CHAPTER 1

1.0 INTRODUCTION

1.1 Background of Study

Composites are replacing several traditional materials due to their superior properties such as high strength to weight ratio, high stiffness to weight ratio, better impact characteristics, corrosion resistance and design flexibility. Since oil and gas industry has slowly strives towards more challenging environment like deepwater exploration and production activities, the use of advanced and more efficient materials are needed to cope up with the challenges faced by oil operators. From the field experiences, composite have proved to be advantageous in selected application in the industry, i.e. composite riser and particularly in the upstream sector (well drilling and completion). These proved that there is an increasing need for improved materials which can demonstrate significant property enhancement over and above those which already available.

1.2 Problem Statement

Composite pup joint may offer high strength and superior corrosion resistance properties compared to conventional metallic (low alloy steel) pup joint material. However, mechanical properties of fiberglass polyester pup joint are not fully established and the present data may be inadequate to make its introduction into well completion. Research is required to resolve these deficiencies which are an encumbrance to possible application of glass fiber reinforced polyester composite pup joint into oil and gas well completion string.

1.2.1 Problem Identification

Conventional low alloy steel pup joint is easily corroded (Figure 1.1) when expose to corrosive surrounding. With that, the pup joint cannot sustain for longer lifetime performance in the well because the corrosion can easily affect their tensile strength. Besides, lengthy completion string lead to high tensile loads which can also leads to yielding of pup joint. On the other hand, pup joint made of low alloy steel is also very heavy compared to composite. Hoisting capacity issue is concerned at the well completion stage and with this, high strength and lighter pup joint/tubing is needed in today oil and gas industry.

Figure 1.1: Corroded low alloy steel pup joint

1.2.2 Significant of the Project

The development of composite pup joint can provide significant improvement in tensile strength and stiffness over conventional pup joint. Tubing/pup joint failure pose greater risk and cost as the well go deeper and deeper. Apart from that, glass reinforced polyester pup joint presents possible solution and option for operators to deploy into oilfield. In addition, economic gain of using composite pup joint may present compared to metallic pup joint, in the manner of weight saving, absence of corrosion which make possible weight reduction and overall oil and gas exploration project cost savings. Hence, this project is important to find the mechanical properties of fiberglass reinforced polyester pup joint in well completion application.

1.3 Objectives

The objectives of this Final Year Project are:

1. To study the feasibility for fiberglass reinforced polyester to replace conventional low alloy steel used in pup joint application.
2. To determine the mechanical properties, such as fiber volume fraction (FVF), hardness, threading possibility and tensile strength of the fabricated fiberglass pipe with reference to appropriate standards.

1.4 Scope of Study

Three mechanical properties will be focused in this project: fiber volume fraction, hardness and most importantly tensile strength of composite pup joint. Tensile strength will be calculated first using the theories and verified by conducting mechanical test on the fabricated composite pipe. FVF and hardness will be determined by conducting mechanical tests using appropriate testing procedures specified in the reference standards. With these, the scope is specified to maintain the feasibility of this project.

CHAPTER 2

2.0 LITERATURE REVIEW

2.1 Conventional Pup Joint Material

For tubing and pup joint, we will refer to API 5 CT Standard, which is Specification for Casing and Tubing (U.S. Customary) that currently follow by the oil industry. The most widely used material for tubing and pup joint is L80 steel, with *9.2 pounds per feet* for *3 ½ inch OD* tubular. The chemical composition of L80 steel is clearly shown in Table 2.1.

Table 2.1: Chemical requirement of L80 alloy steel

	Chemical Requirement (by percentage of weight)								
	C	Si	Mn	P	S	Cu	Ni	Cr	Mo
Max	0.43	0.45	1.9	0.030	0.030	0.35	0.25	-	-

Courtesy of American Petroleum Institute

Table 2.1 represents the chemical composition of the L80 pup joint referring to API 5CT Standard, Group 2, L80, Type 1, Tubing, 6^{th} Edition 1999 (PE). According to definition of API (1999), " Steel made to a fine grain practice containing one or more grain refining element intended to result in the steel having a fine austenitic grain size" (p.6). According to this standard (appendix 1), L80 alloy steel pipe shall be manufactured by seamless or electric weld, quenched and tempered heat treatment at 1050^{o}F.

2.2 Mechanical Test for L80 Pup Joint in Real Industry

Taking a real industrial example, the mechanical properties taken from the inspection certificate of seamless L80 alloy steel plain end tubing from JFE Steel Corporation Japan in appendix 2 are shown in Table 2.2. JFE Steel Corporation is one of the companies that manufacture and supply the pup joints to Halliburton.

Table 2.2: Industrial test results on L80 alloy steel

Type of Test	Specification	Results
1. Hydrostatic test	9300 psi (64.12 MPa)	*Good*
2. Hardness test	Max: 23 HRC	*18.2 HRC*
3. Yield Strength	Max: 95 ksi (655 MPa) ; Min: 80 ksi (551.58 MPa)	*88 ksi (606.74 MPa)*
4. Tensile Strength	Min: 95 ksi (655 MPa)	*100.1 ksi (690.17 MPa)*
5. Percent Elongation	Min: 20%	*46.5%*

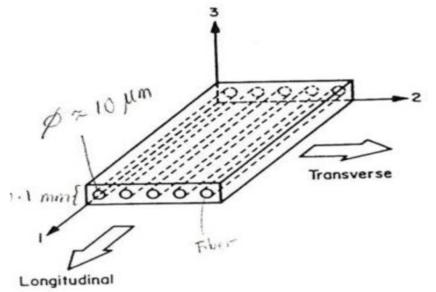
Courtesy of JFE Steel Corporation Japan

Besides from the tests above, the company also constructs bend test, drift test and impact test on L80 alloy steel pipe.

2.3 Unidirectional Composite

A first study of properties and behavior of unidirectional composite is important in this project because a single layer composite represent a basic building block for any composite structural element. The behavior of unidirectional composite will be explained according to fundamental theories stated by Bhagwan D. Agarwal (2005).

Unidirectional composite consists of parallel fibers embedded in a matrix. Figure 2.1 represent a schematic on unidirectional composite. The direction parallel to fibers is generally called *longitudinal direction* (axis 1), perpendicular to fibers or referred to as the material axes is called *transverse direction* (any direction in 2-3 plane). This type of composite has the strongest properties in the longitudinal direction, and material behavior in the other two direction (2,3) is nearly identical.



Courtesy of Bhagwan (2005)

Figure 2.1: Schematic of unidirectional composite

2.3.1 Volume and Weight Fraction

Volume fractions are exclusively used in the theoretical analysis of composite but weight fractions are easier to obtain during fabrication or experimental method. Thus it is desirable to determine the conversion between these two fractions. The volume fraction is defined as follows:

$$V_f = \frac{v_f}{v_c} \qquad V_m = \frac{v_m}{v_c}$$

where *V*= volume fraction and throughout this report, the subscripts c, f and m represent composite material, fibers and matrix, respectively.

2.4 Longitudinal Strength and Stiffness

According to Bhagwan (2005), the mathematical model for studying some of the longitudinal properties of unidirectional composite can be considered as accurate. The behavior prediction for this composite is presented below.

2.4.1 Initial Elastic Behavior

According to Bhagwan (2005), the stress of composite is,

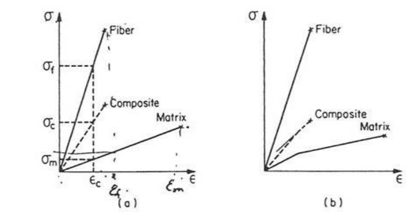
$$\sigma_c = \sigma_f V_f + \sigma_m V_m$$

After integration, *rules of mixture* can be found, with *E* represent the elastic modulus,

$$E_c = E_f V_f + E_m V_m$$

The calculations have shown that the fibers are effective in increasing composite's modulus particularly in the longitudinal direction. This means that elastic modulus of fibers can influence the composite's modulus. This prediction is quite accurate when only tensile load is applied.

Besides, he also shown that the composite stress-strain curves would lie between the stress-strain curves of fibers and matrix, this is represented in Figure 2.2 below.



Courtesy of Bhagwan (2005)

Figure 2.2: Longitudinal stress-strain curve for (a) linear matrix composite and (b) nonlinear matrix composite

After observation, we can see that composite stress-strain curve will depend on the relative volume fractions of the constituents. If volume fraction of fiber is high, the composite curve will be closer to fiber curve. In addition, the assumption of linearly elastic stress-strain curve for polymeric matrices will not cause large error in predicted composite stress values.

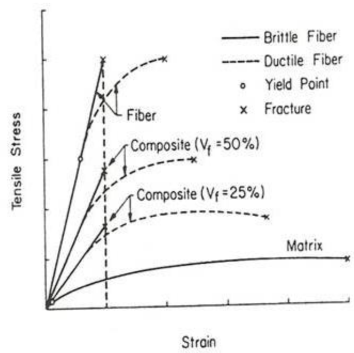
For better understanding, we use some values in the explanation. Although the maximum volume percent of cylindrical fibers in a composite can be almost 91%, above 80% the composite property will usually begin to decrease because of poorly bonded fibers and voids in composite.

2.4.2 Beyond Initial Deformation Behavior

Bhagwan (2005) defines the four stages of deformation for composite in general:

1. Both fiber and matrix in linear elastic deformation
2. Fiber continue elastic deformation, matrix now will plastically deform
3. Both fiber and matrix now deform plastically
4. The fiber fracture and followed by composite fracture

The stress-strain curve will again fall between the curve for fiber and matrix, regarding of using ductile or brittle fiber, this behavior is shown in Figure 2.3. We also can observe that the fracture strain of composite may exceed fiber strain. The difference between two fracture strains increases as fiber strength ratio increases.



Courtesy of Bhagwan (2005)

Figure 2.3: Stress-strain curve for composite with ductile or brittle fibers

2.4.3 Influencing Factor

It is necessary to understand the influencing factors that affect the strength and stiffness because corrections may be needed in the situations stated below:

1. Misorientation of fibers: strength and stiffness may be reduced if high numbers of fibers are not parallel to the loading direction because the contribution of the fibers to the composite property is maximum when they are parallel to the loading direction.
2. Non uniform fiber strength: a high strength composite will be obtained when all the fibers are uniform in their strength values. A longer chain has a higher probability of having a very weak link, thus long fibers have smaller strength.
3. Discontinuous fibers: fibers end can cause stress concentration in which this will cause fibers ends become separated from the matrix at a very small load, thus producing microcrack in the matrix.
4. Interfacial conditions: when strong bond exists between fiber and matrix phases, the crack does not propagate along the length of the fiber, thus fiber reinforcement remains effective and this strong bonding is also essential for higher transverse strength and for good composite environmental performance.

