EFFECT OF LAYER THICKNESS AND RASTER ANGLE ON TENSILE PROPERTIES OF CARBON FIBER REINFORCED ABS PRINTED PART

MUHAMAD FARID BIN RAZALI

UNIVERSITI TEKNIKAL MALAYSIA MELAKA

EFFECT OF LAYER THICKNESS AND RASTER ANGLE ON TENSILE PROPERTIES OF CARBON FIBER REINFORCED ABS PRINTED PART

MUHAMAD FARID BIN RAZALI

A report submitted
in fulfillment of the requirements for the degree of
Bachelor of Mechanical Engineering (Design and Innovation)

Faculty of Mechanical Engineering

UNIVERSITI TEKNIKAL MALAYSIA MELAKA

2015

DECLARATION

I declare that this project entitled "Effect of Layer Thickness and Raster Angle on Tensile Properties of Carbon Fiber Reinforced Abs Printed Part" is the result of my own work except as cited in the references

Signature: :………..………………………………

Name: :…………………………………………..

Date: :…………………………………………..

APPROVAL

I hereby declare that I have read this project report and in my opinion this report is sufficient in term of scope and quality for the award of the degree of Bachelor of Mechanical Engineering (Design and Innovation).

Signature :...

Supervisor's Name :...

Date :...

DEDICATION

To my beloved mother and father

ABSTRACT

Additive Manufacturing (AM) technologies have been developed as a fabrication method to obtain a functional parts in a short time. One of the famous AM techniques is Fused Deposition Modeling (FDM). With the advantages of minimal wastage and ease of material change, FDM is widely used in fabricating a thermoplastic parts and prototypes. Although it is well known, FDM printing material limited to acrylonitrile butadiene styrene (ABS) or poly lactic acid (PLA). This paper present the research done to determine the influence of layer thickness and raster angle on the tensile properties of ABS and on a new material, carbon fiber reinforced ABS. The sample with three different layer thicknesses (0.18mm, 0.25mm and 0.31mm) and raster angles (30°, 45° and 90°) were tested according to the ASTM D638 standard. It was found that both process parameter affect the tensile strength result. The ideal tensile properties for both material samples were found at layer thickness of 0.18mm and a raster angle of 90°. The result revealed that parts build with larger layer thickness produced lower tensile strength. To analyze the performance of carbon fiber reinforced ABS, a comparison was made between the tensile properties of 3D-printed acrylonitrile butadiene styrene (ABS) and carbon fiber reinforced ABS parts. The result shows that the highest tensile strength of ABS parts were 48% higher than those highest tensile strength for carbon fiber reinforced ABS.

ABSTRAK

Teknologi *Additive Manufacturing* (AM) telah dicipta sebagai kaedah fabrikasi untuk mendapatkan bahagian yang berfungsi dalam masa yang singkat. Salah satu teknik AM yang terkenal adalah *Fused Deposition Modeling (FDM).* Dengan kelebihan pembaziran yang minimum dan memudahkan perubahan material, FDM digunakan secara meluas dalam menghasilkan bahagian termoplastik dan prototaip. Walaupun ia terkenal, bahan cetak FDM terhad kepada *acrylonitrile butadiene styrene* (ABS) atau *poly lactic acid* (PLA). Kertas kerja ini membentangkan penyelidikan yang dilakukan untuk menentukan pengaruh ketebalan lapisan dan sudut raster ke atas sifat-sifat tegangan ABS dan bahan baru, gentian karbon bertetulang ABS. Sampel dengan tiga ketebalan lapisan (0.18mm, 0.25mm dan 0.31mm) dan sudut raster (30^o, 45^o and 90^o) telah diuji mengikut standard ASTM D638. Ia telah mendapati bahawa kedua-dua proses parameter itu memberi kesan kepada hasil kekuatan tegangan. Sifat-sifat tegangan yang ideal untuk kedua-dua sampel bahan ditemui pada ketebalan lapisan 0.18mm dan sudut raster pada 90^o. Hasilnya menunjukkan bahawa bahagian yang dibina dengan ketebalan yang lebih besar menghasilkan kekuatan tegangan yang lebih rendah. Untuk menganalisis prestasi gentian karbon bertetulang ABS, perbandingan dibuat antara sampel cetakan 3D *acrylonitrile butadiene styrene* (ABS) dan gentian karbon bertetulang ABS. Hasilnya menunjukkan kekuatan tegangan tertinggi bahagian ABS adalah 48% lebih tinggi daripada kekuatan tegangan tertinggi bagi gentian karbon bertetulang ABS.

ACKNOWLEDGEMENT

Firstly, I would like to express my sincere gratitude to my advisor Dr. MOHD NIZAM BIN SUDIN for the continuous support of my bachelor study and related research, for his patience, motivation, and immense knowledge. His guidance helped me in all the time of research and writing of this final year project. I could not have imagined having a better advisor and mentor for bachelor study.

Besides my advisor, I would like to thank the rest of my research committee: Dr. SITI NURHAIDA BINTI KHALIL, and Dr. MOHD ASRI BIN YUSUFF, for their insightful comments and encouragement, but also for the hard question which helped me to widen my research from various perspectives.

My sincere thanks also goes to technician at Fasa B laboratory who provided me an opportunity and gave access to the laboratory and research facilities. I also want to say a big thank you to student master named SITI MARYAM BINTI MD NOR, who act like my second supervisor and taught me a lot to prepared this research. Without they precious support it would not be possible to conduct this research.

I thank my fellow lab mates in for the stimulating discussions, for the sleepless nights we were working together before deadlines, and for all the fun we have had in the last four years. Also I thank my friends in the following institution; UNIVERSITI TEKNIKAL MALAYSIA MELAKA.

Last but not the least, I would like to thank my family: my parents and to my brothers and sister for supporting me spiritually throughout writing this research and my life in general.

TABLE OF CONTENT

LIST OF TABLES

LIST OF FIGURES

LIST OF FIGURES

LIST OF FIGURES

LIST OF APPENDICES

LIST OF APPENDICES

LIST OF ABBEREVATIONS

CAD	Computer Aided Design
FDM	Fused Deposition Modeling
ABS	Acrylonitrile butadiene styrene
STL	Stereolithography
PLA	Poly Lactic Acid
RP	Rapid Prototyping
DOE	Design Of Experiments
PEEK	Polyther Ether Ketone
MPa	Mega pascal

LIST OF SYMBOL

°	Degree
ε	Strain
σ	Stress
δ	Change in length

CHAPTER 1

INTRODUCTION

1.1 BACKGROUND

Cany Mendosa et al (2015) stated that Additive Manufacturing (AM) is a process where the physical stated of a model was created by the data from three-dimensional computer aided design (CAD) at a quick rate. The advantages of additive manufacturing compared to subtractive manufacturing is minimal wastage.Additive manufacturing first emerged in 1987 with stereolithography (SL). Fused deposition modeling (FDM) is one of the AM techniques that utilizes plastic materials, for example, Acrylonitrile butadiene styrene (ABS) to create models or even practical items. FDM works by depositing a molten layer that come through the heated nozzle to the build platform until it becomes the desired components. Because of the growth of this technology and limitation to the material used, it is crucial to have knowledge of the mechanical properties from the part produced, which can be different from their nominal value.

In this study, the tensile strength of parts produced by FDM machine is evaluated. The test is subjected to compare between pure ABS and carbon fibre reinforced ABS specimens. ABS is comprised a versatile family of readily process able resin used for creating items displaying phenomenal strength, great dimensional solidness and good chemical resistance. Carbon fiber used in this study is a carbon fiber reinforced ABS with 15% of carbon. Back at 1879, the inventor of carbon fibre, Thomas Edison, used carbon fibres as filaments for early light bulb even though that fibres lacked the tensile strength of today's carbon fibres, the fibres are ideal for conducting electricity.

The tensile test conducted in this study was according to ASTM D638 standard. Tensile test is a fundamental type of mechanical test to get the tensile strength of the material to evaluate the maximum stress that can be withstand by a structure in tension. In this study, two process parameter selected are layer thickness and raster angle as it is founded by Fahraz et al (2014) that the layer thickness and raster angle are among the most affected parameter. According to Wenzheng et al (2015), the layer thickness which is known as the height of deposited slice from the FDM nozzle. The layer thickness parameter is used to examine the impact in creating thicker or thinner layers on the outcome quality. The direction of the beads of material relative to the loading of the part is also refers as raster angle or orientation which is measured from the x-axis on the bottom part layer. The deposited road can be built at different angle to fill the interior part. Es-Said et al (2000) declared that raster angle make the alignment of polymer atom along the direction of deposition when the tensile test, flexural and impact strength is fabricated which is depends on the orientation of the sample Sample with three different layer thickness (0.18mm, 0.25mm and 0.31mm) and raster angle (30º, 45º and 90º) were built using FDM machine and their tensile properties were tested.

.

1.2 PROBLEM STATEMENT

It is imperative to decide the right parameters of the FDM machine keeping in mind the end goal is to deliver a section which can satisfy the tensile properties. There are essentially some of parameters which are critical and will impact the details of the delivered part, and these parameters are the layer thickness and raster angle. The mixes of various setting of the parameters will create parts with various particulars. FDM is one the famous rapid prototyping technology, still, in most FDM equipment, they restricted to ABS and PLA printing material.

1.3 OBJECTIVE

The objectives of the project are:

- To study and understand the process parameter of FDM influencing the performance on tensile strength.
- To study and compared the tensile strength between pure ABS and carbon fiber reinforced ABS samples.

1.4 SCOPE OF PROJECT

The study covers the AM process which is the Fused Deposition Modeling (FDM). Besides that, the study also discusses about the parameters of the FDM machine and software for the CAD and STL file which is CATIA software and Flashprint .The focus for this study are the layer thickness and raster angle. The parameters upgraded with a specific end goal to accomplish great execution regarding tossing separation. The material utilized as a part of delivering the part is pure ABS and Carbon fibre reinforced ABS. The universal testing machine was used to decide the tensile properties of the Specimen.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

This chapter provides an overview of previous research on tensile strength of the ABS and composite and also the previous knowledge that involved in the research. It introduces the frames work for the case study that comprises the main focus of the research described. The main purpose of the literature review work was to survey previous study on tensile strength of ABS and composite. This was in order to scope out the key data collection requirements for the primary research to be conducted, and it formed part of the emergent research design process, Denscombe (1998).

In this chapter, the reader will be explained about the related knowledge of the project which covers the introduction of rapid prototyping and fused deposition modeling. The detail of the material tensile strength and process parameter used that affect its mechanical properties in the previous study.

2.2 Rapid prototyping

Rapid Prototyping (RP) can be characterized as a gathering of procedures used to quickly manufacture a scale model of a section or get together utilizing three-dimensional Computer Aided Design (CAD) information. Rapid Prototyping has likewise been known as freestyle producing, PC computerized fabricating, and layered assembling. What's more, RP models can be utilized for testing.

As claimed by Novakova & Novak (2012), the initial condition of material in Rapid Prototyping innovations can come in either solid, fluid or powder state. In solid state, its can come in different structures, for example, pellets, wire or Laminates. The majority of the RP parts are completed or touched up before they are utilized for their expected applications.

Year of inception	Technology
1770	Mechanization
1946	First computer
1952	First Numerical Control (NC) machine tool
1960	First commercial laser
1961	First commercial Robot
1963	First interactive graphics system (early version of Computer Aided Design)
1988	First commercial Rapid Prototyping system

Table 2.1: Historical development of Rapid Prototyping and related technologies (Chua & Fai, 2000)

RP is not at all like subtractive or forming process which is use lathing, milling, grinding and coining that is formed by material evacuation or plastic twisting .On the other hand it have a place with the generative (or additive) creation forms . In all business RP process, the part is created by deposition of layers formed in a (x-y) plane two dimensionally. The third dimension (z) comes about because of single layers being stacked up on top of each other, however not as a persistent z-coordinate. Along these lines, the models are extremely correct on the x-y plane in any case. If that model is stored with fine layers, i.e., littler z-stepping, model looks like original. RP can be classed into two principal steps in particular generation of mathematical layer information and to generation of physical layer display. Pulak M.Pandey et al (2005)

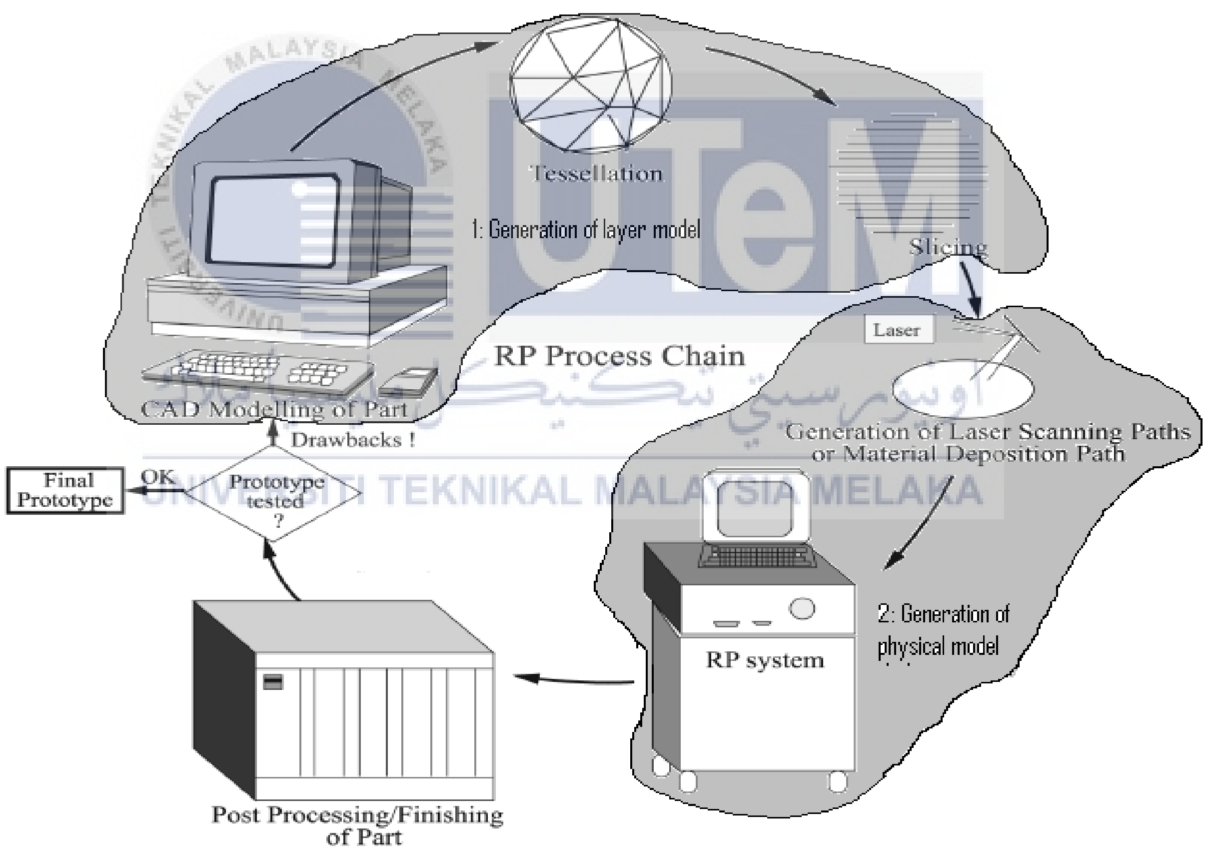


Figure 2.1: RP process chain showing fundamental process steps (Pulak M.Pandey, 2005)

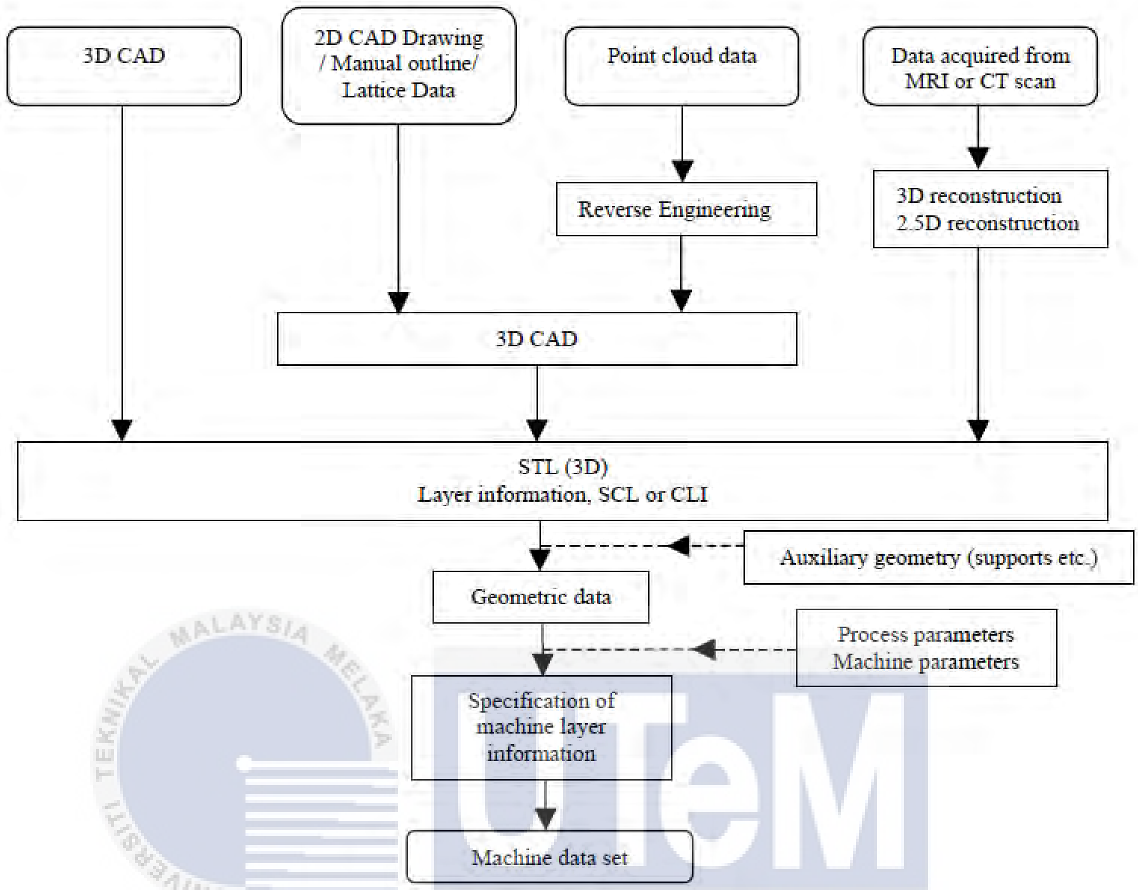


Figure 2.2: Generalized illustration of data flow in RP (Gebhardt, 2003)

There is a multitude of experimental RP techniques either being developed or utilized by small group of individual. This is RP techniques that are currently commercially available, including Fused Deposition Modeling (FDM), Stereolithography (SLA), Selective Laser Sintering (SLS), Laminated Object Manufacturing (LOM), Solid Ground Curing (SGC), and Ink Jet printing techniques.

2.2.1 FUSED DEPOSITION MODELLING (FDM)

Fused Deposition Modelling, or FDM, is a process created by virtual three-dimensional CAD (Computer Aided Design) models which transform into physical objects. It is known as an additive manufacturing technique, which means that objects are created layer by layer. In the process, a thermoplastic extruder is used to deposit small beads (or strings) of plastic to draw a picture as it is moved over the build surface. Once the layer is complete, the build-platform lowers one layer height and the extruder draws the next layer—depositing plastic that fuses to the previous layer. On the authority of William K. Langford (2012), this process is repeated until the complete three-dimensional plastic object is built such that it closely resembles the original CAD model.

Principle of Fused Deposition modelling method

In this process, a nozzle will extrude a plastic or wax material that traces the parts cross sectional geometry layer by layer. The build material is usually supplied in filament form, but some setups utilize plastic pellets fed from a hopper instead. According to Novakova-Marcincinova (2012), the nozzle with the resistive heater can make sure the temperature of the plastic maintain above the melting point so that it can flows through the nozzle and forms the layer easily. After through the heater from a nozzle, the deposited filaments cool down instantly below the glass transition temperature of the polymer and get hardened. Cooper (2001) stated that the whole build system is contained within a temperature- controlled environment with temperatures just below the glass-transition temperature of the polymer to supply an efficient intra-layer bonding. Once a layer is built, the platform lowers, and the extrusion nozzle deposits another layer. The layer thickness and vertical dimensional accuracy is determined by the extruder die diameter. In recent FDM systems, they use two nozzles, one for part material and other for support material. Pulak M. Pandey (2015) had mentioned that the support material is relatively of poor quality and can be broken easily once the complete part is deposited and is removed from substrate.

