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Mechanical Properties of PCL/PLA Composite Sample Produced from 3D Printer and Injection Molding

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Abstract: Currently there are a lot of studies have been carried out regarding on composite material that can be used for 3D printing. The main reasons is to minimize the cost related to the molds that need to be prepared for injection molding. The question is how far will be the differences in term of mechanical properties for part produce from this 2 techniques. This study are done to investigate the mechanical properties of PCL/PLA composite sample prepared from Fused Deposition Modelling (FDM) 3D printer. The mechanical properties that were evaluated are tensile, flexural and impact. The result were later compared with samples produced from injection molding. The dimensional accuracy result shows a very minimal percentage error on samples produced using 3D printer for mechanical testing. The parameter of 3D printer used to produce sample was 136°C print temperature, 0.12mm deposition of height, 20mm/s print speed and 22mm/s travel speed. The mechanical properties of PCL/PLA prepared by injection molding generally came superior in all the conducted test if compared to those of 3D printer. Tensile strength result showed that injection molding value was higher than 3D printer which is 10MPa and 6.513MPa respectively. The results of tensile strength and modulus of elasticity showed injection molding ware better than 3D printing with value of 118.26MPa and 61.223MPa respectively. For flexural strength, the highest values were injection molding which is 7.59MPa while 3D printing is 4.96Mpa. While the highest for flexural modulus are 35.33GPa for injection molding and 30.911GPa for 3D printing. Impact strength for PCL/PLA sample was 1.33 Joule for injection molding and 0.543 Joule for 3D printer method.

Keywords: PCL, PLA, Mechanical Properties, FDM 3D Printing, Injection Molding

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1. Introduction

Over the last few years, the evolution of the manufacturing an object using 3D printing technology has been tremendous. 3D printing, also referred to as additive manufacturing (AM), producing an object by depositing material layer-by-layer, as dissimilar to conventional subtractive manufacturing processes such as milling, casting, forging or welding.

According to Dimitrov et al. (2006) [1], additive manufacturing allows the complex shape product to be fabricate automatically and at once reduce the manufacturing cost, compared to the traditional subtractive manufacturing techniques. Li et al. (2016) [2] mentioned that the fused deposition modelling (FDM) is a best choice for industrial production because of the low costs of printing device and thermoplastic material. There are various parts and devices that have been printed by the FDM.

As stated by Wang et al. (2017) [3], one of the great advantages of 3D printing technology is that it can accurately control the manufacturing of the complicated structure, and the waste from fabricating processes of it is much less. 3D printing enables ideas to be develop faster than ever. Being able to produce or to 3D print a concept the same day it was designed will shrink a development process from what might have been month to a matter of days.

Before now, numerous materials are handy for FDM 3D printing polymers for example like polyamide, polylactic acid (PLA), polyvinyl alcohol (PVA) and acrylonitrile butadiene styrene (ABS) to ceramic, gypsum, metal such as stainless steel, gold and silver, titanium and also concrete. Among these materials, PLA has taken tremendous growth within the 3D printing field due to the fact of its biodegradability [4][5]. PLA is derived out of renewable resources yet have proper mechanical properties, which makes it promising an ecologically friendly material for multiple application.

As indicated by Wang in his research, PLA is an example of biodegradable polymer which currently used as has been elected by the FDA for several biomedical application [3]. However, 3D printing material like PLA shows few downside behaviour factors such as lack of flexibility and elasticity, expense, poor toughness, higher hardness and simply to bending deformation compared with polyvinyl chloride (PVC) and polypropylene (PP) plastics [6].

2. Methodology

The methodology for this research study are explained in details and the step of general research was shown in the Fig. 2.1 of flowchart. The experiment started with preparing PCL/PLA resin. Next the resin is crush and continued with sample preparation using injection molding and FDM 3D printing technique. Later the mechanical properties of both different techniques were compared and investigated. The mechanical properties that been focused on are the tensile, flexural and impact.

