Influence of Internal Fill Pattern, Polishing Time and Z-Axis Orientation on the Tensile Strength of the 3D Printed Part

D Seprianto, Iskandar, R Wilza, EYT Adesta

Abstract--- ***This fourth-generation industrial revolution is characterized by the existence of supercomputers, smart robots, drivers less vehicles, genetic editing and the development of neurotechnology, currently the manufacturing process is entering mass customization era that is how to make more high variety product with low price or known as build to order principle, customized product, but can be mass produced. One method that can answer the challenge is additive manufacturing using three-dimensional printing (3DP). In this research, making an object using 3DP use CAD data which then transformed into G-Code with FlashPrint© v.3.23.1 software. This study aims to determine the effect of the internal shape of the pattern fill, polishing time and z-axis orientation, to the tensile strength of test specimens made using Flashforge® Dreamer 3D Printer type Fused Deposition Modeling (FDM) with Polymaker PolySmooth™ material and refers to ASTM D-638 for the Type I. Factors investigated were Polishing Time, Internal Fill Pattern and Z axis Orientation with tensile strength response from test specimen. The test results data were analyzed using ANOVA with design type 2 factorial level and design 3 factorial interactions (3FI) modeled by Design-Expert® software. The result of the analysis revealed that the main factor that most influences to the tensile strength of the test specimens was the polishing time factor with the contribution percentage of 35%, while the interaction between internal fill pattern and z-axis orientation contributed 52%.***

Keywords: 2 level factorial design; ANOVA; tensile strength; three-dimensional printing

1 INTRODUCTION

This fourth generation of the industrial revolution is characterized by the existence of supercomputers, smart robots, driverless vehicles, genetic editing and the development of neurotechnology. Additive manufacturing technology using 3DP enables the creation of prototypes or end products relatively faster, the time to market is reduced drastically when prototypes are made by 3DP than regular methods. This technology allows for the manufacture of products that might not have been possible using traditional methods. These products may have new abilities, extended useful life, or reduce the time, labor, or natural resources needed to use these products [1]. The evolution of patents related to 3DP technology in the US shows that the number of patents has increased tremendously over the past few years, not only patents are granted but also patent applications in the US, showing the same trend [3]. Innovations in 3DP and patent publications generated starting from the 1990s with a noticeable surge in activity around this technology took place in the last 5 years. It is clear that the activities and trends in the use of this technology will continue and provide more innovation in the near future [4].

2 LITERATURE REVIEW

Additive manufacturing includes many technologies including subset such as 3D Printing, Rapid Prototyping (RP), Direct Digital Manufacturing (DDM), layered manufacturing and additive fabrication. Recently, additive manufacturing is used to make the final product used in aircraft, dental restorations, medical implants, cars, and fashion products. Even the latest 3D printing development has been able to create human organs in integrity [5].

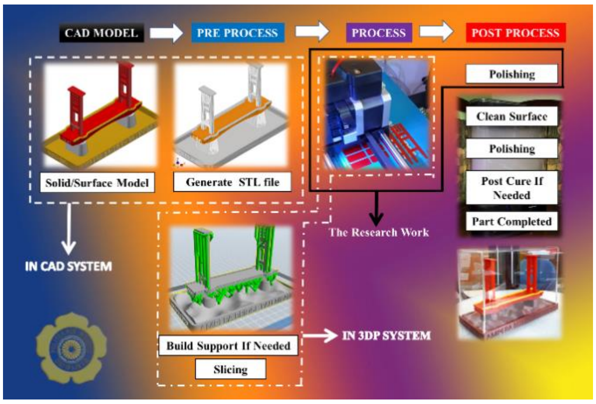

Fig. 1: The principle of 3D printing

The tensile test showed that injection moulded samples have the high tensile strength and among FDM products, 0.1 mm layer thickness gave better results. FDM products have excellent flexural strength than moulded samples and 0.15 mm gave optimum results. The trend of compressive strength also pointed in FDM products capability. 0.2 mm gave the most preferable result [2]. The use of recycled materials will also be more environmentally friendly [6]. The maximum compressive strength for PLA parts (30 MPa) is reached at 80 % infill density. Generally, 3D printing users select smaller infill in order to reduce printing time or save material. If a user wants high mechanical resistance and a fast process, it is preferable to use 80 % infill density [7]. The highest strength can be found at 45 degrees at XY Plane. After the post-processing experiment,

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showed the lowest strength (both in flexural and tensile) for wax and highest for Z-bond 90 [8]. The mechanical properties of 3D-printed polyether-ether-ketone samples (tensile, compressive and three-point bending) were higher than those of ABS samples [9]. 0° raster angle is the optimum raster angle to achieve higher tensile and flexural strength at lower surface roughness [10] and smaller raster angle has an optimal condition for mechanical properties and surface finish [11].