5. Residual stress: this stress is cause by the difference in the coefficient of thermal expansion of the constituents and very much influence by the fabrication temperatures.

2.5 Material Properties for Fiberglass Polyester

Composite consist of reinforcing fiber and matrix material. According to Sanjay (2001), matrix surrounds the fibers and thus protects those fibers against chemical and environmental attack. For fiber to carry maximum load, the matrix must have a lower modulus and greater elongation then the reinforcement. The matrix determines the service operating temperature of composite as well as processing parameter for part manufacturing. Therefore, a detail studies especially for the matrix phase is very important in substituting a conventional material with composite material.

2.5.1 Polyester Matrix

According to Owen (2000), unsaturated polyester resins are often used to make thermoset FRP. Polyester is esters of dibasic organic acids and dihydric glycols that form long chain molecules when reacted together. Unsaturated polyester can be induced to cross-link and solidify by prolonged heating. They tend to be unstable and cross-link slowly even at room temperature. They cross-link more readily through a cross-link agent such as styrene. Styrene is blended with the resin to control the viscosity. Styrene blending takes place at elevated temperature and an inhibitor such as hydroquinone is added in small quantities to slow down cross-linking of basic resins. Commercial resins are not pure. They have a range of molecular weights that result in some variation of properties. For the room temperature curing the most common catalyst is MEKP. According to Sanjay (2001), the maximum continuous-use temperature of polyester thermoset resins are from 60 to 150 ^{o}C. The transition temperature for polyester is from 75 to 150 ^{o}C.

2.5.2 Glass Fiber

According to Owen (2000), glass fibers are produced by melting the raw materials or re-melting broken glass or glass marbles and allowing the molten glass to flow by gravity at controlled temperature through the bottom of a platinum/rhodium bushing containing an array of holes. The emerging beads of glass are drawn down and picked up on a rotating collect and are so drawn into fine fibers. This results in a bundle or strand of parallel single filaments being wrapped on the collect, usually on a paper sleeve. The diameter of the filaments is usually in the range 8-25 μm with the typical product being 17μm diameter. The choice of filament diameter is based on economics – the cost of operating fiber production plant. R-glass will have slightly higher modulus and strength than E-glass. R-glass also finds application in aerospace industry.

2.6 Composite Manufacturing Process

There are three composite manufacturing process highlighted here because they are common technique used and is applicable to the pup joint fabrication. Hand lay up, centrifugal casting and filament winding method are explained in details.

2.6.1 Hand Lay Up Technique

Hand lay-up technique is the simplest and oldest open molding method of the composite fabrication processes. It is a low volume, labor intensive method suited especially for large components, such as boat hulls. Glass or other reinforcing mat or woven fabric or roving is positioned manually in the open mold, and resin is poured, brushed, or sprayed over and into the glass plies. Entrapped air is removed manually with squeegees or rollers to complete the laminates structure. Room temperature curing polyesters and epoxies are the most commonly used matrix resins. Curing is initiated by a catalyst in the resin system, which hardens the fiber reinforced resin composite without external heat. For a high quality part surface, a pigmented gel coat is first applied to the mold surface. According to Matthews and Rawlings (1999), the main disadvantages of this method are the low reinforcement content of about 30 vol % and the difficulty in removing all the trapped air, hence the mechanical properties are in fair to good region.

2.6.2 Centrifugal Molding

According to Daniel & Suong (2003), this process is used for fabrication of tubes. The tube will have homogeneous distribution of resin with good surface condition, especially the internal surface of the tube produced. Rate of production varies with different tube diameter and length. Normally, the rate is up to 500kg of composite per day.

2.6.3 Filament Winding

This is a process of manufacturing designated for fiber reinforced composite. Normally, this technique is used to fabricate composite tubular structures, such as pipes, storage tanks and pressure vessels. In this project, pup joint is considered as a pipe or tubular, therefore this technique is most suitable to be employed to fabricate composite pup joint in an economical way.

2.6.3.1 Process

According to Sanjay (2001), resin-impregnated fibers are wound over a rotating mandrel at the desired angle. A typical filament winding process is shown in Figure 2.4, in which a carriage unit moves in transverse direction and the mandrel rotate at specified speed. By controlling the motion of the carriage unit and the mandrel, the desired angle is generated. Three types of common winding pattern is normally followed by the industries, which are hoop, helical and longitudinal direction. They are shown in Figure 2.5. This process can be automated for making tubular products in a cost-effective manner. Some common products produced by this process are tubular structure, pressure vessel, pipes, storage tanks and tubes.

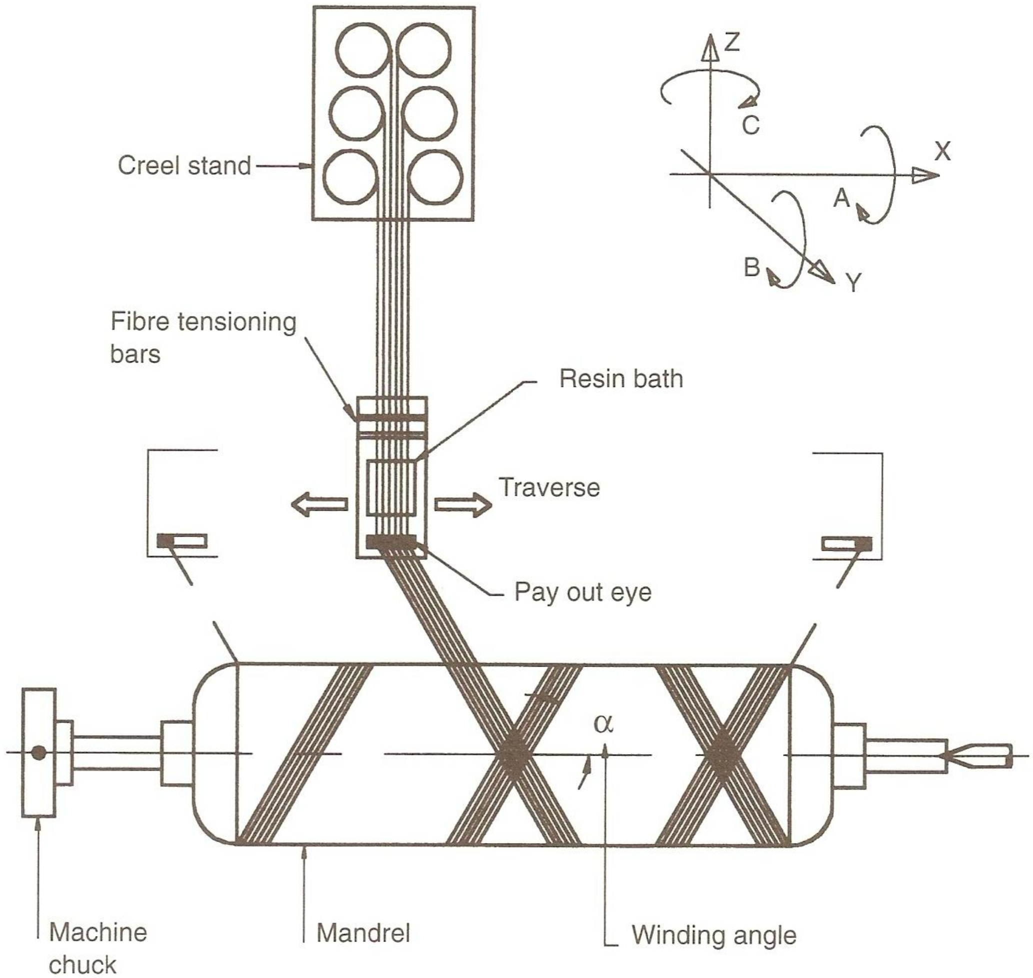


Figure 2.4: Schematic Presentation of Filament Winding Process (Courtesy of Owen(2000))

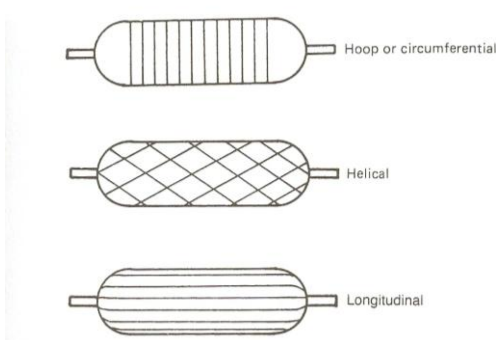


Figure 2.5: Three types of pattern available from filament winding process (Courtesy of Bhagwan (2006))

2.6.3.2 Tooling

The common tooling for this process is steel mandrel. This steel mandrel are chrome plated in certain application to get a high glass finish on the inner surface of composite structure as well as to aid in easy removal of the mandrel (Sanjay 2001). Aluminum is also used for making mandrel plaster and sand is also used to make destructible/ collapsible mandrels. For prototyping purposes, wood, plastic and cardboard can also be used. All the mandrel will finally being assemble to the rotating area of the filament winding machine before the filament winding operation start as shown in Figure 2.6.

