ANALYSIS OF HEAT TREATMENT EFFECT ON TENSILE PROPERTIES OF 3D PRINTED CARBON FIBER COMPOSITE AND COMPARING MECHANICAL PROPERTIES ON MANUFACTURING METHOD

By:

CHAI CHANG YUAN

(Matrix no.: 144736)

Supervisor:

Associate Professor Dr. Jamaluddin Abdullah

July 2022

This dissertation is submitted to

Universiti Sains Malaysia

As partial fulfillment of the requirement to graduate with honors degree in

BACHELOR OF ENGINEERING (MECHANICAL ENGINEERING)

School of Mechanical Engineering

Engineering Campus

Universiti Sains Malaysia

DECLARATION

This work has not previously been accepted in substance for any degree and is not being concurrently submitted in candidature for any degree

Signed……………………………………………………………………………(Chai Chang Yuan)

Date………………………………………………………………………………..(24/7/2022)

STATEMENT 1

This thesis is the result of my own investigations, except where otherwise stated. Other sources are acknowledged by giving explicit references.

Bibliography/references are appended

Signed……………………………………………………………………………(Chai Chang Yuan)

Date………………………………………………………………………………..(24/7/2022)

STATEMENT 2

I hereby give consent for my thesis, if accepted, to be available for photocopying and for interlibrary loan, and for the title and summary to be made available outside organizations.

Signed……………………………………………………………………………(Chai Chang Yuan)

Date………………………………………………………………………………..(24/7/2022)

ACKNOWLEDGEMENT

First of all, I would like to thanks for the help and support from supervisor, technicians, coursemates, friends and my family. Without them, it would not be possible for me to complete this work. I would like to extend my sincere thanks to all of them.

I would like to show my deepest appreciation to everyone who help me to complete this final year report. A special thanks has to be gave to my final year project supervisor, Associate Professor Dr. Jamaluddin Abdullah. He always be there to help me by giving me useful comments and suggestions so that I'm able to complete my report. With every discussion or meeting with him, I always receive something useful to improve my work. I would like to say it would not be possible for me to complete the final year report without his guidance.

Besides, I would also like to express my much appreciation to School of Mechanical Engineering USM, which allows me to handle the machines and equipment by my own. I would like to thanks technicians in my school such as Mr. Fakruruzi Fadzil, Mr. Hazwan Mohamad, Mr. Mohd Ashamuddin Hashim and Mr. Wan Mohd Amri Wan Mamat Ali which helped me during the experiment. Without they guidance, I would not be able the handle those machines and equipment well. They helped me so that I'm able to complete the experiment by collecting the needed data for the report.

Last but not least, I would like to thanks my family, coursemates and friends. Their supports are always the energy for me to carry on when I felt low or stress. They are always be there to lend a hand for me and encourages me during the hard time. Because of the help from everyone, so that I could finish my project in the end.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATION

3D	Three-dimensional
CATIA	Computer Aided Three-Dimensional Interactive Application
CAD	Computer-aided design
FDM	Fused Deposition Modelling
FFF	Fused Filament Fabrication
CFRP	Carbon fiber reinforced polymer
SLS	Selective Laser Sintering
CF-PLA	Carbon fiber reinforced polylactic acid
SEM	Scanning Electron Microscope
STL	Stereolithography
ABS	Acrylonitrile Butadiene Styrene
PETG	Polyethylene Terephthalate Glycol

ABSTRAK

Percetakan 3D adalah teknologi yang sangat popular akhir-akhir ini kerana ia sangat fleksibel untuk mereka bentuk reka bentuk produk yang kompleks dengan kos yang agak rendah. Percetakan 3D ialah pembuatan bahan tambahan yang membuat bahagian dengan membina dengan filamen cair lapisan demi lapisan. Polimer bertetulang gentian karbon adalah bahan yang kuat dengan berat ringan. Komposit gentian karbon agak mahal untuk dibuat dan ia biasanya digunakan dalam bidang automotif, aeroangkasa dan perubatan. Polimer bertetulang gentian karbon bercetak 3D (CFRP) masih menjadi topik yang sangat baru dalam beberapa tahun kebelakangan ini. Dalam projek ini, asid polilaktik bertetulang gentian karbon bercetak 3D (CF-PLA) direka oleh proses Fused Deposition Modeling (FDM). Kesan rawatan haba pada kekuatan tegangan 3D bercetak CF-PLA disiasat. CF-PLA cetakan 3D dengan suhu penyepuhlindapan 95 ℃ dan tempoh penyepuhlindapan 90 minit menunjukkan peningkatan tertinggi dengan 5.8% kekuatan tegangan. Keputusan ujian lenturan menunjukkan komposit gentian karbon susun tangan mempunyai kekuatan mekanikal yang lebih tinggi berbanding CF-PLA cetakan 3D. Walau bagaimanapun, CF-PLA bercetak 3D mempunyai kemuluran yang lebih baik yang mempunyai kira-kira dua kali sambungan lentur maksimum berbanding komposit gentian karbon susun tangan. Gentian karbon yang diperkuat dengan polimer lain seperti Acrylonitrile Butadiene Styrene (ABS) dan Polyethylene Terephthalate Glycol (PETG) dicadangkan untuk penyelidikan masa depan untuk menemui lebih banyak potensi dalam komposit gentian karbon bercetak 3D.

ABSTRACT

3D printing is a very popular technology lately because of it is very flexible to fabricate complex design of product with relatively low cost. 3D printing is additive manufacturing which fabricate parts by building with melted filament layer by layer. Carbon fiber reinforced polymer is a strong material with light weight. Carbon fiber composite can be quite costly to fabricate and it is commonly used in automotive, aerospace and medical field. 3D printed carbon fiber reinforced polymer (CFRP) is still a very new topic in recent years. In this project, 3D printed carbon fiber reinforced polylactic acid (CF-PLA) is fabricated by Fused Deposition Modelling (FDM) process. Effect of heat treatment on tensile strength 3D printed CF-PLA is investigated. 3D printed CF-PLA with 95°C annealing temperature and 90 minutes annealing duration showed highest increase with 5.8% of tensile strength. The result of flexural test showed aircraft component carbon fiber composite has much more mechanical strength compared to 3D printed CF-PLA. However, 3D printed CF-PLA has better ductility which has approximately two times of maximum flexure extension compared to aircraft component carbon fiber composite. Carbon fiber reinforced with other polymer such as Acrylonitrile Butadiene Styrene (ABS) and Polyethylene Terephthalate Glycol (PETG) are suggested for future research to discover more potential in 3D printed carbon fiber composite.

CHAPTER 1 INTRODUCTION

1.1 Overview

3D printing is a very popular technology lately because of it is very flexible to fabricate complex design of product with relatively low cost (Saeed et al.,2021). 3D printing is additive manufacturing which fabricate parts by building with melted filament layer by layer. 3D printed products are actually design by CAD software such as Solidwork, CATIA, etc. 3D printing is a process that melted the raw material, deposited it layer by layer and solidified to form a three-dimensional product. 3D printing has a lot of advantages such as its high material range, capable to product various design of product and it is fast for designing prototype (Ning et al.,2017).

