

Comparison Study of Polylactic Acid on Tensile Properties and Water Absorption

Nazrul Hazmie Suleiman¹, Mazatusziha Ahmad^{1*}

¹Department of Chemical Engineering Technology, Faculty of Engineering Technology, Universiti Tun Hussein Onn Malaysia, Hab Pendidikan Tinggi Pagoh, KM 1, Jalan Panchor, 84600 Panchor, Johor, MALAYSIA

*Corresponding Author: maza@uthm.edu.my

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Abstract

This study discusses the effect of water absorption and printing orientation on the tensile properties of Poly-lactic Acid. PLA is one of the widely used materials in 3D printing due to its biodegradable and recyclable nature. Usually, PLA is used in making prototypes or early designing tests for showcase before the actual product, which will need the understanding of the properties of PLA in different situations. Thus, tensile tests and water absorption tests are used to test the capability of the PLA model (Standard ASTM D638 type-IV) to withstand pulling force after immersion in water for a duration of days. The method used for water absorption is to immerse the sample in water completely for the duration of days that was set early on, which are 0, 2, 4, 8, and 16 days. Also, for the tensile test, the rate of pulling by the UTM is at 5mm/min. With the data obtained from the testing, the study found that the PLA model after being immersed in water has the capability to withstand pulling force after reaching the cracking point of the PLA. This shows that without any treatment, the PLA will break when reaching its breaking point instantly, and with any treatment or mixing, the capability of PLA in any situation may improve with its properties. As for further research, different temperatures of immersion or different types of liquid used for immersion can be explored in finding the best treatment that can improve the PLA properties.

1. Introduction

3D printing or also known as additive manufacturing in the simplest form is the process of creating a three-dimensional (3D) object by using a device with the material which is usually a polymer. To describe a bit of the process, the material which will be heated to its melting point will be laid down continuously in the form of thin-sliced cross-section of the object until the completion of the object. There are several devices that can be used to create the object, which are Fused Deposition Modeling (FDM), Selective Laser Sintering (SLS) and Laminated Object Manufacturing (LOM). These

devices have its own material specificity that can be used due to the different specification of the devices.

The FDM that will be used is low-cost rapid prototyping for making basic proof-of concept models to be test before producing the real product with better device or quick spare for broken part in device. Furthermore, various material can be printing using the FDM due to its generality.

There are many factors contributed by processing parameter on mechanical properties of 3D printed material such as, printing orientation, temperature, layer height, printing speed, and layer cooling. However, most studies which investigated on PLA produce via FDM were focused on printing nozzle orientation, combination of material and temperature. (Nor et al, 2022). A study conducted by Nagarjuna Maguluri et al. (2021) investigated the influence of nozzle temperature, infill density, and printing speed on the tensile properties of specimens printed using PLA filament. The results demonstrate that the nozzle temperature significantly influences the tensile properties of the FDM printed PLA products followed by infill density. The optimum processing parameters were determined for the FDM printed PLA material at a nozzle temperature of 220°C, infill density of 100%, and printing speed of 20 mm/s.

Proper temperature control is crucial for achieving good layer adhesion and, consequently, improved mechanical properties. Therefore, it is important to investigate the thermal properties of PLA such as the melting temperature and degradation temperature of the polymers. Printing temperature affects PLA's flow and bonding characteristics. Too low a temperature may result in poor layer adhesion, while too high a temperature may cause excessive stringing and poor surface quality.

Current publications focused on the effect of nozzle geometry, upon the mechanical properties of the polymers. As pointed out by Turner et al. (2014), the nozzle is composed of three sections. There are different names, but in this investigation the sections are named entry channel, conical section and capillary. During the FDM process, the polymer is heated above its melting point. The molten material exits through a nozzle with a defined strand diameter. The strand is applied onto a build platform layer by layer in a computer controlled geometric shape (Vinzenz et al., 2019)

In this project, it will be focus on the FDM device as it is the device that exist in the university and publicly used by the consumer. These study will investigate on poly-lactic Acid (PLA) of its tensile properties. The PLA is a polymer that is the easiest to print in the FDM, also due to its benefits of biodegradable and odorless which is environmental-friendly. Usually the PLA is used to create concept models of the project or prototypes of the project for testing and experimentation. Each polymer will have its own properties that need to be taken into consideration in making prototype for a model.

