Characterization and Mechanical Analysis of PCL/PLA composites for FDM feedstock filament

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Abstract. In this research, characterization, and the mechanical properties of Polycaprolactone (PCL) and Polylactic Acid (PLA) composites with the objective of determining their suitability as biomaterials for an alternative composites material for Fused Deposition Modelling (FDM) was investigated. The percentage of PLA is varies from 10% to 50% by weight. The PCL/PLA composites were prepared by melting and mixing using Brabender Plastograph machine. The characterization of PCL/PLA composites was characterized using Fourier Transform Infrared (FTIR). Meanwhile, the mechanical properties were evaluated are the Tensile, Flexural and Impact. It demonstrate that by the addition of PLA it improve the mechanical properties of PCL and leads to a better processability of PCL/PLA composites. With the decrement of PLA content in PCL/PLA composites the Tensile Strength the Young’s Modulus and also the Impact Strength of the composites increased. The highest tensile strength was recorded at 10.00 Mpa and the Young’s Modulus was recorded at 118.26 Mpa. The highest Impact Strength was recorded at 1.33 J. However, the Flexural Strength and Flexural Modulus increased when the content of PLA decrease and it slightly drop when the content of PLA is at the 40%. The highest Flexural Strength and Flexural Modulus were recorded at 7.59 Mpa and 35.33 Mpa respectively. Overall it can be concluded that the PCL70PLA30 composites are the best formulation and it gives a better mechanical properties result.

1. Introduction

Fused Deposition Modelling (FDM) is an additive manufacturing technology generally used for prototyping, modeling and production request. FDM is used to dimensions an idea of models, for example, functional prototypes and end-use parts in standard, engineering rating, and high enactment thermoplastic. Therefore, FDM mechanism on an additive principle by a laying down material in layers and then a plastic filament wire or metal that are used is the wind down from a coil and supplies material to fabricate a model. It is the only 3D printing machinery that uses in several productions -grade of thermoplastic, so the parts are incomparable in mechanical, thermal and chemical strength [1]. In FDM, one of the most important parts is the filament. There are several types of filaments available in today’s market which depends on the part to produce and its functionality. There are many types of standard filaments such as Polylactic Acid (PLA), Acrylonitrile Butadiene Styrene (ABS), Polyamide (Nylon) and Polyethylene Terephthalate (PET) which is commonly used for producing prototypes. However, there are recent studies have been carried out to produce filament from composites either from Ceramic Matrix Composite (CMCs) or Metal Matrix Composite (MMCs). The
challenges developing composite filament is to produce this filament in a specific size and strength in order for the filament to be extruded through the printer successfully.

The request of a polymeric material medical partition is growing fast. The polymer has established application in such various bio-medical fields as tissue engineering, implantation of medical, miscellaneous as synthetic organs, prostheses, ophthalmology, dental medicine, bone repair and several other medical branches. Polymer founded delivery as a system assist to measure the slow passing of the drug into the torso [2]. PLA and its copolymer it’s have been used extensively in different fields such as tissue engineering, polymer engineering, drug delivery system and several medical implants of important paramount. As consumption rate in the year 2010, PLA was observed as the world second most important bio plastic [3].

Polycaprolactone (PCL) is semicrystalline polyester that is more stable in ambient conditions; it is significantly less expensive and is readily available in large quantities. Much researcher currently focused on the use of PCL biocomposites and co-polymers of PCL with both natural and synthetic polymers [4, 5]. In the emerging field of tissue engineering, biodegradable polymers are used for realizing polymer scaffolds to assist tissue and cell growth during formation of artificial organs [6]. There are report found that PLA and PCL form a partial miscible blend where it showed an increase of ultimate tensile strain of PLA when PCL was added to this blend system [7].