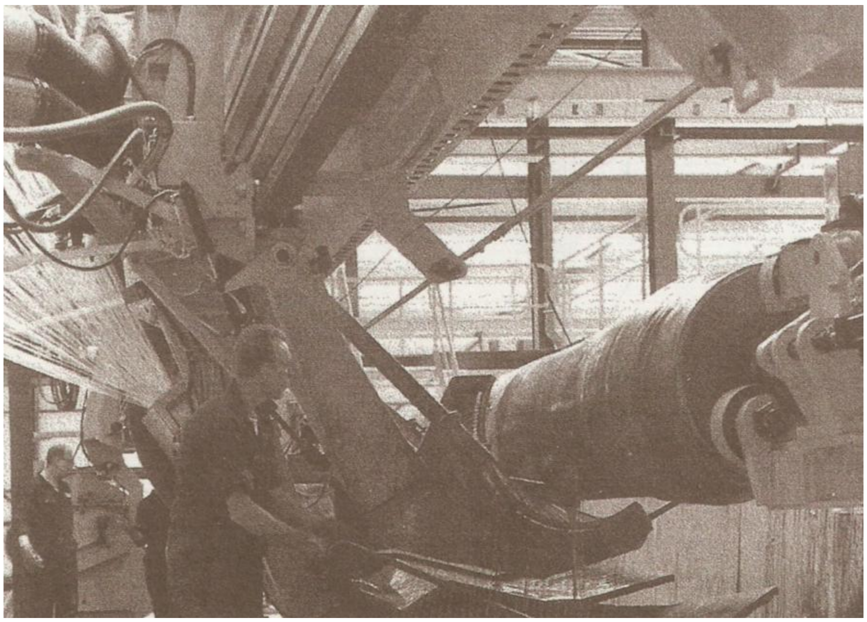


Figure 2.6: Filament winding machine with large diameter mandrel (courtesy of Owen (2000))

2.6.3.3 Basic Processing Steps

To have better idea about this manufacturing process, some basic filament processes are described below. According to Sanjay (2001), these steps are applicable to all wet filament winding process.

1. Spools of fiber yarns are kept on the creels
2. Several yarns from spools are taken and passed through guided pins to the payout eye as in Figure 2.4
3. Mixed hardener and resin systems are poured into the resin bath
4. Release agent and gel coat are applied on the mandrel surface and the mandrel is placed between the head and tail socks of filament winding machine (Figure 2.4)

5. Resin-impregnated fibers are pulled from the payout eye and then placed at the starting point on the mandrel surface. Fiber tension is created using tensioning device
6. The mandrel and payout eye motion are started. The computer system in the machine creates winding motions to get the desired fiber architecture in the laminated pattern as shown in Figure 2.5
7. Fiber bands are laid down on the mandrel surface. The thickness builds up the winding progresses
8. To obtain a smooth surface finish on the outer surface, a Teflon coated bleeder or shrink tape is rolled on top of the outer layer after winding is completed
9. The mandrel with composite laminate is moved to a separate chamber where the composite is cured at room temperature or elevated temperature
10. Finally, after the curing process, the mandrel is extracted from the composite part and then reused to fabricate another parts.

2.6.3.4 Advantages and Limitations

According to Sanjay (2001), filament winding offer the following advantages:

1. Filament winding is the only method that can be used to make cost-effective and high performance composite parts, particularly for pressure vessels and fuel tanks
2. This technique utilizes low-cost raw material systems and low-cost tooling to make cost-effective composite part
3. This process can be automated for the production of high-volume composite parts

However, filament winding also has some limitation, such as:

1. It is limited to producing closed and convex structures. It is not suitable for making open structures such as bathtubs.
2. Not all fiber angles are easily produced during the filament wounding process. Low fiber angles, especially 0 to 15^{o} are not easily produced, although low angle can help to increase the tensile strength of the composite parts
3. The maximum fiber volume fraction attainable during this process is only 60%

4. It is difficult to obtain uniform fiber orientation and resin content throughout the thickness of the laminate.

2.7 Standards

In order to prove that the fiberglass reinforced polyester pup joint can be threaded, we need to refer to Table 14 in API Spec 5B (appendix 3). From the table, we can see that for fiberglass pipe, long round thread can be used. The biggest OD of the fiberglass pipe should be 4.5 inch. Length of effective thread or pitch diameter can be obtained from this table.

API Spec 15LR (appendix 4) is also useful in this project as 15LR is dedicated for low pressure fiberglass line pipe. In section 2, it mentioned that the pipe shall be furnished and produced by centrifugal casting or filament winding method. In section 7, it stated that the pipe ends can be threaded end, taking API Spec 5B as the reference guide for threading. This specification also provides the reporting format for API fiberglass pipe product.

2.8 Commercialized FRP Tubing Products

From extra research on the internet, there is existing several companies already utilized the FRP product in oil and gas industry. Two example of company are Ameron International and National Oilwell Varco. Both companies supply the FRP downhole tubing product. To get further details on the commercialized FRP tubing, we refer to the brochure of both companies in appendix 5 and appendix 6. From the data, we can observe that National Oilwell Varco has provide fiberglass epoxy tubing with unique zero degree fiberglass layering sequence which provide superior tensile performance. It can be installed to depth to 10000 feet as production tubing and withstand temperature up to 93.3^{o}C and with pressure rating 4000psi. Referring to appendix 6, Ameron's tubing also use fiberglass epoxy material with two thread types, round thread and API thread. According to Ameron, these FRP pipes have excellent corrosion resistance and long service life with low installation cost.

CHAPTER 3

3.0 METHODOLOGY

3.1 Research Methodology

The steps shown in Figure 3.1 represent a systematic approach that will ensure the research work is always on the right track. The initial stage of *literature review* will lead to published information synthesis work after problem statements, objectives and scope of study are defined. *Theory and calculation* will focus on the fundamental knowledge and mathematical approach to predict the initial mechanical properties of the composite with reference to trusted sources. In the *product fabrication* stage, the composite pup joint is fabricated to specified dimensions, with reference to the results calculated and standards available.

Figure 3.1: The phases in research work

For *mechanical tests*, several practical tests will be carried out on the fabricated composite pipe, with reference to the recommended procedures from relevant standards to determine the actual mechanical properties. Then, recording of experiment data will be done on the *data gathering* stage. Finally, *data analysis* phase will cover the detailed and critical analysis to the results obtained.

3.2 FYP Project Activities

All the activities conducted (briefly) are shown in Table 3.1 on the next page to provide more insight information than the previous described research method.

Table 3.1: Activities conducted in FYP project

<table>
<tr><td colspan="3" align="center">Semester I</td></tr>
<tr><th>Required time</th><th>Activities</th><th>Remarks</th></tr>
<tr><td>2 weeks</td><td>Start of FYP I
a) approach supervisor
b) title proposal
c) title confirmation</td><td>Submission of Preliminary Report</td></tr>
<tr><td>4 weeks</td><td>Research and detailed studies
a) recent technologies
b) journal research
c) current pup joint properties</td><td>Submission of Progress Report</td></tr>
<tr><td>4 weeks</td><td>Design and Fundamental Knowledge
a) unidirectional composite
b) governing factors
c) fiber orientation and dispersion</td><td>Seminar I</td></tr>
<tr><td>3 weeks</td><td>Pre – fabrication
a) mathematical approach
b) manufacturing method
c) availability</td><td>Submission of Interim Report</td></tr>
<tr><td>1 weeks</td><td>End of FYP I
a) discussion
b) conclusion
c) summarize project work</td><td>FYP I Oral Presentation</td></tr>
<tr><td colspan="3" align="center">Semester II</td></tr>
<tr><td>3 weeks</td><td>Start of FYP II
a) theory and research work
b) required calculation to predict properties
c) product design and drawing</td><td>Submission of Progress Report</td></tr>
<tr><td>4 weeks</td><td>Pup joint fabrication
a) cost calculation
b) fabrication method
c) ordering and monitoring
d) quality control and standard</td><td>Seminar</td></tr>
<tr><td>5 weeks</td><td>Verification mechanical tests
a) test on mechanical properties
b) following industrial test standard
c) data gathering
d) data analysis
e) verify predicted performance</td><td>Poster Presentation</td></tr>
<tr><td>3 weeks</td><td>End of FYP II
a) discussion
b) conclusion
c) recommendation
d) project summary
e) objective review and feasibility</td><td>Submission of Dissertation Draft</td></tr>
</table>

From the table, we can see that some area and scope (i.e. total mechanical test) of FYP project are narrowed down so that this project is feasible and could be completed within the allocated time frame. The Gantt chart for FYP II projects and the expected timelines and milestones are shown in appendix 7.

3.3 Verification Method on Manufacturing Technique

From the literature review, we conclude that filament winding technique should be the best method to fabricate composite pup joint (cylinder/pipe). To verify on this results, we use a simple tooling selection route provided by Owen (2000) as shown in Figure 3.2 below to check whether filament winding process is applicable or not because choice of manufacturing process has significant impact on the cost and performance of the composite product.

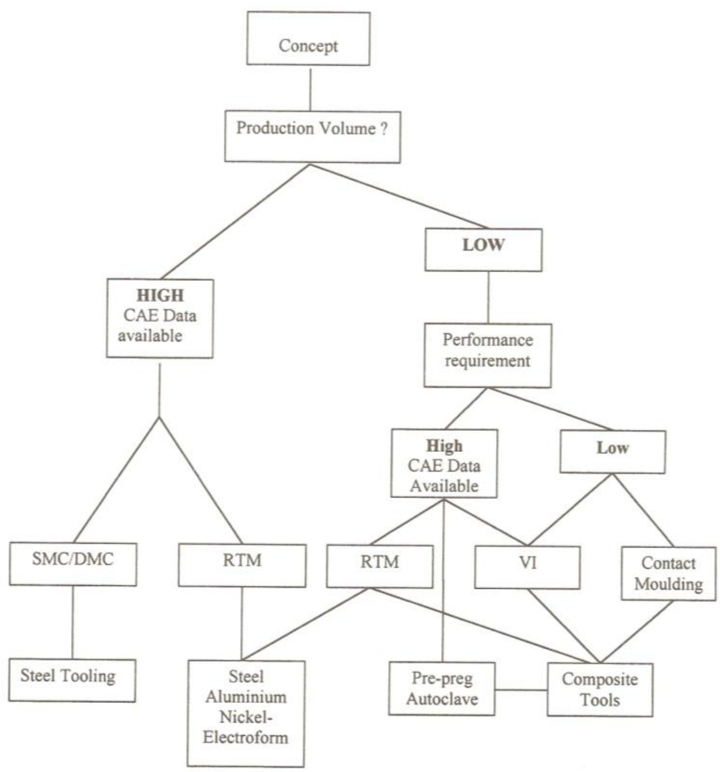


Figure 3.2: Simplified manufacturing process selection route (Courtesy of Owen (2000))

Referring to Figure 3.2, at the concept stage, we can define as a composite cylinder pipe needs to be produced from the bulk material. For the purpose and need of this project, the production volume can be considered very low, as one pup joint of 7 feet can be produced in one time and cut into several segment to form shorter pup joint. Next, the performance requirement can be considered low as the selected material is fiberglass reinforced polyester in this project. Glass and polyester both are very conventional material used as composite and the cost of production of composite pup joint will be lower compared to high performance epoxy resin. With that, contact moulding process is selected as the most suitable process to fabricate composite pup joint since vacuum infusion is use for dry reinforcement and particularly for large moulding. Filament winding process is fall under contact moulding categories as it is the best method to fabricate cylindrical and asymmetric components with relatively low cost comparing to other techniques.

