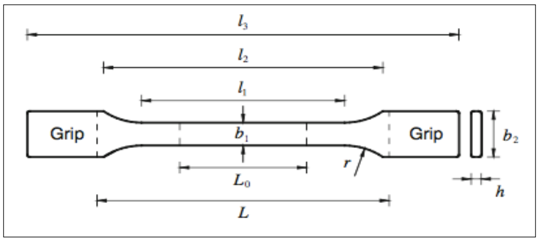

Fig. 1: Dimensions of design specimen

All specimens were fabricated using the same ABS filament, and the diameter of ABS filament used for fabricating the specimens was 2.85 mm. Test part specimens with geometry and dimensions of the 3D printing specimens adapted from the ISO 527-2 were used. The ISO 527-2 (1993) recommended bone-shaped specimens to be molded using the geometry that provided various shapes, including curvature, rectangular, and even reducing support materials for lower probability of printing errors shown in Fig. 1.

B. Build Parameters

In this study, the process parameters determined how they affect process performance. The investigated parameters were the number of shells, slice orientation (SO), layer height, and infill percentage. Besides, this experimental research focused on scrap weight and energy consumption of fabricated parts. The number of shells was considered as outline prints on each layer of the test parts. The SO referring to the orientations such as 0°, 45°, and 90° of the layers was printed. The layer heights considered in this experiment were 0.15 mm and 0.4 mm. For infill percentages, a hexagonal pattern, 15% infill, and 100% infill were selected. Table 1 shows the four selected process parameters and their levels.

Table 1: FDM Process Parameters and their levels

FDM Parameter	Units	Level 1	Center	Level 2
Slice Orientation (SO)	Degree (°)	0	45	90
Number of Shell	N/A	1	2	3
Infill Percentage	%	15	57.5	100
Layer Height	mm	0.15	0.275	0.4

C. Response Surface Methodology

The design optimization method of RSM for analyzing and solving problems by investigating between FDM parameter and response parameters to identify the significant FDM parameters affected the energy consumption and waste produced by fabricated parts. The optimization was based on the four parameters, including slice orientation (SO), a number of shells, infill percentage, and layer height at 2 levels, and a center level was considered. The Minitab Project software, Box-Behnken design was used to analyze the response variables of each experimental run. The Box-Behnken designs can efficiently estimate the first and second-order coefficients. They have 3 levels per factor, so each parameter's center level was included to detect curvature data. Each parameter set's center point provided an average response that showed a higher or lower value than the average response value of all factorial points. Based on the number of factors and levels of factors, 27 runs of design experiments were generated to fully understand the effect of various combinations of parameters on the final 3D fabrication parts and FDM parameters on waste and energy consumption.

IV. RESULT AND DISCUSSION

The response variable results were analyzed using the RSM method to explore the significant effect, relationships between FDM parameters and response variables regarding environmental aspects. Statistical analysis software, Minitab 18, was used for automated calculation, creating various graphs, and allowing users to focus more on analyzing data. Measurement readings for scrap weight and energy consumption were obtained using A2973-LT series 2002 electronic balance and Nicetech LCD blacklight Power Consumption Energy meter.

Table 2: Experimental results

No of Exp.	SO (°)	No of Shell (N/A)	Infill% (%)	Layer Height (mm)	Scrap Weight (g)	Energy Consumption (kWh)
1	90	3	57.5	0.275	0.31	0.031
2	45	2	57.5	0.275	0.23	0.059
3	45	2	57.5	0.275	0.23	0.060
4	45	2	100.0	0.150	0.22	0.096

