STUDY OF MECHANICAL PROPERTIES ON FIBERGLASS REINFORCED PLASTIC PIPE UNDER TENSILE AND BENDING CONDITION

MUHAMMAD NAIEM BIN JOHAN

UNIVERSITI TEKNIKAL MALAYSIA MELAKA

STUDY OF MECHANICAL PROPERTIES ON FIBERGLASS REINFORCED PLASTIC PIPE UNDER TENSILE AND BENDING CONDITION

MUHAMMAD NAIEM BIN JOHAN

This report is submitted
in fulfillment of the requirement for the degree of
Bachelor of Mechanical Engineering (Plant & Maintenance)

Faculty of Mechanical Engineering

UNIVERSITI TEKNIKAL MALAYSIA MELAKA

MAY 2017

DECLARATION

I declare that this project report entitled “Study of Mechanical Properties on Fiberglass Reinfoeced Plastic Pipe Under Tensile And Bending Condition” 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 terms of scope and quality for the award of the degree of Bachelor of Mechanical Engineering (Plant & Maintenance).

Signature : ....

Name of Supervisor: ....

Date : ....

DEDICATION

To my beloved mother and father as well as all researchers specifically on composite materials.

ABSTRACT

Mechanical properties of a structure and materials is essential in designing a product to know the strength of the material as well as the structure. The purpose of this research is to study and analyze the mechanical properties of fiber reinforced plastic pipe. The research is collaborated with Pacific Advance Composites Sdn. Bhd. to know the mechanical strength of their pipe design and the 3 inch in inner diameter welded and plain pipe specimen was prepared by that company. In this study, tensile and bending test was done in order to know the tensile and bending strength of the FRP pipe. In conjunction to that, a jig has been designed according to ASTM D2105 to accommodate the pipe specimen with the Universal Testing Machine for tensile testing. A critical component of the jig has been analyzed with finite element analysis software in order to know the safety factor of the jig while targeted force is applied. The tensile test is conducted in accordance to ASTM D2105 which recommended by ISO 14692-2:2002 while bending test is conducted accordance to ASTM D790. From the tensile testing, it is found that the specimen does not fail despite the maximum force applied was 33.535 kN. Also, it is found that the failure is happening at the stress concentration area from the modification done to the specimen. Next, the bending test was done and found that the failure is happening due to the brittleness and shearing effect on the specimen. From both of the test, it is suggested that the jig need to be modify to have higher gripping pressure for the test and for bending test, the span length of the specimen need to be increase in order to give higher bending moment.

ABSTRAK

Sifat mekanikal sesuatu struktur dan bahan sangat penting dalam merekabentuk sesuatu produk bagi mengetahui kekuatan bahan dan juga struktur produk tersebut. Tujuan kajian ini adalah untuk mengkaji dan menganalisis sifat-sifat mekanik paip plastik bertulang gentian kaca. Kajian ini bekerjasama dengan Pacific Advance Composites Sdn. Bhd. untuk mengetahui kekuatan mekanikal reka bentuk paip mereka. Oleh itu, spesimen paip berdiameter dalaman 3 inci bersambungan dan biasa telah disediakan oleh mereka. Dalam kajian ini, ujian tegangan dan lenturan telah dilakukan untuk mengetahui kekuatan tegangan dan lenturan paip plastik bertulang gentian kaca tersebut. Bersempena dengan itu, sebuah jig telah direka mengikut ASTM D2105 untuk menampung spesimen paip dengan ujian tegangan menggunakan Mesin ujian Universal. Komponen penting bagi jig telah dianalisis dengan perisian analisis unsur terhingga untuk mengetahui faktor keselamatan jig semasa mengenakan daya yang disasarkan. Ujian tegangan dijalankan mengikut ASTM D2105 yang disyorkan oleh ISO 14692-2: 2002 manakala ujian lenturan dijalankan mengikut ASTM D790. Daripada ujian tegangan, didapati bahawa spesimen itu tidak gagal walaupun daya maksimum yang telah dikenakan adalah 33,535 kN. Juga, didapati bahawa kegagalan yang berlaku adalah di kawasan penumpuan tekanan daripada pengubahsuaian yang dilakukan terhadap spesimen. Seterusnya, ujian lenturan telah dilakukan dan mendapati bahawa kegagalan yang berlaku adalah disebabkan kerapuhan dan kesan ricih ke atas spesimen. Dari kedua-dua ujian, adalah dicadangkan bahawa jig perlu diubahsuai supaya mempunyai tekanan menggenggam lebih tinggi untuk ujian tegangan manakala untuk ujian lenturan pula, panjang rentang spesimen perlu ditingkatkan lagi untuk memberi momen lentur yang lebih tinggi.

ACKNOWLEDGEMENT

First of all, thanks to Allah Almighty because of His blessing, I am able to finish my project. Many people have involved and contributed in preparing this thesis. Therefore, I would like to express my sincere appreciation to my supervisor, Dr. Omar Bin Bapokutty for his guidance, supports and trust throughout this project. By showing his willingness to advise and motivate me, this project is going smoothly despites there are some risen issues.

A special thanks go to Pacific Advance Composites Sdn. Bhd. which a subsidiary of Dialog Group Berhad for providing this research the manufacturing of jig and specimen. A good collaboration between Faculty Mechanical Engineering and Pacific Advance Composites Sdn. Bhd. makes this project more beneficial to be used in industry. I am also indebted to Universiti Teknikal Malaysia Melaka for providing me a good environment and sufficient facilities in completing this project.

Next, a million thanks towards my fellow undergraduate students and my colleagues for their assistant and cooperation in various occasion. Finally, I want to thank my parents for their endless support and spirit for continuing my studies. Without their continued support and interest, this project maybe would not be completed.

TABLE OF CONTENT

LIST OF FIGURES

LIST OF TABLES

LIST OF ABBEREVATIONS

ASME	American Society of Mechanical Engineers
ASTM	American Society for Testing and Materials
FRP	Fiber Reinforced Plastic
GRP	Glass Reinforced Plastic
ISO	International Organization for Standardization
MEKP	Methyl Ethyl Ketone Peroxide
PLC	Programable Logic Controller
RPMP	Reinforced Polymer Mortar Pipe
RTRP	Reinforced Thermosetting Resin Pipe
UTM	Universal Testing Machine

LIST OF SYMBOL

r_i	=	Inner radius
A	=	Area
F	=	Force
t	=	Wall thickness
P	=	Pressure
σ	=	Nominal Stress
σ_1	=	Hoop stress
σ_1	=	Longitudinal stress
σ_B	=	Breaking Strength
σ_u	=	Ultimate Tensile Strength
σ_y	=	Yield Strength
σ_f	=	Flexural Stress
σ_{max}	=	Maximum Stress
σ_{min}	=	Minimum Stress
E	=	Modulus of Elasticity
ϵ	=	Strain
$\emptyset$	=	Diameter
FoS	=	Factor of Safety

CHAPTER 1

INTRODUCTION

1.1 BACKGROUND

The common structural materials are basically classified into four categories which is metals, ceramic, polymers, and composites. To form a composite structure, two or more materials is bonded together to form a solid material. FRP is one of example of composite material which the glass fiber act as the reinforcement and the resin (plastic) is the binder, this composition form a compound of composite material. The defined manner of composite brings the fact that any composite material have to be particularized in macroscopic perspective (Schmit, 1998) . Moreover, FRP is a heterogeneous material, the composition varies in different places in the structure.

The FRP has been used in various kind of application including piping material especially in the marine and oil & gas industry. The advantage from both fiberglass and polymer resin material properties makes it superior in handling corrosion and weight problems in comparison with traditional metallic piping in salty offshore environment. (Schmit, 2001) also said that FRP pipe have a good fatigue properties thus making the life of that material is longer.

A tensile test is the fundamental of mechanical test and widely used in selecting the material for engineering purpose (Davis, 2004). In this experiment, the tensile test is conducted using ASTM D2105 procedures. The force required by the specimen is measured until it reach the breaking point. The results of the tensile test and the crack surfaces of the FRP can be used to support the failure analysis (Paiva et al., 2006). From the tensile test, the mechanical properties such as strength and modulus value of the FRP can be determined to fit for the quality control of intended application.

Other than that, the bending properties is also one of the mechanical properties that is crucial in designing the pipe. In the research, the bending test is done by following the recommendation of ASTM D790 for bending testing method that specified for fiber reinforced plastic materials. High precision universal testing machine, the Instron 5585-140kN floor column screw movement machine is used in both tensile and bending testing throughout this experiment. However, most structure have weak point and mostly at the joint of the structure. In this report, the weld of the pipe is selected to be the focus of testing since it suspected to have the weakest point of the design. However, the method of joining selected by the manufacturer exhibit supreme strength for FRP piping. Figure 1.1 below illustrate the butt and strap joint of the piping.

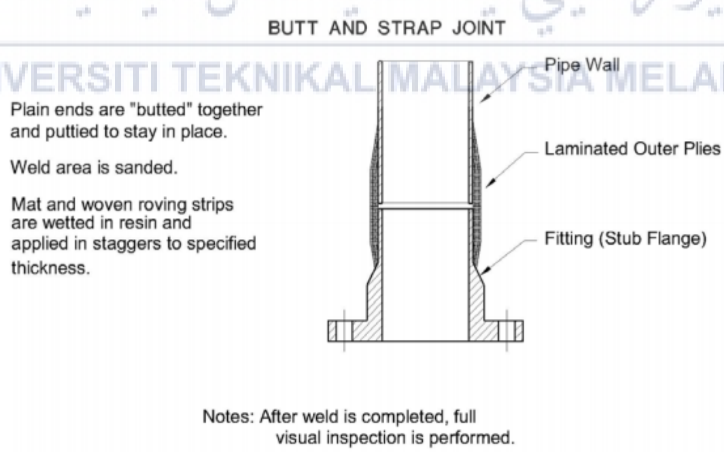


Figure 1.1: Typical butt weld joint

Source: EDO Specialty Plastics, Engineering Series ES-010; The Adhesive Bonded vs The Butt and Strap, 2014

1.2 PROBLEM STATEMENT

Pacific Advance Composites Sdn. Bhd. has providing FRP piping system service mainly in offshore and other petrochemical industry for many years. This company is a subsidiary of Dialog Group Berhad which is one of the giants in oil & gas industry that provide many other services and product. Pacific Advance Composites Sdn. Bhd. introducing new pipe product and the design has been validated in calculation based on international standard in designing FRP piping. In conjunction to that, tests need to be done to their material in order to find the mechanical properties of that new FRP piping product. Moreover, the reliability of the material is also an important factor in developing piping product thus, tensile and bending test is proposed to them as an objective in this collaboration with the industry.

1.3 OBJECTIVE

The objectives of this project are as below:

1) To design a jig according to ASTM 2105 test method for gripping pipe specimen to the Universal Testing Machine (UTM).
2) To conduct and analyze a tensile test in which according to ASTM D2105 in order to study the mechanical behavior of the fiberglass reinforced plastic material.
3) To conduct and analyze a bending test for the fiberglass reinforced plastic material in order to study the bending properties of it.

1.4 SCOPE OF PROJECT

In this study, the mechanical properties of the material are defined by neglecting the effect of vibration, temperature fluctuation, and other effect caused by surrounding. Other than that, the effect of internal pressure is also neglected during the experiment thus, hoop and radial stress is not covered in this research. Other than that, all the calculations are calculated in SI units.

1.5 GENERAL METHODOLOGY

This project discusses on mechanical strength and fatigue properties of FRP material. The research methodology is an important part that shows the work procedure in order to complete the project. There are some research methodologies: -

1) **Literature review:** The methods, fundamentals, and pass research is reviewed in order to produce a quality results.
2) **Proposal:** The research project was proposed to Pacific Advance Composites Sdn. Bhd. for this collaboration so that both side will have clear vision and same understanding.
3) **Design of experiment:** The experiment will be designed according to standard test method and other journals.
4) **Jig detail design:** The design and analysis of jig in order to have robust jig.
5) **Sample preparation:** The sample will be prepared by the company by the design of experiment specifications.

6) **Tensile testing:** This test is need to be done in order to have the material's mechanical properties to do fatigue and finite element analysis.
7) **Report writing:** A report will be written in the end of this research to be evaluated by the university and to hand over to the company.

Figure 1.2 will be summarizing the activity in this whole research methodology.

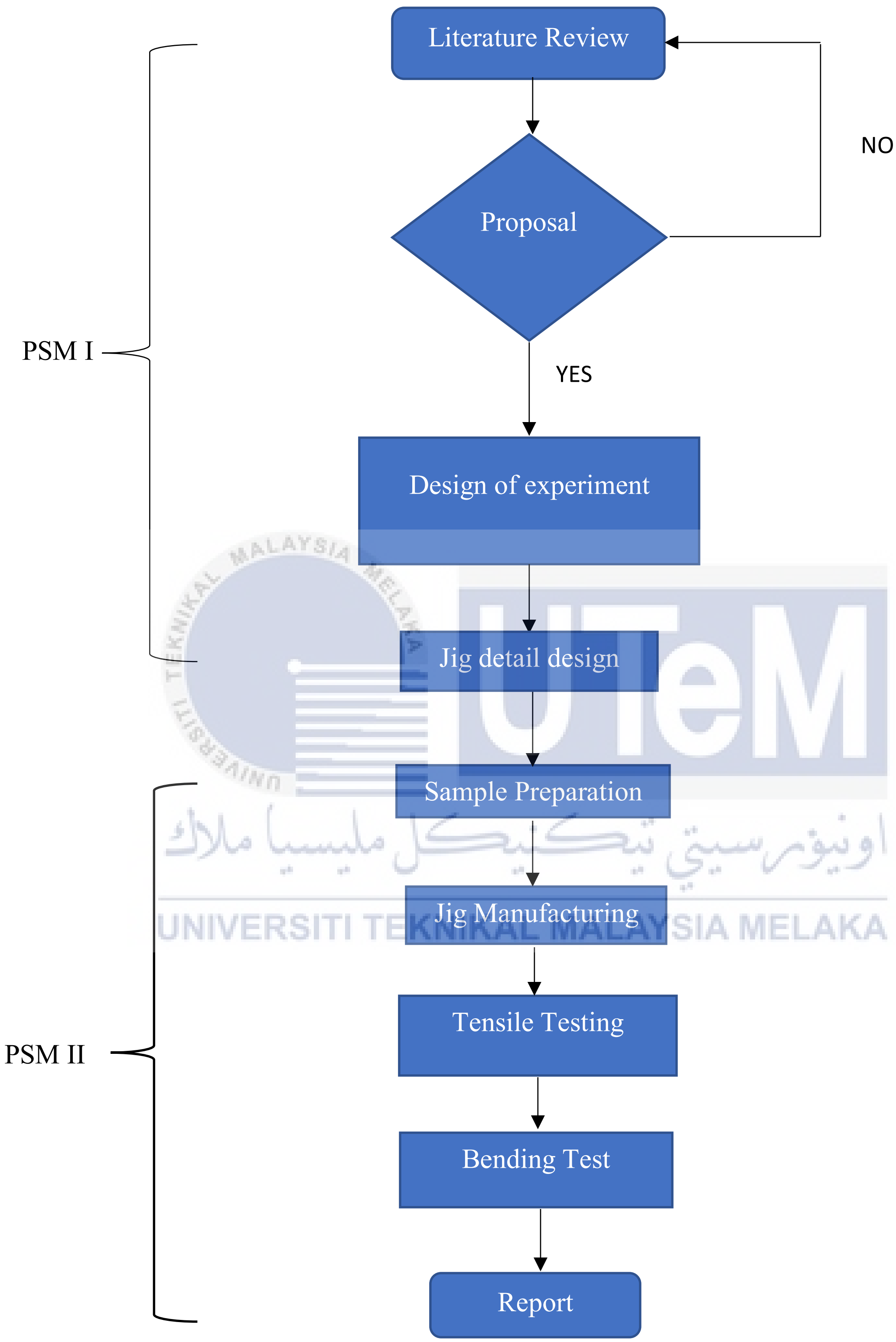


Figure 1.2: Flowchart of the Research

1.6 THESIS OUTLINE

Chapter 1 contains an overview of the research project includes material use and approaches techniques in determining the material properties. The problem statement, objectives, scopes and general methodology are clearly stated.

Chapter 2 provides a review of previous research of FRP piping, standard test method for tensile properties and mechanical properties for fiberglass. This literature review has gathered information and gives an idea for the material and method that suits to be used in this project.

Chapter 3 discusses the flow of the process includes specimen preparation and specification, jig design and design of experiment which is a tensile test. This chapter has explained the procedures that are used to complete this project.

Chapter 4 presents the results of this project. This chapter is explained about the results of a jig analysis. Moreover, the result of the tensile test and bending test is explained in the chapter as well. From there, the findings and outcome of the experiment is discussed.

Chapter 5 explains the conclusion and recommendation based on the results of the research. A specific recommendation is recommended due to the issue that has been raised by the previous researchers and from the obtained results.

CHAPTER 2

LITERATURE REVIEW

2.1 OVERVIEW

In this chapter, in order to gain enough information to recommend the appropriate method that can be used to complete the research, comparison between certain techniques is required to ensure the data is reliable. On top of that, the basic principal and fundamental of the scope also has been reviewed as describe in the following subchapter.

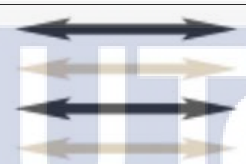
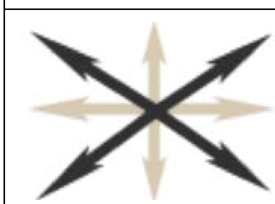
There are a lot of mechanical properties that can be obtain in various tests such as tensile, bending, fatigue, compression, shearing, and bearing stress. In order to start the testing outlined in the objective above, a comprehensive research need to be done at the related area of study to perform smooth and reliable data towards the end of the experiment. On the other hands, there is some papers and journal in this chapter will be the guidance of the experiment in term of the data that they have collected so that by the end of the experiment, the result can be compared.

2.2 COMPOSITE

The term of composite can be mean by most of material exists if taken at face value such as metal alloys, concrete, even polymer. Composite means combining two or more constituent materials with different mechanical properties to gain the strength of the material to adapt the application of it. (Roylance, 2008) said in modern advance materials, the term “matrix” is usually define a material that reinforced with fibers. For more clear understanding, Fiberglass

Reinforced Plastic (FRP) usually indicates a thermosetting polymer matrix that have the properties of both plastic and glass matrix which brings the strength of glass and stiffness of plastic together. In other words, the advance materials of composite can enhance the best properties of both materials suits to the application. Moreover, the arrangement of fiber also give impact on the strength of the material handling stress at certain direction as known, composite materials is heterogenous and it exhibit different strength at different direction as describe in table below.

Table 2.1: Types of fiber orientations

Unidirectional Fiber Orientation	STRENGTH		**Reinforcement types:** Continuous strand roving **Process:** Compression molding, Continuous pultrusion
Bidirectional Fiber Orientation			**Reinforcement types:** Continuous strand roving **Process:** Filament winding, compression molding **Reinforcement types:** Woven fabrics, woven roving **Process:** Hand lay-up
Multidirectional Fiber Orientation			**Reinforcement types:** Chopped strand mat **Process:** Compression and injection molding, pressure bag, hand lay-up

Source: Molded Fiber Glass Companies, 2016

2.3 FRP PIPING

Since Fiberglass Reinforced Plastic (FRP) is widely used in the industry as it exhibits high flexibility of design. Today, the material has been widely used to fabricate pipe as it maintains the durability of transporting fluids even have the high corrosion resistance. FRP pipe is commonly classified as Reinforced Thermosetting Resin Pipe (RTRP) as well as Glass Fiber Reinforced Polymer Mortar Pipe (RPMP) which is a type of tubular product embedded with fiberglass reinforced added to the resin or binder matrix according to the ASTM standards (Laney, 2002).

2.3.1 STRESS DISTRIBUTION

Pipe structure is classified as pressured cylindrical vessel when considering the nature of its application. Most pipe structure are in the thin-walled pressure vessel family as it satisfies the equation:

$$\frac{ri}{t} \geq 10 \tag{1}$$

Where: r_i = Inner radius

t = Wall thickness

The equation shows the wall thickness should be 10 times smaller than inner diameter of the structure. Generally, pipe consist of three stress components which is: a) hoop stress, σ_1 b) longitudinal stress, σ_2 and c) radial stress, σ_3. Seen in Figure 2.1 is the direction of the stress acting on the pipe which hoop stress is acting at the pipe circumferential direction as the pipe expand while longitudinal stress is the fore acting in axial direction of the pipe and radial is the force acting tangentially on wall of the pipe. The equation below explains stress behavior on thin walled pipe:

Hoop stress:

$$\sigma_1 = \frac{Pr}{t} \tag{2}$$

Longitudinal stress:

$$\sigma_2 = \frac{Pr}{2t} \tag{3}$$

Where: P = Internal pressure

r = Inner radius

t = Wall thickness

From the equation above, note that the hoop stress is stronger by two times than the longitudinal stress: $\sigma_1 = 2\,\sigma_2$. This means the tendency of failure is two times higher in hoop direction. Other than that, the radial stress in thin walled structure is considerably too low and can be neglected (Ibrahim, Ryu, & Saidpour, 2015). However, according to (ISO 14692-3:2002) under clause **6.2.6.** state that the FRP pipe has a lower axial modulus of elasticity than the equivalent steel pipe, longitudinal oscillations are generally more significant.

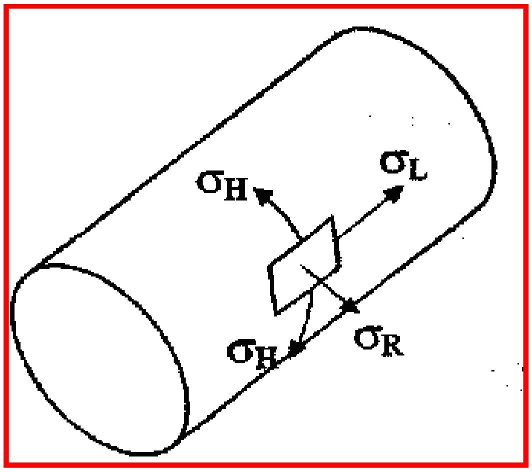


Figure 2.1: Stresses in pipe

Source: Ahadlin, Lecture note Solid Mechanics 2, 2013

2.3.2 MANUFACTURING

In the making of FRP pipes, the correct selection of manufacturing technique is crucial to obtain the highest efficiency of design and manufacturing. There are several manufacturing techniques that has been available and practice in the industry of making FRP piping. One of it is the filament winding process. This technic is the most common technique in making pressured and non-pressured piping as it emphasizes the hoop design of a pipe as it wound the fiber around the pipe. The machine is usually Programmable Logic Controller (PLC) controlled to accommodate the designed winding angle (Gashoot & Al-madani, 2014).

The fiberglass is initially dip into resin bath and into the rotating cylindrical mandrel by the guider in tension force as in figure 2.2 (a). Other than that, continuous pultrusion is one of the manufacturing technique which arranging the filament into the longitudinal axis. This method of manufacturing intended to manufacture pipe with longitudinal stress application. As seen in figure 2.2(b), the filament is pulled through a guide plate and into the resin impregnator while surfacing veil is added to cover the surface of finished parts. The pipe is formed at the forming and curing die which adding the heat to cure the pipe. Next, the centrifugal casting is seen in figure 2.2(c) below, this method of manufacturing uses the heated rotating mold to cure and give shape to the pipe while oscillating arm carrying resin and roving adding the matrix depending on the required thickness. This method will control the outer diameter and gives smooth finishing on the pipe outer surface. Using centrifugal casting also is a labor intensive because the inner pipe need to be buffer before operating.

