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Effect of Bed Temperature and Extruded Height on 3D Printed PLA Mechanical Properties

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Abstract

Additive manufacturing or commonly known as 3D printing is rapidly developed and widely used throughout the world. 3D printing technology is increasingly being used for mass modification and manufacture of opensource designs in agriculture, healthcare, automotive, and aviation industries. PLA is the most common plastic filament material used in 3D printing due to its biodegradability and ease of use. PLA has low melting point, strong strength, minimal thermal expansion, good layer adhesion, and high heat resistance when annealed. The mechanical properties of 3D printed Polylactic Acid (PLA) are influenced by various printing parameters including bed temperature and layer height. This parameter gave a big impact to the mechanical properties and qualities of the fabricated components. PLA was printed with different bed temperature which is 80°C, 90°C, and 100°C, while the layer height at 0.12mm, 0.16mm, and 0.20mm for each bed temperature. The impact of this parameter shown by the research conducted to fabricate the 3D specimens using Fused Deposition Modelling machine and analysis the properties through tensile and flexural testing to get the tensile and flexural strength.

1. Introduction

The term "3D printing" that are using typically refers to a manufacturing method which constructs objects one layer at a time, adding numerous to create an object, use layers. Rapid prototyping is another name for this process, which is more accurately referred to as additive manufacturing. Many of the techniques utilised today were created and employed for the first time in the late 1980s and 1990s3, and the author treated a patient using 3D printing for the first time in 1999. Robotic gadgets are frequently relatively simple in 3D printers. CAD software is widely used in the fields of industrial design, engineering, and manufacturing, as well as in the dental laboratory and increasingly in many dental offices.

3D printing can create a geometric model into a real object using layer-by-layer technique. This 3D technique has become incredibly popular in recent years. In 1980, Charles Hull pioneered the commercialization of 3D printing techniques. At the moment, 3D printing is used to make PGA rocket engines, steel bridges in Amsterdam, prosthetic heart pumps, jewellery collections, 3D printed corneas, and other items relevant to a variety of businesses. Technology for 3D printing was developed through the layer-by-layer creation of three-dimensional (3D) structures directly from CAD models. A highly innovative technology that has become a flexible technology stage is 3D printing. 3D printing is now widely used all around the world. 3D printing technology being utilised more frequently in the industries of agriculture, healthcare, automotive, and aerospace for mass customization and production of any type of open-source design.

2. Materials and Methods

The prefabrication process includes filament and printing bed preparation and designing process. The designing process is done according to the parameter elevated for both tensile test and 3-point bending test purpose with different heat and layer height by using Solidwork software. Then, the fabrication process is done where the printed PLA specimen were printed using Fused Deposition Modelling (FDM) type of 3D printing machine which is Ender-3.

2.1 Materials

As the study is focused on the effect of changing the parameters used against the qualities of the printed PLA, only one material used for this project which is poly lactic acid (PLA) filament. Due to its ease of use, low cost, and ability to make parts with a variety of purposes, PLA is a great material to use while learning about 3D printing. It's also one of the greenest/most environmentally friendly filaments currently on the market. The primary benefit of PLA is that it is biodegradable and renewable because it is made from sugarcane and corn. This has the added benefit of allowing the plastic to emit a pleasant scent during printing. The PLA filament used is 1.75mm PLA Pro Filament.

2.2 Methods

In this project, a total of 18 specimens will be printed which is 9 specimens for both tensile test purpose and 3-point bending test purpose. 3 bed temperature setting will be used while printing the specimens for both test purpose which is 90°C, 100°C and 110°C. for the layer height per extrusion, 3 settings will be applied for each temperature which is 0.12mm, 0.16mm, 0.20mm.