Fused Filament Fabrication (FFF) and Fused Deposition Modelling (FDM) are common technique that deposited desired pattern layer by layer on a printing bed with molten material that melted by hot nozzle (Saroia et al.,2020). 3D printing models are usually design with CAD software. Design of CAD models are easier than before because there are lots of different tutorials online. Preview of CAD models is able to check the details such as dimension and tolerance, any correction can be easily made with CAD software.

Carbon fiber reinforced polymer is a strong material with light weight. Carbon fiber composite can be quite costly to fabricate and it is commonly used in automotive, aerospace and medical field. The reinforced fibre can be either continuous or discontinuous. Continuous carbon fibre will have better strength-to-weight ratio, high stiffness, low in weight and excellent wear resistance (E. Uhlmann et al.,2016). However, composite with complex design is hard to fabricate due to complicated molds with high cost and low automation (Ngo et al., 2018). In addition, manufacturing cost of composite material is quite high. Hence, study on more cost-effective, flexible and automated manufacturing process of carbon fiber composite is focused in this project.

3D printed carbon fibre reinforced polymer (CFRP) is still a very new topic in recent years. There are few studies stated that reinforced with continuous fibre will increase more strength to the 3D printed CFRP compared to short fibre (Blok et al., 2018). However, interlaminar adhesions of 3D printed part is lower. This is because 3D printing process produce voids and weak interactions between deposited material and between the printing layers (Justo et al., 2018). Mechanical properties improvement of 3D printed CFRP still need further study before it uses in automotive, aerospace, or biomedical application.

1.2 Project Background

Carbon fiber composite is attractive material due to its high strength and stiffness to weight ratio, corrosion resistant and chemical inertness compare to metal. In aircraft manufacturing, more and more carbon fiber composite is being used. 3D printing technology provide opportunity for better design of complex structure, ease of processing and digital manufacturing of components for niche industry such as aerospace. Fused Deposition Modelling (FDM) is a common process used to fabricate 3D model of carbon fiber reinforced polymer. FDM is a process that melted the material filament with heated nozzle and extrude on printing bed layer by layer to form 3D model.

Fabrication of 3D printed composite has a good way to improve strength and mechanical properties of 3D printing model with reinforcement of carbon fiber (Love et al.,2014). Due to the high stiffness and high strength to weight ratio, 3D printing of carbon fiber composite become new trend for manufacturing and new material choice to replace traditional metal. 3D printing is a cheaper and faster manufacturing method to fabricate carbon fiber composite parts compared to traditional manufacturing method. The advantages of 3D printing is worth for more research and development to discover more potential (Yoh and Goh, 2020)

One of the carbon fiber composite manufacturing method is aircraft component. In the aircraft component process, the resin or polymer will be added into a mold and short fiber will also add into the mold. A brusher or roller will help to combine the material layer by layer. This manufacturing method can use to design custom dimension of carbon fiber composite part. It requires a lot of skills to produce good quality model but it is the least expensive compare to other manufacturing method. This method allows the part produced lighter and higher strength. Manufacturing method of aircraft component technique and 3D printed carbon fiber composite in mechanical properties are studied.

1.3 Problem Statement

From the researches done previously, 3D printing process is more focus on produce polymer such as thermosetting plastic. 3D printing on carbon fiber composite is still very new technology that have great potential to be discover. 3D printing of carbon fiber composite is not an easy process due to its properties and characteristics. Due to the limited research on 3D printed carbon fiber reinforced polylactic acid (CF-PLA), this project will be focus on study the mechanical properties of the 3D printed carbon fiber reinforced polylactic acid. Besides, the cost of fabricate carbon fiber composite component is also quite high, so this project will be discussed about the pros and cons of each manufacturing method.

1.4 Project Objectives

1. To investigate the effect of heat treatment process on tensile properties of 3D printed CF-PLA
2. To determine the fractural properties of aircraft component manufacturing method compare to 3D printed CF-PLA

1.5 Scope of Work

In early stage of this project, lots of literature review are done to understand the basic knowledge of the topic. The research is more focus on the properties and application of carbon fiber composite. 3D printing manufacturing process also studied to determine the parameter that suitable for printing CF-PLA. Then, the experiment started from design CAD model of the 3D printing model. The CAD model is then saved to stl file. Stl file of the 3D model will import to slicing software such as Creatware and Ultimaker Cura to generate g codes. Then, heat treatment is done for the parts on the parameters that already set. The results and discuss will more focus on the tensile test, 3 point bending test and microstructure of the specimens compare to traditional aircraft component carbon fiber composite.

CHAPTER 2 LITERATURE REVIEW

2.1 Carbon fiber composite

Fabrication of carbon fiber reinforced composite by 3D printing is a potential field for next-generation of composite fabrication (Matsuzaki et.al, 2016). Based on the volume content of carbon fiber composite, Saeed,K et.al proved that the stiffness and strength of the carbon fiber composite increase when the volume content increase. When the volume content of fiber increase by 6% which is from 29% to 35%, the tensile strength of the specimens is also increase by 27% (Saeed et.al, 2021). In the study of friction and wear behavior of carbon fiber composite, the friction coefficient rise quickly in 10 hours under pressure of 1 MPa whereas the sample failed under 2 MPa pressure after 6 hours due to the thermal softening of the sample (Man et.al, 2021). Li et.al compare the modified 3D printed carbon fiber reinforced polylactic acid (CF-PLA) with original printed CF-PLA samples, they found out the samples printed by modified nozzle have increased tensile strength and flexural strength by 13.8% and 164% respectively.

Hazer et.al studied composite of polylactic acid and polycarbonate with weightage of 90% and 10% respectively. Tensile properties of the composite is strengthen by adding carbon fiber to the specimens. The highest increase in tensile strength is the specimen added with 30 wt % of carbon fiber. In this study, the result showed carbon fiber reinforced with 50% polylactic acid and 50% polycarbonate has higher strength and thermal properties than 90% polylactic acid and 10% polycarbonate (Hazer et.al, 2018).

With the simulation by Gaussian Process modelling, the result shows that the best mechanical properties of carbon fiber reinforced polylactic acid is the composite added with 6.7 wt% of carbon fiber (Hu et.al, 2021). They stated the limitation of FDM fabrication process is when the carbon content of the filament is high, it is difficult for the 3D printer extruder to extrude and complete the printing process.

The increase of infill density of 3D printing will also increase the tensile strength of the part produced. It is because the structure of the part is more packed with higher density. The increased nozzle temperature resulted better fusion between layers (Arjun, 2022).

2.2 3d printing method

3D printing is an additive manufacturing that consists of extrusion-based method. Fused Filament Fabrication (FFF) is a 3D printing techniques to produce polymer-based composite. FFF is a process of melting the thermoplastic filaments and extrudes them through a nozzle on a bed to form a part (Ning et.al, 2016). The limitation of this method is the part is build layer by layer, when the nozzle laying the molten filaments on an already solid part, it produces weak fusion between the layers. The part produced is has lower strength and lower elastic properties compare to other manufacturing method.

