Effect of infill pattern on mechanical properties of 3D printed PLA and cPLA

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Abstract. PLA are the most sustainable alternatives and can fit in a wide-range of applications of electronics, nonwoven fabrics and food packaging. With these PLA’s adaptability and suitability in many techniques of production such as injection moulding, extrusion, and blow moulding, PLA has become high interest in the production process. Besides, PLA as a thermoplastic polyester that mostly obtained from renewable materials [1]. Infill patterns can affect the mechanical properties of 3D printed PLA and cPLA. PLA with zig zag infill pattern has higher tensile strength of 23.409 MPa compared to PLA with grid and concentric infill pattern. Meanwhile, cPLA with grid infill pattern has higher tensile strength of 30.5638 MPa compared to cPLA with concentric and zig zag infill pattern. By using the suitable infill pattern parameter, the 3D printed PLA and cPLA can have good mechanical properties and can be applied in packaging, pharmaceuticals, textiles, automotive, biomedical and tissue engineering. It has been widely investigated for biomedical applications due to its biodegradability and biocompatibility.

1 Introduction

3D printers can be used to fabricate more complex designed objects, allow flexible large design and also improve the performance of the fabricated objects [5]. In FDM, the thermoplastics polymer filament heated above its glass transition temperature, Tg and extruded through a movable nozzle in the x-y plane to form a 3D structure [5].

PLA as a thermoplastic polyester is versatile and mostly obtained from materials that are annually renewable. The materials are normally fermented into agriculturally originated lactic acid. PLA possesses high strength, modulus of elasticity, stiffness, brittleness and is a completely biodegradable matrix [1]. Additionally, PLA has a low glass transition temperature (Tg = 60–65 °C) and melting temperature (Tm = 173–178 °C), making it very useful for 3D printing since it does not require a heated surface for the objects being printed. While there is a good amount of evidence that PLA materials supplied by various vendors produces final prints which vary considerably in terms of mechanical properties, interlayer adhesion, and appearance, very few published studies exist which discuss the

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relationship between source material chemistry and the properties of the structures created by desktop FDM printers, despite their use in research applications [6].

Although PLA is an eco-friendly bioplastic with excellent biocompatibility, processibility, and less energy dependence, it still has drawbacks as well, which limit PLA use in certain applications [7]. The main drawback for PLA is they are very brittle material with less than 10% elongation at break. Although its tensile strength and elastic modulus are comparable to polyethyleneteraphthalate (PET), the poor toughness limits its use in the applications that need plastic deformation at higher stress levels. Therefore, incorporation of plasticizers and impact modifiers into the composites of PLA for the improvement of the toughening and impact properties of the material becomes necessary.

The different parameter of 3D printing will affect the mechanical properties of produced objects. Thus, the mechanical properties of different 3D printing parameter of the 3D printed PLA and cPLA are the focus of this study.

2 Methodology

2.1 Preparation of PLA and cPLA by RepRap 3D printer

The design of PLA and cPLA structure are drawn according to ASTM D638. Appropriate composition of raw materials, poly lactic acids (PLA) and cPLA are fed in the RepRap 3D printer to produce PLA and cPLA products. The printing parameters are shown in Table 2.1.1.

| Printing Parameters | Values     |
|---------------------|------------|
| Printing temperature| 200 °C     |
| Layer height        | 0.2 mm     |
| Printing speed      | 14 mm/s    |
| Layer thickness     | 0.2 mm     |
| Wall thickness      | 0.8 mm     |

The infill pattern of the printed PLA and cPLA are varied during the fabrication of the PLA and cPLA products. The infill density is set at 80% while the infill pattern is varied with zigzag, grid and concentric pattern. At the end of preparation of products, the different density with different infill patterns of the PLA and cPLA are produced.

2.2 Mechanical properties lab testing for different parameters of PLA and cPLA

There are several mechanical properties tests that used to identify the mechanical properties of PLA and cPLA. The mechanical properties tests are:
2.2.1 Tensile test

The tensile test is used to identify the stress, strain and Young’s modulus of the samples under a specific tension. The test is conducted according to ASTM D638 and the Universal Testing Machine with its model Instron 5569 is used. The crosshead speed or strain rate that used is 5mm/mins with surrounding temperature at around 25±2oC. Before the tensile test, the dimension of the sample is measured by the Vernier calliper for the use of calculate the stress, strain and the Young’s modulus of the samples. To make sure the accuracy of the results, 5 specimens for each different parameter were used to obtain the average tensile properties.

2.2.2 Microhardness Vickers Test

To determine the microhardness of the samples, ASTM E384 will be the standard for the whole microhardness Vickers testing. A square-based diamond indenter with 136o between the face of the samples is used or equipped on the microhardness Vickers machine. During the testing, the indenter with a load of 9.807N is used and a dwelling time around 10 seconds is apply to make sure the accurate microhardness of the samples. Besides that, each sample is tested by the indenter at 5 different points on the surface of the sample to obtain average values.

3 Results and Discussion

3.1 Tensile test results for different infill pattern of PLA

The value of the stress and strain of PLA with three different infill pattern had been used to compare their tensile properties. Figure 3.1 show the stress-strain graph for three different infill patterns of PLA. Figure 3.2 and 3.3 show the bar chart for the mean of tensile strength and elongation at break of three infill pattern of PLA.

