Jurnal Media Mesin, Vol. 25 No. 1
Printed ISSN: 1411-4348
Online ISSN: 2541-4577

EFFECT OF ZIGZAG AND LINE PRINTING PATTERN ON TENSILE STRENGTH AND SURFACE ROUGHNESS OF FUSED DEPOSITION MODELING PRODUCT

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ABSTRAK

Proses produksi material plastik dengan 3D printing terkendala dengan problem akurasi dan kekuatan mekanik. Penelitian ini bertujuan untuk menunjukkan visual hasil 3D printing yang menggunakan filamen jenis *Polylactic acid* (PLA) dengan berbagai macam pola pengerjaan mempengaruhi kekasaran permukaan dan kekuatan tarik. Eksperimen dilakukan dengan mengatur perbedaan kerapatan pengisian pencetakan terhadap pola yang digunakan. Pada penelitian ini, kerapatan pengisian menggunakan variasi 60%, 80% dan 100% pada pola pengerjaan lurus dan zig-zag. Diameter *nozzle* 0,4 mm, suhu *nozzle* 220 °C, dan suhu *heat bed* 60 °C. Specimen pengujian menggunakan model dan ukuran standar ASTM D638 type 4, kemudian pengujian tarik dilakukan untuk mengukur sifat mekanik tarik polimer (σ). Uji kekasaran untuk mengetahui kekasaran permukaan rata-rata (Ra), *Root Mean Square* roughness (Rq), *ten-point height* (Rz) dengan foto mikro. Hasil uji sifat mekanik dari pola percetakan diperoleh bahwa pola zig-zag memiliki nilai *yield strength, maximum load* dan *elongation* tertinggi, yaitu sebesar 0,97 N/mm^2, 52,99 N dan 9,43%. Sedangkan, secara berurutan pada pola *line* nilai *yield strength, maximum load* dan *elongation* tertinggi sebesar 1,51 N/mm^2, 62,72 N, dan 3,54% dan hasil tertinggi dari kedua pola adalah pada variasi pengisian 100%. Pada situasi ini, foto mikro menunjukkan ekspansi lebar filamen adalah yang terkecil. Sehingga, pola zig-zag pada pengerjaan material plastik dengan *3D-printing* mempengaruhi ukuran lebar dari filamen yang berdampak pada meningkatnya kekasaran permukaan akan tetapi kekuatan material yang lebih tinggi daripada pola *line*.

Kata kunci: 3D *printing*, *polylactic acid* (pla), pola pengisian, uji tarik.

ABSTRACT

Problems of accuracy and mechanical strength constrain the production process of plastic materials with 3D printing. This study aims to show the visual results of 3D printing using Polylactic acid (PLA) filaments with various working patterns affecting surface roughness and tensile strength. Experiments were conducted by adjusting the difference in printing filling density to the pattern used. In this study, the filling density used 60%, 80%, and 100% variations in straight and zig-zag working patterns. Nozzle diameter of 0.4 mm, nozzle temperature of 220°C, and heat bed temperature of 60°C. The test specimens used ASTM D638 type 4 standard models and sizes; then tensile testing was carried out to measure the tensile mechanical properties of the polymer (σ). Micro-photos pay rules in determining the average surface roughness (Ra), Root Mean Square roughness (Rq), and ten-point height (Rz). The mechanical properties test results of the printing pattern found that the zig-zag pattern has the highest yield strength, maximum load, and elongation values of 0.97 N/mm^2, 52.99 N, and 9.43%. In the line pattern, the highest values of yield strength, maximum load, and elongation are 1.51 N/mm^2, 62.72 N, and 3.54%, respectively, and the highest result of both patterns is at 100% filling variation. The microphotograph shows that the filament width expansion is the smallest in this situation. Thus, the zig-zag pattern in 3D-printing plastic materials affects the filament's width, resulting in increased surface roughness but higher material strength than the line pattern.

Keywords: *3D printing, poly lactic acid* (pla*), filling pattern, tensile test.*

1. INTRODUCTION

3D Printing is an additive manufacturing (AM) process for creating 3D objects with processes that are carried out in layers. 3D object printing is done by reading 3D designs that have been made on computer software such as computer-aided design (CAD)[1]. This technology is widely developed in manufacturing techniques because it has high flexibility in determining the model with less material waste. Thus, the use of materials is more efficient than other manufacturing processes [2]. In general, the application of 3D printing technology is now increasingly widespread to be used in various sectors such a**s** manufacturing, automotive, industry, medicine, construction, and many other applications [3].

