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3D Printing of Lightweight for Lighter and Denser Parts

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Abstract: The lightweight nature of Polylactic acid is a new material that is being used in the additive manufacturing sector for the production of filament. This filament will produce wing components, which need particular features for the part to fly and be balanced with saves battery by reducing the material used. This study was conducted to determine the temperature at which it is best to print filaments produced from lightweight polylactic acid (LW-PLA) material to acquire optimal quality settings for components on the drone as well as something that can be installed and flown. The research findings have provided us with the knowledge that may be used to examine the outcomes of other studies and testing. Started with a dumbbell and cube preparation material that had 0 infills and was printed with four various types of temperatures. After that, we carried out tests broken down into three categories: thermal, mechanical, and physical testing. Various recommendations for changes are presented and discussed; among these recommendations is the proposal that the samples be managed and preserved. The part with a 200℃-printing setting has the largest mass, according to the results of the physical features, although it is still quite light. The mechanical testing results demonstrate that printing setting 200℃ is the greatest value needed to fracture the specimen. The experiment of physical, mechanical, and thermal qualities yielded 200 as the optimal temperature setting for the material (LW-PLA) print drone.

Keywords: Additive Manufacturing, Lightweight Polylactic Acids, Temperature, Infill

1. Introduction

Additive Manufacturing, also known as AM, is the generic term for the advanced manufacturing technologies that build parts layer by layer. The layers are produced by adding material instead of removing or subtractive[1] for manufacturing, such as machining. G-codes control the material addition or fusion generated directly from 3D CAD models [2]. Fused Deposition Modelling (FDM) or Fused Filament Fabrication (FFF) is an additive manufacturing technology that extrudes thermoplastic polymers from a print nozzle under pressure and at exact temperatures [3].

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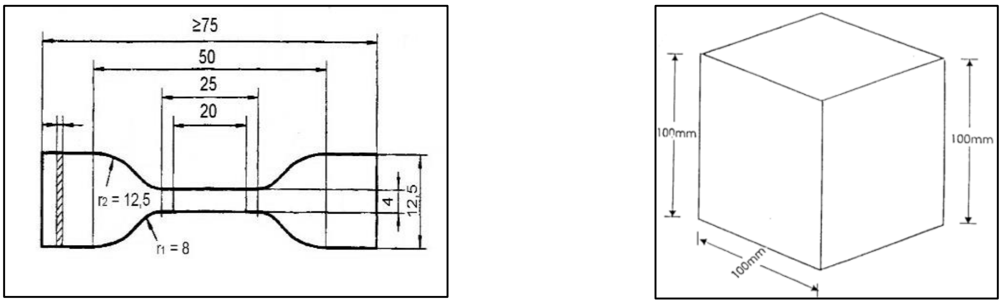
Polylactic acid (PLA) is a common thermoplastic for accessible FDM machines. FDM-produced PLA components' mechanical properties and performance must be understood. Admittance and fully accessible FDM-type machines can process a wide range of thermoplastics [4]. The foaming technique saves material in PLA material can printing with little time by producing a considerable model with little material. Fabricators state that lightweight Polyplastics Acids (LW-PLA) may cut filament flow by 50% and can yield 65%. LW-PLA works at high temperatures [5]. The investigation was conducted due to the objective, which is to evaluate the effect of printing temperature setting of Lightweight Polylactic Acids and to analyse the influence of the process parameter on the physical, mechanical and thermal properties. The scope of this study is to use the LW-PLA material from Colorfabb, Ender 3D printing 3 Pro machine and various printing setting parameters (200℃ to 260℃).

2. Methodology

An experiment was created to investigate the impact of printing temperature settings on the expansion of lightweight PLA filaments. The physical, mechanical, and thermal properties of LW-PLA as the nozzle temperature varies during printing using Ender 3 Pro were selected as the study parameters to be considered. The study subjects included a model cube with 0% infill and a dumbbell made by the ISO 527 criteria sample, both of which are shown in Figures 1: (a) Dumbbell dimension- 75 × 12.5 × 2 mm and Cube dimension- 50 × 50 × 50 mm.



