Effect of Physical Fiber Lay of FRP Winding Composite on Mechanical Properties

by

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14904

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CERTIFICATION OF APPROVAL

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A project dissertation submitted to the

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Approved by,

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TRONOH, PERAK

January 2015

CERTIFICATION OF ORIGINALITY

This is 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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NUR AMALINA BINTI RAMLAN

ABSTRACT

Nowadays, fiber-reinforced plastic (FRP), a composite material made of a polymer matrix reinforced with fibers, are widely used for many industries especially construction and oil and gas industry. Filament winding is one of the fabrication techniques used to wound FRP and contributes in enhancing the mechanical properties as well as great reduction of weight of the composite. This project discusses on the effect of physical arrangement of Carbon Fiber Wound to HDPE Composite Pipe (CFWHCP) on its mechanical properties. Instead of similar size of fiber tow, different sizes of fiber tow are used in the winding process. 2 types of sample with winding angle of 57°: CFWHCP of 6 fiber tows of same size (12k) and different size (12k and 6k); were fabricated with epoxy as binder in SIRIM Permatang Pauh. The properties of the samples were studied by SEM analysis and tensile test. It was found that the no-fiber triangle area for 12k and 6k Carbon Fiber with Epoxy resin (CFE) is larger than 12k CFE. This is due to the lower fiber content in 12k and 6k CFE. The result from the tensile test shows that CFE with 12k fiber tows have higher tensile strength and elastic modulus as compared to 12k and 6k CFE. Hence it is concluded that the different size of fiber tow with the maintained number of tows and bandwidth size has reduced the original properties of tensile strength and elastic modulus. The area of no-fiber triangle also has increased.

ACKNOWLEDGEMENT

Alhamdulillah, Praise to Allah, the Most Gracious, Most Merciful, Most Wise for His Blessings, giving me the opportunity to still live in this world and oblige my duties as a Muslim. Blessings by Allah S.W.T to Prophet Muhammad (peace be upon him) for his sacrifices in his duty, spreading knowledge in the name of Allah S.W.T and teaching us the beauty of Islam.

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CHAPTER 1
INTRODUCTION

1.1 Background

The technological advances in various sectors have created demand for newer materials, where they are required to perform in tough conditions such as high pressure and temperature, high corrosive environments, high strength requirement, which the conventional materials failed to service. Industry has recognize that the capability of composite materials in producing high quality, cost-effective and durable products.

In the context of one of the composite materials, fiber-reinforced plastics (FRP), the strength and stiffness depends on the proportions of fiber and resin, distribution and orientation of fiber, type of resin, type of fiber, length of fiber for discontinuous fiber, and void content. Nowadays, filament winding is used widely to wound the composite pipe and pressure vessel to enhance the mechanical properties as well as great reduction of weight of the composite. In filament winding, winding tension, winding angle and resin content in each layer of reinforcement can be varied until desired thickness and strength of the composite are achieved [1].

Usually, similar sizes of fiber tow are used in winding process. It is noticed that, by using similar sizes of fiber tow it will form a triangle at every crossing part, which will then give tendency to produce larger voids and affect the stiffness and strength of the product. Tendency of producing voids can be reduced by introducing varied sizes of fiber tow of the band width. This will enhance the mechanical properties of the product.

This project will investigate the effect of physical arrangement of carbon fiber tow to wind FRP composite on mechanical properties. Instead of similar size of fiber tow, different sizes of fiber tow will be used in the winding process. Optimum wrap-angle for the filament winding will be identified and used in the fabrication of the test sample.

1.2 Problem Statement

Usually, 5 to 8 of similar fiber tow which vary from 12k, 6k and 3k are used in winding process. It is detected by using same sizes of fiber tows, a triangle will form at every crossing part which will lead to forming larger void content, thus, affect the stiffness and strength of the FRP. Figure 1 illustrates the cross section of FRP with large voids when using similar fiber tow.

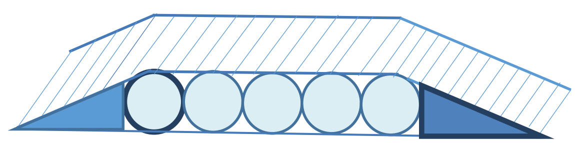

Figure 1: Cross section model of fiber bandwidth with similar fiber tow

Tendency of producing voids can be reduced by introducing varied sizes of fiber tow of the band width. Even though the void will be filled by matrix, the strength and stiffness of the wound composite cannot achieve the optimum. However, by introducing the different size of fiber tow at the both end of fibers bandwidth it will fill in the empty space thus increasing the strength and stiffness.

1.3 Objectives and Scope of Study

The objectives of this study are:

1. To review on wrap-up of fiber composite using the filament winding method and their optimum wrap-up angle
2. To investigate the effect of the physical arrangement of Carbon Fiber Wound to HDPE Composite Pipe (CFWHCP) on its mechanical properties.

The scopes of study of this project are:

1. The principle of operation of filament winding on FRP.
2. Understanding the variables affecting the strength and stiffness of FRP.
3. Optimum wrap-up angle of winding FRP using filament winding method.
4. Effect of the physical arrangement of carbon fiber tow to wind FRP composite on mechanical properties.

CHAPTER 2
LITERATURE REVIEW

2.1 Composite Material

Composite materials are materials made from two or more constituent materials with significantly different physical or chemical properties that will produce a material with different characteristics from individual components when combined. Most composites are composed of a bulk material and a reinforcement material, generally fibers. The reinforcement materials will have extremely high compressive and tensile strength. However, these theoretical values are not achieved in structural form. This is due to the surface flaws or material impurities, which results in crack formation and failure of the piece below its theoretical strength [2].