5	0	1	57.5	0.275	0.20	0.053
6	0	3	57.5	0.275	0.14	0.047
7	45	2	15.0	0.400	0.21	0.038
8	45	1	15.0	0.275	0.23	0.070
9	90	2	100.0	0.275	0.24	0.042
10	45	3	57.5	0.150	0.24	0.068
11	45	1	57.5	0.150	0.24	0.121
12	90	2	15.0	0.275	0.31	0.038
13	90	2	57.5	0.400	0.31	0.029
14	45	1	100.0	0.275	0.22	0.069
15	0	2	57.5	0.150	0.19	0.102
16	45	3	100.0	0.275	0.19	0.038
17	45	2	57.5	0.275	0.22	0.057
18	45	3	15.0	0.275	0.22	0.039
19	0	2	100.0	0.275	0.19	0.050
20	45	2	100.0	0.400	0.23	0.041
21	90	1	57.5	0.275	0.29	0.056
22	90	2	57.5	0.150	0.23	0.071
23	45	3	57.5	0.400	0.21	0.028
24	45	2	15.0	0.150	0.23	0.099
25	0	2	15.0	0.275	0.18	0.050
26	45	1	57.5	0.400	0.21	0.055
27	0	2	57.5	0.400	0.16	0.036

A. *Scrap Weight*

A Pareto chart for scrap weight indicated the standardized effect's absolute values from the largest effect to the smallest effect. In Fig. 2, the bars representing SO and SO-layer height over the reference line were at 2.18, where SO-Infill% and SO-No of shell stood just over the reference line. These factors were statistically significant at the 0.05 level with the scrap weight. From Fig. 3, the number of materials to build the support can be influenced by the SO. The change in SO at 0° orientation gave the minimum result of scrap weight, whereas it showed a significant reduction. It was reported by [2] that SO indicated the highest importance and the infill percentage influence on scrap weight. For the experimental runs, it can be seen that an increase in the number of shells and infill % reduced scrap weight. In this case, layer height gave an insignificant effect on the scrap weight. For optimum scrap weight, zero degrees of SO, three shells and 100% infill gave the lowest scrap weight values.

The contour plot in Fig. 4 was used graphically to present the interaction effect of two significant factors determined in ANOVA: SO and Infill % on the scrap weight, where other factors were held constant at its center levels. A significant interaction between SO and Infill % on scrap weight was located at the dark blue region at the lower left side, directly proportional to SO, Infill%, and part weight. It can be seen that the scrap weight can be reduced by decreasing the SO and Infill %. As the zero degrees SO did not require support material to hold the specimen part in shape and low infill %, the part's weight was decreased. Hence, this study's optimum level setting was zero degrees SO and 15% infill to produce a specimen's minimum scrap weightier.