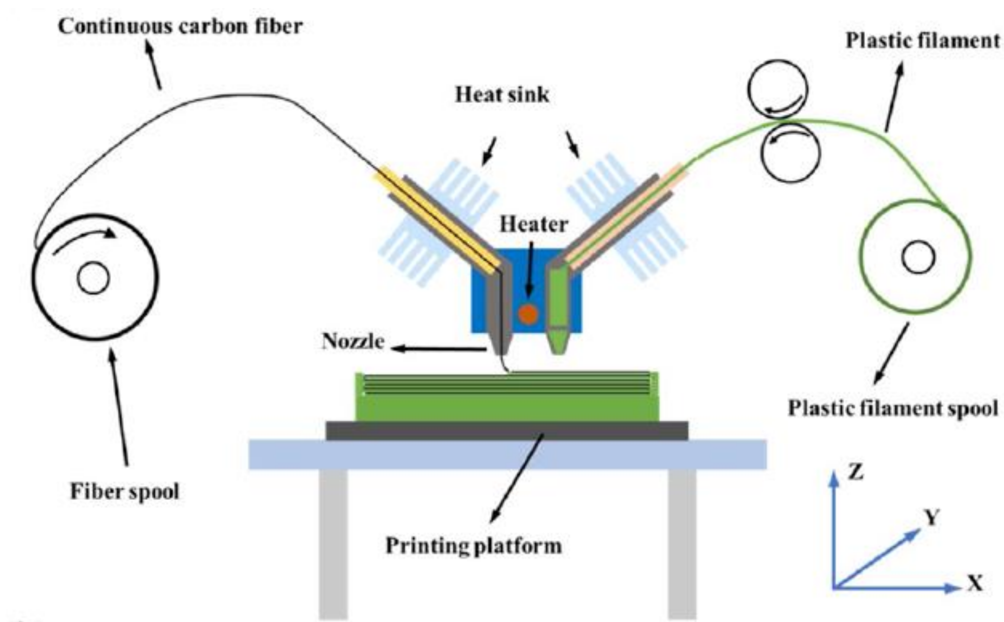


Figure 2.1 : Example of Fused filament fabrication schematic. (F.Wang, et al.)

Fusion Deposition Modelling (FDM) is another extrusion-based process. The process started with produce a CAD drawing from a CAD drawing software and convert it to a 3D model which is a stl file. The file will then be import to a slicing software such as Creatware or Ultimaker Cura to produce a series of g code for the 3D printing process. A FDM process started with attached the filament of thermoplastic to the heated nozzle. The melted filament will extrude through the nozzle and deposited on the printing bed layer by layer. The 3D printer will follow the g codes that generated and move the printing head in X-Y direction where the platform will move in z-direction to produce the desired part.

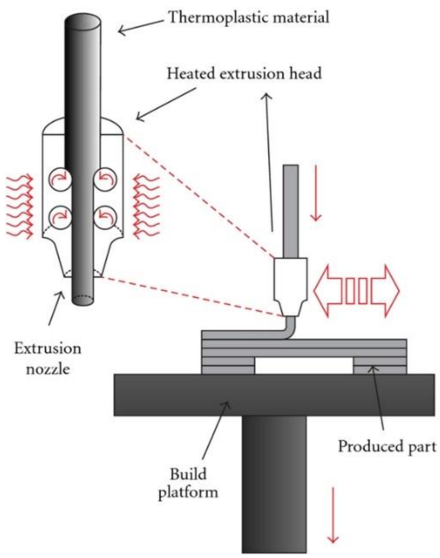


Figure 2.2: Example of fused deposition modelling schematic (Tsouknidas, 2011)

Parameter settings will also effect the mechanical properties of 3D printed part. Durga et.al studied the process parameter such as layer thickness, extrusion temperature and infill pattern effect on the tensile strength. It is observed that sample with layer thickness of 0.1mm has 24.7% higher tensile strength compare to sample with 0.2mm layer thickness which have 25.69MPa and 20.6MPa respectively. For the extrusion temperature, the sample printed in 225℃ has 9.7% higher tensile strength compare to the sample printed at 205℃. For the infill pattern, cubic infill specimens has higher tensile strength compare to quarter cubic infill pattern (Durga et.al, 2019).

2.3 Heat treatment

Heat treatment is used to rearrangement the crystallization and improve the mechanical properties of the object (Wang et al. 2021). The heat treatment process that involved in this project is annealing process. In term of material science, annealing is a process that change the mechanical properties of an object. It makes the object to become more ductile and reduces the hardness of the object. It is done by heating a material with a certain temperature for a suitable amount of time and cooling in the air at room temperature. The atoms of the object will recrystallize the structure during the heating and cooling time.

During the process, the ductility of the material changes due to the atoms rearrange its position in the lattice and reduces the number of dislocations. This process is usually done to improve low carbon steel. Carbon fiber PLA has a glass transition temperature of 60-65 ℃ and a melting point of 180-200 ℃. To investigate the influence of annealing on tensile strength, the time length is varied from a minimum to maximum duration (Arjun et al.,2022).

2.4 Tensile test

Tensile test is a common test a test that apply load and stretches the specimen until it breaks. This test measures the tensile strength, elastic modulus, Young's modulus, yield strength, breaking strength and area of reduction of the specimen by using the force that break the specimen. The test will usually produce information such as stress over strain graph. The ductility of the specimen can also be detected by the data given from the test such as percent of elongation at yield and elongation at break. The thickness of the specimen will affect the result of tensile test due to the shear stress is influenced by the thickness of the specimen.

Besides, alignment of the specimen is an important factor that affect the result of the tensile test. When the applied load is parallel to the printed direction or fiber direction, the tensile strength of the specimen is very high. In the other hand, the tensile strength of the specimen will be much weaker if the applied force is differing from the printing direction (Saba et.al, 2019).

The tensile specimen prepared for each experiment might differs due to the objectives and type of the material. Tensile specimens are usually fabricated in dog bone shape which look like two shoulders and a gauge in the center. The deformation will usually happen in the gauge area due to the smaller diameter (Davis & Joseph, 2004). The test is normally done by a universal testing machine. The machine has two crossheads in an up and down position, the crosshead at the bottom is fixed and another crosshead will apply tension to the specimen during the experiment.

2.5 Flexural test

Flexural test is a simple and common test to determine the elasticity, flexural stress and flexural strain of a specimen. There are two basic type of flexural test which are 3-point bending and 4-point bending. 3-point bending is more frequently used to test specimen with different extensibility. Advantage of using 3-point bending test is the specimens are easy to be prepared. The theory of the test is applying load to bend a specimen with two supports underneath. It tests the flexing properties of the specimen and determine the maximum load before the specimen deformed permanently which is the yield point. The specimen will go back to its original shape if the stress applied does not reach the yield point. For a brittle material, it has higher chance to break when flexed. The test is usually run with a universal testing machine.

2.6 Scanning Electron Microscope (SEM)

Scanning Electron Microscope (SEM) is a widely used apparatus to observe the microstructure from a solid surface. It is a type of microscope that used high-energy beam of electrons to produces images of a sample. It works with powering the primary electron beam in a vacuum and scans on the sample. When the focused beam of electron interaction with the atom of the specimen, the secondary electrons will have emitted by the atoms on the surface. The secondary electron will be detected by using a secondary electron detector, the information will be integrated to useful data such as specimen microstructure, signal intensity, etc. The purpose of using SEM is usually to understand the microstructure on the sample surface for analysis. It used widely in many fields such as nanotechnology and biomedical fields.

