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Research Article

Optimization of 3D Printing Process Parameters of Polylactic Acid Filament Based on the Mechanical Test

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The main objective of this research study is to optimize the printing parameters that can be used in the FDM (fusion deposition modeling) production method to obtain the lowest production time and best printing parameter of PLA (polylactic acid) filament with the tensile test. The printing parameter that can be used in FDM machines such as extruder temperature, bed temperature, layer height, printing speed, travel speed, infill, and shell count is taken into account for optimization. In addition, the tensile specimens from ASTM (American Society for Testing and Materials) D638 standard were manufactured by PLA filament with the above-modified printing parameters. The best printing parameters for PLA products were found by the time recorded during production and tensile test results after production. Thus, through this research, one can find the best PLA filament printing parameters and their timing.

1. Introduction

Additive manufacturing (AM) attracts attention in various fields of manufacturing sectors for producing slightly more difficult geometrical designs products. Moreover, AM has been considered by researchers in recent decades and can be future manufacturing technology instead of the CM (conventional manufacturing) method and digital data alone are considered sufficient in AM to produce an object. Digital data are converted to STL (standard triangle language) and sliced by slicing software and fed as input to a 3D printer machine, and the 3D printer generates the given input data layer-by-layer as the final product. It can easily produce the final products with less wastage and in a very short time [1–3].

Earlier researchers described AM-based types, characteristics, policies, presence, and potential in the market in [4–9]. Some studies show that manufacturers focus only on production costs and time. Various tactics are employed for this. The PLA filament that can be used in FDM machine attracts the attention of the manufacturers due to its low cost and high availability.

Therefore, this research study aims to determine the best printing parameters of PLA filament based on production time and tensile test (mechanical property). A large number of previous researchers have experimented with 3D-printed material. Fragassa et al. [10] explored the properties of four photopolymer resins. This research ensured the physical characteristics and nominal mechanical properties of tensile and bending strength. However, the authors of this study recommend personal evaluation when considering other characteristics.

According to Talic et al. [11], ABS (acrylonitrile–butadiene–styrene) and PLA filament are considered the most popular filament in the field. PLA filament has slightly higher strength and stiffness compared to ABS filament. PLA filament is also considered to be slightly easier to print and PLA filament as a good alternative to ABS filament in a material extrusion method. It has been considered by previous researchers [12–14].

Today, PLA filament is utilised in a variety of applications, and its availability in the market is substantial. Sugarcane and maize starch are the two primary components used in the production of PLA filament, a type of biodegradable thermoplastic. Therefore, neither the consumers nor the environment are harmed by it in any way [15–17].

Polyether-ether-ketone (PEEK) has been considered by earlier researchers as an alternative to PLA filament and ABS filament [18]. But this is not immediately useable on the 3D printing machine.

Finally, Galeta et al. [19] explored the tensile strength influence of processing factor in the 3D printing model on their research.

2. Methods and Materials

In this test, the minimum production time is first calculated by modifying several printing parameters of the FDM machine that can be used in AM and creating tensile specimens for the same ASTM D638.

This research study calculates the breaking point, true strain at maximum load, and true strain at break percentage of the five tensile specimens produced. For this, the previously mentioned printing parameters such as extruder temperature, bed temperature, layer height, print speed, travel speed, and shell count are taken into account. Flash forge for slicing software and Botzlab Wanhao Duplicator 4S were used as the manufacturing machine.

The procedure for producing ASTM D638 tensile specimens is as follows:

(1) Designing model by solid works SP2.0
(2) Converting solid works the SP 2.0 model in to STL file (a standard format for 3D printers)
(3) During the .STL conversion, the printing parameters given in Table 1 are taken into account by change common for all 5 tensile specimens
(4) Creating a 3D physical model by the FDM machine
(5) The making time of each specimen is given in Table 1 (ensure the slicing software time and actual time).

2.1. Printing Parameters in Additive Manufacturing. The printing parameters are commonly considered in 3D printing by previous researchers, as given in Table 1. The extruder temperature was found to be above 200°C as the melting point of the PLA filament by previous researchers [15–19].