3 METHODOLOGY

3.1. Fabrication of tensile specimen

The materials tested in this study is polymaker polysmooth™ which were used to produce samples in Flashforge® Dreamer 3D Printer type Fused Deposition Modelling (FDM). The specimen geometries followed specifications outlined in ASTM D-638 for the Type I tensile specimens. The entire list of 3D printing condition constant values used during this study are shown in table 1 and table 2 for tensile specimen condition. Then the process continued with surface refinement (polishing) using 90% alcohol with Polysher™.

Table 1: Tensile Specimen Variable Process Condition

Process parameter	Value
Internal fill pattern (variable)	Line/Hexagon
Polishing time (min) (variable)	0/20
Z axis orientation (^{o}) (variable)	0/45

Table 2: Constant 3D-Printing Process Settings

Parameter	Value
Layer height (mm)	0.14
Perimeter sheel (count)	3
Top solid layers	3
Bottom solid layers	3
Fill density (%)	15
Temperature extruder (^{o}C)	220
Temperature platform (^{o}C)	50
Nozzle diameter (mm)	0.4
Filament diameter (mm)	1.75
Base print speed (mm/s)	60
Travel speed (mm/s)	80

3.2. Tensile Testing and Experimental Set-Up

The tensile specimens prepared by above method were loaded for tensile testing until the specimen fracture using Hung-Ta Type HT 9502 universal testing machine. The tensile test was based on the following governing equation:

$$\sigma t = F / A \qquad (1)$$

Where: F = Force (N); A = Surface area (mm^2). The levels of the two independent variables studied are indicated in Table 1. A statistical analysis of the data was performed using the trial software Design-Expert® 10. The analysis of variance (ANOVA) provided a study of the variation present in the results of experiments carried out and the test of statistical significance, *P* value, was determined according to the total error criteria considering a confidence level of 95%. The influence of a factor will be significant if the value of critical level (*P*) is lower than 0.05, discarding the meaningless parameters for *P* values over 0.05 [12].

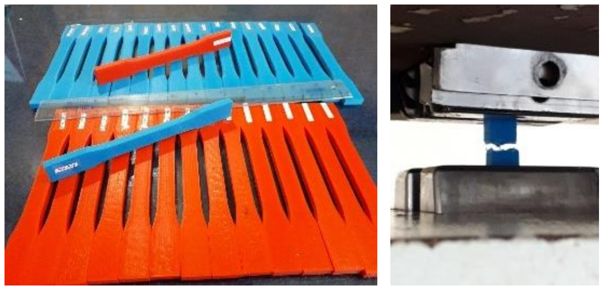

Fig. 2: Tensile testing

3.3. Factorial Design Methodology

The levels of the two independent variables studied are indicated in table 1. A statistical analysis of the data was performed using the trial software Design-Expert® 10. The analysis of variance (ANOVA) provided a study of the variation present in the results of experiments carried out and the test of statistical significance, *P* value, was determined according to the total error criteria considering a confidence level of 95%. The influence of a factor will be significant if the value of critical level (*P*) is lower than 0.05, discarding the meaningless parameters for *P* values over 0.05 [12].

4 EXPERIMENTAL RESULTS AND DISCUSSION

The tensile strength of the specimens was measured in the mechanical laboratory using Hung-Ta Type HT 9502 universal testing machine based on ASTM D-638 standard, each specimen was tested 3 times, the same condition and randomly. The result can be seen in table 3.

4.1. Effects estimated using the ANOVA

To identify the influences of an internal factor of fill pattern, z-orientation and polishing time to specimen tensile test value, analyzed data of test result using analysis of variance (ANOVA). This analysis is a calculation technique that allows quantitatively estimates the contribution of each factor on all measurement of response results by identifying hypothesis testing on the influence of controlled factors and their interactions. The hypothesis (H_0) tested that there is no influence of the factors on the tensile strength of test specimens. Results from ANOVA using Design-Expert® software are shown in table 4. The Model F-value of 233.77 implies the model is significant. There is only a 0.01% chance that an F-value this large could occur due to noise. Values of "Prob > F" less than 0.0500 indicate model terms are significant. In this case, B, C, AC, BC are significant model terms. Values greater than 0.1000 indicate the model terms are not significant. From result of ANOVA calculation assisted by Design-Expert® software shown in table 5, it can be seen that the biggest F_{Value} is the interaction between fill pattern factor with z-axis orientation, while the main factor that most influence the tensile strength of the test specimen is polishing time, it can be concluded that there is influence of main factor and interaction to tensile strength of test specimen, so H_0 is rejected. Percentage contribution from each main factor and interaction that

