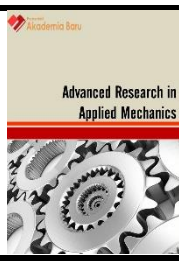
Penerbit Akademia Baru

Journal of Advanced Research in Applied Mechanics

Journal homepage: www.akademiabaru.com/aram.html
ISSN: 2289-7895



Study on Mechanical Properties of Pla Printed using 3D Printer

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ABSTRACT

The aims of this study are to investigate the tensile strength of polylactic acid (PLA) material using Taguchi Method and to evaluate the best parameters which have the highest significant impact on the tensile properties of PLA. Three parameters are used to investigate the tensile properties of PLA which include printing speed, infill pattern, and layer thickness. The PLA filament is printed using a 3D printer. The printed parts are tested under tensile test according to standards ASTM test samples. The number of experiment is determined by using Taguchi method. Based on the ANOVA analysis, optimum parameter for the tensile strength of PLA are obtained through validation test. The ANOVA analysis shows that the significant variable is infill pattern which gives highest impact on tensile strength.

Keywords:
PLA, Tensile Test, Taguchi Method, 3D Printer

1. Introduction

In 3D printing technology, polylactic acid (PLA) is known as the most popular material compared to other materials. The characteristics of PLA with lower printing temperature than other materials which is in range of 180°C – 230°C cause this material to not misshape easily, meaning that heating bed does not require even though it definitely helps [6].

Nowadays, many polymer products are not biodegradable. It takes long time to degrade in environment. Furthermore, the mechanical properties of the polymer are that it has low strength and easy to become failure in operation. However, PLA has the ability to degrade when exposed to the environment and has good mechanical properties for any normal application. The objectives of this study are:

(i) To optimize the process parameters on Polylactic acid (PLA) material using Taguchi Method.

(ii) To evaluate the best parameters which have the highest significant impact on the mechanical properties of PLA.

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2. Literature review

2.1 Polylactic acid

A study is conducted to compare the mechanical properties of PLA and ABS components via tensile test to investigate tensile strength, strain at maximum strength and elastic modulus [4]. Both materials are created using several desktop open-sources RepRap 3D printers. The results show that PLA has more flexibility compared to ABS material and it requires high strength of tensile before it breaks.

The biomedical, textile mainly in Japan and the packaging of food are three different markets for PLA-based materials. The manufacturing process of PLA material includes injection-moulded forks, spoons, and cups, blow-moulded bottles, thermoformed cups and trays, fibres for textile industry or sutures, films and various moulded articles [5].

In biomedical applications, PLA has been extensively investigated due to its biocompatible properties in the human body application. PLA is commonly used in orthopaedic medicine, soft tissue repair, and synthetic grafts. There is a wide study indicates the usage and application of PLA and its polymeric composites in biomedical fields [8]. Among biomedical applications are fracture fixation devices like screws, sutures, delivery systems and micro-titration plates which can be biocompatible in the human body [5].

2.2 Tensile test

Tensile test is executed by applying an increasing load to a specimen until to the point of failure. This is done by using Universal Testing Machine. Stress/strain curve is developed as a result after the material reacts when applied tensile test. Mechanical properties of materials can be determined from the data generated during tensile testing and provides the quantitative measurements of tensile strength. Also known as Ultimate Tensile Strength (UTS), tensile strength is the maximum tensile stress carried by the specimen, can be defined as the maximum load divided by the original cross-sectional area of the test sample [7].

There is a study regarding the comparison of mechanical properties of ABS and PLA components made using various desktop open-sources RepRap 3D printers. Both materials were characterized through standard tensile tests to determine tensile strength, strain at maximum strength and elastic modulus. The results show that PLA has more flexibility compared to ABS material and it requires high strength of tensile before it breaks [4].

3. Methodology

3.1 3D printer machine

A new open-source 3D Printer are used comprises of four stepper motors with three axes as shown in Fig. 1. To gain more accuracy, the lead screw has been used for all the three axes movement [1]. The maximum building parts for this machine is 190 mm (length) x 190 mm (width) x 150 mm (height).