In its development, 3D printing uses various techniques according to the type of material used. The most popular additive manufacturing (AM) process technique approaches are currently utilized in fused deposition modeling (FDM) [4][5]. The advantages of this FDM technique are the simple fabrication process, more cost-effective production, and environmentally friendly [6][7]. On the other hand, it also has disadvantages such as limited accuracy, relatively slow production process speed, and shrinkage due to temperature changes [8].

Filament materials used in additive manufacturing processes have various types with special specifications that are adjusted based on their application. The types of filaments commonly used in 3D printing technology are Acrylonitrile Butadiene Styrene (ABS), Polycarbonate (PC), and Poly Lactic Acid (PLA) polyamide 12 (PA12) [9]. Poly Lactic Acid (PLA) is the most widely used type of filament in 3D printing technology [10]. PLA filament is also a biodegradable filament because it comes from lactic acid synthesized from natural materials and has elastic properties and a high tensile modulus [11][12]. The use of PLA for manufacturing additives (AM) materials in FDM techniques can improve the physical, mechanical**,** and thermal properties of 3D printed composites [13].

B.M. Tymrak et al conducted research on the mechanical properties of 3D printing with the development of the RepRap method on Poly Lactic Acid (PLA) filaments and Acrylonitrile Butadiene Styrene (ABS) obtained the results that Poly Lactic Acid (PLA) has a tensile strength value of 56.6 MPa and a modulus of elasticity of 33.68 MPa so that the bond between layers is very strong, so it works more rigidly. While ABS has a tensile strength value of 28.5 MPa and a modulus of elasticity of 1807 MPa [14]. Rodriguez et al conducted research using Poly Lactic Acid (PLA) filaments and Acrylonitrile Butadiene Styrene (ABS) with the Fused Deposition Modeling (FDM) additive manufacturing technique method. In the study, it was found that Poly Lactic Acid (PLA) is more rigid and has greater tensile strength than Acrylonitrile Butadiene Styrene (ABS) so this type of filament is more suitable for use in the additive manufacturing process [15].

Samarthya Bhagia et all researched 3D printing by fused deposition modeling (FDM) with Poly Lactic Acid (PLA) filament made from biomass. The study was conducted to determine the effect of FDM printing on the results of 3D printing objects using PLA filaments. The result is that FDM printing affects the surface characteristics of the printing result. In addition, other factors such as nozzle printing temperature, Filling Pattern, and pattern manufacturing can also affect the quality of the printing results [16].

Benoît Pernet et al examined the influence of 3D printing pattern geometry with ASTM D695 using Poly Lactic Acid (PLA) material in FDM printing models. The results of the study obtained that the printing pattern affects printing

Printed ISSN: 1411-4348
Online ISSN: 2541-4577

time and can reduce production costs. However, this study has not discussed the test of the resulting printing pattern [17]. Lactic acid is a source of biodegradable filaments known as PLA and is the most popular material for 3D printing processes involving material extrusion. In addition, the advantage of PLA filament is that it is easy to use in 3D printing because it has strength and does not suffer from major distortion when printing due to the low extrusion temperature (melting point) [18][19]. The selection of thermoplastic materials (filaments) is very important, as each commercially available thermoplastic filament has different physical, thermal, chemical, rheological, and mechanical properties.

Therefore, these experimental studies support the widespread use of polylactic acid (PLA) as a primary material by first trialing its characteristics in manufacturing with varying parameters and using a unique manufacturing machine. The variation of filling density and working pattern, surface roughness, and tensile test results will determine the ability of 3D-printed specimens to overcome the mass production challenge.

2. METHOD

This study uses PLA-type filaments that have a diameter of 1.75 mm. The specimen was made with a commercial 3D printing machine, Ender-5Plus, which has reality slicer software used to control the settings of the 3D printing process and exports the 3D design file for reading with a G-code compatible with the manufacturer's machine. The filament is printed using a nozzle of diameter 0.4 mm at a temperature of 220 °C with a heat bed at a temperature of 60 °C. It is clearly seen in Figure 1.