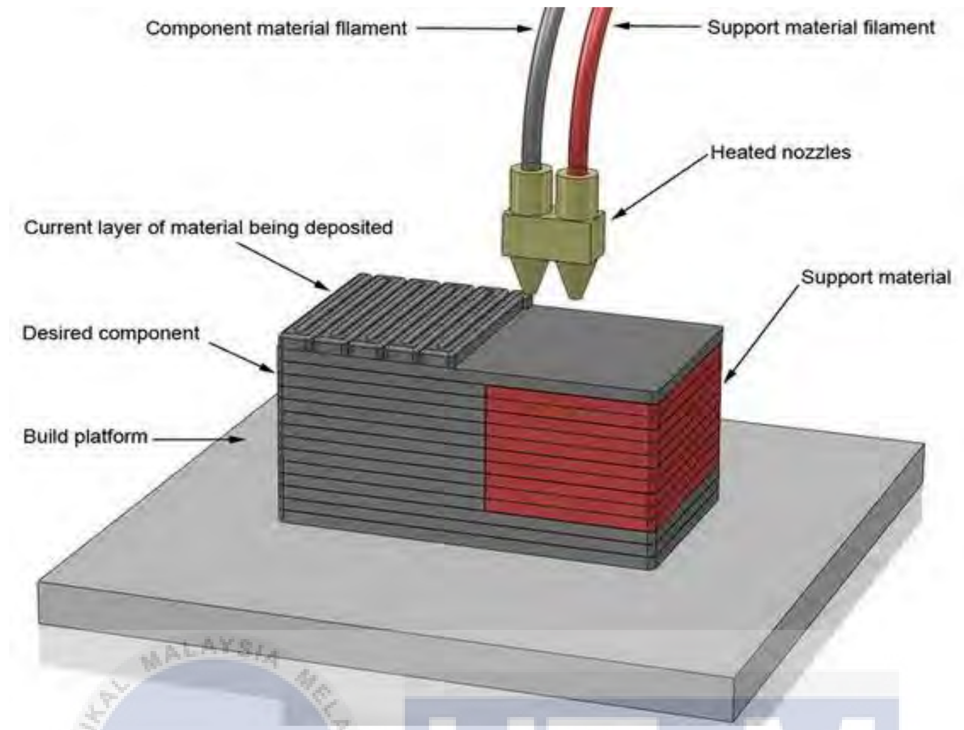


Figure 2.3: Principle of Fused Deposition Modeling technology

Part production process of FDM

Computer aided design (CAD) software is use as the first steps in the making of the virtual model for the Fused deposition modelling production. Then the part file from the CAD software is transfer and transform into Stereolithography (STL) file with a help from specific translator on the CAD system. After that, the STL file is export to QuickSlice (QS) software and then slicing them into thin cross sections at a desired resolution to convert it into SLC file. On the report of Wang et al (2001), the sliced model is then changed into Stratasys modelling language (SML) file, which contains actual instructions code for the FDM machine tip to follow the specified tool path before turn them into the physical model .

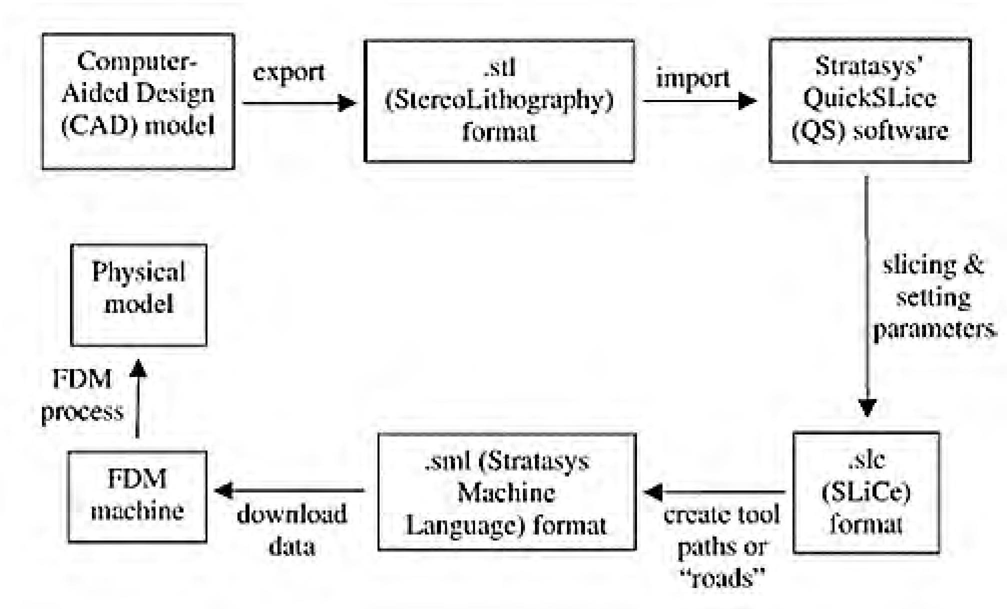


Figure 2.4: Fused Deposition Modelling General process (Zein et al. 2002)

In addition, there a different sorts of FDM machine utilizes universally and each sorts of the machine have its own particular special styles and exhibitions to produce a parts. These eventual depend on the manufacturer, the extent of the machine, the kind of expulsion head utilized, the scope of materials the machine can utilize and numerous more. They are additionally utilized as a part of investment casting and increasingly being used in medical applications, like filling for damaged section of brain. Mohd Izham (2015), stated that recent research in this field has prompt to more organizations beginning to replace customary techniques for machining and using for making parts which might be utilized as a littler part of an assembly or even utilized as end user parts.

2.3 ABS (Acrylonitrile Butadiene Styrene) and its tensile strength

ABS is one of the famous material use in variety of application in the industry nowadays such as for the manufacturing of pipe, electronic assemblies, protective headgear, automotive components, kitchen appliance, toys and also for the music instruments. According to S Yang et al (2004), 3D printers can process the ABS plastics normally at a rate of temperature around 210-250^{o} C because it's naturally very durable, strong and quite heat resistant. To prevent warping or cracking of the printed material, a 3D printer is necessarily equipped with a heated print bed. For the cost, ABS is known as the one of the economy cost and still the most use as the printing material. Some of the disadvantages using ABS is that it is a petroleum-based non-biodegradable plastic and ABS also produce fumes which harmful to sensitive person. ABS must kept out from exposure to sunlight over a longer time because it attract moisture from the ambient air that can affect the printing. M.Suzuki & CA Wilkie, (1995).

There are some studies attempt in order to analyse the relation of the printing material and its mechanical properties. According to B. Eng. Eno Ebel (2013) , the research is about to examines the material properties (ABS or PLA) of objects that are manufactured using FDM technology. The result from tensile test concluded that PLA can reach a higher mechanical strength than printed ABS. Later, the research from Mohamad Azhar B. Azahari (2014), show about capability of joining ABS and PLA material because of the difference temperature in bed print. The test use is tensile test and flexural test. The conclusion from the research state that ABS and PLA is more flexural compared to other combination, while for the tensile test, ABS and ABS joining has the highest value.

Michael Montero et al (2001) have conducted an experiment where he investigated the process parameter with the Design of Experiment (DOE) method. The result from the study expose that the typical tensile strength of FDM parts made with a 0.003 air gap has a range from 65% to 72% of the strength of injection molded ABS P400.

2.4 Carbon and its tensile strength

Carbon atoms can be bonded together in different ways, the famous known as graphite, diamond, and amorphous carbon. Recently, there are researchers that study about carbon fibres. Carbon fibres are usually combined with other material to form a composite. Because of the limitation to pure thermoplastic material mechanical properties, there are demand to improve mechanical properties for pure thermoplastic printed parts. One the suggestion is adding reinforced material like carbon fibres into plastic material. On the experiment conducted by F. Ning et al (2015), the researchers show a test if adding carbon fibres to thermoplastic from FDM can affect the tensile properties (including tensile strength, young's modulus, toughness, yield strength and ductility) and also flexural properties. The study conclude that the composite with carbon fibre can increase tensile strength and young's modulus compare to pure plastic specimen. However, toughness, yield strength, and ductility may decrease.

Halil L. Tekinalp et al, (2014) have experimentally demonstrated that short carbon fibre reinforced acrylonitrile-butadiene-styrene composite can increase the tensile strength and modulus up to ~115% and ~700% of the printed sample. This phenomenon is due to changes in fibre orientation, dispersion and void formation.

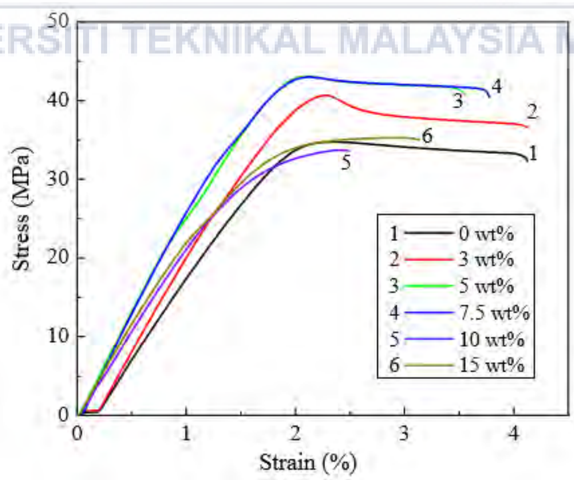


Figure 2.5: Tensile stress-strain curves with different percentage of carbon

(F. Ning et al, 2015)

2.5 FDM process parameter

The process parameters from FDM play a quite role in determining the best build for the printed parts from FDM printer. The variation of process parameter like air gap, layer thickness, raster angle, and raster width or part orientation can really effect the mechanical properties of the printed parts.

Anoop K. Sood (2012) defined these parameter as follows:

1. *Orientation:* Part builds orientation or orientation refers to the inclination of the part in the build platform with respect to X, Y, and Z axis.
2. *Layer thickness:* It is a thickness of layer deposited by nozzle and depends upon the type of nozzle used.
3. *Raster angle:* It is a direction of raster relative to the X-axis of the build table.
4. *Raster width* :It is the width of raster pattern used to infill interior regions of part curves
5. *Air gap:* It is the gap between two adjacent rasters on same layer.

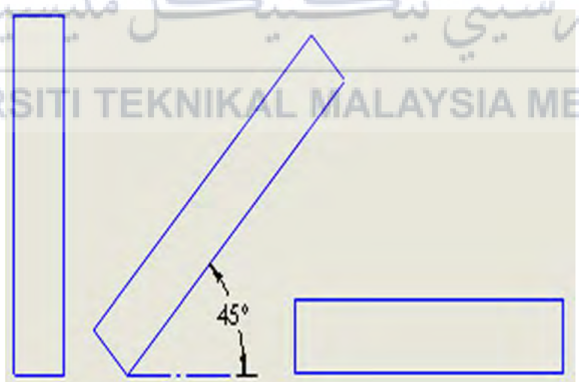


Figure 2.6: Orientation part (Anoop K. Sood 2012).

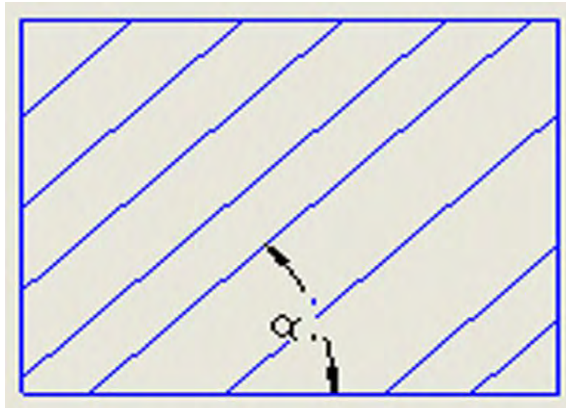


Figure 2.7: Raster angle parameter **(**Anoop K. Sood 2012).

From the study of Ana Pilipovic et al (2007) , their attempt were determined the analysis of dimensions, surfaces roughness and mechanical properties of material of the produced test specimens .The experiment conducted show the result that in the Zprinter 310 , some parameters may be change to reduce the production time that affect the properties of the specimens . Farzad Rayegani & Godfrey C. Onwubolu (2014) mentioned in their research about investigates the relationship between process parameter and tensile strength for the Fused Deposition Modelling (FDM), an early test was conducted to determine whether part orientation and raster angle variations can make an impact on tensile strength. It find out that both affect the tensile strength data.

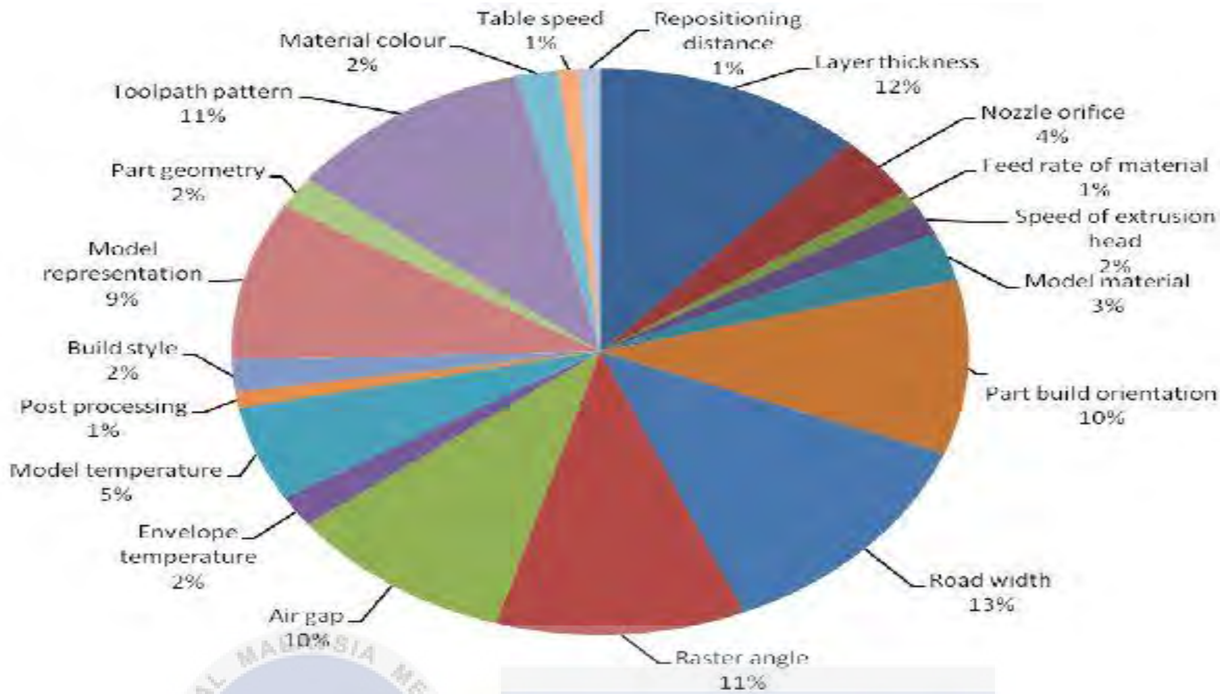


Figure 2.8: Percentage of process parameter influence (Fahraz et al, 2004)

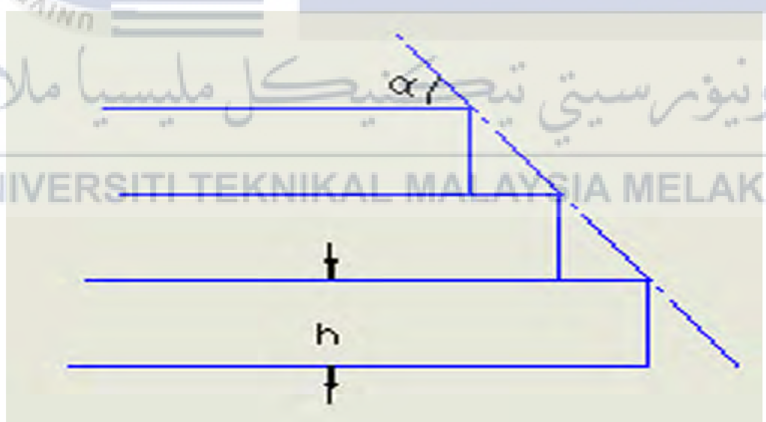


Figure 2.9: Height of slices or layer of thickness (K.Thrimurthulu et al, 2004)

An early experiment in determining the surface finish and part deposition time as two of the important concerns in rapid prototyping had been developed by K.Thrimurthulu et al (2004). The study proposed a real coded genetic algorithm to achieve the best part deposition orientation for enhancing part surface finish and cut loss the build time. In addition, the Taguchi method is use to find the optimum process parameters for fused deposition modelling (FDM). Through the study, other than discover the optimal process parameters to get optimum elastic performances of ABS prototype the study also found out layer thickness, raster angle and air gap really can bring an impact to those ABS elastic performances. B. H. Lee et al (2005).

Figure 2.10: Effect of layer thickness on build time and quality (K.Thrimurthulu et al, 2004)

2.6 Tensile test

A tensile test, otherwise called strain test, is presumably the most essential kind of mechanical test that can perform on material. Ductile tests are basic, generally modest, and completely institutionalized. By pulling on something, we will rapidly decide how the material will respond to strengths being connected in strain. As the material is being pulled, we will discover its quality alongside the amount it will stretch.

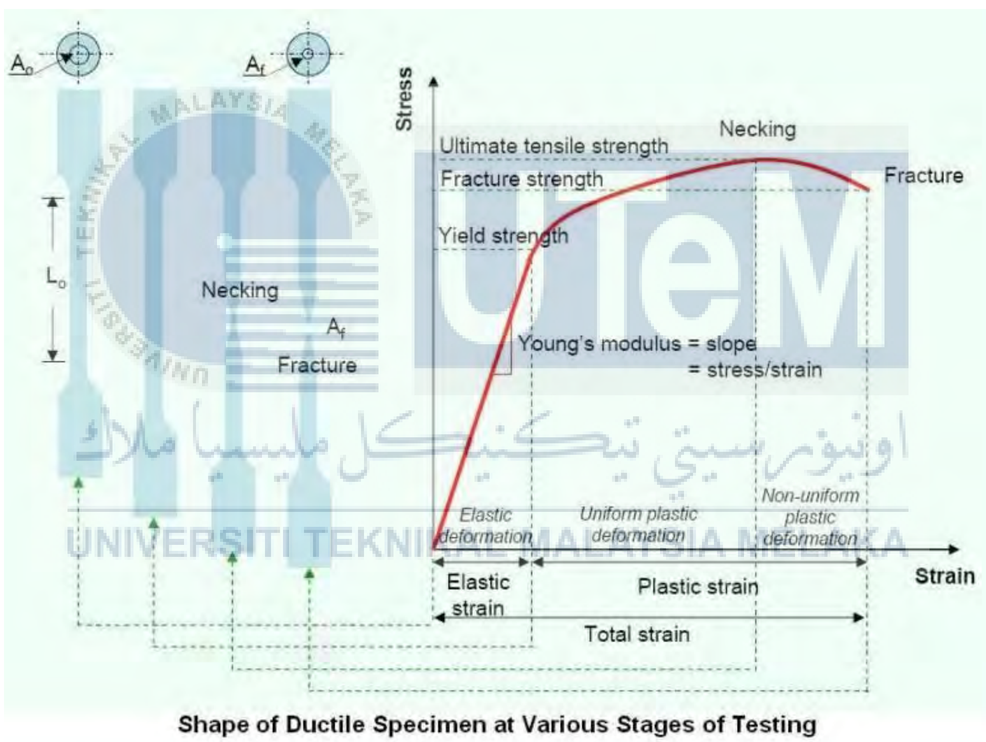


Figure 2.11: Engineering stress-strain graph (http://practicalmaintenance.net/?p=948)

2.6.1 ASTM D638

ASTM D638 is a standard test method for polymer. From the study on the website of https://www.astm.org/Standards/D638.htm, the test cover the assurance of the elastic properties of unreinforced and fortified plastics as standard dumbbell-formed test examples when tried under characterized states of pre-treatment, temperature, mugginess, and testing machine speed.

From the same website, it is understood that a material can't be tried without additionally testing the technique for planning of that material. Consequently, when similar trial of materials in essence are craved, the best care must be practiced to guarantee that all specimens are set up in the very same way, unless the test is to incorporate the impacts of test arrangement. Also, for arbitrator purposes or correlations within any given series of specimens, care must be taken to secure the greatest level of consistency in details of planning, treatment, and taking care of.

The apparatus to run a tensile test for ASTM D638 are:

Testing Machine, Fixed Member, Movable Member, Grips, and movable members of the testing machine in such a manner that they will move freely into alignment as soon as any load is applied so that the long axis of the test specimen will coincide with the direction of the applied pull though the centre line of the grip assembly and The test specimen shall be held in such a way that slippage relative to the grips is prevented insofar as possible.

