EFFECT OF LAYER THICKNESS AND FILL ANGLE ON FLEXURAL PROPERTIES OF CARBON FIBRE REINFORCED ABS PRINTED PART

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A report submitted
in fulfillment of the requirements for the degree of
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DECLARATION

"I hereby declare that the work in this report is my own except for summaries and quotations which have been duly acknowledged."

Signature: ....

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Date : ....

SUPERVISOR'S DECLARATION

I have checked this report and the report can now be submitted to JK-PSM to be delivered back to supervisor and to the second examiner.

Signature : ....

Name of Supervisor : DR. MOHD NIZAM BIN SUDIN

Date : ....

DEDICATION

For my beloved parents

for raising me to believe everything is possible!

and

my family

ABSTRACT

Fused deposition modelling (FDM) is a rapidly growing 3D printing technology. However, printing materials are restricted to acrylonitrile butadiene styrene (ABS) or polylactic acid (PLA) in most Fused deposition modelling (FDM) equipment. Here, this project on a new high-performance printing material, Carbon Fibre reinforced ABS, which could surmount these shortcomings. This project is dedicated to studying the influence of layer thickness and fill angle on the mechanical properties of 3D-printed specimens. Specimens with three different layer thicknesses (0.18mm, 0.25mm and 0.31mm) and fill angles (30º, 45º and 90º) were built using a 3D printing system and their flexural strengths were tested. The optimal mechanical properties of ABS specimens were found at a layer thickness of 0.25mm and a fill angle of 45° and for Carbon Fibre reinforced ABS obtained 0.18mm layer thickness and 45° fill angle. To evaluate the flexural properties of Carbon Fibre reinforced ABS specimens, a comparison was made between the mechanical properties of 3D-printed Carbon Fibre reinforced ABS and acrylonitrile butadiene styrene (ABS) parts.

ABSTRAK

Pemodelan Pemendapan Bersatu (FDM) adalah teknologi percetakan 3D berkembang pesat. Walau bagaimanapun, bahan-bahan percetakan adalah terhad kepada styrene acrylonitrile butadiene (ABS) atau asid polylactic (PLA) dalam kebanyakan terlakur pemodelan pemendapan (FDM) peralatan. Di sini, melaporkan pada bahan cetak yang berprestasi tinggi yang baru, gentian karbon bertetulang ABS, yang boleh mengatasi kelemahan ini. Kertas ini adalah khusus untuk mengkaji pengaruh ketebalan lapisan dan mengisi sudut atas sifat mekanik spesimen 3D bercetak. Spesimen dengan tiga ketebalan lapisan (0.18mm, 0.25mm dan 0.31mm) dan mengisi sudut (30º, 45º dan 90º) telah dibina menggunakan sistem percetakan 3D dan kekuatan lenturan mereka telah diuji. Sifat-sifat mekanikal yang optimum spesimen ABS ditemui pada ketebalan lapisan 0.25 mm dan sudut mengisi 45 ° dan untuk serat karbon bertetulang ABS diperolehi 0.18mm ketebalan lapisan dan 45 ° mengisi sudut. Untuk menilai sifat-sifat lenturan gentian karbon bertetulang spesimen ABS, perbandingan yang telah dibuat di antara sifat-sifat mekanikal 3D bercetak Fiber Carbon bertetulang ABS dan acrylonitrile butadiene styrene (ABS) bahagian.

ACKNOWLEDGEMENTS

Thanks to Allah SWT, whom with His willing giving me the opportunity to complete this Final Year Project which is title Effect Of Layer Thickness and Fill Angle on Flexural Properties of Carbon Fibre Reinforced ABS Printed Part. This final year project report was prepared for Universiti Teknikal Malaysia Melaka (UTeM), basically for student in final year to complete the undergraduate program that leads to the degree of Bachelor of Mechanical Engineering (Design and Innovation). This report is based on the methods given by the university.

Firstly, I would like to express my deepest thanks to, Dr Mohd. Nizam Bin Sudin, as my supervisor who had guided be a lot of task during two semesters session 2016/2017. I also want to thanks the lecturers and staffs of UTeM for their cooperation during I complete the final year project that had given valuable information, suggestions and guidance in the compilation and preparation this final year project report.

Deepest thanks and appreciation to my parents, family, special mate of mine, and others for their cooperation, encouragement, constructive suggestion and full of support for the report completion, from the beginning till the end. Also thanks to all of my friends and everyone, that have been contributed by supporting my work and help myself during the final year project progress till it is fully completed.

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LIST OF ABBEREVATIONS

ABS	Acrylonitrile Butadiene Styrene
PLA	Polylactic acid
3D	3 Dimensional
ASTM	American Society for Testing and Materials
FDM	Fused-Deposition Modelling
CAD	Computer Aided Design

LIST OF APPENDICES

LIST OF SYMBOL

C = Celcius

mm = Milimeter

CHAPTER 1

INTRODUCTION

1.1 Background

The material extrusion additive manufacturing (AM) process, commonly known as fused deposition modeling (FDM) is well known for its use in producing prototypes for concept modeling, pre-surgical models in medical applications, and various other uses. Fused deposition modeling (FDM) is such a layered manufacturing technology that produces parts with complex geometries by the layering of extruded materials, such as durable acrylonitrile butadiene styrene (ABS) plastic. In this process, the build material is initially in the raw form of a flexible filament. The feedstock filament is then partially melted and extruded though a heated nozzle within a temperature controlled build environment. According to Sun (2008), the material is extruded in a thin layer onto the previously built model layer on the build platform in the form of a prescribed two-dimensional (x-y) layer pattern. The deposited material cools, solidifies, and bonds with adjoining material. After an entire layer is deposited, the build platform moves downward along the z-axis by an increment equal to the filament height (layer thickness) and the next layer is deposited on top of it.

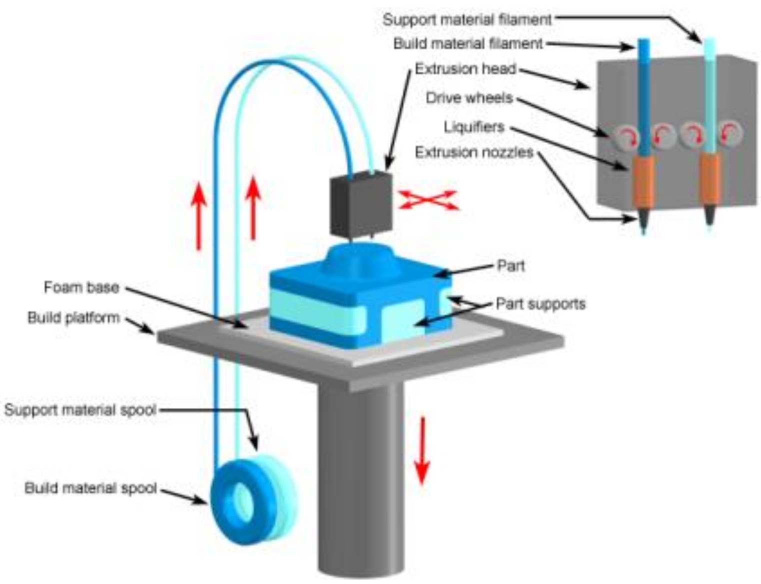


Figure 1.1: Schematic of the FDM process

Now days, there has been an ever-increasing study in composite materials for many types of industry in the world such as automotive industry and in many other fields (A.S Singha, 2009). Acrylonitrile-Butadiene-Styrene (ABS) currently used in making the filament. It is a rubber toughened thermoplastic, characterized by its notch insensitivity and low cost. Other than that, the disadvantages of ABS are poor flame and chemical resistance, and low thermal stability (L.A Utracki, 2002).

This paper presents the flexural test are carried out to determine the flexural properties of carbon fiber reinforced abs printed parts. By verifying the effect of layer thickness (0.18mm, 0.25mm and 0.31mm) and fill angle (30º, 45º and 90º) for the printed parts.

1.2 Problem Statement

Printed part layer by layer by using ABS material reported brittle due to the flexural strength and studies on ABS reinforced with carbon fiber have received less attention. The previous studies mainly usually focus on ABS only. The present study will focus on the effect of adding carbon fiber into ABS. The effect of adding certain percent of carbon into ABS has not yet been reported. This proposed study hopefully will contribute to further the knowledge in the area of carbon fiber reinforced ABS printed part.

1.3 Objective

The objectives of this project are as follows:

1. Comparing and evaluating the effect of layer thickness and fill angle on flexural properties of carbon fibre reinforced ABS.

1.4 Scope of Project

The scopes of this project are:

1. Flexural test carried out to determine effect of layer thickness and fill angle.
2. Preparing the specimen by using 3D printing technique with specific dimension and composition (pure ABS and 15% carbon).

CHAPTER 2

LITERATURE REVIEW

2.1 Acrylonitrile Butadiene Styrene (ABS)

2.1.1 Introduction

Acrylonitrile Butadiene Styrene (ABS) is a common end-use engineering material that allows to perform functional tests on sample parts in FDM. ABS is the combination of three different monomers Acrylonitrile, Butadiene, and Styrene to form a single polymer as shown in Figure 2.1(a). Acrylonitrile primarily offers chemical resistance and heat stability; butadiene delivers toughness and impact strength; and the styrene component provides ABS with balance of clarity, rigidity, and ease of processing (Svec, 1990). ABS has the highest use for thermoplastic in worldwide due to the characteristic itself.

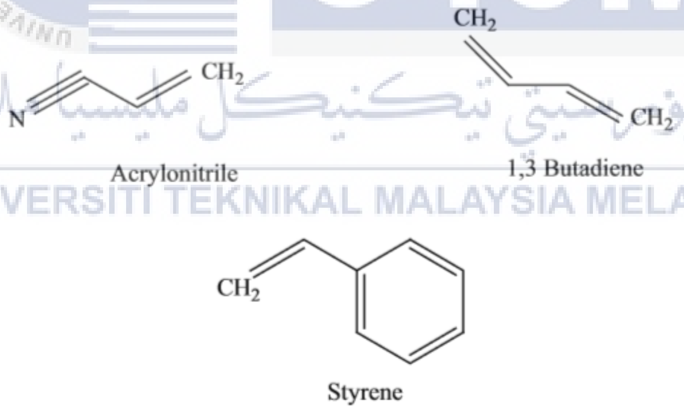


Figure 2.1(a): Monomers unit of ABS

As stated by Norbert (1971), the important characteristic of ABS in engineering thermoplastics is their stress-strain behaviour in flexure. Such measurements are usually made using a simple supported beam test specimen loaded at mid-span according to ASTM D790. The flexural strength at yield and flexural modulus can be used to determine the resistance of a product to short-term loadings. They are also useful in comparing the strength and rigidity of the many ABS products. According to Sharon (2016), ABS polymers exhibit high toughness (even in cold conditions), adequate rigidity, good thermal stability, and high resistance to chemical attack and environmental stress cracking. Other significant properties of ABS include cheapness, durability, and low coefficient of thermal expansion. This high impact ABS marks the boundary in price and performance between commodity and engineering thermoplastics (Fried, 2009). The common properties of ABS are it have a good resistance to heat and high toughness. Properties of ABS determined by morphological parameters and molecular parameter.

Acrylonitrile butadiene styrene (ABS) is one of the most widely used of the rubber toughened commercial plastics. A blend of polybutadiene rubber phase and styrene acrylonitrile copolymer (SAN) rigid phase are the phases of ABS. ABS is found in an extensive range of applications because of its excellent balance of mechanical properties, processing latitude, recyclability and economics. It can be further blended with other materials, thus the scope of possible applications is broadened (Jin, D. W. H, 1998).