2. Methodology

2.1 Materials.
The biodegradable used in these studies was polycaprolactone, medical grade of BGH600C meanwhile polylactic acid (PLA) that used in this research is a medical grade of PTG600C. Both of the polymers are in pellet form and supplied by Shenzhen Bright China Industrial Co, China. Table 1 below shows the different composition of PCL and PLA blends.

| Designation | PCL (wt%) | PLA (wt%) |
|-------------|-----------|-----------|
| PCL30PLA70  | 30        | 70        |
| PCL40PLA60  | 40        | 60        |
| PCL50PLA50  | 50        | 50        |
| PCL60PLA40  | 60        | 40        |
| PCL70PLA30  | 70        | 30        |

2.2 Sample preparation.
The PCL and PLA which is in resin form are mix manually. These uniformly dry-mixed batches are melt-blended in Brabender Plastograph (Figure 1) machine where the temperatures were set at 160°C before it is crush into pellet form. All the compounded materials were then fed into injection section. The tensile, flexural and impact specimens were produced on an injection moulding machine with an injection temperature between 40 °C – 80 °C. Injection pressure was set to 140 MPa.
2.3 Sample Characterization
Fourier Transform Infrared Spectroscopy (FTIR) machine were used for samples characterizations of all the different composition PCL/PLA composites.

2.4 Mechanical Analysis

2.4.1 Tensile Test
By using the ASTM D638, the tensile tests were carried out. Five specimens were tested for each blend. Crosshead speeds of 5 mm/min by using an Instron 5567 universal testing machine under ambient condition the test was conducted.

2.4.2 Flexural Test
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. Flexural strength can be defined as stress in a material just before it yields in a flexure test. Meanwhile, flexural modulus is the tendency of material to bend.

2.4.3 Impact Test
Charpy impact test was done according to ASTM D6110 is a standardized high strain-rate to determine the amount of energy absorbed by each composition of PCL and PLA during fracture.

3. Result and Discussion

3.1 Fourier Transform Infrared (FTIR) of PCL/PLA Composite
FTIR spectrum of PCL and PLA formulation are shown in Figure 2. Characteristics of PCL and PLA features were found in agreement with spectrum reported in the literature [8]. Obviously the effect can be seen at 2600 to 3100 with more PCL loading increase and the decreasing of the PLA. Broad peak at 2918.96 cm\(^{-1}\) correspond to symmetric and asymmetric in group CH stretching vibration (CH\(_2\)). The second peak with the value of 1723.818 cm\(^{-1}\) was correspond to the C=O stretching vibration (Nonconjugated). The last peak was found in C-O-C vibration in Esters (Formates) with the value 1163.977 cm\(^{-1}\).
3.2 Mechanical Analysis

There were three types of test conducted in this research which are tensile, flexural and impact test.

3.2.1 Tensile Strength and Modulus of Elasticity of PCL/PLA Composite

The tensile strength of PCL/PLA composites is shown in Figure 3. The highest values of tensile strength were recorded at 10.00MPa for PCL70PLA30 formulation. Meanwhile the lowest value of tensile strength is 3.75MPa when the weightage of PCL is at 30%. The tensile strength of the composites increased moderately as the percentage of PCL increase from 40% to 70%. It can be seen that by higher content of PLA indirectly decreases the tensile strength of the PCL/PLA composites.

Meanwhile in Figure 4, it shows the Modulus of elasticity of PCL/PLA composites. The lowest values of modulus of elasticity were recorded at 32.92MPa where the content of PLA were higher which were 70% compare to PCL which only 30% by weight. The highest value of modulus of elasticity were recorded when the weightage of PCL is higher which were at 70% where the modulus
of elasticity is 118.26Mpa. From the graph it can be concluded that the modulus of elasticity increases as the PCL concentration increase from 30% to 70% by weight.

![The Modulus of Elasticity of PCL/PLA](image)

**Figure 4: Modulus of elasticity of PCL/PLA composite**

The results for tensile strength and modulus of elasticity of PCL/PLA do not deviate far from the work done by other researcher [9]. As for Modulus of elasticity, this observation can attribute to the amount of PCL present. The tensile strength and Modulus of elasticity become higher when the increment of PCL contain in the compositions.

3.2.2 **Flexural Strength and Flexural Modulus of PCL/PLA composite**

The flexural strength of PCL/PLA composites is shown in Figure 5. The highest flexural strength was recorded at when the percentage of PCL was higher than PLA where the value is 7.59MPa. Meanwhile the lowest value for the flexural strength was recorded when the weightage of PCL is 30% and weightage of PLA is 70% where the value was 0.42Mpa. As it can be seen from the graph, the flexural strength increase moderately when the weightage of PCL increase from 40% to 50% where the value were recorded were 0.99 MPa and 3.59MPa respectively. However, there are slight decrement on the flexural strength as the amount of PCL were 60% before it start to increase again as the percentage of PCL were increased to 70% by weight. Overall the pattern shows an increasing in flexural strength as the concentration of PLA was decrease from 70% to 30%.