3.4 Filament Winding Manufacturer

In Malaysia, there is limited number of manufacturer for fiber reinforced polyester pipe. After contacting, Joncan Composites Sdn Bhd is agreed to manufacture the composite pup joint with the dimensions specified in section 4.1. A pup joint drawing is sent to the manufacturer before the fabrication. Filament winding process is used in fabrication of the pipe. The fabricated composite pipe is shown in Figure 3.3 and 3.4 below.

Figure 3.3: 7ft composite pipe

Figure 3.4: Closer look at pipe end

3.5 Project Claiming

Before the claiming, a quotation as in appendix 8 is taken form Joncan Composite, RM900 is needed for the finished composite pipe. Next, a supporting letter (appendix 9) is wrote and obtained the signature from the Supervisor. The support letter, quotation and pipe drawing is then attached to a requisition form to start the claiming application. A completed requisition form as shown in appendix 10 is endorsed by both FYP coordinator and FYP Committee Chairman, who is Head of Mechanical Department.

3.6 Dimensions of Fabricated Pup Joint

ASTM D3567 – Standard Practice for Determining Dimensions of Fiberglass Pipe and Fittings (appendix 11) is the reference standard used in determining the pipe actual dimensions like outer diameter, inner diameter and wall thickness. Caliper with graduation of 0.02mm can be used for measuring thickness greater than 5.1mm. A series of eight readings is taken at random selected locations, approximately equally spaced around the circumference. Next, a circumferential vernier wrap tape is used to measure the pipe OD. Measurement is taken by placing the wrap tape around the pipe, with right angles to the pipe axis. Eight measurements are taken at different intermediate locations on the pipe.

3.7 Hardness Test

This test in conducted in Material Lab at ground level in Block 17 at Universiti Teknologi PETRONAS. A lab technician accompanied when conducting this hardness test. Pipe sample A (from Table 4.1) is used as the specimen for hardness test. Hardness Rockwell B (HRB) scales is normally used to test medium/low hard material such as annealed carbon steel. Hardness Rockwell C (HRC) scales is used to test material harder than HRB 100. Table 3.2 shows their range and load conditions.

Table 3.2: Rockwell Hardness Scales

Hardness	Suggested Range	Condition
HRB	41 – 100	Ø1/16 inch steel ball, 100kg load
HRC	19 – 69	120^{o} diamond indenter, 150kg load

The testing procedures are stated as follows, with reference to standard operating procedure available in the lab:

1. Before operation, the hardness tester is checked to make sure it is in safe and good condition.
2. The upper lever is checked and turned until it comes to a standstill, towards the user.
3. Sample A is put on the retainer seat. The hand wheel is turned to raise the test sample until it comes in contact with the indenter. The display showed value 9 and yellow light. The wheel is continue to turned and is stopped when the value 0 appear.
4. The lever is pushed in clockwise direction with the word STOP remained to display for the pre-set time. The red LED is flashed intermittently and an acoustic sound is heard.
5. At this point. The lever is pulled in a counterclockwise direction until it stopped. The hardness value on the comparator screen is read and recorded.
6. The hand wheel is unscrewed to free the test sample, the sample is turned to find for another testing surface and process 2-5 is repeated. Total of 18 readings is taken.
7. Lastly, the wheel is unscrewed and test sample is removed. The machine is switched off and cleaning process is conducted.

3.8 Threading Possibility

From the literature review in Chapter 2.7, it is advisable from the API Spec 5B that long round thread should be used for fiberglass pipe. However, the objective of this project is to produce a pup joint. Since K-FOX thread, a type of API Premium thread is currently used for conventional 3.5 inch OD low alloy steel pup joint, therefore the fabricated fiberglass polyester pipe will be thread with K-FOX thread. The shape and type of K-FOX thread are shown in Figure 3.5 and the threading company is Scomi OMS Oilfield Services Sdn Bhd located at Labuan. An application letter is sent to Workshop Manager at Scomi OMS to request for sponsoring for the threading of composite pipe and is approved.

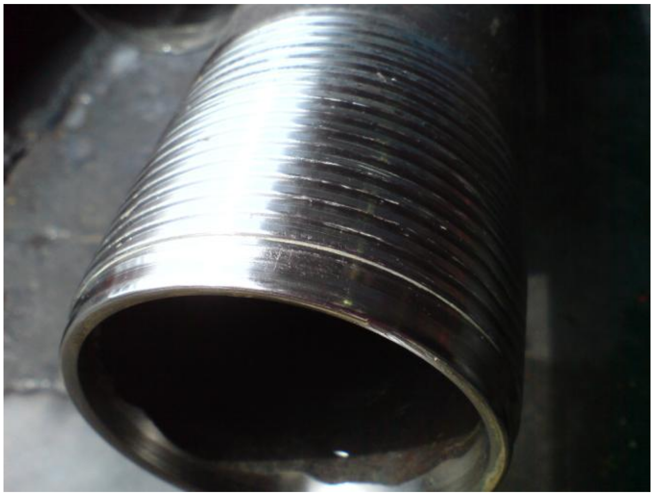


Figure 3.5: K-FOX thread on conventional L80 pup joint

The threading procedures observed are:

1. The machine is switched on and the workplace is cleaned to remove any hazards.
2. The threading machine is then pre-set with specified values so that the x, y and z-axis are well defined (Figure 3.6).

Figure 3.6: Technician is conducting pre-adjusting on the machine

3. Steel tubing is inserted and a trial is run to create a K-FOX thread on the tubing. The 3-axis dimensions and cutting head is adjusted to perform the threading correctly.

4. The finished tubing thread dimension is measured (Figure 3.7) so that it complies with specified quality and standard before proceed to composite threading.

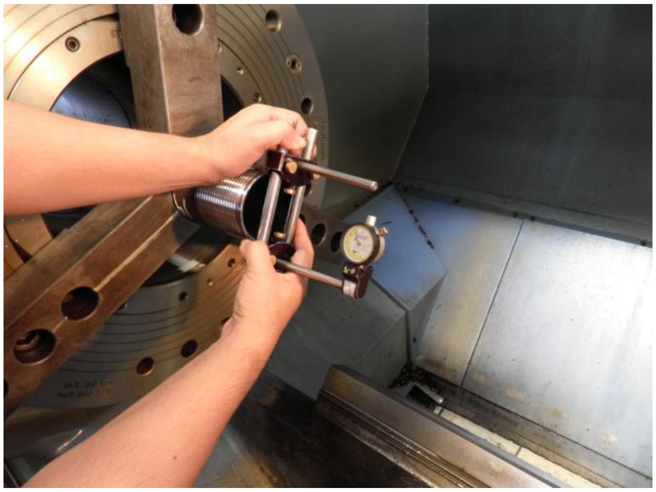


Figure 3.7: Measure the OD of the thread sealing area using a gauge

5. Composite pipe is inserted and threading began.
6. Some process is stop so that image can be captured on certain defects. The machine is turned off when threading for 4 pipe end is finished.
7. Housekeeping is conducted after work.

3.9 Fiber Volume Fraction Test

This test is conducted with the intention to find the actual fiber volume fraction of the fabricated pipe. The Appendix A as shown in appendix 12 from API Spec 15LR standard is used and the actual test procedures are outlines below:

1. Two 1 inch x 1 inch x thickness samples is cut from the pipe wall. Note that the samples shall not been tested for other mechanical properties before. Samples are dried in room temperature and fractured area is removed, leaving square and unfrayed sample. One sample shall have approximately 5g.
2. Two porcelain crucibles are heated to 550^{o}C for 15 minutes. They are cooled to room temperature in the furnace and weighted to nearest 1mg.
3. Two samples are placed in two crucibles respectively, labeled with specimen A and B and weighted to the nearest 1mg.

4. Contained crucibles are placed into the furnace and make sure the furnace is closed completely. The sample is left to ignite when temperature increase (at any furnace temperature less than 565^{o}C).
5. The temperature is finally increased to 568oC and the time set is one and half hour, so that all carbonaceous material has disappeared. The crucible is then cooled to room temperature in the furnace and later weighted to the nearest mg.

3.10 Tensile Test

Tensile test is done with full reference to ASTM D3039 Standard (appendix 13). Referring to the produces specifies in the standard, refined procedures are outlined as follows:

1. Four specimens are cut from the pipe wall that has the same thickness with the original pipe. Precautions must be taken to avoid notches, undercuts or delaminating caused by inappropriate machining methods.
2. Dimensions of the each specimen are measured and the specimen's cross sectional area is calculated.
3. One specimen is placed in the grips of the testing machine with the long axis of the gripped specimen is aligned with the test direction. The grip shall apply sufficient lateral pressure to prevent slippage between grip face and specimen.
4. The specimen is then loaded monotonically at the standard head displacement rate of 2mm/min.
5. Graph produced using the computer attached to the testing machine is recorded. Steps 3 to 5 are repeated for the remaining test specimens.

CHAPTER 4

4.0 RESULTS AND DISCUSSION

4.1 Size of Composite Pup Joint

In this project, the composite pup joint will be manufactured to predetermined size according to API 5CT standard. Industrial pup joint sizes have a range from 2 $^{3}/_{8}$ inch to 5 ½ inch. The difference in the total price is small when small quantity is ordered. Therefore, due to the ease of manufacture and filament winding machine available from the manufacturer, the most common size of 3.5 inch OD is selected. In this case, increasing the size of the pup joint will automatically increase the material cost since more raw materials are used. The configuration for 3.5 inch pup joint is shown in Figure 4.1 below. To reduce the cost of filament winding, the pipe should be manufactured in single operation. If two or three pup joints of 2 feet each are needed, the pup should be manufactured in 7 feet and cut into three different sections.