2.1 Material

Material that have been used for this study are the combination of Polycaprolactone (PCL) and Polylactic Acid (PLA) polymer. Both is used in the form of FDM filament with diameter of 1.75mm. We used the combination of 30 wt% of PLA and 70% wt% of PCL.

2.2 Preparation of Sample

The sample of tensile, flexural and impact testing were prepared using Fused Deposition Modeling (FDM) 3D printing method. First the mix PCL/PLA composites were extruded using single screw extruder, cooled using water bath and pulled with roller puller to produce constant size of filament. The objective of this process is to produce the material filament in range of 1.75 mm to 1.8 mm diameter before it can used to print samples using FlashForge creator pro 2016 machine.

2.3 Mechanical Testing

The tensile tests were carried out by using the ISO 527-5A. Three specimens were printed and tested. The tests were conducted using Crosshead speeds of 5 mm/min by using Instron 5567 universal testing machine under ambient condition.

Using Instron 5567 universal testing machine, the flexural test was done according to ASTM D790. With a support span of 64mm and the crosshead speed of 5 mm/min was used. The flexural strength modulus values can be calculated from the equations below. Flexural strength can be defined as stress in a material just before it yields in a flexural test.

Charpy impact test was done according to ASRM D6110 is a standardized high strain-rate to determine the amount of energy absorbed by each composition of PCL and PLA during fracture. These tests were applied of this study to evaluate the impact of toughness for each composite.

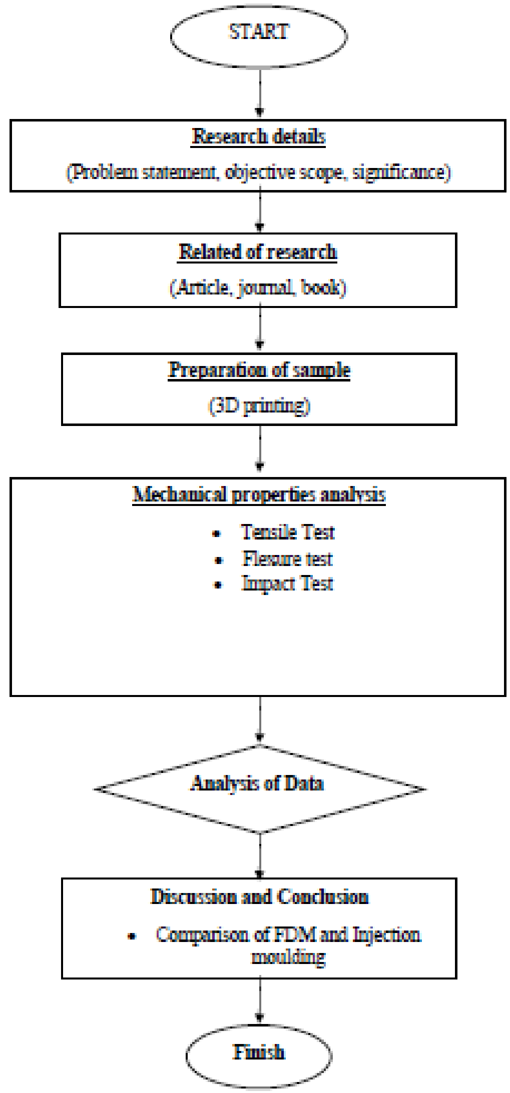

Fig 2.1 – Flowchart of research

3. Result and Discussion

In this study, several testings was conducted such as tensile, flexural and impact test in order to examine the mechanical properties of the sample printed by FDM 3D printing using material of PCL/PLA blend which is 70% of PCL and 30% of PLA. After that, the results of the testing were compared with result of mechanical properties of the sample produced by injection molding method. The chosen values of the most important software parameters are tabulated in Table 3.1.

Table 3.1 - FlashPrint software chosen in this study

Parameter Name	Used Value
Print Temperature	136ºC
Deposition of Height	0.12 mm
Print Speed	20 mm/s
Travel Speed	22 m/s

3.1 Tensile Strength and Modulus of Elasticity of PCL/PLA composites

Fig. 4.1a shows the tensile strength of PCL/PLA composites produced by using FDM 3D printing method with 3 samples. The highest value of tensile strength was recorded at 7.9 MPa which is sample 3. Meanwhile the lowest value of tensile strength is 5.29 MPa which is sample 2. For sample 1, the value recorded for tensile strength is 6.35. Hence, we took the average value of tensile strength of three specimen is 6.513 MPa.