In order to overcome this problem, reinforcement is produced in fiber form, which prevents crack formation through the whole body. However, a matrix should be used to hold these fibers together, and improve material properties in the transverse direction of the fiber. Composites are commonly classified based on the type of matrix used: polymer, metallic and ceramic. Apart from holding the fibers together, the matrix also functions to protect the fiber from damage due to elevated temperatures, humidity and corrosion, as well as spreading the load equally to each individual fiber.

2.2 Fiber-Reinforced Plastic

Fiber-reinforced plastic (FRP) is a composite material made of a polymer matrix reinforced with fibers. Usually, the fibers are glass, carbon, basalt and aramid. The polymer is usually epoxy, vinylester and phenol formaldehyde. FRPs are usually used in the automotive, aerospace, construction industries, marine and ballistic armor. FRPs are a category of composite plastics that specifically use fiber materials to mechanically enhance the strength and elasticity of plastics.

FRPs consist of high modulus reinforcing fibers embedded in a low modulus polymeric matrix. The combination of the two distinct phases allows load to be transferred between fibers due to elasticity in the matrix. The matrix also serves to separate and protect fibers. The stiffness and strength of a FRP depends on proportions of fiber and resin, distribution and orientation of fiber, type of fiber, type of resin, length of fiber for discontinuous fiber and void content [3].

Composite stiffness can be predicted using a micro-mechanics approach termed the rule of mixtures. Where the rule of mixtures' equation is as Eq (1) below;

$$E_C = E_F V_F + E_M V_M = E_F V_F + E_M (1-V_F) \qquad (1)[4]$$

where : E_C = tensile strength of the composite

E_F = tensile strength of the fiber

E_M = tensile strength of the matrix

V_F = volume fractions of the fiber

V_M = volume fractions of the matrix

The strength of the composite is contributed by those factors. With fibers having larger tensile strength than matrix, fibers contributed higher than matrix to the strength of the composite. Higher volume fraction of fibers will lead to higher tensile strength of the composite.

Void content play an important role to the strength and stiffness of FRP. An investigation on the random-chopped FRP composites containing high volume fraction of air voids found that higher volume fraction of voids leads to a lower effective stiffness of the composites [5]. Figure 2 shows the Young's modulus of composites against void contents graph where the Young's modulus decreases with increasing void content. Figure 3 shows the stress-strain curves of different volume fraction of fiber. It indicates the higher the fiber content, the higher the tensile strength.

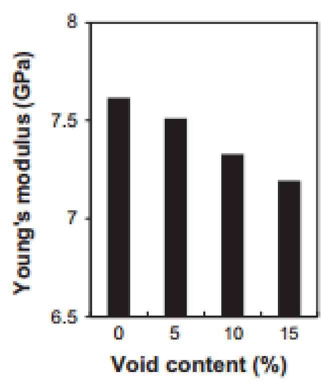

Figure 2: Young's modulus of composites with respect to void content

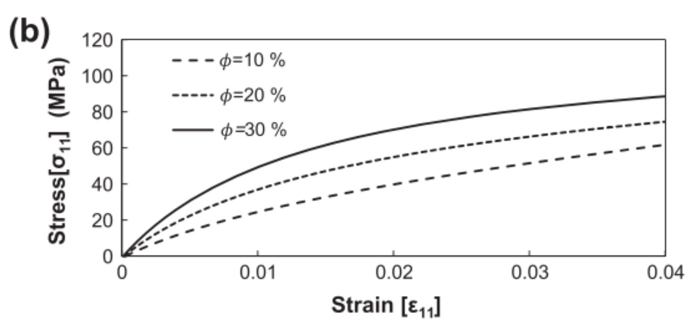

Figure 3: Stress-strain curves with different volume fraction of fiber

Zhang et al [6] studied the tensile strength of hygrothermally (related to heat and moisture) conditioned carbon fiber composites with voids. The experimental results had shown that the rate of water uptake increases when porosity (void) increases which proves that voids facilitate moisture absorption. The tensile strength of non-aged specimens decreased 0.8% with porosity of 0.33% to 1.5%. This proofs that tensile strength decreased with increasing amount of voids.

2.3 Filament Winding

Filament winding is a type of fabrication technique for manufacturing open or closed end structures. The process involves winding fiber tows over a male mandrel under tension. The fiber tows are passed through a resin bath to impregnate the tow and then wrapped around a mandrel prior to curing at elevated temperature in an oven. The mandrel rotates while a wind eye on a carriage moves horizontally, putting down fibers according to the desired pattern. Once the mandrel has been covered completely according to the thickness desired, the mandrel is placed in an oven to solidify the resin. The mandrel is then removed thus producing the hollow final product.

In filament winding, there are some parameters that can be varied, which are mandrel temperature, winding tension, bandwidth, winding angle and resin content in each layer of reinforcement. This is to ensure desired thickness and strength of the composite is achieved. Bandwidth is the amount of tow advance per one revolution of the mandrel. These parameters will affect the composition of the cured composite material in terms of the fiber, resin and void content [3]. The properties of the finished composite can be varied by the type of winding pattern selected. Three basic filament winding patterns are hoop winding, helical winding and polar winding. However most popular and great versatility of winding been used in the industry such as vessel and piping is helical winding.