2.1.2 Uses

ABS usually used in many technology industry such as automotive industry as shown in Figure 2.1(b). This is because of the price is cheap compared to other polymers. The performance ratio is a high rank. For interior injection molded application, high heat, general purpose, and low-gloss grade have been developed for application (Shahrir, 2006). Other manufacturers also use ABS to their product to product better quality of product. It is a commonly and extremely used thermoplastic that is used to manufacture appliance housings, shoe heels, pipes, chairs, insulated wires, automotive parts and pump impellers for 8 washing machines. Some notable properties of ABS are excellent impact strength and high rigidity, very good chemical and heat resistance properties, good creep resistance under heavy load and very low moisture absorption (Basdekis, C. H., 1964).

Figure 2.1(b): Example components in automotive industry

2.1.3 3D filament

When ABS act as 3D filament in Figure 2.1(c), printing with ABS usually operates with hot end nozzle and bed in the certain temperature. The melt temperature for ABS is about 200ºC to 250ºC. Furthermore, ABS have difficulty during moulding process because of low thermal conductivity. Thermal properties of ABS depends on their glass transition temperature, T_g. When the temperature of T_g increase, the flexural strength will decrease.

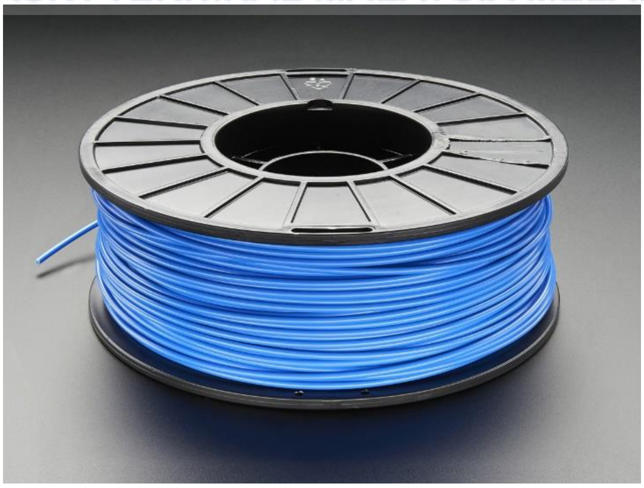


Figure 2.1(c): 3D Filament

A research of Sood (2009), study on parameter orientation layer thickness, raster angle, air gap and raster width effect on mechanical strengths, like tensile, flexural and impact strength. The surface plot is analysed to distortion between layers.

At the University of Texas at El Paso, Torrado et al. tested the hypothesis that varying additives in ABS reduces the change in effects between orientations. In this experiment, ABS was combined with plant fibers, metal oxides and other polymers creating four different blends. ABS was also mixed with two different ratios of styrene ethylene butadiene styrene (SEBS). In addition two combinations of ABS, SEBS, and ultra-high molecular weight polyethylene (UHMWPE) were tested. Each polymer combination was tested at two layer orientations; horizontal (XYZ) and vertical (ZXY). The experiment concluded that the polymer blend of ABS, SEBS, and UHMWPE was the most successful at reducing anisotropy of ultimate tensile strength due to a lower complex velocity above the glass transition temperature, creating stronger layer to layer bond. As a result, failure did not happen between layers, but rather occurred within layers.

2.1.4 Advantages and Disadvantages

ABS is good at toughness, cheap in price and high strength of impact. Shahrir (2006) state that in his study, the dimensional stability is good; it replaces die-cast metal components and can be electroplated for ABS. Also, properties for balancing by ABS are the best among the other polymers. Besides that, ABS have disadvantages which are the polymer is resistant to solar radiation and precipitation.

2.2 Composite Material

2.2.1 Introduction

A composite material can be defined as a combination of two or more materials that results in better properties than those of the individual components used alone (F.C Cambell, 2010). Now days, composite material becomes high demand on produce a product. The reinforcement can be in layers, but also as yarn or woven or as short fibres without specific organisation (Johannesson, 2013)

The advantages of composite materials are high strength, relatively low weight, and corrosion resistance. While, it also high raw material costs and usually high fabrication and assembly costs. For carbon composites, basically carbon composites is from carbon fibres and polymetric resins. It is very stiff and strong material.

2.2.2 Fibres

Fibre have high quality of strength behaviour. Fibre composites commonly consist of many layers, and the fibres in continuous-fibre composites laminated materials are normally oriented in directions that will enhance the strength in the primary load direction (Campbell, 2010). Orientation is one of the influence factor for strength. Unidirectional laminates fibre reinforced polymers have a fibre orientation of 0° and is very tough and stiff compared to 90° are very weak in the direction as the load must be carried by the polymer matrix that is much weaker (Campbell, 2010).

Fibres-reinforced composites are composed of two or more materials which, when properly combined, form a different material with properties not available from the ingredients alone. Depending on the ingredients chosen and the method of combining them, a large spectrum of material properties can be achieved. A brittle material can be made more ductile (flexible) by adding a softer material; conversely a soft material can be made stiffer. Wood is a good example of a composite. The cellulose fibers provide the strength and are held together by the resin (Scoot Roben, 2002).

Modern composites or FRP (Fiber reinforced polymers, or plastics) are the newest addition to the structural engineers toolbox. Although the materials have been available for decades, a reduction in cost, combined with newer understanding of the versatility and benefits of the material properties, has allowed composites to move into mainstream construction.

2.3 Fused-Deposition Modelling (FDM)

2.3.1 Introduction

Fused Deposition Modelling (FDM) is one of the most widely used 3D printing technique. In fused deposition process a plastic polymer in the form of a filament is used as the raw material for printing. Its structure and mechanics is similar to that of a CNC machines and its print head is known as an extruder. The tip of the extruder has a nozzle that is heated to a certain temperature, as the filament will be a semi solid state when it reaches this nozzle. This molten polymer is will extrude through the nozzle and deposited onto a heat bed, layer by layer. Some machines work by using of acrylonitrile butadiene styrene (ABS) polymer as its filament (Jim, 2014).

FDM was developed and patented in the year 1898 by Scott crump. Immediately after in 1990, he then setup Stratasys, a company which now specializes in manufacturing of additive fabrication machines for direct digital manufacturing .In 2007, almost half the amount of all fabrication systems worldwide was supplied by Stratasys making it a consecutive 6th time market leader. FDM in its working is quiet similar to the other rapid prototyping systems in which a STL file is fed into the fabrication machine which then builds the model layer by layer (K. G. Cooper, 2001). The parts are created as soon as the popularity has come with a proportionate increase in the study of 3D-printed techniques to investigate the properties and behaviour of different parts materials. Several previous studies utilized ASTM standard tensile test methods to determine the tensile properties as a function of the build and fill angles the specimens were printed (Bellini & Güçeri 2003; Giannatsis et al. 2012; Hill & Haghi 2014; Tymrak et al. 2014; Wittbrodt & Pearce 2015; Torrado Perez et al. 2014; Torrado et al. 2015; Es-Said et al. 2007; Ahn et al. 2003; Ahn et al. 2002; Montero et al. 2001).

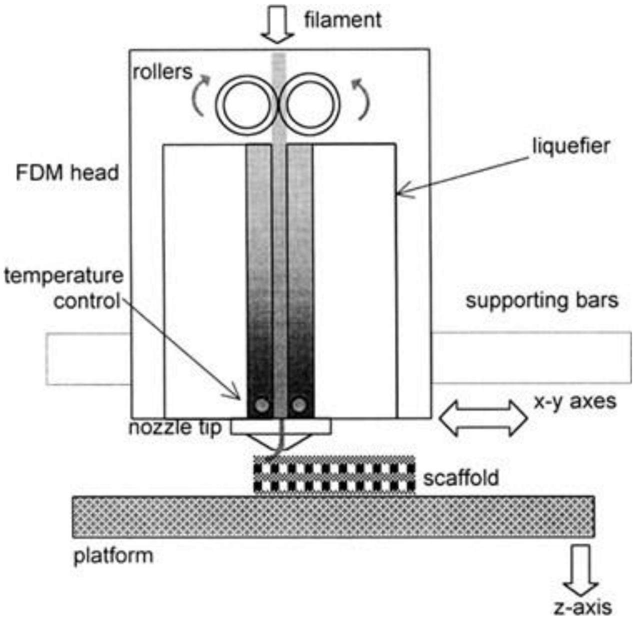


Figure 2.3(a): Schematic Diagram of 3D Printing

In this process, the 3D object designed with CAD software is imported as an STL file to the 3D printing software that would enable temperature controlled and the thermoplastic material layer by layer. The material changes from solid to semi-liquid state during the extrusion process to form layers upon layers. Each new layer will stack on top and the previous layer is harden immediately.

Technology RP use a single raw material for model is usual in RP technology but recently the Multiple material some research group are developing and improving their RP system such as MarkerBot machine that can enable to make a 3D model with two colors, but creating a 3D model that works in this way is still fairly tricky. Recently the developing of FDM machine that use a dual extrusion and two material is widely improving, such as MakerBot-Replicator-2X, Markerbotreplicator ,Leapfrog BV Xeed, leapfrog BV Creatr Dual Extruder ,Flash forge Creator 1 and others. These machines are developing that had a dual extruder and can print two of material.

Very little research work has been published on the advancement dual material printing and multiple extrusion heads. W.K Chiu and S.T Tan paper study about the multiple material objects from CAD representation to data format for rapid prototyping. This paper proposes a scheme for representing multiple material objects in a CAD system. N.A. Langrana, on her paper had describes a process planning method for a virtual simulation system (VSS) of FDM in RP. In this system, people can check or test a variety of the RP process parameters to make the best selection of multi-material tool-path and other parameters. Others paper by David Espalin, Jorge Ramirez, Francisco Medina, Ryan Wicker study about the Multi-Material, Multi-Technology FDM System, this study is using the two FDM machine that was modified and use LabView to control fabrication process and FDM motion software as an interface to control pneumatic slide. An FDM machine builds parts by driving a thermoplastic filament 1.59mm diameter into a heated liquefier and extruding a semi-molten polymer fiber through small diameter nozzle 0.127 to 0.330mm. This study successfully demonstrated the fabrication of discrete ABS-ABS parts; much work is required to fabricate using four extrusion tips. This study successfully demonstrated the fabrication of discrete ABS-ABS .The dissimilar material is the recommendation for other research.

According to Sood (2009) in his this study, five parameters orientation, layer thickness, raster angle, air gap and raster width effect is studied on different mechanical strengths like tensile, flexural, impact strength is done. By study about parameters, it can determined the quality and performance of the printed object. Response surface plots for each plot is analysed and weak strength is attributes to distortion between layers. FDM is the example of technology that mostly produce printed object from ABS. Based on Jaimin Patel (2012) experiment, about tensile strength and flexural strength on 3 types of parameter which are layer thickness, orientation angle and raster width. The output was orientation angle and layer thickness is important response on properties.

FDM materials such as ABS allow you to manufacture real parts that are tough enough for prototyping, functional testing, installation, and most importantly for end use. The production of thermoplastics are stable and have no appreciable warpage, shrinkage, or moisture absorption, like the resins (and powders) in competitive processes. Because thermoplastics are environmentally stable, part accuracy (or tolerance) does not change with ambient conditions or time.