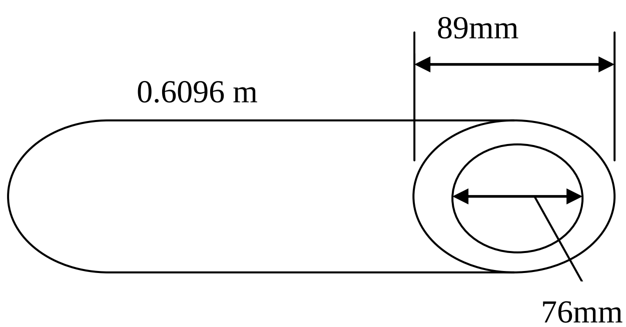


Figure 4.1: Proposed dimensions for composite pup joint

OD = 3.5inch = 89mm (88.9mm)

ID = 2.992inch = 76mm (75.9968mm)

Using πr^2 , the cross sectional area of this pup joint is $\pi(89)^2 - \pi(76)^2 = 6738.72\, mm^2$

The length of the composite pup joint is predetermined as 2 feet = 0.3048 x 2 = 0.6096 m = 610mm (609.6 mm).

4.2 Properties of Unidirectional Composite

According to Callister (2003), elastic modulus of composite can be calculated using:

$$E_c = E_f V_f + E_m V_m$$

also,

$$\sigma_c = \sigma_f V_f + \sigma_m V_m$$

Using the above rule-of-mixture for polyester matrix phase, the iteration on both the elastic modulus and longitudinal tensile strength are conducted and the result is presented in Table 4.1. Refer to appendix 14, the value for E_m for polyester is 4GPa, value for σ_m for polyester is 80MPa, and then refer to appendix 15, E_f for glass is 74GPa and σ_f for glass is 2500MPa.

Table 4.1: Elastic modulus and tensile strength for 5% to 95% E-glass fiber reinforcement of polyester matrix composite

Fiber: Glass, Matrix Resin: Polyester			
V_f	E_c (Gpa)	V_f	σ_c (Mpa)
0.05	7.5	0.05	201
0.1	11	0.1	322
0.15	14.5	0.15	443
0.2	18	0.2	564
0.25	21.5	0.25	685
0.3	25	0.3	806
0.35	28.5	0.35	927
0.4	32	0.4	1048
0.45	35.5	0.45	1169
0.5	39	0.5	1290
0.55	42.5	0.55	1411
0.6	46	0.6	1532
0.65	49.5	0.65	1653
0.7	53	0.7	1774
0.75	56.5	0.75	1895
0.8	60	0.8	2016
0.85	63.5	0.85	2137
0.9	67	0.9	2258
0.95	70.5	0.95	2379

In addition, the graphs are plotted and shown in Figure 4.2 and 4.3 below.

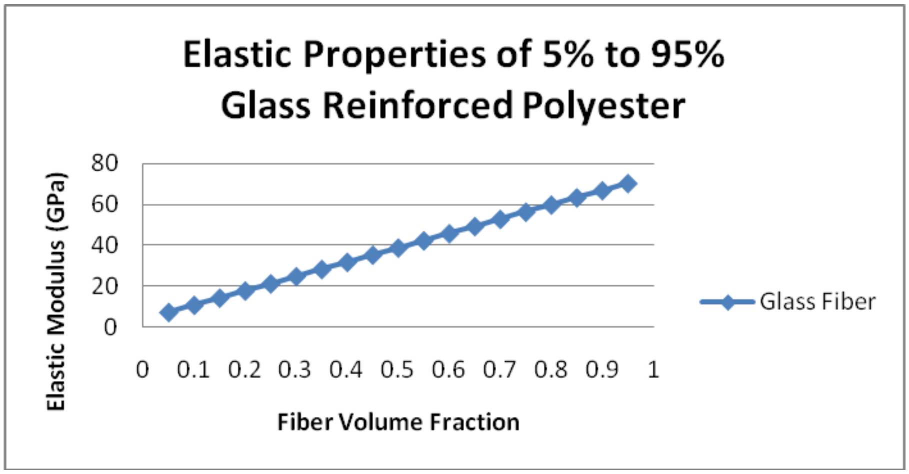


Figure 4.2: Graph of elastic modulus versus fiber volume fraction

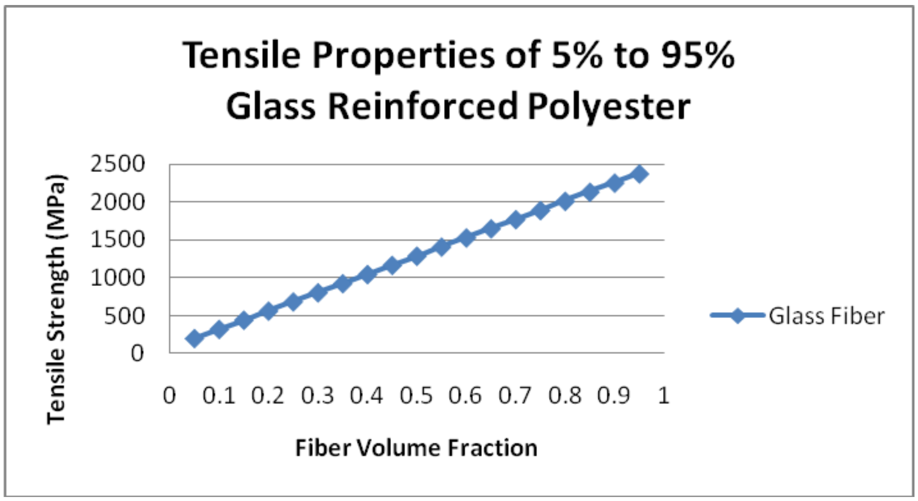


Figure 4.3: Graph of tensile strength versus fiber volume fraction

From the calculation, we can observe in Table 4.1 that the increase in the fiber volume fraction will definitely increase the tensile strength. The reference tensile strength of L80 pup joint is 655MPa. Twenty five percents of fiber reinforcement is not selected because a safety factor of 1.5 is added to the reference value, results to 721MPa, which is higher than the correspond value, 685MPa. This safety factor is necessary since there are several assumptions made in this unidirectional composite calculation. Therefore, 30% glass reinforcement is selected as the minimum fiber reinforcement for this pup joint because the corresponds tensile strength is 806MPa. The composite pup joint fabricated may have higher FVF than the minimum recommended value since the FVF is not a control variable during the pipe fabrication process. For the feasibility of this project, it is acceptable as long as the fabricated pipe will have FVF higher than 30%. The purchased pup joint can still undergo different mechanical tests to practically determine its actual mechanical properties.

4.3 Calculation for Filament Winding Pup Joint

In this project, the proposed machining technique for this fiberglass polyester pup joint is filament winding process. Therefore, it is important to taking into account the properties of pup joint affected by this process. First, we need to determine the required longitudinal modulus of elasticity for the pup joint, therefore the value calculated from the unidirectional composite is used. It is first assume the filament wounded pup joint is in unidirectional fiber direction, which is zero degree deviation from the centre axis, the modulus of elasticity can be obtained from Table 4.1, which is $E_c = 25\ GPa$ for 30% glass fiber volume fraction.

A circumferential winding pattern is to be used similar to that shown in Figure 4.4.

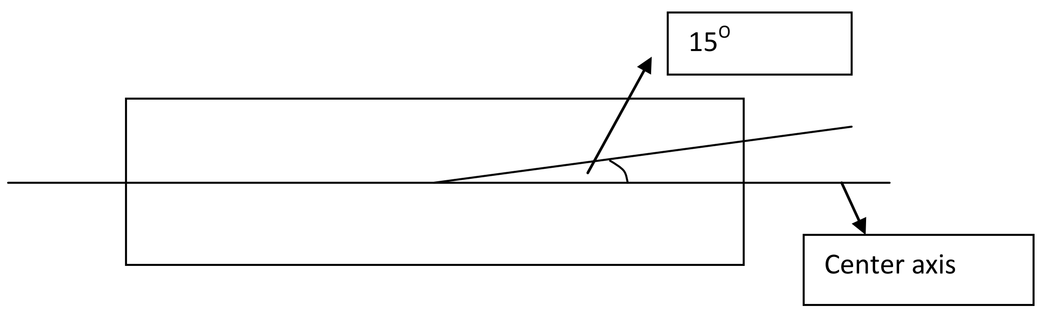


Figure 4.4: Winding pattern of pup joint

The winding pitch of the fibers, expressed in term of the angle, θ should be relatively small, to maximize stiffness in the longitudinal direction, therefore, in this design we assumed $\theta=15^o$ and this value will be used in the calculation below. Next, we need to determine the fiber and matrix volume fraction for two candidates in glass fiber, which are E-glass and R-glass. This is possible by using equation similar to rule-of-mixture, which must be modified to take into account that the continuous fibers are filament wounded and that the fiber orientation is not parallel to the pipe's longitudinal centre axis. Thus, we may use the equation below:

$$E_c = (\cos\theta)(E_f V_f + E_m V_m)$$

For θ = 15°, cos θ = cos (15) = 0.966

Substituting,

$$E_c = 0.966(E_f V_f + E_m V_m)$$

$$25 = 0.966(74\,V_f + 4\,V_m)$$

Calculating, $V_m = 0.68$ and $V_f = 0.32$. Using the similar equation, Table 4.2 can be constructed. E-glass is normally used for common application while R-glass is used particularly for high performance.

Table 4.2: Fiber and matrix volume fraction of 2 glass fiber type

Glass fiber type	**Elastic Modulus (GPa)**	$\boldsymbol{V_m}$	$\boldsymbol{V_f}$
E-glass	74	0.68	0.32
R-glass	86	0.73	0.27

At this point, it becomes necessary to determine the volume of fiber and matrix for each of the two glass fiber type. The total tube volume V_c in centimeters is

$$V_c = \frac{\pi L}{4}({d_o}^2 - {d_i}^2)$$

$$V_c = \frac{\pi(61cm)}{4}(8.9^2 - 7.6^2)$$

$$V_c = 1027.65cm^3$$

Thus, the fiber and matrix volumes result from products of this value to the V_m and V_f values cited in Table 4.2. These volume values are presented in Table 4.3 which are then converted into masses using densities, and finally, into material costs, from the per unit mass cost (Table 4.3). Fiber and matrix density is taken from appendix 14 and 15 respectively.

Table 4.3: Cost in MYR for 3.5inch composite pup joint for 2 glass fiber type.