Almost any combination of diameter and length may be wound by trading off wind angle and circuits to close the patterns. Usually, all composite tubes and pressure vessels are produced by means of helical winding. Figure 4 shows the mandrel rotates at a constant speed while the fiber feed carriage transverses back and forth at a speed regulated to generate the desired helical angles.

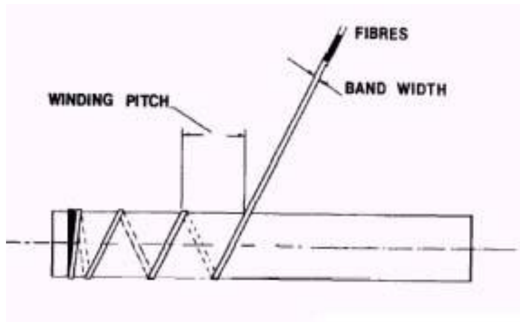

Figure 4: Helical angle of winding

It is important to find the optimum winding angle for filament winding. Several efforts have been done to achieve this purpose. Netting analysis is one of the attempts to optimize composite tubular structures. This technique assumes that fibers supported all loads, neglecting the contribution of the matrix and the interaction between the fibers [7]. The optimum angle obtained from this technique which is 54.74° is normally used to manufacture composite tubular structures under close-end loading condition.

Optimum winding angle can be estimated by using ultimate tensile strength along with applying netting analysis respect to 2:1 hoop-to-axial stress ratio as it is shown at Eqs. (2) and (3)., as illustrated in Figure 5. The body diagram of the cylinder consists of axial and hoop forces wrapped with the fibers at the angle of "α" is indicated at Figure 5 [8].

$$N_\theta = \sigma_u t \, sin^2\alpha \quad , \quad N_\phi = \sigma_u t \, cos^2\alpha \qquad (2)$$

$$\frac{N_\theta}{N_\phi} = tan^2\alpha = 2 \rightarrow \alpha = arc\,tan\,(\sqrt{2}\,) = 54.70 \qquad (3)$$

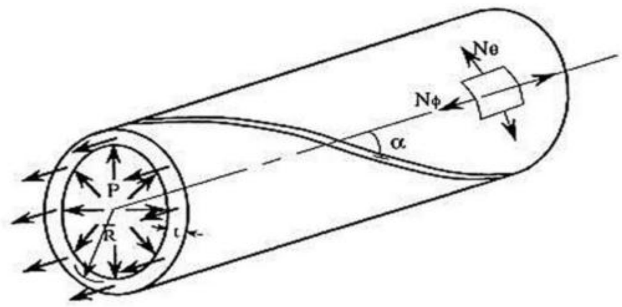

Figure 5: Body diagram of axial and hoop forces and internal pressure

Rosenow [9] performed experimental studies on composite tubes under uniaxial and biaxial loading to predict the optimum angle through stress and strain analysis. It shows that filament wound composite tubes should be wound at 75° for open-end tubes, at 54.75° for closed-end tubes. Parnas and Katirci [10] developed an analytical procedure to design and predict the behavior of fiber reinforced composite pressure vessels based on classical laminate theory. From that procedure for internal pressure loading, they found optimum winding angles to range between 52.1° and 54.2° depending on the geometry and failure criteria used.

Carbon fiber is commonly used in industry application especially on winding because the mechanical properties are excellent. In common practices, 5 to 8 similar fiber tows are used, varying from 12k, 6k and 3k in winding process. Figure 6 shows the hypothesis model of fiber band width of winding composite by using similar sizes of fiber tow. It is noticed as demonstrated by Figure 7, by using the similar sizes of fiber tow; a triangle will be formed at every crossing part, which give the tendency to provide large non-fiber triangles and will affect the stiffness and the strength of the product.

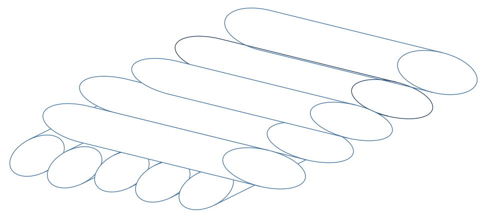

Figure 6: Model of fiber band width of winding

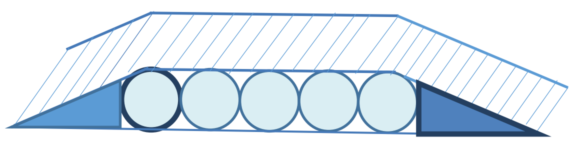

Figure 7: Cross section model of fiber bandwidth with similar fiber tow

Tendency of producing voids can be reduced by introducing the physical arrangement of varying fiber tow of the band width as illustrated in Figure 8. This will enhance the mechanical properties of the product.

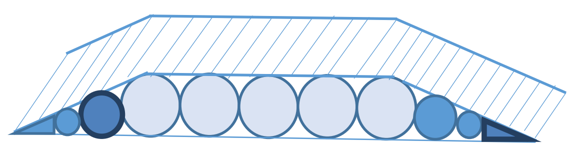

Figure 8: Cross section model of fiber band width with additional fiber tows

2.4 Application of FRP in Oil and Gas Industry

Fiber-reinforced plastics also give contribution to oil and gas industry especially making pipelines for transportation of oil and gas. FRP pipelines are believed to be better as compared to steel pipelines. Figure 9 shows an example of FRP winding pipelines. A research on Reinforced Composite Piping (RCP) Technology using FRP found that FRP are better than steel in terms of the weight which is lighter, able to withstand high internal pressures, good corrosion resistance, impact resistance and torsional stiffness, lower life cycle cost, have smooth surface and better dimensional stability over temperature fluctuations [11].