In this study five parameters orientation, layer thickness, raster angle, air gap and raster width effect is studied on different mechanical strengths like tensile, flexural, impact strength is done. Response surface plots for each plot is analysed and weak strength is attributes to distortion between layers (Sood, 2009). Sood et al. performed experimental investigations on the influence of FDM process parameters such as layer thickness, part orientation, air gap, raster angle, and raster width on dimensional accuracy of an acrylonitrile-butadine-styrene (ABS) part. Percentage change in width, length and thickness of the part, resulting in three responses or performance measures determined the dimensional accurancy shows in Figure 2.3(b)

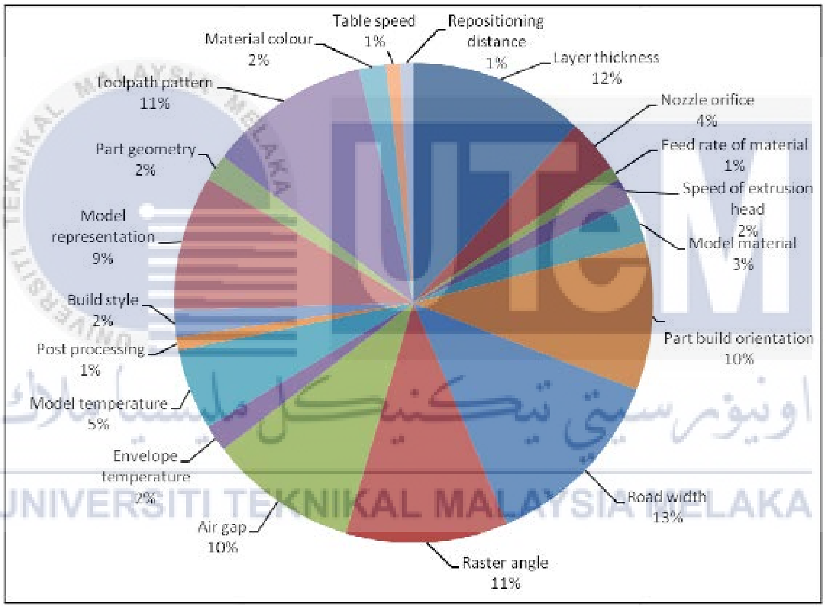


Figure 2.3(b): Distribution of influential parameters in the fabrication of FDM parts

2.4 Flexural Test

2.4.1 Introduction

Flexural testing when a force is applied as shown in Figure 2.4(a) directly to the longitudinal axis of the sample that determines the strength of material that used (Mithun, 2011). Flexural testing is a test beam under compressive stress at the concave surface. It also usually be tested to determine the flexibility of materials such as wood, polymers and composites (T. Kanie, 2000).

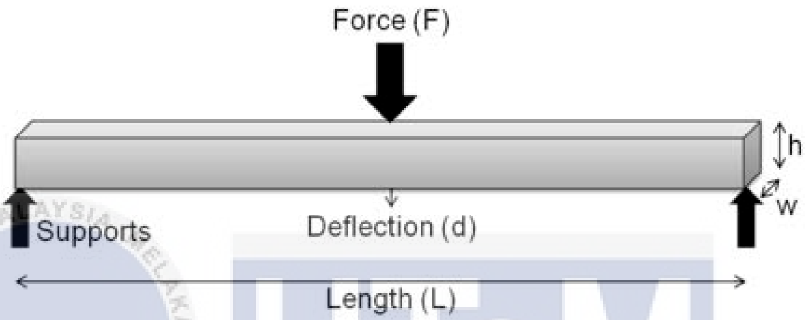


Figure 2.4(a): Flexural testing

There are two types of Flexural test which are 3-point flex and 4-point flex. 3-point flex test is a typical test for polymers. It test the area of uniform stress is small and concentrated under the centre loading point. While 4-point flex, the area of uniform stress exists between the inner span loading points. The specimens shapes can be used for this test, commonly used specimen size for ASTM is 3.2mm x 12.7mm x 125mm (0.125" x 0.5" x 5.0") and for ISO is 10mm x 4mm x 80mm as shown in Figure 2.4(b) and Figure 2.4(c). For ASTM D790, the test is stopped when the specimen reaches 5% deflection or the specimen breaks before 5%. For ISO 178, the test is stopped when the specimen breaks.

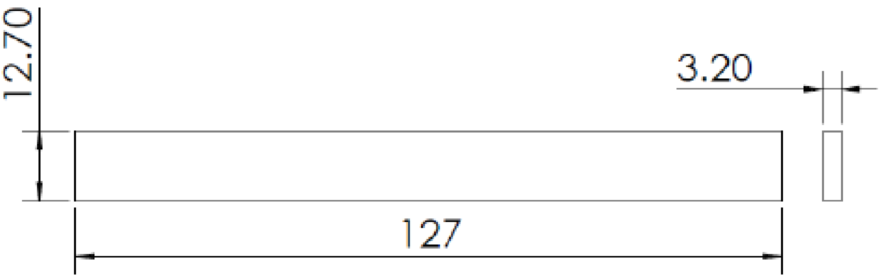


Figure 2.4(b): Specimen size for ASTM D790

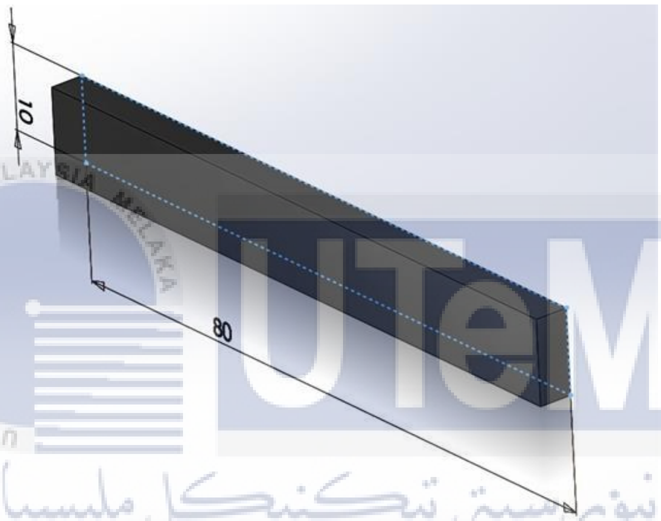


Figure 2.4(c): Specimen size for ISO 178

Flexural strength of a specimen is its ability to resist deformation under load. This test determined flexural stress at yield, flexural strain at yield, flexural stress at break, flexural strain at break, flexural stress at 3.5% (ISO) or 5.0% (ASTM) deflection, flexural modulus. Stress/Strain curves and raw data can be provided.

CHAPTER 3

METHODOLOGY

3.1 Introduction

This chapter describes the methodology used in this project to obtain data for flexural properties. For the third chapter of this project, the methodology for completing this project will go through one by one in order to list down all important things from this project. Next, study on machine involve for preparation of materials and testing for specimens. Sample preparation starting with draw the part by using specific dimension and lastly print by using 3D printer. Thus, all the specification is based on the literature review of this project. The flow process in Figure 3.1 has been made to identify the all work for this project.

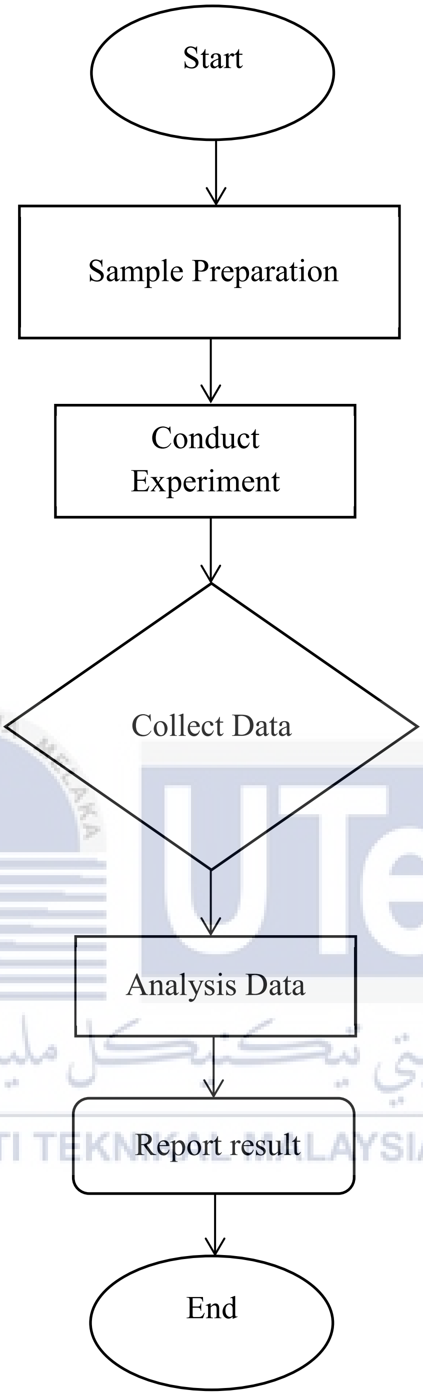


Figure 3.1: Flow Chart of the Project

3.2 Sample Preparation

The standard size of parts for flexural test is based on ASTM D790 as shown in Figure 3.2(a). Mechanical test parts were designed in CATIA V5 and then tesselated shown in Figure 3.2(b). This process is same for other rapid protoyping type to have an accurate part design. Next, design were exported as files in Stereolithography (STL) format for import to the FDM software. This STL is standard to rapid prototyping format. It contains the 3D model that is used to make a physical object before the design parts transfer to any 3D printer software.

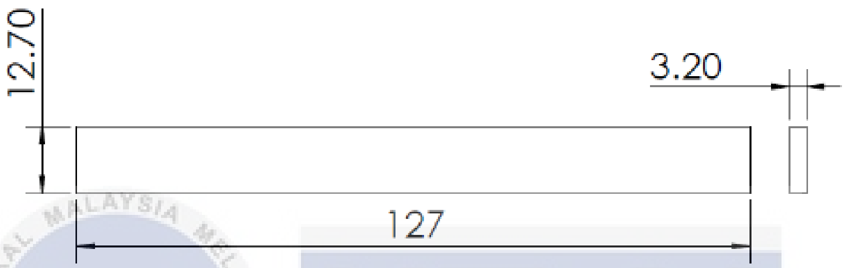


Figure 3.2(a): Parts size in unit mm

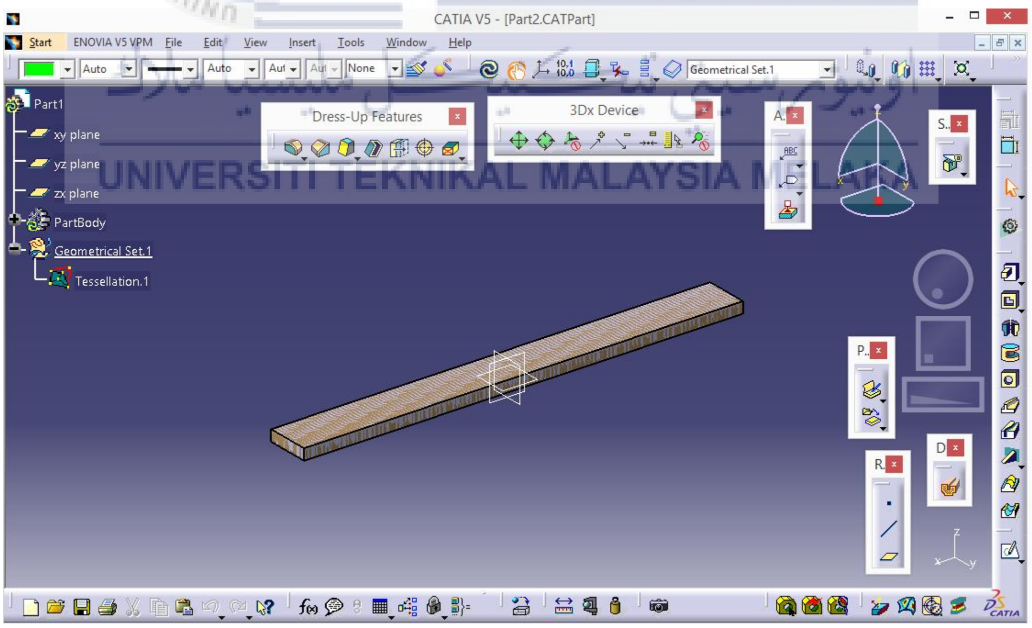


Figure 3.2(b): CATIA V5 software

After that, the parts design in STL format will transfer to Flash Print software. This software used to connect to the 3D printer. It will convert the STL format to a 3D printed parts format which is .g shown in Figure 3.2(c). Parameters be changed manually, from temperature to printing speed and even the first layer thickness and raster angle. Last but not least, the parts design were printed by using 3D printer in Figure 3.2(d). In this project, layer thickness and fill angle is changing to investigate the strength of the specimens in changing the parameters. The flexural properties will be analyse. The result of analysis will be different from one specimen to other specimen because of changing of layer thickness and fill angle. Flexural test has been used as a test method in this research involving two different material which are ABS and Carbon Fibre Reinforced ABS.