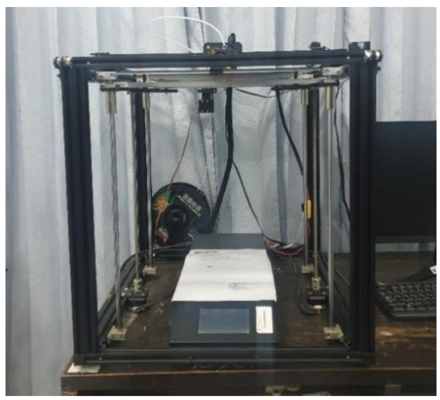


Figure 1. 3D Printing Ender-5 Plus

A tensile testing machine (Gotech Testing - AI - 7000 L, Taiwan) is used to measure the tensile mechanical properties of polymers. Tests were conducted to determine the effect of 3D printing parameters (print orientation and Filling Pattern) on tensile strength (σ). It is clearly seen in Figure 2.

Figure 2. Gotech Testing-AI-7000 L

Roughness test on 3D printed specimens (Mitutoyo roughness test tool) is carried out in three parts on each test specimen to then be averaged. The roughness test results are to obtain parameters of average surface roughness (Ra), root means square roughness (Rq), and ten-point height (Rz).

The 3D design of the test specimen followed the ASTM D638 type 4 standard [20][21]. Shown in Figure 3 are the sketch drawings made using CAD software, namely CATIA, print orientation is done with two patterns, that is, zigzag printing patterns, and line printing patterns. Filling Pattern is one of the parameters that is set before the slicer process in 3D printing. In this research the specimens were printed with filling of 60%, 80%, and 100% at nozzle temperature of 220°C.

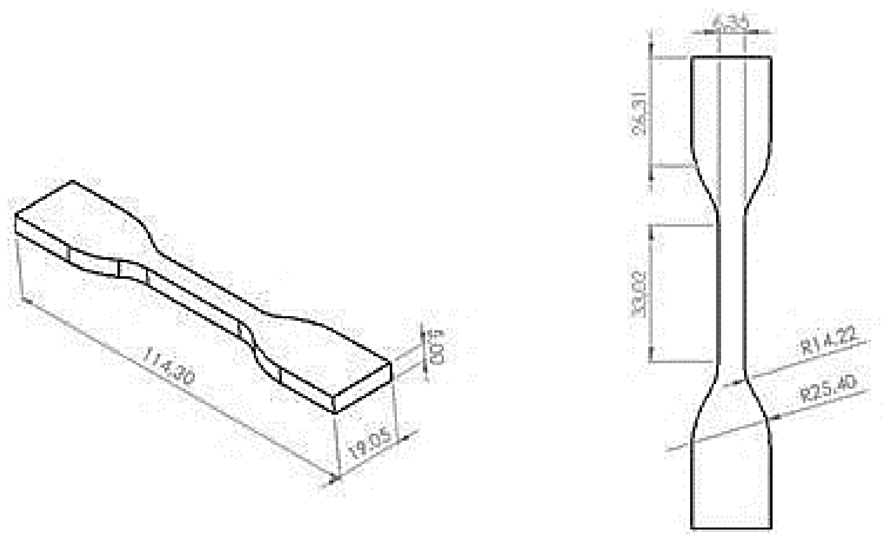


Figure 3. Design of The 3D Printed Specimen

3. RESULTS AND DISCUSSION

3.1 Specimen Prints

The 3D printing specimens that have different printing patterns, namely zigzag patterns and line patterns with Filling Patterns of 60%, 80%, and 100% shown in Figure 4 were tested for surface roughness and tensile mechanical properties.

