Hydrostatic Burst Test of Multi-Angle Filament Wound Composite Pipe

By

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CERTIFICATION OF APPROVAL

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Mechanical Engineering Programme
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May 2015

CERTIFICATION OF ORIGINALITY

This is a written evidence to certify that I am responsible for the work submitted in this project, that the original work is my own except as specified in the references and acknowledgements, and that the original work contained herein have not been undertaken or done by unspecified sources or persons.

(…………………………………………………….)

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ABSTRACT

Due to corrosion resistance, light-weighted and high mechanical properties, non-metallic composite pipe has been identified as a great alternative to conventional carbon steel pipe in oil and gas industries. The aim of this study is to determine the internal ultimate strength of non-metallic filament wound composite pipe working under monotonic pressure load. This study was also focused on the designing of the end-cap setup that was used throughout burst test. The test samples were first manufactured by filament winding method, employing E-glass fiber as reinforcement, epoxy resin as matrix and high density polyethylene (HDPE) as the liner through 30°/60° multi-angle configurations. The length of the sample pipe was approximately 500 mm with 94 mm thickness.

In order to suffice all requirements, internal pressure tests were done on the filament wound composite tube specimens according to ISO 11439 standard. The entire fabrication and testing of the pipes took place at SIRIM Permatang Pauh, Penang. The study was unfortunately hindered due to some problem associated with leakages. Improper design of the end-caps was identified as the main cause. The study was then preceded after several improvements were made. The burst test revealed that the modified end-cap design exhibited a burst performance of 125 Bar without any leakage. However, in an effort to replicate the test, it was found that the modified end-caps were yet still failed due to leakage. Therefore, further end-cap modification is required for future researches.

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CHAPTER 1

INTRODUCTION

1.1. Background of study

A normal tube or pipe can be classified as an element with a good structural integrity. It is well adapted to load due to bending, axial, and torsional action acted on it [1]. Generally in composite pipes, mechanical properties such as strength, stiffness and thermal expansion, can easily been manipulated and controlled by varying the pipe composition and also through angle displacement of the filament winding process [2].

Most of the time, those pipes used in oil and gas industry are operating under high pressure in a turbulent water surrounding [3]. Their structures are hence often subjected into fatigue. The science of materials described fatigue as the weakening of material mainly due to applied load that is repeatedly acting on the structures [4].

In a sense of a fatigue concept, whenever any certain object or structure is under repeated motion for a certain period, the structure will become weak and eventually ruptures even below the nominal strength of its material. If the loads are above certain threshold point, this could results in formation of microscopic cracks on the stress concentrators [5]. In a long run, these small cracks will eventually pass on its critical size, the size in which the crack will vigorously propagate hence leading to fractures. Fatigue lifetime and residual strength are therefore affected by interactions between microstructures, distribution of flaws, and the formation of damage zones and shear cracking [6].

The occurrences of failure by fatigue are commonly inevitable as the main components of the object are subjected fluctuating or cyclic loads throughout their service life. Many high volume applications of composite materials involve cycling loading situations hence fatigue can be classified as one of the prominent cause of all mechanical service failure especially in oil and gas application [7].

Conventionally, standard material use in oil and gas pipe like carbon steel or stainless steel tends to be heavy and expensive. They are also vulnerable to corrosions [8]. Prospectively, the usage of non-metal composite pipe could greatly reduce the cost of production of certain oil and gas company. In the last several decades, the usage of non-metal composite piping or any fiber reinforced product (FRP) in oil and gas industry; mainly in drilling sector has been pleasantly booming in numbers particularly due to its ability in withstand vigorous surrounding condition, at the same time stay conveniently with its light weight properties. Generally, a composite is a combination of two or more materials with distinct physical and chemical properties but at some level remain separate as they do not fully merge or dissolve among another [9]. Although filament winding is a promising trend, there are still rooms for improvement; in terms of internal pressure loading since little research has been put to improvise said mechanical properties.

1.2. Problem statement

Although the integrities of FRP pipes have been studied for the last several decades, limited studies were performed on hydrostatic pressure limit. Most of the studies covered on the hoop and axial stress performance. This is essential in order to give a glimpse of an idea upon the life span of a non-metallic composite pipe specifically oil and gas standard requirement. It also acts as a preliminary study into further fatigue analysis.

1.3. Objective

The main objective of this study is to determine the internal ultimate strength of non-metallic composite glass fiber filament wound pipe under hydrostatic pressure application.

1.4. Scope of study

This study will focus on the design of the burst test setup in determining ultimate burst pressure of non-metallic composites pipe as per described in ASTM D2143- Standard Test Method for Cyclic Pressure Strength of Reinforced, Thermosetting Plastic Pipe .The burst test will also be referred to ISO: 11439 standards in validating an ultimate point of pressure for the burst test. The composite pipe fabrication utilized epoxy as matrix resin supported by glass fiber as reinforcement. The inner liner of the composite pipe is using a High Density Polyethylene pipe. The fabrication for this pipe is undergoing through a process called filament winding using multi-axis filament winding machine. Filament winding is a fabrication technique mainly used for manufacturing open or closed end structures by winding fibrous material to form a helical formation under specific winding angles over a rotating mandrel or tubular body. This study will also be focused on the design of the fixtures setup that will be used throughout the burst test in withstanding the pressure applied based on average parameter provided by Petronas SKO pipeline data [10]. The filament winding machine is located at the Standards and Industrial Research Institute of Malaysia, SIRIM's research facilities in Permatang Pauh, Penang. The composite pipes fabrication will be based on the paper by P. Mertiny et al. [11] as well as reference from paper by Richard H. Lea and Chihdar Yang [12] for standard offshore pipes.