The dimension for SEM samples is relatively small so that it can be fit to the observation stage. For some of the specimens, there might need to have other process to stable their electric conductivity, so that the samples capable to withstand excited beam of electrons. Mounting process needed to be done to hold the sample in place. Besides, for samples with low conductivity or without conductivity will collect charge from the electrons and causing errors to the scanning results.

CHAPTER 3 METHODOLOGY

3.1 Overview of methodology

This chapter presents the overall methods used to investigate the heat treatment process effect on tensile properties of 3d printed carbon fiber composite. Starting of the experiment is the 3d printing process with Creatbot 600D pro printer. Filament was ordered from online shop and parameters for 3d printing was studied. CAD design was developed by using Solidwork software. Then, CAD file is turned into STL file for 3d printing slicing. G code is produced by using Creatware slicing software. The specimens were taken to heat treatment process after 3d printing process is done. Microstructure of specimens were investigated by using SEM. Tensile test was carried out to test the tensile properties of the specimens. Besides, there are also few samples of carbon fiber reinforced composite then taken from company outside. Traditional aircraft component process is used to produce these samples. 3-point bending-test was also setup to test the mechanical properties of 3D printed samples and aircraft component samples.

3.2 Material

The carbon fiber reinforced polylactic acid (CF-PLA) filament was brought from online shop as raw material for 3d printing. The filament is made up of PLA and premium high-modulus carbon fiber. The filament is a good material for 3d printing, it produces component with high modulus, excellent surface quality, dimensional stability and light weight.

Carbon fiber reinforced PLA can be print without a heated bed with no enclosure required. It can be print with extruder temperature in range from 190°C to 220°C, bed temperature with 23°C to 60°C, layer height at least 0.25mm and bed adhesion.

Figure 3.1 : Filament of carbon fiber reinforced polylactic acid (CF-PLA)

3.3 Design of experiment

In this experiment, the tensile properties and fractural properties of 3D printed carbon fiber reinforced PLA were investigated. 21 specimens were printed and 18 specimens were treated with heat treatment process. The heat treatment process varies with different temperature and duration. All 21 specimens were taken to tensile testing to investigate the effect of heat treatment process on tensile properties of the specimens. Microstructure of the specimens are studied both before and after heat treatment to identity how heat treatment process effect on microstructure of carbon fiber reinforced PLA specimens. Besides, 3-point flexural test also done on both 3D printed CF-PLA and aircraft component carbon fiber composite sample.

3.4 3D printing process

3D printing is an important process in this experiment. 3D printing process starting on drawing CAD model in design software such as Solidworks. Dimension of the model followed the standard that could be found on online platform. 3D model design of tensile test specimen and 3-point bending test specimen are shown in the figure below.