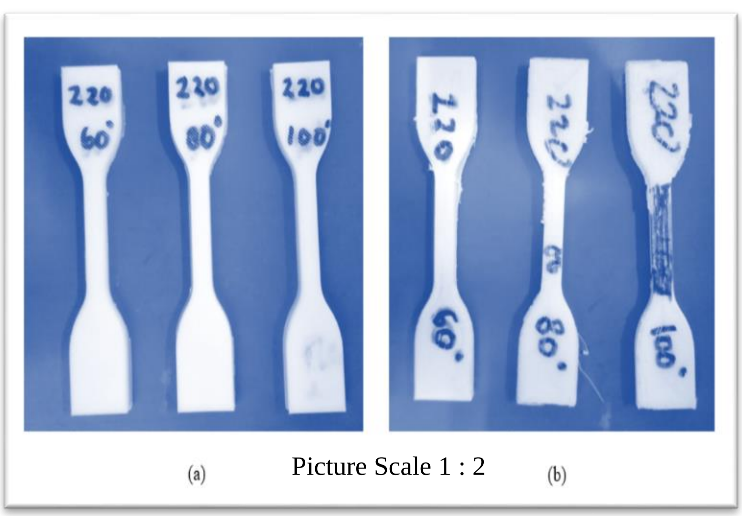
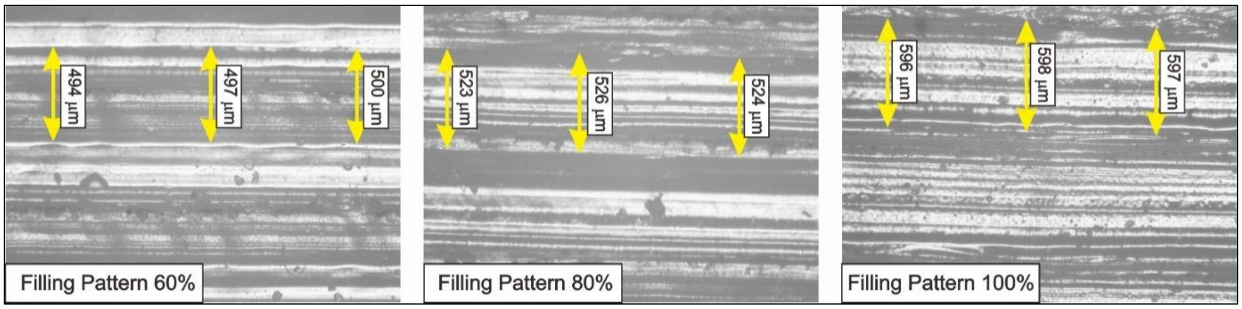


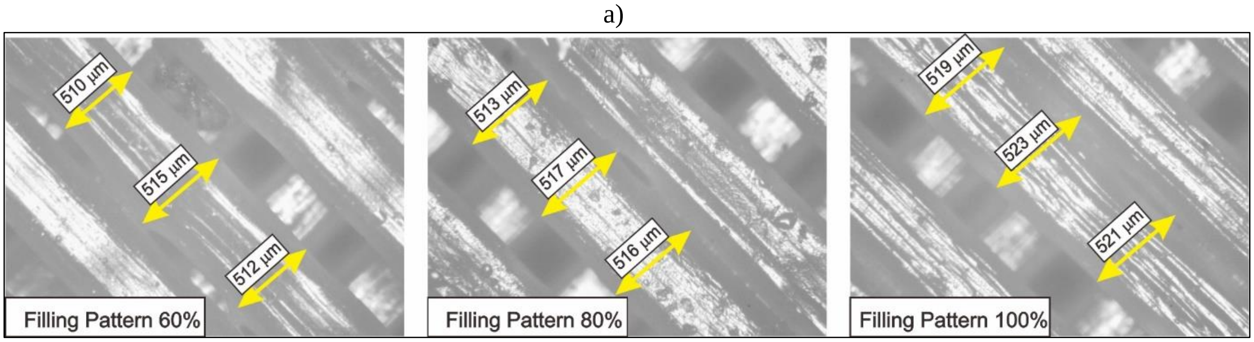
Figure 4. (a) Zigzag Pattern Specimen (b) Line Pattern Specimen

3.2 Microstructure characteristics

The Microstructure characteristics of the specimen printed by the 3D printing test in Figure 5 show the Microstructure characteristics test results of the impact of filament pattern and Filling Pattern on filament width. The prints with Filling Patterns of 60%, 80%, and 100% in the zigzag pattern have an average filament width of 512.33 µm, 515.33 µm and 521 µm. With the same Filling Pattern, the line pattern has an average filament width of 497 µm, 524.33 µ m, and 597 µm. The results show the similarity of the two filaments, namely the increase in filament width as the Filling Pattern increases. This happens because the higher the Filling Pattern will cause the cooling time on the filament to be faster [22].



a)



b)

Figure 5. (a) Line Pattern (b) Zigzag Pattern

3.3 Surface Roughness Test

After testing the surface roughness average (Ra) and root mean square roughness (Rq) of specimens with zigzag patterns and line patterns, significant differences in results were obtained. The influence of higher Filling Pattern makes the surface roughness average (Ra), and root mean square roughness (Rq) increase and this to be rougher. This significant difference in roughness values is seen between the zigzag pattern and the line pattern. Of the three variations of Filling Pattern used, the lowest value is at the Filling Pattern of 60%, the average value obtained in the zigzag pattern is 20,37 µm while in the line pattern is 11,24 µm. This also occurs in root mean square roughness (Rq) where the zigzag pattern has a higher value than the line pattern, which is 26,29 µm and 14,74 µm respectively. These are depicted in Figures 6 and 7 as follows:

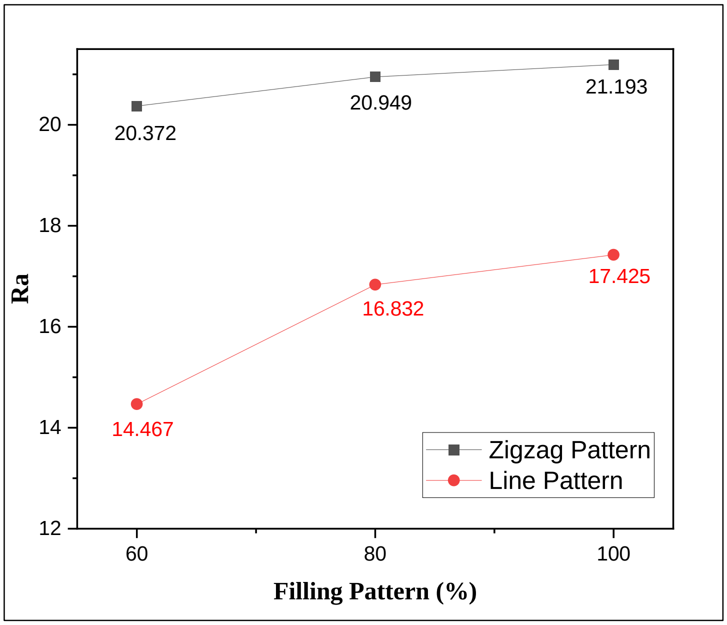


Figure 6. Graph of Average Roughness (Ra) in µm

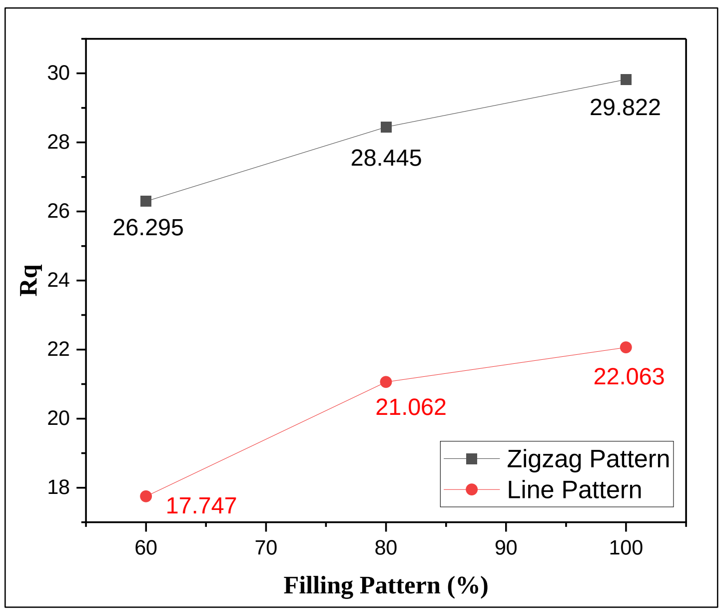


Figure 7. Graph of Root Mean Square Roughness (Rq) in µm

Figure 8 depicts a graph illustrating the average maximum height of the profile (Rz), representing the peak length and maximum valley depth. The graph demonstrates an increase in roughness values as the Filling Pattern rises, displaying zigzag patterns and line patterns. At a Filling Pattern of 100%, the zigzag pattern and line pattern exhibit the highest average maximum height of the profile (Rz) values, which are 121.76 µm and 93.25 µm respectively.