(a) **(b)**

Figure 1: Drawing on Dumbbell and Cube 0% infill

2.1 Materials and equipment

For this investigation, a 3D printer called an Ender 3 Pro and the software version 4.13.0 of Cura were utilized. A single-nozzle FDM printer, the Ender 3 Pro uses a 0.4 mm nozzle to print the model. Then, LW-PLA filament was the material that will be utilized as the material for the testing. LW-PLA filament manufactured by "eSUN" was selected for this testing and can be handled with the following 3D printers. Filament storage requires oven-dried LW-PLA to reduce environmental moisture. This prevents filament defects.

2.2 Sample Preparation

For the Cura parameter, all samples have the same layer height. All four cube examples have 0% infill since a cube has no fill. Cubes have no void. Other samples, dumbbell ISO527 are 100% because mechanical testing is done on the complete infill. The build plate temperature was set at 60 °C, and the print speed was 55 to 100%. Wall line count to 1, layer height to 0.25 mm, and printing temperature to 200°C, 240°C, 240°C, and 260°C. Enable retraction when printing a sample to avoid stringing, which may destroy its structure.

2.3 Expansion Test

Measure the thickness of each cube's sides to estimate how much the cube and Dumbbell have expanded. The equipment used to measure the thickness of each specimen is a Mitutoyo Micrometer with an accuracy of ±0.001 mm and the measuring of dumbbell size using a machine called a profile projector. The lens used for the profile projector was 10× magnificent. The digital readout multi-function digital display processing system is used on profile projectors to precisely measure geometrical work pieces.

2.4 Surface Roughness

After the expansion test, the same cube specimen was utilized to quantify the LW-PLA specimen's surface roughness. The cube's edges are cut and attached to the test handle using plasticine to prevent the specimens from sliding as the detector goes through the surface testing material. The speed sensor travels above the specimen surface is 0.5 mm/s, Lamda C is 0.8 mm, and all samples are 5 m to calculate the surface roughness average.

2.5 Weight Measurement

The specimen was measured using a weight scale to compare the weights of the four sets of three dumbbells that were each printed at a different temperature.

2.6 Morphological Testing

Eventually, the surfaces of the broken specimens (from mechanical testing) were observed using a scanning electron microscopy Hitachi U151O, Japan for Scanning Electron Machine. All samples were coated with the silver sputter coater vacuum was used. Imaging was performed with a magnification of 100×.

2.7 Mechanical Testing

The printed specimen was tested for tensile test using Universal Tensile Testing Machine (AGS-J) according to ISO 527 using a parameter setting speed of 50 mm/s, grip length of 12 mm and a gauge length of 20 mm also following the ISO standard shape in Figure 1. The four sets of dumbbell specimens were tested like the below after all machine settings are adjusted and started to grasp it to the tensile machine before clicking the start on the computer screen.

2.8 Thermal Gravimetry Analysis (TGA) and Differential Scanning Calorimetry (DSC).

The materials were examined using Mettler-DSC Toledo's 822e simultaneous thermal analysis machine and helium gas as the combustion material. In the furnace, the sample burned. The sample must be cut and weighed using a Shimadzu Balanced electronic weight ATY2242 with precession 0.001 g to configure the DSC and TGA machines. 5 – 15 mg. Under nitrogen, the material was heated from 20 to 800 °C at 10 °C/min.

3. Results and Discussion

3.1 Specimen Preparation

Obtaining the necessary size and standard, specimen production, or material preparation utilizing LW-PLA has been completed. The 3D printer produced a dumbbell and cube with 0% infill. (a) Samples printed at 200°C had a white tone, unlike the yellowish 260°C samples because the nozzle is overheating at a temperature of 260℃. The cube has no dents since its walls are thicker than a 200°C sample. The dumbbell has strings connected, and its corners have melted and bent because the nozzle stay at that part too long until it melts the corner of the specimen in Figure (b) dumbbell with stringing.