In this study, the tensile properties of PLA produced via FDM will be explored. The effect of printing parameter such as printing orientation angle, and strain rate on tensile properties after being exposed to water will be investigated.

2. Material & Method

For this study several methods can be used to investigate the properties of the PLA. For specific these study will focus on printing orientation, water exposure and tensile test. These three test will be explained briefly on these chapters. The flow of these study was refered to the flowchart based on the objective of the study. For information, in these chapter sample shape will refer to sample standard ASTM D570 type IV.

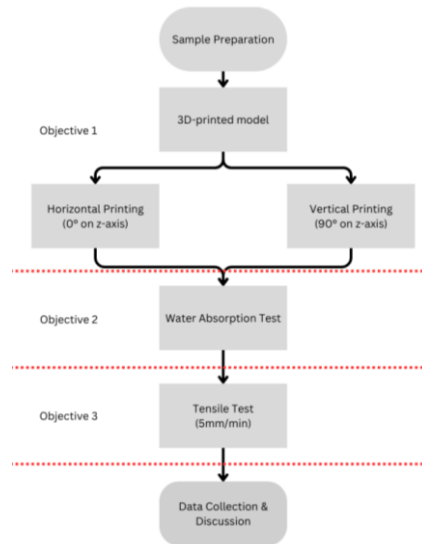


Figure 1 Flowchart of Project

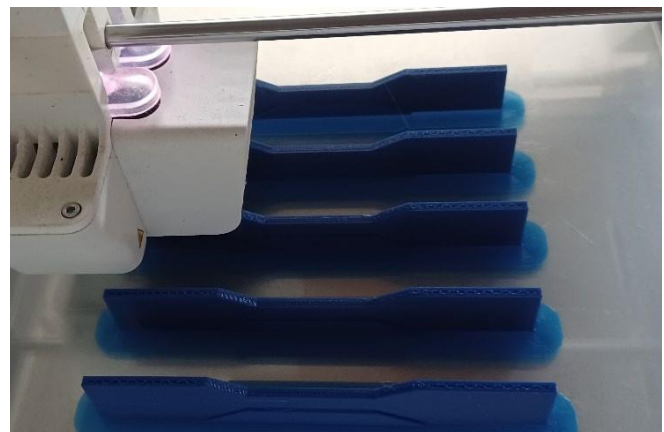
2.1 Sample Preparation by 3D printing model

In sample preparation, a design of model will need to be done to allow the 3D-printer to read the data from digital concept to physical concept. Thus, by designing the sample model and exchanging its format to coding with the proper machine was done. 3D printer that was used were Ultimaker 3 extended printer. The printer need the data to be encode in file format of g-code for the printer to be able to read in its system for printing.

Once the digital model has been done and encode, print the model with the parameter that was set during the encoding and ensure that there is no issue with the printer. After that, the 3D-printer will do its job and when finished take out the model from the printing plate carefully to ensure no breakage occur or bending that is not conform to your digital model.



(a)



(b)

Figure 2 Printing of (a) horizontal model and (b) vertical model

2.2 Water Absorption Test

Water Absorption test is a test that determine the capability of a material to absorb water in a situation and for a certain duration. The data that was obtained were from weighing the sample before and after soaking the sample completely in water. From the difference of the weight divide by the final weight determine the amount of water that was absorbed by the sample. In these testing, a duration of zero, two, four, eight and sixteen days were set. Formula that was used was as below:

$$\frac{(W_f - W_i)}{W_f} = W_{abs} \quad (1)$$

The flow of these test, started with weighing the dry sample after heating in an oven for 30 minutes and weigh the sample, W_i . After that, soaking the sample in water at a room temperature and for a certain amount of duration. Then, dry the soaked sample with cloth and weigh the soaked sample, W_f .

2.3 Tensile Test

In testing mechanical properties, there were several ways of testing but ultimately these study focused on the tensile properties of the sample after being soaked in water for a certain amount of duration. For these testing, several data were obtained and data that were focused on were the Tensile stress, Tensile strain, Young's modulus and Upper yield strength of the sample. The sample that were used for testing were printed according to sample standard ASTM D638 type-IV. The UTM Instron 5569A were used to do the tensile test where the data obtained were from pulling the sample from two sides until breakage. From the data obtained, three formulas were used to calculate the data to obtain the result that were used in these study which were the tensile stress, tensile strain and the Young's modulus.