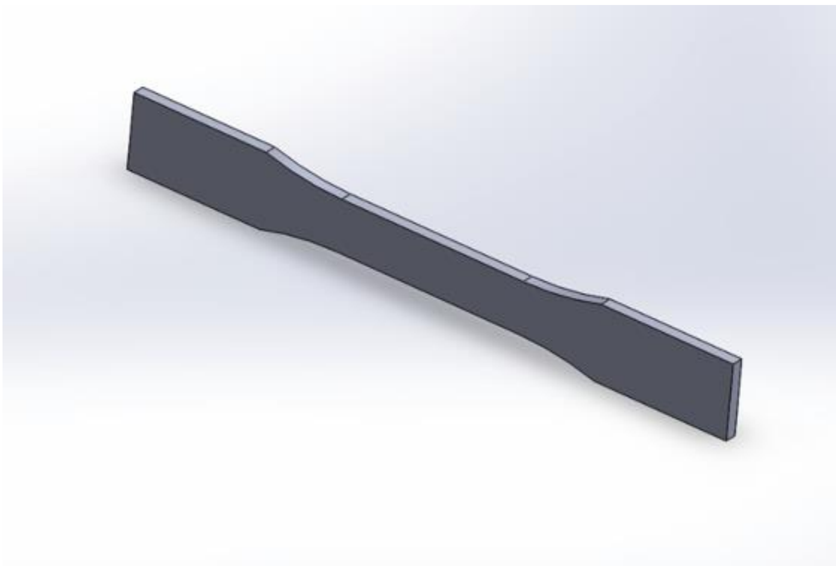


Figure 3.2: CAD drawing of dog bone sample

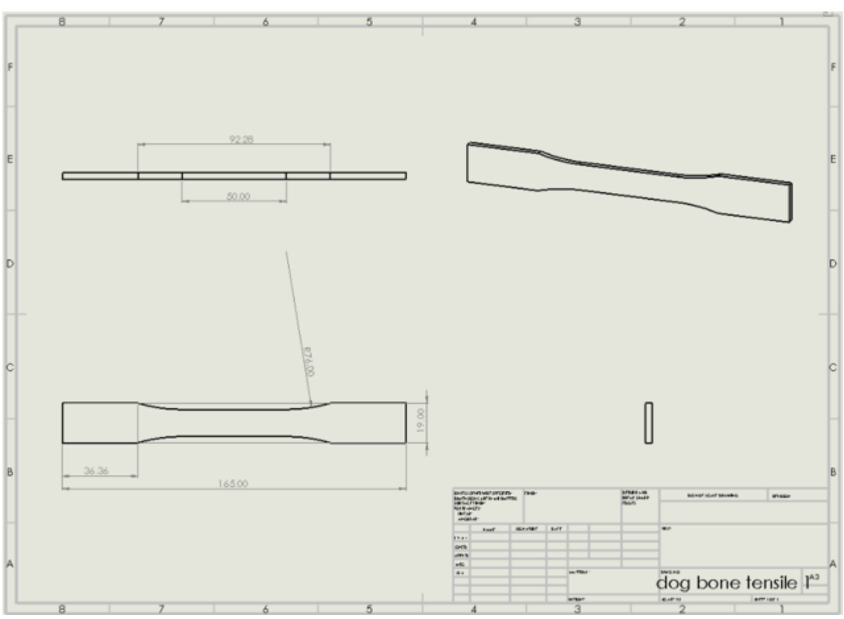


Figure 3.3: Mechanical drawing of dog bone sample

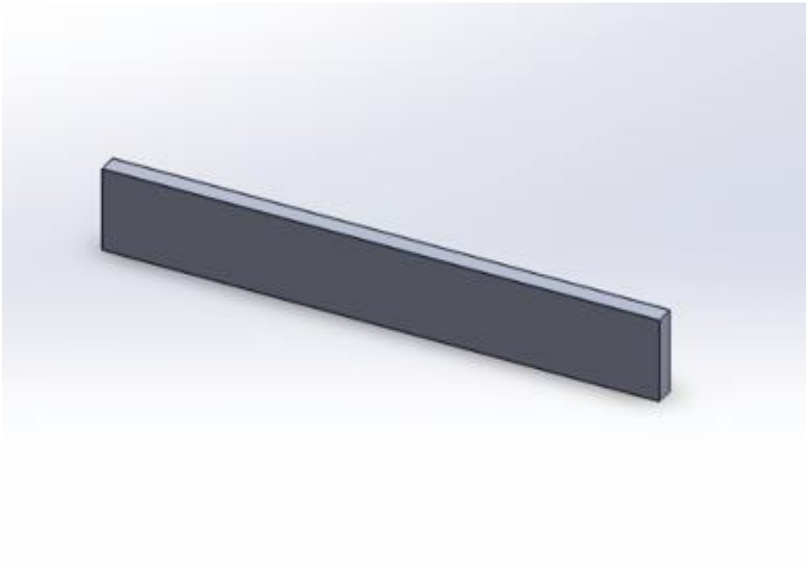


Figure 3.4: CAD drawing of bending sample

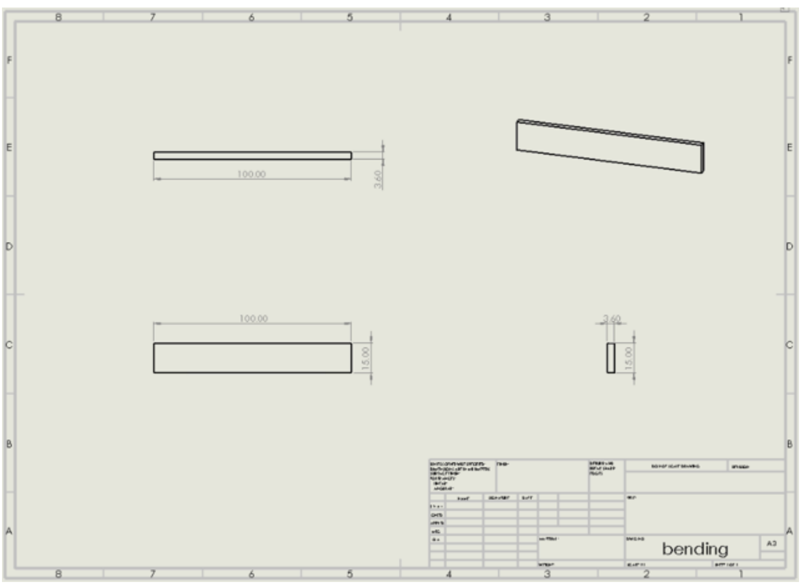


Figure 3.5: Mechanical drawing of bending sample

After the CAD model has been drawn, the CAD model must be save or convert into stl file type. For the 3D printing process to work, the G codes of the model must be generated. This is done by using slicing software name Creatware V7.0.0 which is the suggested software for Creatbot printers. The stl file of the model was opened in the Creatware software, parameters of the 3D printing can be adjusted in the software. The parameters for this process are fixed which are printing temperature of 210°C, 20mm/s printing speed and 50°C of bed temperature.