Figure 9: FRP Winding Pipelines

It is proved that FRPs are better in terms of corrosion resistance as compared to steel where an experience from an oil company's use of Glass FRP pipes in low pressure water injection networks at offshore installations outside the coast of Africa finds that there are no signs of corrosion detected with Glass FRP pipes after 2 years whereas the first holes were observed after approximately 6 months with carbon steel [12]. Candidate materials for tubular for West Kuwait oil fields including three FRPs - phenolic, vinyl ester and epoxy resin; two steels - N-80 and L-80 steels were tested for Microbially Influenced Corrosion (MIC) attack at high salt concentrations. All steel coupons were attacked. There was no evidence of attack of the vinyl ester or epoxy based FRP coupons by microorganisms. The surface gel coat of the vinyl ester and epoxy materials did not change in appearance and was not attacked or damaged by the bacteria. This shows FRP tubulars performed better than those from low alloy steels [13].

The potential for weight savings by substitution of steel pipes with FRP pipes is one of a major reason for the increasing application of FRP pipes in oil and gas industry. Several investigations made had shown it can be concluded that the use of FRP pipes generally reduces the weight in the range of 50-60%. In some cases weight savings can be up to 80%. The weight savings obtained will depend on the design of the pipe system, working conditions and the pipe dimensions. An analysis of total weight/installed costs for different material alternatives (Glass FRP and stainless steel) has been made for selected parts of the sea water system on the Gullfaks A platform. Comparison of results for Glass FRP pipes and high molybdenum alloyed stainless steel indicated a weight savings for GRP of about 50 % for the selected part [12].

Carbon fiber reinforced composite (CFRP) is also found to be ideally suitable material for deep ocean applications. CFRP specimens when exposed at four depths namely 500, 1200, 3500, 4800 and 5100 m depths for 174 days did not lost in weight from weight loss measurement [14]. Tensile test results showed that ultimate tensile strength of exposed specimens compared very well with control specimens. Tensile modulus data showed no significant variation in property compared to control specimens. Compressive strength of exposed specimens also matched well with control specimens. Flexure strength is also not affected by deep sea exposure. Inter-lamellar shear strength also had not undergone any change to show that fiber/matrix interface is not affected by deep-sea environment.

This is further confirmed from high temperature test (150°C), material had not undergone any change in property even after exposure in deepwater. It is proved from scanning electron microscope (SEM) observations that fiber pull-out and fiber-matrix interface failure were not seen. Microbiological observations revealed that bio-film formation on composite surface was not observed at all depth levels studied. From these observations it is concluded that carbon fiber reinforced composite is a suitable material for deepwater applications.

CHAPTER 3
METHODOLOGY

3.1 Process Flow

Figure 10 illustrates the flow chart of the project. The project starts with preliminary studies on the fiber reinforced plastics. The samples are then fabricated and lab experiments are done. The results are then analyzed and the project concluded.