CHAPTER 2

LITERATURE REVIEW

2.1. Conventional carbon steel pipe

According to American Iron & Steel Institute [13], steel is considered to be carbon steel when no minimum content is specified or required for chromium, cobalt niobium, molybdenum, nickel, titanium, tungsten vanadium or zirconium or any other element to be added to obtain a desired alloying effect; when the specified minimum for copper does not exceed 0.40 percent; or when the maximum content specified for any of the following elements does not exceed the percentages noted: manganese 1.65, silicon 0.60, copper 0.60.

The most widely used material for a line pipe is carbon steel, to be specifically, A106 Grade B seamless carbon steel pipe. A106 Grade B Seamless Carbon Steel Pipe is commonly used in the construction of oil and gas refineries, power plants, petrochemical plants, boilers and ships where the piping must transport fluids and gases that exhibit higher temperatures and pressure levels [14].

A specific carbon steel pipe labeled SKOL026 is used to transfer crude oil through Baronia field near Miri [10]. This pipe extends up to 17.5 km and most of the diameter throughout the pipeline is approximately to be 3 inches (76.2 mm in diameter). The SKOPL026 carbon steel pipeline is used as platform pipeline and also as production riser, to export crude oil to main pipelines that connects to the onshore processing platforms. It is designed based upon ASTM A106 Grade B specifications. The physical properties of the pipeline are as shown in the Table 2.1 below.

Table 2.1: Physical properties of SKOPL026 pipeline [10].

Nominal Pipe Size (Inch)	Diameter Nominal (mm)	Minimum Tensile Strength (MPa)	Minimum Yield Strength (MPa)	Design Pressure (MPa)	Operating Pressure (MPa)
3”	76.2	415.0	240.0	9.93	2.8

The pipe specifications were referring to API 5L Standard, which is Specification for Line Pipe that currently applied throughout the oil and gas industry. All the important parameter such as maximum allowable pressure and temperature ratings for oil and gas application of the pipe will be solemnly under the discretion of ANSI/ASME B31.3 Process Piping standard.

2.2. Composite pipe

Fiber reinforced product are been widely used in many engineering application since they are much stronger and have a higher stiffness along with their excellent ability to withstand corrosion and fatigue failure and are relatively cheap compare to conventional steel pipe [15]. Although carbon steel and copper nickel alloy pipe had traditionally been used on offshore platforms, advanced composites were known to be stronger, more resistant to corrosion, and lighter than steel. For example, composite pipe with a 6-inch diameter weighs 4 pounds per foot, whereas copper nickel pipe with the same diameter weighs 24 pounds per foot. Advanced composites also cost less initially than steel piping and have a longer life cycle. The past usage of composite materials in piping can be track down as early as the 1950’s era. During that period, due to the high cost of stainless steel, coated steels and other metal alloys, composite or fiberglass piping are prospected as the viable solution in substituting the common process for a much cheaper price.

Any composite pipes can be generalized into categories; metallic composite pipe and non-metallic composite pipe. Structures can be defined as composites based when if there are any presence upon two or more different material within a structure constituent on a macro-scale view. This combination of materials will subsequently provide a significant rectification in term of the composites performance properties [9]. An example of composite products is as Figure 2.1 below.

Figure 2.1: Example of a fiber reinforced product (pressure vessel).

2.3. Manufacturing of composite pipes through filament winding

These composite pipes are manufactured through a process called filament winding. According to Sanjay [16], filament winding can be defined as a process in which a band of continuous fiber been impregnated with a matrix of resin or monofilaments being wrapped onto a mandrel through the mean of mandrel rotation at desired angle. The rotating mandrels can be either round, cylindrical or any other shapes that does not have reentrant curvature. On top of that, as mentioned by ACMA and CNBM technology a mandrel can be described as male mold. The end product should possess the same shape as the used mandrel. It is also often been replaced with a liner; a thermoplastic or thermosets resin that will melt along with the fiber and matrix during the curing period in production of pressure vessels and tubes [9] [15].

A typical filament wound composite pipe or tube consist of 3 major building element upon fabrication; reinforcement, matrix, and liner. A liner act as a temporary support structure as well is a filter membrane [15]. The wound is then been cured under room temperature or at higher in an oven to produce the final product.

According to Sanjay [16], 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 further studies especially regards to the matrix phase is very important in substituting a conventional material with composite material.

The usage of glass fiber as the reinforcement fiber will be taken account into the fabrication of these composite pipes. According to Owen [17], 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.