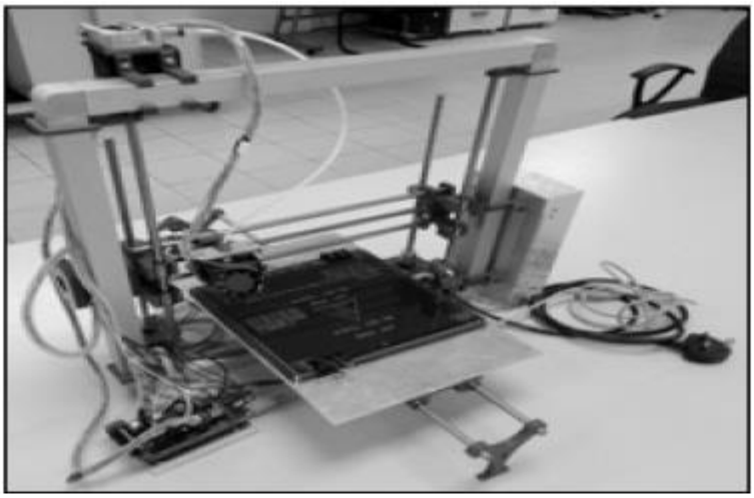

Fig. 1. The new open source 3D printer

3.2 Sample fabrication

Tensile test design samples are designed using an Autodesk Inventor Software (Autodesk, USA) according to the ASTM test samples (ASTM D638-10 Standard Test Method for Tensile Properties of Plastics) as shown in Fig 2 [2]. The methodology of the tensile test sample fabrication follow the previous research [9].

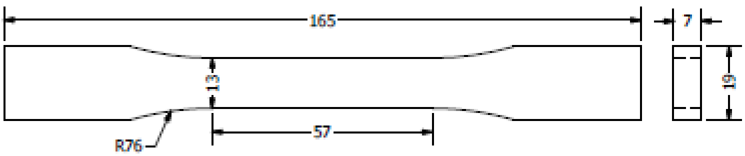

Fig. 2. Tensile test design specimen

3.3 Infill pattern

There are three type of infill pattern that have been used in this study. There is grid, lines, and concentric line. Even though there are non-numerical parameters, this parameter still can be analyse using Minitab DOE [3]. The infill pattern structure from Repetier Host software are shown in Figuer 3 until Fig5. The sample of infill pattern after printing by 3D printer is shown in Figure 7.

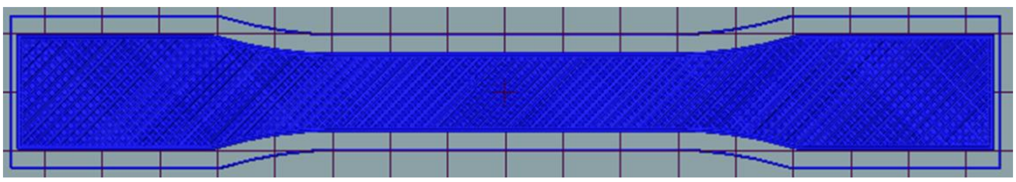

Fig. 3. Grid infill pattern

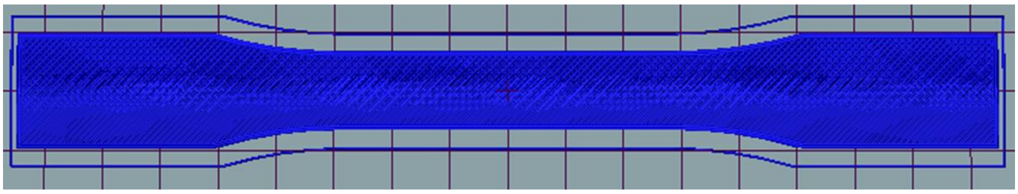

Fig. 4. Line infill pattern

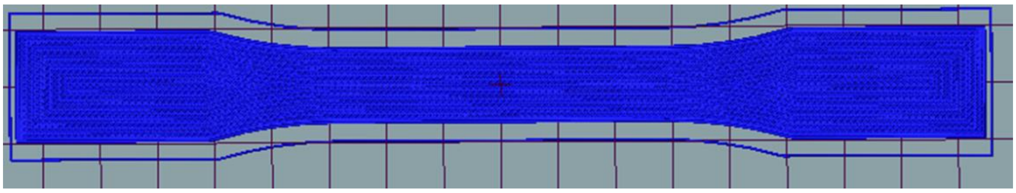

Fig. 5. Concentric line infill pattern

3.4 Materials and method

The tensile, flexural and impact test sample were printed with 1.75 mm diameter of Polylactic acid (PLA) filament in red colour. All the parameters were controlled using Repetier-Host Software (Hot-World GmbH & Co. KG, Germany). Design of experiment (DOE) was performed using Minitab 16.0 (Minitab, USA) software.