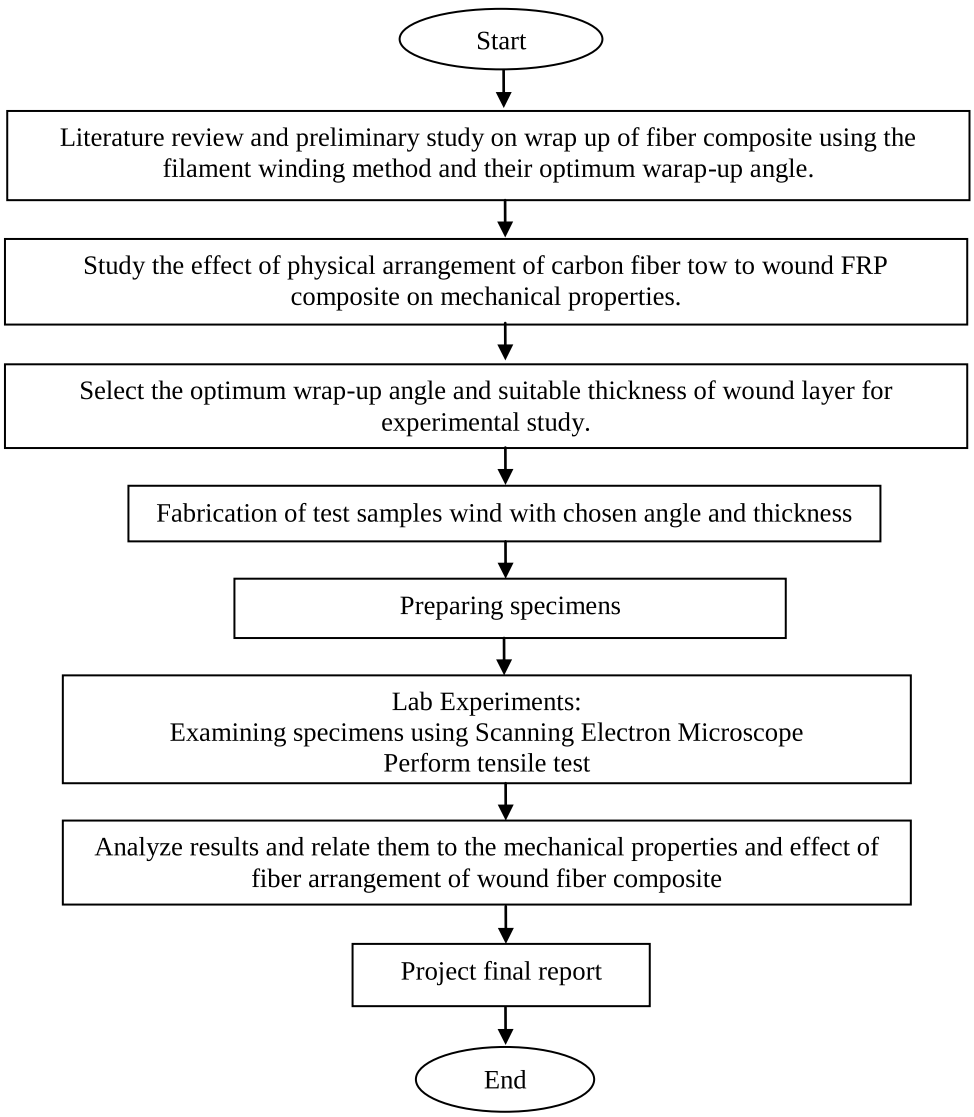

Figure 10: Flow Chart of the Project

3.2 Research Methodology

3.2.1 Preliminary Research Work

This stage focuses on data collection related to the project. All information from journals, articles, technical papers and books that are related to this project are gathered and compiled to have a better understanding to the project. Meeting with the supervisor are also done to have a better overview regarding the project that will be done including recommendations suggested by the supervisor.

3.2.2 Fabrication of Carbon Fiber Wound to HDPE Composite Pipe (CFWHCP)

In this project, two samples of CFWHCP at selected winding angle and similar thickness, but one with same carbon fiber tow size and one with different sizes of carbon fiber tow are produced by using filament winding machine in SIRIM Berhad.

Sample 1:

- HDPE Liner : Internal diameter – 2”
  External diameter – 2.375”
- Carbon Fiber : Six 12k Fiber Tow (arrangement as in Figure 11; 6 layers; using TORAY carbon fiber
- Matrix : Epoxy
- Winding Angle : 57°

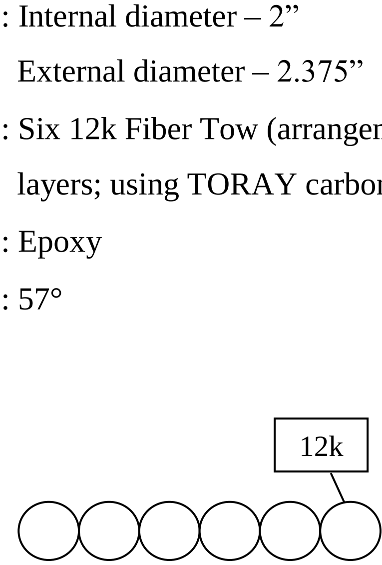

Figure 11: Arrangement of Sample 1

Sample 2:

- HDPE Liner : Internal diameter – 2"
  External diameter – 2.375"
- Carbon Fiber : Two 12k and four 6k Fiber Tow (arrangement as in Figure 12); 6 layers; using TORAY carbon fiber
- Matrix : Epoxy
- Winding Angle : 57°

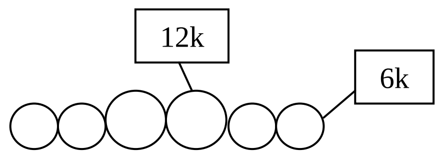

Figure 12: Arrangement of Sample 2

3.2.2.1 Filament Winding Machine

The fabrication process was done in SIRIM Permatang Pauh using filament winding machine. The 3-spindle, 4-axis filament winding machine was produced by SIRIM Berhad which is used to wound the compressed natural gas (CNG) tank used in natural gas vehicle (NGV) for industrial application.

3.2.2.2 Fabrication Process

The process of fabricating the carbon fiber reinforces plastics is as below:

1) The mandrel consisting of HDPE pipe (Figure 13) is attached to the machine.

Figure 13: Liner for Winding

2) Six 12k fiber tows of carbon fibers are passed through the resin bath (as shown in Figure 14) consists of epoxy. This process is shown in Figure 15. As it rotates, the roller comes in contact with the fibers, so that the fibers are coated with the resin.

Figure 14: Resin Bath

Figure 15: Passing Through the Carbon Fibers into the Resin Bath

3) Then, the fibers coated with epoxy are wound around the mandrel (Figure 16).
4) The fibers move in lateral movement while the mandrel rotates with constant speed. Several lateral movements are made to achieve the 6 layers thickness. The setup of filament winding is shown in Figure 17.