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influence the tensile strength of the test specimen, that is:
Polishing time (B) = (0.10-0.0001612)/0.27 = 35 %
Z-axis orientation (C) = (0.017-0.0001612)/0.27 = 8 %
The interaction between internal fill pattern with Z-axis orientation (AC) = (0.14-0.0001612)/0.27 = 52 %
Final equation in terms of coded factors:

$$\text{Tensile Strength} = 1.67 + 6.917E\text{-}003*A + 0.063*B + 0.031*C + 6.583E\text{-}003*AB - 0.076*AC - 0.016*BC + 4.750E\text{-}003*ABC \quad (2)$$

4.2. Model validation

The analysis of residuals is one way of measuring the validity of the experimental design. The plots of residuals for the tensile strength are presented in figures 3. In these figures, one can observe that the residuals present a normal behavior for the test. The data points on the straight line confirm the normality and independence of the residuals, it can be seen that the residuals have a normal behavior. Another form of evaluating the goodness of fit of the regression model is by comparing the experimental data with those predicted by the model. In figure 4, we can observe that there exists a very good correlation between the experimental data and data calculated with the statistical model for tensile strength since the points are very close to the diagonal. As can be seen in the results of the analysis of variance (ANOVA) shown in table 4, the interaction between the internal fill pattern and the Z-axis orientation was statistically significant for tensile strength specimen. The interaction plots for tensile strength are shown in Figure 5. It is evident in Figure 5 that the cross each other. This behavior is typical of synergistic or antagonistic effects. In the case of tensile strength.

4.3. The influence of factors on the value of tensile strength Model validation

From the actual test result of the test specimen, the highest tensile strength value is obtained in combination of the internal fill pattern = line, polishing time = 20 minutes and Z axis orientation = 45°. figure 6 shows the relationship between factors to the tensile strength of the test specimen. Polishing time is the most influential factor, this is caused by the polishing process that causes the surface of the specimen to melt due to chemical reactions that occur between the alcohol 90% with PolySmooth™ material, so the bond between the layers is stronger resulting an increased value of tensile strength of test specimens.