(a)

(b)

Figure 1: The appearance of (a) a printed sample of cube 0% infill and (b) a dumbbell ISO527

3.2 Effect of temperature on expansion test

Results data of the average thickness of the cube wall with infill of 0% is rising, which corresponds to the extruder printing temperature rising from 200°C to 260°C. This can be seen in Figure 2 value of thickness with initial values 0.375, 0.489,0.551 and 0.603 mm. Both sides should have the same length. But grip length one and width two data show differently. Figure 3 shows the measure of grip width increases as the temperature rises. But samples 1 and 2 had different grip width measurements, this is because of the foaming effect and small bubbles exist at higher printing temperatures and measurements of the melting part there are not needed. The foaming effect during printing expands the sample, according to the results. The foaming effect makes the area and diameter for each specimen increase and expand the cube with the highest temperature. The different value of both sides of the dumbbell is due to the same problem as specimen preparation which is due to the nozzle stay too long while the printing process happens and causing the melt over the corner for both sides of the dumbbell.

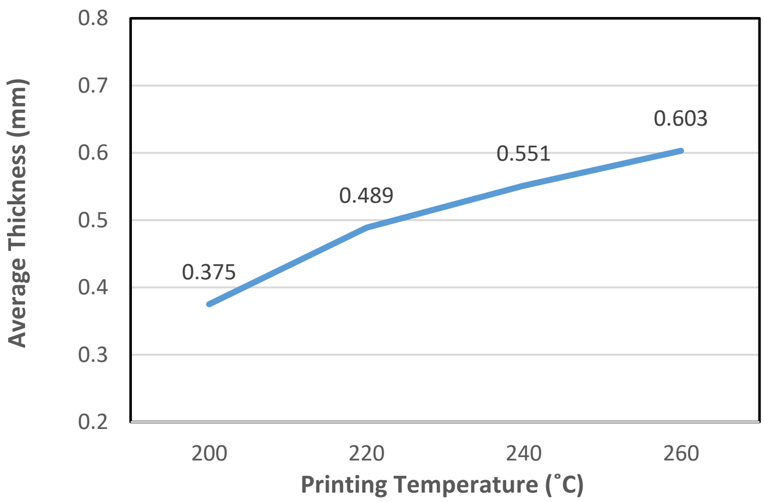


Figure 2: Expansion of Cube with infill 0%

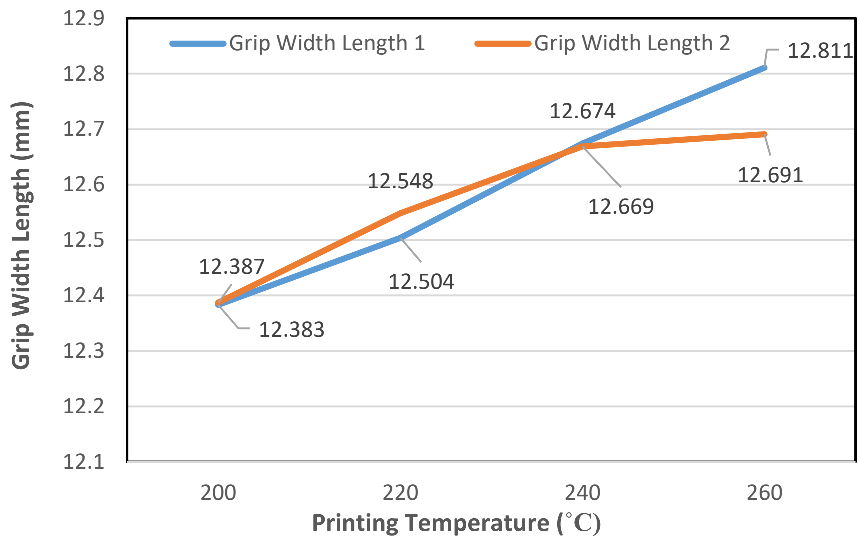


Figure 3: Expansion Grip Width Length of Dumbbell

3.3 Effect on Temperature Printing to Roughness

The foaming effect that occurs during the extrude of filament layer by layer when the printing process is carried out causes the surface to mate to the surface of the model cube. The increase in average roughness is due to the increasing foaming effect and the effect of the increase in printing temperature. Figure 4, shows four samples from a cube produced with variable nozzle temperature cut into a piece that has been examined using a surface roughness