As for the matrix resin, it can be classified onto 2 different categories; thermoset and thermoplastic. The thermoset type will cure to produce an insoluble material that does not melt whereby for thermoplastic resin, it has a definite melting point. Epoxy will be chosen as the matrix resin .This type of resin is selected according to its resistance to absorption of water, oil and gas which in this case epoxy catered all the necessary properties.

As for the liner, this study will be fully utilizes High Density Poly-Ethylene, HDPE since it inherit a high strength-to-density ratio.

Nowadays, filament winding have a major position in producing a light weight and durable vessels or tube for any applications such as liquid or gas storage and tubular pipes particularly in oil and gas application. The technique offers high speed and precise method for placing many composite layers at certain predefined angle [16]. Several justifications upon potential material selection are as shown in Table 2.2.

Table 2.2: Material justification of sample composite pipe material.

Building elements	Type of material used	Description
Reinforcement fiber	Glass fibers	• Fabrication of these composite pipe specimens are specifically from the E-glass category as the reinforcement structure. • E-glass possesses a moderate modulus of 73GPa and has a good tensile strength of 2000MPa. • It is also one of the lowest cost fiber can be found in market.
Matrix resin	Epoxy	• These are the most expensive of the three resin types, but the cost of it is economically justified. • Epoxy resins are typically about three times stronger than the next strongest resin type. • Epoxy adheres to Carbon Fiber, Fiberglass, and Aramid (Kevlar), very well and forms a virtually leak- proof barrier.
Liner	Poly-Ethylene, PE	• PE can be classified as one of the thermoplastic materials that have a high strength-to-density ratio • Commonly used in the production of corrosion-resistant piping. • It is also harder and more opaque and can withstand high temperatures.

A sample specimens have been fabricate through the filament winding process following the specifications as per described in the paper by Richard H. Lea and Chihdar Yang [12] for standard offshore pipe. The paper suggested winding angles of $[70°/20°]_2$ (50% of 70° angle, 50% of 20° angle) provides a better balance strength integrity in term of axial and hoop compares to traditional single lay-up of 54° winding angle. Conventionally, most manufacturers will utilize a traditional 54° winding angle in accommodation of internal pressure for a standard pressure vessel where the hoop stress is twice the axial stress. Richard H. Lea and Chihdar Yang [12] also imply that different moduli can be achieved with different wind angles. The assumption stated that a great axial modulus can be achieve through 0° angle, a great shear modulus through 45° angle and a great hoop modulus through 90° angle. Hence, from their observation it can be conclude that a 20°/70° configuration wound pipe will gives a balanced hoop and axial properties and both are higher than the traditional 54° single angle winding. This study also suggested that the use of composite pipe could greatly reduce the use of pipe spool as well as the cost which inherit 75% cheaper than steel and any other materials. Unfortunately, since this paper is not really much in-depth in term of its definition and methodology, hence it can be deduced that it is not much reliable for this particular project but still can be used as reference purposes only.

A following study conducted by P. Mertiny et al. [11] suggested that a multi-angle winding combination of $[30°/60°]_2$ and $45°/[60°]_2$ possess an overall greater strength with reduction of axial strain and a minor decrease of hoop strain when compared to single lay-up of 60°. The study seems to use 60° winding angle as a baseline angle instead of 54° since it identifies the winding angle to be more suited in pipeline application. While both study suggested multi-angle winding combination portrays advantage in terms of cost savings and strength, there is no lead that specify it use towards oil and gas pipelines based on gas and crude oil properties.

2.4. Fabrication standards

In order to suffice all the criteria for a fabrication upon conventional pipe the study will refer to the API spec 5B as well as API Spec 15LR. It is known that 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 also 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.

2.5. Mechanical tests

There are several mechanical tests in evaluating significance pressure capacity within a body. These tests can be divided into several parts; hydrostatic burst testing and cyclic testing. Both setups would be a bit different in order to determined different parameters but will be basically having the same objective which is testing the internal performance and strength integrities of a pipe structure. There was one study which investigates the fatigue behavior of filament wound graphite/ epoxy tubes under cyclic loading done by H. Masudi and J. Green [2] from A&M University in 2000. Their experiment generally based on upon two criteria; 1. One million-cycle specification set by the manufacturer on the tubes being tested and 2. Points of failure based on the one million-cycle specification.

These procedures underwent through four different degrees of temperature namely 75°, 125°, 150°, and 175° F. All 10 samples are loaded with 7500 to 42500 lbs. of pressure consisted seven graphite/epoxy tubes that will be test under tensile testing and cyclic loading testing. The result for tensile test and cyclic test are shown in Figure 2.2 and Figure 2.3 respectively. The test results upon seven composite tubes showed that the failure occurred on the weakest ply which is on the 90° ply in the $0°_3/\pm25°/90°_3$ winding configuration. The conclusion of this experiment only four of the samples broke as soon as they were load. The failure of these samples indicates that certain imperfection must have been present during fabrication.