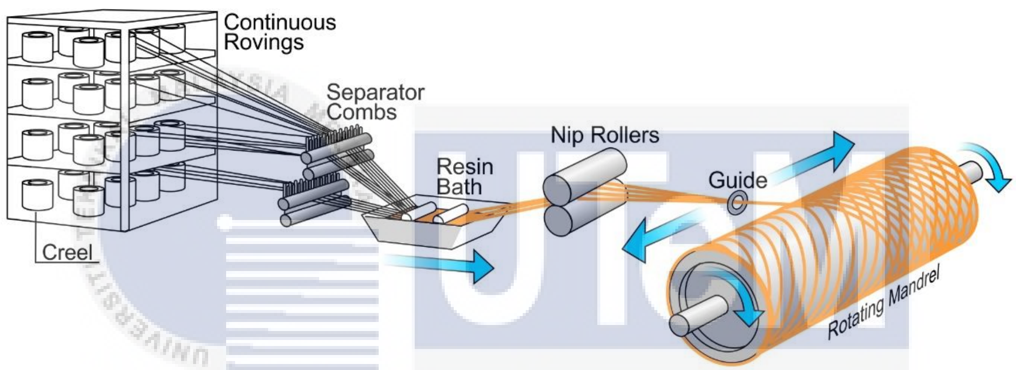


Figure 2.2(a): Filament winding

Source: Nuplex, 2014

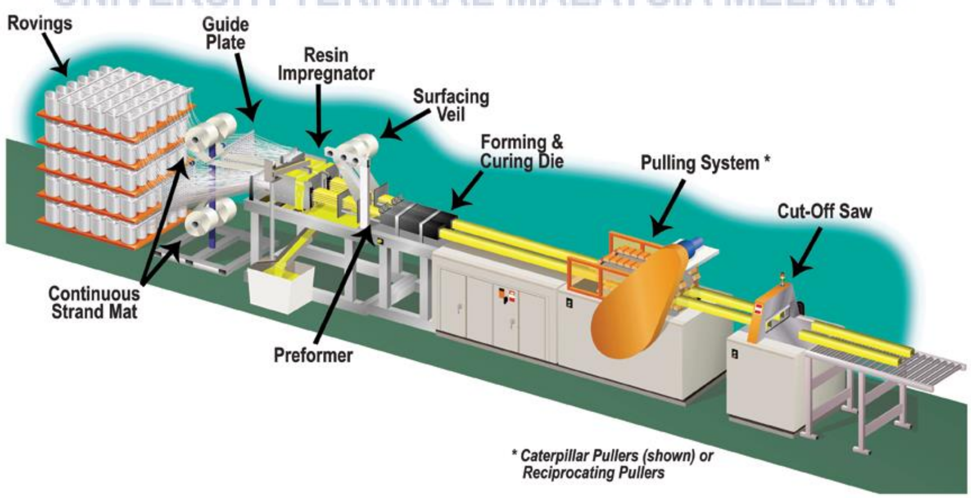


Figure 2.2(b): Continuous pultrusion

Source: Strongwell, 2016

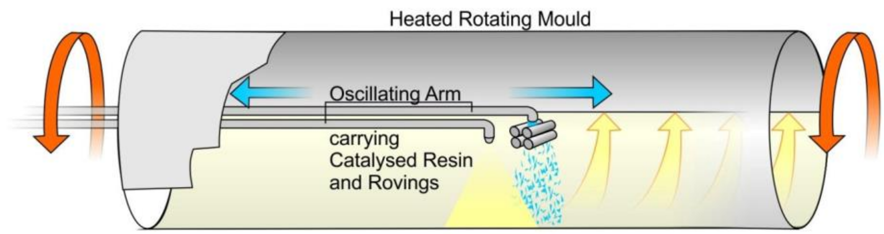


Figure 2.2(c): Centrifugal casting

Source: JPS Pipe, 2015

2.3.3 BONDING

The use of composite material brings new form of challenges since it is uncommon compared to metals which exist thousands of years earlier. Performing weld on a metal pipe is known to be reliable as it bonds into the material by fusion. There are several types of joining method that has been widely used in the industry right now which is; a) Butt & strap join b) Adhesive bond join. These two types of weld method has been reported reliable for over twenty years operating in offshore environment (Knox, Lafferty, Cowling, & Hashim, 2001).

The adhesive bonding usually utilizes the method of tapper to perform weld on pipe this method is reliable for low pressure application and it is easy method as it is designed to perform a quick joining. Next is the butt and strap join, this method is using hand lay-up technique to perform it. Moreover, this method is known to be the most reliable bonding technique as it provides strength to the structure. Adding into that, the butt and strap bonding can provide excellent strength looked-for a flanged valve fitting on a piping system compared to adhesive bonding method that require additional support at the valve location.

2.4 MECHANICAL PROPERTIES

In this subchapter, the component of mechanical properties of the pipe is stated as below which is ultimate tensile strength, modulus of elasticity and fatigue strength. The mechanical properties are important in designing a product because it indicate the structure's strength and limitation. Static failure usually closely related to the ultimate tensile strength while fatigue failure is caused by cyclic loading on the structure. Determination of these parameters is crucial to know the limitation and lifetime of the structure design.

2.4.1 STATIC STRENGTH

Static strength is the ability of a material or structure to withstand certain direction of loading until the subject comes to rupture phase. The static failure can be found due to axial, torsion, or bending loadings. Basically, this parameter is important for an engineer to design a structure or component for the particular material chosen to know the limitation of the design due to the loading applied. The static strength data enable engineers to make decision for design optimization. According to (Budynas & Nisbett, 2011) the testing specimen need to be prepared exactly the same procedure as it manufactured.

In order to obtain the static strength of a structure, tensile test (uniaxial) is the best testing method for axial loading conditions. The properties of the material also can be determined by that test by observing the fracture failure of the specimen and stress – strain diagram obtained. Fiberglass reinforced plastic (FRP) usually exhibit brittle characteristic as it inherits the character of a glass. The rupture of a brittle material like glass usually occurs without any noticeable change in the rate of elongation as seen in the Figure 2.3 the *ultimate tensile strength*

= σ_u of the brittle material is the same *breaking strength* = σ_B while the ductile material exhibit different point of ultimate tensile strength and breaking strength (Beer, Russell Johnston, et.al, 2011).

In this testing, the normal stresses are obtained due to the formula σ = F/A where F is the force acting on the A, cross-sectional area of the specimen. However, normal stress is varying along the structure, due to the variable cross sectional area cases, it is necessary to define the point of strain by averaging the thickness of the specimen. Next, strain is defined by $\epsilon = \delta/L$ where the total elongation of the specimen is divided by the original length of it. Thus, by this parameter, stress-strain diagram is plotted.

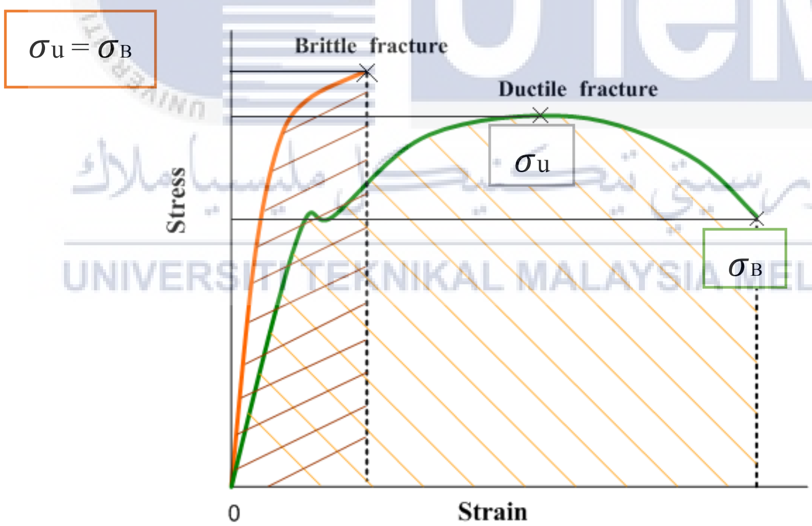


Figure 2.3: Typical Stress-strain diagram for brittle and ductile materials.
Source: Beer, Russell Johnston, et.al, 2011,

Modulus of elasticity or Young's Modulus is one of the mechanical properties in static strength which describe the material's deformation before entering the phase where it became plastic and cannot be reverse to the original length or strength. In engineering world, this phase is considered as failure because it defects the structure. The modulus of elasticity is the ratio of stress and strain of the material before it reaches the plastic region where E = σ / ϵ.

It is essential to choose the right method to perform the testing procedure to a structure. Firstly, knowing the application of the structure and the shape of it. From that, the direction of forces that need to be applied is known due to the working nature of it. In order to obtain the longitudinal mechanical properties of the butt welded FRP piping, ISO 14692-2:2002 under clause **6.2.6** has clarified that ASTM D2105 shall be used as a guideline.

A previous study using this standard has been carried out using plane filament wound pipe as a specimen to study about the tensile strength and acoustic emission. However, the resin used in this experiment is vinylester resin and the average maximum tensile strength over 4 sample is 55.49 MPa (Ben, Zidi, & Abdelwahed, 2012). In other study, the mechanical properties of each individual matrix of epoxy resin and E-glass fiber has been studied to perform fatigue test stated in the Table 2.2 below. Also, in that research hoop stress based on burst test is known to be 405 MPa with E = 23.2 GPa.

Table 2.2: Mechanical properties of the reinforcement and the binder

	E(GPa)	σ_{TS} **(MPa)**	ρ**(g/cm^3)**	ε_t**(%)**
E-glass	73	2400	2.6	4-5
Epoxy resin	3.4	50-60	1.2	6-7

Source: (Gemi & Yapici, 2005)

Other than that, bending strength is also classified as a static strength. Bending test is also one of the crucial information in designing an engineering products. There is two types of bending test, which is three point bending and four point bending test. The test is carried out usually in a manner in which the specimen is placed on a simply supported pin and force acting at the center of the span area using loading nose as seen in the figure 2.4 below as recommended by the ASTM D790 which is Standard test methods for flexural properties of unreinforced and reinforced plastics and electrical insulating materials.

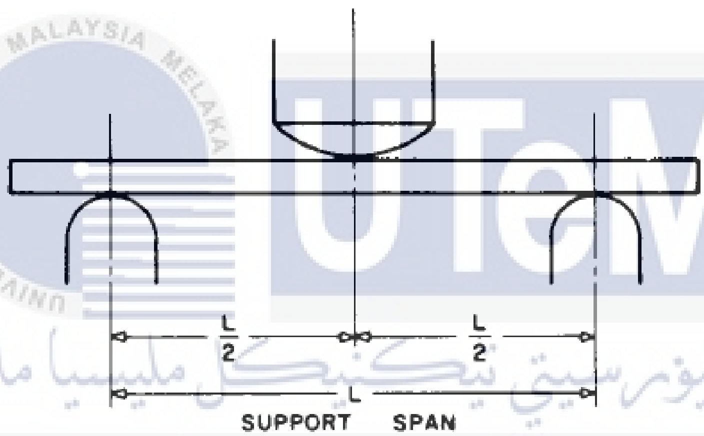


Figure 2.4: Bending test experimental setup.
Source: ASTM D790, 2003

The outcome of this test will be the bending strength which let the designers know on how strong the material can withstand the bending forces. Also, the bending moment and the shear diagram can be plotted to analyze the force acting on the specimen during the test. There are past researcher who has done the experiment using the same standard and specimen as referred in the table 2.3 below. However, the researcher using variable wall thickness for the experiment.

Table 2.3: Experimental result for bending test

N	L (mm)	t (mm)	D_{in} (mm)	D_{out}(mm)	σ_f(MPa)
1	800	6	100	112.0	55.7
2	800	10.45	100	120.9	78.1
3	800	10.55	100	121.1	126.6
4	800	10.51	100	121.0	129.3

Source: (Stefanovska, Risteska, Samakoski, Maneski, & Kostadinoska, 2015)

2.4.2 FATIGUE STRENGTH

Fatigue strength is the ability of a structure to withstand continuous cyclic loading. This parameter of analysis is also important to determine the material's life cycle due to variable, repeated, alternating, or fluctuating stresses whichever the structure is designed to be. The fatigue failure occurs when there are actions of repeated or fluctuating stresses in a very large number of times even at below the ultimate tensile stress of the structure. Thus, the needs of comprehensive study are needed to understand the fatigue behavior of the structure to determine the life of the design (Beer, Russell Johnston, et.al, 2011).

Fatigue failure is dangerous when involving the critical component of a system because it does not give any sign of failure and the failure is sudden. Unlike the static failure, the damage can be estimated and have the visible warning in advance. (Gemi & Yapici, 2005) said that the fatigue fracture exhibit by the FRP pipe is divided into three stage were: 1) Whitening (fiber/matrix interface debonding and delamination), 2) Progressive from microcracks to macrocrack, 3) Final failure where the remaining material cannot support the loads. Figure 2.5 shows the final fracture of the specimen due to fatigue test using pressure.

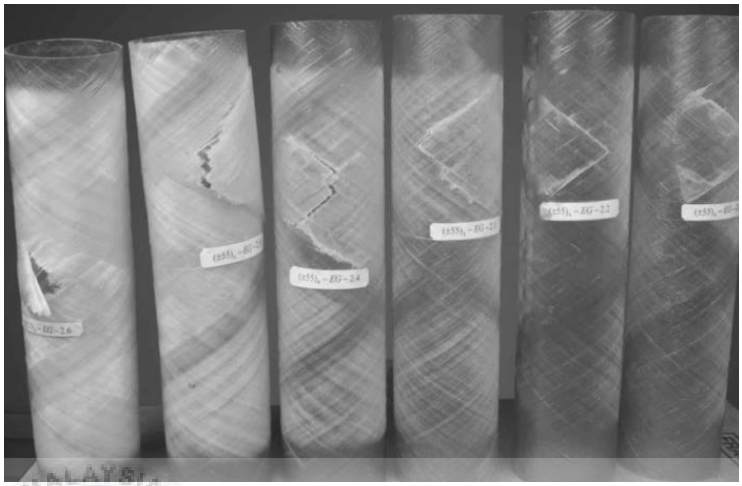


Figure 2.5: Fatigue failure of FRP pipe due to internal pressure.
Source: (Gemi & Yapici, 2005)

Fatigue strength S_f usually been plotted with the number of cycle N to get the overall behavior of the structure. The basis of Stress-Life method is to apply the S-N diagram as figure 2.6 below where S is the stress amplitude and N is the number of cycle. Also, seen in the figure below curve A shows the endurance limit which represents a stress level below which the material does not fail and can be cycled infinitely. However, many non-ferrous material do not exhibit well defined endurance limit as seen in the curve B. this material behaving continuous decreasing S-N curve. For this case, the endurance limit shall be defined to have endurance limit at the cycle of 1×10^6 equivalent to 1 million cycle.

The selection of stress direction in the experiment is important due to the application of the design. For FRP pipe structure, the longitudinal direction is chosen as the direction of the stress applied. According to ISO 14692-3:2002 (Petroleum and natural gas industry – Glass reinforced plastic (GRP) piping) under clause 6.2.6, "*A typical cause of water hammer is the* *fast closing of the valves. The longer the pipeline and the higher the liquid velocity, the greater the shock will be. Shock loading generally includes oscillation in the pipe. Since GRP pipe has lower axial modulus of elasticity than equivalent steel pipe, longitudinal oscillations are generally more significant.*" From that, it is known that the direction that need to be studied on fatigue strength is at the longitudinal direction and the amplitude of stresses is obtained by the static tensile test.

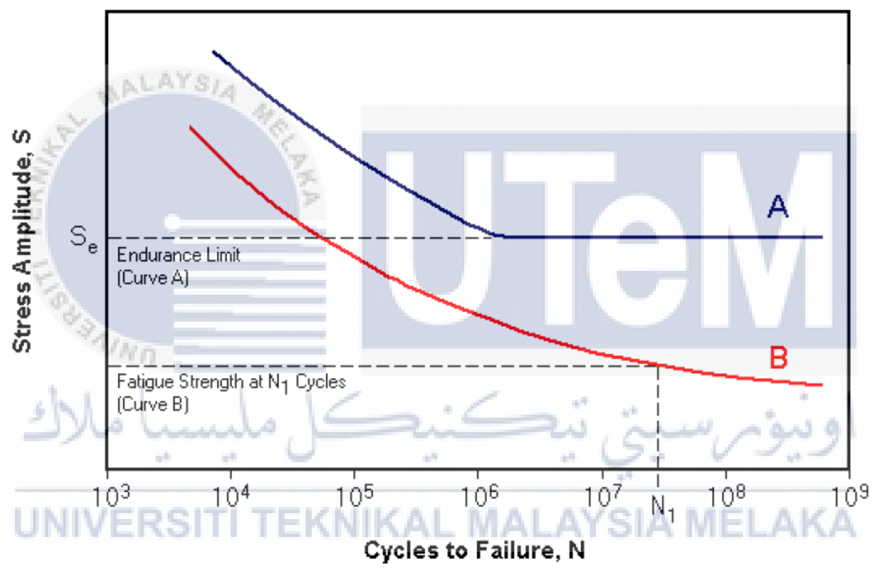


Figure 2.6: Typical S-N curve.

Source: Total Materia, 2010

2.5 PREVIOUS RESEARCH

There are several journals, papers, books, and international standard that have been reviewed to this project in order to improve the fundamental and method that been used in testing this type of material. In this finding, there are several techniques to conduct testing in which to acquire FRP material mechanical properties. Table 2.4 shows the list of references that been reviewed by the researcher:

Table 2.4: Reviewed reference

No.	Title	Author	Description
1	ASTM D3039- Standard Test Method for Tensile Properties of Polymer Matrix Composite Materials	American Society for Testing and Materials	• Tensile test method • Determining the specimen dimension as in Table 1 and Table 2 (Chapter 8. Sampling and Test Specimens). However, the specimen thickness may be subjected to the pipe wall thickness that intended to be tested or as needed. • The dimension is applicable for fatigue test as well.
2.	ISO 14692- Petroleum and natural gas industry – Glass reinforced plastic (GRP) piping	The International Organization for Standardization	• The experiment on fatigue behavior on the pipe plus joint is selected based on the stress concentration acting on the pipe structure as stated in ISO 14692-3:2002 under clause 6.2.6. • In order to obtain the longitudinal stress of the pipe, test method of ASTM D2105 shall be used stated in ISO 14692-2:2002 under clause 6.2.6.
3.	Standard Test Method for Longitudinal Tensile Properties of “Fiberglass” (Glass Fiber-Reinforced Thermosetting-Resin) Pipe and Tube	American Society for Testing and Materials	• A tensile test method suitable to test pipe or tubular specimen for thermosetting FRP structure. • Jig design is proposed in the standard. However, the material of the jig is not specified.

4.	Fatigue Behavior of Glass-Reinforced Epoxy Resin Submitted to Hot-Wet Aging	Giorgio Zaffaroni & Claudio Cappelletti (2000)	• The research is about study the difference in fatigue properties in dry, wet and hot, cold experiment. • There is no difference between wet and dry tension fatigue behavior. Thus, no degradation generated by moisture absorption. • Static degradation occurs in elevated temperature.
5.	Accelerated testing for long-term fatigue strength of various FRP laminates for marine use	Masayuki Nakada, Yasushi Miyano (2008)	• Fatigue test on several types of laminates. • Using three point bending fatigue and creep test method • Water absorption and temperature elevated were controlled to test the material later.
6.	On estimates of durability of FRP based on accelerated tests	Manuel A.G. Silva, B. Sena da Fonseca, Hugo Biscaia (2014)	• The test was conducted in two different method which is immersion in salt water, and salt fog for 750h, 1500h, 2500h, 5000h, of immersion. • The tensile test was described to predict the tensile using linear regression. • Each set of the test, 3 specimens were used to have the reliable results.
7.	Fatigue failure behavior of glass/epoxy ±55 filament wound pipes under internal pressure	(Gemi & Yapici, 2005)	• Study on hoop direction of static and fatigue strength of FRP piping. • 6 sets of hoop stresses from the ultimate hoop stress were tested which from 70%, 60%, 50%, 40%, 30%. • The applied stress ratio had a change in the leakage curve, extending from a burst type of leakage to slow leakage commencement with a slow growth in the leakage rate until rapid leakage.

8.	Mechanical characterization of glass/vinylester ±55◦ filament wound pipes by acoustic emission under axial monotonic loading	(Ben et al., 2012)	• The article study the fracture behavior under pure tensile stress. ASTM D2105 is used as a method in this experiment. • Matrix cracking, microscopic cracks to the fiber/matrix interfaces, propagation of cracks in the matrix and fiber failure is determined in the article.
9.	Theoretical and Experimental Bending Properties of Composite Pipes	(Stefanovska et al., 2015)	• The research journal study the comparison between theoretical and experimental bending properties using variable thickness of composite pipes. • There is a big difference on term of stress when comparing to the theoretical calculation • The paper also do the SEM microscopic experiment to examine the matrix failure, debonding, crack propagation, and delamination.
10	Analysis of Mechanical properties of Glass and Carbon Fiber Reinforced Polymer Material	(Raja et al., 2015)	• The paper is conducted tensile and compressive test on glass fiber reinforced plastic and hybrid composites with glass fiber and carbon fiber using new setup and system. • The test is followed the ACI440 3R, ASTM 3410 code and ASTMD3039 specifications procedure. • Both test is applied to obtain young's modulus of the specimens. • By comparing both materials, hybrid composites with glass fiber and carbon fiber shows good mechanical properties.

11	Experimental and Numerical Study of Adhesively Bonded ± 55° Filament Wound Tubular Specimens Under Uniaxial Tensile Loading	(Braiek et al., 2017)	• The research is to study the resin nature effect on mechanical behavior of joined E glass reinforced thermoset resins using a tensile test. • X-ray-technique and SEM observations on specimens make a few of mechanism is damage. • However, a numerical model based on meso-model concept shows a good result in predicting the mechanical behavior.
12	Probabilistic Failure Assessment of Fibreglass Composites	(Carpinteri et al., 2017)	• The paper proposed the Generalised Probabilistic Approach (GPA) to analyze the failure behavior of short fibre-reinforced material. • Several tests are conducted on commercial Fibreglass composite which are tension test, three and four-point bending test. • The comparison between the Primary Cumulative Distribution Function of Failure (PCDFF) and experimental failure probability (GPA) is made and GPA shows excellent tools to analyze cumulative failure probability of short fibre-reinforced material.

CHAPTER 3

METHODOLOGY

3.1 OVERVIEW

In this chapter, the process of the research is described in detail from the beginning to the end of this project. The project methodology also consists of the approaches applied to this project as a problem-solving method. Firstly, the sample preparation is described from manufacturing of the pipe until the joining method used in the research. Secondly, the pipe needs a holding device to perform tensile test, the method of designing the jig and their analysis is explained in this chapter as well. The method of testing on both tensile and bending test is described from the consideration, parameter to the procedure. All of the considerations in the research are based on ISO and ASTM standard which is focused on the testing methods. However, when it comes to FRP pipe, there is needs to review the methods from the journals and paper since this material is still new to the industry compared to metal pipes.