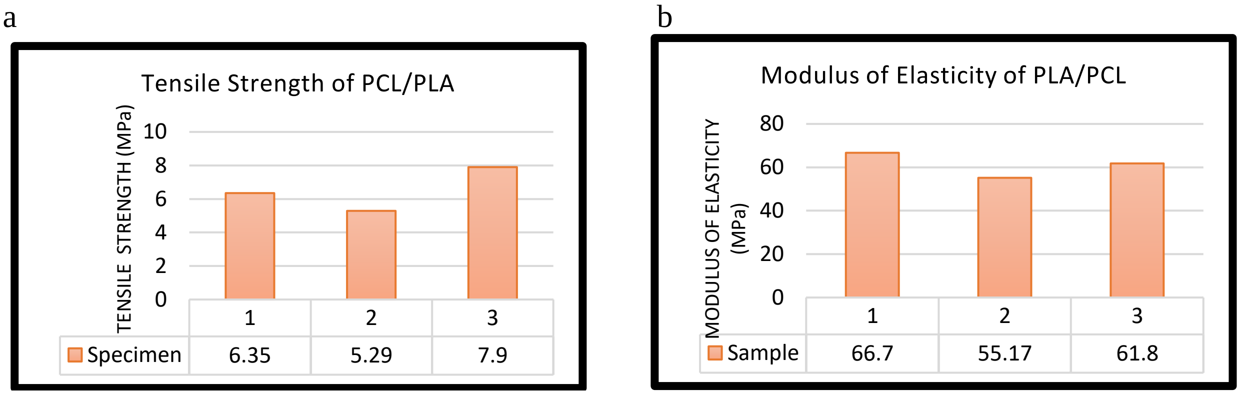

Fig.4.1 – (a) Tensile strength and (b) Modulus of elasticty of PCL/PLA composites

Fig. 4.1b reveals the modulus of elasticity of PLA/PCL samples produced using FDM 3D printing. As it is shown in the graph, sample 1 shows the highest value of modulus of elasticty which is 66.7 MPa and followed with sample 3 which is 61.8 Mpa. While for sample 2, it shows the lowest value of modulus of elasticity which is 55.17 Mpa. Meanwhile, the average value of modulus of elasticy of three sample which is 61.23 MPa. The differences of the tensile strength and modulus of elasticity result for each samples are due to the samples produced are not 100% accurate. This is because while printing the samples there are uncompleted layer occurs. This problem is common for new type of composites especially for PCL/PLA as it is not commerciallize material [11].

3.2 Comparison of Tensile Strength and Modulus of Elasticity between Sample Produced by Injection Molding and FDM 3D Printing.

Fig. 4.2a illustrates the tensile strength of sample produced using FDM 3D printing and injection molding. Overall there was a quite large different between the tensile strength of sample produced using injection molding and 3D printing. It shows that the tensile strength of injection molding and 3D printing are 10.0 MPa and 6.513 MPa respectively. The difference of tensile strength between sample fabricated by injection molding and 3D printing is 34.87%.

Fig. 4.2b reveals the difference of modulus of elasticity between 3D printing and injection molding. The modulus of elasticity of sample fabricated using injection molding is relatively higher than the sample produced by 3D printing which is 118.26 MPa and 61.223 MPa respectively. It proves that the injection molding method is good in term of modulus of elasticity compared to sample produced using 3D printing. The difference of modulus of elasticity between sample produced using injection molding and 3D printing method is 48.23%.