tester. Based on the outcome analysis, all the samples test indicates the non-linear data. The initial data acquired of 3.12 µm for 200℃ gradually raise to 4.792µm (220℃). For the following testing to establish the roughness average of 240℃, which is 4.309µm, where the trend declined, and the final sample of 260℃ was 5.698 µm has the highest value of Ra than all samples. This is due to the sensor of the surface roughness tester detecting the uneven surface and the uneven surface at 260℃ printing temperature has the highest uneven surface.

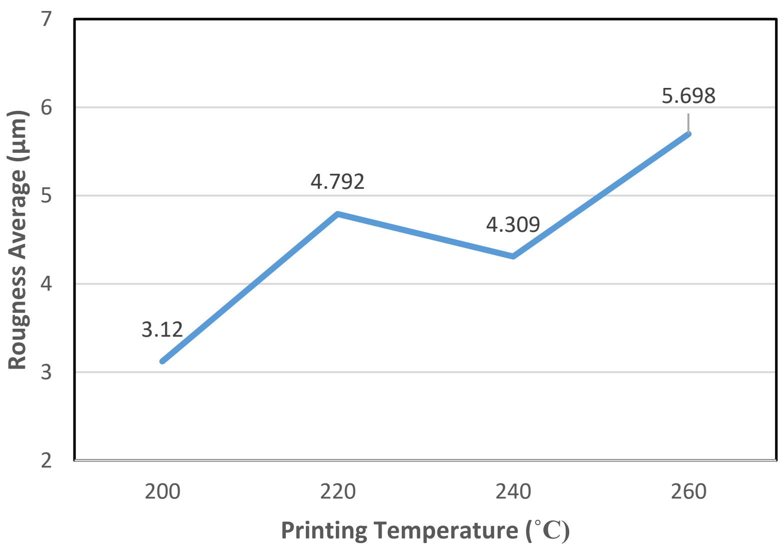


Figure 4: Roughness Average Effect

3.4 Morphological Testing and Weight Measurement

Table 1 below shows the combination and interrelated results of 2 testing weight measurements and a Scanning electron microscope (SEM).

Table 1: Table of Weight, Average Porosity Area and Average Porous Diameter

Sample Printing Temperature (℃)	Dumbbell Weight (g)	Average of Porosity Area (nm)	Average of Porous Diameter (nm)
200	0.83	2894	21.310
220	0.81	3083	27.778
240	0.81	3220	29.419
260	0.76	5072	36.930

Figure 5 shows the SEM image at 100X magnification. Regarding the neatness of the layer arrangement, it is evident that every sample had pores, even if the infill density was 100%. An air gap between the materials might reduce the specimen's weight because there is no infill of LW-PLA composite. As shown in Table 1, the data of dumbbell weight decreases by 0.83 g (200℃), 0.81 g (220℃), 0.81g (240℃) and 0.76g (260℃) respectively while the size and diameter of porous in (nm) increase where there are only air gaps between the material fills. The same cause of this porosity as the surface roughness and the expansion of the sample before the porosity is proven via this experiment. This shows the highest temperature effect on the porosity area and diameter in all samples. The porosity shows that LW-PLA is the lighter material because consists of porosity.