3.2 SPECIMEN PREPARATION & SPECIFICATIONS

The specimen for this research is manufactured and prepared by Pacific Advance Composites Sdn. Bhd. The specimen will be manufactured by the same technique as their products being produced. Firstly, the FRP pipe is manufactured using continuous filament winding technique illustrated in the Figure 2.2(a). The continuous filament winding utilizes an automated machine to cross-weaving the E-glass reinforcement fibers in accordance with the winding angle to form the pipe. The process has the advantage in optimizing the material usage and form a durable product. E-glass fiber reinforcement in form of continuous roving is soaked with the resin bath before wound onto a mandrel controlled by the fiber feeding mechanism. Before that, the mandrel is coated with special coating to avoid from the pipe to stick with the mandrel prior to curing process also, enable the inner pipe to have smooth finishes. Table 3.1 below is the list of materials used for making pipe:

Table 3.1: Material used for FRP pipe manufacturing

Material	Description
Resin	The resin used for making the FRP pipes are the epoxy resin from FIBERBOND®.
Promo`ters	Cobalt Napthenate, CoNap, 6% of active cobalt solution
Catalyst	Methyl Ethyl Ketone Peroxide (MEKP), 9% of active oxygen solution MEKP and plasticizer.
Glass Reinforcement	Continuous rovings E-glass individual fibers.

Source: FIBERBOND® Bonding procedure booklet (2014)

When the pipe is cured and ready, the pipe needs to undergo the surface preparation. The surface preparation includes the removal of contamination including of dust, moisture and all other foreign materials. After that, the surface to be welded need to completely roughened from glossy resin finish with at least 25 mm beyond welded area. Next, the pipe is cut into pieces that satisfy at least half the dimension of the sample to perform bonding process later. After that, all the pipe surface is need to be dry before roughened and beveled to 45˚ angle at the edge of joining area with a grinder. The beveled part then butted together as close as possible by clamp.

The putty is applied around the beveled area to fill the gap and to make the surface before performing bonding procedure. The putty need to be prepared with mixing about 17 liters or 4.5 gallons of Fume Silica, and 9.46 liters or 2.5 gallons of resin (the same resin used to make the pipe). The mixture will produce about 18.9 liters or 5 gallons of unpromoted putty. Figure 3.1 (a), (b), (c) shows the unpromoted putty, catalyzed putty and the application of the putty to the join of the pipe respectively. Prior to the application of the putty onto the join, the putty need to be catalyzed to enable it to cure and harden. The resin which promoted with CoNap needs to be catalyze with MEKP, thus the putty mixture is catalyzed with 8 cc or 8 mL of MEKP for every 454 grams of putty. According to FIBERBOND® bonding procedure booklet, the working time of catalyzed putty is around 10-20 minutes.

Figure 3.1 (a) Figure 3.1 (b) Figure 3.1 (c)

Figure 3.1: (a) Unpromoted putty (b) Catalyzed putty (c) Putty application

Source: FIBERBOND® bonding procedure booklet, 2014

After the putty has completely cured, the bonding procedure can be carried on. Bonding also called as the weld of the FRP pipe which two pipe are joint together. The method of weld used in the research is the butt and strap weld which utilized the hand lay-up technique to bond the two pipe. This bonding technique is known to be the strongest type of joining method. When the sample is ready to begin the weld, the resin need to be catalyze first using MEKP as catalyst. Table 3.2 shows the appropriate catalyst amount by the resin:

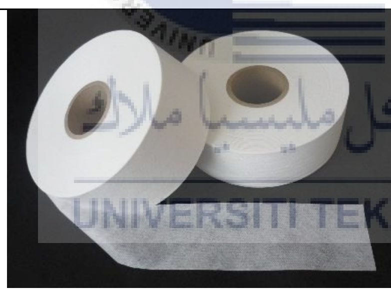
Table 3.2: Recommended resin promotion and catalyzation

Temperature	Percentage	Weight & Volume
30˚C - 35˚C	0.20% CoNap	2.2 mL/L
	1.0 – 1.5% MEKP	10.0 – 15.0 mL/kg
	0.30% CoNap	3.2 mL/L
	1.25 – 1.75% MEKP	11.0 – 15.4 mL/kg
	0.40% CoNap	4.3 mL/L
	1.0 – 1.5% MEKP	15.4 – 19.8 mL/kg

Source: FIBERBOND® Bonding procedure booklet, 2014

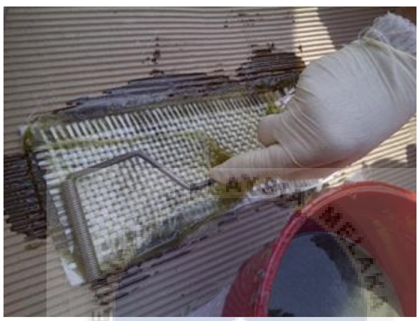
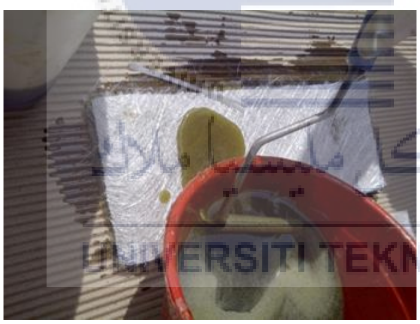
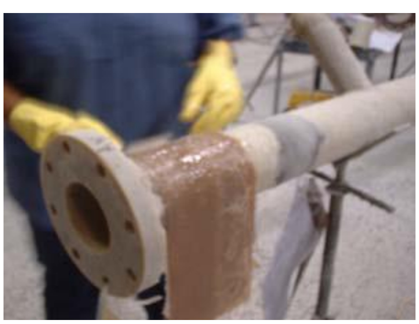
Next, after the preparation of bonding has completed, bonding procedure need to be carried out. Table 3.4 below describe the procedure of bonding of the pipe weld. The material used for this method is quite similar to the material that make the pipe. However, the reinforcement type of this composite is different instead using individual continuous rovings, materials in table 3.3 is used for bonding process. The method of preparation of resin is similar with previous process because all of the pipe component are made with the same materials.

Table 3.3: Reinforcement for bonding of FRP pipe

Reinforcement	Description
 Chopped strand mat	Chopped strand mat is the randomly oriented E-glass fibers used to be combined with woven rovings to make up FRP structures. The 225 g/m^2 of chopped strand mat is used.
 Woven roving	An 800 g/m^2 E-glass $\pm$ 90˚ bidirectional woven roving used to laminate the FRP pipe weld structure.
 Veil	A synthetic veil is used as external surfacing material to cover the reinforcement.

Source: FIBERBOND® Bonding procedure booklet, 2014

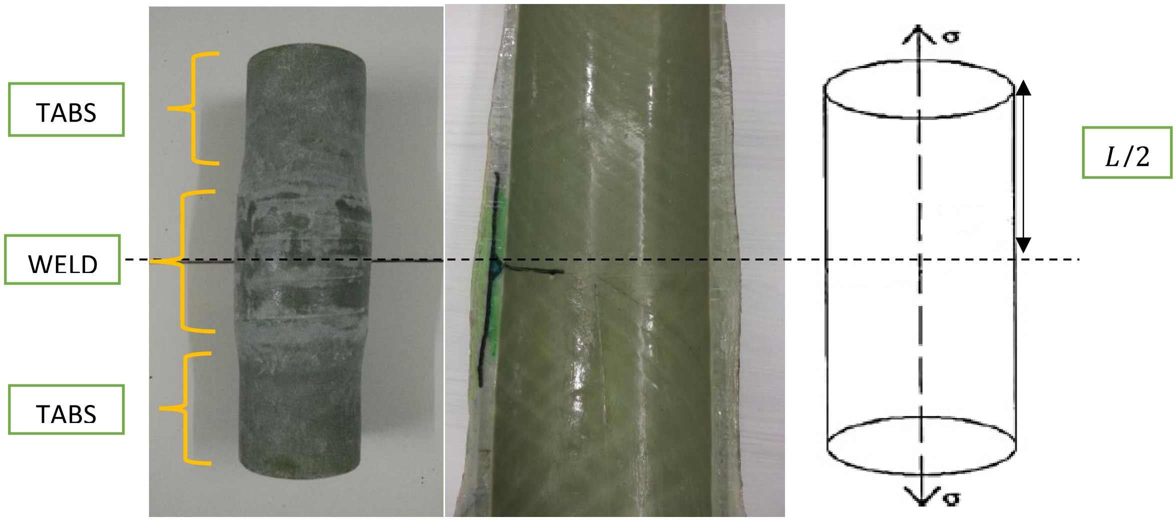
Table 3.4: Bonding procedure

	1) The cardboard surface, a layer of catalyzed resin is applied before doing the weld sequence. Next, apply the resin to the chopped strand mat fiber evenly using serrated roller.
	2) Apply the second sequence of fiber, woven roving on top of the chopped strand mat and reapply resin on top of it. Make sure all bubble is scrapped out.
	3) Repeat step 1 and 2 two times and cover the last layer by chopped strand mat.
	4) The completed laminate then lifted and placed to the puttied join area. The laminate is rolled circumferentially around the pipe for 180˚ from the pipe.

5) The remaining mat was rolled to cover all the weld area. Make sure all the air bubble is removed from the weld
6) Step 1 to 5 was repeated once again.

7) Once the final sequence is applied, the surfacing veil is then applied onto the weld area to cover it. The veil is applied tightly to remove the excess resin and air bubble. The weld then brushed with resin again and let to cure.

For tensile test, the sample to be is the plain pipe without the weld joint and for bending test, both welded and plain pipes is tested and compared. The comparison of these two types of pipe can give more understanding about the strength between two of them. Both specimen have the same nominal inner diameter but the welded pipe has an uneven thickness due to the bonding technique. The welded sample will be joined at the middle of the pipe perpendicular to the length of sample as seen in the Figure 3.2 below. From that technique, the specimen need to be long enough to cover the bonding area as well as the tabs. The nominal diameter selected to perform this research is 3 inch or 80 mm as per ASME B31.3 standard diameter of pipe. However, the specimen has 76.2 mm of inner diameter when measured.



Length, L = 390 mm

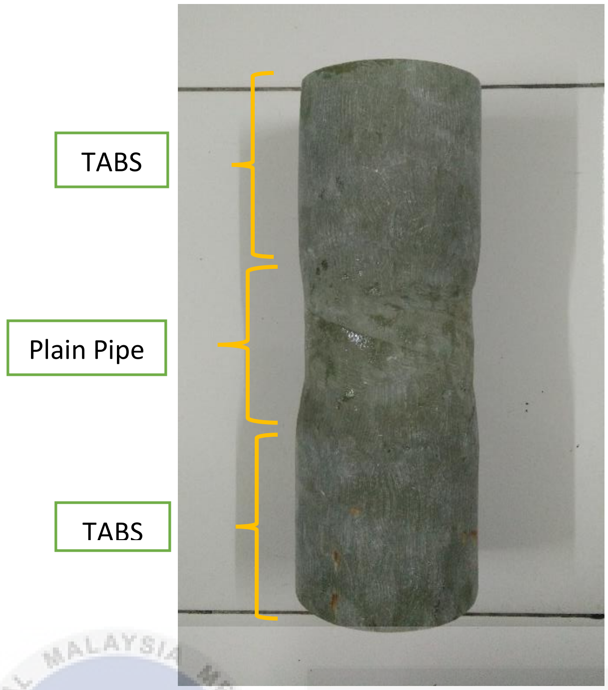
Inner diameter, ∅ = 3 inch / 76.2 mm

Tabs Outer diameter, ∅ = 90 mm

Weld Outer diameter, ∅ = 108.2 mm

Figure 3.2: Specimen Specification for Weld pipe

The pipe length is not following the recommended length of specimen in the ASTM D2105 which require 18 inch or 457 mm due to machine constrain which have the maximum gap of 450 mm between grips. Moreover, there is need a consideration for clearance for the elongation to take place as well as the jig placement on the machine to perform the tensile test. The total length of the specimen is 250 mm for the plain pipe and 390 mm for the welded pipe. For three-point bending test, the span is taken is 200 mm for both plain pipe and the welded pipe. The figure 3.3 below showing the plain pipe specification which have tabs at both ends of the specimen. The tabs were designed to cater the stress occur during tensile test thus making the specimen's stress concentrated at the middle of it as seen in the figure, the tabs are slightly thicker than the center of the specimen.



Length, L = 250 mm

Inner diameter, Ø = 3 inch / 76.2 mm

Tabs Outer diameter, Ø = 90 mm

Plain Pipe Outer diameter, Ø = 83.8 mm

Wall Thickness = 3.8 mm

Figure 3.3: Specimen Specification for Plain pipe

3.3 JIG DESIGN

In order to hold the pipe sample into the universal testing machine Instron 5585-140kN floor column screw movement machine, a custom jig need to be design. The jig is designed to hold hollow cylinder shape sample as well as to withstand uniaxial tension by the testing condition. According to ASTM 2105 test method, there are 4 parts assembly needed for the jig in each ends of pipe: 1) Mandrel, 2) Segmented grip, 3) Reinforcing band, and 4) Sleeve.

However, there is modification in the design where four bolts were added to four symmetrical direction of the sleeve to further reinforce the structure. The jig utilizes the taper shape of mandrel and segmented grip where it expands to push the pipe as the tension load is increasing. The jig is designed using SolidWorks™ 3D modelling software which enable designer to have more flexibility in designing 3D model. The interface of the software is as Figure 3.4 below which shows on how to initiate new part modelling (New > Part > OK).

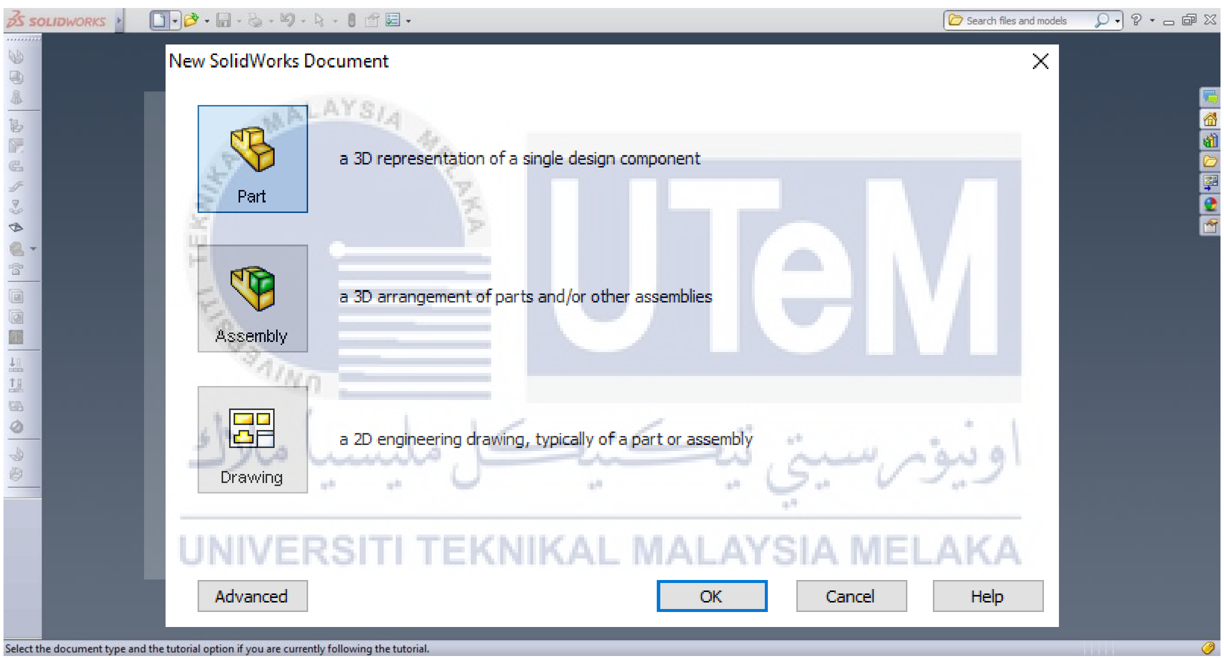


Figure 3.4: New part modelling in SolidWorks™

In order to model the jig, the design needs to be drawn in 2D plane first. Since the jig has circular pattern in all parts, the revolved boss features are used in most of the modelling. This feature convert the 2D drawings into 3D by the method of revolving the 2D sketch under an axis of revolution. For sketching 2D drawing, front plane was chosen to be the plane because the parts need to be revolve by that plane later. A center line is drawn first to be the datum of the sketch and act as reference axis for the revolved boss feature. Using this feature, only half side of the design need to be sketched because later, the drawing is revolved 360˚ to make a 3D model. As seen in the figure 3.5 below, the initiation of the revolved boss is seen by setting up and specify the degree of rotation and reference axis.

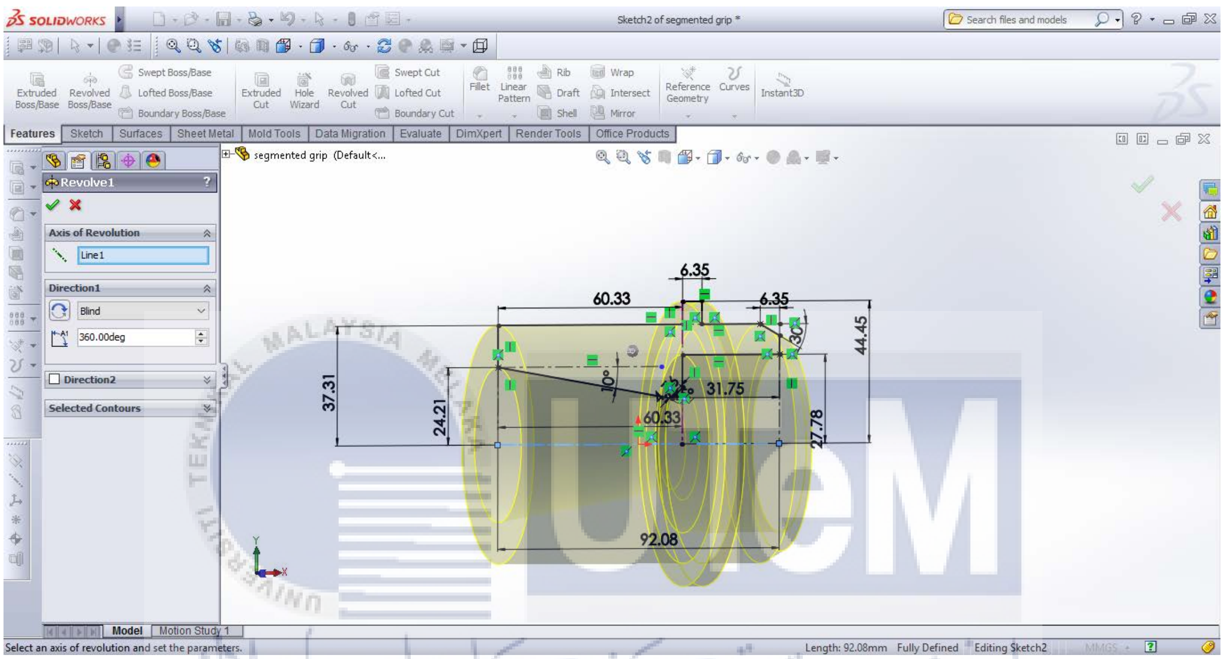


Figure 3.5: SolidWorks™ revolved boss feature

After completing all the four parts, an assembly drawing was initiated to have better projection of the model after combining all parts together. As seen in the modelling interface at the figure 3.4 above, the assembly option was selected to perform assembly drawing. From there, each of the parts need to be mate with each other by defining each component in relation with other parts so that the software assembles the parts according to the preference. After all components has been defined and resolved, the bolts is added into the design by the tools library equipped by the software. Bill of materials also can be added into the interface by just clicking on the bill of materials and the software will display all the parts name within design library based on the parts on the drawing. Figure 3.6 below shows the completed assembly model on the SolidWorks™ software interface.

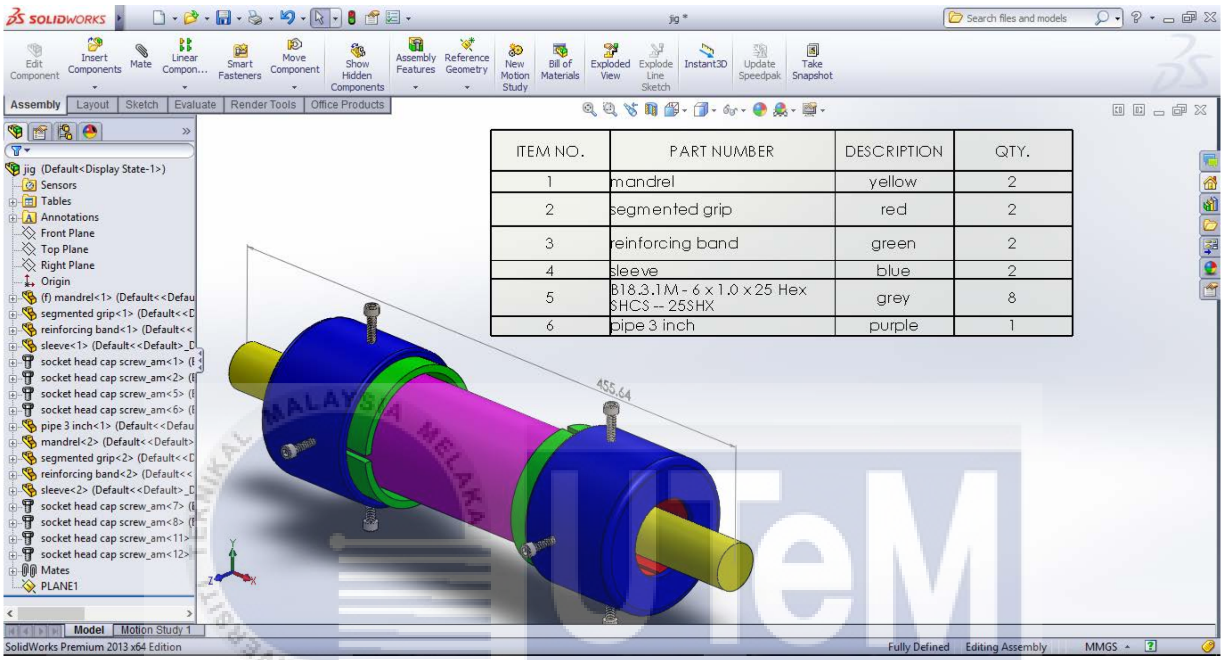


Figure 3.6: Assembly model of the jig with the pipe specimen

3.3.1 JIG ANALYSIS

In designing a mechanical component, it is necessary to have an analysis to know the strength of the design. In this case, the jig is designed to withstand and experience the same load that being applied to the specimen in testing. Thus, the maximum load of the testing is assumed by the previous testing that has been conducted according to (Ben et al., 2012) research. The result of the testing the FRP pipe using vinylester resin as the binder and E-glass fiber as the reinforcement is stated in the table 3.5 below. The test was conducted to 4 specimens using ASTM D2105 standard test method and according to that, the maximum stress is taken as consideration of the load because the design must have a robust structure.