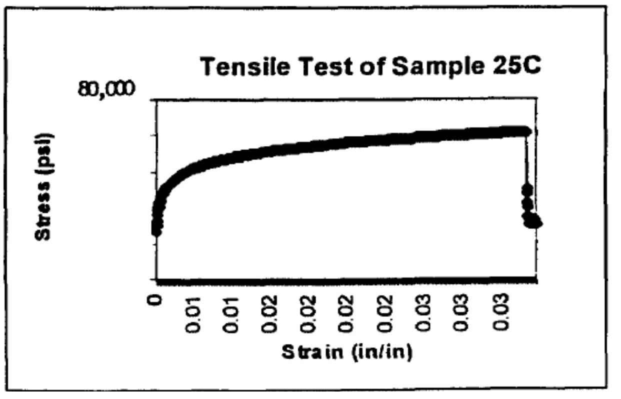

Figure 2.2: Strain-vs-strain diagram [2].

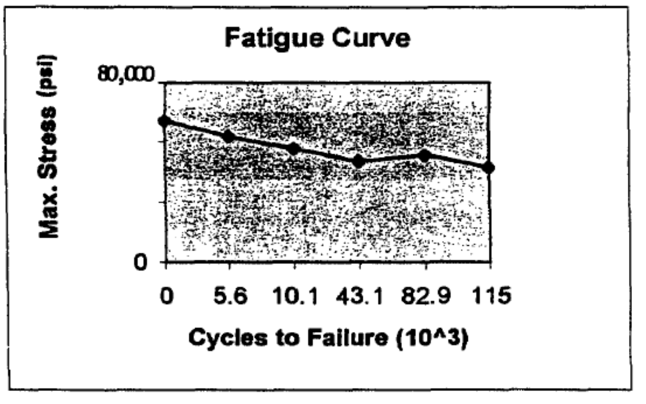

Figure 2.3: Cycles to failure of the tested specimens [2].

Another study made by A.B Isham et al. [18] in 1966 suggests a test in acquiring the strain limits for fiberglass pipes under a long term cyclic loading. The tests resulted in a recommended strain limit for fiberglass tanks intended to prevent leakage of fluid past the internal corrosion barrier under long term repeated loading. The strain limit recommended by Isham [19] was approximately 0.1%. This strain limit has been widely used over the last 30 years for fiberglass tank design. There were two major objectives in this test program. The first objective was to re-evaluate strain limits for fiberglass tank design.

Although the objective are much focused on the integrities of a fiberglass tank design, the particular parameter that is strain limit are much essentials in order to determine the method needs to obtain such results. This objective is motivated by the supposition that resins currently used in tank construction may have considerably higher strain limits than those available at the time of Isham's [19] tests. An increase in design strain limits may permit more economical design of fiberglass tanks.

Hence in an effort to mimic the same outcomes as Isham’s test Guillermo Ramirez et al. [20] paper in his paper described another similar test using composite pipe. His study consisted of 12m long composite glass/vinyl ester tubes that were then cut into 1.5m long test pieces. Each of the pipes was tested under two type of internal pressure test; monotonic and cyclic. All the data and results from the testing are carefully plotted onto a chart as per Figure 2.4 below.

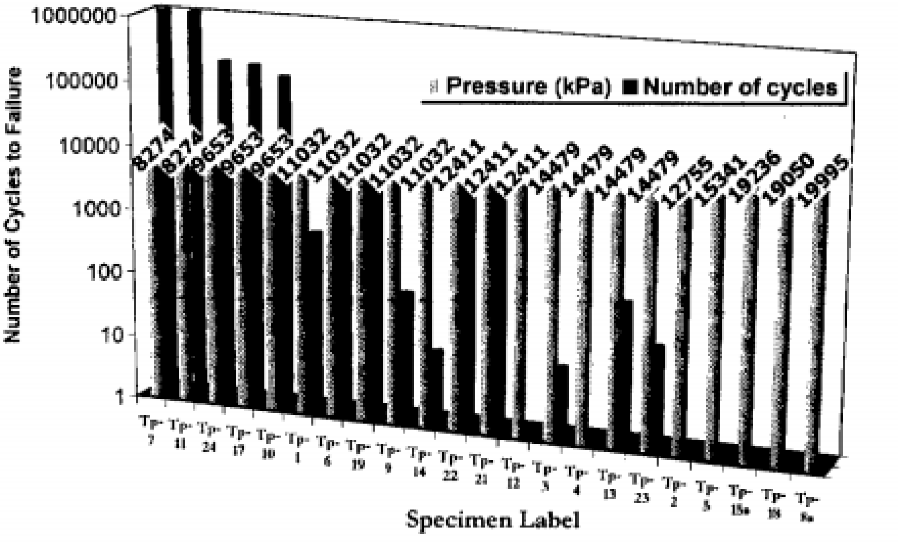

Figure 2.4: Cycles to failure of the tested specimens [20].

Note that also due to some inevitable consequence, this study will only focusing onto the burst testing only even all the requirements is fully achieve in both situation. All necessary methodology from these past papers mainly on burst test procedures will be extracted hence a complete run of setup will be arranged accordingly to adhere to the standard that are acquired from them. Upon the variation of temperature in the set of test, the procedure will not be affected as the temperature will be controlled by thermostat [1].