Figure 3.2(c): Flash Print Software

Figure 3.2(d): Flash Forge Dreamer 3D Printer

The parts were printed by changed the layer thickness which are 0.18mm, 0.25mm and 0.31mm shown in Figure 3.2(e) and fill angle 30º, 45º and 90º . Figure 3.2(f) and Figure 3.2(g) shows the illustrated how the specimens were printed based on the parameter changed. The other parameters were fixed at certain value. Estimation time for printed was about 30 minute for one part. For the total parts was 18 parts.

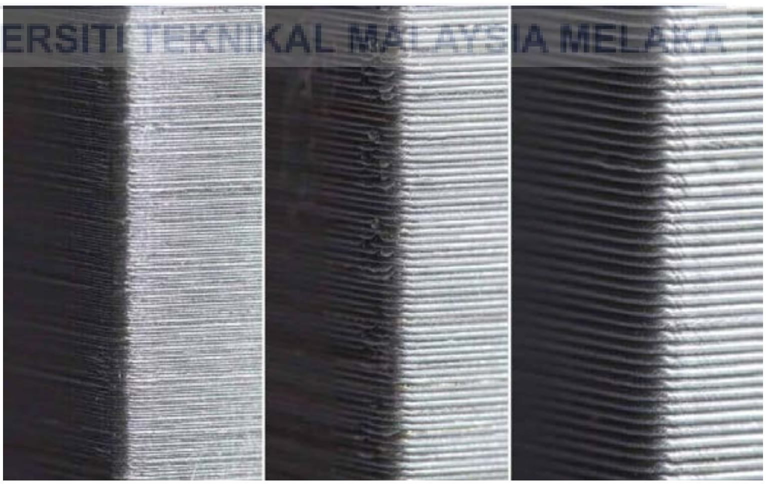


Figure 3.2(e): Layer thickness 0.18mm(left), 0.25mm(middle) and 0.31mm(right)

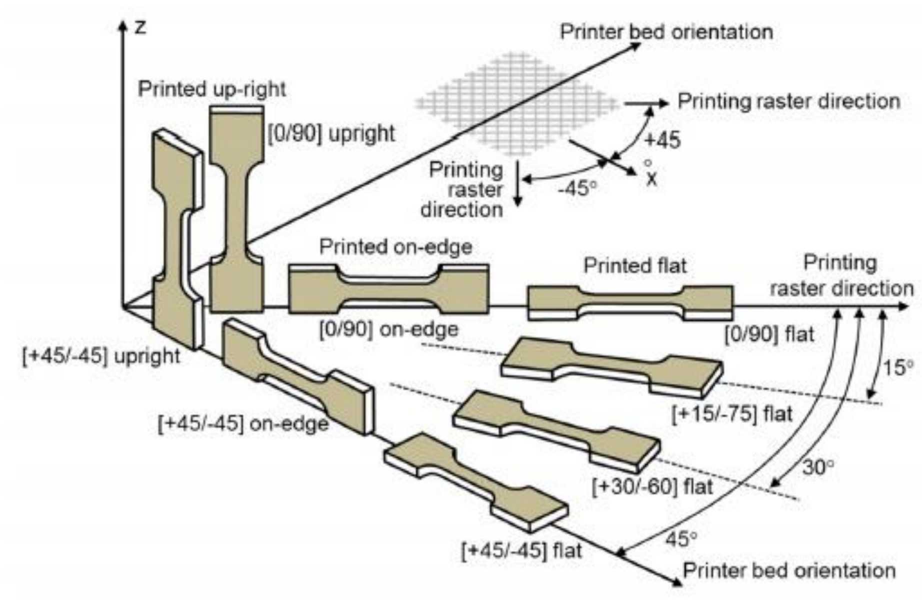


Figure 3.2(f): Illustration of the printer bed fill angles for 30º, 45º and 90º

Figure 3.2(g): Fill angles direction, 30º(middle), 45º(top) and 90º(bottom)

Table 3.2: Default Part Build Parameters

Parameter	Value
Fill Density	90%
Fill Pattern	Hexagon
Build Orientation	Y axis
Extruder Temperature	220 ºC
Platform Temperature	105 ºC
Nozzle diameter	1.8mm

3.3 Flexural Test

The flexural test was done based on ASTM standard which was ASTM D790. It is a standard test method for flexural properties of unreinforced and reinforced plastics and electrical insulating materials. This test can be used on electrical insulating materials and high-modulus composites. At the end the data is often used to select materials for parts that will support loads without flexing. It was carried out on an universal material machine, equipped with a 100N load cell. Eighteen specimens were tested for every parameter modification. The specimens bend at a strain rate of 3mm/min and the span was 100mm. The loading nose and support were aligned in such a way that axes of the cylindrical surfaces are parallel and the loading nose is midway between the supports. The specimen is supported in the center with the long axis of the specimen perpendicular to the loading nose and supports as shown in Figure 3.3.

The test specimen will bent into a “U” or “V” shape with the outside surface experiencing tensile forces and the inside face experiencing compressive forces. The specimen is deflected until a breaking point occurs in the outer surface of the test specimen or until a maximum strain of 5% is reached. The machine will provide flexural properties such as modulus of elasticity in bending, flexural strain, flexural stress, and the flexural stress-strain curves. The test were conducted at room temperature (approximately 25°C).

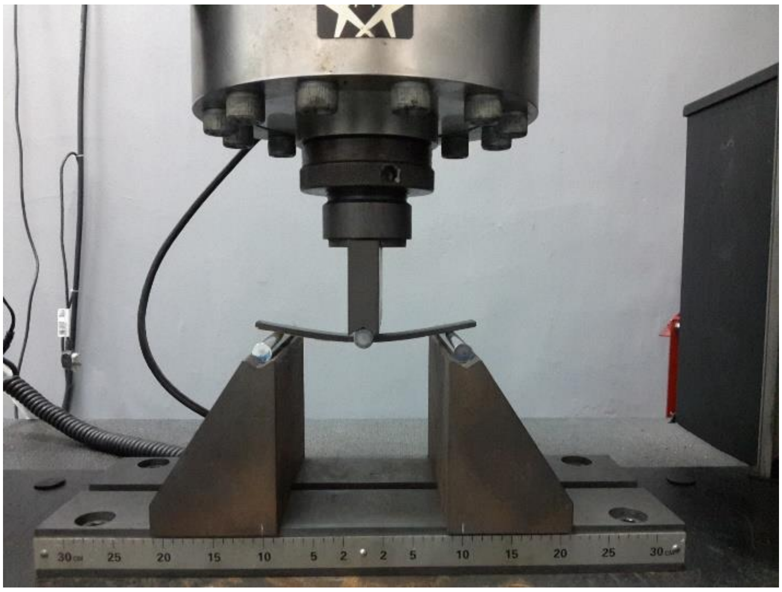


Figure 3.3: Universal Material Machine (INSTRON 5585)

CHAPTER 4

RESULTS AND DISCUSSION

4.1 Experimental Results

Flexural testing is performed to determine the flexural strength of a material. The flexural testing is used to measures the maximum flexural stress that may be sustained before failure of a material. The stresses induced by the flexural load are a combination of compressive and tensile stresses as shown in Figure 4.1(a).

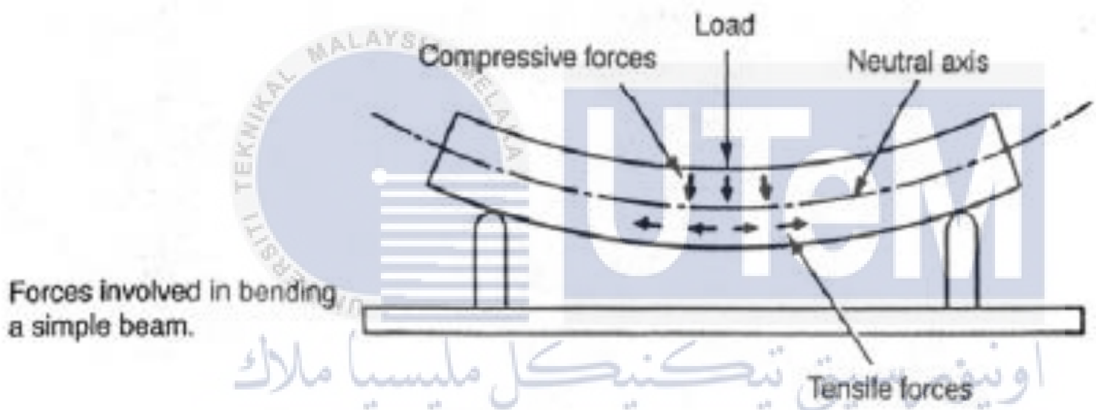


Figure 4.1: Combination of compressive and tensile stresses in flexural test

After conducting the flexural tests for all eighteen specimens for a given materials, the raw data was tabulated. Plots containing all of the stress-strain curves for a given material were created to allow for qualitative comparisons between the different layer thicknesses and fill angle. From these curves, the mechanical properties of the specimens were calculated.

The test result of the specimens for ABS is tabulated in Table 4.1(b). From the table, it can be noted that the higher flexural strength was 45° for 0.25mm layer thickness which was 45.23 MPa. The strength of specimen with 30° and 90° decreased significantly. Next, for Carbon Fibre reinforced ABS is tabulated in Table 3. From the table shows that the higher flexural strength was 45° for 0.18mm layer thickness which was 43.43 MPa. The strength of specimen with 30° and 90° decreased trend.

Table 4.1(a): Tabulated results of flexural specimens for Acrylonitrile Butadiene Styrene (ABS) with different fill angle

Layer Thickness (mm)	*Fill Angle*	*Maximum Flexural Stress (MPa)*	*Maximum Flexural Strain (%)*	*Load at Maximum Flexural Strength (N)*	*Extension at Maximum Load (mm)*
0.18	30°	43.59	13.0	37.79	16.53
	45°	44.90	15.7	38.93	19.91
	90°	44.95	12.9	38.98	16.49
0.25	30°	39.81	14.0	34.51	17.79
	45°	45.23	13.4	39.21	17.27
	90°	44.60	11.1	38.67	14.10
0.31	30°	38.02	15.4	32.96	19.50
	45°	32.87	14.3	28.50	18.16
	90°	37.20	14.3	32.25	18.19

Table 4.1(b): Tabulated results of flexural specimens of Carbon Fibre reinforced ABS with different fill angle

Layer Thickness (mm)	*Fill Angle*	*Maximum Flexural Stress (MPa)*	*Maximum Flexural Strain (%)*	*Load at Maximum Flexural Strength (N)*	*Extension at Maximum Load (mm)*
0.18	30°	41.06	8.5	35.60	10.81
	45°	43.43	9.5	37.65	12.80
	90°	39.84	8.0	34.54	10.28
0.25	30°	40.59	10.3	35.19	13.13
	45°	38.88	10.3	33.71	13.12
	90°	41.86	7.9	36.29	10.13
0.31	30°	38.56	9.7	33.43	12.37
	45°	39.49	9.4	34.24	12.01
	90°	38.91	8.5	33.73	10.82

4.2 Effect of Fill Angle on Flexural Properties

4.2.1 Acrylonitrile Butadiene Styrene (ABS) specimens

Figure 4.2(a) shows that the relationship between flexural stress (MPa) and flexural strain (mm/mm) in graphically. During the test, layer thickness of the specimens is constant which is 0.18mm while the fill angle (°) is changed where 30° the flexural stress is 43.59 MPa which is 3% lowest value of flexural stress compared to the highest. At 45° fill angle the flexural stress shows that 44.90 MPa and for fill angle 90°, the maximum flexural stress appeared is 44.95 MPa. For fill angle 90°, it shows that it has a lowest elastic zone compared to the others. The curves shows decreased and increased trend that show the optimum value of flexural stress. Next testing curves shown in Figure 4.2(b) for the layer thickness is unchanged with value 0.25mm and only the fill angle is being changed in order to obtain flexural stress (MPa) value. The highest flexural stress value is 45.23 MPa on fill angle 45°. Moreover, on fill angle 30°, the flexural stress is 39.81 MPa which is the lowest which is 11.9% lower than the highest one and finally fill angle 90° the flexural stress is 44.60 MPa. The reason why fill angle for 90° was the lowest is the direction of the force being exerted on the specimen was exactly parallel with the layer grain of the specimen.