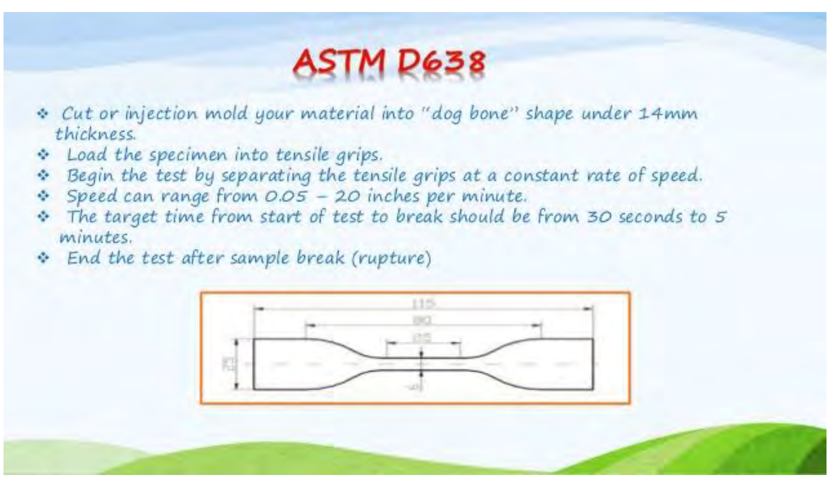


Figure 2.12: ASTM D638- Dogbone specimen (https://www.astm.org/Standards/D638.htm)

2.7 Effect of layer thickness and raster angle on tensile test

Layer thickness and raster angle is two of the process parameter that can affect the mechanical properties of fabricated part. There are studies that focus on this two parameter to investigate the tensile strength. In the journal entitled *Influence of Raster Angle and Layer Thickness on mechanical properties of ABS material using FDM process,* by K.G. Jaya et al (2014) have analysed the detail of the influence between raster angle of 0^{o}, 45^{o} , 60^{o} and 90^{o}, and layer thickness of 0.254 mm and 0.331 mm. The outcome from the research indicated that raster angle only has small influence on the tensile strength of ABS material. Even so, there is significant increase in tensile strength when the layer thickness was increased from 0.254 mm to 0.331 mm

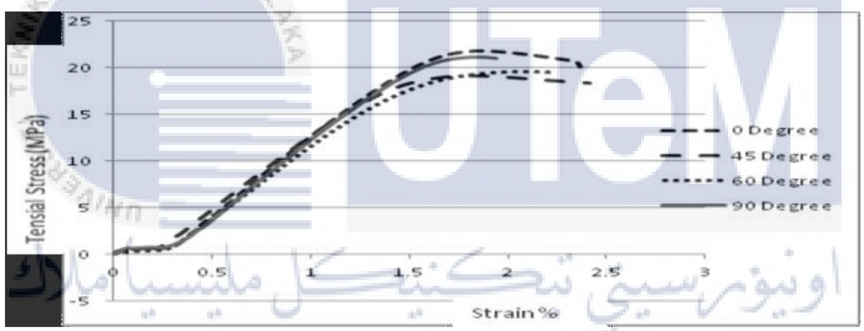


Figure 2.13: Different raster angle with 0.254 Layer Thickness (K.G. Jaya et al, 2014)

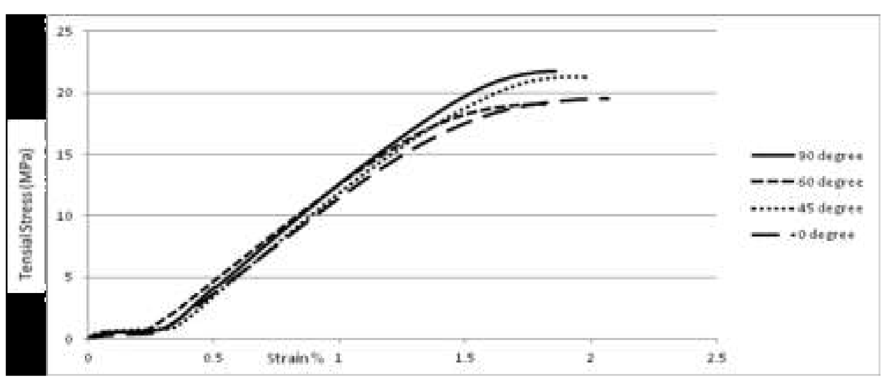


Figure 2.14: Different raster angle with 0.33 Layer thickness (K.G. Jaya et al, 2014)

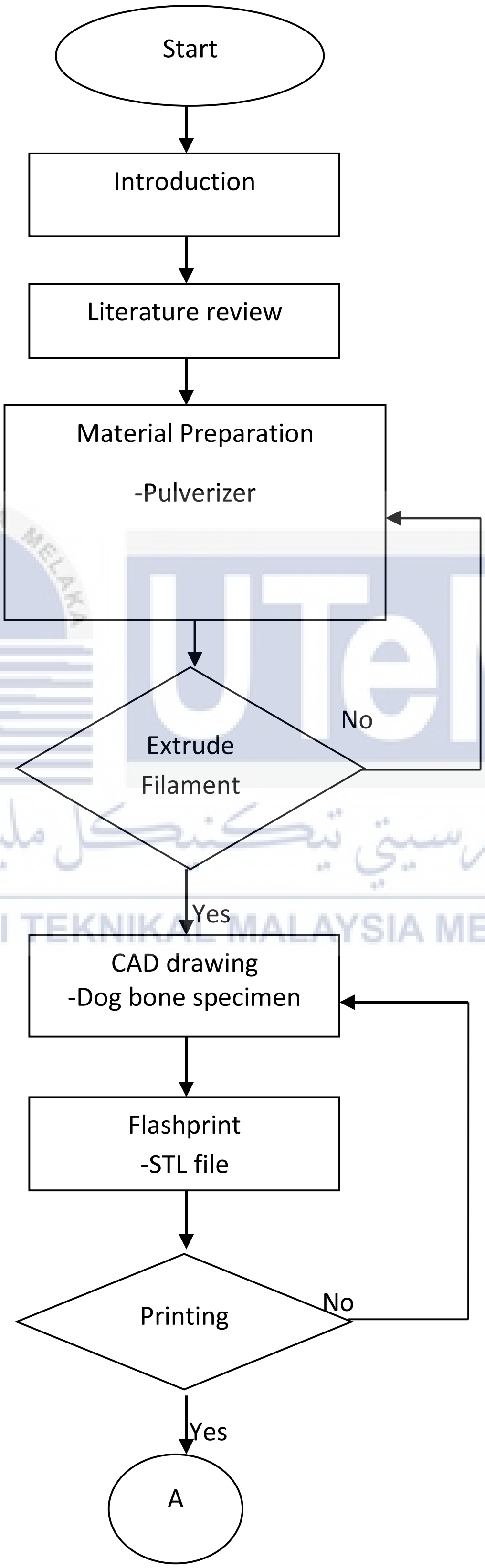
Wenzheng Wu et al (2015) performed experiment on mechanical properties of PEEK and ABS material based on influence of layer thickness and raster angle. In their study, they use three samples with different value of layer thickness (200, 300 and 400) and raster angle (0, 30 and 45) to test the tensile, compressive and bending strength. A comparison is made between the mechanical properties of Polyther-ether-ketone (PEEK) and acrylonitrile butadiene styrene (ABS) specimens. The outcome proposed that average tensile strength, compressive strengths and bending strength of PEEK is higher than ABS. However, the comparison between ABS composite not been study.

CHAPTER 3

METHODOLOGY

3.1 Introduction

This chapter clearly defines the research method used to conduct the study. The researcher explains how the necessary data and information to address the research objective and questions was collected, presented and analyzed. The methodology is divided to research finding, data preparation and research test, Reasons and explanation about the method or the tools used for the research design, research instruments, data source, and data collection technique is given. Figure 3.1 show the general methodology and planning during the research. In this study, a tensile test specimen was created as a 3D CAD geometric model with the dimensions those specified in the ASTM D638.


Start
Introduction
Literature review
Material Preparation
-Pulverizer
Extrude
Filament
No
Yes
CAD drawing
-Dog bone specimen
Flashprint
-STL file
Printing
No
Yes
A

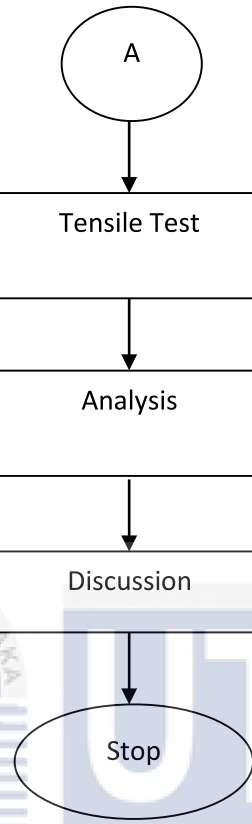


Figure 3.1: The Flow chart of planning and methodology of the research

3.2 Quantitative Approach

Quantitative methods underline target estimations and factual, scientific, or numerical investigation of information gathered through surveys, polls, and studies, or by controlling previous measureable information using computational technique. M. Daniel (2010). Quantitative research concentrates on gathering numerical data and summing it up to explain a particular phenomenon.

The quantitative approach used was by doing research on previous journal, internet and books. The goal in conducted quantitative research is to find the relationship between this study and other previous studies. With the structured research instruments, the data and information was collected.

3.3 Sample Preparation

3.3.1 Computer Aided Design (CAD)

Two-dimensional or three dimensional dog bone created on a computer using CATIA V5R21 software. CATIA support multiple stages of product and one of it is CAD, use to focus in design scope. With the CATIA software, the dog bone specimen was design and creates as CAD model.

3.3.1.1 Fundamental of CAD

CAD software is used to create computer-based models during design process enabling other downstream process to be planned. The graphic model gives clear information so that the development team members will interpret the model unambiguously. On top of this, the data can easily be accessed for revision, modification, as well as for manipulation. For this purpose, there are four elements that structure the CAD system:

I. The hardware- the computer and all the peripherals attached to a normal PC/workstation
II. The software and operating system- the CAD package used to design geometric models and to analyze the model. It is interface between the hardware and the software
III. Data- the information illustrated by or obtained from the geometric model produced by the designer.
IV. User-human factor in term of their knowledge

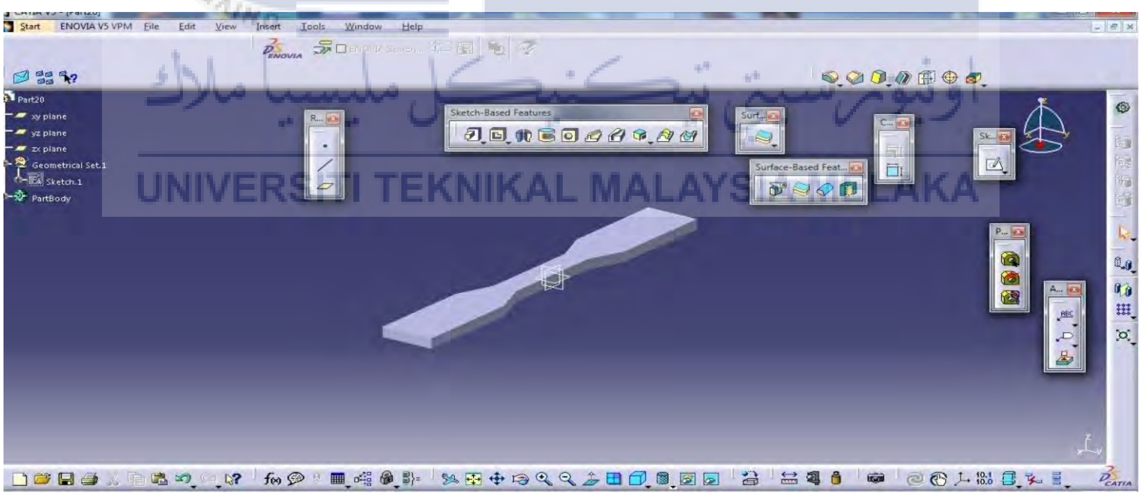


Figure 3.2: Dog bone specimen ASTM D638 created in CAD

There are types of CAD data:

I. **Wire frame**- the geometry is represented in terms of lines and edges. A plane should always be defined by the designer for surfaces and arcs.

II. **Surface Modeling** - surfaces are produced through mathematically complex curves. Normally it is difficult to determine the outer or the inner surface of surface data (in the 'normal' orientation). These complex surfaces could be control points, curved based, or a combination in both. Some control points can be 'globally' modified (any modification would affect the entire surface) some can be 'locally' modified (only certain area of surface is affected when change are made on control point).

III. **Solid modeling** - there are two types of solid modeling available: the constructive solid modeling (CSG) and the B-Rep. Boolean expression are used to construct a model in CSG where instructions like 'union', 'subtract', and 'intersect' are common. On the other side, B-Rep is the enhanced version of surface modeling, which gives information for surface connectivity.

3.3.2 Flashprint (STL File)

Flashprint is a software create by Flashforge Company. Flashprint is the slicing program that uses STL to export and generate the model. Before use the 3D printer, Flashprint convert the CAD data into the STL file. The parameters of the printed object also can be set using Flashprint.

Figure 3.3: The process parameter setting in Flashprint

STL file or known as stereolithography CAD software. This file is support by many software package and commonly be used in rapid prototyping and computer-aided manufacturing. This format focuses both ASCII and Binary representation. An STL file describes a raw unstructured triangulated surface from the unit normal and vertices of the triangles using a three-dimensional Cartesian coordinate system. IANCU et al (2010).

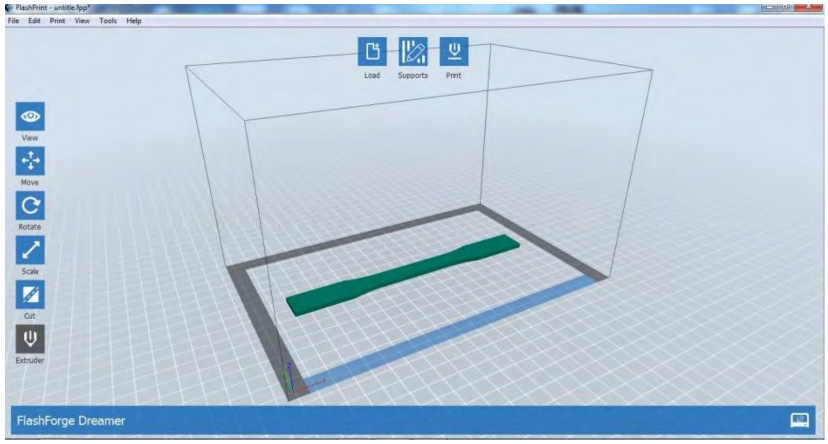


Figure 3.4: The STL file of dog bone open in Flashprint

3.3.3 FlashForge 3D-Printer (FDM machine)

The Flashforge Dreamer is one of the FDM machines that is a fully enclosed plug 'n' play 3D printer by the Chinese manufacture of Flashforge. with a features of Wi-Fi connection to upload files to the machine and has dual extruder mechanism .It can print at a maximum resolution of 100 microns. This FDM machine used due to its ease of use, reliability, heated platform and dual extruder. In addition, Flashforge Dreamer can use 3rd party material. The control and interface is On-printer controls.

The Flashforge dreamer work as FDM machine process which the process comes under additive process. According to (Chennakesave & Narayan , 2014) , In the process, a motor controlled which is fitted with the extruder head move in x and y directions. The table move vertically z-axis. When a layer got saved on the table, it goes down as per the layer thickness and the subsequent layer is built in a similar ways.

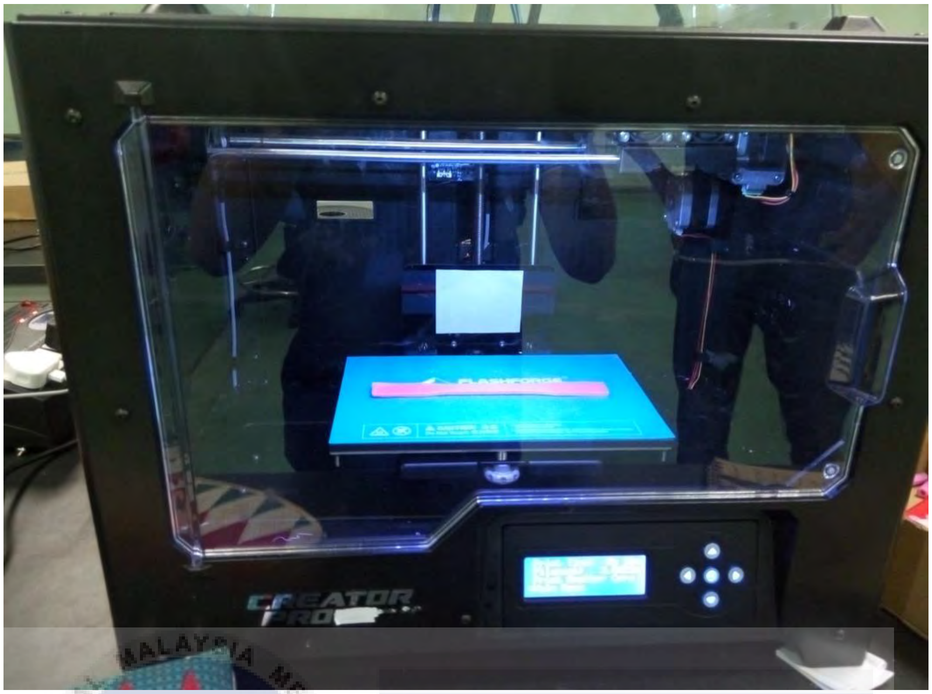


Figure 3.5: The dog bone specimen print with Flashforge 3D printer

Steps to be carried out to build a model:

1) Create a CAD model of the product
2) Save or convert it into Stereolithography (STL) file format
3) Load the .stl file in to the slicing software or the interface platform between the specific machine and the computer
4) upload the sliced file into the FDM machine
5) run the machine with required settings
6) Detach the part from the table after completion

3.4.1 Selection of parameter

The parameter used in this study is layer thickness and raster angle. As Fahraz et al (2014) stated, Layer thickness and raster angle is among the most influenced process parameter. Other parameter like fill pattern is fixed as line pattern and fill density is fixed as 90% because it obtained to be strong build.

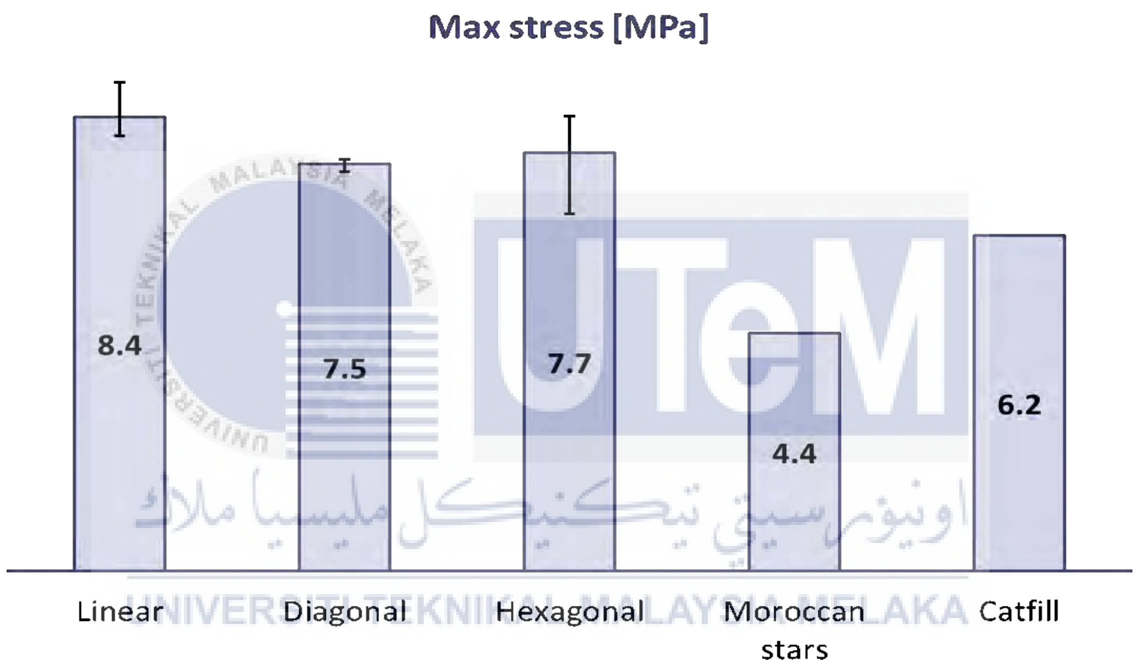


Figure 3.7: Linear pattern strength

3.4.2 Data tabulation

The data collected from the computer will be record in the table.The variation of combination of raster angle and layer thickness is as follow:

Effect of layer thickness on ABS (& carbon fiber reinforced ABS)

Labels	**Raster Angle (º)**	**Layer Thickness (mm)**	**Tensile Stress (MPa)**	**Tensile Strain (mm/mm)**
		0.18		
	30	0.25		
		0.31		

Labels	**Raster Angle (º)**	**Layer Thickness (mm)**	**Tensile Stress (MPa)**	**Tensile Strain (mm/mm)**
		0.18		
	45	0.25		
		0.31		

Labels	**Raster Angle (º)**	**Layer Thickness (mm)**	**Tensile Stress (MPa)**	**Tensile Strain (mm/mm)**
		0.18		
	90	0.25		
		0.31		

Effect of raster angle on ABS (& carbon fiber reinforced ABS)

Labels	**Layer Thickness (mm)**	**Raster Angle (º)**	**Tensile Stress (MPa)**	**Tensile Strain (mm/mm)**
	0.18	30		
		45		
		90		

Labels	**Layer Thickness (mm)**	**Raster Angle (º)**	**Tensile Stress (MPa)**	**Tensile Strain (mm/mm)**
	0.25	30		
		45		
		90		

Labels	**Layer Thickness (mm)**	**Raster Angle (º)**	**Tensile Stress (MPa)**	**Tensile Strain (mm/mm)**
	0.31	30		
		45		
		90		

3.5 Research Test

The research test in this project was tensile strength test. A tensile test, also be called as tension test, is probably one of the fundamental type of mechanical test that can be performed on material. The strength of the material is determines by test the subjected to a simple stretching operation. Typically, standard dimension test sample are pulled slowly and at uniform rate in a testing machine while the strain is define as:

Engineering strain = ε = (change in length/original length) = δ/L_o

Engineering stress = σ = (applied force)/(original area) = P/A_o

3.5.1 Tensile test machine setup

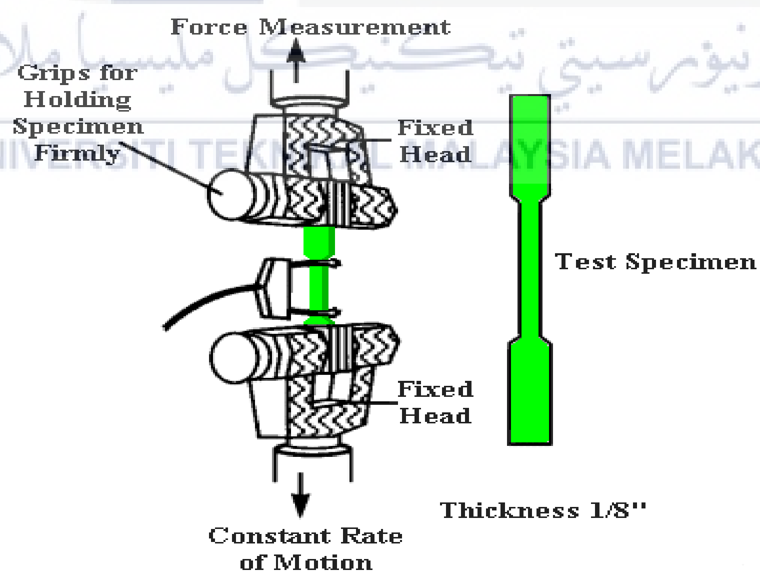
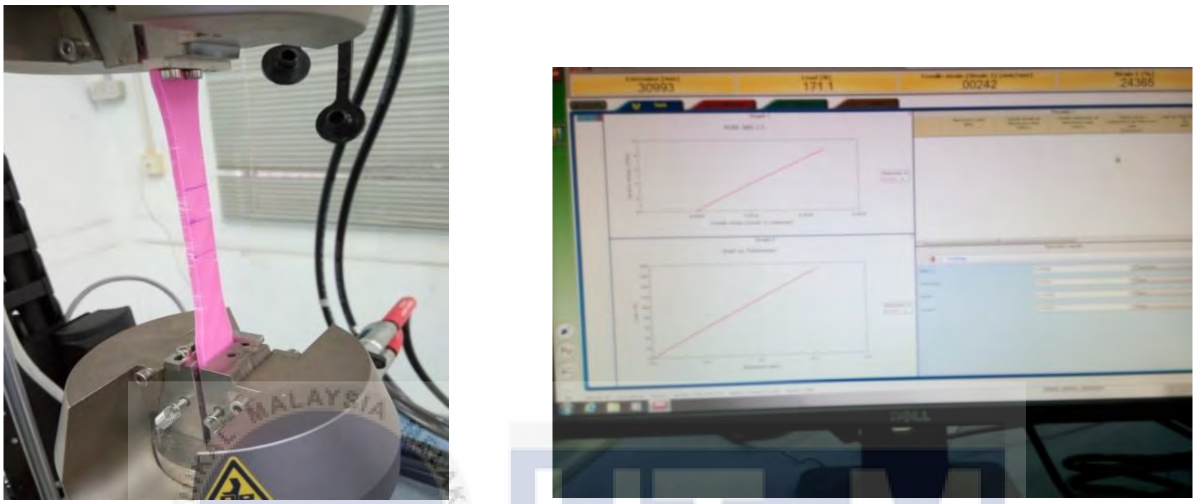


Figure 3.7: Tensile test setup (retrieved from http://www.matweb.com/reference/tensilestrength.aspx)

The tensile machine used in test the Specimens of pure ABS and carbon fiber reinforced ABS was Universal Test Machine: INSTRON 8832. The dog bone of both specimens were clamped and stretched until fracture. The data of the tensile strength was recorded and display to the computer.