CHAPTER 3

METHODOLOGY

3.1. Research methodology

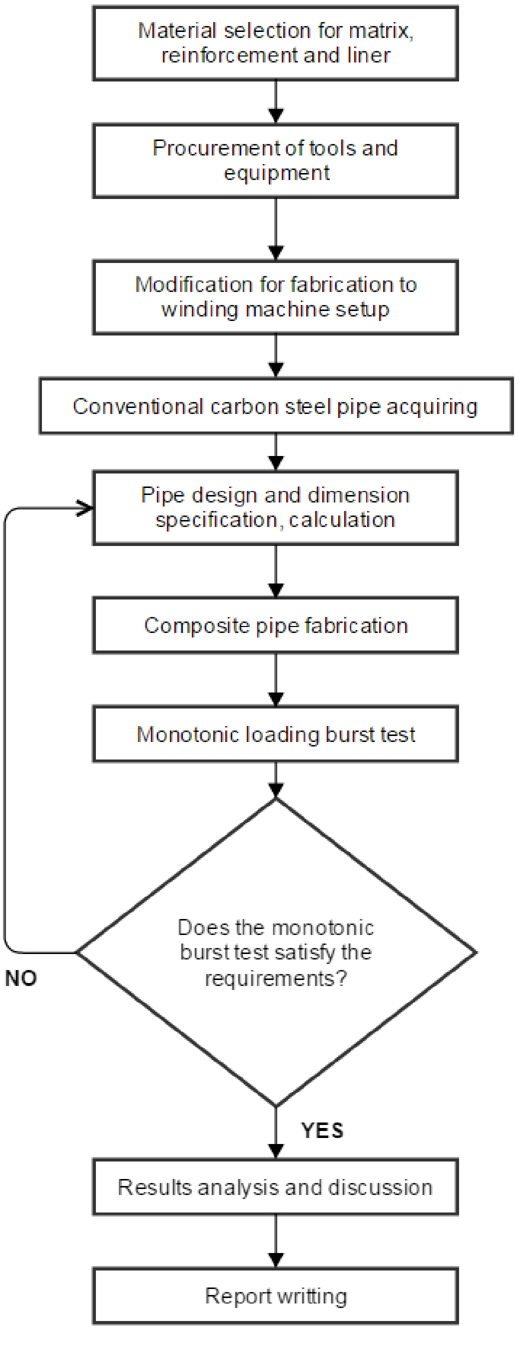

Figure 3.1: Research methodology.

3.2. Composite pipe details and dimension

3.2.1. Sample pipe size

The pipe dimension for this test will be solemnly based upon the specification of average pipe size of Miri pipelines provided by SKO [10]. The proposed design of the specimen is as shown in Figure 3.2.

- Nominal Pipe Size = 3 in.
- Liner ID = 73.6 mm ± 3.05 mm
- Liner OD = 90 mm
- Winding layers = 4 layers (±30°/±60°) approximately 4mm
- Winding preferences= 6000 strains per tow (total of 4 tows)
- Length: 500 mm
- Material preferences:
  - Matrix : Epoxy with hardener application
  - Reinforcement: Fiberglass (E-glass)
  - Liner : Polyethylene (PE) Class H

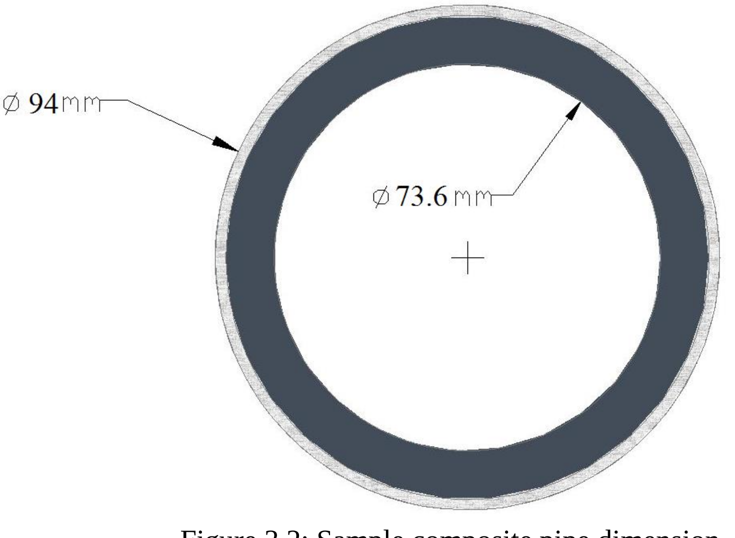

Figure 3.2: Sample composite pipe dimension.

3.3. Material selection

Composite pipe is fabricated through the combination of several elements namely; resin or matrix, reinforcement fiber and liner. All the necessary documents regards to the technical specification upon these materials can be seen in the appendices section. In a sense upon this project, all the material's properties are as follow;

Table 3.1: Material properties for composite pipes.

Material	Tensile strength (MPa)	Elasticity modulus (GPa)	Density (kg/m³)
Glass fiber	2000	73	2600
Epoxy	69	3.5	1.1 - 1.4
Polyethylene	2.75	1.38	970

3.4. Tools and equipment

The project is fully utilizing research equipment in order to obtain results through the set of experiment such as pressure testing machine and cyclic loading machine. Heavy machinery will be used in manufacturing all the pipe samples through the usage of filament winding machine that is provided by SIRIM facilities in Permatang Pauh, Pulau Pinang. The location is as shown in Figure 3.2. Recording and documentation devices such as camera and personal computer are also essentials in documenting all the works done in form of picture proofs and typed report.