Fig. 3.1. Stress-strain graph for three different infill patterns of PLA.
Based on the result, PLA with zigzag infill pattern have the highest tensile strength if compared with PLA with concentric and grid infill pattern. Zigzag infill pattern printing
continuously in one diagonal direction and cause stronger inter raster bonding with tiny raster gap and allow more consistent adhesion between the layers [2]. So, the consistent adhesion between the layers and the inter raster bonding cause the zigzag infill pattern experience highest tensile strength at 23.409 MPa but also cause the zigzag infill pattern to experience the lowest elongation at break, 1.3%, compare to concentric and grid infill pattern of specimens.

The grid infill pattern specimen (Figure 3.5) has lines in both diagonal directions on each layer. This causes the 3D printed specimens to have weak inter raster bonding with large raster gap So, the grid infill pattern specimen experiences the lowest tensile strength at 15.620 MPa compared with other two types of infill pattern but due to weak inter raster bonding and low adhesion between the layers, the grid infill pattern specimen to experience the highest elongation at break of 1.8%.

For concentric infill pattern specimens, they have the moderate tensile strength, 21.442 MPa, and elongation at break, 1.7%. This is because the infill pattern prints from the outside towards the centre causing the 3D printed specimens to have moderate inter raster bonding with moderate raster gap.

As conclusion, the infill pattern of the 3D printing will affect the raster gap, inter raster bonding of the 3D printed specimens and the consistency of the extruder motion that will affect the adhesion between the layers during 3D printing. Hence, infill pattern is the important parameter for 3D printing.

3.2 Microhardness Vickers Test Results for PLA

![Mean hardness, HV](image)

**Fig. 3.7.** Hardness values.

Based on Figure 3.7, grid infill pattern 3D printed PLA has the highest hardness values followed by zigzag infilled pattern and concentric infill pattern. This is due to inter raster bonding in the grid infill pattern are more resistant to deformation [3]. Besides that, the concentric infill pattern has the lowest hardness value, this is due to the inter raster bonding...
in concentric infill pattern are less resistance to deformation. While the zigzag infill pattern 3D printed PLA has the moderate resistance to deformation.

### 3.3 Effect of different infill pattern on stress and strain properties of CPLA

Figure 4.1 shows the effect of the three infill patterns, concentric, grid and zigzag on the stress and strain properties of CPLA. Figure 4.2 and Figure 4.3 shows the effect of the three infill patterns, concentric, grid and zigzag on the mean tensile strength (MPa) and mean break elongation (%) of CPLA.

![Stress-Strain Graph](image)

**Fig. 4.1.** Effect of different infill pattern on stress and strain properties of CPLA.

![Mean Tensile Strength](image)

**Fig. 4.2.** Effect of different infill pattern on mean tensile strength (MPa) of CPLA.
Based on Figure 4.1, CPLA with grid infill pattern has achieved the highest stress value of 30.5638 MPa at a strain percentage of 1.871%. A grid shaped infill has lines in both diagonal directions. Since the lines forms in both directions, therefore it increases the adhesion between print raster reducing the formation of pores or air gap in the print. When the print or specimen has lower pores, it has higher resistance towards external force which eventually resulting in high ultimate tensile strength.

According to Figure 4.2, the specimen which is printed with grid infill pattern has a mean tensile strength of 28.328 MPa. Specimen of grid infill pattern has a higher mean tensile strength. This shows that the specimen with grid infill pattern has stronger tensile properties than the specimen with concentric and zigzag infill pattern. This is due to formation of closely packed raster which increases the adhesion between print layers. Therefore, the bonding formed between the raster becomes stronger and higher force is required to break these bonds resulting in high mean tensile strength.

Figure 4.3 shows that grid infill pattern and zigzag infill pattern has higher break elongation value of 2.42%. Concentric infill pattern has lower break elongation due to print layers which are too compact. This will restrict polymeric chain mobility in the specimen which causes crack propagation [8]. Meanwhile, the grid infill pattern is not too compact which allows for the mobility of polymeric chain.

3.4 Effect of different infill pattern on micro hardness (HV) of CPLA

Figure 4.4 shows the mean micro hardness of specimens with concentric infill pattern is higher than specimens with grid and zigzag infill pattern. Concentric infill pattern is much more compact compared to grid and zigzag pattern since the infill prints from the outside towards the center of the model, making the infill lines to be too close to each other. This would increase the consistency of print layers [9]. Thus, higher load indentation is needed for surface penetration, therefore increases the micro hardness of the specimen.
Fig. 4.4. Effect of different infill pattern on Mean micro hardness (HV) of CPLA with 80% infill density.

4 Conclusion

Based on the results, the infill pattern can affect the mechanical properties of 3D printed PLA and cPLA. PLA with zig zag infill pattern has the highest tensile strength among the three different infill patterns. Meanwhile, PLA with grid pattern has the highest hardness value compared to concentric and zig zag infill pattern. cPLA with grid pattern has the highest tensile strength among the three different infill patterns and cPLA with concentric pattern has the highest hardness value compared to grid and zig zag pattern. As for application, 3D printed PLA and cPLA can be applied in packaging, pharmaceuticals, textiles, automotive, biomedical and tissue engineering.

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