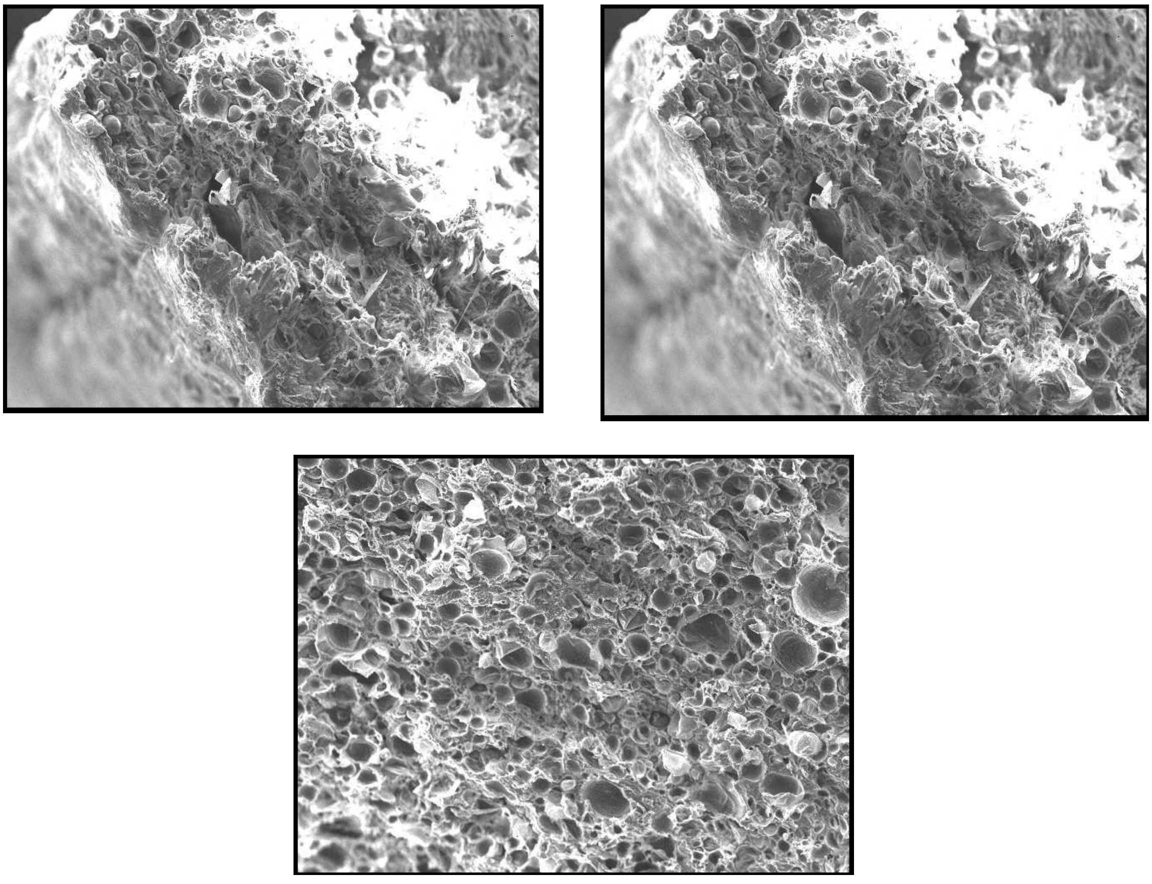


Figure 5: SEM Image of Dumbbell ISO 527

3.5 Effect of Printing Temperature on Tensile Test

The effect of melt compounding on the tensile test of LW-PLA distribution was investigated. Following the execution of the 12 samples of ISO527 dumbbell of printed parts, the experimental results were analysed with universal tensile machine Autograph Shimadzu AG-1 to determine and identify with setting speed 50 mm/s for obtained the result parameter of maximum displacement on 4 samples only. The tensile maximum force is shown in Figure 6. The result indicates that the printing temperature has a significant effect on the maximum force due to the infill of the polymer. According to [6], as the infill percentage dropped, so did the value of the maximum force tensile test. Since the infill percentage dropped, the air gaps in specimen cross-sections become higher. The LW-PLA material's stiffness is lost by improving the contact area between layers. The air gap and porosity consist of each sample affect the maximum force required to break the sample. The highest porosity diameter and area will cause the maximum force to be lesser.