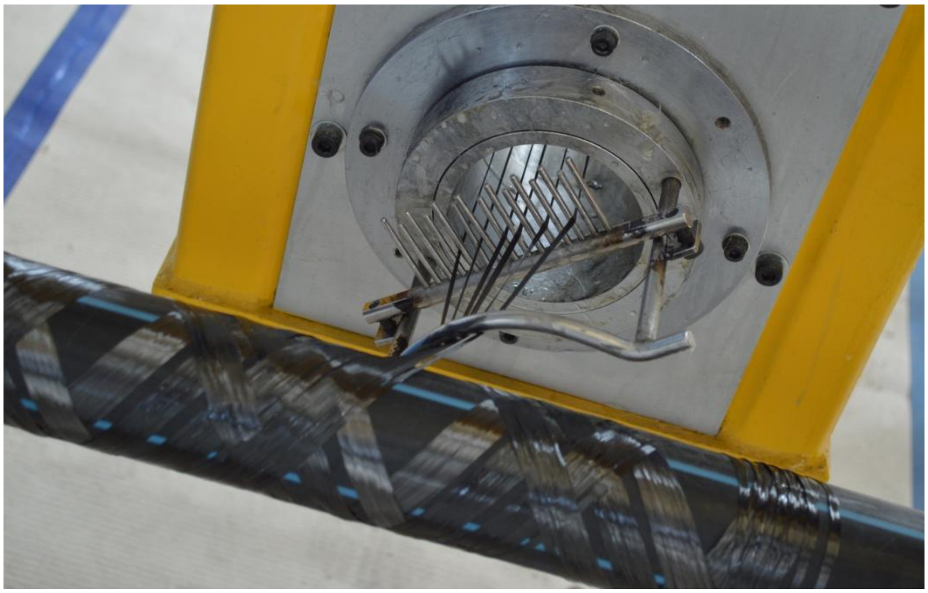

Figure 16: The Fibers Wounding the Mandrel

Figure 17: The Setup of the Filament Winding Process

5) The fiber tows are cut when the sample finished. The mandrel rotates for a few hours until the sample has hardened.
6) The sample was removed from the mandrel and placed in an oven (Figure 18) (60 °C) in duration of 3 hours for curing.

Figure 18: Inside the Curing Oven

7) Steps 2 to 6 are repeated using four 6k fiber tows and two 12k fiber tows.

3.2.3 Scanning Electron Microscope (SEM)

SEM is used to examine microstructure of the Carbon Fiber with Epoxy resin (CFE) samples and the no-fiber triangle at different arrangement of fiber tow (fiber tow of same size and different size). The examination of the microstructure is done using a SEM model Phenom World Pro X (Figure 19) that produces images of a sample by scanning it with a focused beam of electrons. SEM can give information about the sample's surface topography and composition. Table 1 below shows the technical specifications of the SEM.

Figure 19: Scanning Electron Microscope (SEM)

Table 1: Technical Specifications of SEM

	Specifications
Light optical magnification	20 - 135x
Electron optical magnification range	80 - 100,000x
Resolution	< 17 nm
Digital zoom	Max 12x
	Color
High voltages	Adjustable range between 4,8 kV and 15 kV imaging and analysis mode
Sample Size	Up to 32 mm (Ø)
Sample Height	Up to 100 mm

3.2.3.1 Sample preparation

3.2.3.1.1 Sectioning and Cutting

The first step in preparing a specimen to analyse the microstructure is to locate the area of interest. Cutting and sectioning is the most common technique to obtain the area of interest. Proper cutting will produce flat and cut close to the area of interest and minimal damage.

In this project, the area of interest is the area where the group of fiber tows intersects, as shown in Figure 20. At this area is where the no-fiber triangles expected to be seen. After the area of interest is determined and marked, the CFE is cut into smaller specimens (as shown in Figure 21).

Figure 20: The cutting area

Figure 21: The specimens

3.2.3.1.2 Mounting

The specimen must be mounted for convenience in handling and viewing under the microscope, and to protect the edges of the specimen being prepared. Mounting is also purposed to get the flat surface of sample so that it would be easier for grinding process to take place. The specimens are mounted using cold mounting method. The procedure is as follows:

1) The resin mixture is prepared. The ratio of epoxy resin to hardener is 10:1. The epoxy and hardener is shown in Figure 22.

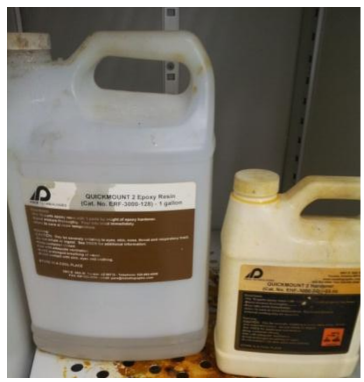

Figure 22: Epoxy and Hardener

2) Mounting cup is prepared by applying release agent into the cup which will help in removing the sample easily later.
3) The specimen is placed in the bottom center of the cup with the surface to be examined faced down.
4) The resin mixture is poured into the mounting cup.
5) The sample is left to solidify in approximately 8 hours.
6) After the sample solidifies, the cap is opened and the sample is removed from the cup (Figure 23).

Figure 23: Removing the sample

3.2.3.1.3 Grinding

Grinding process was performed by using Grinder and Polisher machine model Metaserv 2000 (Figure 24). The samples were grind with SiC paper with running water. The SiC paper used ranged from the 240 grit to 1200 grit. The grinding process is done from coarsest to finest grit paper. This is to eliminate the scratches from the previous grinding stage.

Figure 24: Metaserv 2000

The grinding procedure is shown as below:

1) SiC paper is placed on the grinding place, as shown in Figure 25, starting from 240 grit size. Water line is opened.

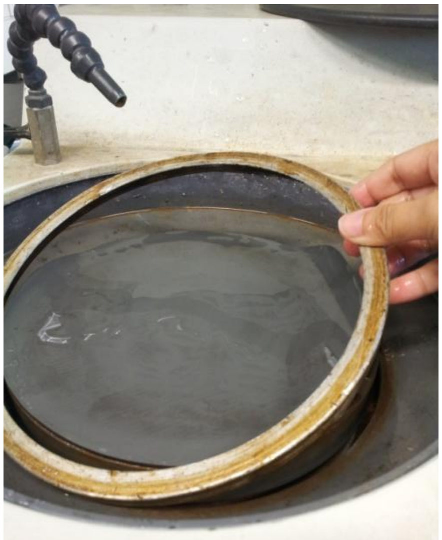

Figure 25: Placing SiC paper

2) The machine is switched on and the specimen is placed on the grinder, with the surface to be examined faced down (Figure 26).