Table 1 *Parameters for specimen*

Bed Temperature (°C)	Layer Height (mm)
80	0.12
	0.16
	0.20
90	0.12
	0.16
	0.20
100	0.12
	0.16
	0.20

2.3 Tensile test

3D-printed PLA test specimens for tensile behaviour is evaluated using the ASTM D638 (Type 1) standard procedure. As illustrated in figure and table, Solidworks software is used to model the geometry of the specimens according to the parameters required in the ASTM D638 (Type 1) standard. After that, the models are saved as stl. Files and imported into the 3D printing slicing software. Testing speed use for this testing is 5 mm/min.

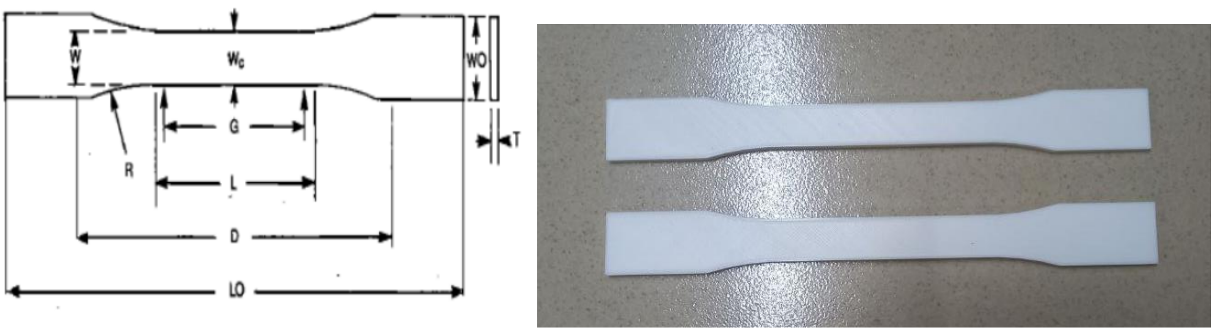

Fig. 1 *Dog-bone sample specimen*

Table 2 *bone sample specimen dimensions*

No.	Particulars	Dimension (mm)
1	Width of a narrow section, W	13
2	Length of a narrow section, L	57
3	Width overall (minimum), WO	19
4	Length overall (minimum), LO	165
5	Gauge length, G	50
6	Distance between grips, D	115
7	Radius of fillet, R	76

Tensile testing is a fundamental material science test in which a sample is subjected to a controlled tension until it fails. Uniaxial tensile testing is the most often used method for assessing the mechanical properties of isotropic materials. In this research, Universal Testing Machine (Shimadzu AG-1 10kN) as shown in figure will be utilized in order to determine the tensile properties of the specimens.

Fig. 2 *Shimadzu AG-1 10kN used for tensile test*

2.4 Flexural Test

The geometry of the specimens for 3-point bending test is designed using Solidwork software according to the ASTM D790 as shown in figure and table. The design then will be saved in. stl format before transferred to slicing software. Used specimen size for ASTM is 125mm x 12.7mm x 3.2mm. Testing speed use for this testing is 2 mm/min