(a) **(b)**

Figure 3.8: (a) The ABS specimen being clamped and stretched until fracture (b) the result of tensile properties display on computer

CHAPTER 4

RESULTS AND DISCUSSION

4.1 Introduction

Mechanical properties is tested because to prevent failure in something that can risk our life or to improve existing inventions by not exceeding the allowed stress or what we define as safe limit. In this research, the tensile testing specimen is constructed according to ASTM D638 to get the tensile properties value for both sample of ABS and carbon fiber reinforced ABS. The result data was collected and tabulated in the table.

4.2 Effect of layer thickness on tensile properties of pure ABS

To study the effect of layer thickness, the table with constant raster angles and different layer thickness were prepared. The test result for the built variation are tabulated in table 4.1, 4.2 and 4.3. For ultimate tensile stress, built with 0.18 mm layer thickness show a great influence for the 30^0, 45^0, and 90^0 raster angle that is 29.643 MPa, 30.478 MPa, and 32.526 MPa respectively. Samples with 0.31 mm layer thickness for all raster angle decreased significantly. K. G Jaya et al (2014) stated that the poor result from high layer thickness samples caused by weak interlayer bonding.

We can also see the same pattern in figure 4.1, 4.2, and 4.3 on how layer thickness affected the sample's tensile properties. For all the layer thickness, from the zero load to some increasing load the graph shown a linear elastic region which is at 0 strain to 0.01 strain. Then at different value of tensile stress, after the plastic region, they start taking more load again as stress increased and entered the strain hardening region until the loads reach at ultimate tensile strength which is at the peak of the curve. After that, the stress start to decrease which the region called as necking region until the strain and stress value and stop gradually. This is where the fracture occur and the sample break.

Table 4.1: ABS printed samples tensile properties result for different layer thickness of 30^0 raster angle.

Labels	Raster Angle (^{o})	Layer Thickness (mm)	Tensile Stress (MPa)	Tensile Strain (mm/mm)
A1		0.18	29.643	0.058
A2	30	0.25	25.851	0.056
A3		0.31	21.043	0.062

Table 4.2: ABS printed samples tensile properties result for different layer thickness of 45^0 raster angle.

Labels	Raster Angle (^{o})	Layer Thickness (mm)	Tensile Stress(MPa)	Tensile Strain (mm/mm)
B1		0.18	30.478	0.064
B2	45	0.25	25.815	0.070
B3		0.31	17.090	0.048

Table 4.3: ABS printed samples tensile properties result for different layer thickness of 90^0 raster angle.

Labels	Raster Angle (^{o})	Layer Thickness (mm)	Tensile Stress (MPa)	Tensile Strain (mm/mm)
C1		0.18	32.526	0.051
C2	90	0.25	29.002	0.056
C3		0.31	22.404	0.047

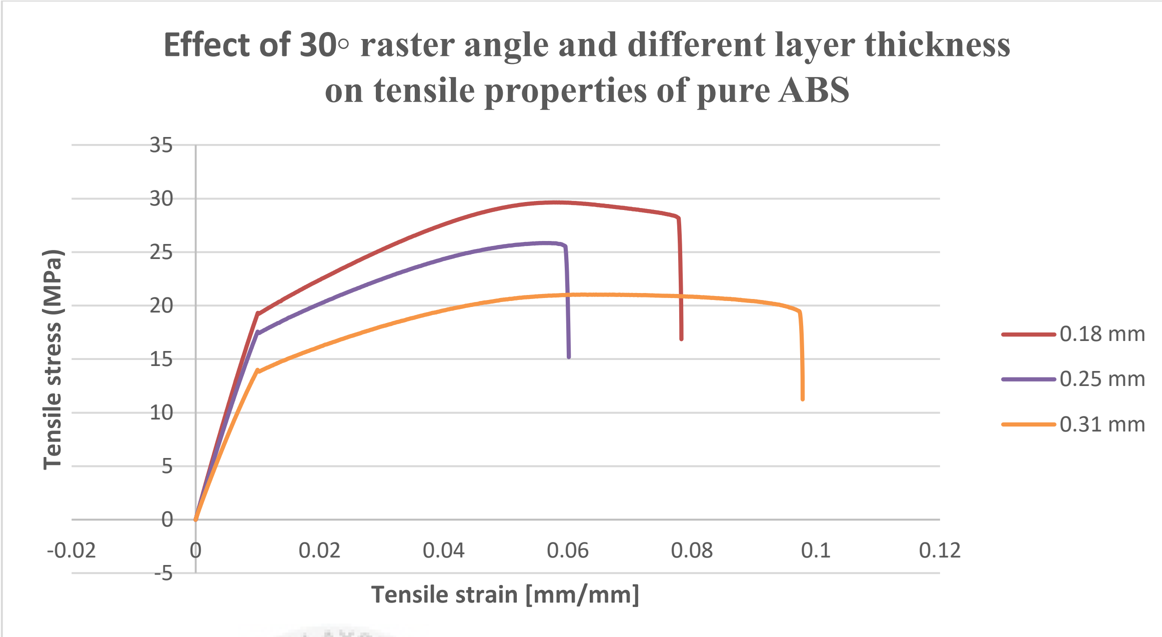


Figure 4.1: ABS with different layer thickness of 30^0 raster angle

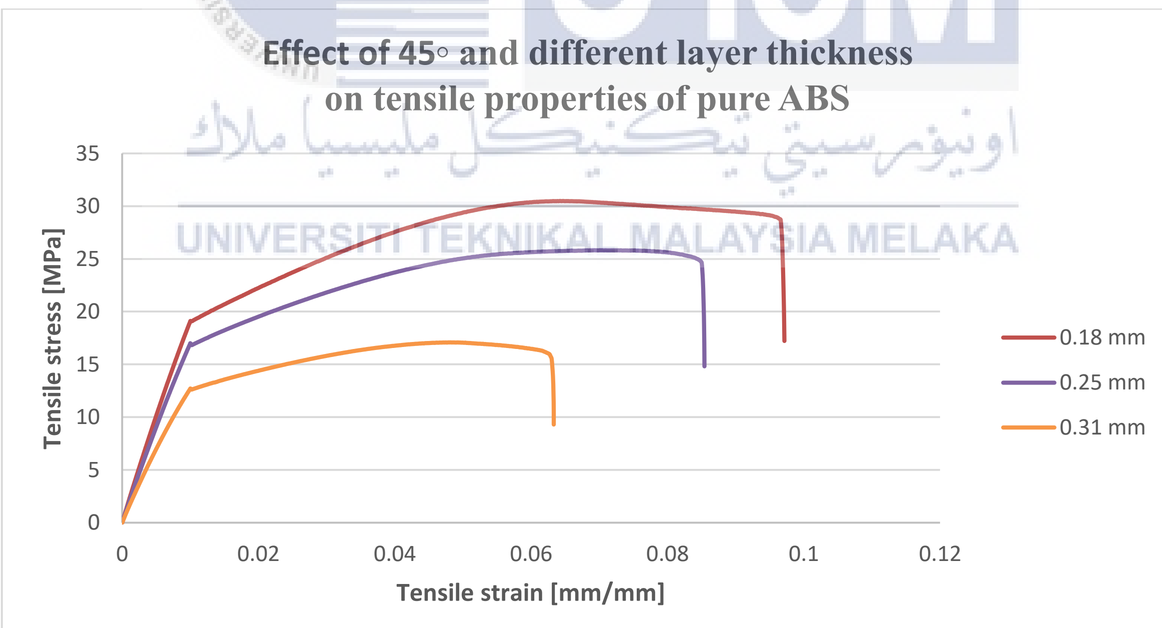


Figure 4.2: ABS with different layer thickness of 45^0 raster angle

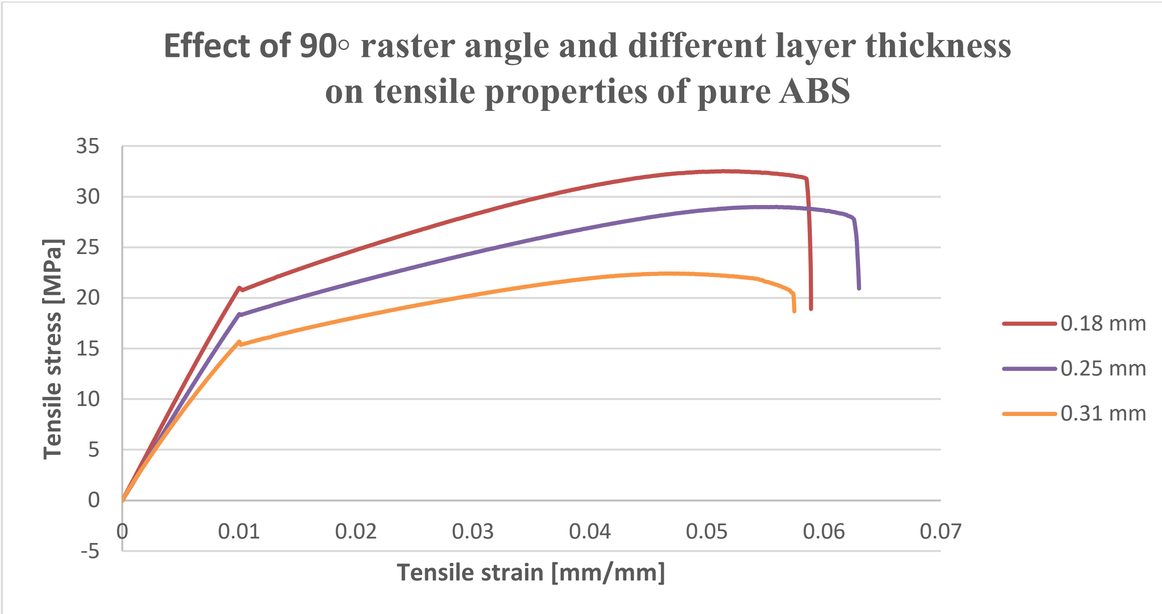


Figure 4.3: ABS with different layer thickness of 90^0 raster angle

The strongest samples in figure 4.2 is the built with 0.18mm layer thickness while the weakest samples is the built with 0.31mm layer thickness. The difference in capabilities to gain more load is very clear for the three sample because the gap from each curve is consistently show about ~15-19 MPa in tensile stress.

Based on the figure 4.3, in term of flexibility, the sample with a built from 0.31mm layer thickness is the most flexible because it has a lowest tensile strength while 0.18mm layer thickness's sample have a great stiffness due to higher value of tensile stress.

4.3 Effect of raster angle on tensile properties of pure ABS

Table 4.4, 4.5, and 4.6 is prepared for the pure ABS sample. It was done to evaluate the effect of raster angle on tensile properties, by changing the raster angle varies with 0.18, 0.25, and 0.31 mm layer thickness. From the test, the graph from figure 4.4, figure 4.5 and figure 4.6 was plotted. The test result show that built with 90◦ have a high effect on the tensile stress where it is the peak value for 0.18, 0.25 and 0.31 mm layer thickness which has a value of 32.526 MPa, 29.002 MPa, and 22.404 MPa respectively. When use 90° raster angle, the molecule printed almost aligned with stress axis direction where it produce the most intense direction. As from the result conducted by Farzad et al (2014), the direction got weaker when the angle got more to the perpendicular or inclined than the direction of stress axis **.**The trend show almost the same for all raster angle variation built with layer thickness.

Table 4.4: ABS printed samples tensile properties result for different raster angle of 0.18 layer thickness.

Labels	**Layer Thickness (mm)**	**Raster Angle (°)**	**Tensile Stress (MPa)**	**Tensile Strain (mm/mm)**
A1		30	29.643	0.058
B1	0.18	45	30.478	0.064
C1		90	32.526	0.051

Table 4.5: ABS printed samples tensile properties result for different raster angle of 0.25 layer thickness.

Labels	Layer Thickness (mm)	Raster Angle (º)	Tensile Stress(MPa)	Tensile Strain (mm/mm)
A2	0.25	30	25.851	0.056
B2		45	25.815	0.070
C2		90	29.002	0.056

Table 4.6: ABS printed samples tensile properties result for different raster angle of 0.31 layer thickness.

Labels	Layer Thickness (mm)	Raster Angle (º)	Tensile Stress (MPa)	Tensile Strain (mm/mm)
A3	0.31	30	21.043	0.062
B3		45	17.090	0.048
C3		90	22.404	0.047

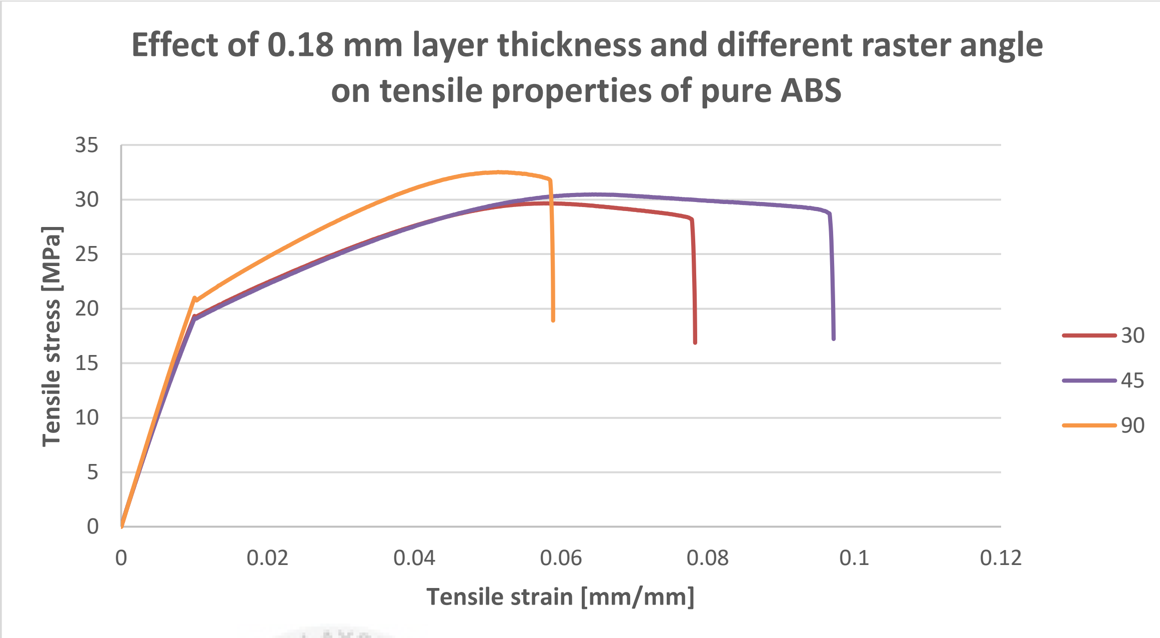


Figure 4.4: ABS with different raster angle of 0.18mm layer thickness

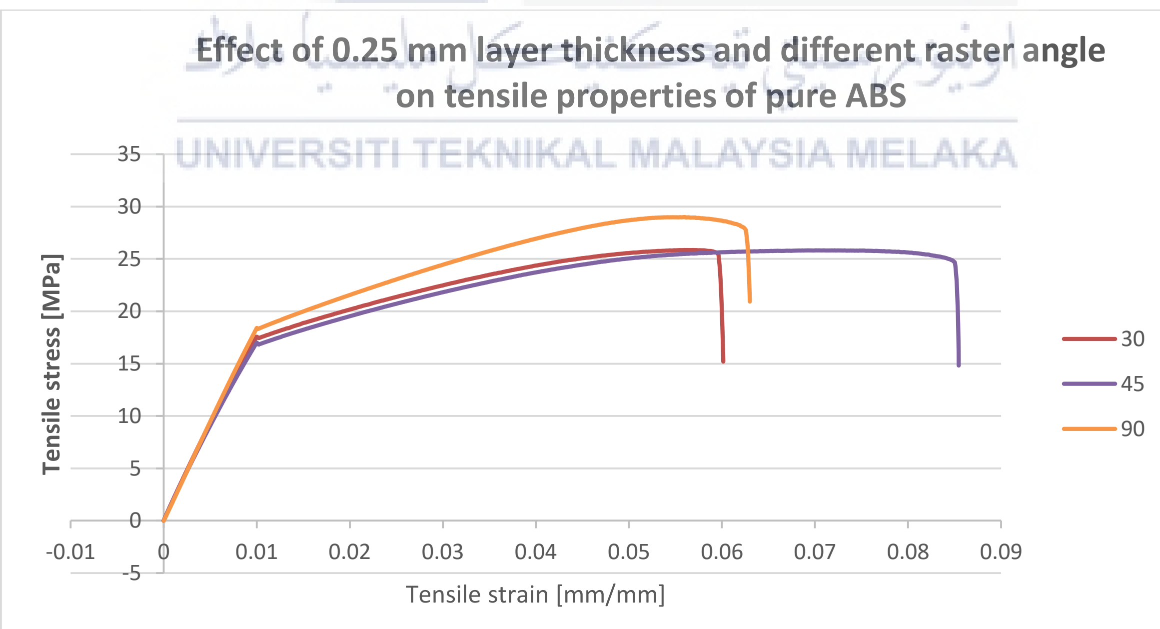


Figure 4.5: ABS with different raster angle of 0.25mm layer thickness

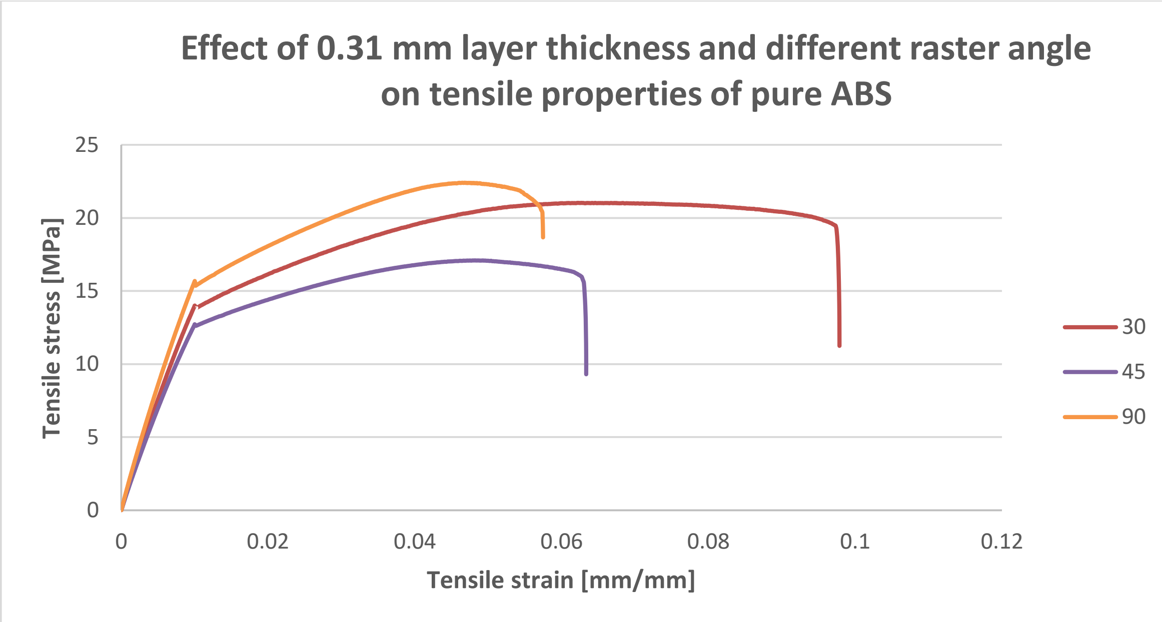


Figure 4.6: ABS with different raster angle of 0.31mm layer thickness

From figure 4.4, clearly the graph produce a highest curve on the 90° raster angle. However, 90° of raster angle have minimum tensile strain compare to 30° and 45° raster angle which is below 0.06 mm/mm. The load for 30° and 45° increasing simultaneously before 30° reach its maximum stress and start to enter the necking region. The sample with 45° raster angle is the toughest compare to other two because it's have a larger area under the graph. Although 90° raster angle built produced a strong sample due to its highest stress value, the sample is the most brittle due to low tensile strain.