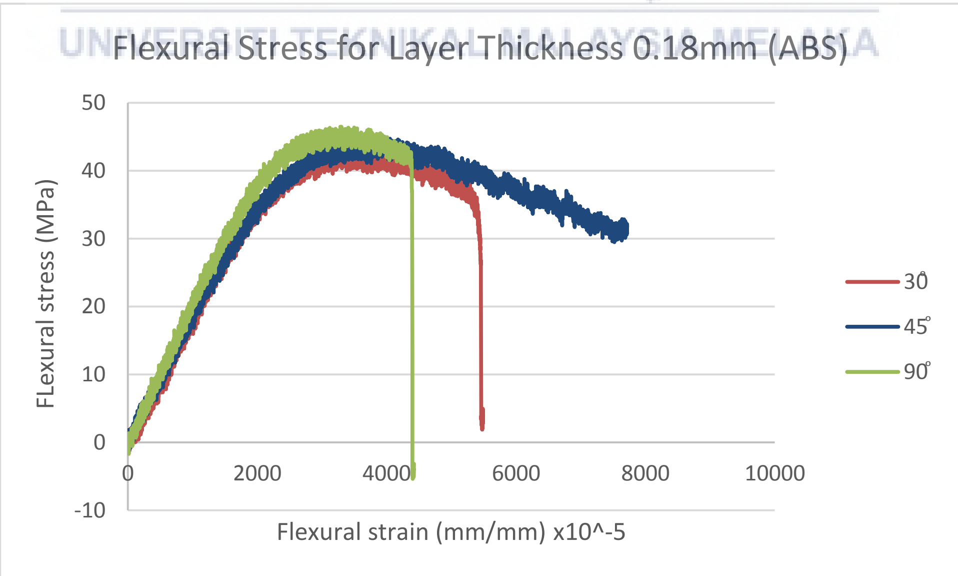


Figure 4.2(a): Stress-strain curve for flexural layer thickness 0.18mm specimens of 30°, 45° and 90° fill angle

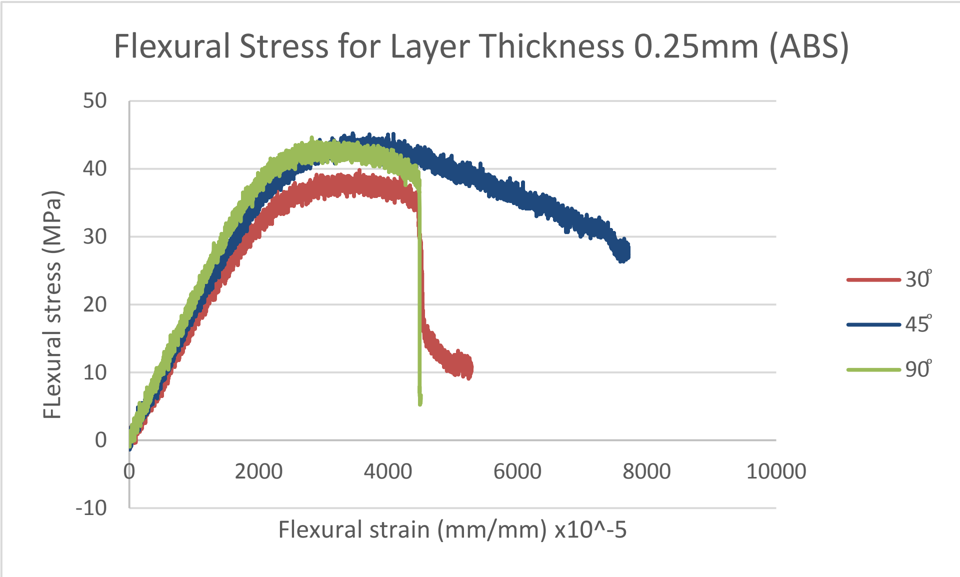


Figure 4.2(b): Stress-strain curve for flexural layer thickness 0.25mm specimens of 30°, 45° and 90° fill angle

Additionally, result for layer thickness 0.31mm curves shown in Figure 4.2(c), the flexural stress is slightly high at fill angle 30° which is 38.02 MPa. The flexural stress decrease when the fill angle 45° and 90° which are 32.87 MPa and 37.20 MPa respectively. This was unexpected result as the fill angle for 90° was higher than 45°. The curves is showing increased and decreased trends. This brittle behaviour because of the angle is parallel to the forced exerted. Figure 4.2(d), Figure 4.2(e) and Figure 4.2(f) shows the fracture Flexural ABS Specimens for the three layer thicknesses.

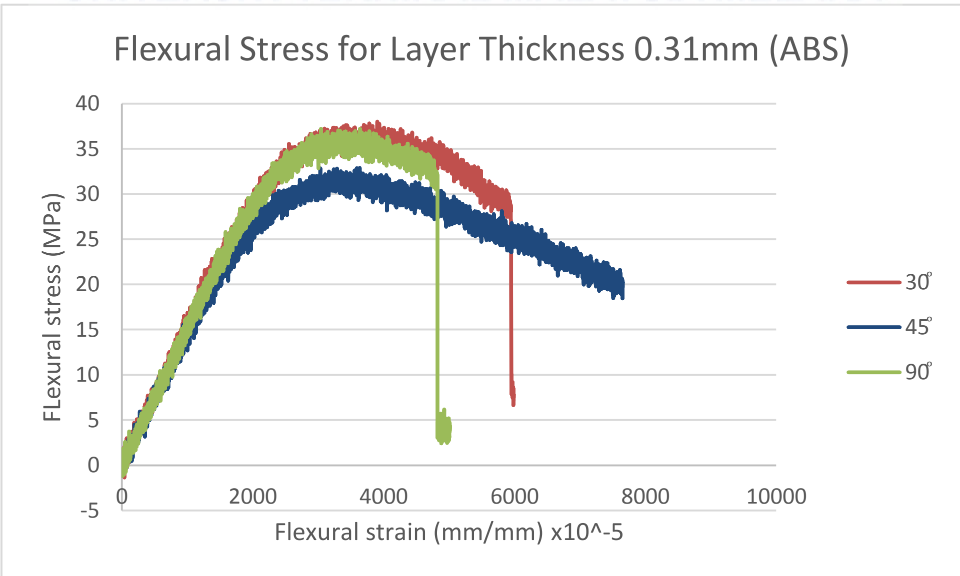


Figure 4.2(c): Stress-strain curve for flexural layer thickness 0.31mm specimens of 30°, 45° and 90° fill angle

Figure 4.2(d): Fracture Flexural ABS Specimens for layer thickness 0.18mm

Figure 4.2(e): Fracture Flexural ABS Specimens for layer thickness 0.25mm

Figure 4.2(f): Fracture Flexural ABS Specimens for layer thickness 0.31mm

4.2.2 Carbon Fibre Reinforced ABS specimens

The data collected from the testing of the Carbon Fibre reinforced ABS specimens, like the ABS specimens, Figure 4.2(g) shows bending engineering stress-strain curves for Carbon Fibre reinforced ABS specimens. The flexural stress for layer thickness 0.18mm on 45° fill angle is 43.43 MPa, 8.2% higher than 90° fill angle which is 39.84 MPa. 90° fill angle is the lower flexural strength compared to 30° which is 41.06 MPa. The result may be explained in terms of the direction of the compressive force being exerted on the sample in relation to the direction of the sample's constituent layers.

Furthermore, for layer thickness 0.25mm, the curves shown in Figure 4.2(h) explained that fill angle for 45° is 7.1% lower than specimen with 90° for the fill angle which is the highest flexural stress obtained, 41.86 MPa. The properties of the printed specimens are anisotropic. Moreover, the results confirms the hypothesis that the strength of anisotropy is affected by the directional processing of the 2D layers. These were because, the direction of weaker point when the fill angle is parallel to the axis of load. Figure 4.2(j), Figure 4.2(k) and Figure 4.2(l) shows the fracture flexural specimens for each of parameter.

Finally for layer thickness 0.31mm, the highest flexural stress value is 39.49 MPa on fill angle 45°. It shows that 45° is the most suitable fill angle for a specimen to sustain before failure of an object. Only 2.4% and 1.5% for 30° and 90° respectively lower than specimen with 45° fill angle. The curves shows in Figure 4.2(i). Anisotropy was found more often when varying when changing fill angle and flexural properties opposed isotropic behaviour.

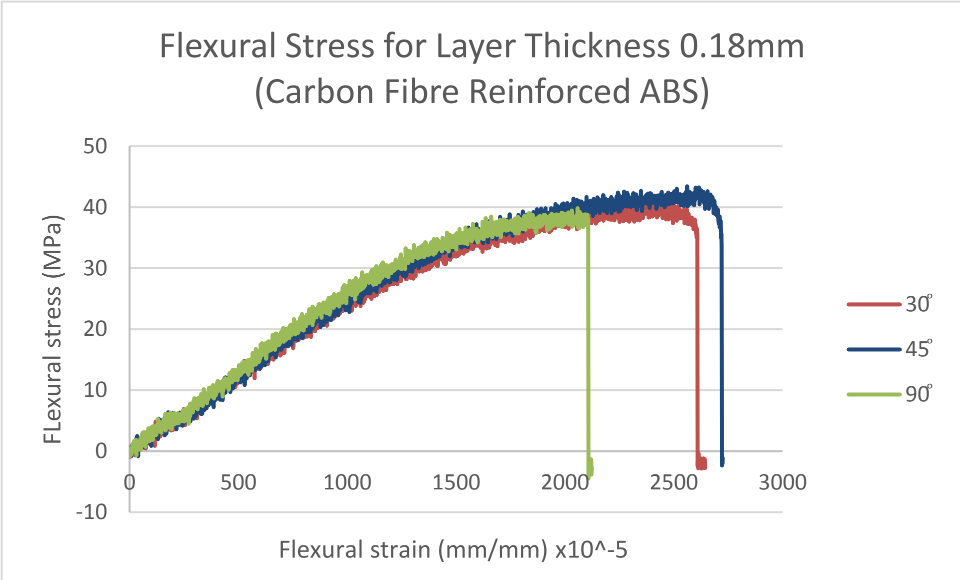


Figure 4.2(g): Stress-strain curve for flexural layer thickness 0.18mm specimens of 30°, 45° and 90° fill angle

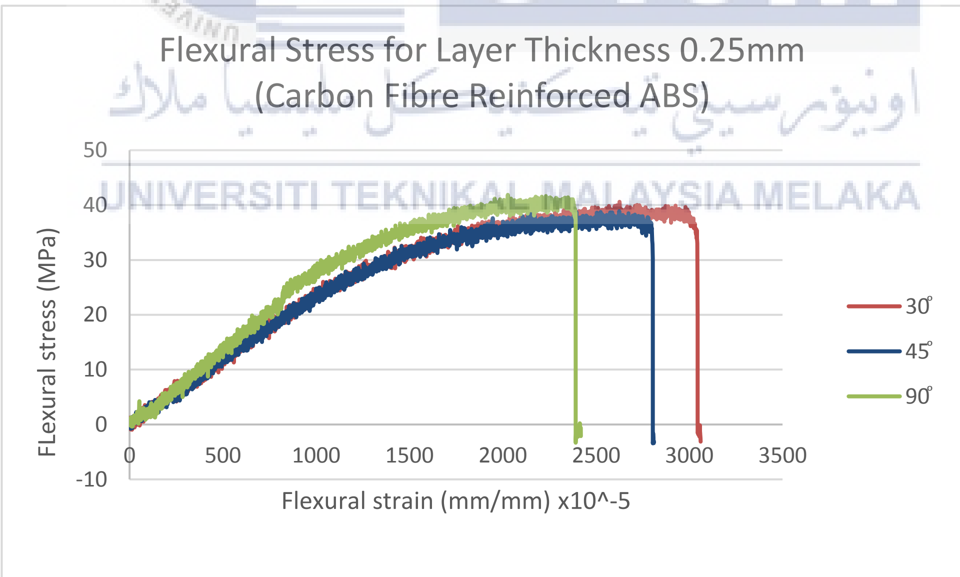


Figure 4.2(h): Stress-strain curve for flexural layer thickness 0.25mm specimens of 30°, 45° and 90° fill angle