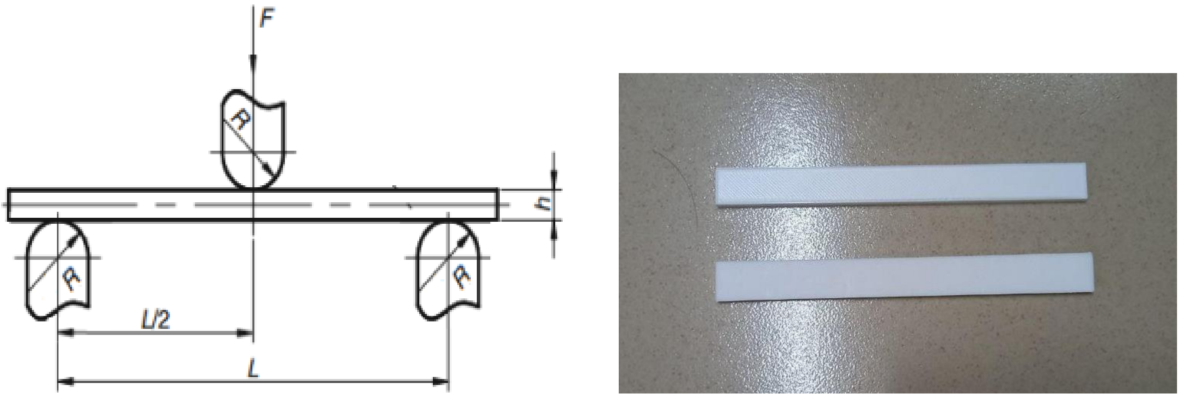

Fig. 3 *Flexural specimen for bending test*

The most used method, meanwhile, is three-point bending with a range of span lengths for plastics with small and high extensibilities rather than four-point bending. These test methods are particularly valuable for quality control and specification purposes since they can determine flexural characteristics. In this research, three-point bending test will use the same machine as for tensile test which is Universal Testing Machine (Shimadzu AG-1 10kN).

Fig. 4 *Three-point bending setup*

2.5 Equations

Tensile strength and Young Modulus can be obtained throughout the test using the following equation;

Tensile strength, $\sigma_{max} = P_{max} / A_0$

Young Modulus, $E = \sigma / \varepsilon$

Flexural stress, σf can be obtained using the following equation;

Flexural stress, $\sigma_f = 3PL/2bd2$

3. Results and Discussion

The results of a tensile and flexural test demonstrate that the tensile strength, elastic modulus and flexural strength of each sample totally different.

3.1 Tensile properties

According to the table, for bed temperature at 80°C and 90°C specimen printed, the tensile strength is nearly the same for specimen with layer heights of 0.16mm and 0.20mm, at 26.32Mpa & 26.31Mpa and 26.39Mpa & 26.01Mpa, respectively, while specimen with layer height 0.12mm tensile strength at 27.00Mpa & 25.17Mpa. A bit different for bed temperature at 100°C, the tensile strength is nearly the same for specimen with layer heights of 0.12mm and 0.20mm, at 25.72Mpa & 25.93Mpa, respectively, while specimen with layer height 0.16mm tensile strength at 27.09Mpa which is the highest tensile strength.

Table 2 *Tensile test results*

Specimen		Tensile Strength	Modulus of Elasticity
Bed Temperature (°C)	Layer Height (mm)	**(MPa)**	**(MPa)**
80	0.12	27.00	428.57
	0.16	26.32	403.06
	0.20	26.31	385.21
90	0.12	25.17	403.37
	0.16	26.39	392.12
	0.20	26.01	389.96
100	0.12	25.72	415.51
	0.16	27.09	399.56
	0.20	25.93	376.89