Glass Fiber Type	E-Glass	R-Glass
Fiber Volume, cm^3	$0.32 \times 1027.65 = 328.85$	$0.27 \times 1027.65 = 277.47$
Fiber Density, g/cm^3	2.6	2.5

Fiber Mass, g	855.01	693.68
Fiber Cost per unit, USD/g	0.002	0.014
Fiber Cost, USD	1.71	9.71
Matrix Volume, cm^3	$0.68 \times 1027.65 = 698.80$	$0.73 \times 1027.65 = 750.18$
Matrix Density, g/cm^3	1.2	
Matrix Mass, g	838.56	900.22
Mat. Cost per unit, USD/g	0.0024	
Matrix Cost, USD	2.01	2.16
Total Cost, RM	$3.72 \times 3.435 = 12.78$	$11.87 \times 3.435 = 40.77$
Weight of 2 ft pup joint, g	1693.57	1593.9
Weight in pound, lb/ft	1.9	1.8

*3.435 is the exchange rate from USD to MYR

From the calculation above, it is affordable to purchase R-glass reinforced polyester pup joint since the cost is estimated to be RM 40.77, not including the labor and machining cost. From the table above, the weight for R-glass pup joint is slightly lower than the E-glass pup joint. 7 feet pup joint will be ordered with cost RM143. Another cost of RM 750 should be added because this include the labor cost and the cost to recover the fabricator's non-productive time to stop the machine for other production and switch to fabricate this one pup joint. Total cost of RM 900 is estimated for this composite pup joint fabrication.

4.4 Fabricated Fiberglass Polyester Pipe

The product is accepted after received from Joncan Composites Sdn Bhd. The procedure to determine the OD, ID and wall thickness is outlined in section 3.6. All the measurements are taken using 30mm Mitutoyo Stainless Hardened Caliper with 0.02mm accuracy. The results are tabulated in tables below.

Table 4.4: Measured pipe outer diameter

Reading	1	2	3	4	5	6	7	8	$\bar{X}$
OD(mm)	89.00	88.94	88.94	88.84	89.18	91.56	93.48	93.74	90.46

Table 4.5: Measured pipe wall thickness

Reading	1	2	3	4	5	6	7	8	$\bar{X}$
Wall(mm)	7.20	7.28	6.78	6.98	6.48	6.64	6.60	6.40	6.80

With that, ID is simply OD – 2(Wall thickness) = 90.46 - 2(6.80) = 76.86mm.

4.4.1 Initial Inspection

Several observations on the fiberglass reinforced polyester pipe is done and recorded when it is received. The observations are highlighted as follow:

1. A small crack is founded at one end of the pipe as shown in Figure 4.5.

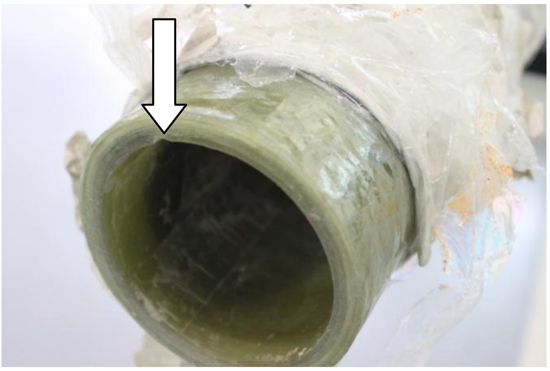


Figure 4.5: The arrow shows the crack area

2. Outside surface finish is not in flat surface. It is a rough surface as shown in Figure 4.6. The fiber laid down orientation if not evenly distributed.

Figure 4.6: Rough surface finish of pipe's outer surface

3. Coating agent (powder type) is put on both surface of the pipe (Figure 4.7).

Figure 4.7: Releasing agent powder in pipe

4. Air bubbles are formed (Figure 4.8) in the inner surface of the pipe.

Figure 4.8: Effects of air bubbles inside the pipe

5. Two long line scratches are found in the inner surface (Figure 4.9).

Figure 4.9: Line scratches are closed to each other inside the pipe

4.4.2 Discussion

A crack is founded may indicate that the area is covered only with polyester resin with no fiber reinforcement. It may be created due to impact force during courier sending process.

The inner surface of this pipe mostly has a good surface finish. The ID is consistent over the pipe because the mandrel used is strong enough to support winding tension and the torque requirement. However, two long line scratches are observed and may produce from the undercuts, undulations or surface scratch of the mandrel during the mandrel extraction process. To produce a fine inner surface, the mandrel winding surface must be smooth and free from any defects.

The impregnated fibers are not laid constantly with zero distance between each other on a revolving mandrel. Hence, one layer of composite with have some gap between filaments during fiber laid down. When the numbers of layers increase, the final outer surface will not be flat anymore and is like a wave type from the side view.

Air bubbles is appeared in the inner surface may due to the first layer of polyester laid on the mandrel is done in a quick process. Polyester resin is laid very fast on the mandrel and the air bubbles cannot escaped. Roller should be used in this case to roll out the bubbles before continuing to the second layer.

In general, the more complex the shape the slower will be the winding process. The winding process for this pipe should very fast because the product is just an axisymmetric shape open ended circular cylinder.

4.4.3 Pipe Cutting

The pipe is then cut into 4 sections so that different test can be conduct on each pipe sample. It is cut using BOSCH abrasive cutter machine shown in Figure 4.10. This composite is easy to cut using abrasive cutter and the cutting surface has a fine surface finish using a new rotating sphere cutting plate. The length and weight of the 4 pipes after cut is listed in Table 4.6.

Figure 4.10: Cutting in progress for composite pipe

Table 4.6: Dimensions of 4 pipe sample and their proposed test

Pipe Sample	Dimension (mm, ft)	Test	Weight (gram)
A	58, 0.19	Hardness	165
B	670, 2.20	Threading	1548
C	697, 2.29	Threading	1684
D	705, 2.31	Tensile, pressure rating	1823

To calculate the weight in pounds per foot for the composite pipe, we only use sample B, C and D in the calculation. Total weight of these 3 samples is 5055g = 11.14 lbs. Total length is 2072mm = 6.79 ft. The weight will be 11.14/6.79 = *1.64 lbs/ft*.

4.5 Hardness Test

The test is conducted initially using Hardness Rockwell C (HRC) scale machine because the low alloy steel tubing has the HRC 23 value. However, the machine fails to give any reading. This indicates that the composite hardness is not within the scale of HRC. Therefore, Brevetti AFFRI Hardness Tester, Model: 251 VRS is used to test with HRB Scales.

4.5.1 Results

Readings taken is tabulated in Table 4.7 below.

Table 4.7: HRB hardness for fiberglass polyester pipe

Reading	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**

Value	79.4	84.3	80.8	80.0	81.4	81.5	80.4	80.8	80.3	78.8

The mean of these values taken will become the reference hardness for this composite pipe. The calculated value is *HRB 81*.

4.5.2 Discussion

According to ASTM E18, which is Standard Test Methods for Rockwell Hardness of Metallic Materials, it suggests that the test piece shall be a smooth and even surface that free from any contaminants. Since in this case, a cylindrical composite pipe is to be measured with its hardness. Therefore, the best approach is that the hardness is only measured to the thickness of the pipe wall, as illustrated in Figure 4.11 below. The specimen preparation is done carefully and any alteration to the specimen surface is minimized.

Figure 4.11: Hardness is measured to the pipe wall thickness

Theoretically, we cannot actually compare the hardness of two different types of material, particularly between a metal and composite in this case. Therefore, we can only differentiate the hardness, by referring to the hardness value obtained. Fiberglass polyester has the HRB 81 and low alloy steel has the hardness of HRC 23, with the clarification that HRC scale is suitable for any hardness higher than HRB 100.

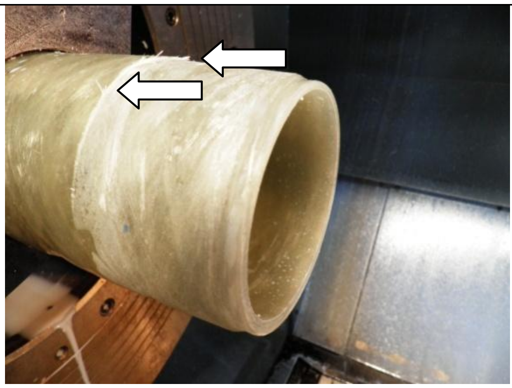
4.6 Threading Possibility

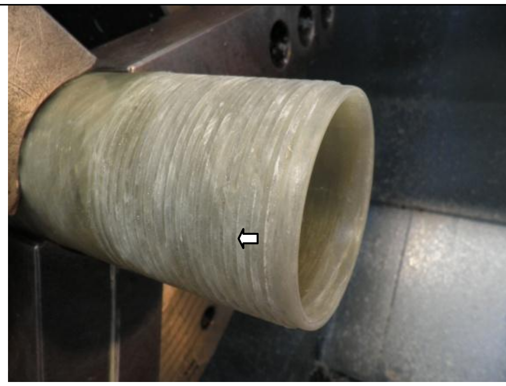
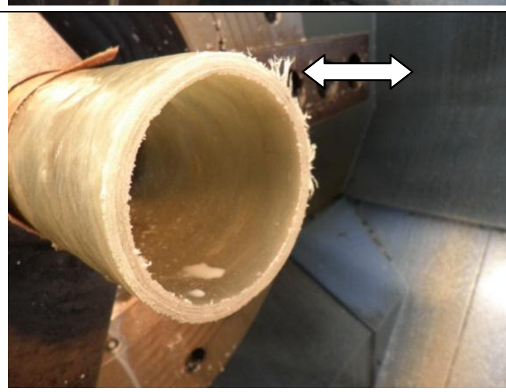
This experiment is done at Scomi OMS Oilfield Services machine shop at Labuan and is fully sponsored by Scomi OMS. MAZATROL 640T threading machine is used and is operated by a Chief Technician.

4.6.1 Results

The observations are listed in Table 4.8 below (continue to the next page).

Table 4.8: Important observations during threading process

Observation	Figure	Description
1		The 3 jaws cannot clamp the pipe effectively because the pipe outer surface is not even, the pipe will not retain in the center axis when rotating, a video is shot for this defects. Crack sound can be heard when the pipe is clamped firmly.
2		After the first layer cut, the fiber can appear (indicated by arrow) at the surface. The fiber orientation also can be observed clearly at the threaded surface.
3		Another part of the pipe end surface is not threaded due to the pipe is not rotating in center axis.