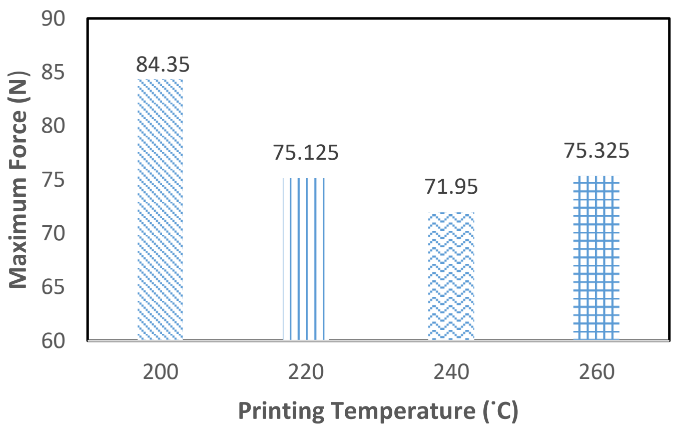


Figure 6: Maximum Force Dumbbell ISO527

3.6 Differential Scanning Calorimetry (DSC) Analysis

To observe the PLA phase transitions, such as glass transition T_g, melting point T_m and cold crystallization, DSC is a useful tool. The semicrystalline LW-PLA, DSC thermograms were produced at a cooling rate of 10 C/min with various compositions. DSC helps observe LW-PLA phase transitions such as Tg, Tm, and cold crystallization. Semi-crystalline PLA DSC thermograms were generated at 10 C/min. Tg and Tm in LW-PLA have the same range as common PLA suggested [7]. The crystallization of LW-PLA has no significant effect on 3D printing component mechanical characteristics. Table 2 shows 3D printed PLA DSC curves and Tg and Tm at various nozzle temperatures (200-260°C). The set temperature does not influence the Tg, and all offset Tg values and melting temperature (Tm) are comparable. Figure 7 shows that the tensile maximum force changes with printing temperature.

Table 2: Tg, Tm and Weight Loss

Sample Printing Temperature (°C)	Offset Tg (°C)	Melting Point (°C)	Average of Porous Diameter (nm)	Degradation Temperature (°C)
200	61.86	163.9	86	325.3
220	62.77	166.6	91.43	328.9
240	62.34	167.3	82	326.6
260	63.51	167.9	85.47	327.0