Tensile stress:

$$\frac{Force(N)}{Area(m^2)} = \sigma \quad (2)$$

Tensile strain:

$$\frac{L_f - L_i}{L_i} = \epsilon \quad (3)$$

Young's Modulus (Modulus of Elasticity):

$$\frac{\sigma}{\epsilon} = \frac{Force(L_i)}{Area(\Delta L)} = E \quad (4)$$

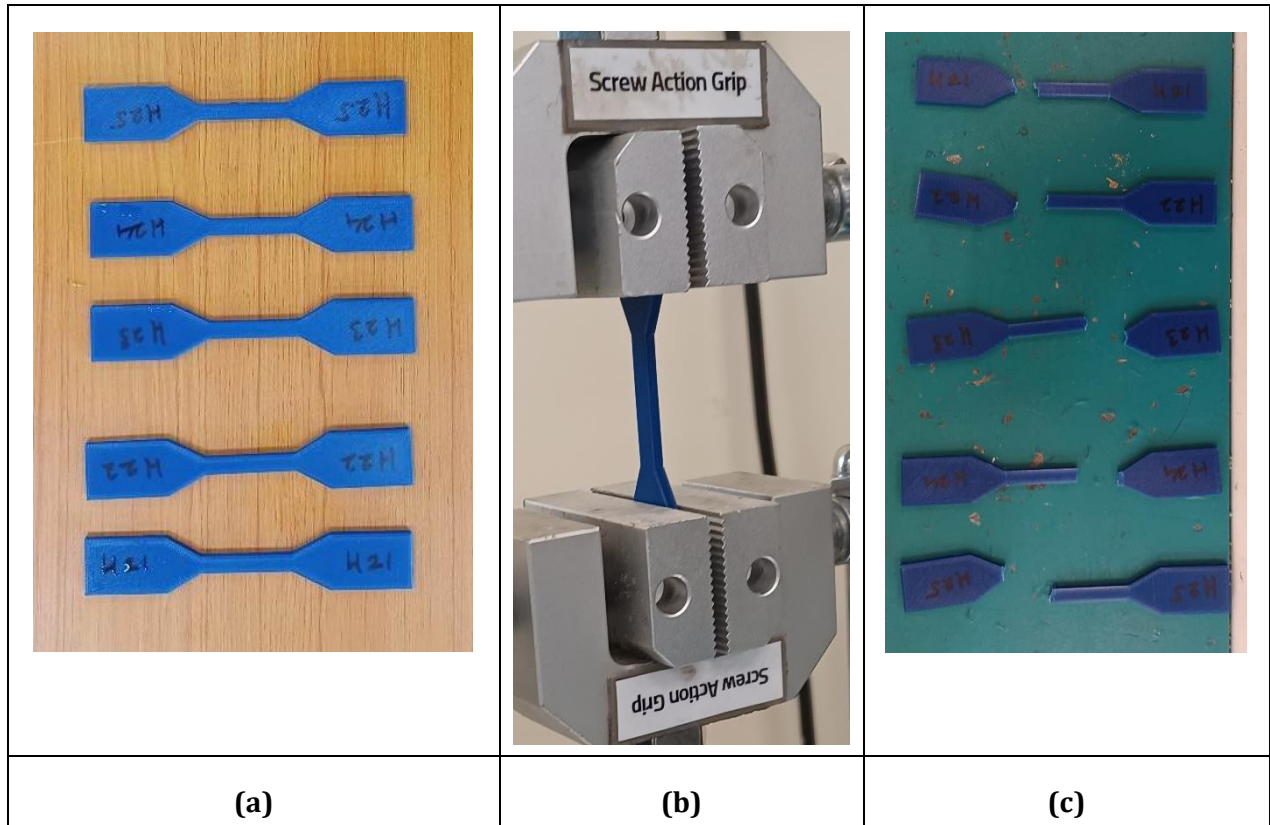


Figure 3 (a) model before testing, (b) model during testing and (c) model after testing

In these study, several difficulties were encountered and promptly solved when the problem can be solved. For example, during the printing of the sample, the 3D-printer may or may not had issues that will disrupt the printing of the sample and will need to be printing from the start which was time consuming. Thus a concession were made to increase the number of sample averaging from three sample for each duration to five sample as to ensure more amount of data can be obtained and ensuring the data will not have issue of sample error. Other than that in maintaining the soaked sample at a room temperature, due to the recent weather behaviour changed, the room temperature of the storage sample fluctuate a bit which will cause a difference in data and these issues were alleviate simply by store the storage container containing the soaked sample in another container that was filled with a certain level of water to ensure the temperature inside the container did not fluctuate by a lot.