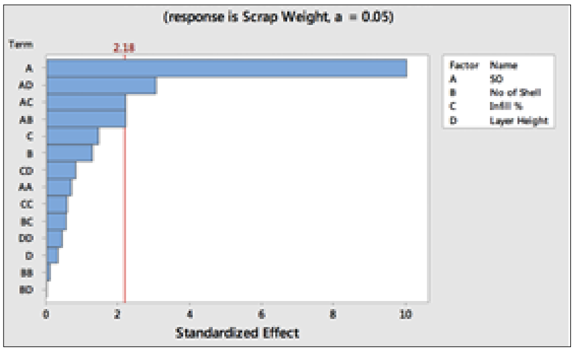

Fig. 2: Pareto chart of Standardized Effect for Scrap weight

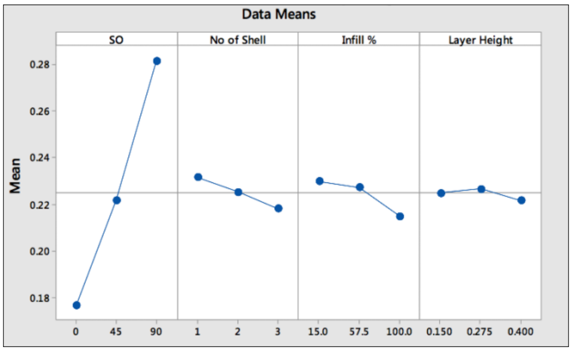

Fig. 3: Main Effect Plot for Scrap weight

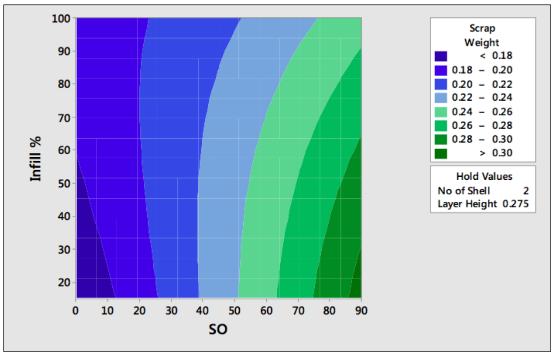

Fig. 4: Contour plot of Infill % vs. SO for Scrap Weight

B. *Energy Consumption*

In this Pareto chart, as shown in Fig. 5, the bars representing layer height and number of shells have a high value of standardized effect beyond the reference line at 2.18, where Layer height-Layer height, Number of Shell-Layer height, SO-SO, and SO crossed just over the reference line. These factors were statistically significant at the 0.05 level with energy consumption. For the experimental runs, it can be seen that an increased number of shell and layer height resulted in optimum energy consumption, as shown in Fig. 6. From Fig. 6, the infill % was not an influential factor, followed by SO. In this case, three numbers of shells and 0.400 mm layer height gave the lowest energy consumption values.

The contour plot shown using the developed regression model presents the response's behavior affected by different parameter levels. From Fig. 7, a significant interaction between layer height and the number of shells on weight was inversely proportional between layer height, the number of shells, and energy consumption. It can be seen that energy consumption can be reduced by increasing the layer height and number of shells. When the layer thickened, the number of layers needed to be decreased, as reported by [14]. Hence, this study's optimum level setting was 0.400 mm layer height and 3 numbers of the shell to produce a specimen's minimum energy consumption.

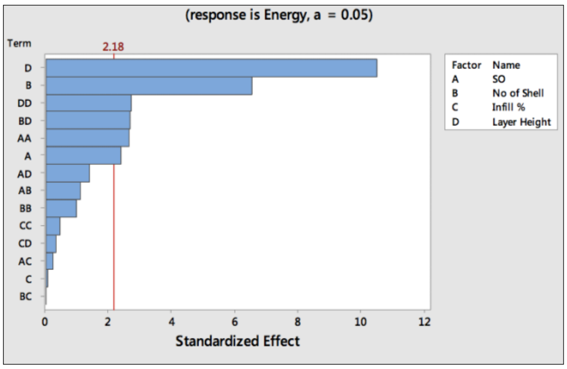

Fig. 5: Pareto chart of Standardized Effects for Energy Consumption

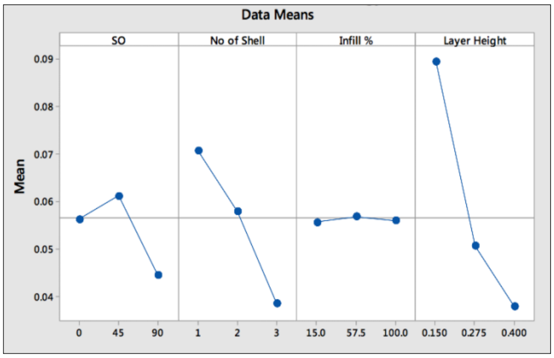

Fig. 6: Main Effect Plot for Energy Consumption

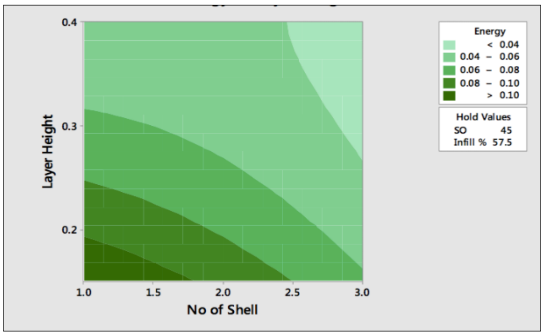

Fig. 7: Contour plot of Layer Height vs. No of Shell for Energy Consumption

V. CONCLUSIONS

This study has established the optimum portable 3D printing build parameter settings for environmental aspects by developing a Response Surface Methodology using Minitab 18 software. Significant process parameters are identified using the Pareto chart, main effect plot, and contour plot, as the responses are plotted and discussed in previous sections. The study presented the slice orientation, number of shells, infill percentage, and layer height processing parameters, and a total of 27 specimens with ABS material. By observing the data, slice orientation and infill percentage are highly affected to scrap weight. On the other hand, energy consumption is significantly affected by the number of shell and layer height. Due to contour plots and response surface plots, the optimum parameters are analyzed with 0 degrees of SO and 15% infill giving the lowest scrap weight and 0.4mm layer value. Three numbers of shells produce minimum energy consumption.