The graph plotted on figure 4.5, shows that the most ductile sample in this variation is a sample with 45° raster angle as its take the longest elongation to fracture. The highest stress value for 0.25mm layer thickness with different raster angle would be at 90° raster angle with a value of 29.002 MPa while the lowest stress value is at 45° raster angle sample with a value of 25.815 MPa

The same trend was noticed in the figure 6, where the highest stress value was produced by 90° raster angle built with a value of 22.404 MPa, and once again the weakest sample came from 45° raster angle built which is 17.090 MPa . From the result, it happen that the most affect tensile strength of pure ABS is when layer thickness at 0.18 and raster angle was set at 90°

4.4 Effect of layer thickness on tensile properties of carbon fiber reinforced ABS

Same as pure ABS, nine sample with different built parameter have been dealing with tensile test following ASTM D638 standard. The result for variant layer thickness is tabulated in the table. The test outcome displayed that the strong sample among each set of 30^{o}, 45^{o} and 90^{o} raster angle with a value of 16.834 MPa, 16.866 MPa, and 21.618 MPa respectively. In table 4.7 and table 4.8, the most influenced layer thickness was at 0.31 mm while in table 4.9, when the printed sample subjected to 90^{o} raster angle, the most influenced layer thickness was at 0.18 mm. The related stress strain curves are plotted in figures 4.7-4.9 for all layer thickness experimental samples.

Table 4.7: Carbon fiber printed samples tensile properties result for different layer thickness of 30^{0} raster angle.

Labels	**Raster Angle (^{o})**	**Layer Thickness (mm)**	**Tensile Stress (MPa)**	**Tensile Strain (mm/mm)**
A1	30	0.18	15.933	0.031
A2		0.25	16.481	0.028
A3		0.31	16.834	0.030

Table 4.8: Carbon fiber printed samples tensile properties result for different layer thickness of 45^0 raster angle.

Labels	Raster Angle (°)	Layer Thickness (mm)	Tensile Stress(MPa)	Tensile Strain (mm/mm)
B1	45	0.18	15.805	0.034
B2		0.25	15.207	0.035
B3		0.31	16.866	0.037

Table 4.9: Carbon fiber printed samples tensile properties result for different layer thickness of 90^0 raster angle.

Labels	Raster Angle (°)	Layer Thickness (mm)	Tensile Stress (MPa)	Tensile Strain (mm/mm)
C1	90	0.18	21.619	0.022
C2		0.25	18.795	0.022
C3		0.31	18.441	0.022

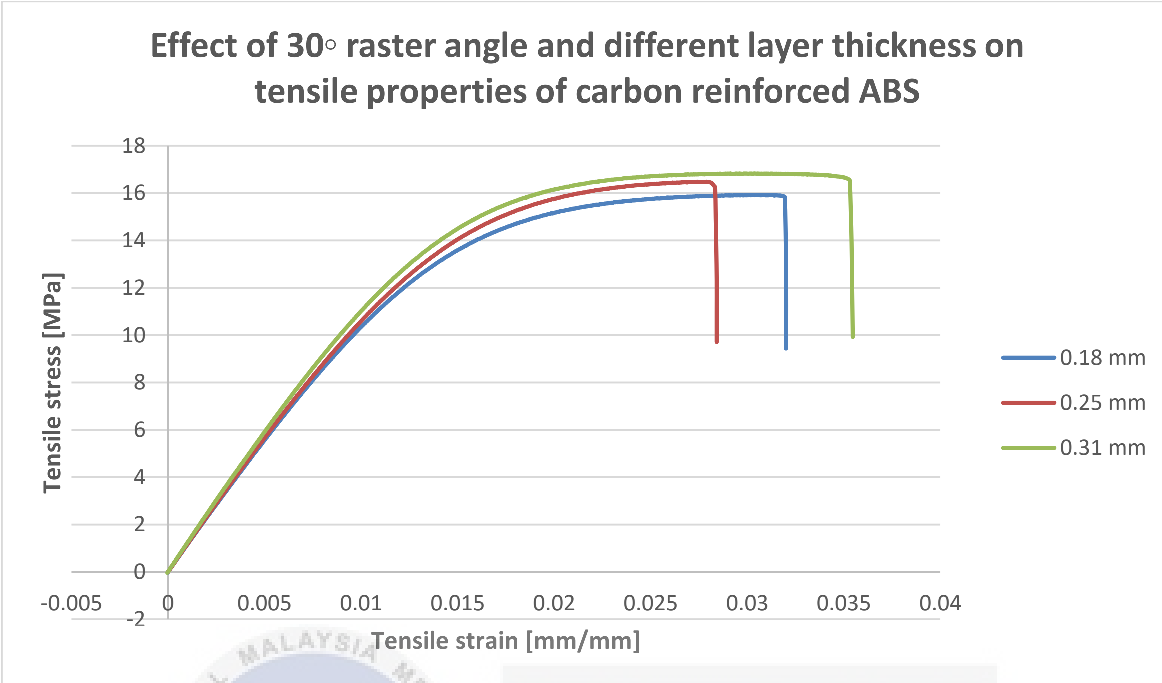


Figure 4.7: Carbon fiber reinforced ABS with different layer thickness of 30° raster angle

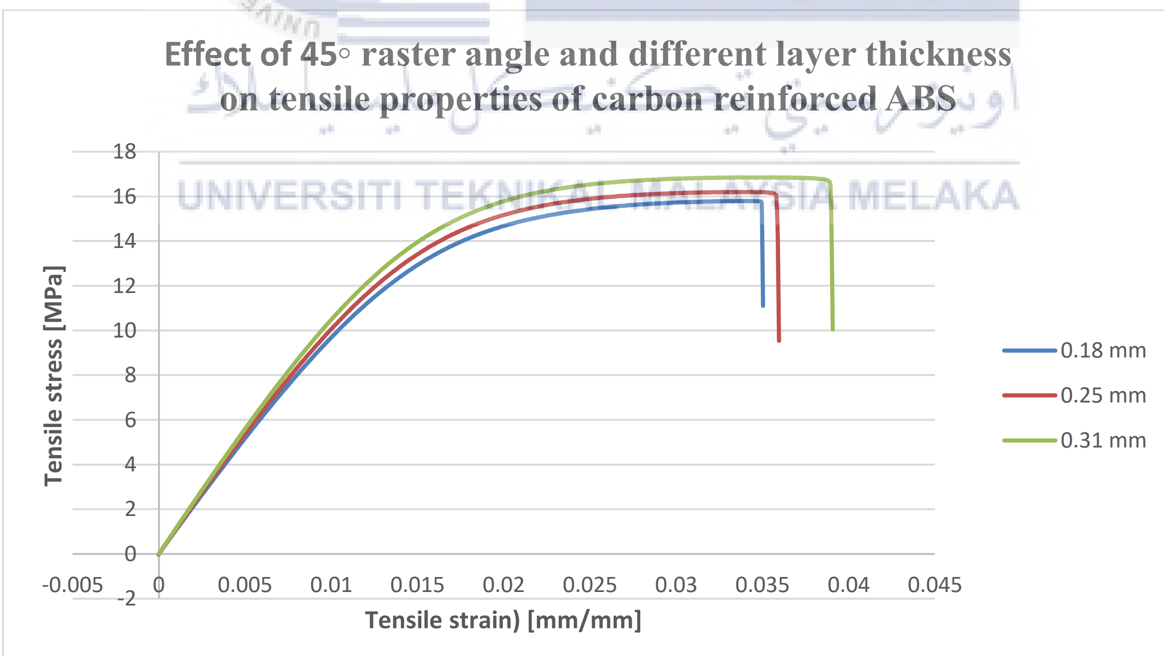


Figure 4.8: Carbon fiber reinforced ABS with different layer thickness of 45° raster angle

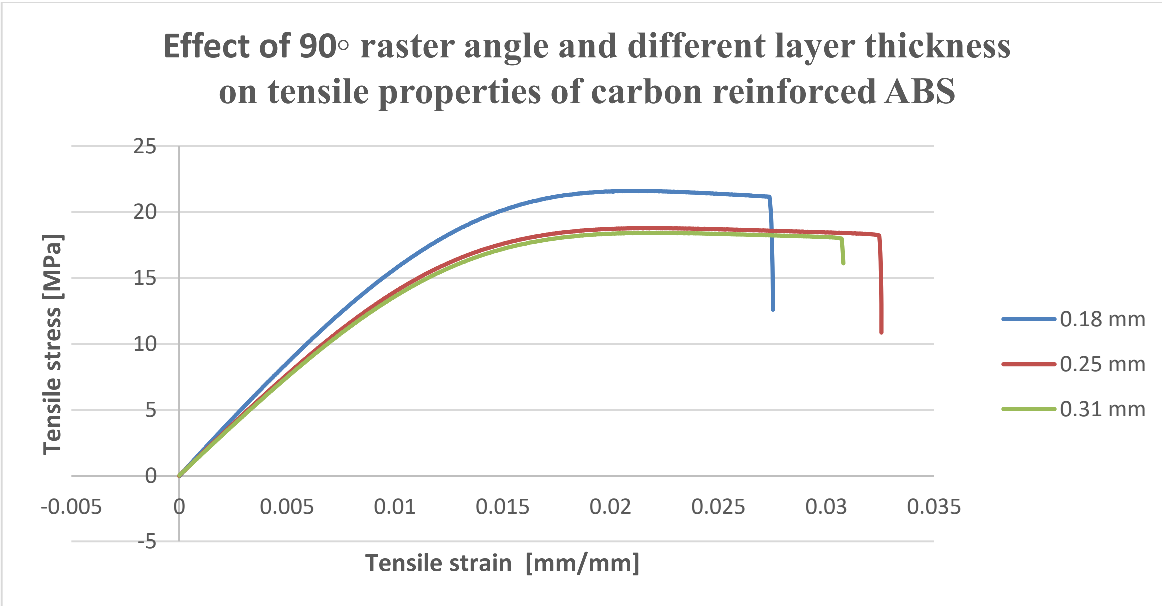


Figure 4.9: Carbon fiber reinforced ABS with different layer thickness of 90^o raster angle

As in figure 4.7, there was not much difference in tensile stress between 0.18, 0.25 and 0.31 layer thickness. However the ductility between the samples have significant difference. The weakest printed sample in table 4.8 was 15.207 MPa when the layer thickness was at 0.25 mm. From figure 4.8, the curve trend between all layer thicknesses is same as figure 4.7.

Table 4.9 and figure 4.9 revealed a different trend where it illustrates that when layer thickness decreased, the tensile stress increased. The result for this built variation displayed almost same trend as the result for pure ABS. There have been a significant contrast between the 0.18 mm layer thickness compared to 0.25 mm and 0.31 layer thickness wheree 0.25 mm layer thickness only had 0.354 MPa difference with 0.31 layer thickness. Therefore, the layer thickness performed a notable role in determining the tensile properties of carbon reinforced ABS material printed with 240^{o}c and with fill density of 90%, K. G. Jaya (2015).

4.5 Effect of raster angle on tensile properties of carbon fiber reinforced ABS

Table 4.10-4.12 are the result of tensile strength with a varying raster angle. It stated that the tensile strength of the printed carbon fiber reinforced ABS were clearly affected by raster angle. From the result, the highest tensile stress for all experimental samples came at raster angle of 90^{o}. 90^{o} printed part mean that the filament was prints parallel to the direction of load, fabricating the strongest sample with a value 21.619 MPa, 18. 795 MPa, and 18.441 MPa for a layer thickness of 0.18mm, 0.25mm and 0.31mm consequently. Wenzheng et al (2015) stated, the tensile strength get weaker when the printed angle depart away from load direction as there was a restricted angle between the microstructural elements and the load direction.

Table 4.10: Carbon fiber reinforced ABS printed samples tensile properties result for different raster angle of 0.18 layer thickness.

Labels	**Layer Thickness (mm)**	**Raster Angle (^{o})**	**Tensile Stress (MPa)**	**Tensile Strain (mm/mm)**
A1	0.18	30	15.933	0.031
B1		45	15.805	0.034
C1		90	21.619	0.022

Table 4.11: Carbon fiber reinforced ABS printed samples tensile properties result for different raster angle of 0.25 layer thickness.

Labels	**Layer Thickness (mm)**	**Raster Angle (º)**	**Tensile Stress(MPa)**	**Tensile Strain (mm/mm)**
A2	0.25	30	16.481	0.028
B2		45	15.207	0.035
C2		90	18.795	0.022

Table 4.12: Carbon fiber reinforced ABS printed samples tensile properties result for different raster angle of 0.31 layer thickness.

Labels	**Layer Thickness (mm)**	**Raster Angle (º)**	**Tensile Stress (MPa)**	**Tensile Strain (mm/mm)**
A3	0.31	30	16.834	0.030
B3		45	16.866	0.035
C3		90	18.441	0.022

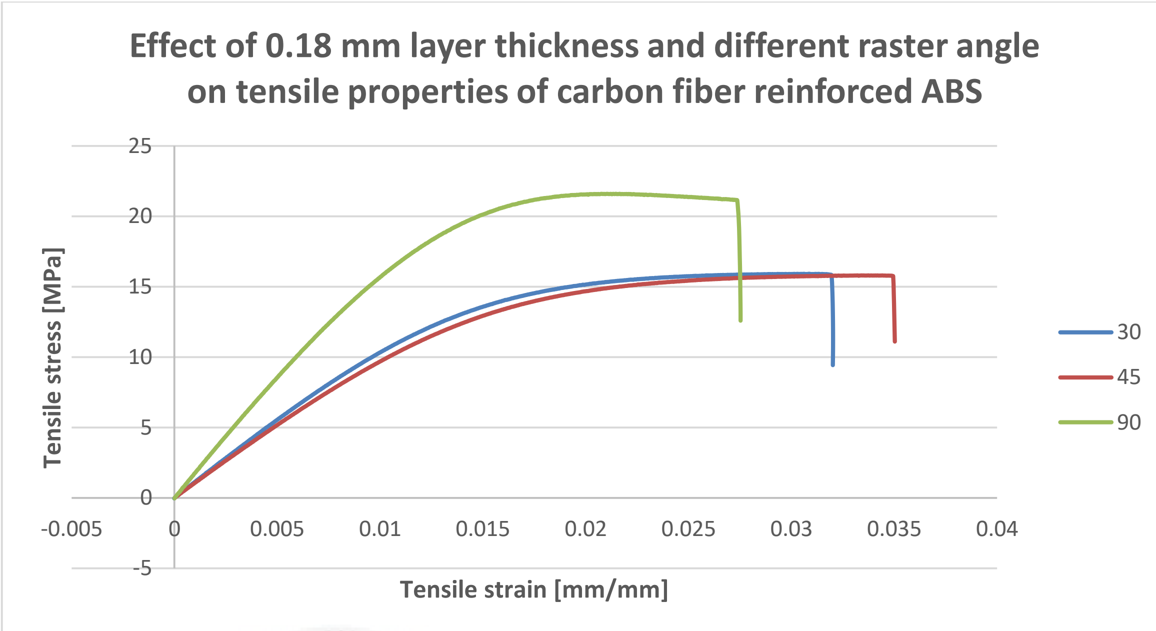


Figure 4.10: Carbon fiber reinforced ABS with different raster angle of 0.18mm layer thickness

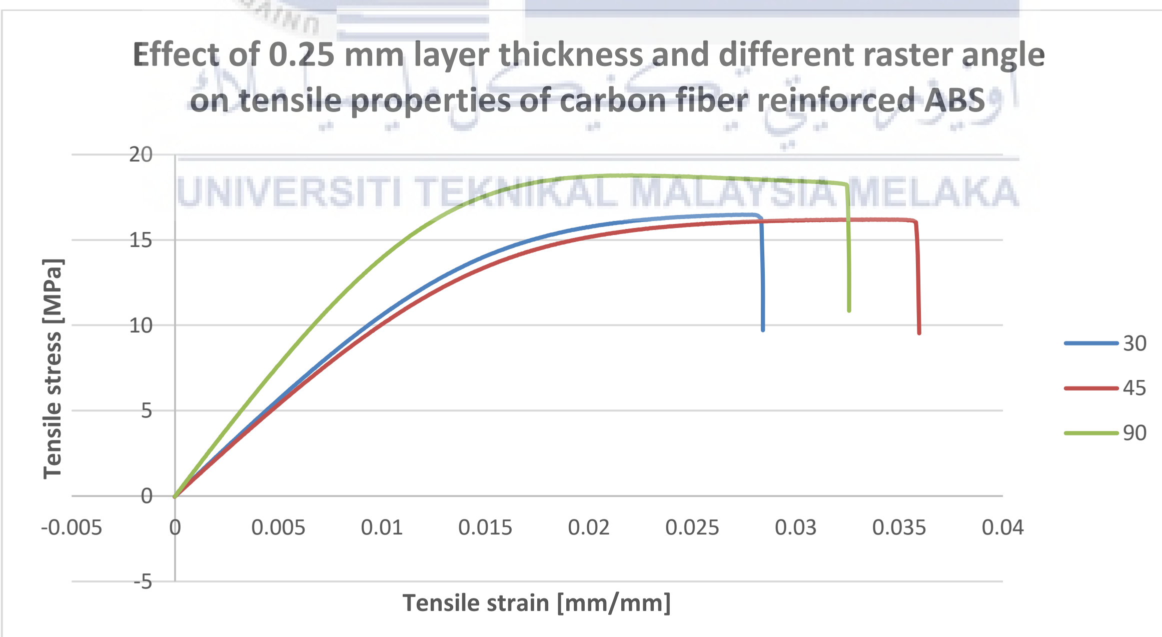


Figure 4.11: Carbon fiber reinforced ABS with different raster angle of 0.25mm layer thickness

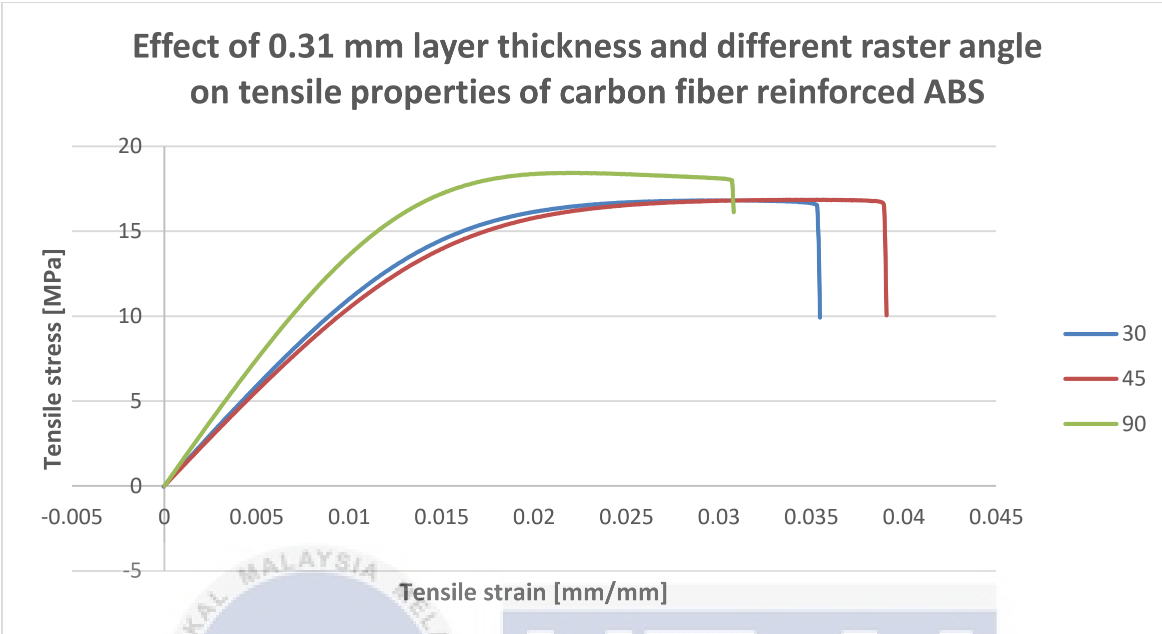


Figure 4.12: Carbon fiber reinforced ABS with different raster angle of 0.31mm layer thickness

Figure 4.10-4.12 shows that the same curve trend between 0.18mm, 0.25mm and 0.31 layer thickness for a different raster angle. As noticed, there are a wide gap between the highest peak curves and second peak curves. The highest peak curves means the strongest printed samples which is belong to samples prints at 90º raster angle. However, in term of ductility, it exhibits the weakest strain value as illustrated in figure 4.10 and 4.12. For a printed sample at 45º raster angle, although it low in tensile stress, it was the most ductile sample compare to samples printed at 30º and 90º raster angle. Obviously, the raster angle had shown the tendency to affect the internal structure of the final product from carbon fiber reinforced ABS.

4.6 Comparison of ABS and carbon fiber reinforced ABS tensile strength

Samples for both ABS and carbon fiber reinforced ABS analyzed regarding their tensile properties with same combination of parameter from raster angle and layer thickness. Figure shows ABS and carbon fiber reinforced ABS samples after completely through tensile test according to ASTM D638. From figure 4.13, the image from both ABS and carbon fiber displays two condition of sample's fracture. ABS seems have a rough and uneven fracture while carbon fiber showed even and same style of fracture.