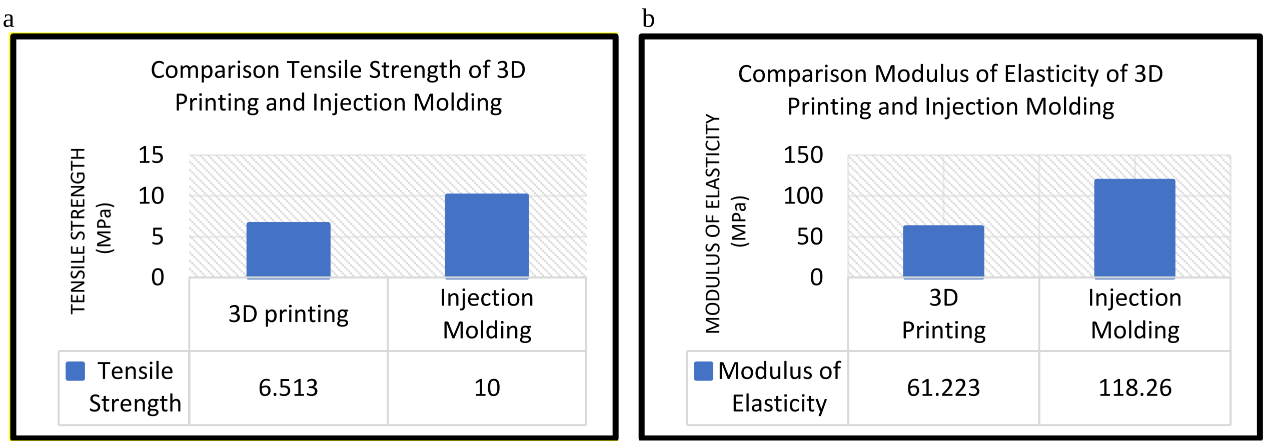

Fig. 4.2 – (a) Tensile strength and (b) Modulus of Elasticity of sample produced using injection molding and 3D printing

The main reason for these differences could be because of the very different orientation of PLA/PCL reinforcements, being almost all parallel to the longitudinal axis of injection-molded specimens leading to highly effective load transfer mechanism for strength and stiffening mechanism for modulus. In the 3D-printed sample, ±45° oriented PCL/PLA reinforcements resulted in decreased level of strengthening and stiffening mechanism [6][9].

3.3 Flexural Strength and Flexural Modulus of PCL/PLA Composites

Figure 4.3a shows the flexural strength of sample fabricated by FDM 3D printing method. It can be seen that the highest flexural strength value are pointed at sample 2 which is 5.18 MPa. Meanwhile, the lowest flexural strength that have been tested in three sample produced by 3D printing is 4.8 MPa which is sample 1. As for sample 3, the flexural strength is 4.9 MPa. However, the average value of flexural strength of three sample shown a value of 4.96 MPa.

Figure 4.3b reveals the flexural modulus of PCL/PLA sample produced using FDM 3D printing. Sample 2 shows the highest value which is 56.9 GPa followed by sample 3 which is 53.685 GPa. For sample 1, it has the lowest value of flexural modulus compared to all three samples which is 47.85 GPa. Meanwhile for the average value of flexural modulus of all three samples is 52.811 GPa.