The validation runs for scrap weight, and energy consumption are conducted based on the best setting value, and it shows that the difference between the predicted value and the actual value is in the range of 11% to 23%. This means that there are some sources of errors that could affect the results between theoretical and experimental. As mentioned by [11], environmental factors such as room temperature and humidity and the FDM materials such as ABS, PLA, or nylon may affect the responses. Besides, the condition of the 3D printer also affects energy consumption directly.

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REFERENCES

[1] R.A. Begum, K. Sohag, S.M.S. Abdullah & M. Jaafar, CO2 emissions, energy consumption, economic and population growth in Malaysia, Renewable and Sustainable Energy Reviews, 41 (2015) 594–601.

[2] [C.A. Griffiths, J. Howarth, G. De Almeida-Rowbotham, A. Rees & R. Kerton, A design of experiments approach for the optimization of energy and waste during the production of parts manufactured by 3D printing, Journal of Cleaner Production, 139 (2016) 74–85.

[3] S. Magar, N.K. Khedkar & S. Kumar, Review of the effect of built orientation on mechanical Properties of metal-plastic composite parts fabricated by Additive Manufacturing Technique, Materials Today: Proceedings, 5(2) (2018) 3926–3935.

[4] S. Raut, V.S. Jatti, N.K. Khedkar & T.P. Singh, Investigation of the Effect of Built Orientation on Mechanical Properties and Total Cost of FDM Parts, Procedia Materials Science, 6(1) (2014) 625–1630.

[5] R. Song & C. Telenko, Material and energy loss due to human and machine error in commercial FDM printers, Journal of Cleaner Production, 148 (2017) 895–904.

[6] T. Sonsalla, A.L. Moore, W.J. Meng, A.D. Radadia & L. Weiss, 3-D printer settings effects on the thermal conductivity of acrylonitrile butadiene styrene (ABS), Polymer Testing, 70 (2018) 389– 395.

[7] Tang, Y., Mak, K., & Zhao, Y. F. A framework to reduce product environmental impact through design optimization for additive manufacturing. Journal of Cleaner Production, 137, (2016) 1560–1572.

[8] Said, K. A. M., & Amin, M. A. M. Overview of the Response Surface Methodology (RSM) in Extraction Processes. Journal of Applied Science & Process Engineering, 2(1), (2015) 8–17.

[9] Chua, C. K., & Leong, K. F. 3D printing and additive manufacturing: principles and applications, 5th Edition. World Scientific, 2017.

[10] Fernandez-Vicente, M., Calle, W., Ferrandiz, S., & Conejero, A. Effect of Infill Parameters on Tensile Mechanical Behavior Desktop 3D Printing. 3D Printing and Additive Manufacturing, 3(3) (2016) 183–192.

[11] Mohamed, O. A., Masood, S. H., & Bhowmik, J. L. Parametric Analysis of the Build Cost for FDM Additive Processed Parts Using Response Surface Methodology. In Reference Module in Materials Science and Materials Engineering. (2016).

[12] Prof. (Dr) .V. R. Naik, Mr.G.C.Mekalke, Mr.A.V.Sutar, Implementation of Response Surface Methodology for Analysis of Milling Process Using Multi Point Cutting Tool for Surface Finish,

[13] SSRG International Journal of Mechanical Engineering 2(7) (2015) 1-7.Chen, D., Heyer, S., Ibbotson, S., Salonitis, K., Steingrímsson, J. G., & Thiede, S. Direct digital manufacturing: Definition, evolution, and sustainability implications. Journal of Cleaner Production, 107 (2015) 615–625.

[14] Guo, N., & Leu, M. C. Additive manufacturing: Technology, applications, and research needs. Frontiers of Mechanical Engineering, 8(3) (2013) 215–243.