3. Result & Discussion

3.1 Water Absorption

All 50 sample was weight on the weighing scale, and the average for each of the category of water exposure was obtained and calculated. It can be seen that the weight of the sample does not change much on the early day of the experiment and the weight increase slightly as time goes by. It shows that as the PLA degrade as it was soaked completely in the water and expose on all surface for a duration of days.

Table 1 Water Absorption Data

Sample	Printing Orientation	Days of water exposure	Average Weight (g) before soaking	Average Weight (g) after soaking	Water absorption percentage (%)
H1-5	Horizontal	0	6.3	6.3	0.00
H6-10		2	6.5	6.6	0.02
H11-15		4	6.6	6.8	0.03
H16-20		8	6.4	6.7	0.04
H21-25		16	6.5	6.8	0.04
V1-5	Vertical	0	6.4	6.4	0.00
V6-10		2	6.3	6.4	0.02
V11-15		4	6.7	6.8	0.01
V16-20		8	6.4	6.6	0.03
V21-25		16	6.5	6.7	0.03

3.2 Tensile Test

For tensile test, two set of data was used to create comparison for the project which were the horizontal and vertical PLA. Further categorisation were into the days of exposure which broken into five specific days which were the zero days, two days, four days, eight days and sixteen days. From the data obtained from UTM, several value were obtained and these project used only the tensile strength, tensile strain, upper yield strength and Young's modulus.

Table 2 Tensile Test Data

Sample	Printing Orientation	Average tensile stress (MPa)	Average strain (%)	Average Young's modulus (MPa)	Upper Yield Strength (MPa)	Average Elongation at break
H1-5	Horizontal	41.03	6.10	672.62	33.74	41.6
H6-10		39.50	7.65	516.68	32.23	42.1
H11-15		40.70	5.60	726.79	39.15	41.4
H16-20		41.10	7.04	583.81	34.76	42.2
H21-25		36.64	5.70	642.92	36.53	41.9
V1-5	Vertical	40.12	4.70	853.62	35.74	41.1
V6-10		37.67	4.52	833.41	34.94	41.1
V11-15		37.18	4.30	864.65	35.83	41.3

V16-20		36.73	4.32	850.23	35.32	41.4
V21-25		32.61	3.86	845.21	32.5	41.2

From the data, it can be deduced that the tensile strength, tensile strain and upper yield strength of the horizontal PLA is better compare to vertical PLA. As table 5.2 shown, the average of tensile strain and stress for horizontal PLA fluctuate but still near to each other value but for the vertical PLA, it was seen that it clearly degraded on both of these data. These may due to the fact that the printing orientation did actually affect the absorption of the water in the PLA. These project infer that the longer the sample PLA was soaked in the water, more degradation occur on holistically level on it properties.