Table 3.5: Mechanical properties of vinylester FRP pipe

Tube	Young Modulus (GPa)	Tensile Strength (MPa)	Maximum Strain (%)
T1	11.88	52.78	4.8
T2	11.73	54.11	2.7
T3	11.59	54.28	3.76
T4	11.37	60.77	2.83
Avg.	11.64	55.49	3.52

Source: (Ben et al., 2012)

From the data above, it is clear that the maximum possible tensile strength is 60.77 MPa which is the data at T4. Next, the force can be determined by calculating the relation of stress and area as seen in equation 4 below. In this case, the area should be the cross-sectional area of the pipe which normal to the direction of force applied using equation 5 where "D" is the pipe diameter. In the research the specimen used is a hollow tube which can be referred at the figure 3.7 below.

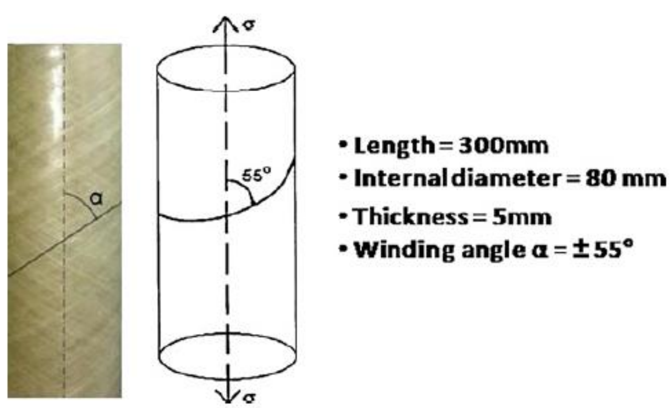


Figure 3.7: Specimen specification from previous research

Source: *(Ben et al., 2012)*

$$F = \sigma A \tag{4}$$

$$A = \frac{\pi D_o^2}{4} - \frac{\pi D_i^2}{4} \tag{5}$$

$$where;\ Outer\ diameter, D_o = \ 0.09\ m$$

$$Inner\ diameter, D_i = 0.08\ m$$

$$nominal\ stress, \sigma = 60.77\ MPa$$

<u>Solution,</u>

$$A = \frac{\pi(0.09)^2}{4} - \frac{\pi(0.08)^2}{4}$$

$$A = 1.3352 \times 10^{-3} m^2$$

$$F = (60.77MPa)(1.3352 \times 10^{-3} m^2)$$

$$F = 81{,}138.69N$$

From the result above, it can be concluded that the maximum force acting on the pipe is approximately 81 kN. This data is needed to estimate the safety factor of the jig and its maximum working stress from the force applied to the jig. The data is required in the simulation analysis by the SolidWorks™ software as a parameter for the static testing. The software is capable to analyze the factor of safety, deformation, and stresses occur due to the load that applied to the design. The mandrel is selected as the critical component because the force is directly being apply to it for the testing. The flow of the analysis on the software is shown in the figure 3.8 below.

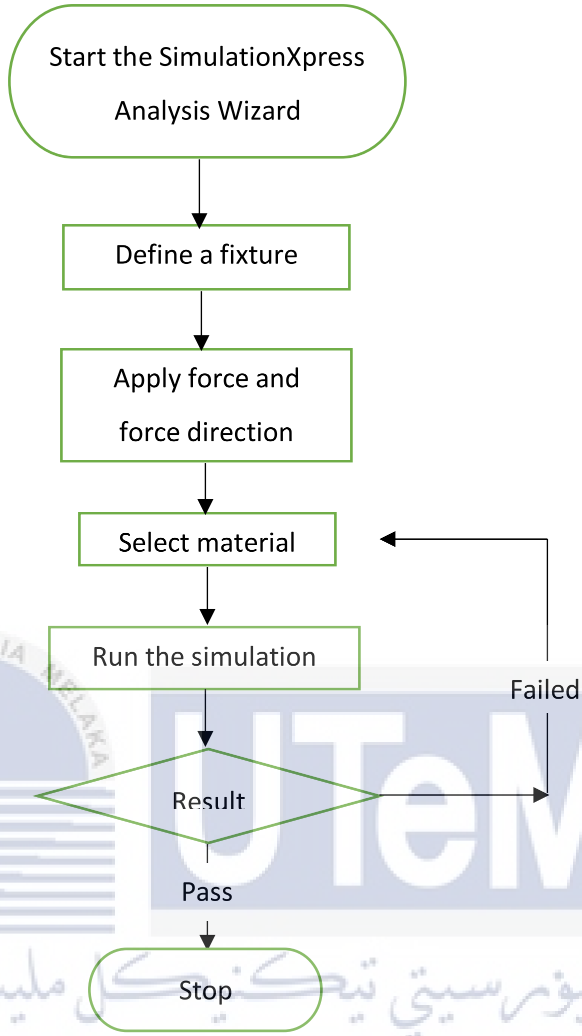


Figure 3.8: Flowchart of static simulation analysis

After completing the 3D model of the mandrel, the SimulationXpress Analysis Wizard was initiated to study the static analysis of the model. The fixture need to be define at the model surface so that the surface is not experience any deformation during the tensile test on the software. Figure 3.10 shows the interface of the SimulationXpress Analysis Wizard's Von Mises stress results and seen there the green arrow is the selected fixture surface of the mandrel. Next, the force is need to be specify in the wizard, seen in Figure 3.10 also, the purple arrow show the direction of the test that need to be specified. Moreover, the force value is as per calculated before in Equation 4 and 5.

The material selection in the software will influence the result of safety factor of the design. This decision phase of designing the jig is crucial in order to obtain the proper safety factor and economical factor as well. For this design, the material that has been selected is AISI 1020 carbon steel which have 351.571 MPa of yield strength. Figure 3.9 below is the material selection option for this analysis. From the option, the mechanical properties of each material are displayed for the designer to estimate the right material to be selected.

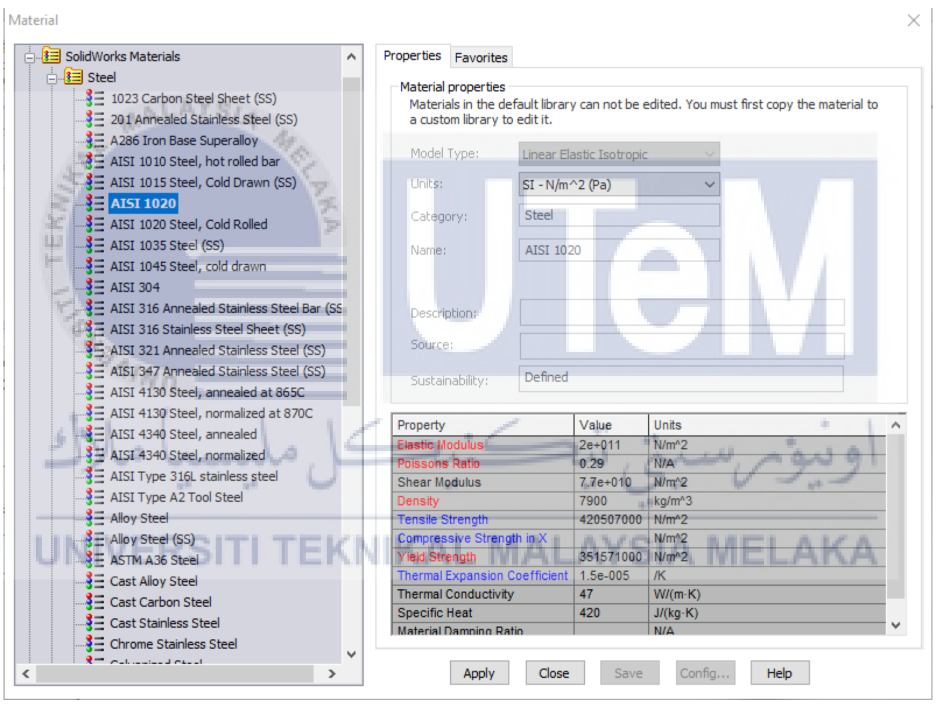


Figure 3.9: Material selection option

After completing the material selection, run the analysis. What the software do in this phase is calculate the highest stress experience by the design in that particular force. Looking at the relationship from the Equation 4, it is obvious that the least area of that particular design will experience the highest stress level. Figure 3.10 confirmed that the least cross-sectional area of the mandrel experience the highest stress level. From that, the factor of safety is also calculated by the software using Equation 6 below. After obtaining the results, if the factor of safety is undesirable, change the material and back to the previous process. The detail design of the jig is attached in the APPENDIX B.

$$FoS = \frac{Yield\ Strength,\ \sigma_y}{Working\ Stress,\ \sigma} \tag{6}$$

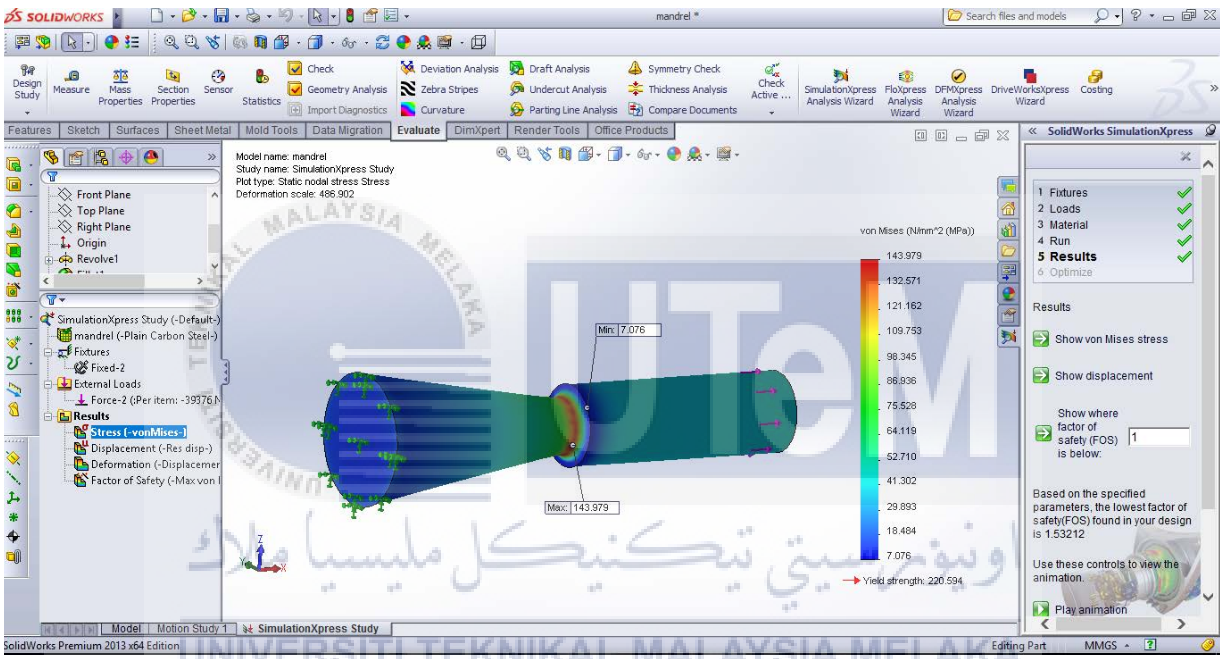


Figure 3.10: SimulationXpress Analysis Wizard results interface

3.4 DESIGN OF EXPERIMENT

The experiment is conducted to study and analyze the mechanical properties of the fiber reinforced plastic pipe structure under real condition, thus, the specimen stated in chapter 3.2 above is the real 3-inch pipe. To simulate the real condition and study on both of the maximum force and stresses that acting on the pipe before failure, the tensile and bending test is selected as the method because it is more related and close to the real working environment of the pipe after the burst test. In this subchapter, the flow of the experiment will be described with flowchart in Figure 3.11 below. In this experiment, it is assuming that there is no external load or stresses that affect the pipe such as the effect of internal pressure and weight of the structure itself.

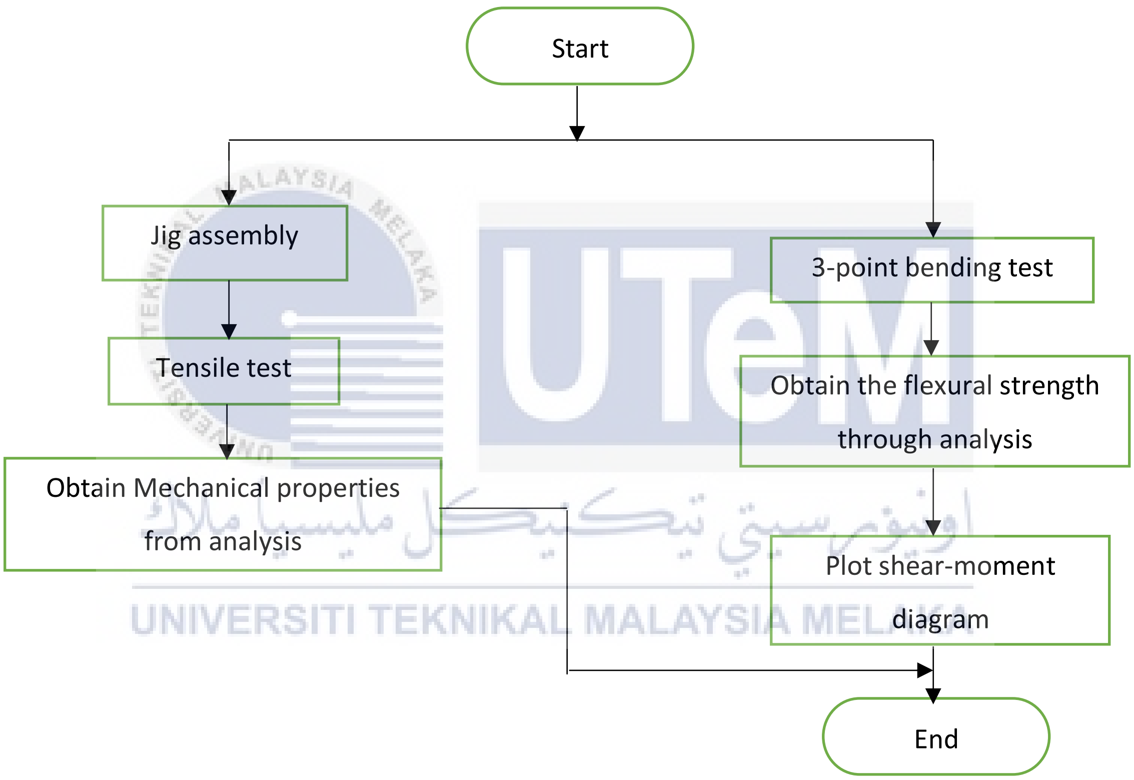


Figure 3.11: Flowchart of experiment

Firstly, the jig need to be placed on the pipe in order to grip the specimen with the machine. The procedure of jig assembly will be detailed on 3.4.1 later. The jig consists of four components which is mandrel, segmented grip, reinforcing band, and sleeve. The component of the jig is illustrated in the Figure 3.12 below. Mandrel is the component where the force is applied to distribute to the specimen since it relates to the machine grips. Segmented grip is a component that grip the inner pipe while force is applied. The grip expands proportional to the displacement in axial direction due to the tapper shape. Next, the reinforcing band and sleeve act as the external grip to hold the specimen while testing.

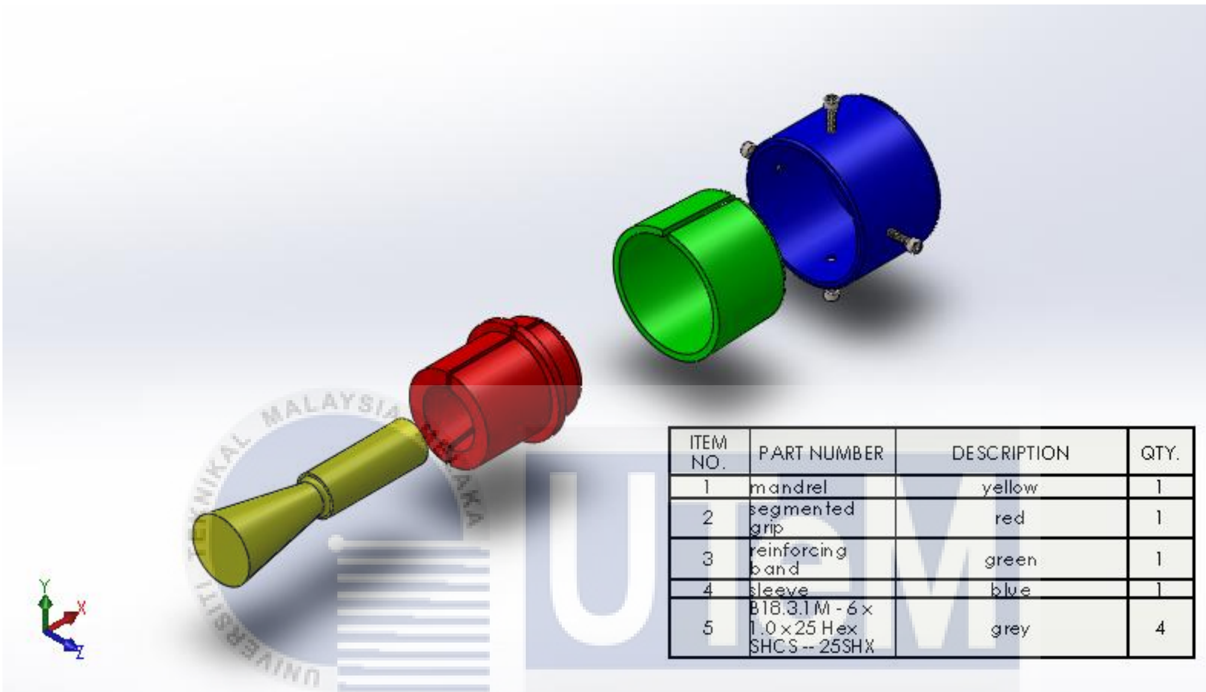


Figure 3.12: Jig components

Next, the tensile test is conducted by referring standard test method ASTM D2105 recommended by ISO 14692-2:2002. According to ISO 14692-2:2002, the short-term axial strength of the pipe can be determined by that standard test method and the experiment procedure as well as setup is explained in the chapter 3.4.2 below. Although, the standard test method recommended that at least five specimens need to be tested, due to time constrain, only one specimens will be tested for tensile test. This approach is to allow the modification of the specimen or the jig due to unpredicted results during the tests. The analysis of the failure during the test has been done in the chapter 4.3 below.

After conducting the tensile test, three-point bending test was conducted in order to know the flexural strength of the pipe subjected to the real condition. According to (Stefanovska et al., 2015), the three point bending test for a composite pipe can be carried out as recommended in ASTM D790 which the speed of the test is 5 mm/s. The test setup is referred in the Figure 2.4 above. The recommended ratio of depth and length of span is 1:16 according to the ASTM 790, however, the ratio is not possible with the specimen and machine capability. Also, the span of the test subject is as stated in chapter 3.2 above. Loading nose and support spacing's tip is a 1 cm cylindrical shape steel attached to triangle holder. All of the test was conducted using the Instron 5585-140kN floor column screw movement machine.

Both experiment is then need to be analyzed due to the fracture and failure occurred at the specimen during testing. The tensile test is using direct stress on the cross-sectional area of the specimen using Equation 4 and 5 above. On the other hands, the three-point bending analysis also been carried out after the testing. According to (Beer, Russell Johnston, et.al, 2011), the flexural strength can be calculated by the *elastic flexural formula* as below:

$$\sigma_f = \frac{Mc}{I} \tag{7}$$

$$I_x = \frac{\left(D_{out}^4 - D_{ins}^4\right)\pi}{64} \tag{8}$$

3.4.1 JIG ASSEMBLY

Before conducting any experiment, the jig need to be assemble to the pipe first. This procedure is required for tensile and fatigue test and with each of the pipe that are needed to be tested. Careful measure in assembling the jig is important to make sure the pipe is tight enough for the test to prevent slippage during test. Below is the procedure of assembling the jig into the test specimen:

1) Mark the mandrel for the gripping length to ensure all tests conducted with the same gripping length.
2) Observe and make sure the gripping area on the pipe is free from flaws or crack.
3) Assemble the mandrel and segmented grip and carefully insert it into the inner pipe of one ends.
4) In that ends of pipe, place the reinforcing band at the outer surface of the pipe until the top segment of the reinforcing band touched the segmented grip. Use rubber mullet if required.
5) Cover the jig with sleeve and gradually tighten the bolts. Do not overt tight the bolts as it can stress the pipe.
6) Turn the pipe ends with finished assembly upside down and grip the mandrel to the bottom grip of the machine.

Note: the mandrel need to be hold until it has been clamp on the machine to prevent it from drop.

7) Repeat step 1 to 4 and grip the upper mandrel with upper grip pf the machine.

3.4.2 TENSILE TEST

Tensile test is carried out to obtain the mechanical properties of the FRP pipe such as yield stress, modulus of elasticity, elongation and the most important for extending to product design is the ultimate tensile strength. However, FRP material has low ductility and sometimes does not exhibit yield point. The stress-strain graph such in Figure 2.3 will be obtained through this test. The tensile test procedures are according to ASTM D2105. Plain pipe specimen are being tested in this experiment with dimension stated in 3.2. The specimen thickness is measured by calculating the outer diameter through circumference of the pipe and subtract with the inner diameter. The experimental setup can be seen in the Figure 3.13 below. Also, the apparatus and procedure of the experiment is as below:

<u>Apparatus:</u>

1) **Testing machine:** A universal testing machine (UTM), Instron 5585-140kN floor column screw movement machine.
2) **Fixed member:** A stationary member which carry one grip at the bottom of the machine
3) **Movable member:** A movable member carrying second grip which pull the specimen
4) **Grips:** Which holds the specimen or jig between movable and fixed member
5) **Jig:** A clamping device that designed to hold the pipe specimen as detailed in 3.3
6) **Drive mechanism:** To move the movable member with controlled and regulated speed.
7) **Load indicator:** A mechanism which showing the tensile load carried by the specimen.

8) **Extension indicator:** The machine equipped with extensiometer for testing large specimen and it records the extension of the specimen by the test.
9) **Micrometer:** Use for measuring the inner diameter of the pipe to determine the cross-sectional area.

Procedure:

1) The power supply and control panel of the UTM was switched on.
2) The machine is then let to warm up for 30 minutes to minimize error due to sudden operation.
3) The specimen was placed according procedure in 3.4.1 and align the specimen about the long axis of it to the machine and close the grips.
4) Insert the cross-sectional area of the pipe, and the parameter for result such as stress and strain into the software.
5) The speed of testing was set to (0.508 to 0.635 cm/min)
6) Run the test until the specimen reach to its failure point.
7) The mechanical properties of the specimen were retrieved from the software.

Figure 3.13: Experimental setup for tensile test

3.4.3 BENDING TEST

This test is carried out to determine the bending strength of the structure of the FRP specimen. As clarified in the design of experiment, the test is carried out in accordance to the ASTM D790 recommendation. The three-point bending test is involve the plain and the welded pipe specimen to be compared whether the welded pipe shows any significant difference strength then the plain pipe. The span of the bending test is taken to have 200 mm in length and the nose applying force at the center of the specimen and there is two support spacing in between the nose of the machine. Moreover, the experiment setup can be seen in the Figure 3.14 below and apparatus of the experiment can be referred as below:

Apparatus:

1) **Testing machine:** A universal testing machine (UTM), Instron 5585-140kN floor column screw movement machine.
2) **Fixed member:** A stationary member which hold the support spacing at the bottom of the machine
3) **Movable member:** A movable member carrying the nose and where the force is applied.
4) **Drive mechanism:** To move the movable member with controlled and regulated speed.
5) **Load indicator:** A mechanism which showing the tensile load carried by the specimen.
6) **Extension indicator:** The machine equipped with extensiometer for testing large specimen and it records the deflection of the specimen by the test.
7) **Micrometer:** Use for measuring the inner diameter of the pipe to determine the cross-sectional area.
8) **Support span:** A triangle steel block to support each ends of the specimen.
9) **Loading nose:** A triangle steel block used to apply force at the center of the specimen.