(a) (b)

Figure 4.13: Fracture tensile sample. (a) Acrylonitrile butadiene styrene (ABS); (b) Carbon fiber reinforced ABS.

Figure 4.14 give an info for the comparison between this two materials, ABS and carbon fiber reinforced ABS. The result taken is from parameter built with 45° raster angle 0.18 mm layer thickness because it has a highest difference in tensile strength value. Furthermore, figure 4.15 displays for a lowest tensile strength value difference when the built at 45° raster angle and 0.31 layer thickness.

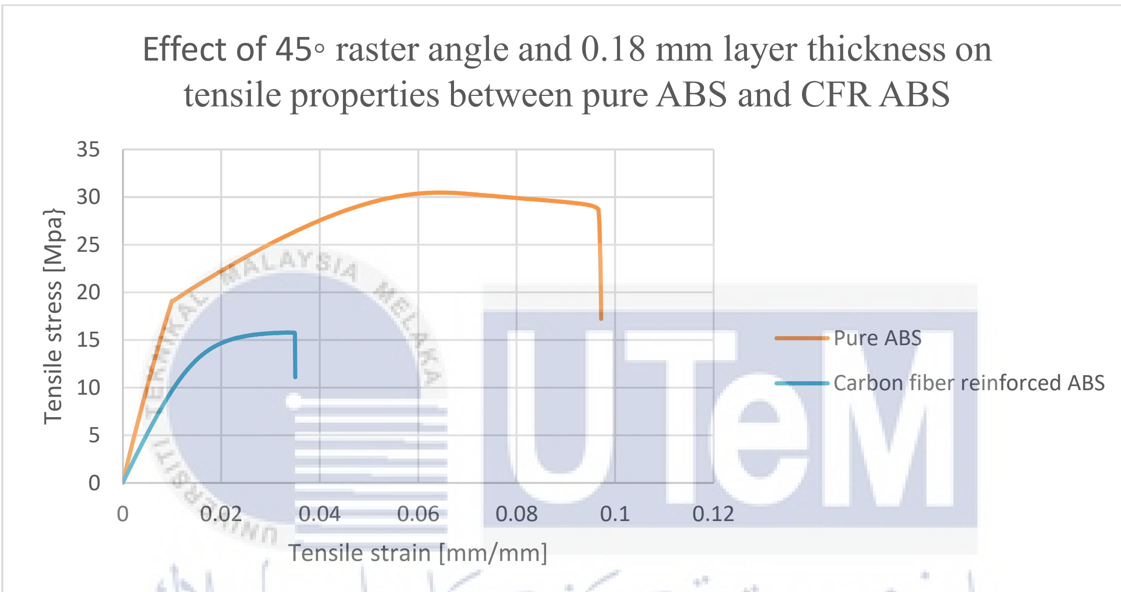


Figure 4.14: Comparison between two materials with the highest difference in tensile strength

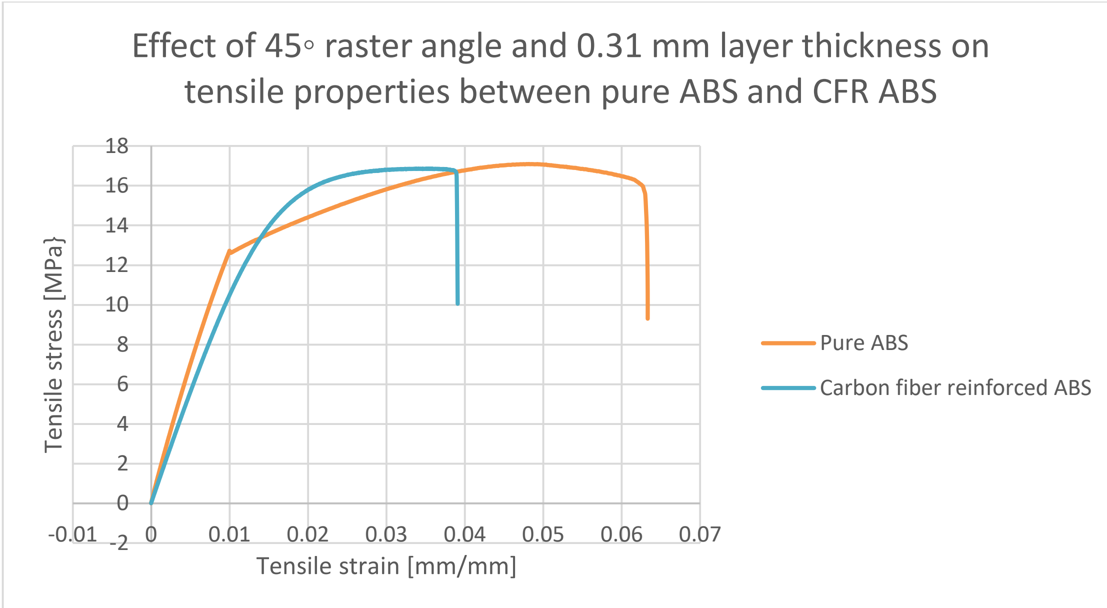


Figure 4.15: Comparison between two materials with the lowest difference in tensile strength

Figure 4.14 illustrates tensile strength of pure ABS with a built of 45° raster angle and 0.18 layer thickness exhibit about 48% more than carbon fiber. The linear line of the ABS shows that the ABS sample gain more load in elastic condition. After both sample reached peak stress, the ABS samples still resist the stress before it fracture until the strain at ~0.1 mm/mm while carbon fiber sample do not wait too long after reaching a peak stress to fracture. In figure 4.15, the load gain for both sample is almost the same. The highest tensile stress achieved by ABS sample is 17.090 MPa which is exceed just 1.3 % from the carbon fiber samples. The carbon fiber sample reached the peak first than ABS sample before it fracture, this shown that ABS material is more ductile compare to carbon fiber sample.

The ABS curves obviously differ from carbon fiber curves. When the load increased, carbon fiber first yielded the maximum stress before necking deformation occurred at the tensile fracture surface. From figure and figure, clearly the raster angle and layer thickness give different value in tensile stress which stated that both parameter significantly affected the samples. Layer thickness may not influence much for end product of carbon fiber but it really affect the end product of pure ABS. As the layer thickness increase, the bond between molecular structure of the sample getting weaken thus affected the tensile strength. For raster angle, each of the layer printed with restrict angle that change the internal structure will affect the tensile strength based on the distance of the angle to the direction load.

The change in trend for both material is shows in figure 4.16 and figure 4.17. In figure 4.16, we can see the linear decreased in tensile stress when the layer thickness is increase. 0.18mm layer thickness exhibit the highest tensile stress. In figure 4.17, the tensile stress change for all raster angle. 90^{o} raster angle display the strongest samples for both material than 30^{o} and 45^{o}. The ideal mechanical properties for ABS and carbon fiber reinforced ABS were found in test with a 0.18mm layer thickness and 90^{o} raster angle.

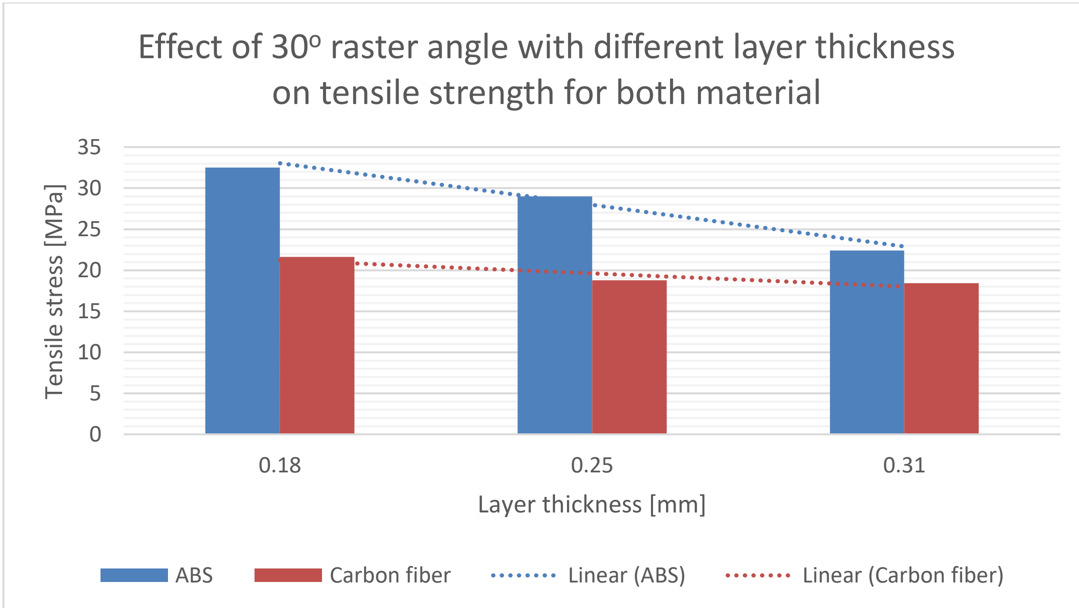


Figure 4.16: Comparison on tensile property of layer thickness between acrylonitrile butadiene styrene (ABS) and Carbon fiber reinforced ABS

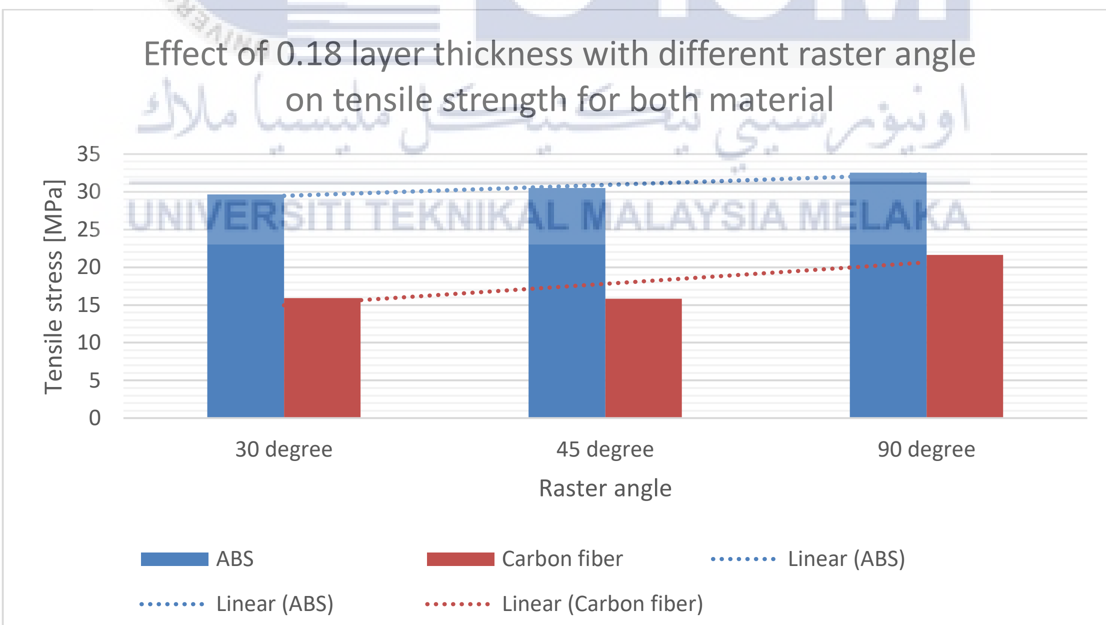


Figure 17: Comparison on tensile property of raster angle between acrylonitrile butadiene styrene (ABS) and Carbon fiber reinforced ABS

CHAPTER 5

CONCLUSION AND RECOMMENDATION

In this study, the relationship between tensile strength and process parameter for FDM process was measured. There are total of nine sample for ABS and nine sample for carbon fiber reinforced ABS with various raster angle (30°, 45° and 90°) and layer thickness (0.18mm, 0.25mm and 0.31mm). The aim of this study is to examine the effect of raster angle and layer thickness for both material. The test was done using universal tensile machine according to ASTM D638. This data is important to know to outline practical parts with this innovation, whose utilization expands more nowadays.

The test results confirmed that layer thickness and raster angles impinge on tensile properties. The highest tensile strength for pure ABS got from the result was 32.526 MPa which is came from 0.18mm layer thickness and 90^0 raster angle. The lowest strength for all experimental pure ABS sample when the layer thickness at 0.31mm and raster angle at 45°. From the stress-strain graph, all data exhibit the same trend. For carbon fiber reinforced ABS material fabricated with 0.18mm layer thickness and 90° raster angle, the tensile strength obtained is the highest with a value of 21.614 MPa. With a tensile strength of 15.207 Mpa, the carbon fiber samples with a 0.25mm layer thickness and 45° raster angle make it as the weakest samples.

From the test conduct, all the result obviously shows that when the layer thickness increase, the tensile strength will increase. This is due to interlayer bonding, where more narrow the layer and thereafter, the bond become stronger. Raster angle also play a significant role in determining the tensile strength of the sample. As noticed, when the raster angle approaching the axis of load direction, the tensile strength become stronger. In this study, 90^o raster angle is in the direction of load.

This study also compared the tensile properties of ABS and carbon fiber reinforced ABS samples parts made by 3D printing. The ABS curves obviously differ from carbon fiber curves. It can be concluded that ABS have more tensile strength. If compare the tensile strength between the highest of ABS and the highest of carbon fiber reinforced ABS, the difference show that ABS exceed carbon fiber as much as 48%. From the figure , the carbon fiber samples display more clean fracture which indicated that carbon fiber do not resist the stress too long and can be categorize as a brittle material. The best parameter built for both material is when layer thickness 0.18 mm and raster angle set at 90^0 as it posed the highest tensile strength. This is because the built parameter have a strong bonding and tendency to align with the load direction.

From the results of experiment, couple of guidelines have been formulated. These guidelines are intend to aid future researcher or designer in improving the strength of their parts made on FDM machine. First of all, make sure printing the all the samples with same FDM machine. The nozzle's temperature of the FDM machine must be at a right temperature because if too hot or not enough temperature it will affect the fabricated parts thus affect the results of mechanical. Consider also to build part that tensile load will be carried axially along the samples. Be aware that all parameter play a role in influencing the tensile strength. To get more precise, prepare three sample with same built parameter. This is because when test is conducted, the result is taken from the mean value of the three reading. Noted that when increasing the layer thickness, the sample geometry will decreases and weaken the tensile properties of the samples printed. Further research also is needed to reduce pore formation during the printing process and to improve inter layer bonding. Try to consider use other process parameter to get more data on strengthening the tensile properties. Carbon fiber has favourable properties in real world, however the percentage of the carbon fiber maybe affect the performance of the material. Consider use different percentage of carbon fiber.

REFERENCE

Cany Mendosa, KV Naveen & Prathik Upadiaya , (**2015**) , *Mechanical Properties of Components Fabricated with Fused Deposition Modelling*

Fahraz Ali, Boppana V. Chowdarry & M. Justin, (**2014**) , *Influenced of Some Process on Build Time, Material Consumption, and Surface Roughness of FDM Processed Parts : Inferences Based on the Taguchi Design of Experiments.*

Wenzheng Wu, Peng Geng & Guiwei Li , (**2015**) , *Influence of Layer Thickness and Raster Angle on the Mechanical Properties of 3D-Printed PEEK and a Comparative Mechanical Study between PEEK and ABS*

Es-Said, O.S., Foyos, J.,Noorani & R., (**2000**) , *Effect of Layer Orientation on Mechanical Properties of Rapid Prototyped Samples*

Denscombe, M. (**1998**), *The Good Research Guide for Small-Scale Social Research Projects*

Novakova-Marcincinova L & Novak-Marcincin J, (**2012**), *Testing of material for rapid prototyping fused deposition modelling technology. World Academy of Science, Engineering and technology*

Chua CK & Fai LK, (**2000**), *Rapid Prototyping: Principle and Application in manufacturing*

Pulak M. Pandey, David IW & L. Jyotish Kumar, (**2015**), *Advances in 3D Printing & Additive Manufacturing Technologies*

Gebhardt A, (**2003**), *Rapid Prototyping*

William K. Langford, (**2012**), *Achieving Precise Flow in Fused Deposition Modeling Extruders. Term paper. Engineering Management*

Kenneth G. Cooper, (**2001**), *Rapid Prototyping Technologies: Selection and Application*

Wang, T.M., Xi, J.T., Jin & Y. (**2001**), *Prototype Surface Micro precision in Fused Deposition Modeling Process.*

Zein I, Hutmacher DW, Tan KC & Teoh SH, (**2002**0, *Fused Deposition modeling of novel scaffold architectures for tissue engineering application. Biomaterials.*

Izham.I, (**2015**), *Feed Rate Effects on Filament Extrusion for Freeform Filament Fabrication.*

S Yang, Castilleja J.R., E.V. Barrera & K. Lozano, (**2004**), *Thermal Analysis of an Acrylonitrile-Butadiene-styrene/SWNT Composite.*

M.suzuki & CA Wilkie, (**1995**), *The thermal degradation of Acrylonitrile-Butadiene-Styrene Terpolymer Grafted with Methacrylic acid. Polym Degrad Stabil*

B.Eng Enno Ebel Fachhochschule Dortmund, (**2013**), *Fabricatio of FDM objects with ABS and PLA and determination of their mechanical properties*

M. AZHAR, (**2014**), *A study on extrusion of multiple material bonding for Fused Deposition Modeling*

F. Ning , Weilong Cong, jingjing Qiu, Junhua Wei & Shiren Wang (**2015**) , *Additive manufacturing of carbon fiber reinforced thermoplastic composites using fused deposition modeling*

Halil L. Tekinalp, Vlastimi kunc, Gregorio M. Velez-Garcia, Chad E. Duty & Lonnie J.Love, (**2014**), *Highly oriented carbon fiber-polymer composite via Additive Manufacturing.*

Anoop K. Sood, Raj K. Ohdar & Siba S. Mahapatra, (**2012**), *Experimental Investigation And Empirical Modelling Of FDM Process For Compressive Strength Improvement.*

Ana Pilipovic, Pero Raos & Mladen Sercer, (**2007**), *Experimental Analysis of Properties of Materials for rapid prototyping*

K.Thrimurthulu, P.M. Pandey & N. Venkata Reddy (**2004**), *Optimal part deposition orientation in FDM by using a multicriteria genetic algorithm.*

K P Shah, *The Hand Book on Mechanical Maintenance. [Online]*

Available at: http://practicalmaintenance.net/?p=948 [Accessed on 29 November 2016]

Standard Test Method for Tensile Properties of Plastics. [Online]
Available at: https://www.astm.org/Standards/D638.htm [Accessed on 30 November 2016]

K. G Jaya Christiyan, U. Chandrasekhar & K. Venkateswarlu, (**2014**), *Influence of raster orientation and layer thickness on mechanical properties of ABS material using FDM process*

M. Daniel, (**2010**), *Doing Quantitative Research in Education with SPSS*

Farzad R., Godfrey C. & Onwubolu, (**2014**), *Fused deposition modelling (FDM) process parameter prediction and optimization using group method for data handling (GMDH) and differential evolution (DE).*

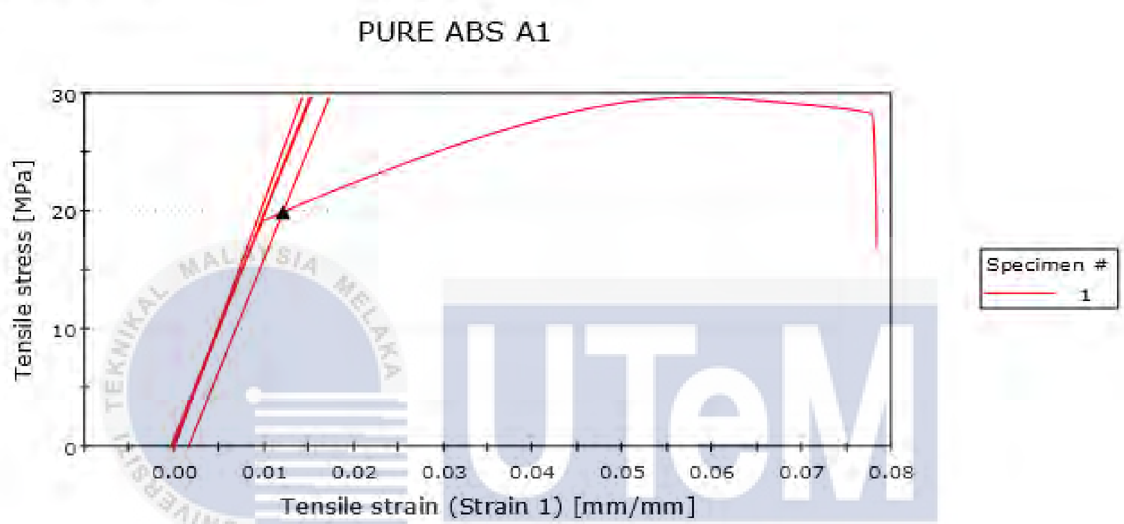
K. G Jaya Christiyan, U. Chandrasekhar & K. Venkateswarlu, (**2015**), *A study on the influence of process parameters on the Mechanical Properties of 3D Printed ABS Composites*

R. Anitha, S. Arunachalam, P. Radhakrishnan, (**2001**), *Critical parameters influencing the quality of the prototypes in fused deposition modelling*

K. savvakis, M. Petousis, A. Vairis, N. Vidakis & A. T. Bikmeyez , (**2014**) , *Experimental determination of the tensile strength of Fused Deposition Modeling Parts*