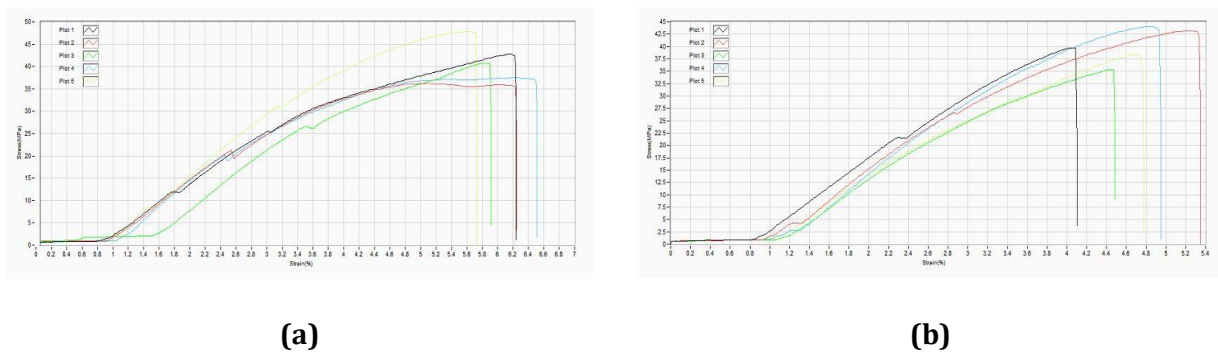


Figure 4 Stress against strain of sample model (a) H1-5 and (b) V1-5

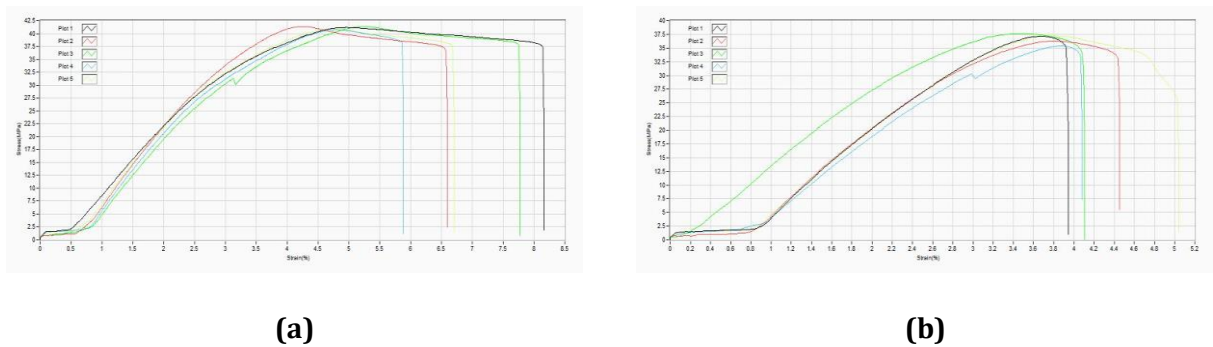


Figure 5 Stress against strain of sample model (a) H16-20 and (b) V16-20

Other than that, it can be seen that the longer the sample is soaked, the higher the capability of the PLA to withstand breaking after reaching its peak strength that the PLA can withstand. As observed in the graph of V1-5 and H1-5, after reaching a peak on tensile stress and strain, it dropped sharply as the sample break instantly during the test. Meanwhile in the graph of V16-V20 and H16-20, the sample seems to withstand breaking after reaching its peak on tensile stress and strain, as it gradually lowering before breaking completely.

4. Conclusion & Recommendation

From these studies with the data obtained, the sample PLA can be summarise that the printing orientation and water absorption did affect the tensile properties. For the printing orientation, it was found that the printing direction of the PLA will affect in the direction of the pulling. As such in the tensile test, the direction of pulling when perpendicular to the printing direction had lower tensile properties compare to parallel printing direction. Also when the pulling was perpendicular to printing direction, the faster the PLA model to break.

As for the immersion of PLA model in water, with the duration of days become longer, the higher the capability of PLA model to withstand breakage after reaching cracking point. From the data obtained, the longer the PLA model were immersed in water, the overall properties may degrade on other properties and other properties may improve. Also physically, the PLA model become less rigid as the PLA composition with water composition which reduce its rigidity and other mechanical properties.

As comparison, the printing orientation of parallel to the pulling direction when immersed in water for a long time reduce its tensile properties as it become softer than its usual composition. As for perpendicular to the direction of pulling when immerse in water for a long time, there was not much difference in the data across the duration of days. So for tensile properties of the PLA model after printing, it was much better if the pulling direction is perpendicular to the printing direction of PLA model.

Thus from these data, several recommendations on further research may be done more on the printing parameter with the water absorption and of other properties that were affect by water exposure to ensure that the PLA can withstand in different situation. Else, the direction of research can focus more on the water absorption of different material mixing with the PLA to print the model or different condition of water absorption such as water mix with particular enzyme or immerse in different temperature of water or immerse to different concentration of chemical to investigate the capability of PLA material on different perspective to obtain holistically of its capability for further used as the material can be considered biodegradable in material that can be used for 3d printing.

Declaration of Competing Interest

Authors declare that there is no conflict of interests regarding the publication of the paper.

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Author Contribution

The authors confirm contribution to the paper as follows: study conception and design: Nazrul Hazmie Suleiman, Mazatusziha Ahmad; data collection: Nazrul Hazmie Suleiman; analysis and interpretation of results: Nazrul Hazmie Suleiman; draft manuscript preparation: Nazrul Hazmie Suleiman, Mazatusaziha Ahmad; All authors reviewed the results and approved the final version of the manuscript.

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