The extruder temperature used in this research study is a minimum of 200°C and a maximum of 219°C. The bed temperature used is a minimum of 0°C and a maximum of 50°C. An initial layer height of 0.12 mm to a maximum of 0.23 mm was used during production. Printing speeds ranging from a minimum of 30 mm/s to a maximum of 75 mm/s are used. Extruder travel speeds range from a minimum of 60 mm/s to a maximum of 90 mm/s.

Infill (pattern/density (%)) is considered as the most important printing parameter in 3D printing in optimization. Hexagonal pattern (15%) for specimen I, line pattern (15%) for specimen II, triangle 35° pattern (30%) for specimen III, 3D infill pattern (20%) for specimen IV, and triangle 55° pattern (35%) for specimen V as infill in this research study have been used.

Finally, the shell count is used as a minimum of 2 and a maximum of 3 in the optimization parameter.

2.2. Tensile Specimens ASTM D638. The design was first selected for ASTM [20] standards D638 type 5 polymers that can be used to determine the mechanical properties of the selected PLA material, and this is shown in Figure 1.

Figure 2 shows 5 tensile specimens generated by different printing parameters. The Boltzlab Wanhao Duplicator 4S, the most popular FDM machine on the market, has been used in this research to produce these tensile specimens, and this is shown in Figure 3.

3. Tensile Test

An Instron 5980 series tensile testing machine was used at 5 mm/min. The tensile testing machine setup is shown in Figure 4, and Figure 5 shows the failure of the tensile specimen.

3.1. Braking Point. Table 2 provides the braking points of the specimens. The minimum specimen II is 0.24185 and the maximum specimen III is 0.98919 braking.

3.2. True Strain at Maximum Load. The minimum specimen IV is calculated to be 0.08958 and the maximum specimen I is calculated to be 0.10823. This is given in Table 3.

3.3. Tensile Strain Brake Percentage. The maximum tensile strain percentage is calculated as specimen III and the minimum tensile percentage is calculated as specimen V and is given in Table 4. The load-extension diagrams of each tensile specimen are shown in Figures 6–10.

3.4. Load-Extension Diagrams. The tensile load-extension curve of specimen 1 is shown in Figure 6. Figure 6 shows that specimen I can withstand weighs up to 750 N and shows the extension up to 13.56%.

The tensile load-extension curve of specimen II is shown in Figure 7. Figure 7 shows that specimen II can withstand weighs up to 650 N, and it shows an extension up to 10.909%.

Table 1: Printing parameters of specimens.

Parameters/specimens	Specimen I	Specimen II	Specimen III	Specimen IV	Specimen V
Extruder temperature	200°C	210°C	215°C	217°C	219°C
Bed temperature	50°C	0°C	0°C	0°C	0°C
Layer height	0.18 mm	0.12 mm	0.20 mm	0.20 mm	0.23 mm
Printing speed	60 mm/s	30 mm/s	70 mm/s	75 mm/s	55 mm/s
Travel speed	80 mm/s	60 mm/s	90 mm/s	80 mm/s	70 mm/s
Infill (density/pattern)	15% hexagonal pattern	15% line pattern	30% triangle 35° pattern	20% 3D infill pattern	35% triangle 55° pattern
Shell count	2	3	2	3	3
Time taken for fabrication	12 minutes	18 minutes	10 minutes	8 minutes	9 minutes

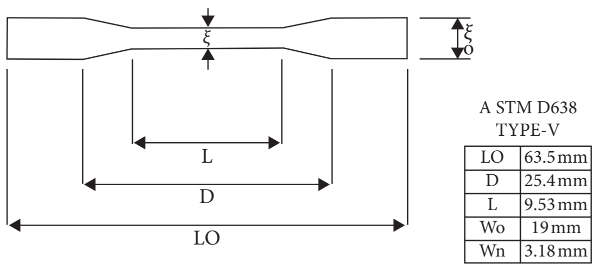

Figure 1: Geometrical parameters of tensile specimens.

Figure 2: Printed tensile specimens.