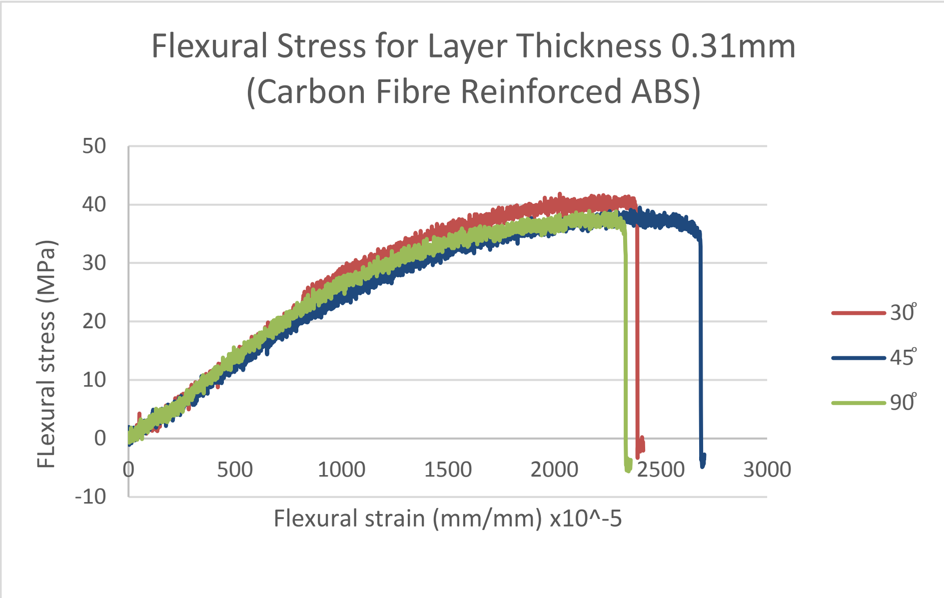


Figure 4.2(i): Stress-strain curve for flexural layer thickness 0.31mm specimens of 30°, 45° and 90° fill angle

Figure 4.2(j): Fracture Flexural Carbon Fibre reinforced ABS Specimens for layer thickness 0.18mm

Figure 4.2(k): Fracture Flexural Carbon Fibre reinforced ABS Specimens for layer thickness 0.25mm

i

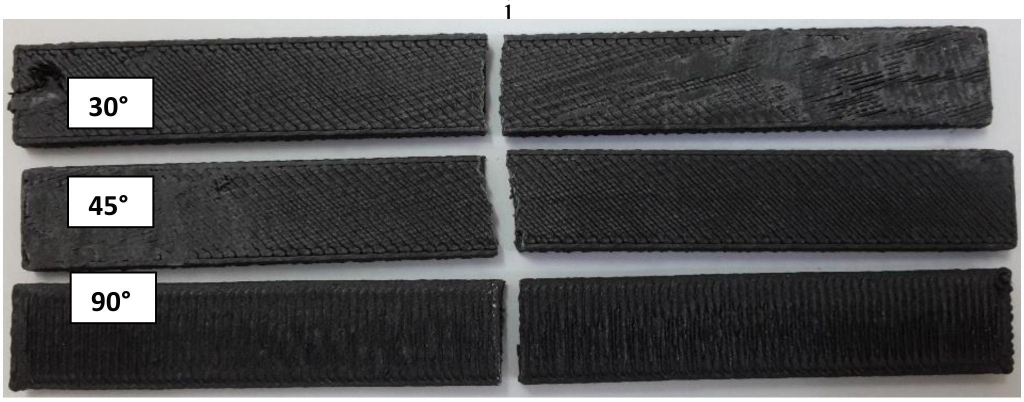


Figure 4.2(l): Fracture Flexural Carbon Fibre reinforced ABS Specimens for layer thickness 0.31mm

4.3 Effect of Layer Thickness on Flexural Properties

4.3.1 Acrylonitrile Butadiene Styrene (ABS) specimens

In this section, the results of flexural properties on fill angle with different layer thickness of specimens of ABS are given. The test result of the specimens for ABS and Carbon Fibre Reinforced ABS are tabulated in Table 4.3(a) and Table 4.3(b) respectively. For this section, fill angle of the specimens is constant and the layer thickness changed according to the tables.

Table 4.3(a): Tabulated results of flexural specimens of ABS with different layer thickness

Fill Angle	*Layer Thickness (mm)*	*Maximum Flexural Stress (MPa)*	*Maximum Flexural Strain (%)*	*Load at Maximum Flexural Strength (N)*	*Extension at Maximum Load (mm)*
30°	0.18	43.59	13.0	37.79	16.53
	0.25	39.81	14.0	34.51	17.79
	0.31	38.02	15.4	32.96	19.50
45°	0.18	44.90	15.7	38.93	19.91
	0.25	45.23	13.4	39.21	17.27
	0.31	32.87	14.3	28.50	18.16
90°	0.18	44.95	12.9	38.98	16.49
	0.25	44.60	11.1	38.67	14.10
	0.31	37.20	14.3	32.25	18.19

Table 4.3(b): Tabulated results of flexural specimens of Carbon Fibre reinforced ABS with different layer thickness

Fill Angle	*Layer Thickness (mm)*	*Maximum Flexural Stress (MPa)*	*Maximum Flexural Strain (%)*	*Load at Maximum Flexural Strength (N)*	*Extension at Maximum Load (mm)*
30°	0.18	41.06	8.5	35.60	10.81
	0.25	40.59	10.3	35.19	13.13
	0.31	38.56	9.7	33.43	12.37
45°	0.18	43.43	9.5	37.65	12.80
	0.25	38.88	10.3	33.71	13.12
	0.31	39.49	9.4	34.24	12.01
90°	0.18	39.84	8.0	34.54	10.28
	0.25	41.86	7.9	36.29	10.13
	0.31	38.91	8.5	33.73	10.82

Curves in Figure 4.3(a) shows that the relationship between flexural stress (MPa) and flexural strain (%) of fill angle 30°. The highest flexural stress appeared is 43.59 MPa which belongs to layer thickness 0.18mm, 8.6% and 12.0% higher than layer thickness 0.25mm and 0.31mm respectively and they have much lower flexure strength than the layer thickness 0.18mm. This shows that the lower the layer thickness use, the greater the flexural strength.

Next testing curves is done by changing the fill angle to 45° shows in Figure 4.3(b). Layer thickness did have an effect on flexural strength and the result shows that lowest flexural stress value is 32.87 MPa on layer thickness 0.31mm. Moreover, on 0.18mm layer thickness shows increasing in flexural stress which is 44.90 MPa. In addition, for layer thickness 0.25mm, flexural stress obtained 27.3% higher than result for layer thickness 0.31mm which is 45.23 MPa.

Figure 4.3(c) illustrates that influence of fill angle 90° with different layer thickness results. The trend of flexural stress for the fill angle is similar to the previous. The lower layer thickness used has higher of flexural strength. The greater of flexural stress is increasing from 37.20 MPa on layer thickness 0.31mm and 44.60 MPa belongs to layer thickness 0.25mm. Last but not least, the highest is 44.95 MPa on layer thickness 0.18mm. Apparently, layer thickness have a marginal effect in flexural properties.

Although the layer thickness had a great influence on flexural strength. The low strength of the test specimen due to weak interlayer bonding. Weak inter layer bonding also caused by the low modular diffusion and low cross-link between the layers deposition during the melt. Besides that, the interlayer porosity reduced the load bearing area across the layers hence there is easy way to create the fracture path.

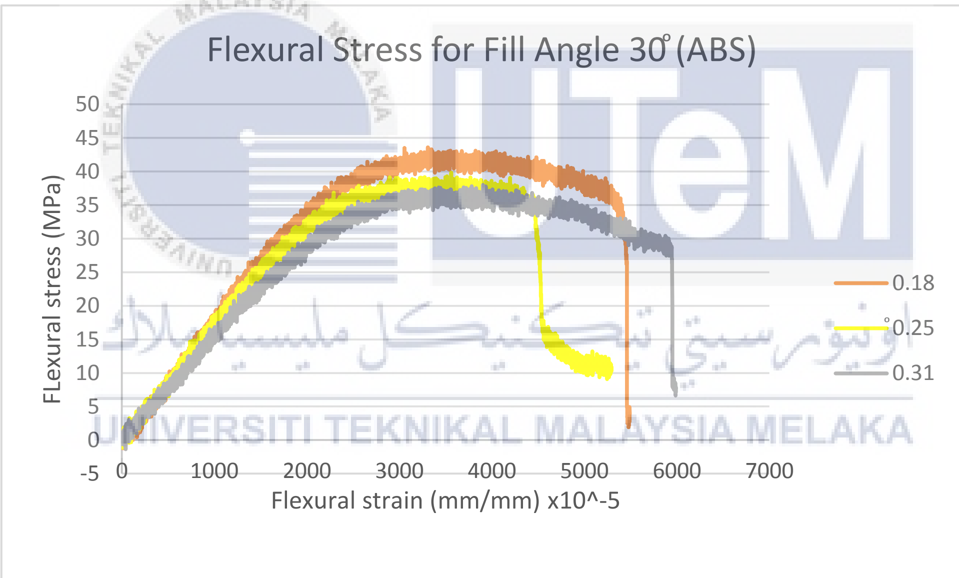


Figure 4.3(a): Stress-strain curve for flexural fill angle 30° specimens of 0.18mm, 0.25mm and 0.31mm layer thickness

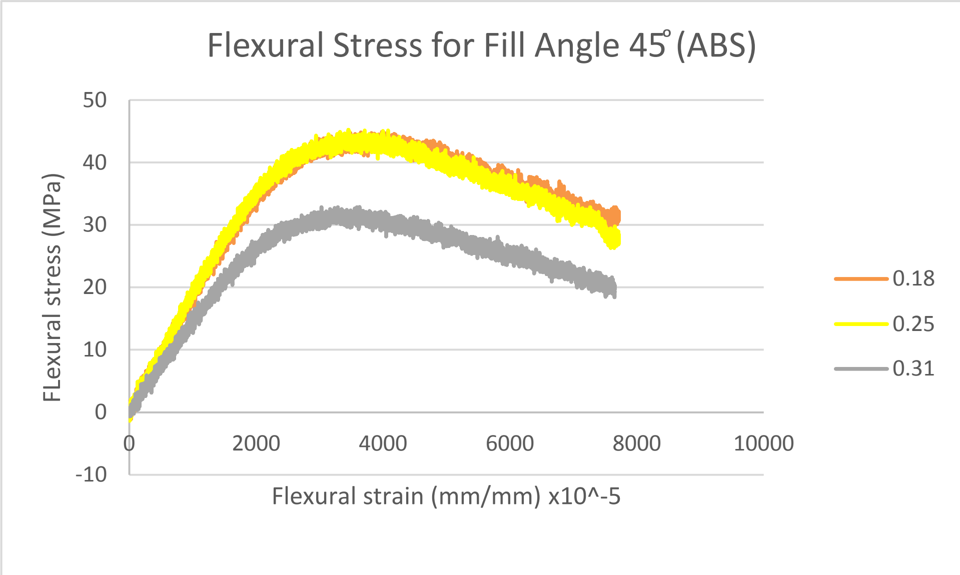


Figure 4.3(b): Stress-strain curve for flexural fill angle 45° specimens of 0.18mm, 0.25mm and 0.31mm layer thickness