Figure 3.3: SIRIM Facilities in Permatang Pauh, Pulau Pinang.

3.5. Fabrication and testing setup

The fabrication of all the tubes was done through process of filament winding as shown in Figure 3.4. For this study, the fabricated composite pipes were layered up to four layers to achieve the required thickness. The specimens' thickness expected to insignificantly vary to one another with the allowable difference up to +-2%. The actual thickness of all the specimens was measured on the top and bottom of its structure.

Figure 3.4: Fabrication using SIRIM's multi-axis filament winding machine.

The fabrication started with the separation of mandrels of glass fiber wound into a setup called a creel. The creel as shown in Figure 3.5 functioning in dividing the strands of the glass fiber equally before it is entering into a separator combs as per Figure 3.6. Inside the setup, there is a resin bath in which all the strands were fully immersed with epoxy resin inside it before the winding take place by the machine itself. This machine is able to wind up to three pipes per run. The entire batch of successful wounded pipe were then be cured inside on a rotating hangar as shown in Figure 3.7 along with its mandrels to ensure the epoxy dried up evenly onto the pipe surface.

Figure 3.5: The creel.

Figure 3.6: The separator combs.

Figure 3.7: The rotating hanger.

In order to compare the strength of the composite pipes, carbon steel will be set as the benchmark of this study. A set of experimental procedures will be made upon the non-metallic composite pipe samples in order to validate the usage of the composite pipe within the real working condition.

The test setup upon this study was carry on as per described in the ASTM D-2143. The minimum number for each specimen sample is around 18 tubes but due to availability and cost factor only 5 to 6 tubes only will be used per run. Despite a fewer number of specimens tested than as per required in ASTM D-2143, a significant data and result could still be achieved through proper means of experimentation as accordance to SIRIM preference plus this study only being a preliminary step upon future project.

The testing methodology are be divided onto two parts; the monotonic and the cyclic loading testing under the application of pneumatic pressure loading but as stated earlier, the study will be only be in terms of burst test preferences. In justifying the burst strength of the composite pipe the monotonic pressure loading testing will be commence. In this test, the pressure will be ramp up into the tubes until it reach the breakage point. The point of rupture from that testing can be used as a reference point for further cyclic testing.

3.6. Requirements and procedures

3.6.1. End-caps design

Since the machine used in SIRIM only for the testing of pressure vessels, a slight modification is required. In accommodating the pressure testing machine application, both ends of the pipe must be secured and sealed in an air tight condition by fitting an internal steel plate with sealant or a set of end-caps. Additional rubber gaskets are used to prevent any unwanted leakage. These end-caps were then been externally supported by six pieces of steel rods, longitudinally. The specification one of these end-caps (inlet end) can be seen in Figure 3.8 while a fully assembled end caps is as shown in Figure 3.9(a) and 3.9(b). The dimensions of the end-caps are as follows;

- Outer diameter: 165mm
- Inner diameter: 92mm
- Height: 30mm
- Depth of cavity slot: 20mm

Figure 3.8: Inlet end of the end-cap.

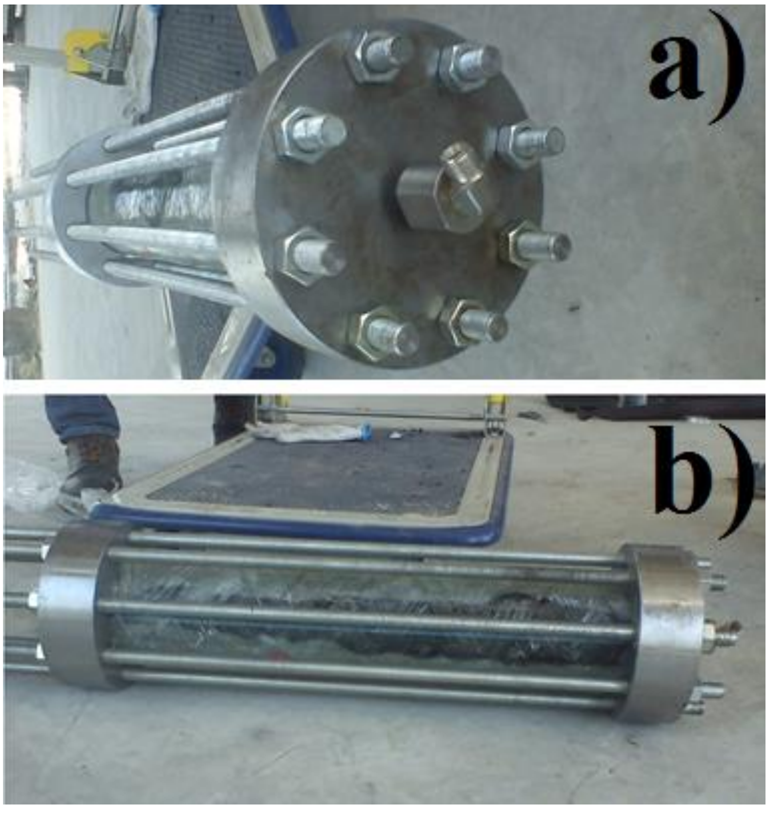

Figure 3.9: Fully assembled end-caps setup a) top view) and b) side view.