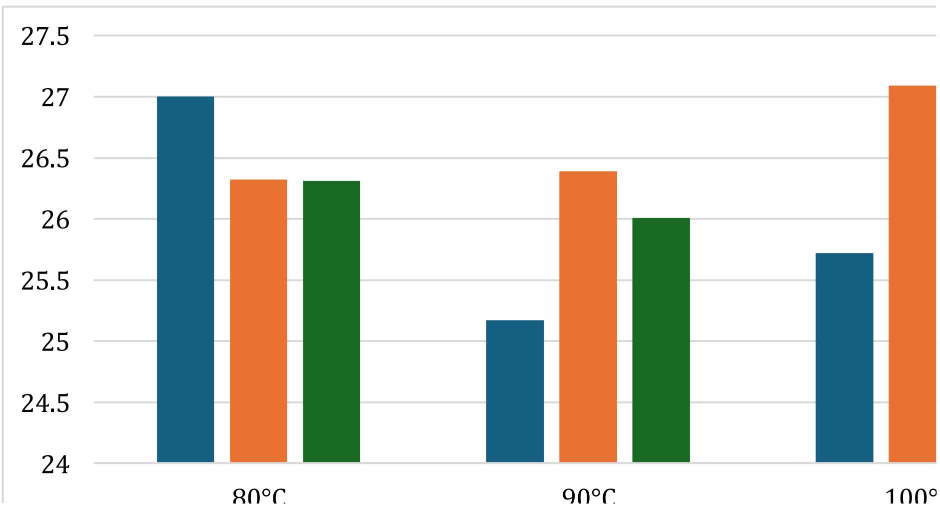

Fig. 5 *Bar chart tensile strength vs bed temperature*

The bar chart shows that when the layer height is increased at the bed temperature for the specimen printed at 80°C, the tensile strength decreased. While the other result for bed temperature a bit different at 90°C and 100°C, the layer height at 0.16mm has the higher tensile strength that 0.12mm and 0.2mm. The average tensile strength improves with layer thickness. This is because smaller layer height improved surface quality and finer detail. As we know finer detail can enhance interlayer bonding that leads to increase the tensile strength. By improving interlayer adhesion, it can help distribute stress more evenly throughout the part and contribute to higher tensile strength.

In terms of how temperature affects tensile strength, the specimen with the highest tensile strength for specimens with layer heights of 0.12mm and 0.20mm is recorded at specimen printed at bed temperature 80°C which is 27.00Mpa and 26.31Mpa, while the specimen with the highest tensile strength for specimens with layer height 0.16mm is recorded at specimen printed at 100°C, which is 27.09Mpa. The specimen with the lower tensile strength for all layer height is measured at 90°C. It was discovered that the part gets stronger as the bed temperature increase. As anticipated, interlayer adhesion decrease as the layer bonding was weak and depends on the specific material being used.

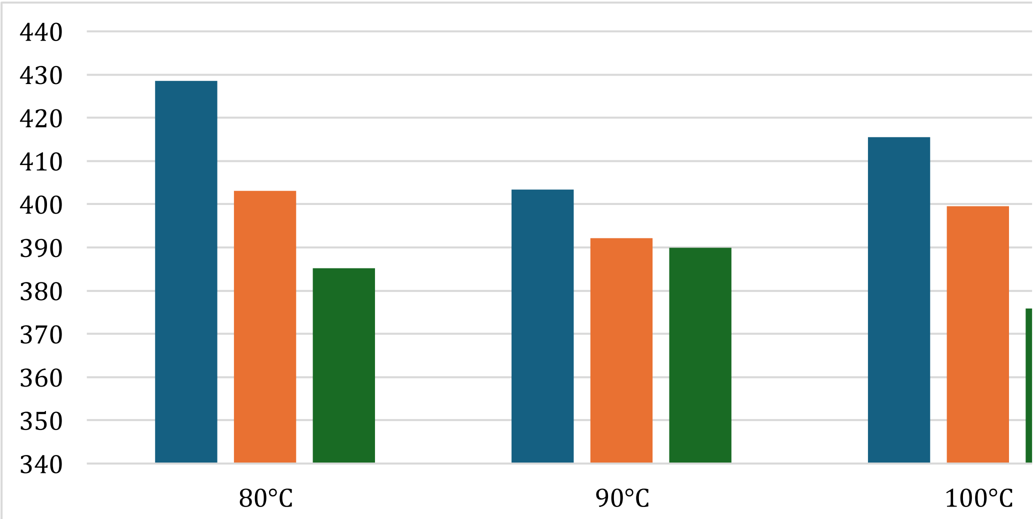

Fig. 6 *Modulus of elasticity vs bed temperature*

The data shows that the modulus of elasticity decrease as the bed temperature increase from 80°C to 100°C for all layer heights. Higher bed temperature can lead to improve interlayer adhesions, this will demonstrate the better bonding between layers. The strong bonding can contribute to an increase in the modulus of elasticity. The specimen with the highest modulus of elasticity for layer height 0.12mm and 0.16mm at specimen printed at bed temperature 80°C, while the specimen with the highest modulus of elasticity for layer height 0.2mm at specimens printed at bed temperatures 90°C. Despite this, the specimen printed with layer height 0.2mm exhibits the lowest modulus of elasticity in comparison to other layer heights at all the temperatures utilised. Modulus of elasticity represents elastic deformity resistance of the specimen when we apply force. Higher modulus of elasticity means the material is a stiffer material.