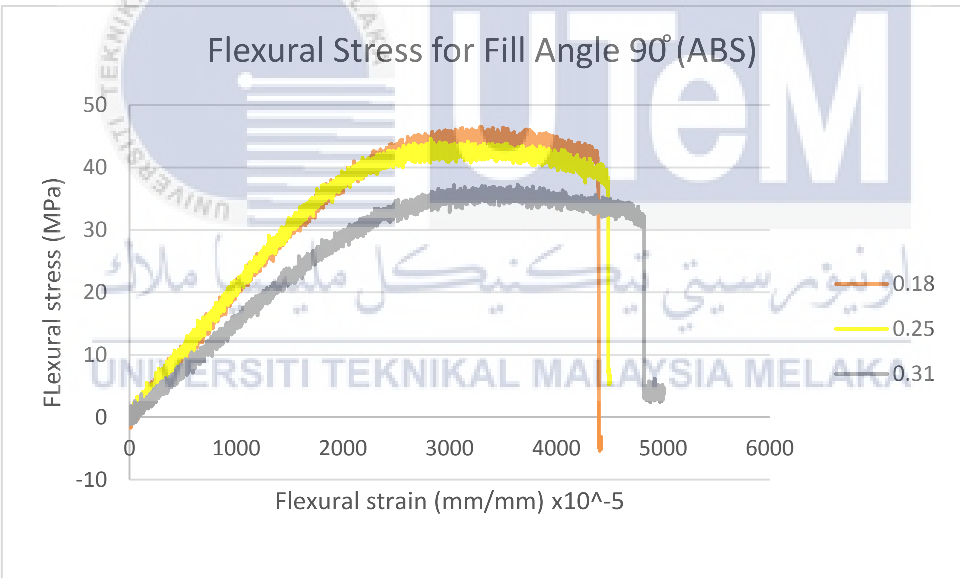


Figure 4.3(c): Stress-strain curve for flexural fill angle 90° specimens of 0.18mm, 0.25mm and 0.31mm layer thickness

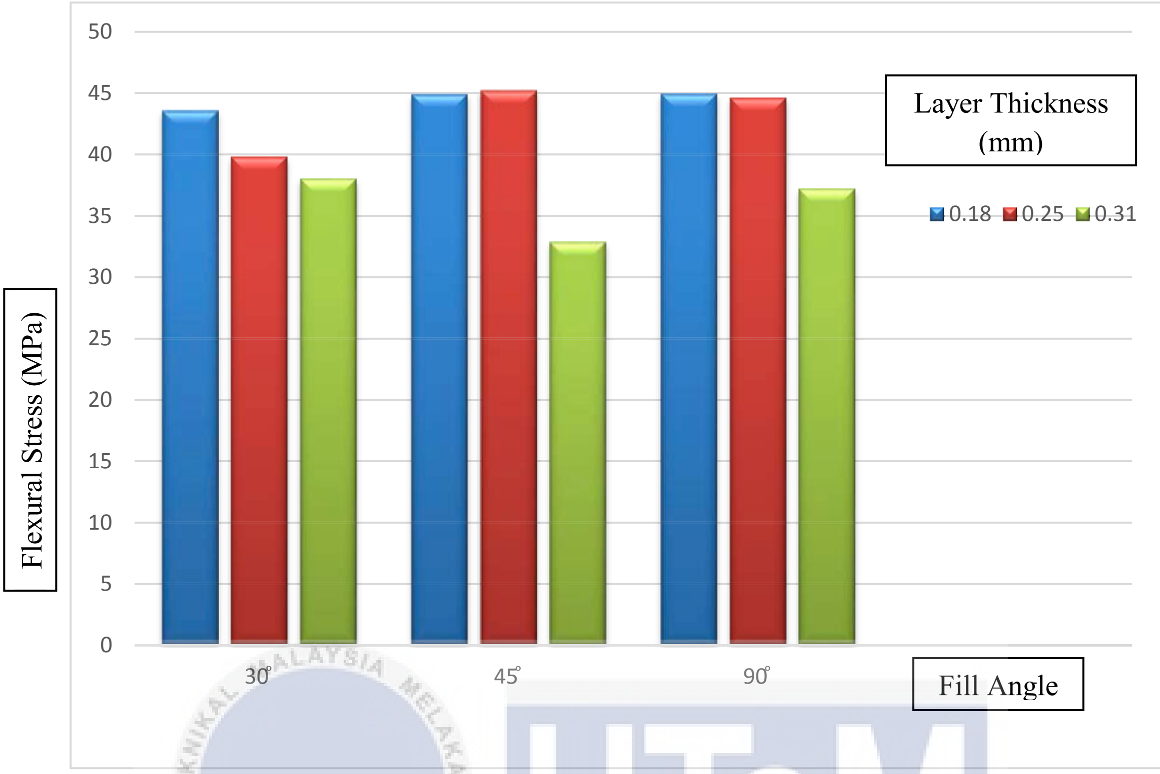


Figure 4.3(d): Bar chart for flexural fill angles for ABS material

4.3.2 Carbon Fibre Reinforced ABS specimens

Enhancement of flexural strength is observed as the material of specimens is changed. Figure 4.3(e) shows that the flexural strength curves for fill angle 30° increase with decreasing the number of layer thickness. 0.18mm layer thickness shows the higher flexural stress which is 41.06 MPa. At layer thickness 0.25mm, the flexural stress obtained is 40.59 MPa which is 1.1% lower than the 0.18mm layer thickness. The lowest between three layer thicknesses at fill angle 30° is 38.56 MPa which belongs to 0.31mm layer thickness.

Figure 4.3(f) indicate the flexural stress result for fill angle 45° specimens. When evaluating the flexural stress of each specimens, 0.25mm layer thickness had the lowest flexural strength and it was 10.0% weaker than the highest. Additionally, 0.18mm layer thickness had the highest flexural stress which was 43.43 MPa. Last but not least for layer thickness 0.31mm, the result was 39.49 MPa only 9% lower than 43.43 MPa.

Images on Figure 4.3(g) illustrating the scatter seen in the flexural stress-strain curves for fill angle 90° specimens. The result were found when evaluating the flexural stress was 41.86 MPa was the highest value of flexural stress which was on layer thickness 0.25mm. Additionally, the same fill angle was seen 4.8% and 7.0% lower than the highest flexural strength was at layer thickness 0.18mm and 0.31mm respectively. These results shows that some insight into the overall properties can be detected from simply observing the specimen failure modes. The fracture lower strength of specimen due to week interlayer bonding between the layers of the filament. This is because of they have low cross link between them. Moreover, low modular diffusion also because the rupture happened.

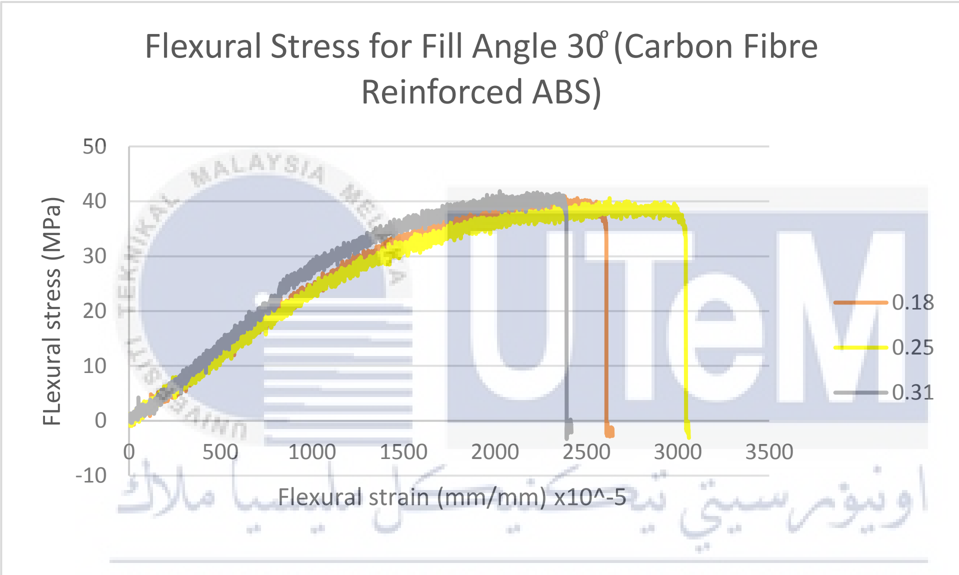


Figure 4.3(e): Stress-strain curve for flexural fill angle 30° specimens of 0.18mm, 0.25mm and 0.31mm layer thickness

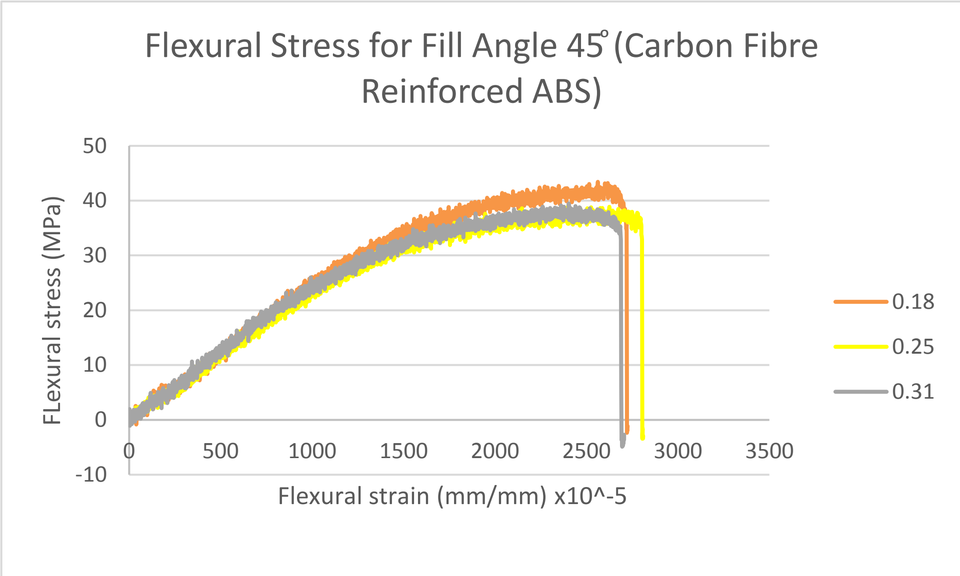


Figure 4.3(f): Stress-strain curve for flexural fill angle 45° specimens of 0.18mm, 0.25mm and 0.31mm layer thickness

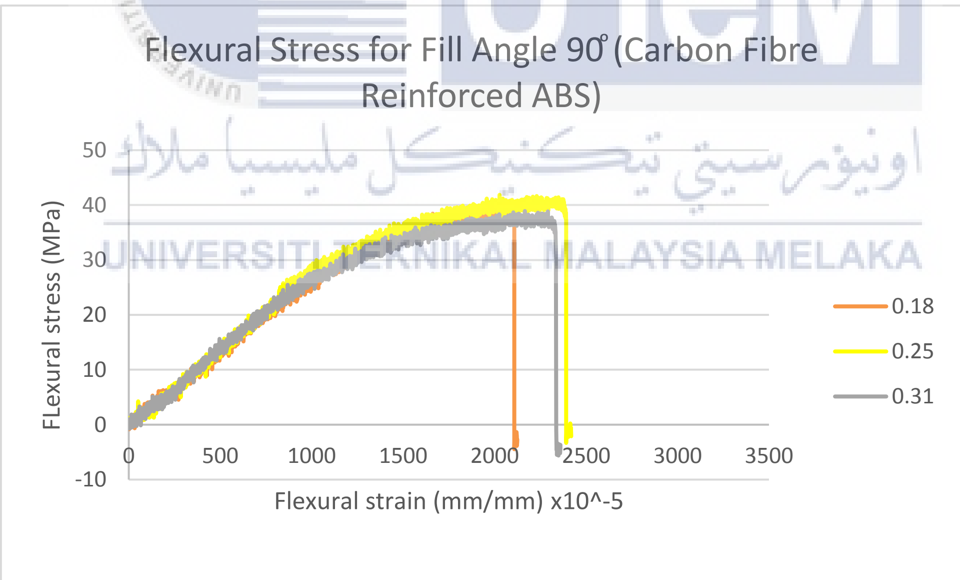


Figure 4.3(g): Stress-strain curve for flexural fill angle 90° specimens of 0.18mm, 0.25mm and 0.31mm layer thickness

4.4 Comparison Flexural Properties on pure ABS and Carbon Fiber Reinforced ABS

While evaluating the ABS and Carbon Fiber reinforced ABS specimens for the flexural material properties, the curves from each test were also evaluated to determine if curves were present that could provide reasons for certain material characteristics. However, the Carbon Fiber reinforced ABS specimens were much more brittle in nature, and practically all specimens experienced complete failure during testing. The ABS specimens provided excellent curves into material behaviour shows in Figure 4.4. By comparing both material with specific parameter selected which is layer thickness 0.25mm and 45° fill angle shown in Table 4.4.