The tensile load-extension curve of specimen III is shown in Figure 8. It shows that specimen III can withstand weighs up to 650 N and shows the extension up to 13.850%

The tensile load-extension curve of specimen IV is shown in Figure 9. It shows that specimen IV can withstand weighs up to 550 N and shows the extension up to 10.974%.

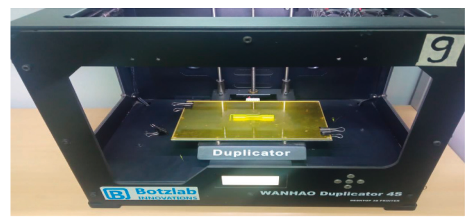

Figure 3: Printed tensile specimens.

The tensile load-extension curve of specimen V is shown in Figure 10. It shows that specimen V can withstand weighs up to 650 N and shows the extension up to 10.311%.

4. Results

This experimental investigation describes the best printing parameters of PLA filament. Table 1 provides the printing parameters and the time it took to produce the specimen. Specimen IV has the shortest time (8 minutes), and next, the specimen V can be produced in 9 minutes. Then, specimen III takes 10 minutes. Specimen I produced in 12 minutes and specimen II in 18 minutes.

Figure 11 shows the printing time of each specimen and specimen II except all the specimens as below the average time. The average time is calculated for conclude normal or least time of making anything, and this practice is also followed in manufacturing sectors. The average time is calculated by the following equation.

$$\text{Average time} = \frac{12 + 18 + 10 + 8 + 9}{5} = 11.4 = 12\,(\text{nearby obtained value}). \quad (1)$$

The load extrusion diagram also describes the maximum weight of the specimen. From this, specimen I withstands weighs 750 N, and the specimen II, III, and V withstand weighs 650 N and the specimen IV withstand 550 N. Figure 12 shows the tensile strength of each specimen.

According to specimen III, tensile strain percentage withstands high extrusion based on 13.850%. Also, specimen I withstands the extrusion to 13.573%, specimen IV to 10.974%, specimen II to 10.979%, and specimen V to 10.311%.

The main purpose of this research is to select an optimal slicing/printing parameter according to the short time and tensile properties. It basically considers less time specimens such as specimens IV, specimen V, specimen III, and specimen I.

Then, on the basis of the tensile test of these four specimens, the specimen I withstands 13.573% longer extension and withstands the weighs 750 N than specimen III, specimen IV, and specimen V.

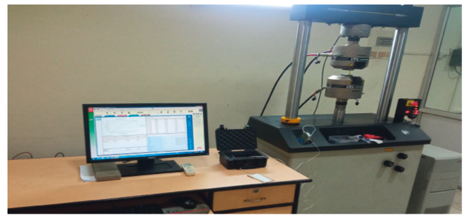

Figure 4: Tensile testing with Instron 5980 series.

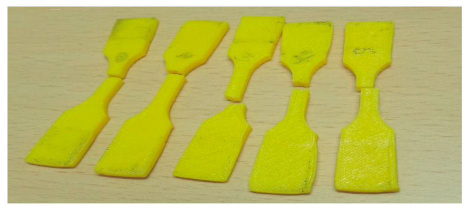

Figure 5: Failure tensile specimens (after tensile test).

Table 2: Braking point of tensile specimens.

Specimens	Breaking points of specimens
1	0.49618
2	0.24185
3	0.98919
4	0.76295
5	0.62404

Table 3: True stain of tensile specimens.

Specimens	True strain at maximum load (mm/mm)
1	0.10823
2	0.10314
3	0.10327
4	0.08958
5	0.09060

Table 4: True stain of tensile specimens.