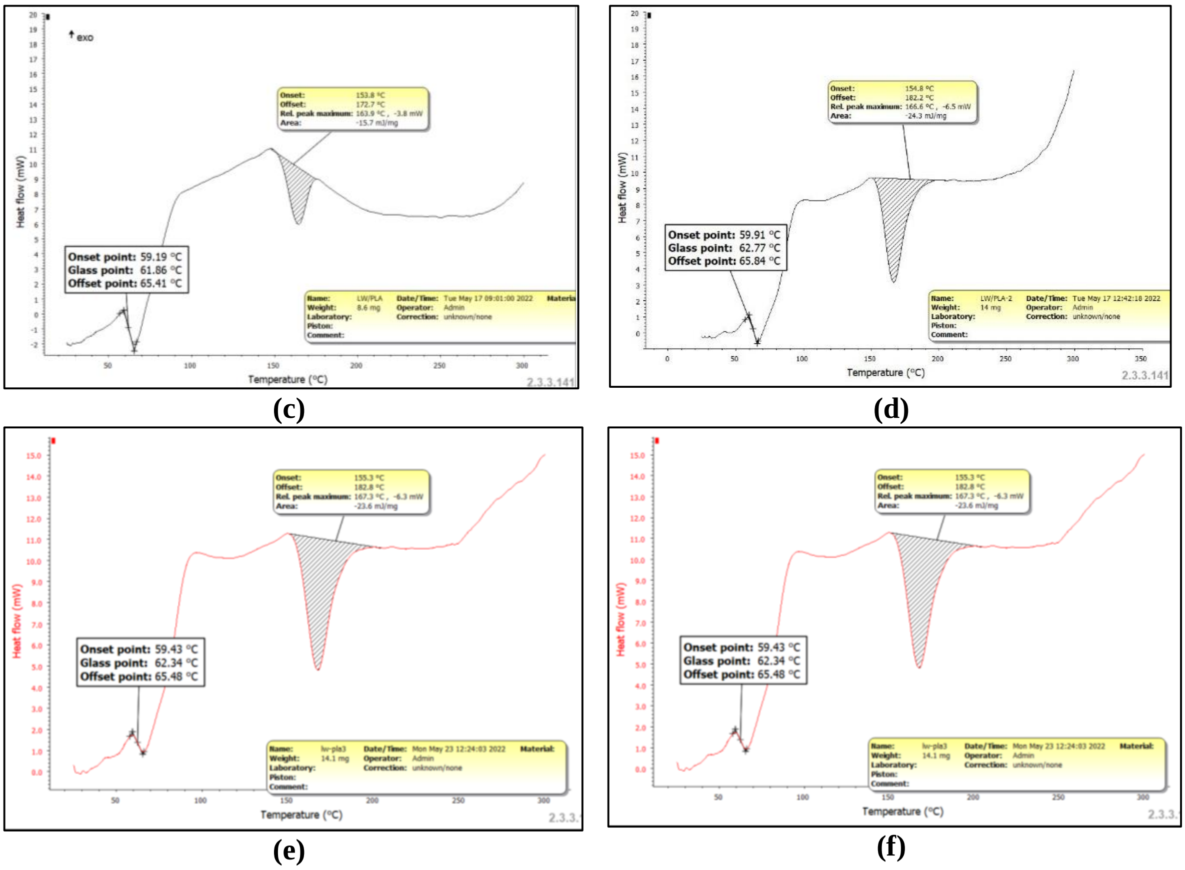


Figure 7: (a) DSC LW-PLA 200℃, (b) DSC LW-PLA 220℃, (c) DSC LW-PLA 240℃, (d) DSC LW-PLA 260℃.

3.6.2 Thermogravimetric Analysis (TGA)

TGA technique result concerning mass change when the sample was heating and cooling and to calculate the ultimate mass loss in the conclusion of the process, also the parameter result is the temperature of LW-PLA degraded while processing at raised temperature when LW-PLA transforms from solid to melt. The % mass loss was calculated to compare each specimen. The largest mass loss in (mg) is a sample with a printing temperature of 220℃, where the mass loss is 91.43%, followed by the sample at 200℃ printing temperature with 86% mass losses in the range of 80 minutes after heating. The lowest mass loss occurs when a sample is heated to 240℃ and then cooled to 20℃. Degradation temperature value as shown in Table 2: 325.3℃ (LW-PLA -200℃), 328.9℃ (LW-PLA-220℃), 326.6℃ (LW-PLA-240℃) and 327.0℃ (LW-PLA-260℃). This is because the highest printing temperature will affect the mass loss and prove the rise of printing temperature will affect the mass as discussed before.

4. Case Study

Various tests have investigated the LW-PLA material's physical, mechanical, and thermal characteristics. The output result achieved has been written and discussed to select and finish the purpose of discovering the optimum setting temperature to apply the usage of LW-PLA type filaments, especially for print drones. A drone, also known as an Unmanned Aerial Vehicle sample printed at a temperature of merely 200℃ weighted results remain taken into account because it considers various elements such as the outcome of a tensile test.

5. Conclusion

The objective stated at the beginning of this study has been fulfilled, based on the data and analysis completed by LW-PLA. Defining and analysing the relationship of printing temperature LW-PLA settings to expansion material has been accomplished. The effect of printing temperature may affect the physical and mechanical properties of print specimens. For thermal properties, there are no effects on the properties. Furthermore, the appropriate printing temperature setting for LW-PLA is recognised according to the findings of tests that were done which is 200°C.