3.5 Experiment result

In this experiment, analysis was carried out according to the run order by Minitab software. Taguchi experimental design of three factors and three levels each was conducted which consist of 9 runs for each material testing. Table 1 shows the experimental result for the tensile test.

Table 1
Result of experimental run for tensile testing specimens

Run	Layer Thickness (mm)	Infill Pattern	Printing Speed (mm/s)	Tensile Strength (MPa)
1	0.2	Grid	50	12.4190
2	0.2	Lines	70	14.8633
3	0.2	Concentric Lines	90	25.9117
4	0.3	Grid	70	11.3475
5	0.3	Lines	90	8.99313
6	0.3	Concentric Lines	50	25.5941
7	0.4	Grid	90	14.6964
8	0.4	Lines	50	19.1985
9	0.4	Concentric Lines	70	28.7929

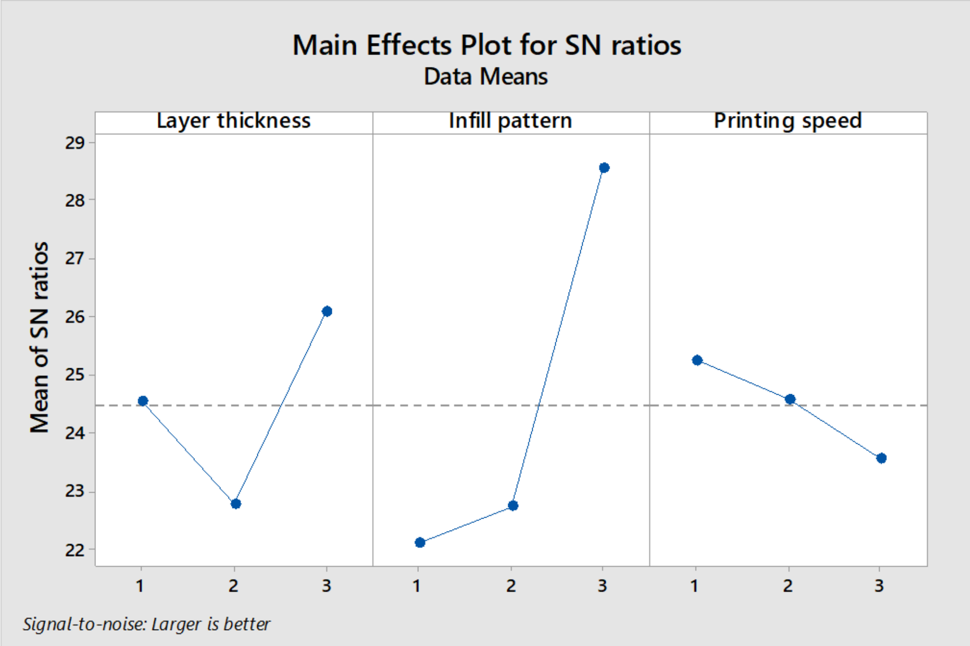

Fig. 6. Main effect plot for tensile test SN ratios

3.6 Response for tensile test

According to the main effect plot for tensile test SN ratios in Figure 6, the optimum parameter for layer thickness is 0.4mm. For infill pattern, due to the structure of the pattern which is continuous line and make it hard to break, concentric line is the best parameter.

Fig. 7. From above, concentric line, line, and grid pattern

Plus, the result for printing speed shows that the slower printing speed is the better for optimum tensile strength. According to this experiment, the lowest speed is 50mm/s. The optimal parameters for validation test are summarized as in Table 2.

Based on Table 3, the most optimum parameter for tensile strength of PLA is infill pattern followed by layer thickness and printing speed. This shows that infill pattern is the most significant parameter to measure the tensile strength of PLA when the tensile test is conducted.