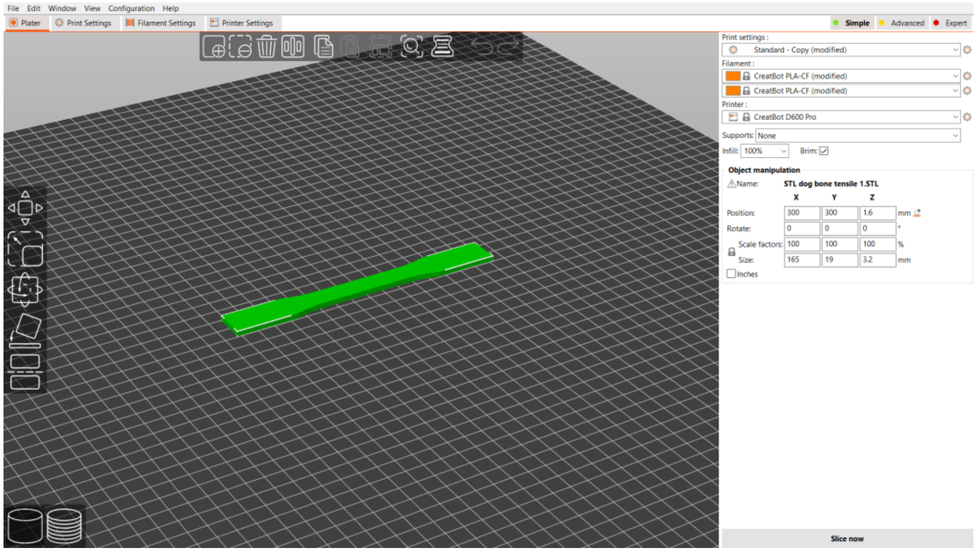


Figure 3.6: Slicing process in CreatWare software

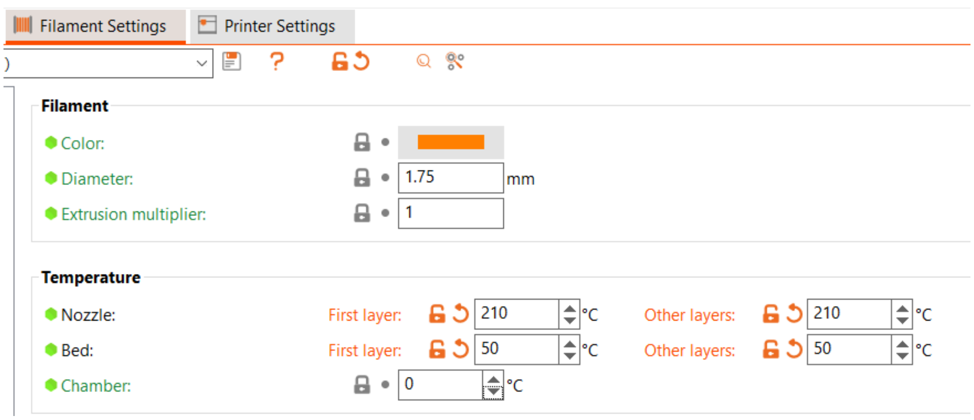


Figure 3.7: Printing temperature and bed temperature settings CreatWare

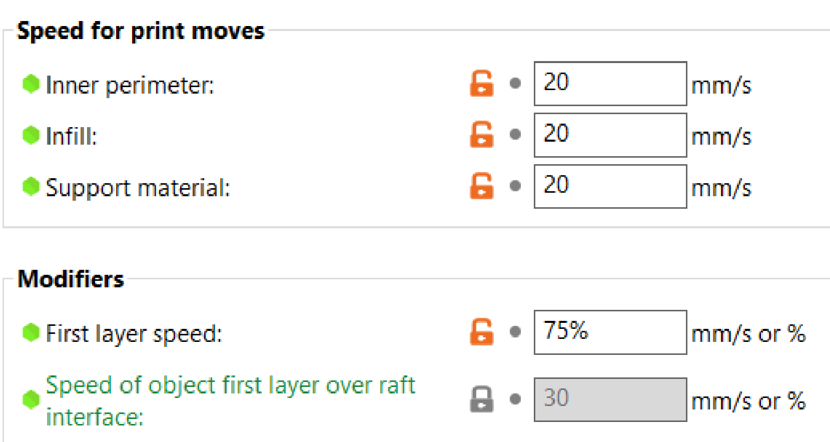


Figure 3.8: Printing speed settings in CreatWare

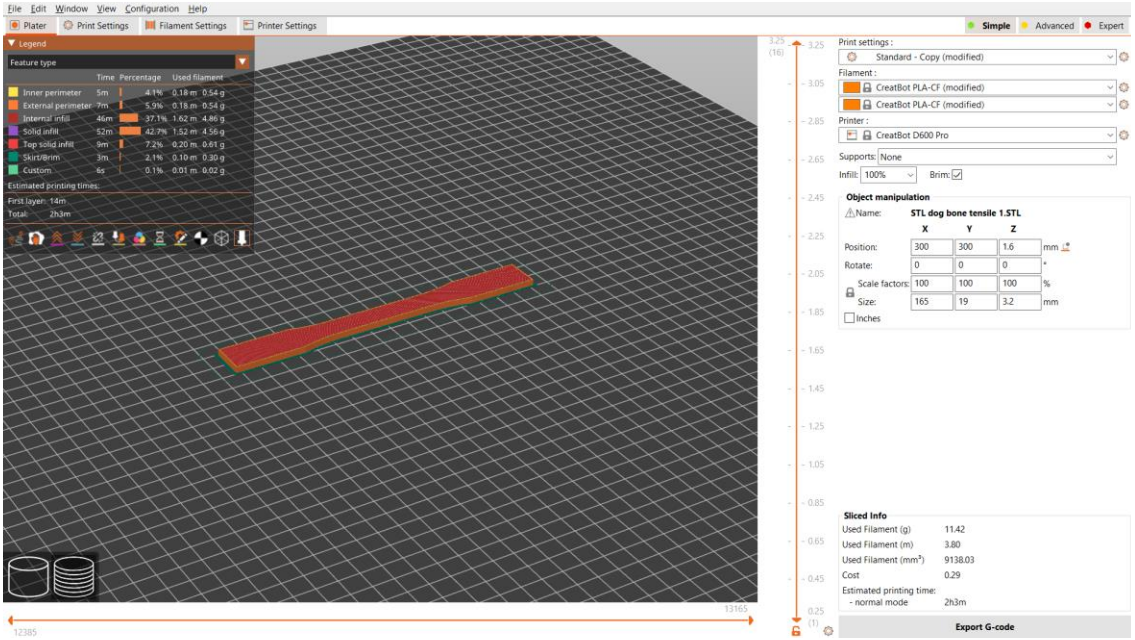
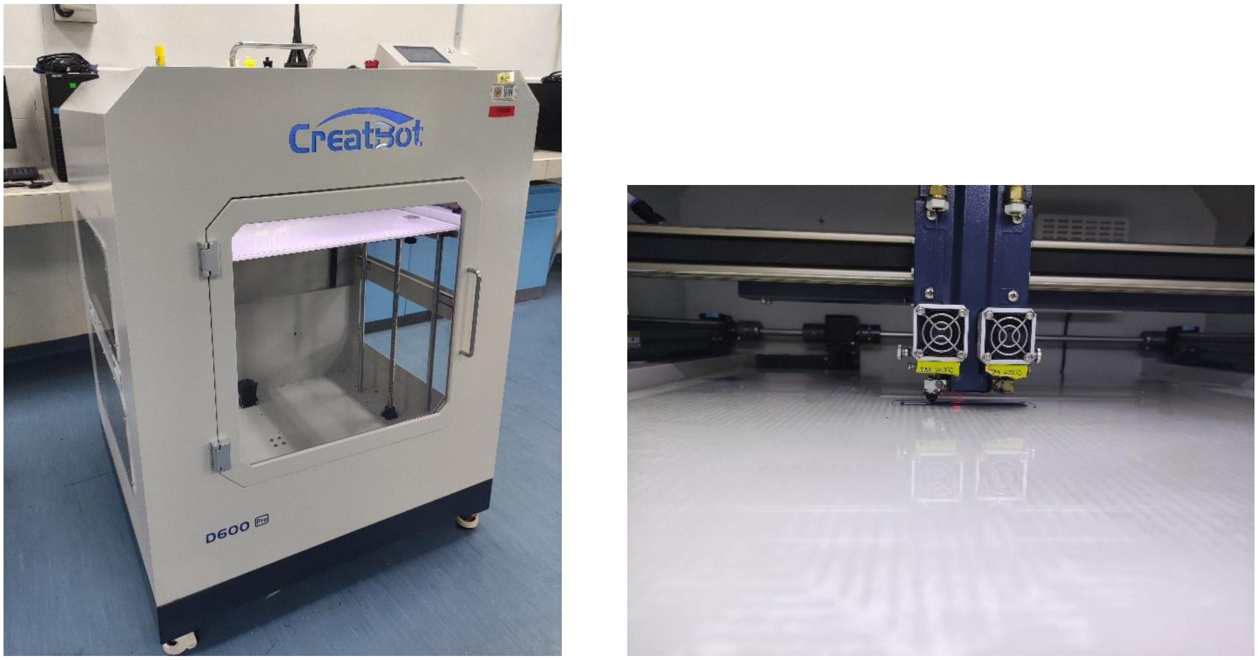


Figure 3.9: Slicing process and sliced info

In the slicing process, the CreatWare software will show the details of the slicing process. It shows the time taken and filament weightage used on each layer. From the CreatWare software, the used filament for one dog bone specimen is 11.42g and the total processing time is 2 hours and 5 minutes. The g codes will automatically generate by the software. It is saved to pendrive and insert to the 3D printer. The printer used in this project is Creatbot D600 Pro. It is a dual nozzle 3D printer which can heated up to 420°C. It has a heat printing bed and capable to print different type of material.

(a) (b)

Figure 3.10: (a) 3D printed dog bone specimen (b) 3D printed bending specimen



(a) (b)

Figure 3.11: (a) CreatBot D600 pro 3D printer (b) Image of 3D printing process

3.5 Heat treatment

The heat treatment process that involved in this project is annealing. The process is aim to determine the change of mechanical properties of the 3D printed carbon fiber reinforced polylactic acid. 21 of the CF-PLA specimens are printed and 18 of them went for annealing process. The parameters of this process is the heating temperature and the heating duration. The heating temperature has 2 levels and heating duration has 3 levels. At first, the furnace is pre-heated to 125°C. Specimens marked with 125°C will be placed in the furnace. Stopwatch of smartphone will be the standard for time calculations. Specimens are then taken out according to the heating time and cooled under air in room temperature. The furnace is set to 95°C after all the specimens with 125°C. The steps were repeated until 18 specimens were done with the process. Due to the tensile test after the heat treatment process, 3 specimens will be heated in each set of the temperature and duration as shown in table 3.1 below.

