Analysis of Printing Pattern and Infiltration Percent over the Tensile Properties of PLA Printed Parts by a Fuse Deposition Modelling Printer

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Abstract. Fuse Deposition Modelling (FDM) 3D printing is nowadays becoming more standard equipment in various fields of study as it can offer both low operating expenses and small investment cost; however, it has been accepted that the printed parts form this kind of printers is not too strong compare with the other Manufacturing technique. This study aims to analyze the effects of both Printing patterns and Infiltration percent on the tensile properties of the specimens obtained by an FDM printer. The specimens have been fabricated with three difference directions that are Horizontal (H), Crosswise (C), and Vertical (V) and within these groups, they are also vary the Infiltration percent at 20% 60% and 100%. After that they had been tested under a Universal tensile testing machine and then these obtained data had been analysed by an Analysis of Variance with 23 level. The result shows that both of Printing Patterns and Infiltration percent can be effect on Tensile strength of the specimens with significant different at 95% confidence level. Beginning with an increase of infiltration percent, it can lead to very strong effect on increasing of the tensile strength. In the case of print patterns, it can be concluded that the maximum stress is C, H and V, respectively. Because of the C pattern printing, tensile testing is a direction that is aligned with the printing of the layer. (For example, like pulling several ropes together)

1. Introduction
3D Printing, is one of additive manufacturing processes, being a prevalent production technology amongst modern-day designers as this technology has continuously progressed over the last ten years. Some of the advantages of 3D printing include the ability to mold complex work pieces that other technologies cannot do and it can offer a printed by only a single process [1]. As this technology is readily available for everyone, no skill workers can make a complex casting just one click. Even if there are many advantages of this technology, one of the main disadvantages of technologies is that it takes a long time to complete the printing parts. Fuse Deposition Modelling (FDM) is becoming famous as it offers both low investment cost and operating cost but its printed parts are weaker in comparison to more common plastic production processes, such as injection, blowing, extrusion, molding and CNC
The heart of an FDM is an extruder, composed of feeding gears, heater and extruder. (see Figure 1) First, the feeding gears are going to convey a plastic wire into a nozzle. After that heater, attached close to the end of extruder, has been energized. The plastic wire will be melt and then be extrude onto a platform layer by layer. The two sizes with the difference diameters of plastic wire, available on the market are 1.75 and 3.00 mm and the nozzle sizes may range from 0.20, 0.40, up to 1.00 mm. Plastic wires would be made from PLA and ABS, however, they could also Nylon, PETG, ASA, PC, ESD and etc.

![Diagram of FDM process](image)

**Figure 1** Fused Deposition model, FDM

Ashu Garg and Anirban Bhattacharya [4] investigated the failure behavior of the specimens resulting from tensile stress at the different layer thicknesses by the FDM 3D Printer. This research had been studied the layer thicknesses of the specimens to be 0.178 mm, 0.254 mm and 0.330 mm and they were performed a tensile strength by a Zwick/Roell Z050 tensile test machine. All of the specimens made form an ABS. The results showed that, the maximum elongation was approximately 4.6% on the specimens with layer thickness of 0.178 mm while the specimen of 0.330 mm offered the highest tensile strength at 34.5 MPa. John Ryan C. Dizon and Alejandro H. Espera, Jr. [5] studied the mechanical properties of polymers obtained from 3D printers from SLA, SLS [2], FDM and Polyjet. The types of polymers studied by the researcher are varied, such as ABS, Nylon, PPSF and PEI. The conditions of the specimen include the printing pattern and structural types of infill. The types of infill are 100 percent infill, honeycombs, drills and stripes. Tensile Testing by ASTM D638-14 for Plastics and ASTM D412-16 for Rubber and Thermoplastic Elastomers were tested. The results showed that the specimen with the honeycomb structure offered the highest tensile strength at break-point while crosswise has the highest tensile strength. Ravinder Sharma and Rupinder Singh [6] investigated the mechanical properties of PVC from FDM by parameter thickness, infill percentage and infill speed. The results showed that the highest yield stress was 3.47 MPa at the conditions of infill 100%; Layer thickness of 0.25 mm; and Deposition speed of 37 mm / min.

The work pieces, obtained from FDM, is well known that they are weakest compared with other traditional processes. Because 3D printing is not melting homogeneous, the printed layers may easier fracture. However, there are no any research has been purposed a mathematical modelling between a mechanical properties and both of percent of infill with difference printing pattern. This research focuses on the technique using a FDM 3D printing technique to investigate the mechanical properties of PLA filament materials. According to ASTM D638, the mechanical properties of specimens had been obtained by a universal tensile testing machine and then they were statistically analysed the by Analysis of Variance (Anova). The useful information from this study could allow any FDM users to understand the mechanical properties for designing any printed parts form this kind of 3D-printer.