Table 2
PLA optimal parameters for tensile test

Parameters	Optimal value for validation test
Layer thickness	0.4mm
Infill pattern	Concentric line
Printing speed	50mm/s

Table 3
Response table for signal to noise ratio by assuming larger is better

Level	Layer thickness	Infill pattern	Printing speed
1	24.53	22.11	25.24
2	22.78	22.73	24.58
3	26.07	28.54	23.56
Delta	3.29	6.43	1.67
Rank	2	1	3

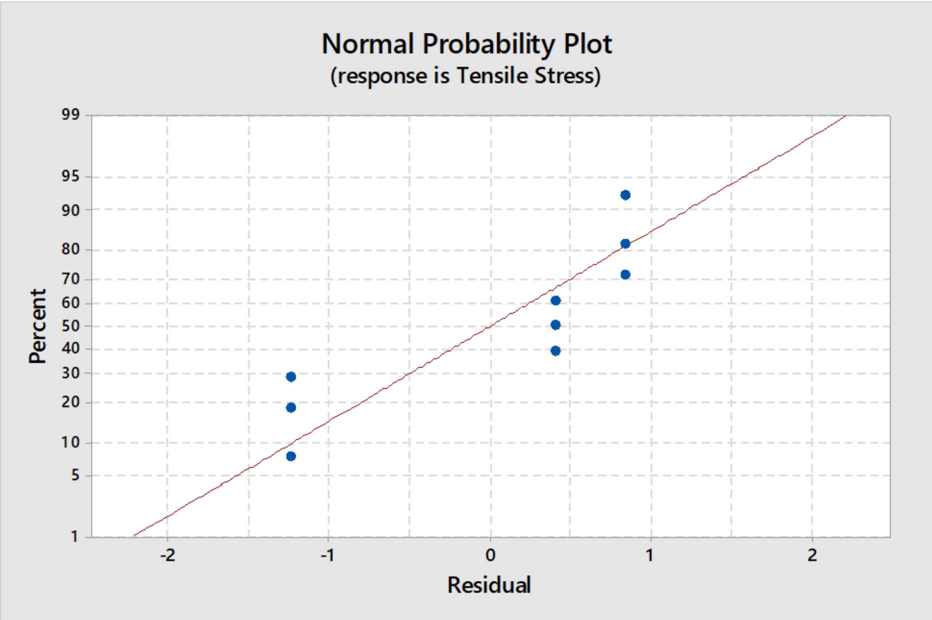

Fig. 8. Normal probability plot of residual of tensile stress

Fig. 8 shows that the residuals fall on a straight line indicating that the errors are distributed normally.

Table 4 summarized the P-Value for each parameter. The parameter with P-value below 0.05 is considered as a significant parameter. For infill pattern, the P-value is 0.020. This value can be considered as a statistically significant parameter for 3D printed PLA material while the P-value for layer thickness and printing speed is 0.134 and 0.415. This can be categorized as near-marginal significance parameter.

Table 4
ANOVA table of tensile stress

Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Layer thickness	2	47.055	23.527	6.49	0.134
Infill pattern	2	350.935	175.468	48.38	0.020
Printing speed	2	10.220	5.110	1.41	0.415
Error	2	7.254	3.627		
Total	8	415.464			

Model Summary

S	R-sq	R-sq(adj)	R-sq(pred)
1.90447	98.25%	93.02%	64.64%

Table 5
Regression equation model for PLA tensile strength

Regression Equation

$$\sigma = 17.980 - 0.248\ A\_1 - 2.668\ A\_2 + 2.916\ A\_3 - 5.159\ B\_1 - 3.628\ B\_2 + 8.787\ B\_3 + 1.091\ C\_1 + 0.355\ C\_2 - 1.446\ C\_3$$

Based on the analysis of variance (ANOVA), a regression equation is created as a model of the tensile experiment to predict the result of optimal process parameter through a validation test. From the regression equation in Table 5, the value of tensile strength is predicted to be 30.9238 MPa.

3.7 Validation test of PLA tensile sample

For validation test, according to parameters in Table 2, three samples were printed using the same 3D printer. Then, all the samples were run a validation test as shown in Fig. 9. The result average is calculated.

Fig. 9. Sample PLA fabrication undergoing tensile test

Table 6
Result of the validation test

	Initial Process Parameter	Optimal Process Parameter	
		Prediction	Experiment
Tensile test S/N ratio (MPa)	17.9796	30.9238	33.6940

Based on Table 6, the result of validation test shows that the maximum tensile stress is 33.6940MPa. This result shows enhancement of 87.4% which is 15.7144MPa higher strength than initial process parameters. Therefore, the optimum process parameter from validation test provide better strength compared to initial process parameter.

4. Conclusion

All responses with optimum parameters successfully recorded 87.4% improvements after validation test. The process parameters on PLA material printed using 3D printer have been optimized. The best parameters which have the highest significant impact on the mechanical properties of PLA have been evaluated based on ANOVA analysis.

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