3.6.2. Thickness and pipe dimension gauging

The cured pipe samples as shown in Figure 3.10 are labelled from A to F in no particular order for personal tracing purposes only. The sample length will be first measured using a ruler. All test samples are recorded the approximately the same length of 500mm. the wall thickness is then be measure using a Vernier caliper by choosing three point on the pipe's lips that are 60 degrees apart from each other at both end of the pipes. The average thickness of all the samples is calculated using the three points measured before. All the recorded measurements are carefully tabulated in the Table 3.2.

Table 3.2: Specimen thickness measurement.

Specimen	Measured length (mm)	Measured thickness (mm)			Average thickness (mm)
		Point 1 (0°)	Point 2 (120°)	Point 3 (240°)	
A	497.8	10.31	10.32	10.33	10.32
B	498.1	10.08	10.07	10.11	10.09
C	502.3	10.33	10.29	10.3	10.31
D	497.5	10.35	10.32	10.35	10.34
E	501.7	10.21	10.21	10.23	10.22
F	499.3	10.64	10.63	10.65	10.64

Figure 3.10: Cured composite pipe samples.

3.6.3. Burst test (monotonic loading)

The purpose upon this testing is to determine the peak load of each sample as well as to set the first point for the cyclic loading testing. This test will requires one or two test only in obtaining the data with accordance to availability and necessity. In this testing, the pipe will be first been filled with water. After both ends have been securely closed, the setup will be place inside a bunker as shown in Figure 3.11. The pressure will ramp up into the pipe in a significant increment rate through the modified inlet through a controller unit. The pressure will continuously force into the pipe up till one point the pipe burst or started to fail. The time taken and cycles to failure for the pipe to burst will be recorded. Note that the testing will be done under constant room temperature. All ultimate pressure and burst pattern are carefully observed and recorded.

Figure 3.11: Test bunker.

3.7. Project activities

Table 3.3: Project activities for FYP 1.

REQUIRED TIME (WEEKS)	ACTIVITIES
2	**1) Starts of FYP 1** - Title proposal - Title confirmation
3	**2) Research and detailed studies** - Recent technology - Journal research - Carbon steel properties
3	**3) Design and fundamentals knowledge** - Pipe in oil and gas - Non-metal composites - Filament winding
2	**4) Project planning** - ‘What, when, why, who and how’ planning - Gantt chart
3	**5) Pre-fabrication** - Material selection - Manufacturing method - Availability
1	**6) End of FYP 1** - Conclusion an discussion - Future planning for FYP 2 - Summarize project paper

Table 3.4: Project activities for FYP 2.

REQUIRED TIME (WEEKS)	**ACTIVITIES**
3	**1) Starts of FYP 2** - Theory and research works - Product design and specification
4	**2) Composite pipe fabrication** - Fabrication method - Material selection - Quality control and standards
5	**3) Mechanical test validation** - Test on mechanical properties regards to monotonic loading - Following industrial standard - Data gathering and ordering - Data analysis - Verify justified performance based on carbon steel pipes
3	**4) End of FYP 2** - Conclusion and discussion - Recommendation - Summarize project paper - Objective review and feasibility

3.8. Gantt chart and key milestone

Table 3.5 shows a general process flow upon of this study along with appointed key milestone set throughout the FYP 1 and FYP 2 periods.

Table 3.5: Gantt chart and key milestone for FYP 1 and FYP 2.

Key Milestones and Project Activities	Duration (Week)																												
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29
Preliminary Research Work						10/11																							
-Selection of fabrication method																													
-Determination of winding angle																													
-Selection of Pipe Material																													
-Quality controls and standards																													
Materials and Tool Procurement														11/01															
-HDPE Liner																													
-Fiberglass Reinforcement																													
-Epoxy Resin																													
Fabrication of Pipe																				16/02									
-Equipment and material setup																													
-Winding of ±30°/±60° angle composite pipe																													
-Finishing and segmentation of the samples																													
Fabrication of Testing Apparatus																							13/03						
-End cap design																													
-End cap modification																													
-End cap fabrication																													
Testing of Hoop Tensile																										02/04			
-End cap installation																													
-Test run for burst test																													
-Actual test for burst test																													
Data Analysis and Report Writing																													20/04

CHAPTER 4

RESULT AND DISCUSSION

4.1. Results analysis

This section mainly focuses on the burst performance under ambient temperature of 27°C in the monotonic loading test. At the initial stage of the test, it was found that the pipe managed to withstand a hydrostatic pressure load up to 106 Bar. However, the result was compromised since there was no burst or punctured pattern observed in the inner liner. The composite pipe was breaking underneath the composite layers due to water leakage from the inner system. The leaking problem was due to poor end-cap design. Both of the end-caps tend to become loose as the pipe sample started to expand. After a few discussions with SIRIM's design team, the end-caps configuration is redesigned hence solving the leakage problem. The new end-cap design consists of a pair of additional internal slip-on cartridge with three silicon O-rings attached to each of its body as shown in Figure 4.1. The O-rings provide an extra grip as well as to prevent any potential leakage that might happen. This component was slotted into the inner side of the test pipe. Two pairs of pipe clamp as shown in Figure 4.2 were installed in both ends to ensure a firm grip between the pipe and the end-caps. The test was successfully performed, resulting in expected range of pressure before bursting.