Figure 26: Grinding the specimen

3) Grind for 1 to 2 minutes.
4) .Step 1 to 3 are repeated using different grit paper; 320, 400, 600, 800, 1200 grit size.
5) Close water line.

3.2.3.2 SEM Procedure

The SEM is done based on the procedures as follows:

1) The sample is placed in the holder (Figure 27).

Figure 27: Placing the sample in holder

2) The holder height is adjusted (Figure 28).

Figure 28: Adjusting the holder height

3) The holder is placed in the Phenom (Figure 29).

Figure 29: Placing the holder in the Phenom

4) The microstructure is observed from the desktop. The resolution can be adjusted accordingly.

3.2.4 Tensile Tests

Tensile tests were performed to measure the tensile properties like tensile strength, tensile modulus and elongation at break. The tensile tests were measured by using a universal testing machine model AI-7000 M (Figure 30) according to ASTM D638. Table 2 shows the technical specifications of the machine.

Figure 30: AI-7000 M Universal Testing Machine

Table 2: Technical specifications of universal testing machine

	Specification
Capacity	10, 20 kN
Load Resolution	1/200,000 (or 1/300,000 specified by user)
Stroke (exclude the grips)	1100 mm
Effective width	410 mm
Test Speed	0.001~1000 mm/min or 0.001~1500 mm/min selectable
Sample Rate	1000 times/sec
Motor	AC Servo Motor
Power	1∮, 220V, 15A , 50Hz/60Hz or specified by user

3.2.4.1 Tensile Test Procedure

Two samples for each different type of sample are tested. The examples of each sample are shown in Figure 31 and Figure 32. The crosshead speed for each type of sample is shown in Table 3.

Table 3: Crosshead speed for each type of sample

Sample	**Crosshead Speed**
12k CFE	2 mm/min
12k & 6k CFE	2 mm/min
HDPE	50 mm/min

Figure 31: Example of CFE sample

Figure 32: Example of HDPE sample

The procedures of tensile test are as follows:

1) The width and thickness of the middle part of the specimen are measured using vernier calipers.
2) The specimen is loaded in the machine grips (Figure 33).
3) The extensometer is attached and zeroed; secured with a lanyard so it will not fall and break if specimen fracture occurs before the extensometer can be removed.
4) Load indicator is made to zero and the right side hydraulic valve is opened about ½ turn.
5) As the sample is loaded, the load is recorded automatically by the UTM system up to the yield point (when the load starts increasing more slowly and the strain starts increasing more rapidly).
6) The sample is continued to be loaded until it breaks.
7) The maximum load is observed and recorded. The graph of stress-strain is generated.
8) The steps are repeated for the other samples.

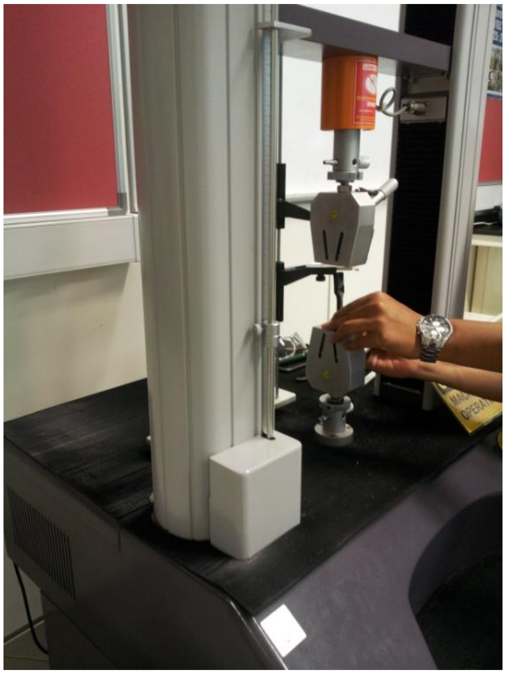

Figure 33: Clamping the sample to the UTM.

3.3 Gantt Chart & Key Milestone for FYP

Table 3 and 4 shows the Gantt chart for the project.

Table 4: Gantt Chart for FYP 1

No	Detail/Week	1	2	3	4	5	6	7	8	9	10	11	12	13	14
1	Selection of Project Topic	■	■												
2	Preliminary research of on wrap up of fiber composite using the filament winding method and their optimum wrap-up angle.		■	■	■										
3	Study the effect of physical arrangement of carbon fiber tow to wound FRP composite on mechanical properties.					■	■								
4	Submission of Extended Proposal						●								
5	Proposal Defense								■	■					
6	Study on the application of FRP in oil and gas industry										■	■	■		
7	Submission of Interim Draft Report													●	
8	Submission of Interim Report														●

● Key milestone ■ Process

Table 5: Gantt Chart for FYP 2

No	**Detail/Week**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**
1	Preparation on testing methods (SEM, Tensile Test and Compression test)	■	■	■	■	■	■								
2	Fabrication of Samples							■	■	■					
3	Submission of Progress Report									●					
4	Lab Experiments: - Density - SEM - Tensile Test - Compression Test										■	■	■		
5	Pre-Sedex										●				
6	Analyse experiments results												■		
7	Submission of Draft Final Report													●	
8	Viva														●
9	Submission of Dissertation														●
10	Submission of Technical Paper														●

● Key milestone ■ Process

CHAPTER 4
RESULTS AND DISCUSSION

4.1 SEM Analysis

The analysis will focus on the evaluation of the size of no-fiber triangle for both types of samples which are Carbon Fiber with Epoxy resin (CFE) using 12k fiber tows only and combining 12k and 6k fiber tows. Figure 34 shows the microstructure for CFE using 12k fiber tows. It can be seen that there is a no-fiber triangle in between the overlapping layer of fiber tows.