Procedure:

1) The power supply and control panel of the UTM was switched on.
2) The machine is then let to warm up for 30 minutes to minimize error due to sudden operation.
3) The span length and nose spot was marked on the specimen as in figure 3.15
4) The specimen was placed onto the support spacing directly at the marked area of span.
5) The movable member which hold the nose was lowered slowly until it touched the surface of the specimen.
6) Insert the cross-sectional area of the pipe, and the parameter for result such as stress and strain into the software.
7) The speed of testing was set to (5 mm/min)
8) The test was initiated until the specimen reach to its failure point.
9) The force acting on the specimen was retrieved from the software.
10) Step (3) to (9) was repeated for the welded pipe.

Figure 3.14: Experimental setup for three-point bending test

Figure 3.15: Specimen marking

CHAPTER 4

RESULT & DISCUSSION

4.1 OVERVIEW

In this chapter, the result and analysis of jig, tensile test, and three-point bending test are being explain and discussed. The jig analysis discusses about the simulation testing done in the SolidWorks™ SimulationXpress. The maximum stress is shown in the chapter and from there the safety factor showed by the simulation is verified by calculation. Next, the outcome of tensile test on the FRP specimen is detailed. Also, the improvement in force acted on the specimen after modification as well as the analysis on the failure of the specimen is discussed in the chapter. Finally, the result and findings of three-point bending test is also detailed in this chapter. The behavior of the structure due to the three-point bending test that designed for this research is known and the failure due to the test is discussed.

4.2 JIG ANALYSIS

The jig is designed in accordance to recommendation of ASTM D2105 to grip the pipe specimen for all of the test. The mandrel is suspected to be the critical component and seen in Figure 4.1 below, the highest stress is concentrated at the least cross-sectional area of the jig which satisfy the Equation 4 is illustrated in the SolidWorks™ SimulationXpress Analysis Wizard. Also, in this analysis, the load is assumed based on other related research as seen in 3.3.1. AISI 1020 carbon steel was selected as the material for the jig and Table 4.1 shows the independent variable for the analysis. Moreover, the factor of safety of the mandrel is calculated by substituting the yield strength of the carbon steel and maximum working stress experienced by that component into the Equation 6. Also, it also can be seen in the Figure 4.2 which the software shows where the maximum and minimum factor of safety is. The results of the analysis are shown in Table 4.2 and the detail analysis result is attached in APPENDIX B.

Table 4.1: Independent variable of the analysis

Material	Yield strength, (MPa)	Load (N)
AISI 1020 carbon steel	351.571	81,138.69

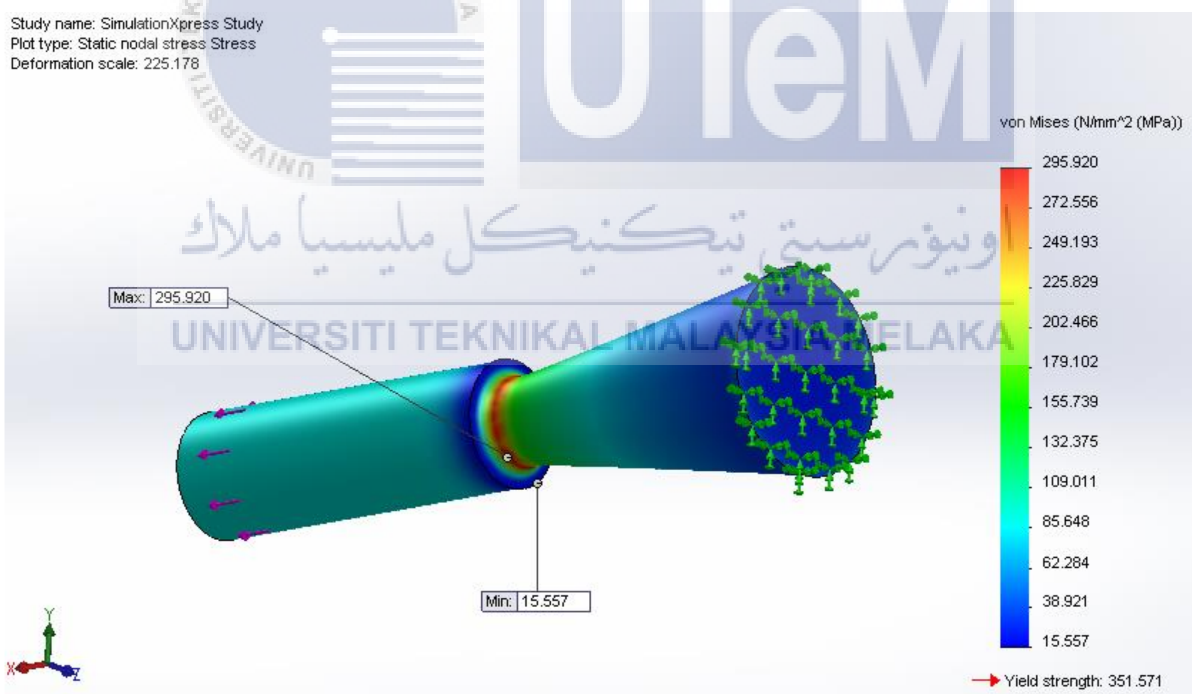


Figure 4.1: Critical working stress of mandrel

From equation 6:

$$FoS = \frac{351.571MPa}{295.920MPa}$$

$$FoS = 1.19$$

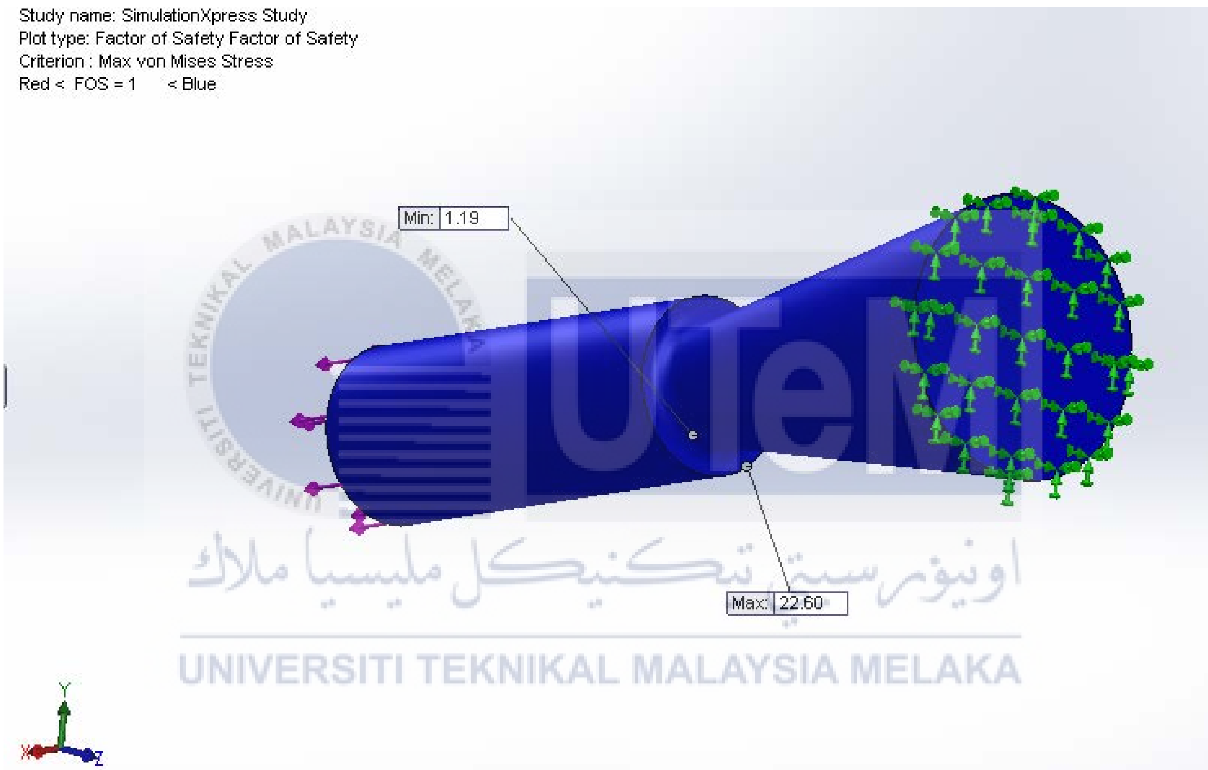


Figure 4.2: Factor of safety of the mandrel

Table 4.2: Results of jig analysis

Working stress, (MPa)	Factor of safety
295.920	1.19

4.3 TENSILE TEST

The tensile test was conducted as per ASTM 2105 which recommended by ISO 14692-2:2002 to determine the short-term axial strength of the fiber reinforced plastic pipe. The test was conducted as per tensile test procedure as stated in 3.4.2 above. The specimen was inserted perfectly into the jig that has been manufactured as the design in chapter 3.3 above. However, the specimen slipped during the test after two consecutive times which recorded to have the maximum force acting on it of 3.824 kN and 7.553 kN respectively. The specimen that has been tested is as specified in the chapter 3.2 above. Thus, the stress that experienced by the specimen can be determined by the relationship of Equation 4 and 5 above and the modulus of elasticity is derived from the equation in chapter 2.4.1 above considering the load at yield. However, the modulus of elasticity cannot be defined because the specimen does not break and thus, the yield stress is not valid at all. The result for the tensile test for these two condition is stated in the Table 4.3 below.

The reinforcing band which holds the outer surface of the pipe is suspected have low friction and grip which makes the specimen slipped all the way during the test. The smooth inner surface of the reinforcing band is contributing to the low grip and friction to the specimen. As seen in the results, the jig slipped at very low from targeted force that has been designed as stated in 3.3.1 above which have the strength of 81 kN.

$$where;\ Outer\ diameter, D_o = \ 0.0838\ m$$

$$Inner\ diameter, D_i = 0.0762\ m$$

$$Force, F_{T1} = 3.824\ kN$$

$$Force, F_{T2} = 7.553\ kN$$

<u>**Solution:**</u>

$$A = \frac{\pi(0.0838)^2}{4} - \frac{\pi(0.0762)^2}{4}$$

$$A = 9.5768 \times 10^{-4} m^2$$

$$\sigma_{T1} = \frac{3.824\ kN}{9.5768 \times 10^{-4} m^2}$$

$$\sigma_{T1} = 3.993\ MPa$$

$$\sigma_{T2} = \frac{7.553\ kN}{9.5768 \times 10^{-4} m^2}$$

$$\sigma_{T2} = 7.887\ MPa$$

Table 4.3: Preliminary tensile test result

Specimen	Maximum Force, F (kN)	Maximum Stress, σ_T (MPa)
T_1	3.824	3.993
T_2	7.553	7.887

After these two tests were conducted, the specimen is then modified in order to achieve higher level of force that can be applied to the specimen. The specimen was then drilled with four hole for each end parallel to the screw hole at the sleeve of the jig. The modification was done by removing the reinforcing band and directly insert the sleeve screw into the specimen. The hole that has been drilled for the specimen is M6 size suites the original design of the jig's screw. The result for the modification was successfully increasing the maximum force that can be exerted to the specimen which showing 13.345 kN of force. However, the test was also failed because the screw has been failed before seeing any failure on the specimen. The result of this modification is not valid because the force captured by the software of the machine is indicating the direct shear force for the screws as seen in the Figure 4.3 below. The shear stress that experienced by the screw is higher than the allowable shearing stress of the screw is what makes the screw failed and the allowable shearing force that has been shared by all eight screws possibly is lower than tensile strength of the specimen.

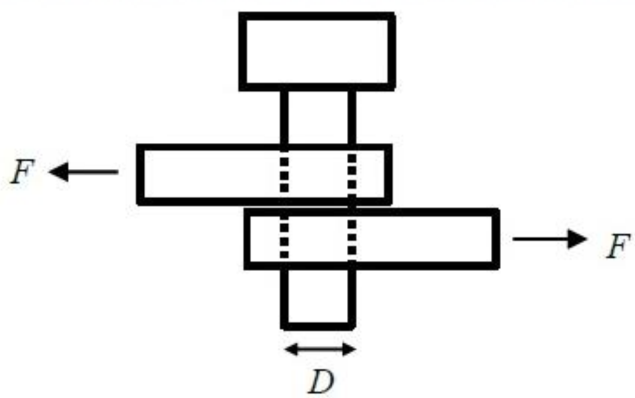


Figure 4.3: Shearing force of the screws
Source: Autodesk Community Inventor Forum, 2017

After the modification has failed, second attempt for modification has been made to cater the targeted force need to be applied on the specimen as stated in chapter 3.3.1 above which is approximately 81 kN of force. The second modification by changing the screws on the jig's sleeve size to M12. The specimen and sleeve were reborred with the 12 mm bore to fit the M12 screws on each ends of the specimen as seen in the Figure 4.4 below. The modification was made in order to have higher allowable shearing stress on the screws to overcome the force needed to break the specimen.

Figure 4.4: Modified specimen with 12 mm bore

The tests were conducted in the same environment and test requirement recommended by the ASTM 2105 after this second modification which follows the same speed rate. The modification however successful in term of conserving the screws. The screws are survived for the test and not seeing any failure happening to it. However, there are some failure happened on both specimen and the sleeve instead. The machine has recorded the maximum tensile force acting on the specimen is 33.535 kN. The data showing increasing force is happening when comparing to the normal jig setup, the first modification and second modification. The data of these two modifications can be seen in the Table 4.4 below.

There is failure to the specimen during the second modification which can be seen in the Figure 4.5 below, the crack propagates from the drilled bore on the specimen. The bore on the specimen was act as stress riser for this case because high concentration of force acting over a small area. The early target for the modification is to ensure the center of the specimen experiencing high level of stress since the cross-sectional area at the center of the specimen is much lower than the tabs at both ends. Since the tabs have more thickness than the center of the specimen, the stress should be higher at the center and the thicker tabs should have higher strength. On the other hands, the impact of this modification, the jig sleeve was also dented from holding the force between the machine and the screws as seen in the Figure 4.6 below.

Figure 4.5: Crack propagation on the failure area

Figure 4.6: Sleeve of the jig after second modification

When observing the Figure 4.5, the cracks propagates upwards from where the force is applied. Figure 4.7 below show the inside and upper surface of the specimen and showing the delamination of the fiber laminates. From the failure, it shows the white spots inside the material which indicates the fiber reinforced composites behavior. The cracks on fiberglass reinforced plastic materials distributing the stress from inside of the material itself and propagated towards outer surface of the specimen, as seen in the same figure, the delamination seen at the top of the specimen occur at the middle of the thickness side of the specimen.

Figure 4.7: Failure from inside view

For this case, by considering and looking into the failure happened which at the bore of the drilled hole, the stress acting on the contact area of the bore is as illustrated as Figure 4.8 below. The stress is divided into eight hole in total which drilled on the specimen. As seen in the figure below, the stress is acting on half of the hole in which the force is acting because the other half does not experience the force. From the calculation below, the body is treated as a rigid body and the clearance between the screws and the contact area is neglected because there is so small clearance. The calculation was done by deriving the Equation 5 from chapter 2.4.1 which the force acting on the projected area. The projected area is the diameter of the bore multiply by thickness of the tabs and multiply the number of holes which is 4 since the stress is shared by only 4 bore and the other 4 is neglected because it is act as resultant force. The calculation resulting the bearing stress experienced by each bore on the specimen so that the stress that makes the specimen fail at the bore is discovered.

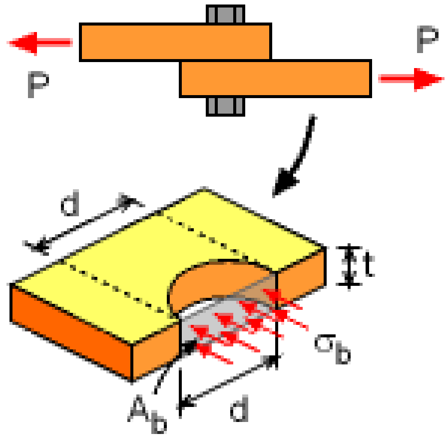


Figure 4.8: Stress experienced on each bore

Source: Beer, Russell Johnston, et.al, 2011

Force, P	= 33.535 kN
Diameter of bore, D	= 12 mm / 0.012 M
Thickness of specimen, t	= 7 mm / 0.007 M
Number of bore, n	= 4

$$from\ eqn\ 5;\ \sigma_b = \frac{P}{D \times t \times n}$$

$$\sigma_b = \frac{33.535\ kN}{0.012 \times 0.007 \times 4}$$

$$\sigma_b = 99.8\ MPa$$

From the calculation, the maximum bearing stress that experience by the bore is 99.8 MPa for the failure to happen. In term of stress gained form the bore crack, it is almost double to the previous research done by (Ben et al., 2012) referred at Table 3.5 above which have the average stress value of 55.49 MPa. However, the stress that experienced by the center of the specimen which is the main concern in the experiment and it is calculated as below. The calculation is using the derived formula in Equation 5 above which tabulated in the Table 4.4 below. Moreover, the test conducted is improving from one modification to another as seen in the bar graph from Figure 4.9 below in term of force. The bar chart also indicated the targeted breaking force estimated from chapter 3.3.1 above using previous research as guidance. Also, from all of the work that has been done, there is still at least 50% of force needed in order to achieve the targeted force. The full result of the test generated by the machine's software can be referred at APPENDIX C.

$$Force, F_{T3} = 13.345\ kN$$

$$Force, F_{T4} = 33.535\ kN$$

$$\sigma_T = \frac{F_T}{A}$$

$$\sigma_{T3} = \frac{13.345\ kN}{9.5768 \times 10^{-4} m^2}$$

$$\sigma_{T3} = 13.935\ MPa$$

$$\sigma_{T4} = \frac{33.535\ kN}{9.5768 \times 10^{-4} m^2}$$

$$\sigma_{T4} = 35.017\ MPa$$

Table 4.4: Tensile test result after modification

Specimen	Maximum Force, F (kN)	Maximum Stress, $\boldsymbol{\sigma_T}$ (MPa)
$\boldsymbol{T_3}$	13.345	13.935
$\boldsymbol{T_4}$	33.535	35.017

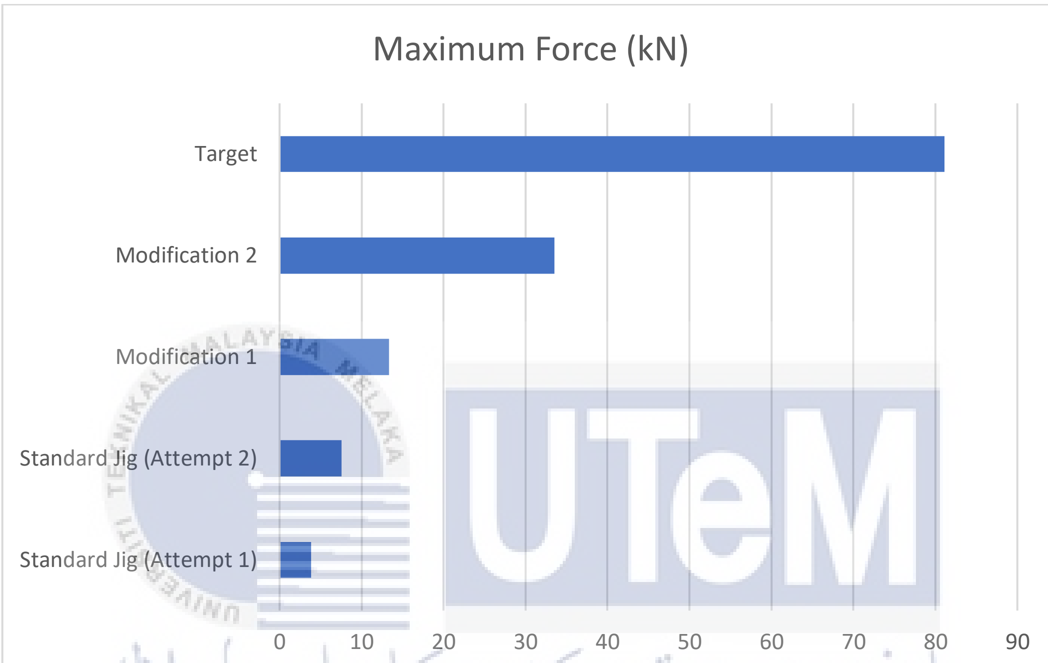


Figure 4.9: Comparison between test results and target

4.4 BENDING TEST

The three-point bending test was conducted in accordance to recommendation of ASTM D790 and the procedure of the experiment is stated in chapter 3.4.3 above. From the test, the maximum force applied to the both welded and plain pipe specimen is retrieve from the machine's software. The test was stopped when the specimen reach severe damage. The bending stress can be calculated using Equation 7 and 8 in chapter 3.4 above. As seen in the Equation 7, moment, M can be calculated by force acting on the center of the specimen multiply by distance to support span which is half of span length and 'c' is the distance between center of the pipe to outer surface of it and I is the moment of inertia of cross section with respect to centroidal axis perpendicular to the plane of the couple M. from that, the bending stress is tabulated in the Table 4.5 below.

Table 4.5: Bending stress result

Specimen	Span, L (m)	D_{ins} (m)	D_{out} (m)	Force max, F (kN)	I_x (m^4)	σ_f (MPa)
Plain	0.2	0.0762	0.0838	25.321	0.766×10^{-6}	138.505
Welded	0.2	0.0762	0.1082	56.130	5.073×10^{-6}	598.587

From the result above, bending stress is equal to the bending strength of the pipe due to the experiment condition. There is a significant difference in strength of the welded and plain pipe. The welded pipe showing more superior strength then the plain pipe due to the higher force acting on it making the bending moment, M higher than the plain pipe. To get better understanding on the phenomena, Figure 4.10 below showing the shear moment diagram on the designed experiment condition.