![The Flexural Strength (Mpa) of PCL/PLA](image)

**Figure 5: Flexural Strength of PCL/PLA composite**
Figure 6 below shows the flexural modulus of PCL/PLA composites. The lowest values of flexural modulus were recorded at 2.05 MPa as the percentages of PCL were lower compared to PLA. Meanwhile, the highest values of flexural modulus were recorded at 35.33 MPa when the weightage of PCL was much higher compared to PLA. The flexural modulus increased moderately as the PCL concentration increased from 40% to 50% with the value of the flexural modulus being 4.4 MPa and 17.19 MPa respectively. Finally, the flexural modulus decreased slightly at 60% concentration of PCL where the modulus is 15.55 MPa. Overall, the pattern shows an increase in flexural modulus as the concentration of PCL decrease from 70% to 30%. The result does not deviate far from the prediction by the simple rule of mixtures. As stated by other researchers in their work, PLA has poor thermal and mechanical analysis which restricting its widespread applications. As the weightage of PCL increases, it increases the mechanical properties of the composites [10].

Other than that, the result of flexural strength shows an opposite from the result gain from tensile test as in flexural test the bending forces induce tension and compressive forces while in tensile test the applied force is a pulling force so the ability of the composite to support applied load is different [11].

3.2.3 Impact Strength of PCL/PLA Composite

As for the impact strength, the lowest value of impact was recorded at 0.42 J when the percentage of PCL only at 30%. Meanwhile, the highest value of impact strength were recorded when the weightage of PCL is 70% where the impact strength is 1.33 J. The impact strength increases as the PCL concentration increase to 40% where the strength is 0.43 J. Finally, the impact strength increases moderately at 50% and 60% concentration of PCL where the strength is 0.61 J and 1.19 J respectively. In overall, the pattern shows an increase in impact strength as the concentration of PLA decrease from 70% to 30%. The result agrees with work reported by other researcher where they have concluded that PLA is high brittle so to increase PLA flexibility PLA has been blended with others more flexible biodegradable polymers such as poly(e-caprolactone) (PCL) [12]. Figure 7 below shows the impact strength of PCL/PLA composites.
It also have been reported that PCL will acts as a polymeric plasticizer, lowering the yield stress and the initial modulus. PCL enhanced the ductility and flexibility of a blend. With the addition of PCL, it offers higher impact toughness and decreasing the brittleness of the composites materials. The impact toughness of PLA decreases with the addition of PCL [13].

4. Conclusion
The effect of PLA added into PCL on the mechanical properties of the composite and also the morphology properties were studied. From the study, the following conclusions can be conclude:

1. The morphology properties of the composites under Fourier Transform Infrared Spectroscopy proved that FTIR spectra of PCL and PLA are merely mixture. As the weightage of PLA decrease, the spectra increased along with the increasing of the PCL.
2. The tensile strength and Modulus of elasticity is highest at 30 wt% of PLA and 70 wt% of PCL. These features suggested that this formulation was strong and flexible elastomer. As the weightage of the PCL increased, the tensile and modulus of the composites shows an improvement.
3. Flexural strength is highest at 30 wt% of PLA. It shows that PCL particles has dispersed in PLA and have a good interaction toward PLA.
4. From the experiment, it shows that the impact strength was also highest at 30 wt% of PLA. With the addition of PCL, it gives the composites higher impact toughness and also decreased the brittleness.
5. From the analysis that had been done, it can be conclude that the best formulation PCL/PLA composites is PCL70PLA30. Besides having a high tensile strength and modulus, it also good in flexural strength and modulus. Lastly for the impact strength, it shows that the same formulation also gives a better in impact strength compare to others.

In developing PCL/PLA composites, there are many aspects that can be further investigated in the future. There were several recommendations and some suggestions for the future studies are as follows:

1. For the investigation on the characteristic and properties of PCL/PLA composites, also can do the Scanning Electron Microscopy Machine (SEM) to reveal information about the sample including external morphology (texture), chemical composition and crystalline structure.
2. It would be great to investigate more composition of PCL/PLA instead of five formulations as in this experiment.

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