APPENDIX A1

Tensile Test for ABS



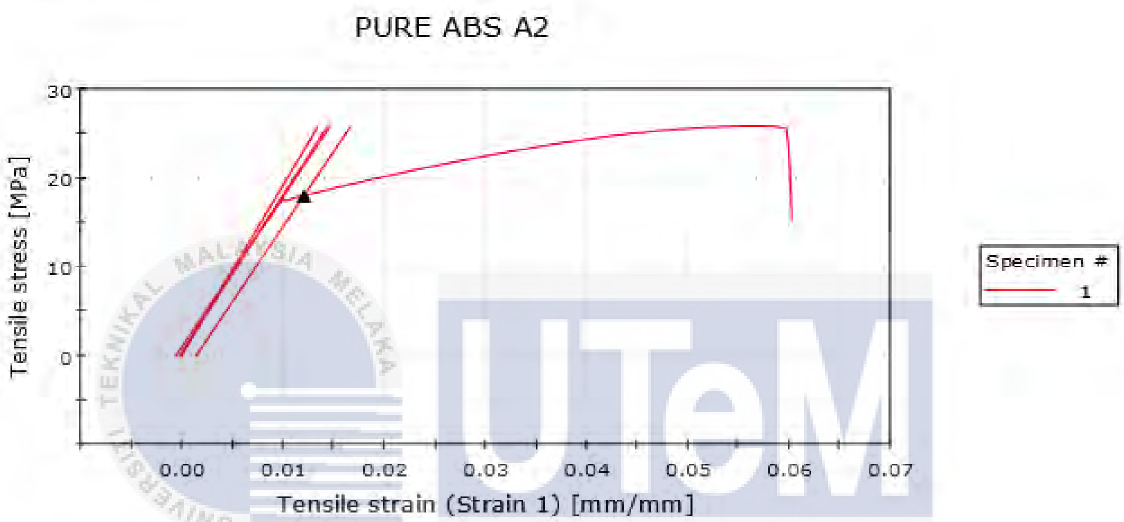
	Maximum Load [kN]	Tensile stress at Maximum Load [MPa]	Tensile extension at Maximum Load [mm]
1	1.156	29.643	1.439

	Tensile strain (Extension) at Maximum Load [mm/mm]	Load at Yield (Offset 0.2 %) [kN]	Tensile stress at Yield (Offset 0.2 %) [MPa]
1	0.058	0.777	19.925

	Modulus (Automatic) [MPa]	Modulus (E-modulus) [MPa]	Modulus (Automatic Young's) [MPa]
1	1935.356	1885.738	2068.669

APPENDIX A2

Tensile Test for ABS



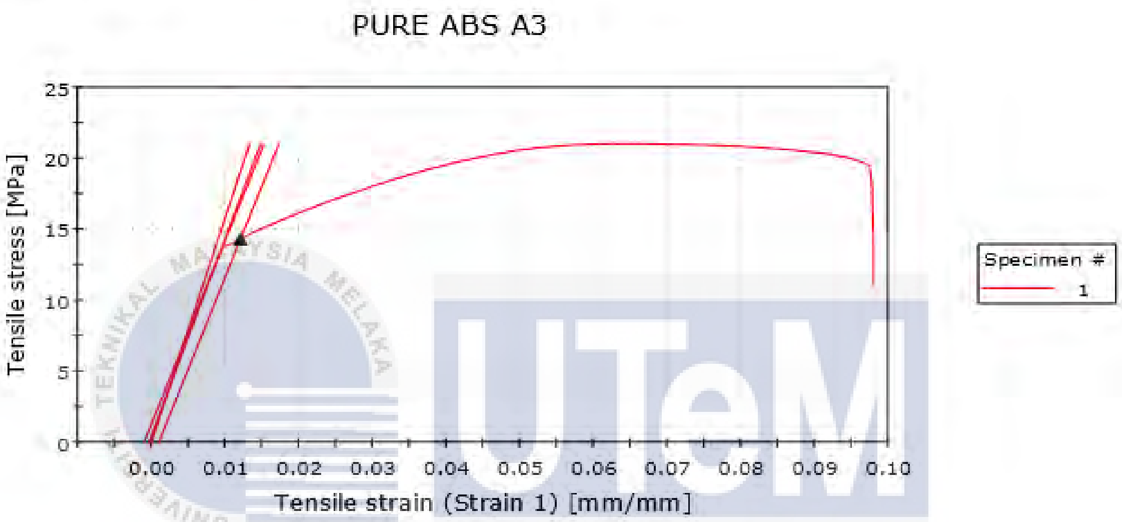
	Maximum Load [kN]	Tensile stress at Maximum Load [MPa]	Tensile extension at Maximum Load [mm]
1	1.008	25.851	1.400

	Tensile strain (Extension) at Maximum Load [mm/mm]	Load at Yield (Offset 0.2 %) [kN]	Tensile stress at Yield (Offset 0.2 %) [MPa]
1	0.056	0.703	18.014

	Modulus (Automatic) [MPa]	Modulus (E-modulus) [MPa]	Modulus (Automatic Young's) [MPa]
1	1765.115	1692.151	1909.659

APPENDIX A3

Tensile Test for ABS



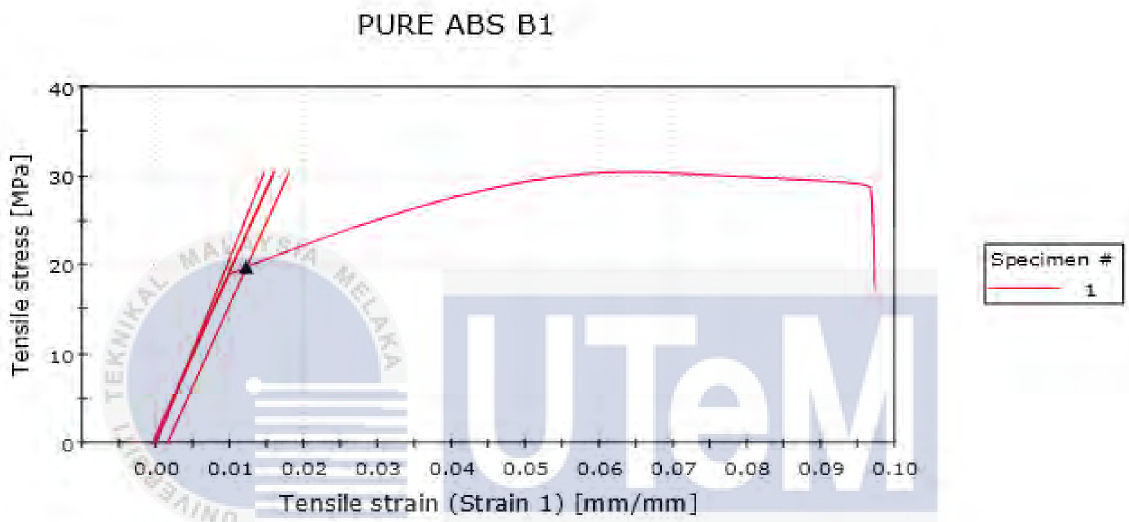
	Maximum Load [kN]	Tensile stress at Maximum Load [MPa]	Tensile extension at Maximum Load [mm]
1	0.821	21.043	1.556

	Tensile strain (Extension) at Maximum Load [mm/mm]	Load at Yield (Offset 0.2 %) [kN]	Tensile stress at Yield (Offset 0.2 %) [MPa]
1	0.062	0.560	14.355

	Modulus (Automatic) [MPa]	Modulus (E-modulus) [MPa]	Modulus (Automatic Young's) [MPa]
1	1384.762	1289.549	1569.519

APPENDIX A4

Tensile Test for ABS



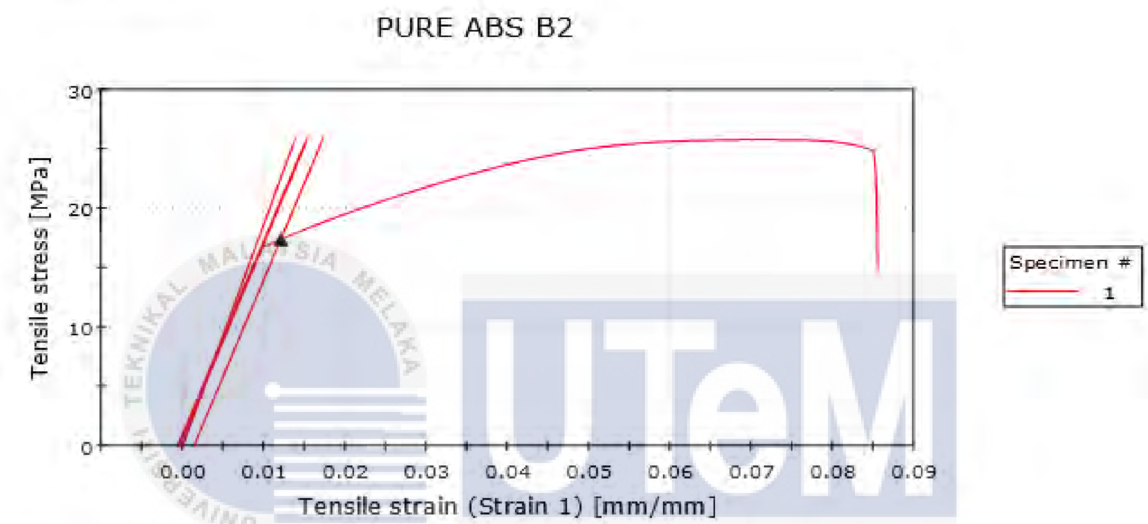
	Maximum Load [kN]	Tensile stress at Maximum Load [MPa]	Tensile extension at Maximum Load [mm]
1	1.189	30.478	1.605

	Tensile strain (Extension) at Maximum Load [mm/mm]	Load at Yield (Offset 0.2 %) [kN]	Tensile stress at Yield (Offset 0.2 %) [MPa]
1	0.064	0.771	19.774

	Modulus (Automatic) [MPa]	Modulus (E-modulus) [MPa]	Modulus (Automatic Young's) [MPa]
1	1884.877	1843.071	2071.350

APPENDIX A5

Tensile Test for ABS



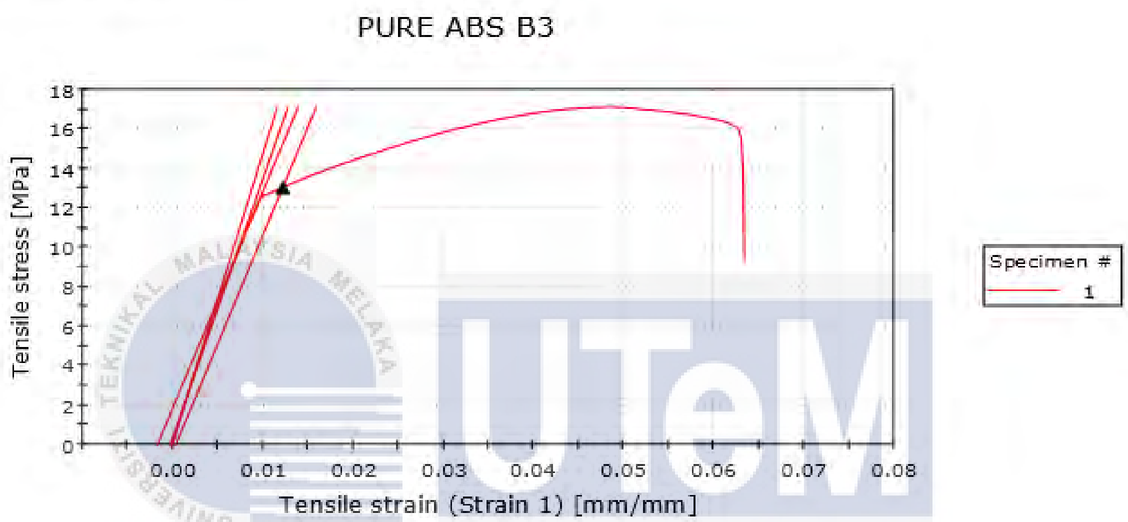
	Maximum Load [kN]	Tensile stress at Maximum Load [MPa]	Tensile extension at Maximum Load [mm]
1	1.007	25.815	1.753

	Tensile strain (Extension) at Maximum Load [mm/mm]	Load at Yield (Offset 0.2 %) [kN]	Tensile stress at Yield (Offset 0.2 %) [MPa]
1	0.070	0.679	17.402

	Modulus (Automatic) [MPa]	Modulus (E-modulus) [MPa]	Modulus (Automatic Young's) [MPa]
1	1641.575	1624.149	1860.439

APPENDIX A6

Tensile Test for ABS



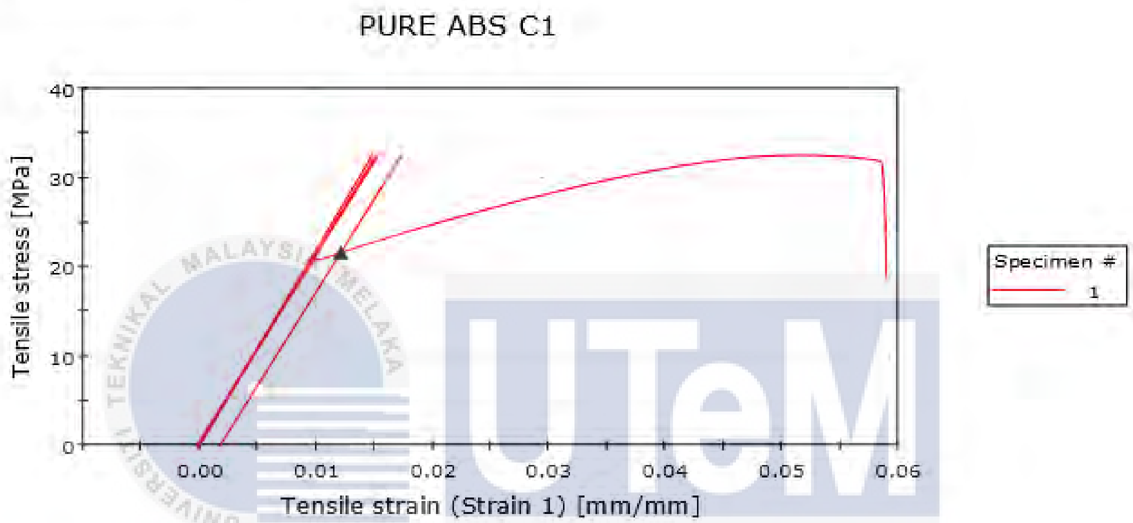
	Maximum Load [kN]	Tensile stress at Maximum Load [MPa]	Tensile extension at Maximum Load [mm]
1	0.666	17.090	1.205

	Tensile strain (Extension) at Maximum Load [mm/mm]	Load at Yield (Offset 0.2 %) [kN]	Tensile stress at Yield (Offset 0.2 %) [MPa]
1	0.048	0.509	13.048

	Modulus (Automatic) [MPa]	Modulus (E-modulus) [MPa]	Modulus (Automatic Young's) [MPa]
1	1307.011	1095.917	1465.901

APPENDIX A7

Tensile Test for ABS



	Maximum Load [kN]	Tensile stress at Maximum Load [MPa]	Tensile extension at Maximum Load [mm]
1	1.269	32.526	1.284

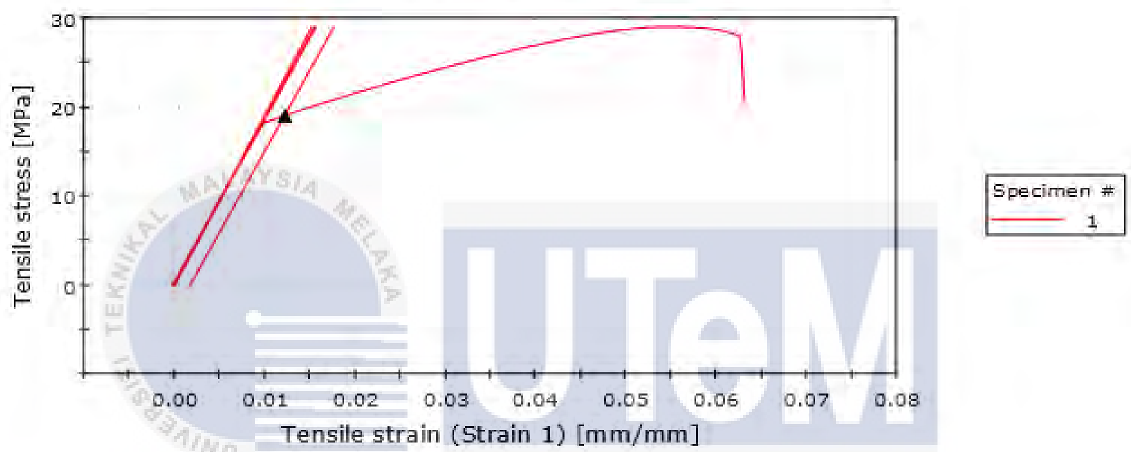
	Tensile strain (Extension) at Maximum Load [mm/mm]	Load at Yield (Offset 0.2 %) [kN]	Tensile stress at Yield (Offset 0.2 %) [MPa]
1	0.051	0.842	21.600

	Modulus (Automatic) [MPa]	Modulus (E-modulus) [MPa]	Modulus (Automatic Young's) [MPa]
1	2132.188	2082.264	2189.931

APPENDIX A8

Tensile Test for ABS

PURE ABS C2



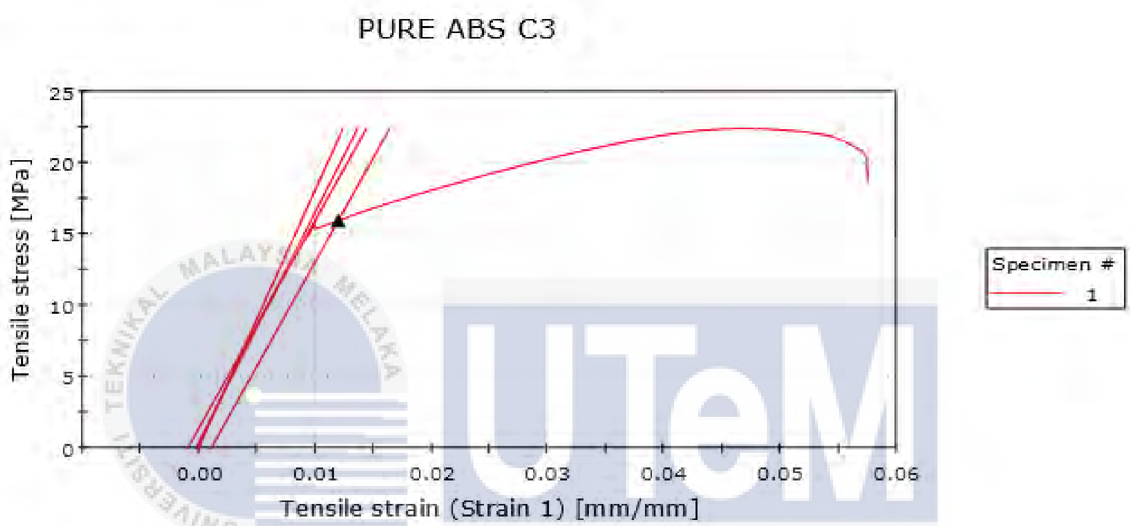
	Maximum Load [kN]	Tensile stress at Maximum Load [MPa]	Tensile extension at Maximum Load [mm]
1	1.131	29.002	1.399

	Tensile strain (Extension) at Maximum Load [mm/mm]	Load at Yield (Offset 0.2 %) [kN]	Tensile stress at Yield (Offset 0.2 %) [MPa]
1	0.056	0.744	19.067

	Modulus (Automatic) [MPa]	Modulus (E-modulus) [MPa]	Modulus (Automatic Young's) [MPa]
1	1857.178	1819.325	1904.253

APPENDIX A9

Tensile Test for ABS



	Maximum Load [kN]	Tensile stress at Maximum Load [MPa]	Tensile extension at Maximum Load [mm]
1	0.874	22.404	1.171

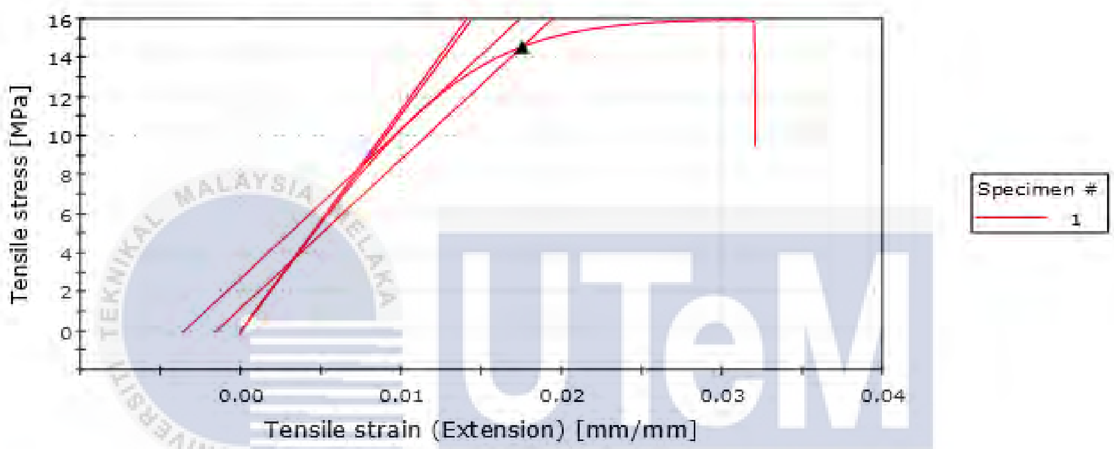
	Tensile strain (Extension) at Maximum Load [mm/mm]	Load at Yield (Offset 0.2 %) [kN]	Tensile stress at Yield (Offset 0.2 %) [MPa]
1	0.047	0.622	15.947