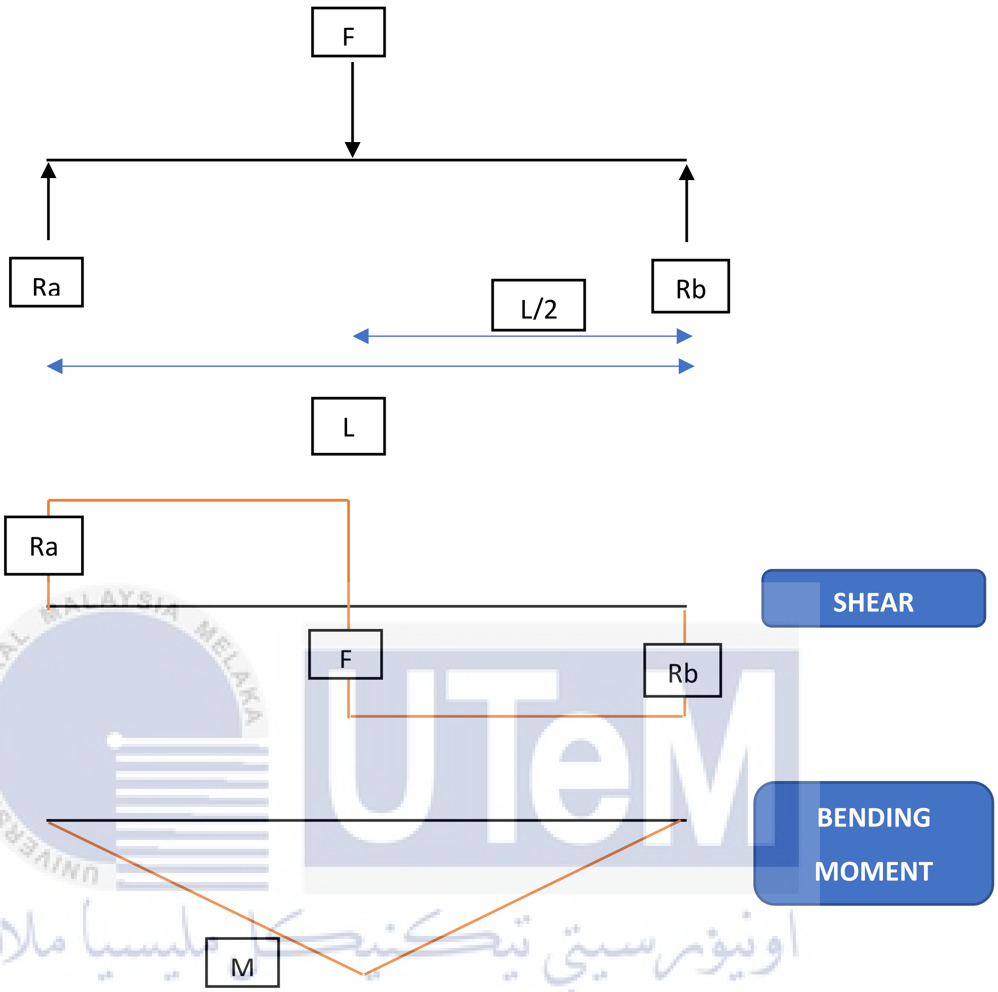


Figure 4.10: Shear moment diagram

F - Load applied by testing equipment

Ra, Rb - Reactions at pipe supports

M – Moment

Despite all that, when look into the specimen, both of them not showing bending failure. Specimen subjected to bending usually break at the bottom due to tensile force acting longitudinally to the pipe during bending. As seen in the Figure 4.11, the plain pipe has failure only at the top where the machine's nose acting on it. Due to the brittleness of the FRP material, specimen breaks due to high stress acting on the center where the force is acting. Other than that, the span is also plays a big role in the failure. Shorter span making bending moment lower. So, the specimen does fail due to shearing rather than bending stress.

Figure 4.11: Plain pipe failure due to bending test

On the other hands, the failure of the welded pipe is also most likely caused by the shearing as seen in the Figure 4.12 below, the failure of the pipe is at the support spacing. This is because the end of the pipe has lower thickness than the joining of the pipe itself. The stress at that area is supposed to be half of the center of the pipe, however the weld area does not fail at all. This showing that the butt join has higher reliability when handling stresses when comparing the result with the plain pipe. The full result can be referred at the APPENDIX D. However, the stresses value at the result retrieve from the software is not valid because the software do not have tubular shape geometry for flexural test to specify the real specimen that has been tested. Thus, the geometry selected is solid cylinder. The stress-strain graph also showing distortion at certain point indicating crack propagate as seen in Figure 4.13 below. The slight distortion happens when there is new major crack happening on the specimen and this is because the specimen is brittle and crack happens at the top where the nose at.

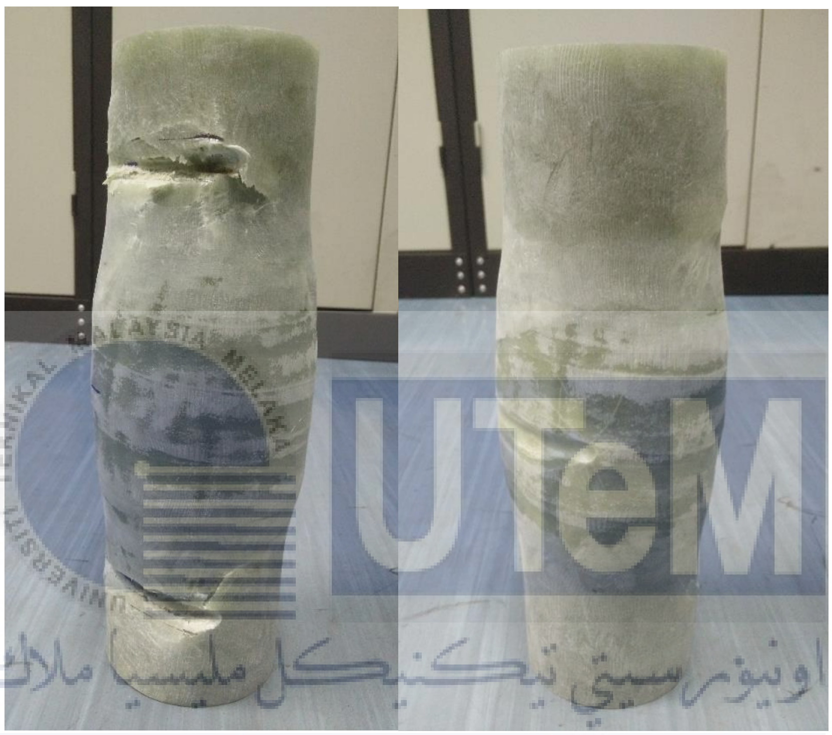


Figure 4.12: Welded pipe failure due to bending test

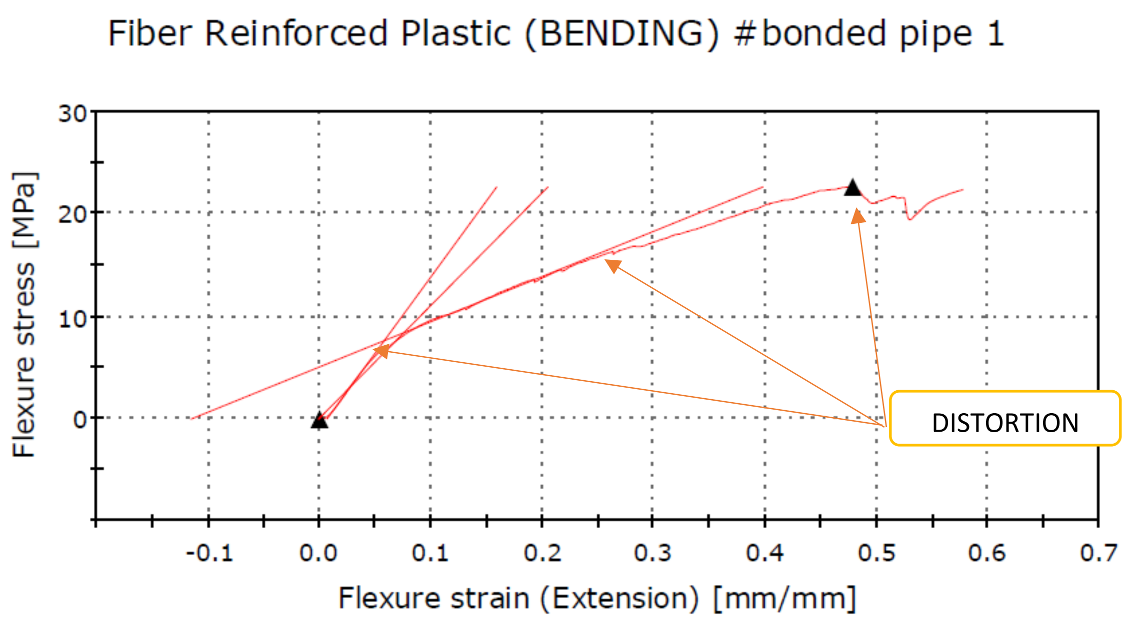


Figure 4.13: Distortion on stress-strain graph

CHAPTER 5

CONCLUSION & RECOMMENDATIONS

The research is pertaining to study on the mechanical properties of FRP pipe. The mechanical properties discussed in the research was focused on tensile and bending strength of the structure. The design, and analysis of the jig has been done which has been manufactured by the company. The analysis on the critical component of the jig has been done which exhibit the safety factor of 1.19 and the component successfully perform and give the aid to grip the pipe during the test without failure. However, there is slippage during the tensile test despite the jig design is according to ASTM D2105. Next, the tensile test has been conducted and some modification has been made to cater the slippage problem during testing. The analysis of the results is stated in the chapter 4. Other than that, bending test was also has been conducted and analyze in order to obtain the bending properties of FRP pipe. The findings of the test was the specimen achieve its breaking point is due to shearing rather than bending because, there is no sufficient bending moment happens to the specimen while testing thus it exhibit shearing stress rather than bending stress.

As for the recommendation, the reinforcing band on the jig component need higher level of friction in order to hold the specimen to a higher tensile force. The surface of the reinforcing band need to be modified in order to achieve high pressure gripping. Also, for future research, the specimen tested in material level rather than structural. For bending test, the length of the specimen need to be increased to gain higher level of bending moment so that the failure is based on bending stress.

REFERENCES

Ahadlin. 2013. Solid Mechanics 2 lecture notes, Chapter 2: Stresses in Thin Walled Pressure Vessel. Universiti Teknikal Malaysia Melaka.

ASTM D3039 14 - Standard Test Method for Tensile Properties of Polymer Matrix Composite Materials, American Society for Testing and Materials

ASTM D2105 01 (14) - Standard Test Method for Longitudinal Tensile Properties of "Fiberglass" (Glass Fiber-Reinforced Thermosetting-Resin) Pipe and Tube, American Society for Testing and Materials

ASTM D3479 12 - Standard Test Method for Tension-Tension Fatigue of Polymer Matrix Composite Materials, American Society for Testing and Materials

Beer, F., DeWolf, J., Johnston Jr, E.R. and Mazurek, D., 2011. Mechanics of materials.

Braiek, S., Zitoune, R., Khalifa, A.B. and Zidi, M., 2017. Experimental and numerical study of adhesively bonded±55° filament wound tubular specimens under uniaxial tensile loading. *Composite Structures*, *172*, pp.297-310.

Carpinteri, A., Fernández-Canteli, A., Fortese, G., Muñiz-Calvente, M., Ronchei, C., Scorza, D. and Vantadori, S., 2017. Probabilistic failure assessment of Fibreglass composites. *Composite Structures*, *160*, pp.1163-1170.

Davis, J.R. ed., 2004. *Tensile testing*. ASM international.

Form EKGS-ES-042-001 This paper last revised June 1998. (1998), (June).

Gashoot, S.R. and Al-Madani, R.A., A survey of GRP Pipes Defects and Damage Due to Fabrication Processes.

Ibrahim, A., Ryu, Y. and Saidpour, M., 2015. Stress analysis of thin-walled pressure vessels. *Modern Mechanical Engineering*, *5*(01), p.1.

ISO 14692-2:2002 - Petroleum and natural gas industry – Glass reinforced plastic (GRP) piping, Part 2 - Qualification and Manufacture, The International Organization for Standardization

ISO 14692-3:2002 - Petroleum and natural gas industry – Glass reinforced plastic (GRP) piping, Part 3 - System Design, The International Organization for Standardization

JPS Pipe, (2015). FRP GRP Pipe Manufacturer and Fitting Company. http://jpspipe.blogspot.my/2015/11/manufacturing-process-of-grp-pipe-jps.html [21 September 2016]

Khalifa, A.B., Zidi, M. and Abdelwahed, L., 2012. Mechanical characterization of glass/vinylester±55° filament wound pipes by acoustic emission under axial monotonic loading. *Comptes Rendus Mecanique*, *340*(6), pp.453-460.

Knox, E.M., Lafferty, S., Cowling, M.J. and Hashim, S.A., 2001. Design guidance and structural integrity of bonded connections in GRE pipes. *Composites Part A: applied science and manufacturing*, *32*(2), pp.231-241.

Laney, P., 2002. Use of composite pipe materials in the transportation of natural gas. *Idaho International Engineering and Environmental Laboratory, Bechtel BWXT Idaho, LLC*.

Materion Brush. 2013. Technical Tidbits: Issue No.53, Fatigue and Stress Ratios

Molded Fiber Glass Companies. (2016). http://www.moldedfiberglass.com/materials/reinforcements [2 September 2016]

Nuplex. (2014). Filament Winding. http://www.nuplex.com/Composites/processes/filamentwinding [21 September 2016]

Paiva, J.M.F.D., Mayer, S. and Rezende, M.C., 2006. Comparison of tensile strength of different carbon fabric reinforced epoxy composites. *Materials Research*, *9*(1), pp.83-90.

Roylance, D. (2008). Mechanical properties of materials

Schmit, K., 2001. Fiberglass Fiberglass Reinforced Plastic (FRP) Piping Systems Column Pipe Applications on Offshore Structures

Schmit, K. and Rouge, B., 1998. Fiberglass Reinforced Plastic (FRP) Piping Systems: Designing process/facilities piping systems with FRP: A comparison to traditional metallic materials. *Specialty Plastics Inc*.

Shigley, J.E., 2011. *Shigley's mechanical engineering design*. Tata McGraw-Hill Education.

Silva, M.A., da Fonseca, B.S. and Biscaia, H., 2014. On estimates of durability of FRP based on accelerated tests. *Composite Structures*, *116*, pp.377-387.

Stefanovska, M., Risteska, S., Samakoski, B., Maneski, G., & Kostadinoska, B. (2015). Composite Pipes, *9*(6), 706–710.

Strongwell. (2016). Continuous Pultrusion. http://www.strongwell.com/about/the-pultrusionprocess/ [21 September 2016]

Tarakçioğlu, N., Gemi, L. and Yapici, A., 2005. Fatigue failure behavior of glass/epoxy±55 filament wound pipes under internal pressure. *Composites Science and Technology*, *65*(3), pp.703-708.

Total Materia. 2010. http://apac.totalmateria.com/page.aspx?ID=CheckArticle&site=kts&LN=NL&NM=282. [15 September 2016]

APPENDIX A

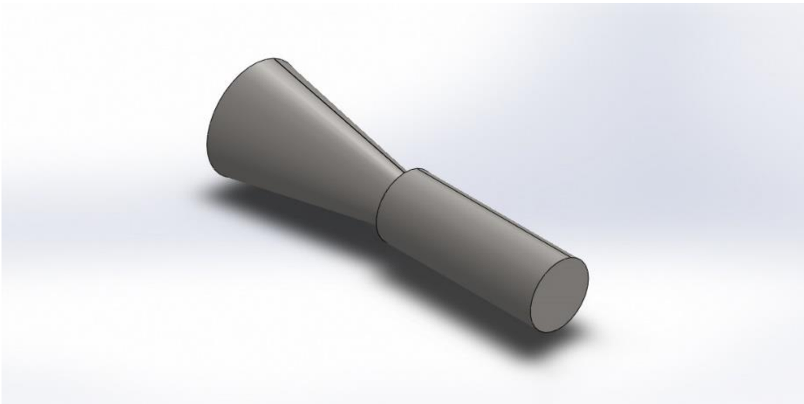
PROJECT PLANNING (GANTT CHART)

List of all the relevant activities of the proposed project and mark the period of time that is needed for each of the activities.

	SEM I																			**SEM BREAK**					**SEM II**															
Aktiviti Projek *Project Activities*	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**	**23**	**24**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**
Literature review																																								
Proposal preparation																																								
Proposal presentation																																								
Design of experiment																																								
Jig design																																								
Report writing														X					**SEMINAR PSM I**																			**SEMINAR PSM II**	**X**	
Presentation preparation																																								
Sample preparation & jig manufacturing																																								
Tensile test																																								
Modification																																								
Bending test																																								

"X" on the Gantt chart for the expected milestones (submission)

APPENDIX B



Simulation of mandrel

Date: Thursday, May 11, 2017
Designer: Naiem Johan
Study name: SimulationXpress Study
Analysis type: Static

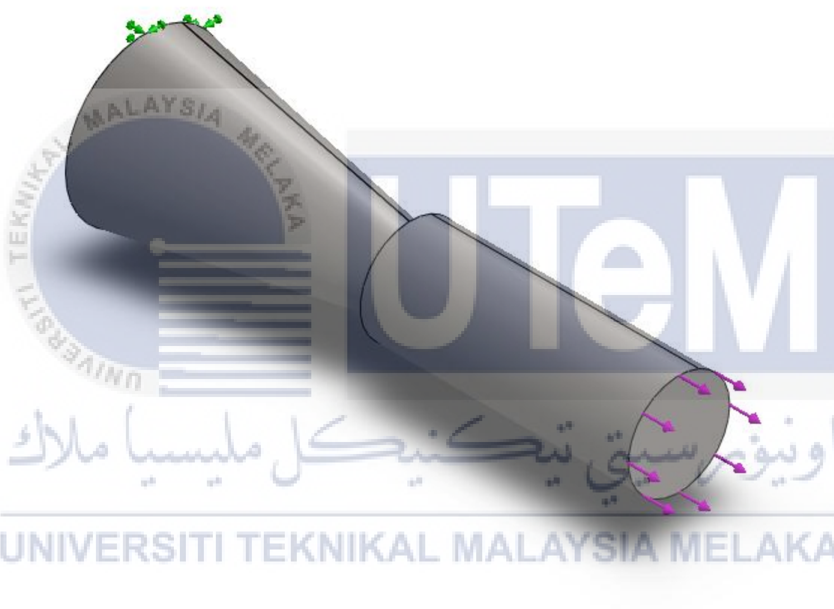
Table of Contents

Description

Mandrel simulation analysis

Assumptions

Model Information

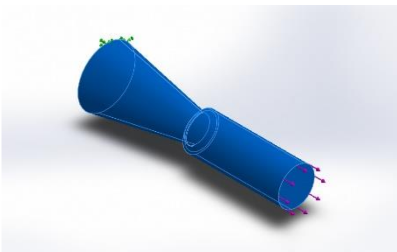


Model name: mandrel
Current Configuration: Default

Solid Bodies

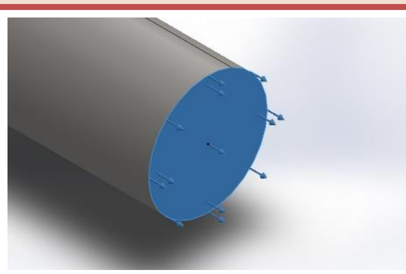
Document Name and Reference	Treated As	Volumetric Properties	Document Path/Date Modified
Fillet1 	Solid Body	Mass:1.50179 kg Volume:0.000190099 m^3 Density:7900 kg/m^3 Weight:14.7175 N	C:\Users\test\Documents\Utem\PSM\drawings\mandrel.SLDPRT Jan 10 16:31:37 2017

Material Properties

Model Reference	Properties	Components
	Name: AISI 1020 Model type: Linear Elastic Isotropic Default failure criterion: Max von Mises Stress Yield strength: 351.571 N/mm^2 Tensile strength: 420.507 N/mm^2	SolidBody 1(Fillet1)(mandrel)

Loads and Fixtures

Fixture name	Fixture Image	Fixture Details
Fixed-2		Entities: 1 face(s) Type: Fixed Geometry

Load name	Load Image	Load Details
Force-2		Entities: 1 face(s) Type: Apply normal force Value: -81138.7 N

Mesh Information

Mesh type	Solid Mesh
Mesher Used:	Curvature based mesh
Jacobian points	4 Points
Maximum element size	0 mm
Minimum element size	0 mm
Mesh Quality	High

Mesh Information - Details

Total Nodes	67107
Total Elements	45933
Maximum Aspect Ratio	4.228
% of elements with Aspect Ratio < 3	99.9
% of elements with Aspect Ratio > 10	0
% of distorted elements(Jacobian)	0
Time to complete mesh(hh;mm;ss):	00:00:04
Computer name:	NAIEMJOHAN