Figure 4.1: Internal slip-cartridges.

Figure 4.2: Steel pipe clamp.

The burst test was carried out without any leakage, producing a maximum pressure of 125 Bar. The burst pattern of 106 Bar with leaking problem is shown in Figure 4.3, while the burst pattern of 125 Bar without any leakage is presented in Figure 4.4. The result may be used as a reference point for cyclic loading test. Note that the burst test was performed under room temperature.

Figure 4.3: 106 Bar burst pattern before end-caps modification.

Figure 4.4: 125 Bar burst pattern upon end-caps modification.

Repeated burst test using the modified end-caps were not successfully due to leakage problems. These results indicate that further improvement of the end caps is required. The recommended design of end caps is discussed in the next chapter. At the beginning of this project, the main focus was to perform burst test successfully followed by cyclic loading test. However, by the end of this project, the focus was shifted into designing a working end caps for burst test. Therefore, it is imperative for future researchers to solve the end-cap issue first before any repeated burst test and cyclic loading test can be carried out successfully.

CHAPTER 5

CONCLUSION AND RECOMMENDATION

5.1. Conclusion

The aim of this project is to create a test setup in evaluating internal pressure performance of a non-metallic composite pipe based on local average condition of oil and gas industries. The fabrication of these non-metallic composite pipes was successfully done using filament winding machine. Several conclusions can be made from this project:

i. Leakage problem of the end-caps hindered the project progress.

ii. Improper design of end-cap was identified as the main issue.

iii. Burst test result of 106 Bar was achieved with the non-metallic composite pipe. However, leaking problem was still observed.

iv. After several modification been made towards the end-cap design, 125 Bar burst test result was obtained without any leakage problem. However, repeating burst tests using the modified end-caps failed due to same continuous leaking problem.

v. Therefore, a further modification and enhancement in the end cap design is essentials in ensuring the smoothness of future endeavors.

5.2. Recommendation

For future work, some recommendations are presented according to priority in solving or improving certain scopes. The suggestions are as follows:

i. Further improvement of the end-caps design is required to avoid any unwanted leakage problems. A suggested design improvisation can be implied as shown in Figure 5.1 with a much better design consideration for an end cap in evaluating burst limit and cyclic loading application test.

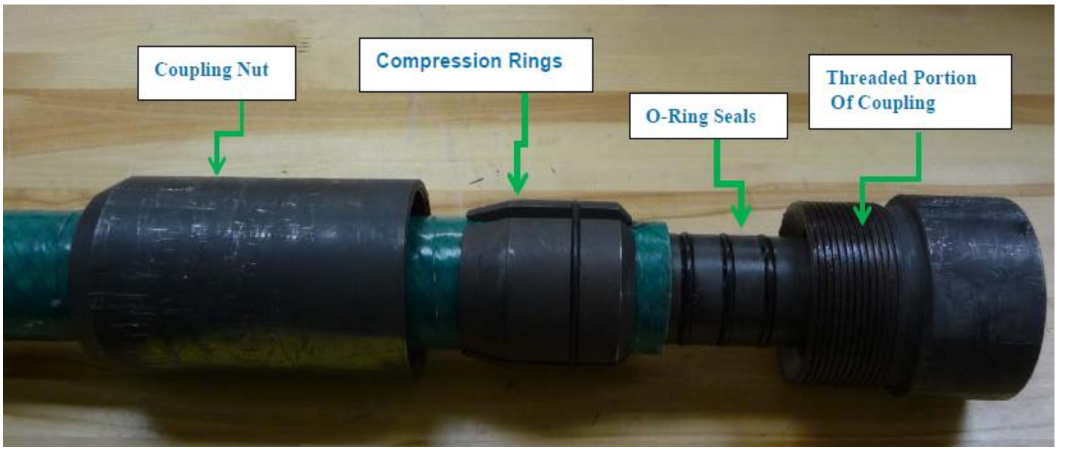

Figure 5.1: Improved end-cap design.

ii. Due to the high thickness of HDPE, the liner material can be substituted with of a much lighter material such as poly-amide or PA11 in order to reduce the overall weight upon the composite pipe.

iii. Optimization of the manufacturing parameter in filament winding process should be carefully monitored to enable a high quality filament wound pipe.

Since this study is just on its preliminary stage, several modifications can be made especially for the filament winding process. Extra effort should be continued to alter the manufacturing parameters to improve mechanical properties of the filament wound composite pipe. Substitution of liner, matrix, and fiber materials should also be done to ensure the pipe can withstand higher loading application.

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