Table 3.1: Process parameters of heat treatment

Runs	Specimen	Heating temperature (°C)	Heating duration (mins)
1	A, B, C	95	30
2	D, E, F	95	60
3	G, H, I	95	90
4	J, K, L	125	30
5	M, N, O	125	60
6	P, Q, R	125	90

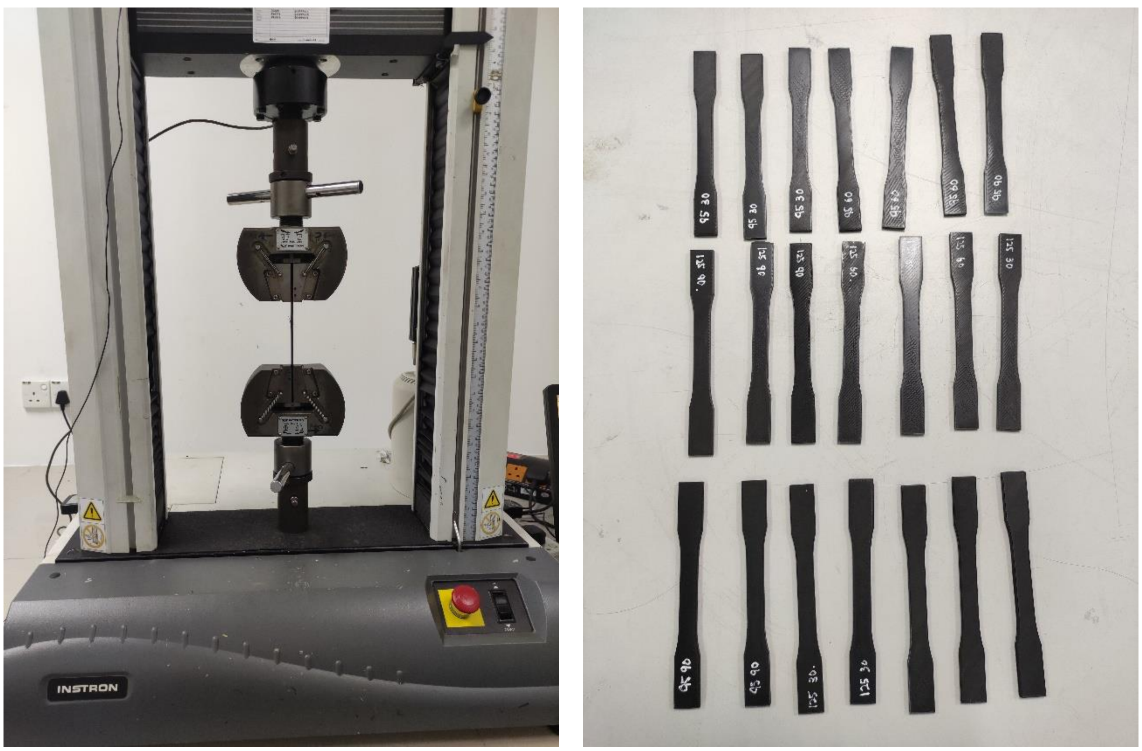
(a)

(b)

Figure 3.12: (a) Furnace used for heat treatment (b) Specimens placing in furnace

3.6 Tensile test

Tensile test is done in this project to get information about the mechanical properties such as maximum tensile strength, elastic modulus and Young's modulus. The tensile specimens dimension is followed with the ASTM-D638 type 1 standard. There are 21 runs tensile test done in this project. 18 specimens with heat treatment and 3 specimens without heat treatment. The tensile test was done by Instron universal testing machine. The speed for the tensile test used is 2mm/s. The universal machine used is integrated to the computer next to it. The results such as ultimate tensile strength, stress-strain graph are recorded by the software in the computer. The data was then retracted out by using pendrive and online source such as google drive and Onedrive.



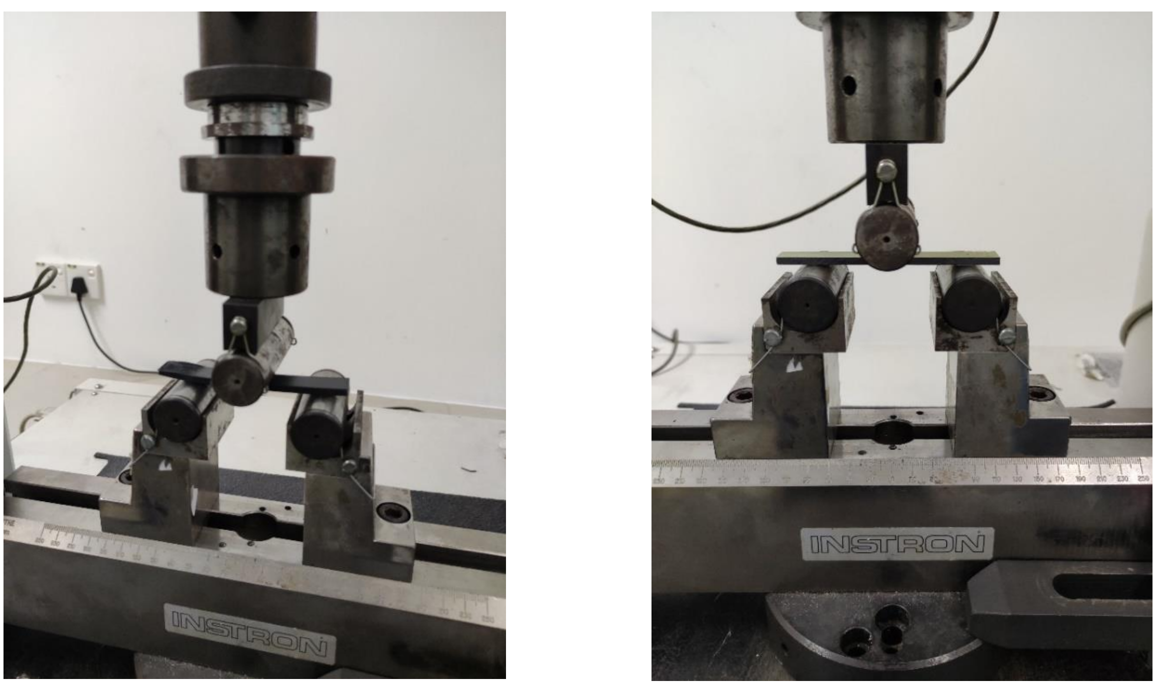
(a) (b)

Figure 3.13: (a) Tensile test by universal testing machine (b) 3D printed dog bone specimens

3.7 3-point flexural test

3- point flexural test is carried out to obtain the information from the 3D printed CF-PLA and aircraft component carbon fiber composite. For the 3D printing process, the specimens were printed that followed ASTM D790 standard for flexural test. In the other hand, the aircraft component carbon fiber composite samples were received in a bigger dimension. The specimens were cut into shape of ASTM D790 standard.

After that, the universal testing machine was setup for both 3D printed and aircraft component specimens. Both types of the specimens were using different load speed which are 2mm/s for 3D printed parts and 0.5 mm/s for aircraft component part. This is because the aircraft component samples are more brittle compare to 3D printed, hence a slower speed is used. The specimens were setup as shown in figure 3.14 (a) and figure 3.14 (b).



(a) (b)

Figure 3.14: Tensile test of (a) 3D printed specimens and (b) aircraft component specimens

3.8 Scanning electron microscope (SEM)

Scanning electron microscope (SEM) is a common apparatus use to observe the microstructure of the specimens. The information of the specimens was determined by the signal reflected by the high-energy electron beam. The dimension of scanning specimens used for SEM should have horizontal dimension less than 100mm and vertical dimension less than 40mm. 3 samples of specimens are scanned by SEM to obtain microstructure information which are 3D printed CF-PLA without heat treatment, 3D printed CF-PLA 95/90 and aircraft component carbon fiber composite samples. Each of the samples are placed on the scanning bed to observe. First, x100 magnification is selected to observe the sample followed by x200, x300 and x500 magnification. Screenshots are taken on each of the specific magnification. The microstructure of the specimens was discussed further in chapter 4 of the project. Screenshot of x100, x200, x300 and x500 magnifications were taken for each of the specimens.