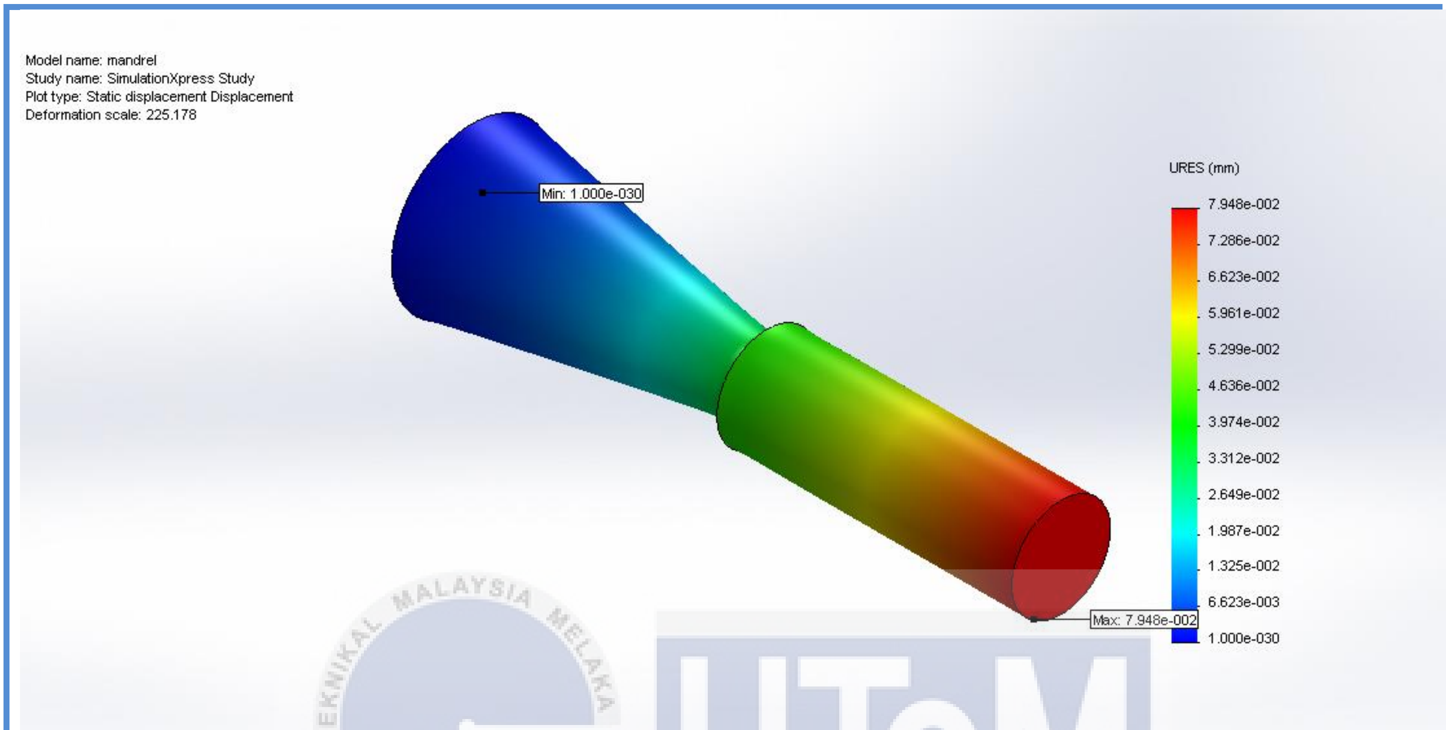

Model name: mandrel
Study name: SimulationXpress Study
Mesh type: Solid mesh

Study Results

Name	Type	Min	Max
Stress	VON: von Mises Stress	15.5571 N/mm^2 (MPa) Node: 76	295.92 N/mm^2 (MPa) Node: 67018

mandrel-SimulationXpress Study-Stress-Stress

Name	Type	Min	Max
Displacement	URES: Resultant Displacement	0 mm Node: 923	0.0794815 mm Node: 66229



mandrel-SimulationXpress Study-Displacement-Displacement

Name	Type
Deformation	Deformed Shape

mandrel-SimulationXpress Study-Displacement-Deformation

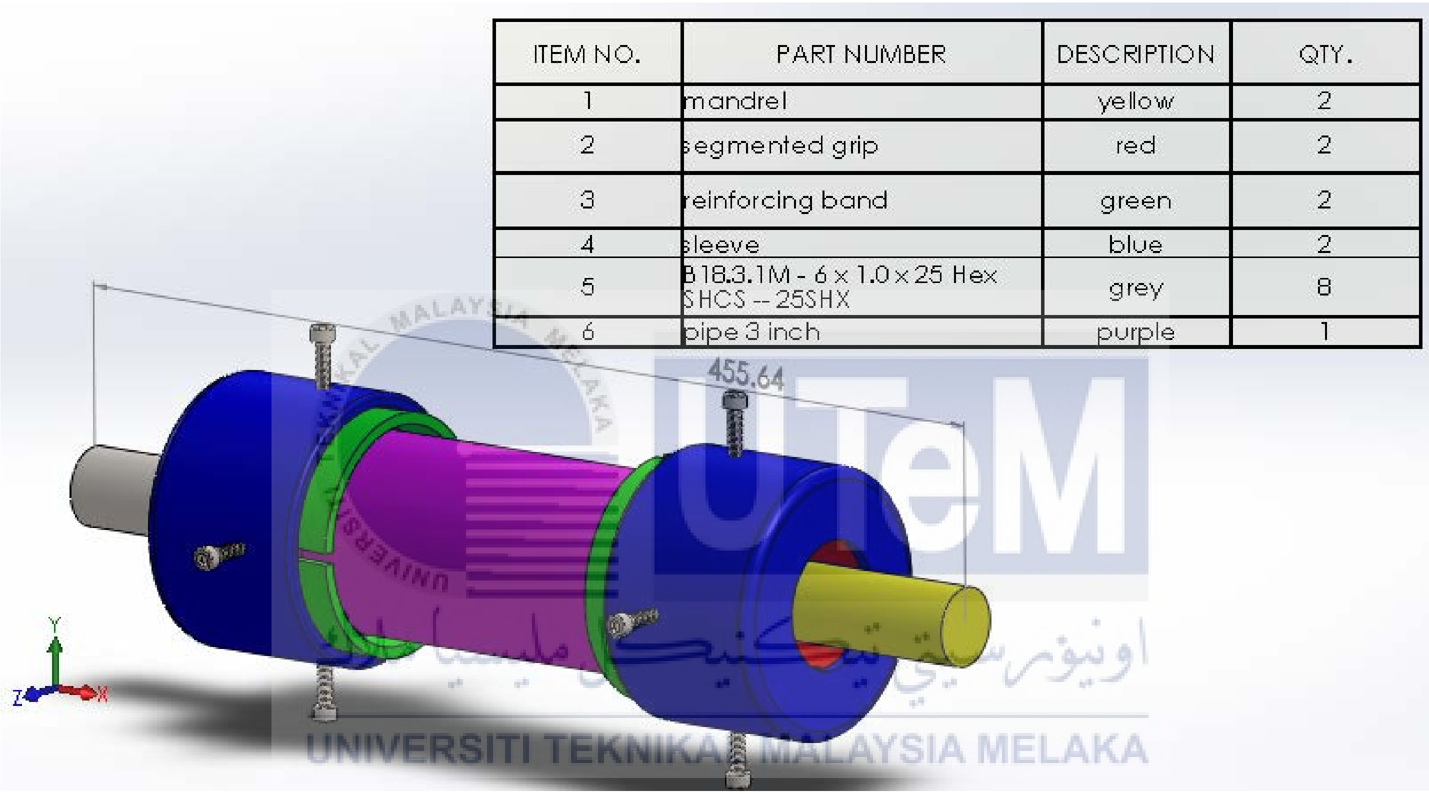
Name	Type	Min	Max
Factor of Safety	Max von Mises Stress	1.18806 Node: 67018	22.5987 Node: 76

mandrel-SimulationXpress Study-Factor of Safety-Factor of Safety

Conclusion

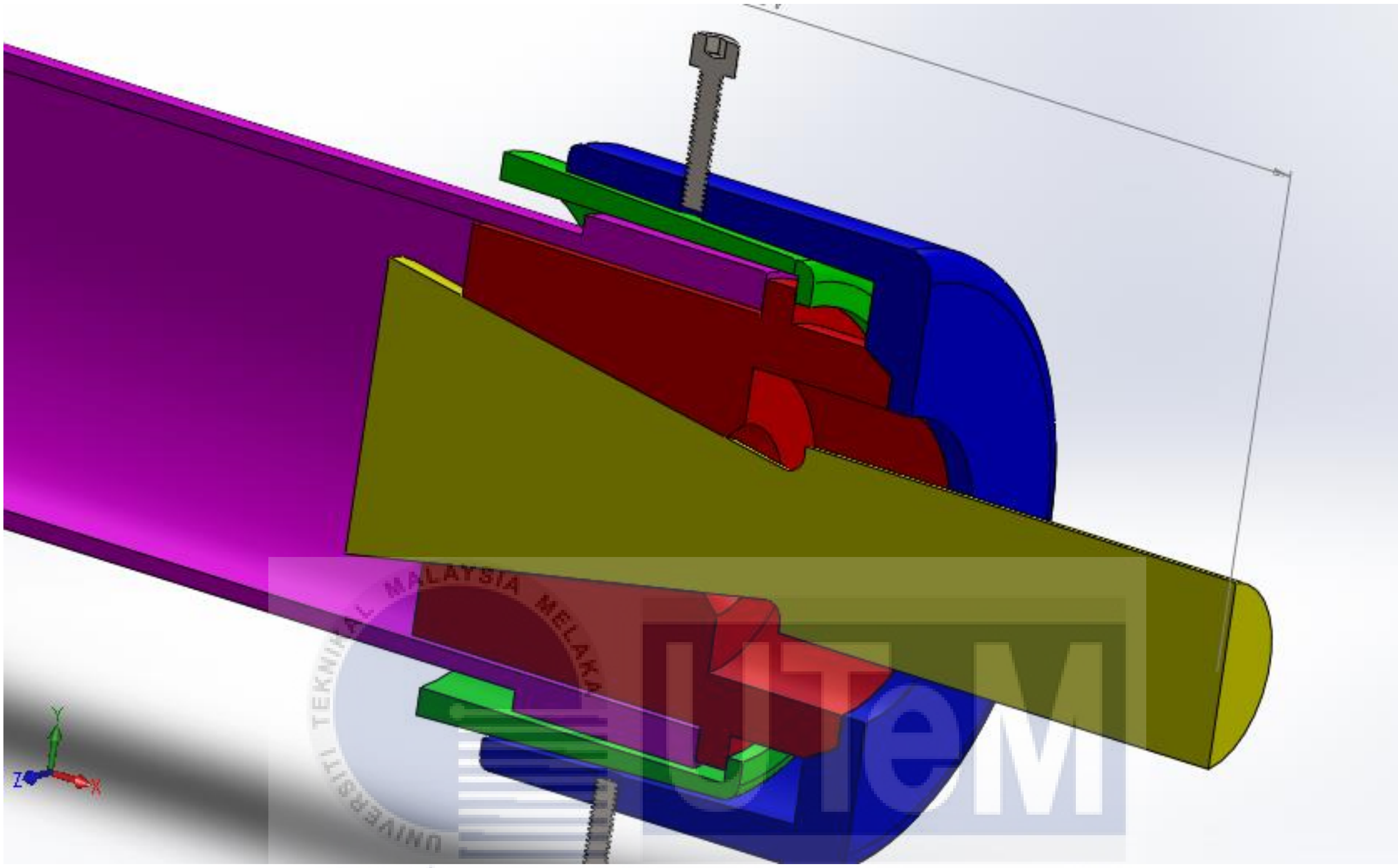
The design and specified material is acceptable for tensile testing FRP piping since the applied force is approximately 81kN which is from the ultimate tensile strength of previous research testing using ASTM D2015 with 80mm ID and 5mm wall thickness. The design and material also have a safety factor of 1.19 and not exceeding the yield point of carbon steel for that specified cross sectional area. For this research, the AISI 1020 carbon steel mandrel is more than enough to accommodate the 3.8 mm wall thickness stress load.

Detail Design

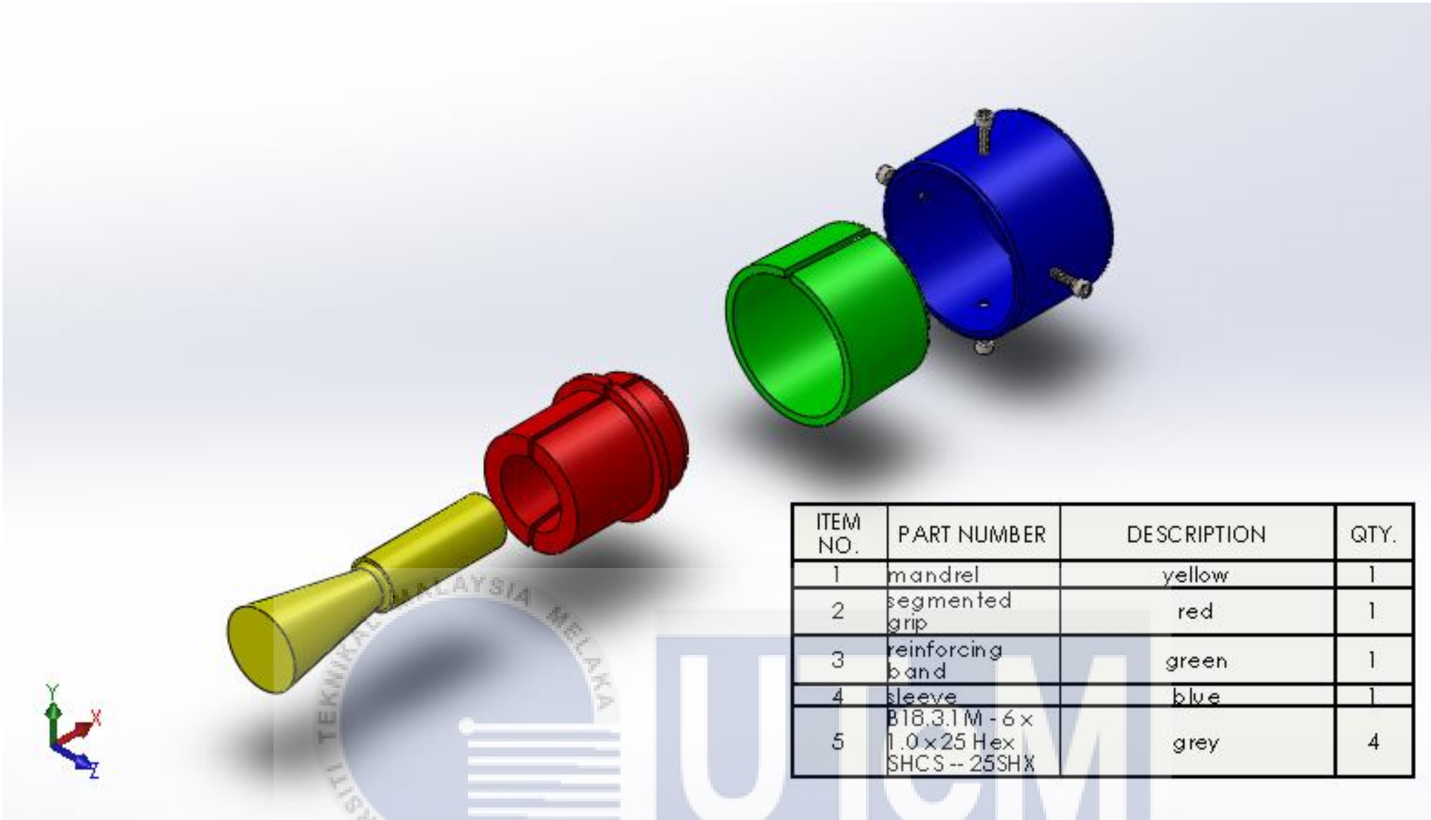


ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	mandrel	yellow	2
2	segmented grip	red	2
3	reinforcing band	green	2
4	sleeve	blue	2
5	B18.3.1M - 6 x 1.0 x 25 Hex SHCS -- 25SHX	grey	8
6	pipe 3 inch	purple	1

Complete assembly of designed jig

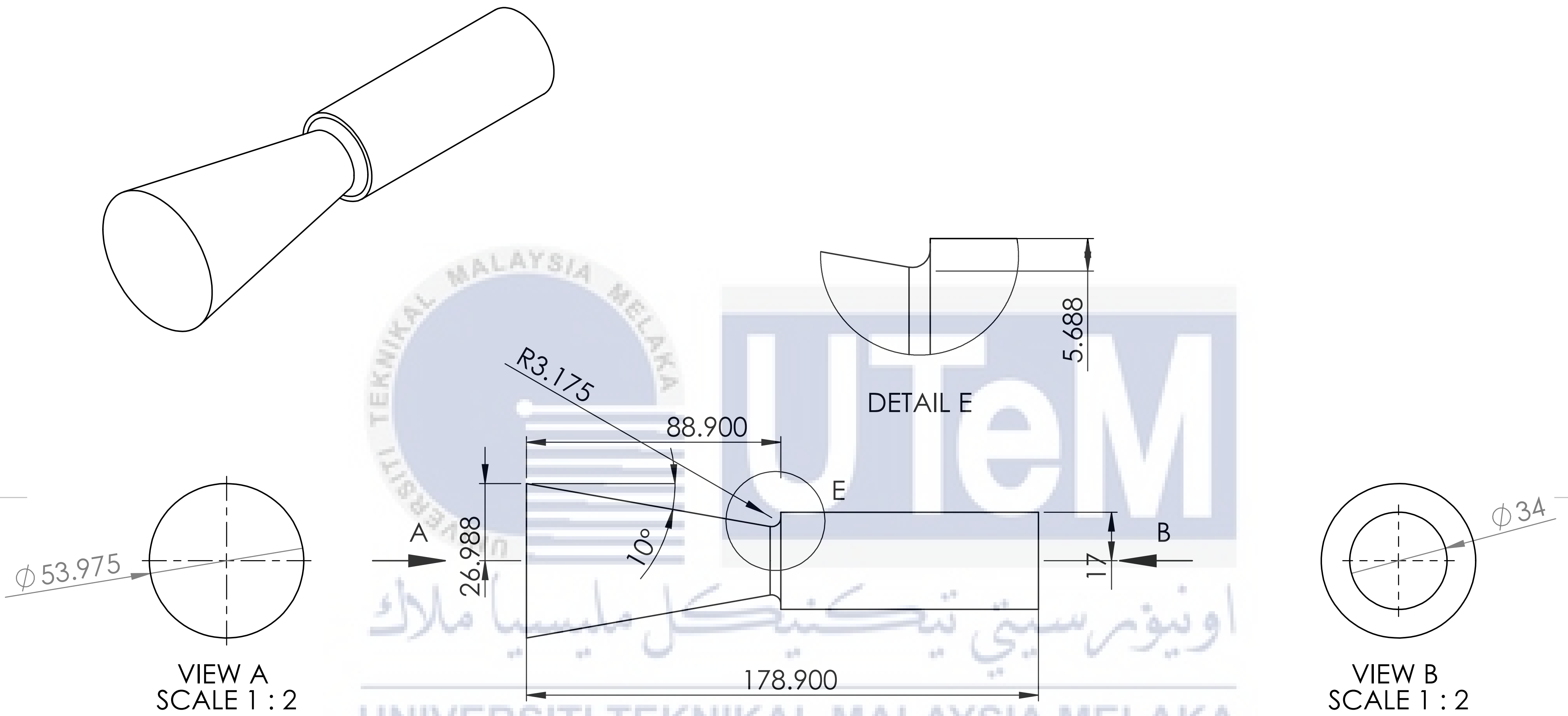


Cross section view



ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	mandrel	yellow	1
2	segmented grip	red	1
3	reinforcing band	green	1
4	sleeve	blue	1
5	B18.3.1M - 6 x 1.0 x 25 Hex SHCS -- 25SHX	grey	4

Exploded view



UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN MILLIMETERS
SURFACE FINISH: NONE
TOLERANCES: 0.1 MM
LINEAR:
ANGULAR:

FINISH:SMOOTH

DEBUR AND BREAK SHARP EDGES

DO NOT SCALE DRAWING

REVISION 1

	NAME	SIGNATURE	DATE
DRAWN	NAIEM JOHAN		9/1/2017
CHK'D			
APPV'D			
MFG			
Q.A			

MATERIAL: CARBON STEEL

WEIGHT:

TITLE: JIG DESIGN FOR 3 INCH FRP PIPE (ASTM D2105)

yellow

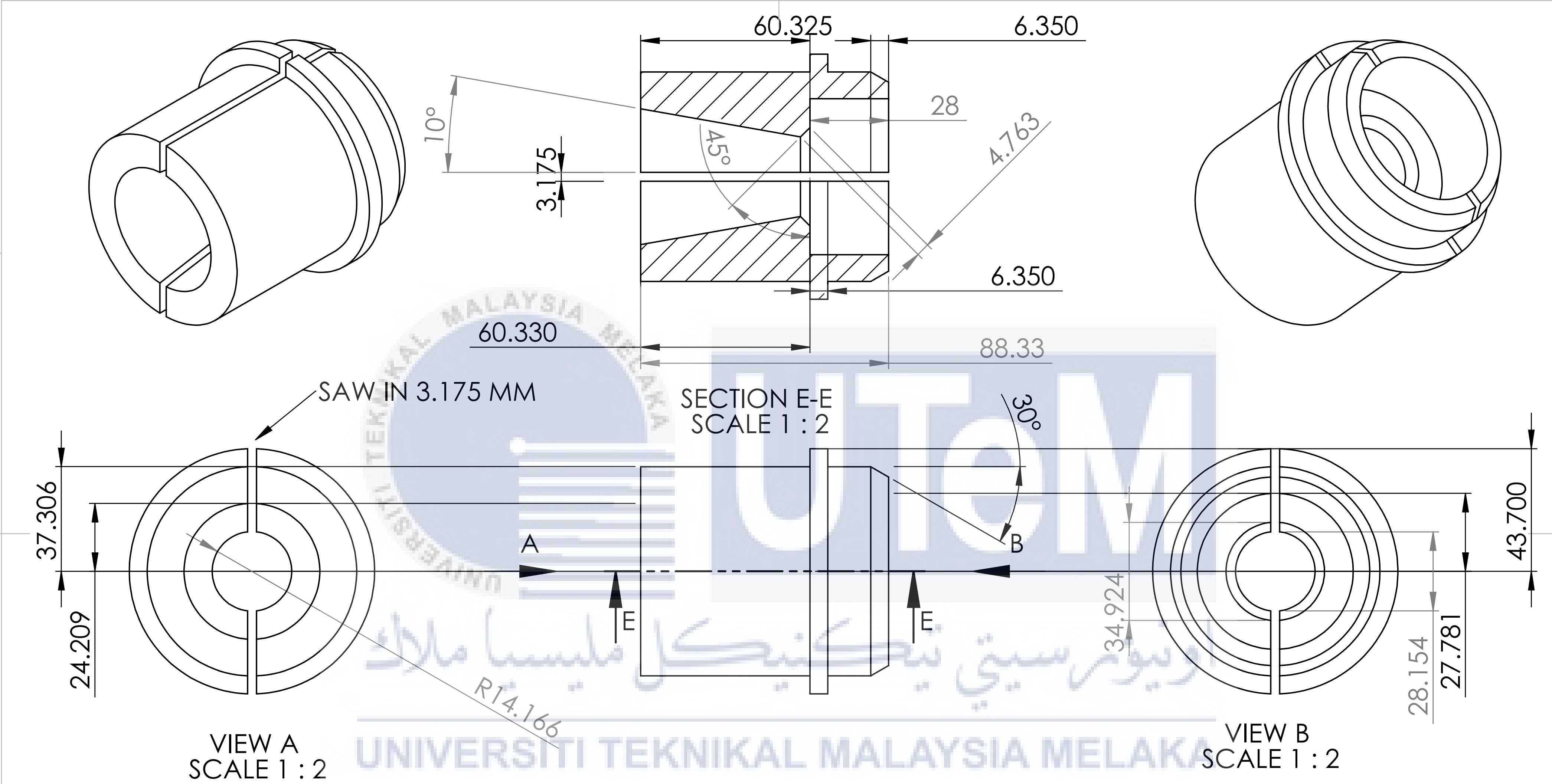
DWG NO.

mandrel

A4

SCALE:1:2

SHEET 1 OF 4



UNLESS OTHERWISE SPECIFIED: DIMENSIONS ARE IN MILLIMETERS SURFACE FINISH: NONE TOLERANCES: 0.1 MM LINEAR: ANGULAR:	FINISH:	DEBUR AND BREAK SHARP EDGES	DO NOT SCALE DRAWING	REVISION

	NAME	SIGNATURE	DATE
DRAWN	NAIEM JOHAN		9/1/2017
CHK'D			
APPV'D			
MFG			
Q.A			

MATERIAL: CARBON STEEL

WEIGHT:

TITLE: JIG DESIGN FOR 3 INCH FRP PIPE (ASTM D2105)