4		The thread far inside from the pipe end is not formed effectively and small cracks is occurs all around a small area. Some of them are observed as effects of air bubbles trap inside the composite surface.
5		After full threading process, only 2 effective threads (indicated by arrow) are formed. Crack may also occur at the thread when only polyester area is threaded.
6		The fiber will also appear and clearly shown (indicated by arrow) if the pipe is reduced length by rotating cut at the pipe end
7		The cutting pieces of composite are very small.

4.6.2 Discussion

In order for the jaws to clamp the pipe firmly, the pipe must have a flat outer surface. In this composite case, the pipe shall be ordered with bigger OD, i.e. 4 inch so that OD can be turned in flat into 3.5 inch. Hence, the jaws can clamp and keep the pipe in center axis so that all effective thread can be formed.

The orientation of fiber lay down on the mandrel during filament winding process is very important to retain the properties of the fiberglass polyester pipe. From the observation, the fiber may appear and pulled out of the matrix. This indicates wear is take place at this point. The wear is high when the sliding direction is parallel to the fiber. Observation 2 and 6 shows that both the threading and cutting direction is almost parallel to the fiber direction, therefore the fiber is pulled out easily.

The composite fragmented cutting produced by the threading is different from metal, as metal chips will form is steel is use. On the other hand, big amount of small composite cuttings are formed during the threading process. Form the observation, the temperature on the thread cutting surface is not high can still can be touched by fingers to virtually check the quality if the thread.

4.7 Fiber Volume Fraction Test

This test is conducted in full accordance to the procedures specified in Appendix A in API Spec 15LR, which is Method of Test for Glass-Resin Ratio of Fiberglass Pipe. The detailed procedures are outlined in Section 3.9. This test is done in the material lab in Academic Building 17 with the major equipments including EUROTHERM 2416 Furnace with digital thermometer. The weight is of the crucible and samples are measured by using METTLER TOLEDO DRAGON 303 with maximum capacity 310g.

Two crucibles, after heated to 550^{o}C and cooled are weighted and result is tabulated in Table 4.9.

Table 4.9: Crucible weight after heated and cooled (550^{o}C)

Reading	Porcelain Crucible	
	A	B
1	122.163	123.891
2	122.165	123.893
3	122.168	123.892
4	122.165	123.892
5	122.166	123.892

Mean, (gram)	**122.165**	**123.892**

Table 4.10: Crucible + specimen weight

Reading	Porcelain Crucible	
	A	B
1	127.936	129.796
2	127.939	129.796
3	127.940	129.796
4	127.940	129.797
5	127.940	129.796
Mean, (gram)	**127.939**	**129.796**

From the two tables, the specimen weight can be calculated. Specimen A has the weight of *5.774g* and specimen B has the weight of *5.904g*. After both specimes are heated to 568oC for one and half hour, the weight of the residue and crucible is weighted again, the result is show in Table 4.11 below:

Table 4.10: Crucible + residue weight

Reading	Porcelain Crucible	
	A	B
1	124.845	126.606
2	124.848	126.605
3	124.850	126.607
4	124.853	126.608
5	124.853	126.607
Mean, (gram)	**124.850**	**126.607**

From the value obtained, the residue weight can be calculated.

Weight of Residue A = 124.850 – 122.165 = 2.685g.

Weight of Residue B = 126.607 – 123.892 = 2.715g.

To calculate the percent of fiber reinforcement, we must first calculate the ignition loss, which represent the percentage of matrix in the composite:

$$Ignition\ Loss, A = \frac{weight\ of\ sample - weight\ of\ residue}{weight\ of\ sample} x100\%$$

$$= \frac{5.774 - 2.685}{5.774} x100\% = 53.5\%$$

$$Ignition\ Loss, B = \frac{weight\ of\ sample - weight\ of\ residue}{weight\ of\ sample} x100\%$$

$$= \frac{5.904 - 2.751}{5.904} x100\% = 53.4\%$$

From here, the matrix volume is calculated to be 53.5% and fiber volume fraction of this fiberglass polyester pup joint is *46.5%*.

4.8 Tensile Test

This test is performed to determine the uniaxial tensile strength of this filament wounded fiberglass polyester pipe. ASTM Standard D2105 specifies that fiberglass pipe can be test using special holding device/test fixture which has the sleeves, reinforcing band, mandrel and segmented grips. However, this test fixture and testing machine is not available in the university. Several test houses and private laboratories are contacted and all rejected to conduct the tensile test due to the size limitation of the test fixture available. Therefore, this standard is not applicable and finally ASTM D3039 – Standard Test Method for Tensile of Polymer Matrix Composite is recommended.

ASTM D3039 specifies that the tensile specimen shall be a straight-sided, of constant cross-section and beveled tabs for load introduction. However, it is not recommended to produce a flat specimen from the pipe body because the tensile strength of this specimen is not adequate and cannot represent the tensile strength of this fiberglass polyester pipe material. Due to this limitation, a better approach is used. The test specimen is cut directly from the pipe wall with pipe thickness maintained. Cutting is done slowly using handsaw to avoid damages to cutting edges. Specimens as shown in Figure 4.12 are produced. Although the specimen is not having fully rectangular cross section, this effect can be neglected since the variation is assumed to be small compare to the total cross sectional area.

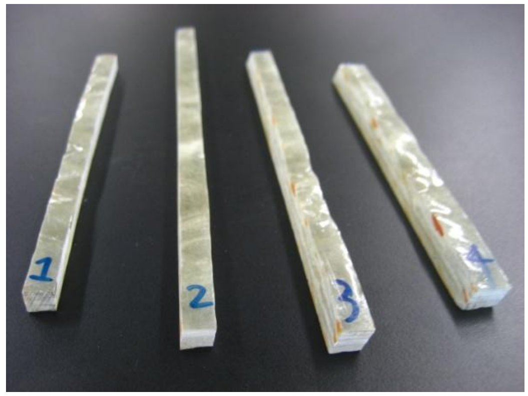


Figure 4.12: Four specimens cut from pipe wall

Tensile test is conducted utilizing Zwick Roell Universal Testing Machine, Model: Amsler HA100 as shown in Figure 4.13 using friction grip, indicates by the arrow. The specimen is then load monotonically at a rate of 2mm/min until the specimen breaks. The graph recorded using the computer is shown below for 3 specimens. The specimen 4 in Figure 4.12 is used as initial trial run to make sure the machine function accordingly.

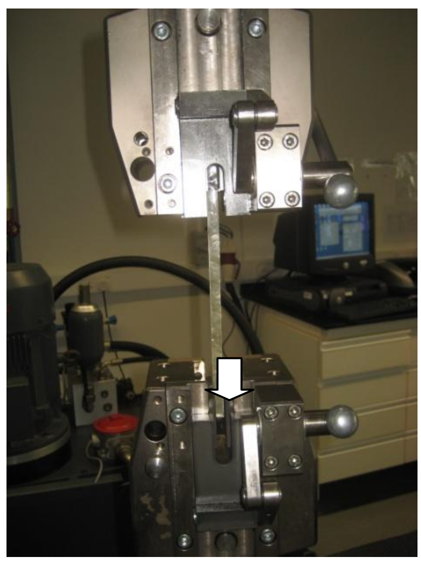


Figure 4.13: Friction grips hold and tightened test specimen in place

Figure 4.14: Geometry of fiberglass polyester plastic deformation after tensile test

Graph recorded using computer for 3 specimens are shown on the next pages. Tensile strength can be calculated using ration of highest load obtained from the graph to total cross section area of specimen. Table 4.11 tabulates the test results.