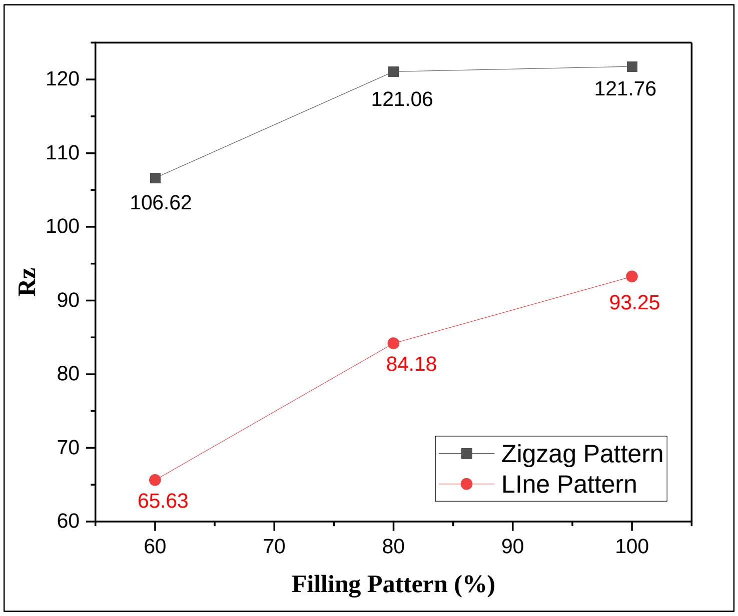


Figure 8. The Ten-Point Height Value (Rz), in µm

3.4 Tensile Test and Microstructure Characteristics

Figure 9 presents the visual representation of the specimens after undergoing a tensile test. The impact of printing patterns on Poly Lactic Acid (PLA) tensile test values is detailed in Table 1. Comparing the tensile test results of the specimen print patterns, it was observed that the zigzag pattern yielded higher values compared to the line pattern. Additionally, when the specimen was printed using zigzag patterns and line patterns at Filling Patterns of 60%, 80%, and 100%, there was not a significant increase in yield strength. However, a significant disparity is observed in the elongation value between the zigzag pattern and the line pattern. It has been determined that the average elongation value in the line pattern is only 50% of the elongation value observed in the zigzag pattern. This indicates a substantial difference in the ability of the two patterns to withstand elongation without fracturing or breaking. This is by Hooke's law where the relationship between a given force and a change in length is directly proportional. Another significant cause of the difference is that the mold direction line pattern is perpendicular to the applied load, so it has a brittle failure and lower tensile strength compared to the zigzag printing pattern. Other parameters such as the value of modulus of elasticity in the specimen printing pattern decrease as the Filling Pattern increases. The maximum load value with a zigzag pattern with a Filling Pattern of 60%, 80%, and 100% obtained values of 48.38 N, 49.14 N, and 52.99 N while in the line pattern with the same parameters obtained values of 59.07 N, 59.88 N, and 62.72 N. So, it can be concluded that there is an enhancement in the maximum tensile stress value in both types of specimens which is directly proportional to the Filling Pattern.

Table 1. Tensile Test Result Data

Pattern Variations	Filling Percentage (%)	Yield Strength (N/mm^2)	Elongation (%)	Elastic Modulus (N/mm^2)	Maximum Load (N)
PLA Zigzag	60%	0.92	6.76	197.02	48.38
	80%	0.93	6.98	178.15	49.14
	100%	0.97	9.43	151.40	52.99
PLA Line	60%	1.15	2.79	134.21	59.07
	80%	1.05	3.00	127.01	59.88
	100%	1.51	3.54	94.30	62.72

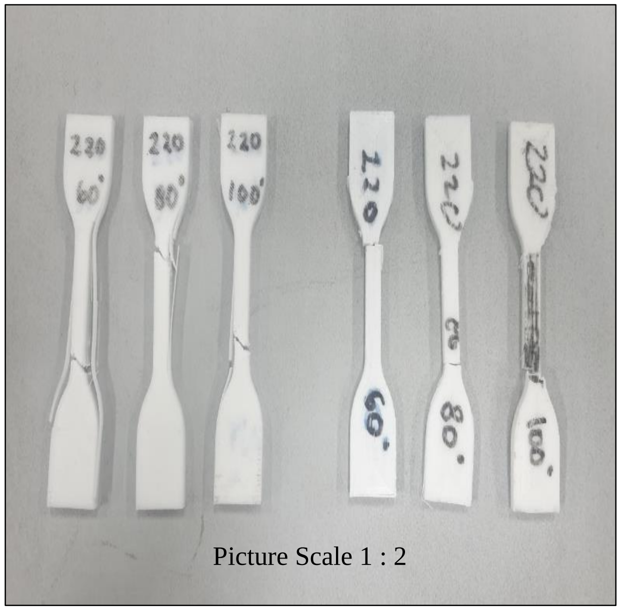


Figure 9. Specimens After The Tensile Test

4. CONCLUSION

Based on the test study, the conclusions drawn regarding Poly Lactic Acid (PLA) specimen printing using the fused deposition modelling (FDM) method with different printing patterns. The result of the mechanical properties related to tensile strength, such as yield strength and maximum load, tend to increase as the filling pattern rises. This implies that higher filling patterns result in stronger PLA specimens. The research observed that as the filling pattern increases, the surface roughness of the printed PLA specimens becomes more pronounced. This means that higher Filling Patterns result in a larger surface roughness value, indicating a rougher surface texture. This shows that the correlation between surface roughness and mechanical properties of tensile tests is directly proportional.

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