	Modulus (Automatic) [MPa]	Modulus (E-modulus) [MPa]	Modulus (Automatic Young's) [MPa]
1	1607.976	1455.841	1795.731

APPENDIX B1

Tensile Test for Carbon Fibre Reinforce ABS

Carbon Reinforced ABS A1

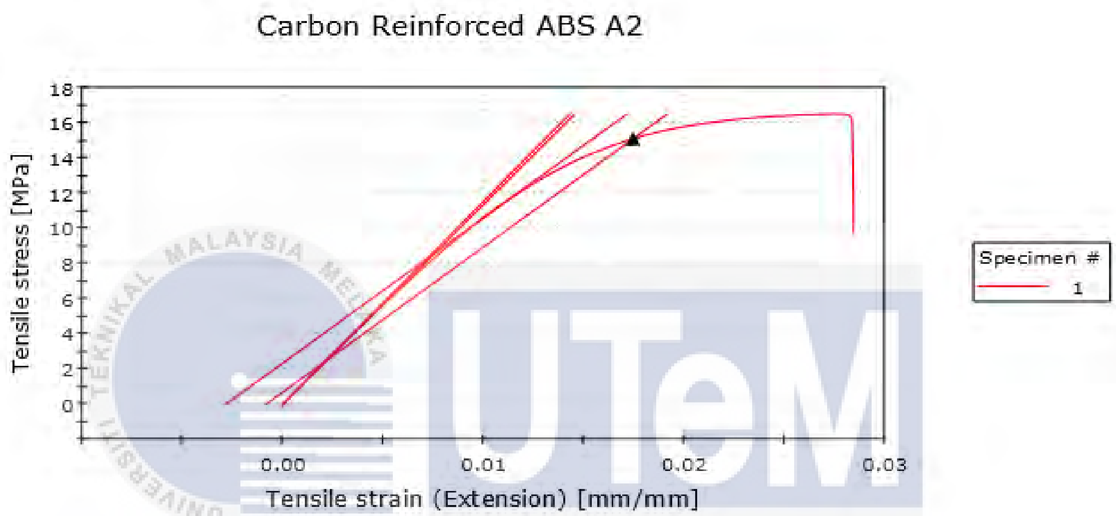


	Maximum Load [kN]	Tensile stress at Maximum Load [MPa]	Tensile extension at Maximum Load [mm]
1	0.7871	15.9328	2.1597

	Tensile strain (Extension) at Maximum Load [mm/mm]	Load at Yield (Offset 0.2 %) [kN]	Tensile stress at Yield (Offset 0.2 %) [MPa]
1	0.0309	0.7191	14.5576

APPENDIX B2

Tensile Test for Carbon Fibre Reinforce ABS

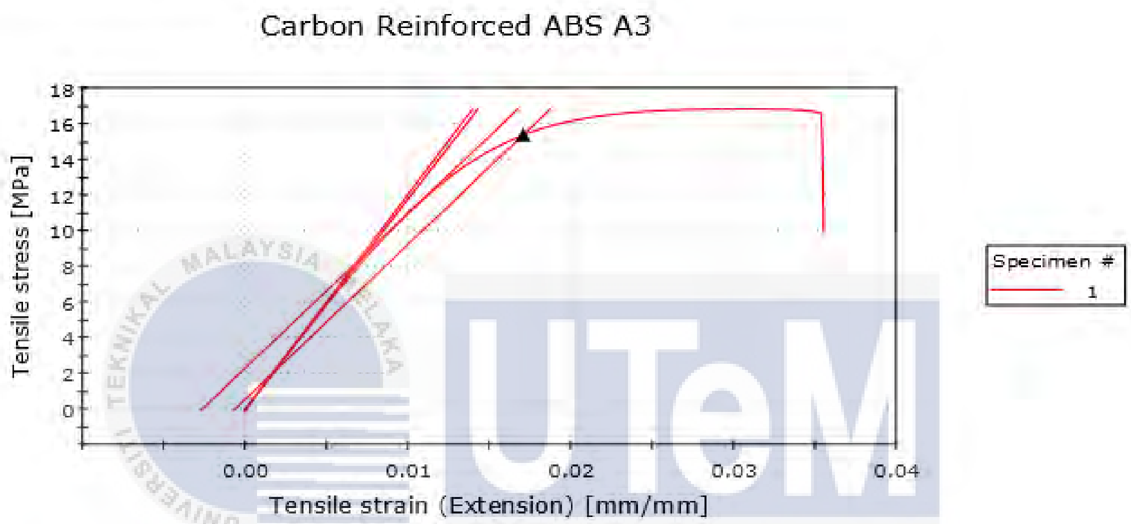


	Maximum Load [kN]	Tensile stress at Maximum Load [MPa]	Tensile extension at Maximum Load [mm]
1	0.8141	16.4808	1.9528

	Tensile strain (Extension) at Maximum Load [mm/mm]	Load at Yield (Offset 0.2 %) [kN]	Tensile stress at Yield (Offset 0.2 %) [MPa]
1	0.0279	0.7446	15.0730

APPENDIX B3

Tensile Test for Carbon Fibre Reinforce ABS

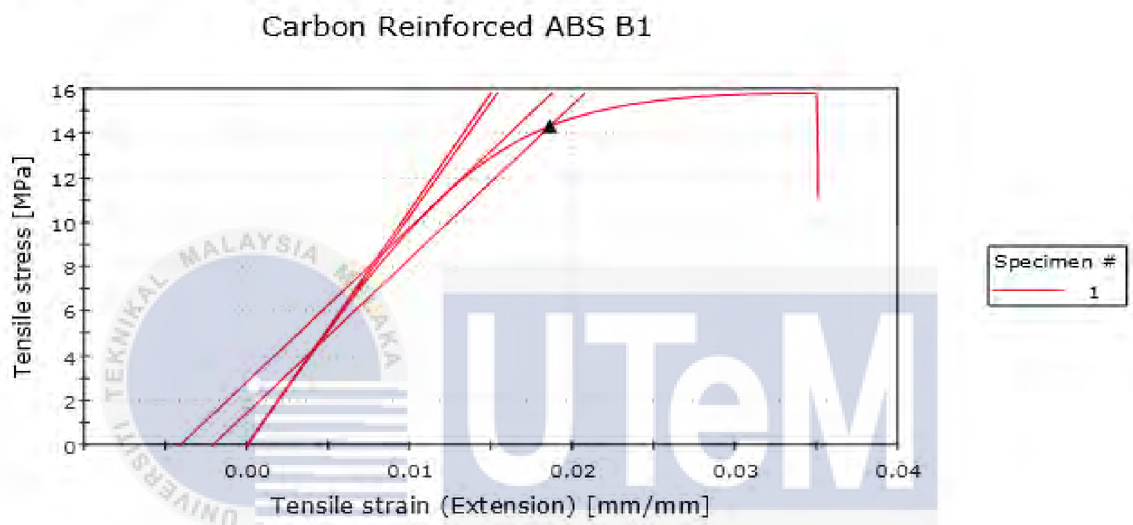


	Maximum Load [kN]	Tensile stress at Maximum Load [MPa]	Tensile extension at Maximum Load [mm]
1	0.8316	16.8336	2.1259

	Tensile strain (Extension) at Maximum Load [mm/mm]	Load at Yield (Offset 0.2 %) [kN]	Tensile stress at Yield (Offset 0.2 %) [MPa]
1	0.0304	0.7592	15.3685

APPENDIX B4

Tensile Test for Carbon Fibre Reinforce ABS

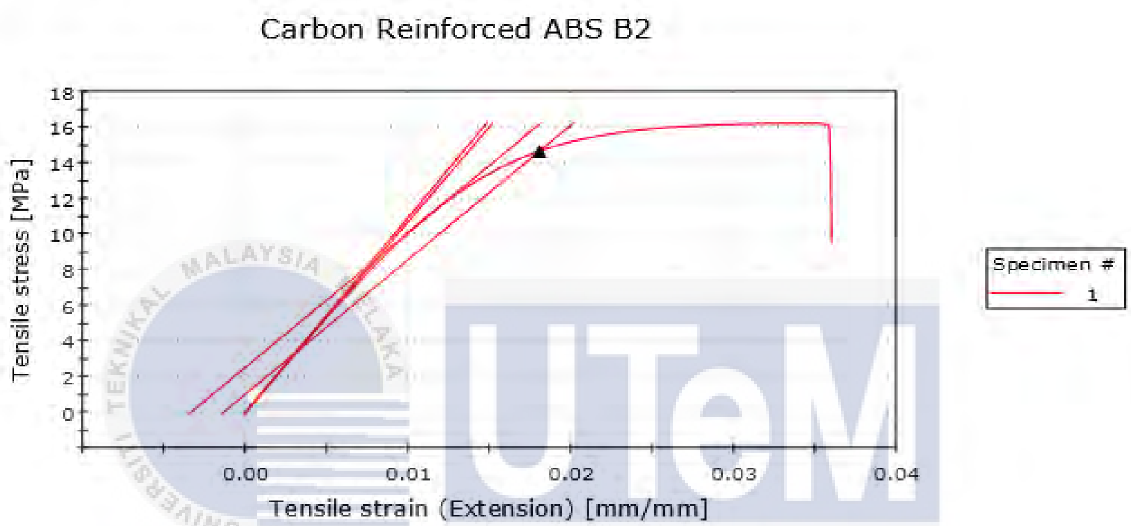


	Maximum Load [kN]	Tensile stress at Maximum Load [MPa]	Tensile extension at Maximum Load [mm]
1	0.7808	15.8054	2.3633

	Tensile strain (Extension) at Maximum Load [mm/mm]	Load at Yield (Offset 0.2 %) [kN]	Tensile stress at Yield (Offset 0.2 %) [MPa]
1	0.0338	0.7071	14.3134

APPENDIX B5

Tensile Test for Carbon Fibre Reinforce ABS

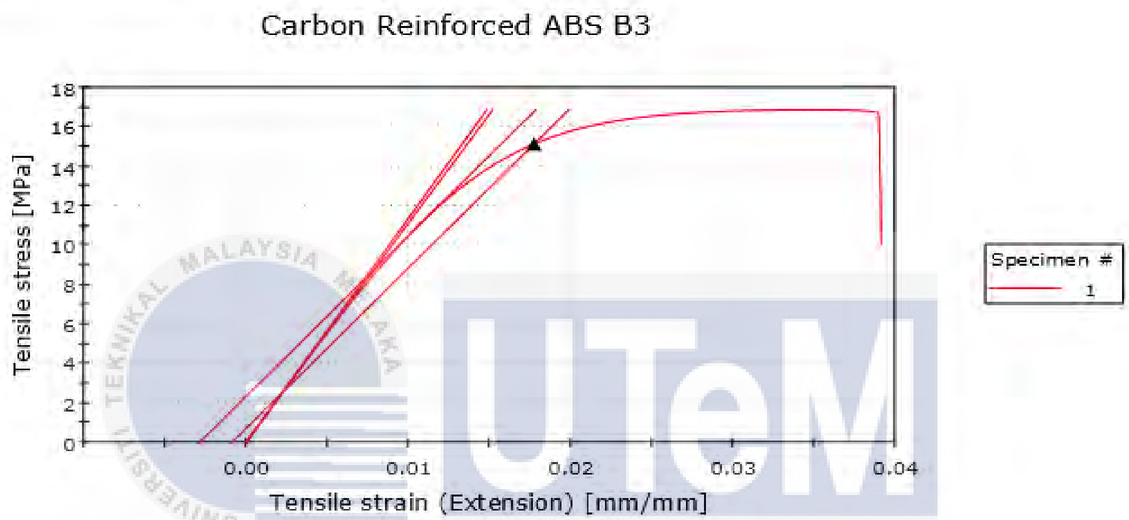


	Maximum Load [kN]	Tensile stress at Maximum Load [MPa]	Tensile extension at Maximum Load [mm]
1	0.8006	16.2066	2.3530

	Tensile strain (Extension) at Maximum Load [mm/mm]	Load at Yield (Offset 0.2 %) [kN]	Tensile stress at Yield (Offset 0.2 %) [MPa]
1	0.0336	0.7236	14.6487

APPENDIX B6

Tensile Test for Carbon Fibre Reinforce ABS

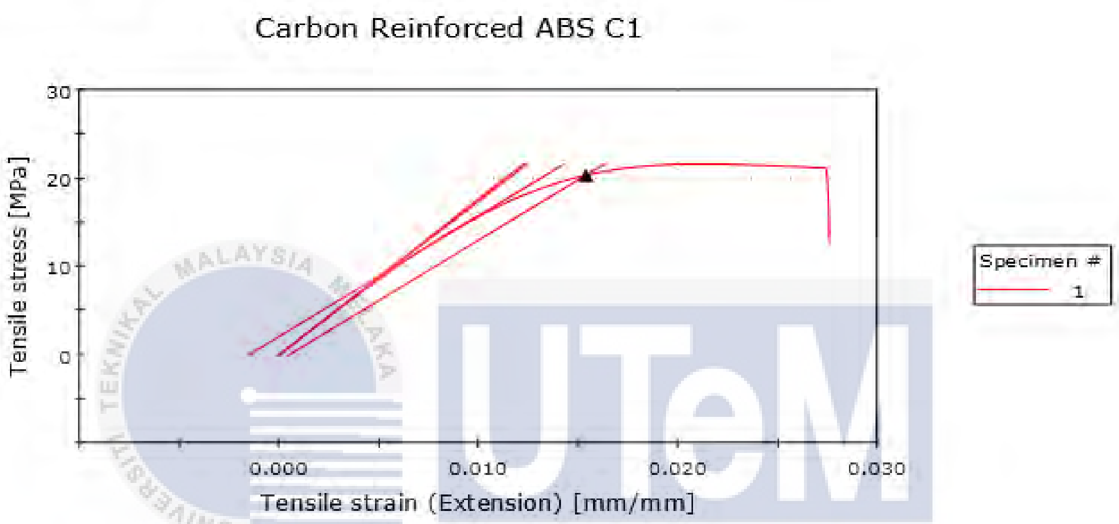


	Maximum Load [kN]	Tensile stress at Maximum Load [MPa]	Tensile extension at Maximum Load [mm]
1	0.8332	16.8662	2.4735

	Tensile strain (Extension) at Maximum Load [mm/mm]	Load at Yield (Offset 0.2 %) [kN]	Tensile stress at Yield (Offset 0.2 %) [MPa]
1	0.0353	0.7479	15.1396

APPENDIX B7

Tensile Test for Carbon Fibre Reinforce ABS

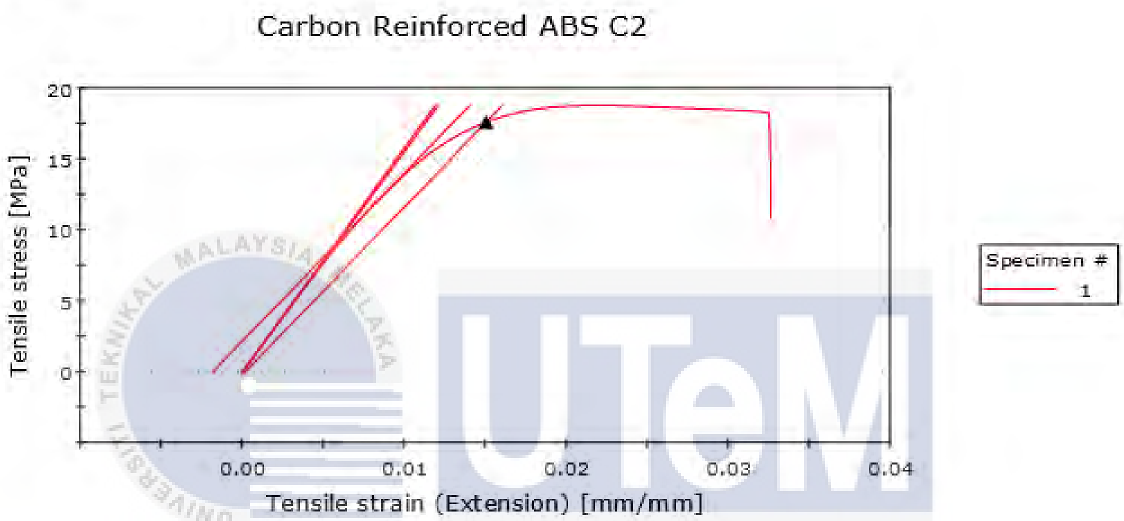


	Maximum Load [kN]	Tensile stress at Maximum Load [MPa]	Tensile extension at Maximum Load [mm]
1	1.0675	21.6099	1.5029

	Tensile strain (Extension) at Maximum Load [mm/mm]	Load at Yield (Offset 0.2 %) [kN]	Tensile stress at Yield (Offset 0.2 %) [MPa]
1	0.0215	1.0052	20.3472

APPENDIX B8

Tensile Test for Carbon Fibre Reinforce ABS

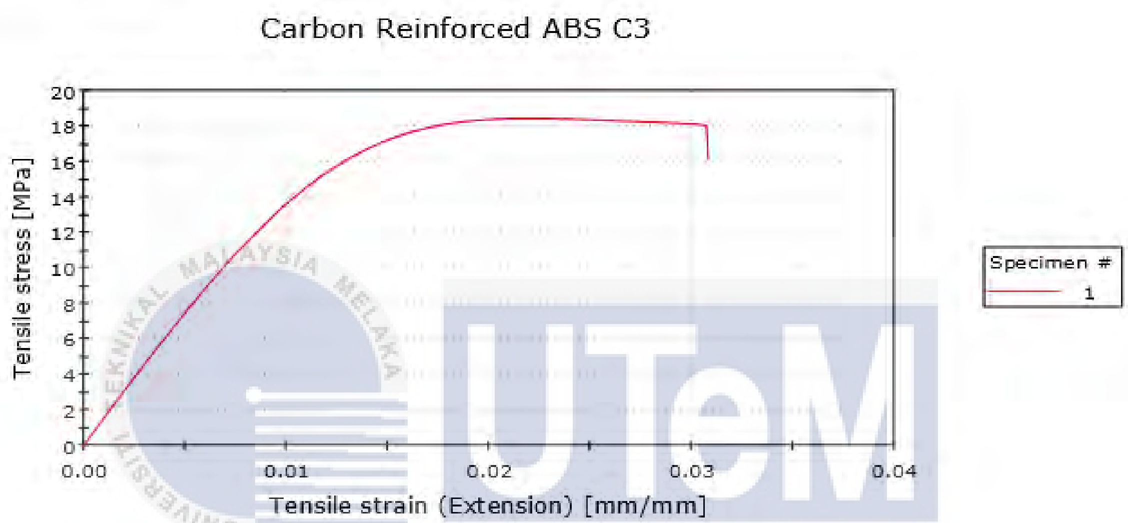


	Maximum Load [kN]	Tensile stress at Maximum Load [MPa]	Tensile extension at Maximum Load [mm]
1	0.9285	18.7949	1.5466

	Tensile strain (Extension) at Maximum Load [mm/mm]	Load at Yield (Offset 0.2 %) [kN]	Tensile stress at Yield (Offset 0.2 %) [MPa]
1	0.0221	0.8702	17.6146

APPENDIX B9

Tensile Test for Carbon Fibre Reinforce ABS

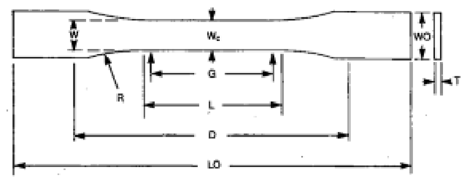


	Maximum Load [kN]	Tensile stress at Maximum Load [MPa]	Tensile extension at Maximum Load [mm]
1	-----	-----	-----

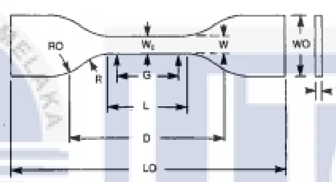
	Tensile strain (Extension) at Maximum Load [mm/mm]	Load at Yield (Offset 0.2 %) [kN]	Tensile stress at Yield (Offset 0.2 %) [MPa]
1	-----	-----	-----

APPENDIX C1

D 638 – 02a



TYPES I, II, III & V



TYPE IV

Specimen Dimensions for Thickness, *T*, mm (in.)[A]

Dimensions (see drawings)	7 (0.28) or under		Over 7 to 14 (0.28 to 0.55), incl	4 (0.16) or under		Tolerances
	Type I	Type II	Type III	Type IV[B]	Type V[C,D]	
W—Width of narrow section[E,F]	13 (0.50)	6 (0.25)	19 (0.75)	6 (0.25)	3.18 (0.125)	±0.5 (±0.02)[B,C]
L—Length of narrow section	57 (2.25)	57 (2.25)	57 (2.25)	33 (1.30)	9.53 (0.375)	±0.5 (±0.02)[C]
WO—Width overall, min[G]	19 (0.75)	19 (0.75)	29 (1.13)	19 (0.75)	...	+ 6.4 (+ 0.25)
WO—Width overall, min[G]	...	...	...	...	9.53 (0.375)	+ 3.18 (+ 0.125)
LO—Length overall, min[H]	165 (6.5)	183 (7.2)	246 (9.7)	115 (4.5)	63.5 (2.5)	no max (no max)
G—Gage length[I]	50 (2.00)	50 (2.00)	50 (2.00)	...	7.62 (0.300)	±0.25 (±0.010)[C]
G—Gage length[I]	...	...	...	25 (1.00)	...	±0.13 (±0.005)
D—Distance between grips	115 (4.5)	135 (5.3)	115 (4.5)	65 (2.5)[J]	25.4 (1.0)	±5 (±0.2)
R—Radius of fillet	76 (3.00)	76 (3.00)	76 (3.00)	14 (0.56)	12.7 (0.5)	±1 (±0.04)[C]
RO—Outer radius (Type IV)	...	...	...	25 (1.00)	...	±1 (±0.04)