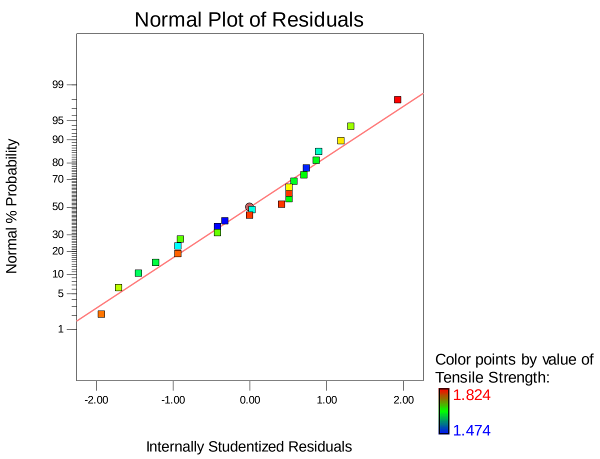

Fig. 3: Residuals for tensile strength

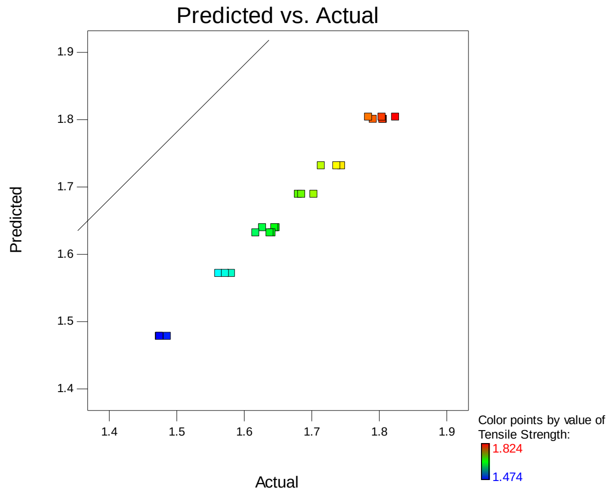

Fig. 4: Predicted versus experimental data for tensile strength

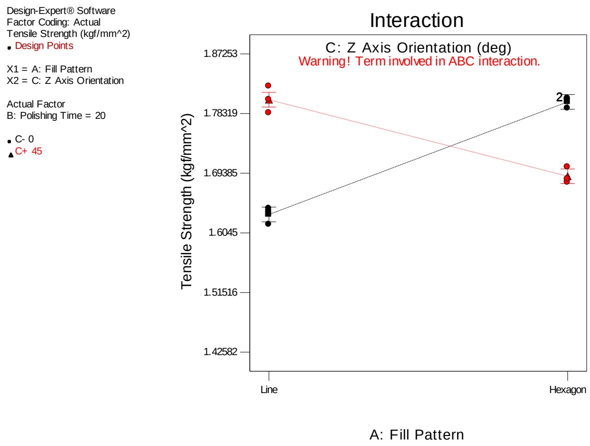

Fig. 5: Interaction plots for tensile strength

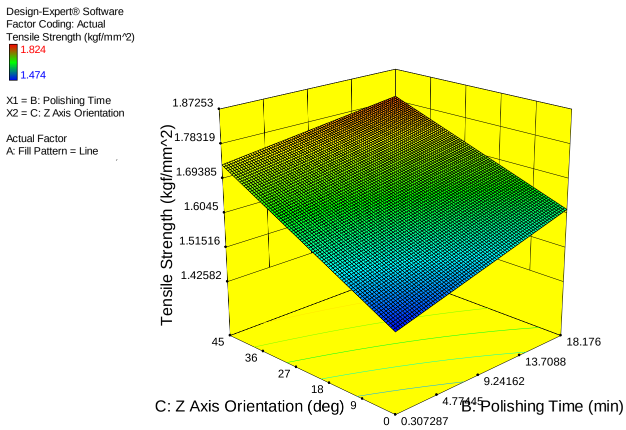

Fig. 6: Influence factors against the value of tensile strength

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Table 3: Design Summary

Study Type		Factorial					Subtype	Randomized			
Design Type		2 Level Factorial					Runs	24			
Design Model		3FI					Blocks	No Blocks			
Center Points		0									
Factor	Name	Units	Type	Subtype	Minimum	Maximum	Coded	Values	Mean	Std. Dev.	
A	Fill Pattern	-	Categoric	Nominal	Line	Hexagon			Levels:	2	
B	Polishing Time	min	Numeric	Continuous	0	20	-1.000=0	1.000=20	10	10.2151	
C	Z Axis Orientation	degree	Numeric	Continuous	0	45	-1.000=0	1.000=45	22.5	22.9839	
Response	Name	Units	Obs	Analysis	Minimum	Maximum	Mean	Std. Dev.	Ratio	Trans	Model
R1	Tensile Strength	kgf/mm^2	24	Factorial	1.474	1.824	1.66842	0.10763	1.23745	None	3FI

Table 4: Constant 3D-Printing Process Settings

Response	1	Tensile Strength				
ANOVA for selected factorial model						
Analysis of variance table [Partial sum of squares - Type III]						
Source	Sum of Squares	df	Mean Square	F Value	p-value Prob > F	
Model	0.26387	7	0.0377	233.77	6.7159E-15	significant
A-Fill Pattern	0.00115	1	0.0011	7.12	1.6825E-02	
B-Polishing Time	0.09551	1	0.0955	592.30	4.5526E-14	
C-Z Axis Orientation	0.02269	1	0.0227	140.73	2.4289E-09	
AB	0.00104	1	0.0010	6.45	2.1848E-02	
AC	0.13711	1	0.1371	850.28	2.6815E-15	
BC	0.00583	1	0.0058	36.14	1.8108E-05	
ABC	0.00054	1	0.0005	3.36	8.5551E-02	
Pure Error	0.00258	16	0.0002			
Cor Total	0.26645	23				

5 CONCLUSION

In this research, a 23 factorial design was used to study the effect of Internal Fill Pattern, Polishing Time and Z-Axis Orientation on the tensile strength of specimen produced using the three-dimensional printing type Fused Deposition Modelling (FDM) with Polymaker PolySmooth™ material. Based on the results of research and data analysis of specimens can be concluded as follows:

- The main factor that most influence the tensile strength of test specimens is polishing time, with the contribution percentage of = 35%.
- Based on statistical analysis using Design-Expert® software with design type 2 level factorial known interaction between internal fill pattern with Z-axis orientation contribute 52% to the tensile strength of specimens.
- From the actual test result is known the highest tensile strength value = 1.824 kgf/mm^2, obtained in combination of internal factors fill pattern = line, polishing time = 20 minutes and Z axis orientation = 45^o.

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