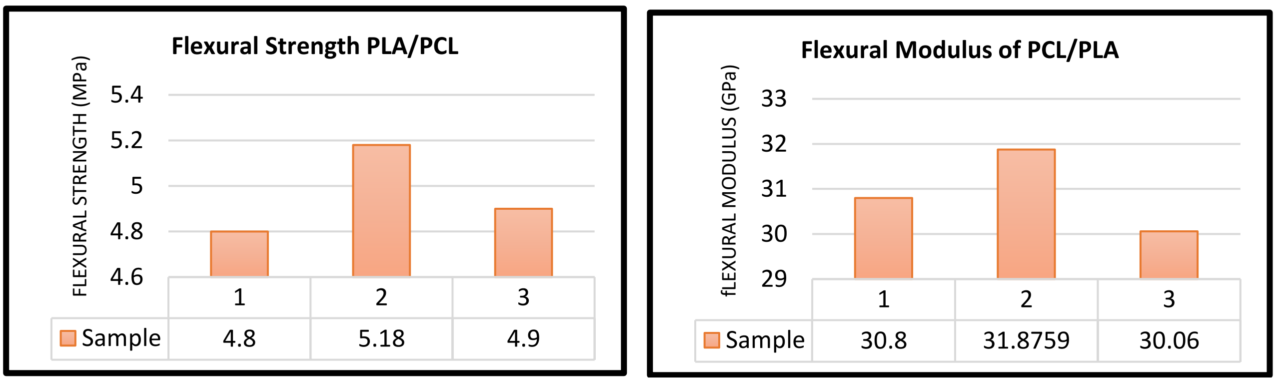

Fig. 4.3 – (a) Flexural Strength and (b) Flexural Modulus of PLA/PCL sample produced by 3D printing.

3.4 Comparison of Flexural Strength and Flexural Modulus between Sample Produced by Injection Molding and FDM 3D Printing.

Figure 4.4a below shows the comparison of flexural strength between samples fabricated using injection molding and FDM 3D printing. From the Figure 4.4a, it reveals that the highest flexural strength for both 3D printing and injection molding is pointed at injection molding with the flexural strength of 7.59 MPa. 3D printing had quite less flexural strength compared to injection molding which is 4.96 MPa. This might because of injection molding method produced a compact solid while FDM 3D printing principle is producing object layer by layer.

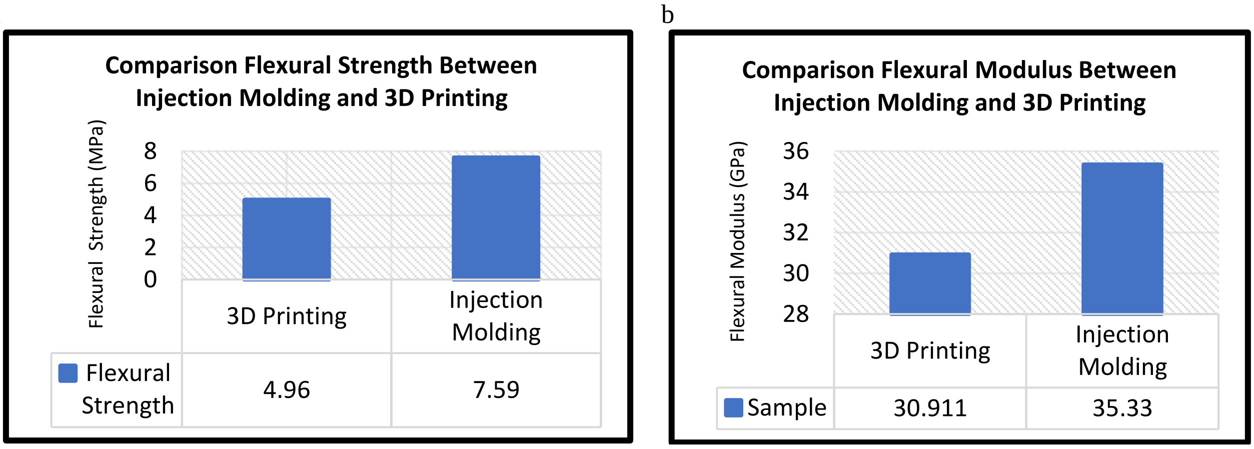

Fig. 4.4 – (a) Flexural strength and (b) Flexural modulus of sample produced using 3D printing and injection molding

Figure 4.4b reveals comparison of flexural modulus between samples produced using injection molding and 3D printing. It shows that injection molding has higher value compared to 3D printing in terms of flexural modulus which was 35.33 GPa while 3D printing was recorded at 30.911 GPa. The percentage difference of both method in term of flexural modulus is 12.5%.

The flexural strength and flexural modulus of PCL/PLA produced by injection molding mostly come better in flexural tests if compared to those of 3D printing. This is because of the nature on injection molding process which result in higher material compaction in addition to the enhancement of crystalline structure, thus improving mechanical strength [7].

3.5 Impact Strength of PCL/PLA Composite

Figure 4.5 shows the impact strength of PCL/PLA prepared by 3D printing. It can be noted that sample 3 shows the highest reading which is 0.59 Joule followed by sample 1 which is 0.54 Joule. While for sample 2, it shows the lowest reading among all sample which is 0.50 Joule. The average reading of impact strength of three samples is 0.543 Joule.