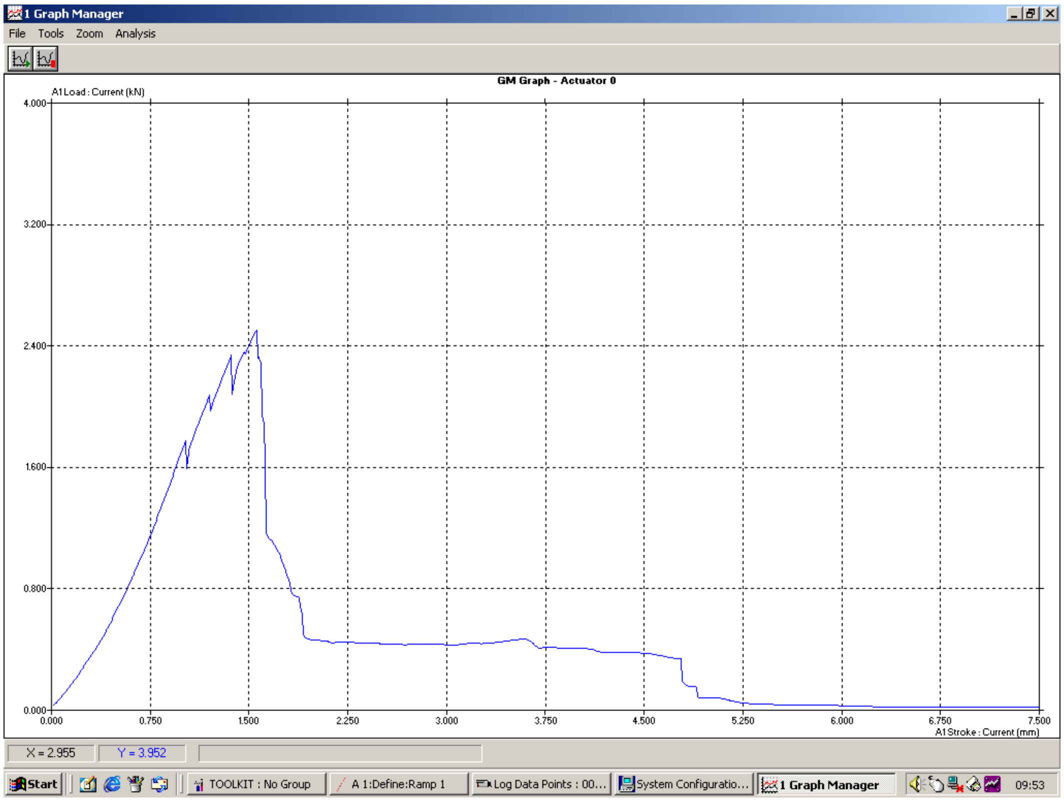


Figure 4.15: Graph for specimen 1

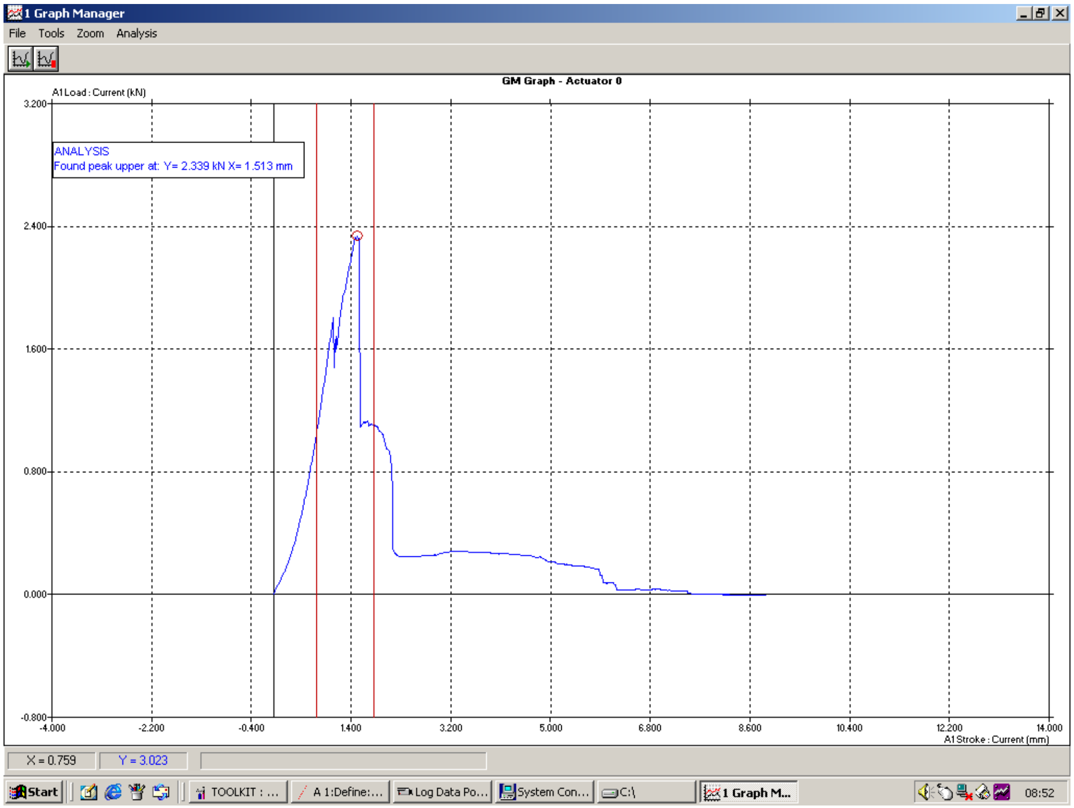


Figure 4.16: Graph for specimen 2

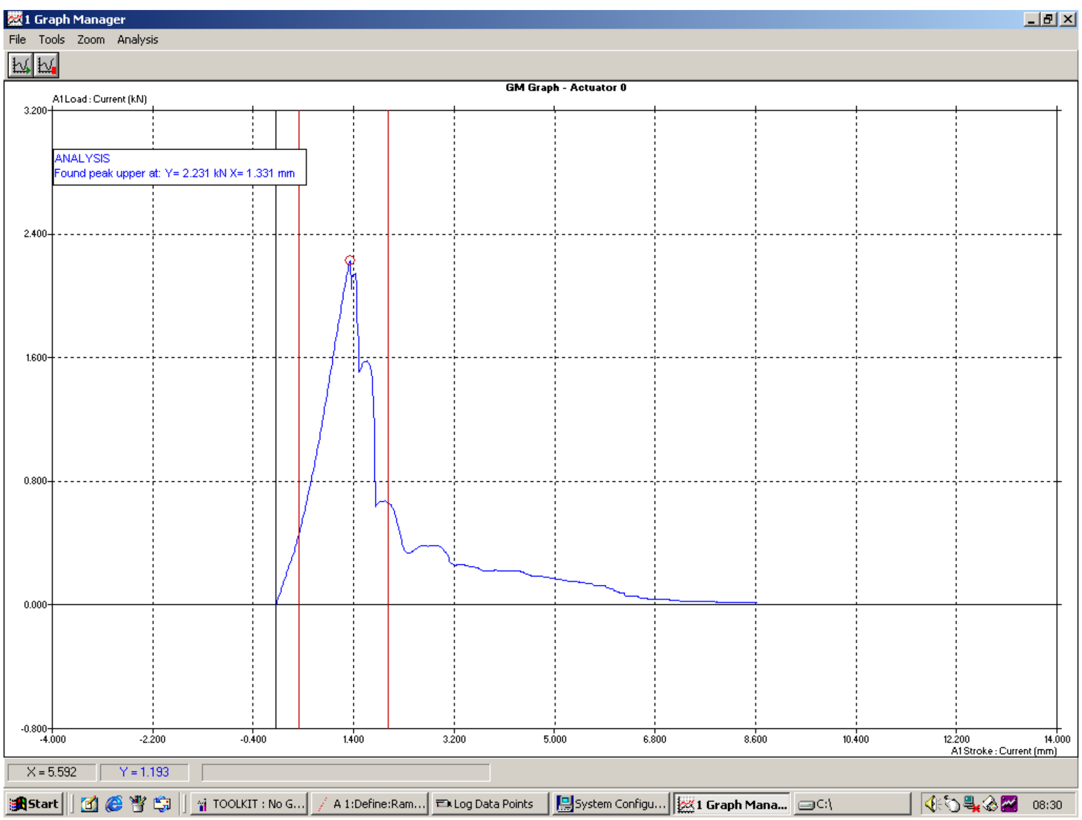


Figure 4.17: Graph for specimen 3

Table 4.11: Calculated specimen tensile strength

Specimen	1	2	3
Highest Load, N	2507	2339	2231
Area, mm^2	23.86	23.15	22.52
Tensile Strength, MPa	105	101	99

4.8.1 Discussion

The results show that the actual tensile strength of the fabricated fiberglass polyester pup joint is 105MPa, in this case we take the highest value obtained from the tensile test. The actual filament winding angle is 60^o and the FVF calculated is 46.5%. The theoretical tensile strength of fiberglass polyester pup joint with 46.5% FVF and $\theta = 60^o$ is calculated to be 603MPa. From here, we can observe that the actual tensile strength is 17.4% of the theoretical tensile value. This may due to poor material fabrication practices, lack of control of fiber alignment and edge effects in angle ply laminates. Premature failure may exist as a result of edge softening in laminates containing off-axis plies, since the specimen is directly cut from the pipe wall with uneven outer surface. Because of this, the tensile strength can be drastically reduced.

To optimize the performance, the fabricated fiberglass pipe winding angle, θ shall change from 60^o back to to 0^o (unidirectional) and the maximum attainable FVF for filament winding (60%) is taken, the theoretical tensile strength is calculated to be 1532MPa. The actual tensile strength of the fiberglass polyester pup joint if fabricated in the same way is 267MPa, with the condition that same performance index percentage (17.4%) is applied. However, to increase the actual tensile strength so that it is close to the reference value (655MPa), proper optimization shall be done especially in the fabrication method or manufacturing parameters so that the performance index percentage can increase from 17.4% to 43%, similarly from 267MPa to 659MPa.

CHAPTER 5

5.0 CONCLUSION

A lightweight *1.64 lbs/ft, 3.5 inch* fiberglass polyester pup joint is fabricated. It is not in optimum quality from observations as this can affect the mechanical test results and may cause deviation to the pup joint's actual mechanical properties. Optimization of the manufacturing parameter in filament winding process should be carefully monitored to enable a higher quality filament wounded pipe.

Threading of K-FOX thread (used by low alloy steel pup joint) is possible on both end of fiberglass polyester pup joint. However, this thread is not suitable for fiberglass pup joint because the sealing area will not seal off the connection when the pup joint is connected to the coupling of the same thread. Further work should be continued to find the best connection/thread type for fiberglass reinforced polyester pup joint.

Three tests have been successfully conducted with close reference to two standards, API and ASTM standard. They are hardness test, fiber volume fraction test and tensile test. The hardness of this fiberglass polyester pup joint is found to be *HRB 81*. The FVF is found to be 46.5% glass reinforcement and most importantly, the tensile strength of this composite pup joint is found to be 105MPa. It shows that the actual tensile strength is 17.4% of the theoretical calculated tensile strength. Therefore, a fiberglass reinforced polyester pup joint with 60% FVF, filament winding angle of 0^o (unidirectional) can obtain an theoretical tensile strength higher than the conventional low alloy steel pup joint and actual tensile strength can surpass the conventional pup joint's tensile strength subjected to proper optimization in the fabrication method. Referring to this mechanical property, this composite pup joint is possible to replace the conventional low alloy steel pup joint used in well completion application.

As a conclusion, the objectives of this project are achieved. Nevertheless, fiberglass reinforced polyester pup joint is more feasible to be deployed into the oilfield operation with further determination of other relevant mechanical properties highlighted in the recommendation section below.

5.1 Recommendations

Fiberglass polyester pup joint is not yet fully compatible with the conventional low alloy steel pup joint if the pressure rating of this pup joint is not yet determined. A good approach to test the pressure rating, or even the collapse pressure or operating pressure of this pup joint is to connect the threaded test fixture to the threaded pup joint. This test is also known as hydrostatic test.

Further work to determine the pup joint's cyclic strength at operating level shall be done because the tubing string may subject to substantial amount of torque during installation. Test procedures shall establish the service life of the composite pup joint under cyclic pressure and hydrostatic loading to demonstrate considerable application under these service conditions.

Another recommended type of modification is to put a layer of low alloy steel liner as the fiberglass reinforced polyester will become the outer layer of the pup joint. The purpose is to reduce the corrosion of flowing hydrocarbon fluid to the inner surface, in the same time reduce the corrosion of the tubing at outer surface using reinforced polymer. The thickness of both layers shall be determined to give optimal performance to the pup joint.

For the filament winding process, extra effort shall be continued by altering the manufacturing parameters and find out their effects to the mechanical properties on the filament wounded composite pipe. This analysis can help in our further understanding on proper controlling of manufacturing process parameter and how it affects the composite performances.