Acknowledgement

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Appendix

Tensile Test Graph

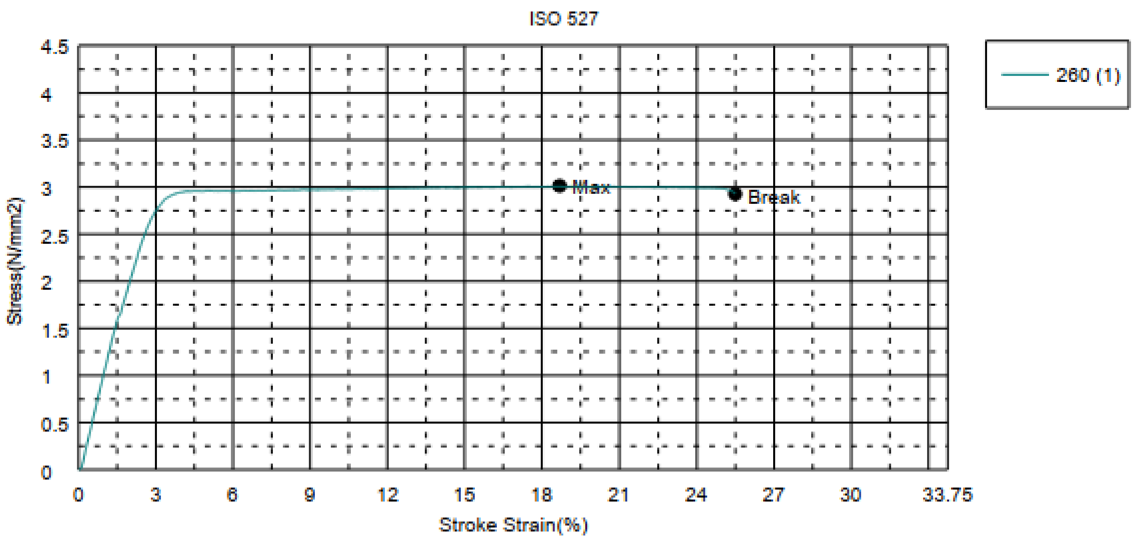
ISO 527

Shape: Plate

	Thickness	Width	Gauge Length
Units	mm	mm	mm
260 (1)	2.0000	12.5000	20.0000

Name	Max_Force	Max_Disp	Max_Stress	Max_Strain	Break_Force
Units	N	mm	N/mm2	%	N
260 (1)	75.3250	3.73600	3.01300	18.6800	73.1750

Name	Break_Disp	Break_Stress	Break_Strain	YS1_Force	LYP_Force
Parameter				0.2 %	
Units	mm	N/mm2	%	N	N
260 (1)	5.10000	2.92700	25.5000	-.-	-.-



References

[1] J. J. Ramsden, "What is sustainability?," *Nanotechnol. Perceptions*, vol. 6, no. 3, pp. 179–195, 2010.

[2] A. Alafaghani, A. Qattawi, B. Alrawi, and A. Guzman, "Experimental Optimization of Fused Deposition Modelling Processing Parameters: A Design-for-Manufacturing Approach," *Procedia Manuf.*, vol. 10, pp. 791–803, 2017.

[3] S. Khan, K. Joshi, and S. Deshmukh, "A comprehensive review on effect of printing parameters on mechanical properties of FDM printed parts," *Mater. Today Proc.*, 2021.

[4] V. Kostakis, V. Niaros, and C. Giotitsas, "Open source 3D printing as a means of learning: An educational experiment in two high schools in Greece," *Telemat. Informatics*, vol. 32, no. 1, pp. 118–128, 2015.

[5] "How to print with LW-PLA", [Online]. Available: https://www.facebook.com/ColorFabb?ref=hl. (2019, April 11). How to print with LW-PLA - Learn ColorFabb. Learn ColorFabb. https://learn.colorfabb.com/print-lw-pla/%0A%0A

[6] M. Hsueh, C. Lai, K. Liu, C. Chung, and S. Wang, "Effects of Printing Temperature and Filling Percentage on the Mechanical Behavior of Fused Deposition Molding Technology Components for 3D Printing," 2021.

[7] C. Abeykoon, P. Sri-amphorn, and A. Fernando, "Optimization of fused deposition modelling parameters for improved PLA and ABS 3D printed structures," *Int. J. Light. Mater. Manuf.*, vol. 3, no. 3, pp. 284–297, 2020.