Specimens	Tensile strain brake percentage
1	13.573
2	10.909
3	13.850
4	10.974
5	10.311

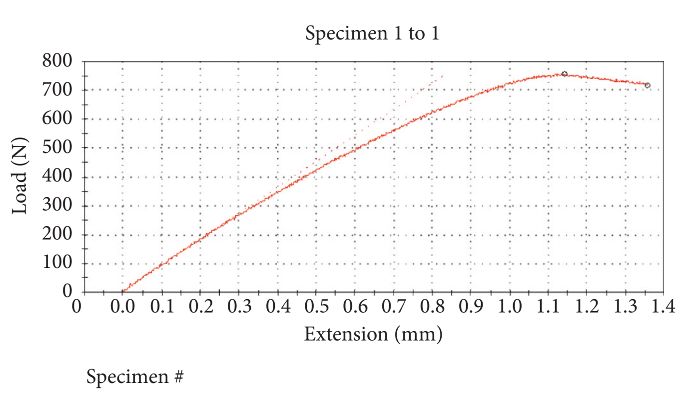

Figure 6: Tensile load-extension curve for specimen I.

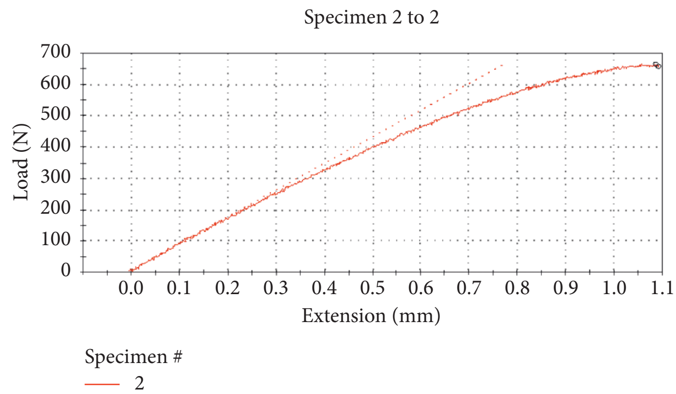

FIGURE 7: Tensile load-extension curve for specimen II.

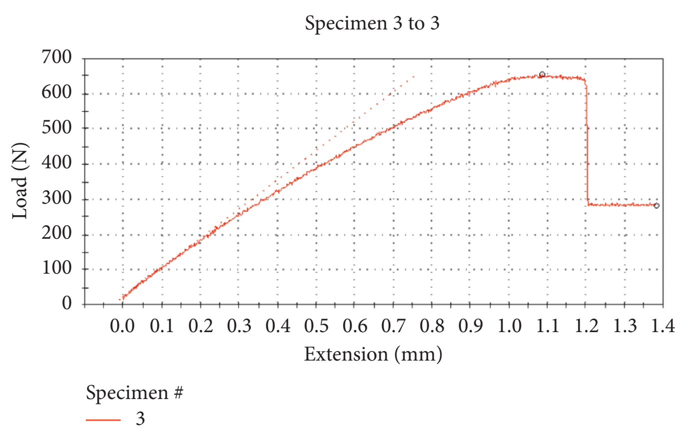

FIGURE 8: Tensile load-extension curve for specimen III.

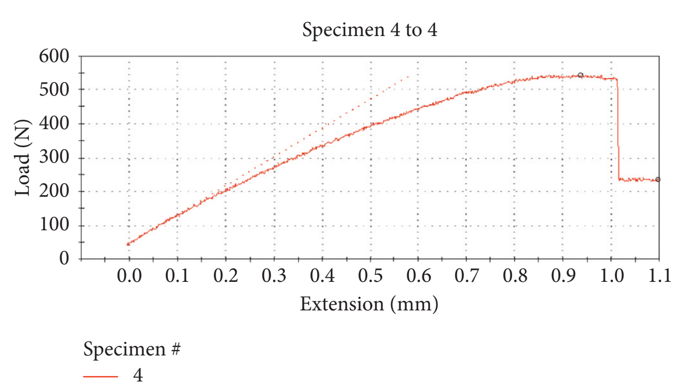

FIGURE 9: Tensile load-extension curve for specimen IV.