Table 4.4: Tabulated results of flexural properties for 2 materials

Layer Thickness (mm)	*Fill Angle*	*Material*	*Maximum Flexural Stress (MPa)*	*Maximum Flexural Strain (%)*	*Load at Maximum Flexural Strength (N)*	*Extension at Maximum Load (mm)*
0.25	***45°***	ABS	45.23	13.4	39.21	17.27
		Carbon Fiber reinforced ABS	38.88	10.3	33.71	13.12

The result has also shown that when pure ABS are compared with the Carbon Fiber reinforced ABS material, high rigidity ABS has the high flexural strength because it has positive properties, including excellent mechanical properties in both static and dynamic tests. However, the addition of 15% Carbon Fibre in ABS generally will decrease the flexural strength. The Carbon Fibres act as a source of reinforcement. The Carbon Fibres are very strong in other mechanical test but tend not to resist compression.

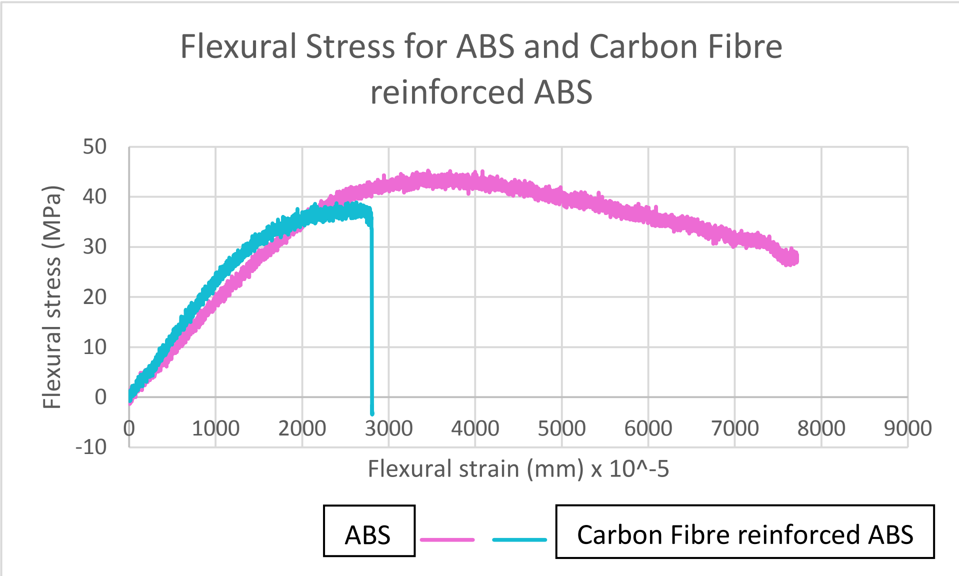


Figure 4.4: Stress-strain curves for materials ABS and Carbon Fibre reinforced ABS

CHAPTER 5

CONCLUSION AND RECOMMENDATION

5.1 Conclusion

The objective of present work was to investigate the effect of layer thickness and fill angle on flexural properties of carbon fibre reinforced ABS. The specimens was printed by using 3D printer technique. Three different layer thickness (0.18mm, 0.25mm and 0.31mm) and also three different fill angle (30°, 45° and 90°) have been incorporated while making the specimens to investigate and comparing the influence of these different parameters on flexural properties of the specimens. The experiments confirmed that layer thickness and fill angle both have a marked effect on flexural properties. The best mechanical properties of ABS was found in specimen with a 0.25mm layer thickness and fill angle 45°. The fracture paths of the specimens were also depending on the fill angle. Next the optimum flexural properties of carbon fibre reinforced ABS was at layer thickness 0.18mm and fill angle 45°. Fill angle 45° given the better strength than fill angle 30° and 90°. 90° fill angle had the worst material properties. The fracture paths of the specimens were depending on the fill angle. The overall trend shows a marked increase in flexural strength with lower layer thickness.

5.2 Recommendation

This study also compared the flexural properties of ABS and carbon fibre reinforced ABS specimen. The result of flexural strength of the pure ABS is found to be higher than the Carbon Fibre reinforced ABS. It was observed that when 15% Carbon Fibre blend into the ABS, the flexural stress of the specimen decreased. Studies have shown that 15% of Carbon Fibre blend in ABS. It would be attractive to investigate the mechanical properties by decrease the content of Carbon Fibre to know the mechanical properties and do the comparison between them. Therefore, in order to increase the mechanical properties of carbon fibre reinforced ABS specimen, lower the percentage of Carbon Fibre blend in the ABS and this should be investigate.

When printing the carbon fibre reinforced ABS specimen, use the suitable temperature of the 3D printer's nozzle because if the nozzle is too hot, the behaviour of carbon fibre will decrease and will affect the result of mechanical properties. The suggested temperature was probably in between of 230 to 240˚C. In addition, the future studied by changing other parameter such as fill density and fill angle instead of change layer thickness and fill angle. So that there more information about the mechanical properties. Results are also useful to benchmark future analytical or computational models of FDM strength or stiffness of an object.

REFERENCES

Svec, P., Rosik, L., Horak, R. Z. and Vecerka, F. (1990). Styrene-Based Plastics and Their Modification. London : Ellis Horwood. 145-161.

Sharon Olivera1, Handanahally Basavarajaiah Muralidhara, Krishna Venkatesh (2016). Plating on acrylonitrile–butadiene–styrene (ABS) plastic: a review. New York.

Fried, J. R., 2009. Polymer Science & Technology. 2nd ed.. Westford: Pearson Education, Inc.

Sood A.K,Ohdar R.K , and Mahapatra S.S ,(2009)"Improving dimensional accuracy of processed part using grey taguchi method", Journal of materials and design.Vol30(9),pp (4243-4252).

T. Kanie, K.Fujii, H Arikawa, K Inoue, "Flexural properties and impact strength of denture base polymer reinforced with woven glass fibers", Dental Material 16 (2000) 150-158.

Johannesson, T., 2013. Retrived from: http://www.ne.se/lang/kompositer/228479

Campbell, F., 2010c. Introduction to Composite Materials. In: Structrual Composite Materials. s.l.:ASM International, pp. 1-30.

Norbert, M. B. (Ed). (1971). " Mechanical Properties of Polymers." New Jersey: Wiley Interscience. 175-222.

Jim Jose, Rajakannu (2014). International Journal of Latest Trends in Engineering and Technology (IJLTET). Vol. 4 Issue 4 November 2014.

K. G. Cooper, "Fused Deposition Modeling," in Rapid prototyping technology selection and application New York: Marcel Dekker, 2001, pp. 68-87.

Sood A.K,Ohdar R.K , and Mahapatra S.S ,(2009)"Improving dimensional acuuracy of processed part using grey taguchi method",Journal of materials and design.Vol30(9),pp(4243-4252).

Jaimin P. Patel, M.Tech –Thesis (2012), " An experimental investigation of process variable influencing the quality of FDM fabricated polycarbonate parts"

Wamungo (2017) Print Model Detail Retrieved from: http://www.wamungo.co.uk/PrintModel/Detail/Flexural-Test-Specimen-ISO-178-ASTM-D790-5419a8f68970281dbcce155c .

Research Gate (2008-2017) Figure 5. Bending Testing Specimen Dimensions Retrieved from: https://www.researchgate.net/figure/272623242_fig5_Figure-5-Bending-Testing-Specimen-Dimensions

Ch'ng Boon,(2015)"Characterization Of Flame Retardants Added Abs", Journal of materials,pp (48-73)

ProtoParadigm LLC (2011) The Difference Between ABS and PLA for 3D Printing Retrieved from: http://www.protoparadigm.com/news-updates/the-difference-between-abs-and-pla-for-3d-printing/

Bellini, A. & Güçeri, S., (2003). Mechanical characterization of parts fabricated using fused deposition modeling. *Rapid Prototyping Journal*, 9(4), pp.252–264.

Fu-da Ning, Junhua (2015)" Additive manufacturing of carbon fiber reinforced thermoplastic composites using fused deposition modelling", Journal of carbon fibre reinforced ABS material.

K.G Jaya, U. Cahndrasekhar, K. Venkateswarlu (2014)" Influence Of Fill angle And Layer Thickness On Mechanical Properties Of ABS Material Using FDM Process", International Journal of Advance Research In Science And Engineering, IJARSE, Vol. No.3, Special Issue (01),pp.1-6

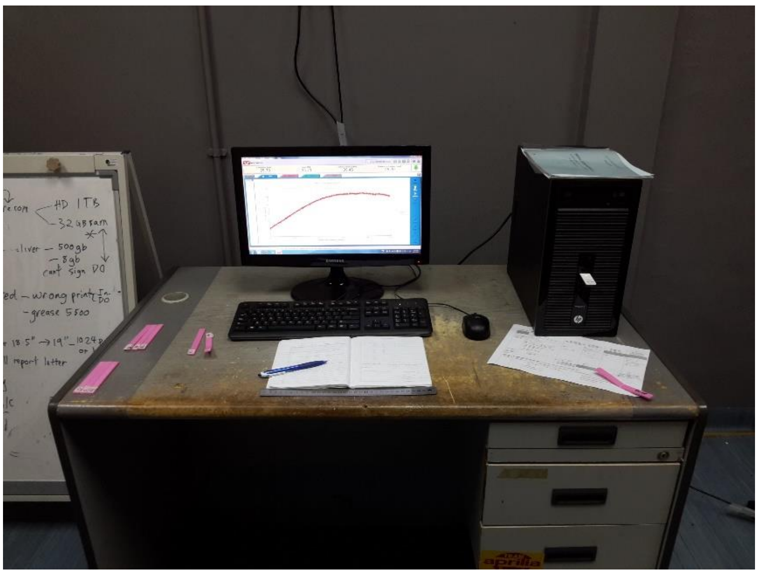
Constance Zieman, Mala Sharma (2012)" Anisotropic Mechanical Properties of ABS Parts Fabricated by Fused Deposition Modelling", USA: Bucknell University, Duke University 160-180

Jason Cantrell, Sean Rohde (2012)" Experimental Characterization of the Mechanical Properties of 3D-Printed ABS and Polycarbonate Parts" FL: University of Florida, Gainesville

APPENDICES

APPENDICE A1- Universal Material Machine (INSTRON 5585)

APPENDICE A2- Computer Connected to the INSTRON 5585



APPENDICE A3- Flash Forge Dreamer 3D Printer