3.2 Flexural properties

According to the table, for bed temperature at 90°C specimen printed, the flexural strength is nearly the same for specimen with layer heights of 0.12mm and 0.20mm, at 51.95Mpa & 51.06Mpa, respectively, while specimen with layer height 0.16mm flexural strength at 56.97Mpa. A bit different for bed temperature at 80°C and 100°C, the flexural strength is different and the value did not nearly same.

Table 3 *Flexural test result*

Specimen		**Flexural Strength**
Bed Temperature (°C)	Layer Height (mm)	**(Mpa)**
80	0.12	48.52
	0.16	52.21
	0.20	50.70
90	0.12	51.95
	0.16	56.97
	0.20	51.06
100	0.12	70.53
	0.16	71.83
	0.20	67.57

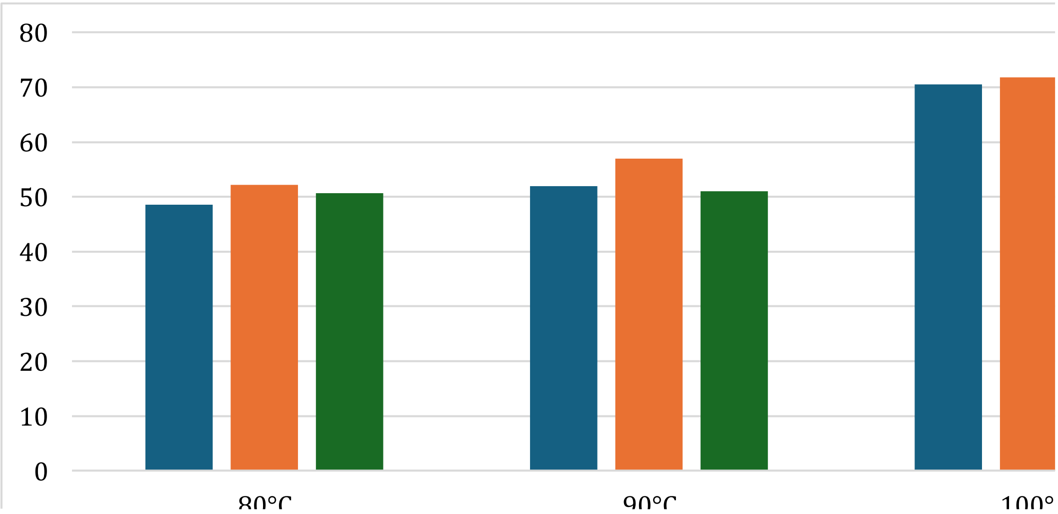

Fig. 7 *Flexural strength vs bed temperature*

According to the data from the chart, increasing of the bed temperature leads to increasing of the flexural strength. We can see the highest flexural strength is recorded at specimen printed with bed temperature 100°C which is 71.83Mpa. The flexural strength of the samples because of the increase in heat dissipation from one layer to another layer which leads the post heating of layer which are already bonded and improve the strength. By increasing the interlayer adhesion between the layers to high bed temperatures, this will demonstrate the increasing of the flexural strength due to the strong bonding between layers. Flexural strength for all bed temperature increases from 0.12mm to 0.16mm and decrease as the layer height increased to 0.20mm. Due to the layer's stronger layer bond in supporting the load bending, the more the layer thickness, the better the flexural strength. The distortions caused by the accumulation of stress during bond formation is minimised by reducing the number of layers.

4. Conclusions

The mechanical test analysis revealed distinct variations in mechanical properties resulting from the use of different extruders and layer heights during printing. Based on the results obtained according to the mechanical properties, the printing parameter with the best tensile strength and modulus of elasticity is specimen printed at temperature 80°C with layer height 0.12mm while the best flexural strength is the specimen printed at temperature 100°C with 0.16mm layer height. From the results, we can conclude that the tensile and flexural strength of 3D printed specimens are influenced by bed temperature and layer height. This study able to assess the impact on the mechanical properties of the printed specimens.

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