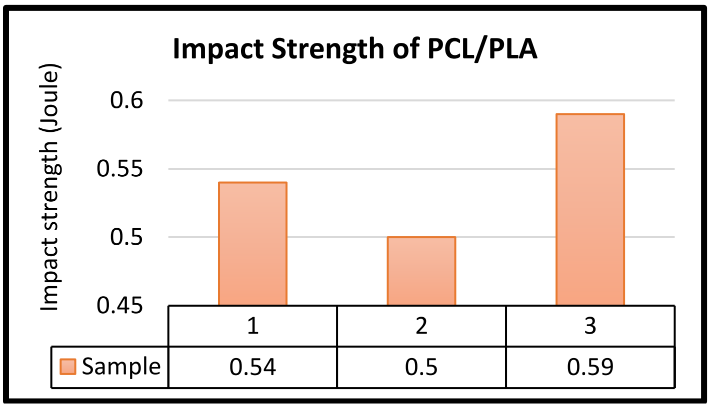

Fig. 4.5 - Impact strength of PCL/PLA sample prepared using 3D printing.

3.6 Comparison of Impact Strength and Flexural Modulus between Sample Produced by Injection Molding and FDM 3D Printing

Figure 4.6 shows the result of comparison of impact strength between sample prepared by 3D printing and injection molding. The result shows that the impact strength of sample prepared by injection molding which is 1.33 Joule, is higher than the impact strength of sample prepared using 3D printing which is 0.543 Joule. The percentage of the difference is about 59%.

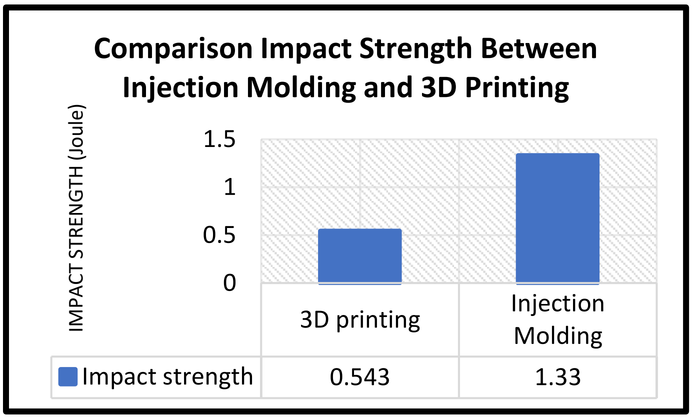

Fig. 4.6 - Comparison of impact strength of PCL/PLA between samples produced using injection molding and 3D printing method.

According to Dawoud et al. (2016) [8], the FDM technology causes thermal stress between the raster because of the deposition of a newly molten raster next to a partially solidified raster. These internal stresses cause the crack to easily propagate between the deposited filaments.

4 Conclusion

The mechanical properties of PCL/PLA sample prepared using injection molding shows higher results in all the conducted test compared to sample prepared by 3D printing. This is due to the injection molding process that results in higher compaction of materials which will improve the crystalline structure and at the same time improve the mechanical strength [10].

Tensile and flexural tests indicated that because of lower efficiency of ±45º oriented PCL/PLA reinforcements in the strengthening and stiffing mechanism, there were notable decrease in the strength and elastic modules values of sample that prepared by 3D printing compared to injection molding.

The impact strength of PCL/PLA sample prepared by injection molding is the highest compared to sample prepared by 3D printing. This is due to the deposition of newly molten raster next to partially solidified raster that causes thermal stresses between rasters which produced when using FDM technology. These internal stresses cause the crack to easily propagate between the deposited filaments.

The results indicate that there are quite difference of strength and stiffness between sample prepared by injection molding and 3D printing. So, it means that fabrication of implant of PCL/PLA fabricated by 3D printing is not suitable for implants that need a high strength but can be put with the implant which needs low strength and stiffness.

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