2. Materials and Method
2.1 Plastic filament
The plastic filament used in this study is a Poly-Lactic acid; PLA, Brand AGRU. This filament is a thermoplastic made from natural materials with a low melting point, and is easy to degrade in the atmospheric condition. This PLA’s properties have been listed in a Table 1.

| Parameter             | Value | Unit |
|-----------------------|-------|------|
| Diameter              | 1.75  | mm   |
| Diameter Tolerance    | ±0.05 | mm   |
| Melt Temperature      | 190-230 | °C  |
| Density               | 1.24  | g/cm³ |
| Tensile Strength      | 60    | N/mm² |
| Color                 | Dark  |      |

The 3D printer (FDM) used in the experiment developed in house with 300 × 500 × 300 mm printed part. This printer has a 0.4 mm single nozzle and Repetier-Host V 2.0.1 software is a control software in this experiment.

2.2 Specimen fabrication
In this experiment, the standard specimens were printed as referring to the American Society for Testing and Materials D638 (See Figure 2 Left). For all of the specimens were printed as hexagonal honeycomb interior because it is very popular among designers. Moreover, this pattern has high stresses, good pressures and tensile strength compared to other types of infill pattern. [9] The print speed has set at 80 mm/s with 0.18 mm layer thickness and double shell lines. The infiltration percent were 20%, 60% and 100%. The printing patterns of the specimen follow these forms: Horizontal; H, Crosswise; C and Vertical; V (See Figure 3 Left and Right). In each of these forms, the specimens were fabricated on a different printer bases. Figure 3-right shows the front view of the specimen while it was printing. All of specimens were tested by a universal testing machine (INSTRON Model 5969) [8] with a 50 kN load cell. According to ASTM D638, the standard testing for mechanical properties was performed with pulling speed 5 mm/min at the 25 °C.
In this study, there were nine conditions that are H20%, H 60%, H 100%, C 20%, C 60%, C 100%, V 20%, V 60%, and V 100%. Each condition was repeated by five replications. The Yield stress (MPa), percent elongation at the yield point (% Elongation at Yield), and elongation at break (% Elongation at Break) were their responses. In addition, printing time (Modeling Time) of each specimen might be recorded for further investigation.

3. Results and discussion

Table 2 shows the mechanical properties for the specimens. The maximum yield stress at 48.53 MPa printing condition at C100% and minimum yield stress at 13.88 MPa printing conditions of C20%. At the same infill percentage, crosswise pattern (C) would offer the highest yield stress because the direction of force is in the same direction of printing direction. The highest and lowest percentages of Elongation at Yield were 2.90% and 1.34% at the C 100% and V 20% respectively. The highest and lowest recordings of Young's Modulus were 2398.57 and 1122.86 at the C 100% and H 20% respectively. Figure 4 shows the relationship between strain and stress; it can be seen that most fracture patterns are of a brittle nature. This type of fracture, when passed through a yield point, will have little or no stretching. However, the condition of the horizontal (H) printing pattern is the ductile fracture pattern. This fracture is very flexible or Elongation when pulled. The horizontal (H) printing patterns are shown in Figure 2 Right. Because of this pattern, the surface pattern is an alternate type of print path with an angle of reference (x) of 45°.
Table 2. Observed values of mechanical testing.

| Exp. N | Printing Patterns | Infill (%) | Printing time (Minute) | Yield stress (MPa) | Elongation at Yield (%) | Young's Modulus (MPa) |
|--------|-------------------|------------|------------------------|--------------------|-------------------------|-----------------------|
| 1      | H                 | 20         | 21                     | 45.89              | 3.47                    | 2324.29               |
| 2      | H                 | 60         | 37                     | 20.63              | 2.52                    | 1122.86               |
| 3      | H                 | 100        | 39                     | 24.06              | 2.58                    | 1368.57               |
| 4      | C                 | 20         | 45 (*Support)          | 41.66              | 2.78                    | 2171.43               |
| 5      | C                 | 60         | 59 (*Support)          | 27.77              | 2.59                    | 1580.00               |
| 6      | C                 | 100        | 61 (*Support)          | 34.11              | 2.58                    | 1981.43               |
| 7      | V                 | 20         | 31                     | 48.53              | 2.90                    | 2398.57               |
| 8      | V                 | 60         | 42                     | 13.87              | 1.34                    | 1441.43               |
| 9      | V                 | 100        | 44                     | 19.49              | 1.52                    | 1852.86               |

* Filament is PLA Filament Cross-section circle area and Diameter 1.75 mm. (Pulling speed is 5 m/min)  
* Support structure is used to support steep overhangs and Float of model. (Show in Fig 1)

The print time varies depending on the conditions as shown in Table 2. A low percentage of infill will take less time while the higher can lead to increase print time because the printer head needs longer time to travel with the higher density. The Crosswise (C) pattern took a longer printing time because it was necessary to print support parts, help in fabrication of the work pieces as same as a scuffle. And the less time is horizontal (H) pattern because it was no need to print any support.