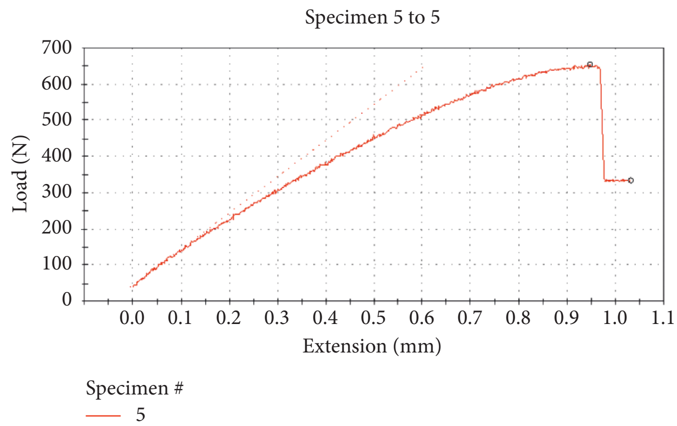

FIGURE 10: Tensile load-extension curve for specimen V.

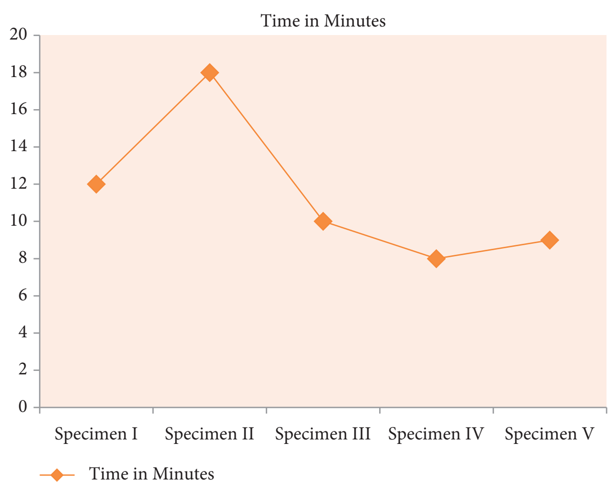

FIGURE 11: Printing time of each specimen.

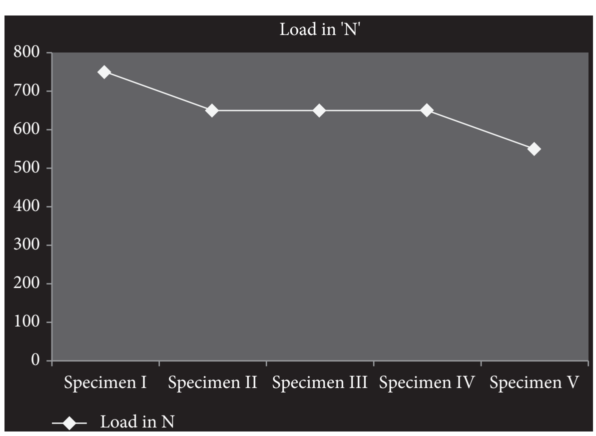

FIGURE 12: Tensile strength of each specimen.

Therefore, the printing parameters of specimen I are selected as the best one for the PLA filament. Thus, the extruder temperature is 200°C, the bed temperature is 50°C the layer height is 0.18 mm, the printing speed is 60 mm/s, and the travel speed is 80 mm/s. The most important printing parameter is infill pattern hexagonal and infill density 15%, and the shell count is chosen to be 2.

5. Conclusion

Nowadays, manufacturers are trying to produce more finished products in less time. There are many tactics used to do this. This research study aims to determine the best printing parameter for PLA filament based on time and tensile test. For this purpose, 5 ASTM D638 tensile specimens were manufactured with PLA filament with the help of the modern 3D printer, and the tensile test was performed on it. On basis of time, specimen IV, specimen V, specimen III, and specimen I are less than specimen II.

Only the production time of the specimen was taken into account in this research study. This is because the time to change is often determined when slicing the model produced by the slicing software. Thus, the time available after slicing the model by the slicing software is sometimes subject to change.

Then, based on the tensile test, compared to specimen IV, specimen III, and specimen V, specimen I withstands more weight and moderate extension. So, the printing parameter of specimen I is said to be the best printing parameter at the end of this research.

The continuation of this research is to produce homogeneous specimens that are identical to the printing parameters of future selected specimens and to analyze microstructures based on temperature.

Data Availability

The data used to support the findings of this study are available from the corresponding author upon request.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

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