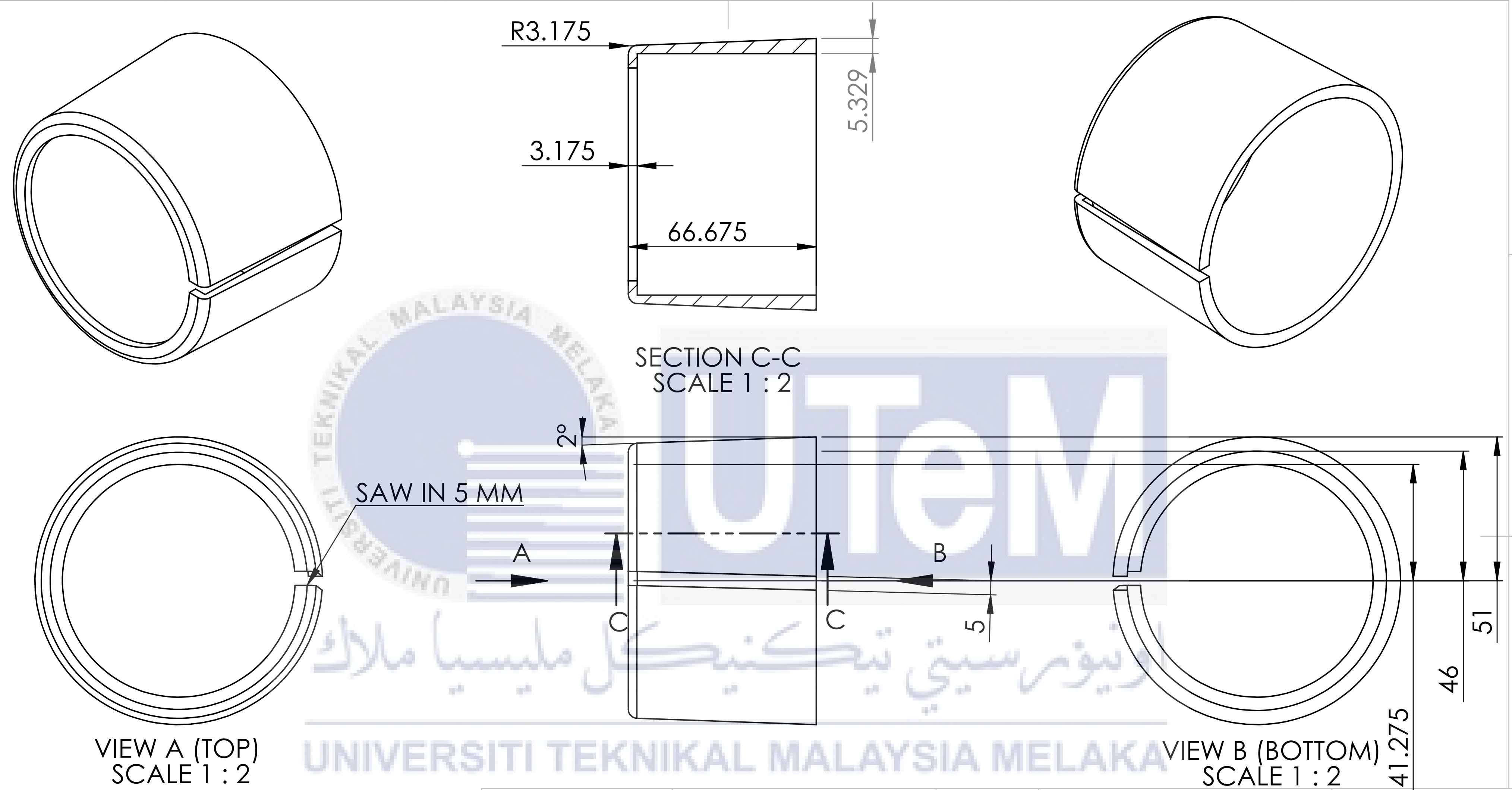
red

DWG NO. segmented grip

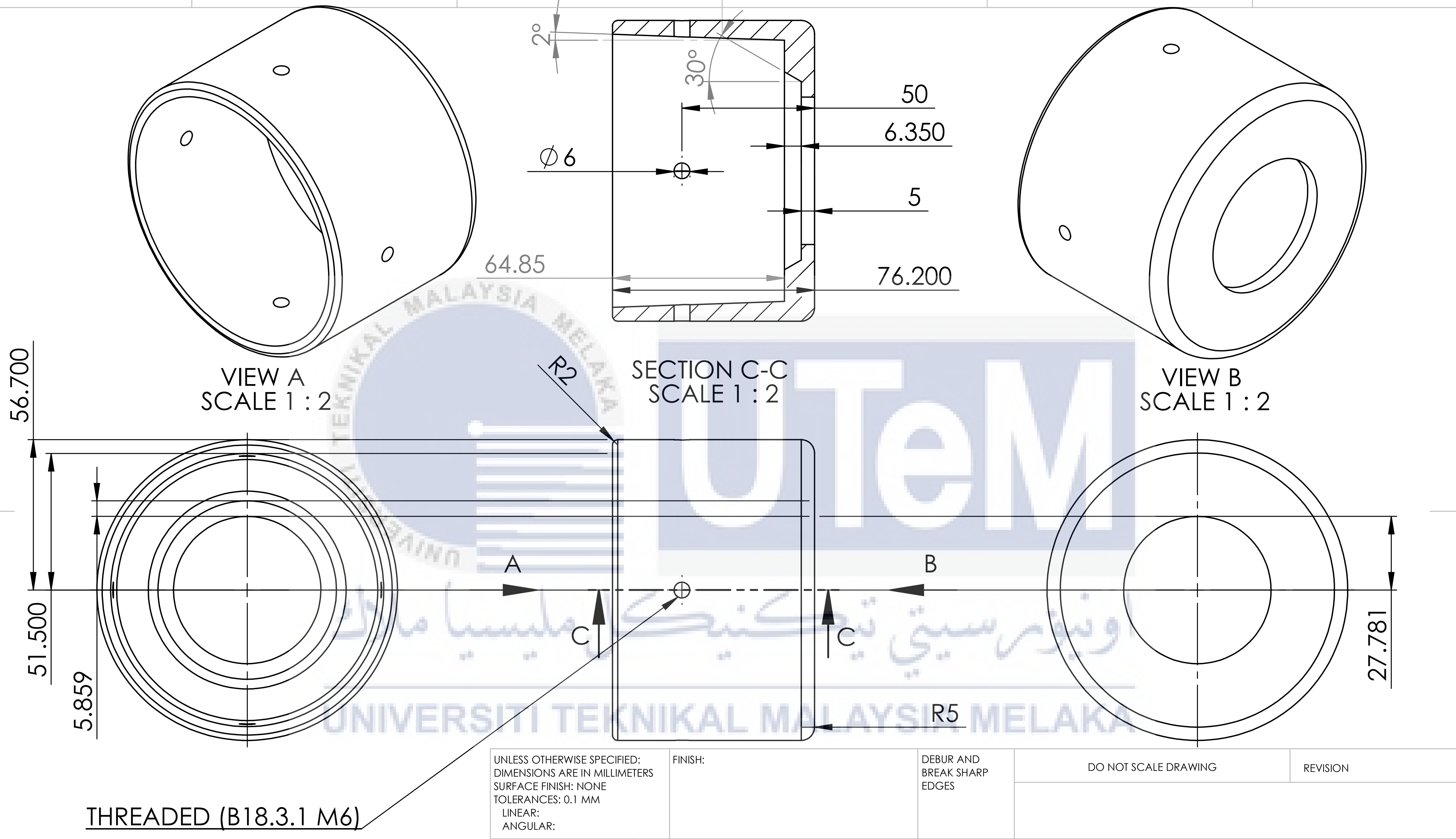
A4

SCALE: 1:2

SHEET 2 OF 4



UNLESS OTHERWISE SPECIFIED: DIMENSIONS ARE IN MILLIMETERS SURFACE FINISH: NONE TOLERANCES: 0.1 MM LINEAR: ANGULAR:		FINISH: ROUGH SURFACE INNER RING		DEBUR AND BREAK SHARP EDGES	DO NOT SCALE DRAWING	REVISION
	NAME	SIGNATURE	DATE		TITLE: JIG DESIGN FOR 3 INCH FRP PIPE (ASTM D2105)	
DRAWN	NAIEM JOHAN		9/1/2017		green	
CHK'D						
APPV'D						
MFG						
Q.A				MATERIAL: CARBON STEEL	DWG NO. reinforcing band	A4
				WEIGHT:	SCALE:1:2	SHEET 3 OF 4

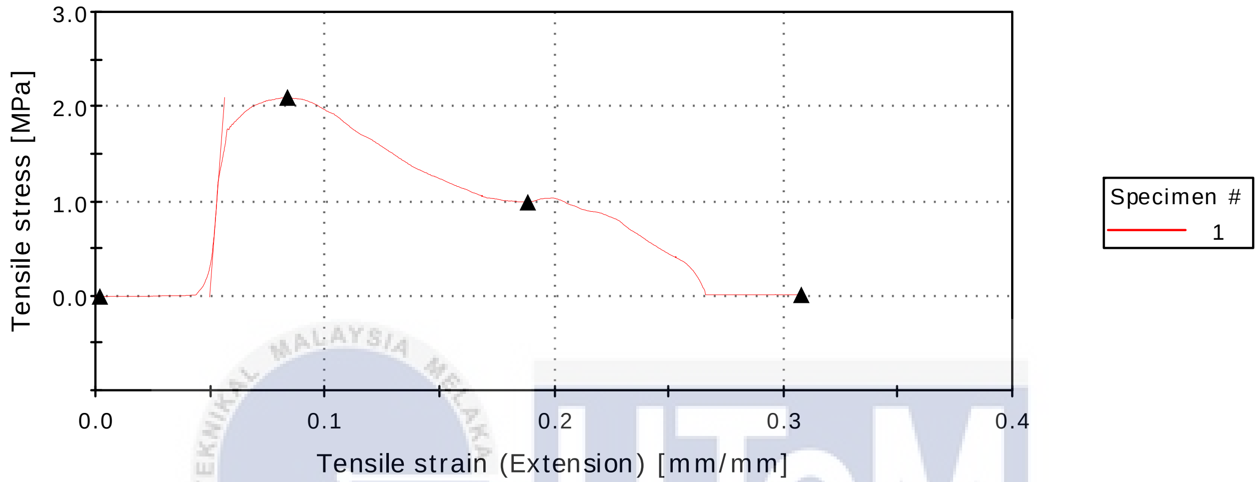


UNLESS OTHERWISE SPECIFIED: DIMENSIONS ARE IN MILLIMETERS SURFACE FINISH: NONE TOLERANCES: 0.1 MM LINEAR: ANGULAR:	FINISH:		DEBUR AND BREAK SHARP EDGES	DO NOT SCALE DRAWING	REVISION
	NAME	SIGNATURE	DATE	TITLE: JIG DESIGN FOR 3 INCH FRP PIPE (ASTM D2105)	
DRAWN	NAIEM JOHAN		9/1/2017	blue	
CHK'D					
APPV'D					
MFG					
Q.A			MATERIAL: CARBON STEEL	DWG NO. sleeve	A4
			WEIGHT:	SCALE:1:2	SHEET 4 OF 4

APPENDIX C

Fiber Glass Reinforced Plastic

STRESS VS STRAIN (FRP PIPE * STANDARD)

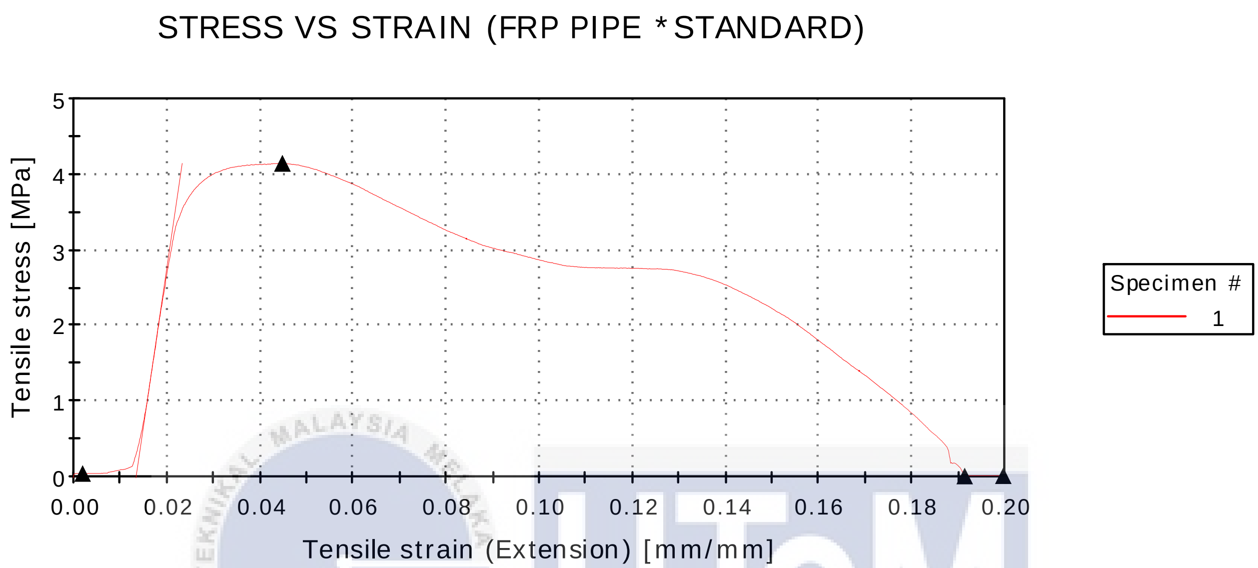


	Maximum Load [kN]	Tensile stress at Maximum Load [MPa]	Tensile strain (Extension) at Maximum Load [mm/mm]	Load at Yield (Zero slope) [kN]
1	3.824	2.096	0.084	3.824

	Tensile stress at Yield (Zero slope) [MPa]	Load at Yield (EUL yield) [kN]	Tensile stress at Yield (EUL yield) [MPa]	Modulus (Automatic) [GPa]
1	2.096	0.007	0.004	0.189

	Modulus (E-modulus) [GPa]
1	-----

Fiber Glass Reinforced Plastic

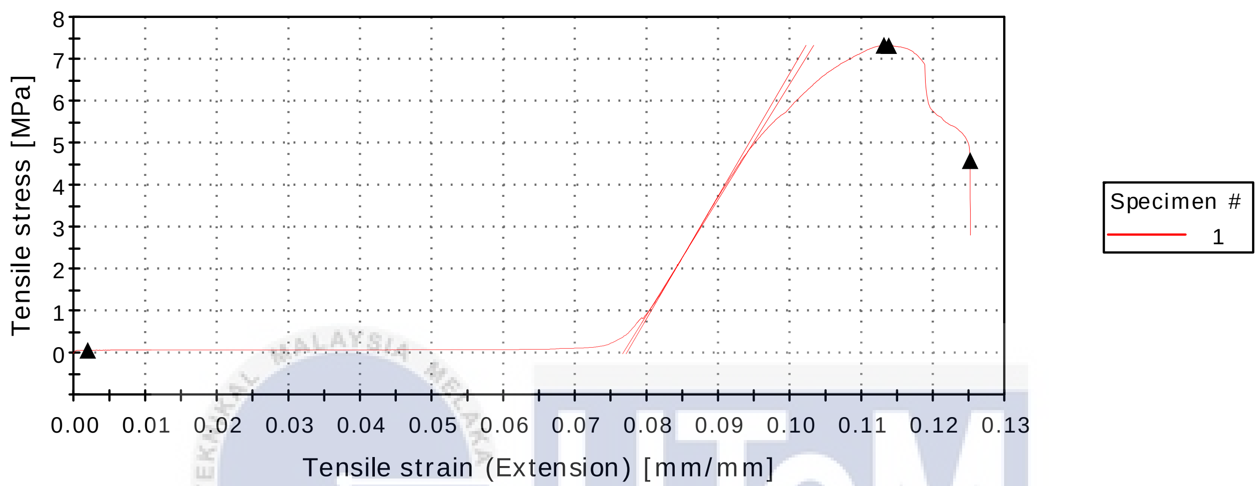


	Maximum Load [kN]	Tensile stress at Maximum Load [MPa]	Tensile strain (Extension) at Maximum Load [mm/mm]	Load at Yield (Zero slope) [kN]
1	7.553	4.141	0.045	7.553

	Tensile stress at Yield (Zero slope) [MPa]	Load at Yield (EUL yield) [kN]	Tensile stress at Yield (EUL yield) [MPa]	Modulus (Automatic) [GPa]
1	4.141	0.105	0.057	0.389

	Modulus (E-modulus) [GPa]
1	-----

Fiber Glass Reinforced Plastic



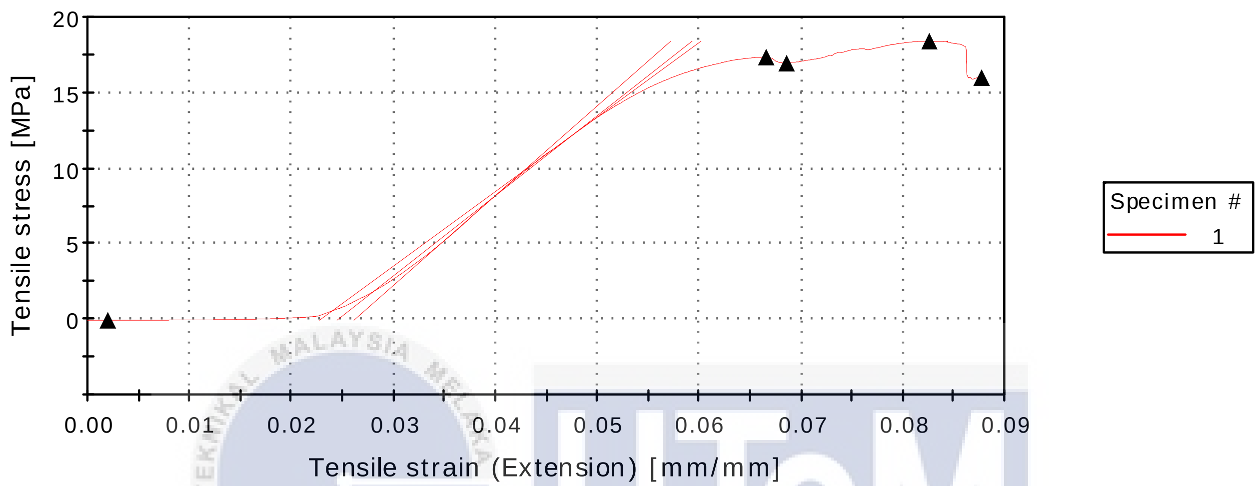
	Maximum Load [kN]	Tensile stress at Maximum Load [MPa]	Tensile strain (Extension) at Maximum Load [mm/mm]	Load at Yield (Zero slope) [kN]
1	13.345	7.316	0.113	13.345

	Tensile stress at Yield (Zero slope) [MPa]	Load at Yield (EUL yield) [kN]	Tensile stress at Yield (EUL yield) [MPa]	Modulus (Automatic) [GPa]
1	7.316	0.158	0.087	0.285

	Modulus (E-modulus) [GPa]
1	-----

Fiber Glass Reinforced Plastic

STRESS VS STRAIN (FRP PIPE *STANDARD) A2



	Maximum Load [kN]	Tensile stress at Maximum Load [MPa]	Tensile strain (Extension) at Maximum Load [mm/mm]	Load at Yield (Zero slope) [kN]
1	33.535	18.384	0.082	31.583

	Tensile stress at Yield (Zero slope) [MPa]	Load at Yield (EUL yield) [kN]	Tensile stress at Yield (EUL yield) [MPa]	Modulus (Automatic) [GPa]
1	17.314	0.002	0.001	0.568

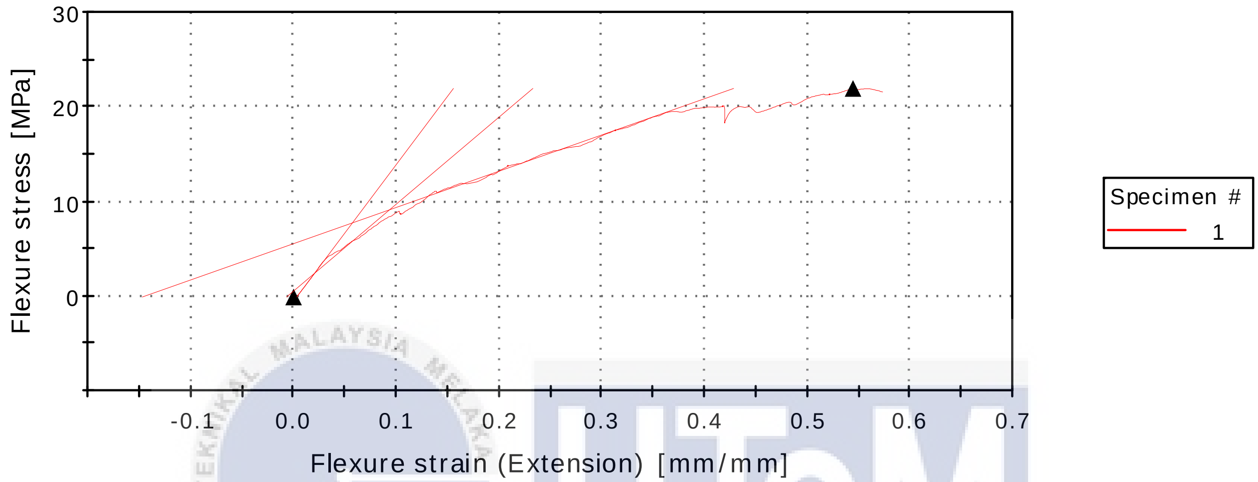
	Modulus (E-modulus) [GPa]
1	0.492

APPENDIX D

Fiber Reinforced Plastic (BENDING) #plain pipe

Fiber Reinforced Plastic (BENDING) #plain pipe

Fiber Reinforced Plastic (BENDING) #plain pipe 1



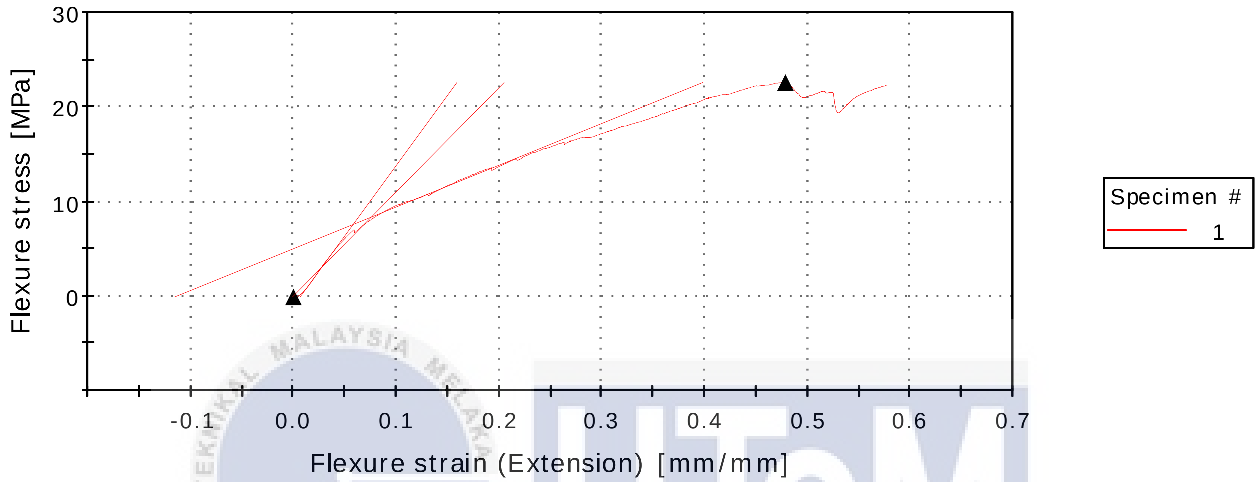
	Maximum Load [N]	Flexure stress at Maximum Load [MPa]	Modulus (Automatic) [MPa]	Load at Yield (Zero slope) [N]
1	25321.953	21.899	91.538	23233.559

	Flexure stress at Yield (Zero slope) [MPa]
1	20.093

Fiber Reinforced Plastic (BENDING) #plain pipe

Fiber Reinforced Plastic (BENDING) #plain pipe

Fiber Reinforced Plastic (BENDING) #bonded pipe 1



	Maximum Load [N]	Flexure stress at Maximum Load [MPa]	Modulus (Automatic) [MPa]	Load at Yield (Zero slope) [N]
1	56130.086	22.552	109.711	56130.086

	Flexure stress at Yield (Zero slope) [MPa]
1	22.552