**ASTM D638**

![Figure 4 Relationship of Stress and Strain](image)

Each printing pattern offered the different types of fracture. As shown in Figure 5, it was observed that fragment of the vertical (V) was perpendicular with the direction of force as same as the fragment happen on the non-elastic materials or brittle material. This can offer the less mechanical properties base on relatively low interfacial strength; therefore, it should avoid for loading a printed part in this
direction. Facture pattern of Crosswise (C) and Horizontal (H) can lead to the same facture as happening in any elastic material. The most effective tensile stress was Crosswise (C), resulting in the fracture occurred unevenly because these specimens have the same load direction for each single filament.

![Figure 5](image_url)

**Figure 5** Left: Specimen of horizontal print; H at Infill% of a) 20% b) 60% and c) 100%
Right: Specimen of Infill 100% conditions after tensile test

### 3.1 Yield Stress

Table 3 shown an Analysis of Variance on Yield Stress (MPa). It can see that all of these factors including their relations are statically significant on Yield Stress (MPa). It can see that figure 6 shows the effect of both printing patterns at the differences of infill over Yield Stress. All of the samples offers lower Yield Stress than single Filament test as these can be evidence that all of the filaments do not perfectly melt. This can result in low Yield Stress compared to conventional melting processes.

**Table 3** Analysis of Variance for Yield Stress (MPa)

| Factor            | DF | Adj SS  | Adj MS  | F-Value | P-Value |
|-------------------|----|---------|---------|---------|---------|
| Patterns          | 2  | 3268.17 | 1634.08 | 511.28  | 0.00    |
| % Infill          | 2  | 3345.69 | 1672.85 | 523.41  | 0.00    |
| Patterns * % Infill| 4  | 394.64  | 98.66   | 30.87   | 2.2 × 10^{-13} |
| Error             | 54 | 172.59  | 3.20    |         |         |
| Total             | 62 | 7181.09 |         |         |         |

The highest Yield Stress at the same of infill was C, H and V, and the highest stress values at the same printing pattern were 100%, 60% and 20%, respectively. At 100 percent of infill, it offered a maximum Yield Stress but its average was lower than Yield Stress of single fiber.
Figure 6 Data Mean for Yield Stress (MPa)

3.2 Young Modulus; E

Table 4 shows an Analysis of Variance on Young Modulus; E (MPa). Both factors had a significant effect on Young Modulus; E (MPa). Figure 7 shows the Means Young Modulus of each condition. The maximum Young Modulus was C, V and H, respectively, these were similar affect in a composite material at the low Share Modulus. The Maximum Young Modulus values are unsurprisingly 100%, 60% and 20%, respectively.

Table 4 Analysis of Variance for Young Modulus; E (MPa)

| Factor       | DF  | Adj SS  | Adj MS  | F-Value | P-Value |
|--------------|-----|---------|---------|---------|---------|
| Patterns     | 2   | 1963022.22 | 981511.11 | 103.62  | 0.00    |
| % Infill     | 2   | 7020422.22 | 3510211.11 | 370.57  | 0.00    |
| Patterns * % Infill | 4   | 776702.59   | 194175.40  | 20.50   | 2.6 × 10^{-10} |
| Error        | 54  | 511514.29  | 9472.49   |         |         |
| Total        | 62  | 10271660.32 |         |         |         |
Figure 7 Data Mean for Young Modulus; E (MPa)

Figure 8 shows the effect of Yield Stress over percent of infiltration at the different printing patterns. It can see that all of test results can be model base on logarithmical model. Surprisingly, the maximum of Yield stress of Crosswise (C) was above the average of single filament test by 1 percent. However, this is not a statically significant at 95 percent of confidence level. Based on these results, it can lead to a drop of Yield stress by 20 percent of their maximum on both of Crosswise (C) and Horizontal (H) specimens and 10 percent for vertical (V) specimen.

Figure 8 Interaction Plot for Yield Stress (MPa)
4. Conclusions
The results from this experiment show the mechanical properties of PLA specimens after performing a tensile testing. The experiments were clearly showed that at the C100 printing conditions, the maximum Yield stress is at 48.53 MPa and the V20 printing condition had the lowest Yield stress at 13.87 MPa. At the C100 printing conditions, the maximum Young's Modulus value was recorded at 2398.57 MPa and the H20 printing condition had the lowest Young's Modulus value at 1123.86 MPa. From this, it can be concluded that the type of printing pattern is one of the most parameter in FDM 3d printing, the highest yield stress would be happening in Crosswise (C), Horizontal (H) and Vertical (V), respectively. In addition, it could be separated the print pattern into two groups that are Crosswise (C) with Horizontal (H) and Vertical (V). In case of Crosswise (C) with Horizontal (H) at infill between 20% and 100% may offer increasing in Yield strength by 39 percent while Vertical (V) offers less yield strength as this pattern have a fracture like brittle material. The Infiltration percentages, that produced the highest yield stress is 100%, 60%, and 20%, respectively.

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