CHAPTER 4   RESULT AND DISCUSSION

4.1   Overview

The result of tensile test, flexural test and scanning electron microscope (SEM) are shown and analyzed in details. The effect on the heat treatment process on 3D printed carbon fiber reinforced polylactic acid (CF-PLA) on tensile strength has been discussed to find out the best parameters for heat treatment process. Besides, the result of 3D printed CF-PLA The comparison of 3D printing and aircraft component manufacturing method have been studied for more understanding.

4.2   Effect of heat treatment process on tensile properties

Total of 21 3D printed carbon fibre reinforced polylactic acid (CF-PLA) had done heat treatment process and tensile test. The data of the experiments are analysed, the result is discussed here.

4.2.1   Tensile test analysis

There are total 21 3D printed CF-PLA specimens and heat treatment is done on 18 specimens with different treatment temperature and treatment duration. The heat treatment runs and process parameters have been shown in table 3.1. All of the 3D printed samples were tensile tested using universal testing machine. The process is to determine the process parameters of heat treatment effect on tensile strength of 3D printed CF-PLA. In theory, annealing process will allow the atoms of the specimens to recrystallize their structures to get a fine grain. The process will reduce the hardness of the samples and increase their strength if the temperature used is suitable. A proper annealing temperature will maximize the mechanical properties of the specimens. Table 4.1 shows the tensile strength, maximum load and Young' Modulus of each test specimens.

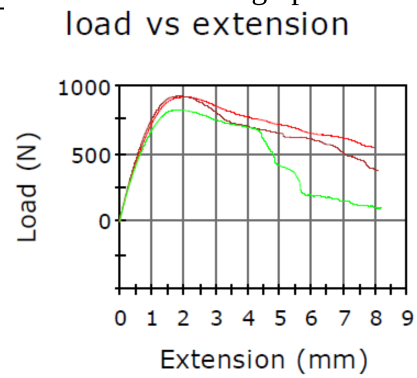
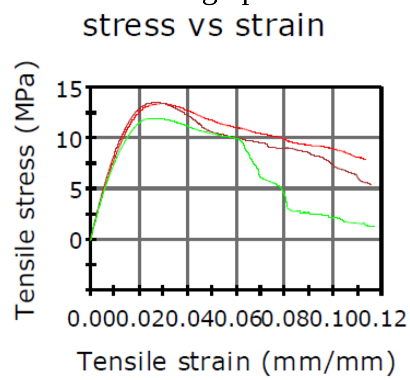
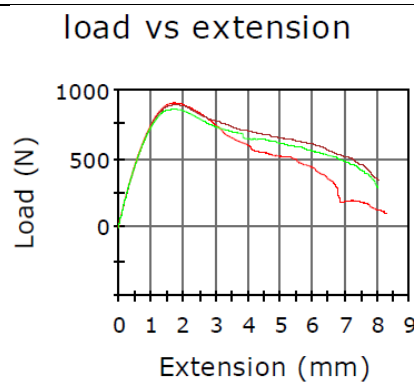
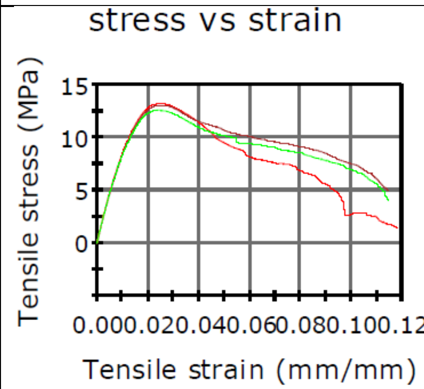
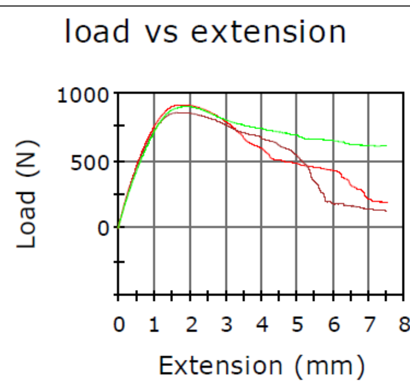
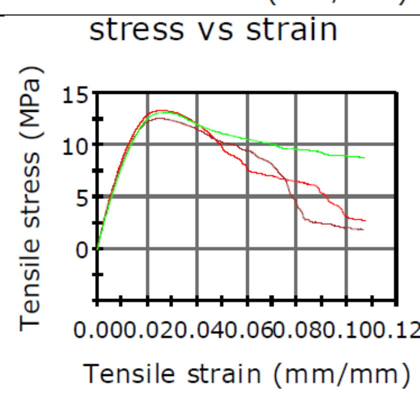
In result, specimens with annealing temperature of 95℃ and 90 minutes annealing duration (CF-PLA 95/90) shows the highest tensile strength which has 13.14MPa. It increased with 5.80% in tensile strength from 12.42MPa to 13.14MPa if compared with specimens without heat treatment. Specimens of same temperature 95℃ but with 30 minutes and 60 minutes (CF-PLA 95/30 & 95/60) also show some significant increase in tensile strength. It can be said that 95℃ is a good annealing temperature for 3D printed CF-PLA. In the other hand, specimens with 125℃ annealing temperature does not show significant changes after the heat treatment process. Its tensile strength remains similar to the specimens without heat treatment process.

Besides, CF-PLA 95/90 specimens have the highest maximum load before fracture and the highest value of Young's Modulus. CF-PLA 95/90 has an 4.11% increase of maximum load before fracture from 849.58N to 889.45N and 10.24% increase in Young's Modulus if compared to specimens without heat treatment process. CF-PLA 95/60 and CF-PLA 95/30 also show similar increase in maximum load withstand and increase in Young's Modulus. CF-PLA specimens with 125℃ heat treatment do not show significant increase of maximum load but they show increase value of Young's Modulus. Therefore, heat treatment with 95℃ and 90 minutes heating duration shows the greater increase in tensile strength, maximum load and Young's Modulus. Young's Modulus graph is shown in table 4.2.

Table 4.1: Tensile analysis of CF-PLA with different annealing conditions

Specimens	Temperature (℃)	Durations (mins)	Avg. maximum load (N)	Avg. Strain at Maximum(%)	Avg. tensile strength (MPa)	Avg. Young's Modulus (MPa)
A,B,C	95	30	884.57	2.77	12.93	971.04
D,E,F	95	60	883.1	2.49	12.91	1004.51
G,H,I	95	90	889.45	2.42	13.14	1011.34
J,K,L	125	30	844.02	2.61	12.34	984.01
M,N,O	125	60	846.98	2.73	12.38	975.6
P,Q,R	125	90	856.71	2.48	12.39	943.03
S,T,U	/	/	849.58	2.82	12.42	917.41

Table 4.2: preview of load vs extension and stress vs strain graphs of all the tensile specimens

Specimens no.	Load vs Extension graph	Stress vs Strain graph
A, B, C		
D, E, F		
G, H, I		
J, K, L