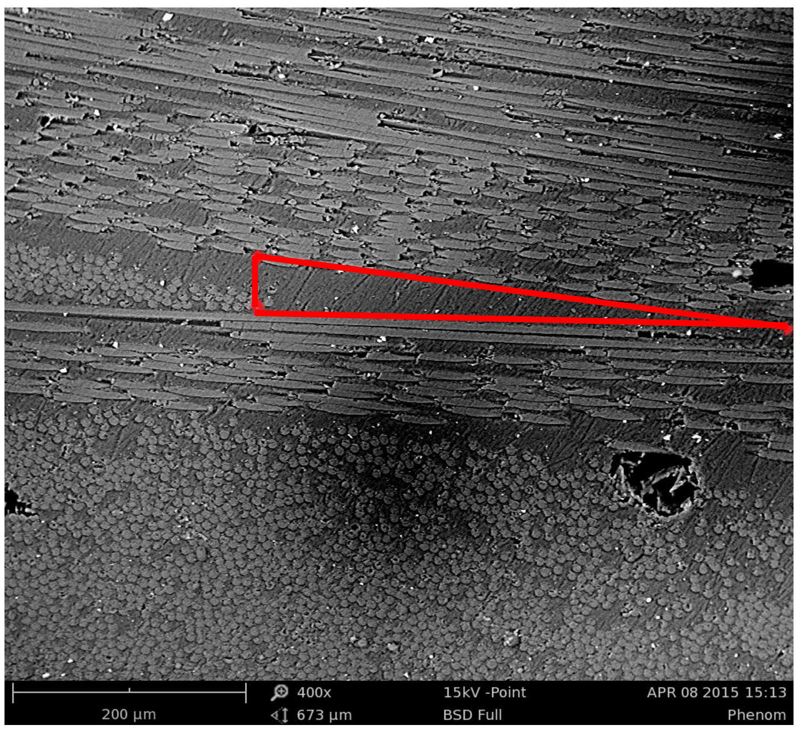

Figure 34: No-fiber triangle of 12k fiber tows CFE

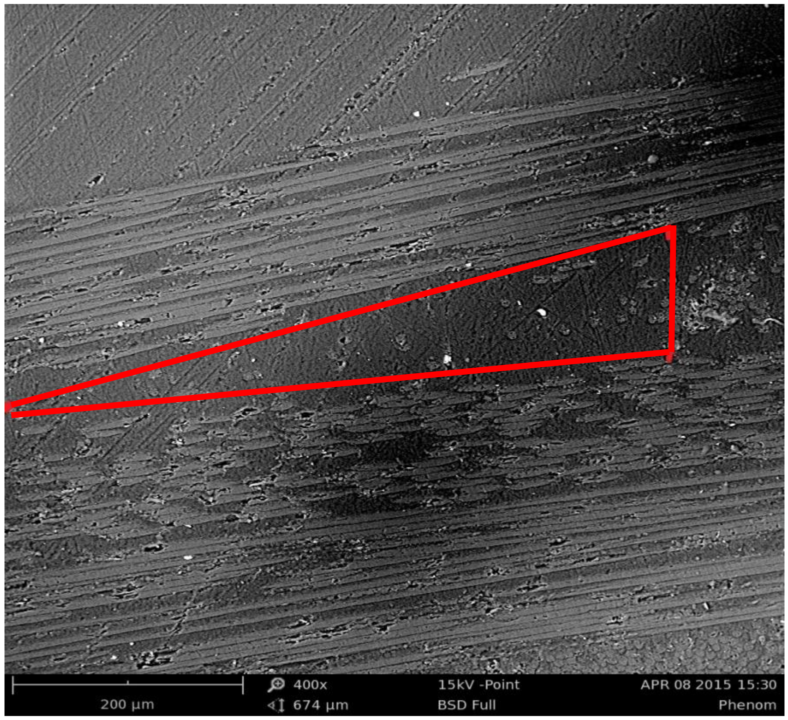

Figure 35: No-fiber triangle of 12k and 6k fiber tows CFE

In Figure 35, the no-fiber triangle can also be seen for 12k and 6k fiber tow sample. Table 6 and Table 7 justify that the area of no-fiber triangle for 12k and 6k fiber tow sample is bigger than 12k fiber tow sample. Figure 36 shows the comparison of the no-fiber triangle size. The 12k and 6k sample has bigger area than 12k sample by 113 %. This is because both types of sample are using same amount of fiber tows (6 fiber tows) where 12k and 6k samples are using two 12k fiber tows and four 6k fiber tows. This shows that the reduction of fiber content lead to the increase in the area of no-fiber triangle. Furthermore, during the fabrication of the samples, the bandwidth of both types of sample are maintained the same. This leads to the increase in space between each tow of 12k and 6k CFWHCP sample.

Table 6: Area of no-fiber triangle for 12k fiber tow sample

Sample	**Height (m)**	**Base (m)**	**Area (m^2)**
12A	0.00005546070062	0.000455755078	1.263825E-08
Average			**1.263825E-08**

Table 7: Area of no-fiber triangle for 12k and 6k fiber tow sample

Sample	**Height (m)**	**Base (m)**	**Area (m^2)**
126A	0.0001377234199	0.0005801896733	3.995285E-08
126B	0.00008984126984	0.0004687830688	2.105803E-08
126C	0.00006238914971	0.0006434011476	2.007063E-08
Average			**2.702717E-08**

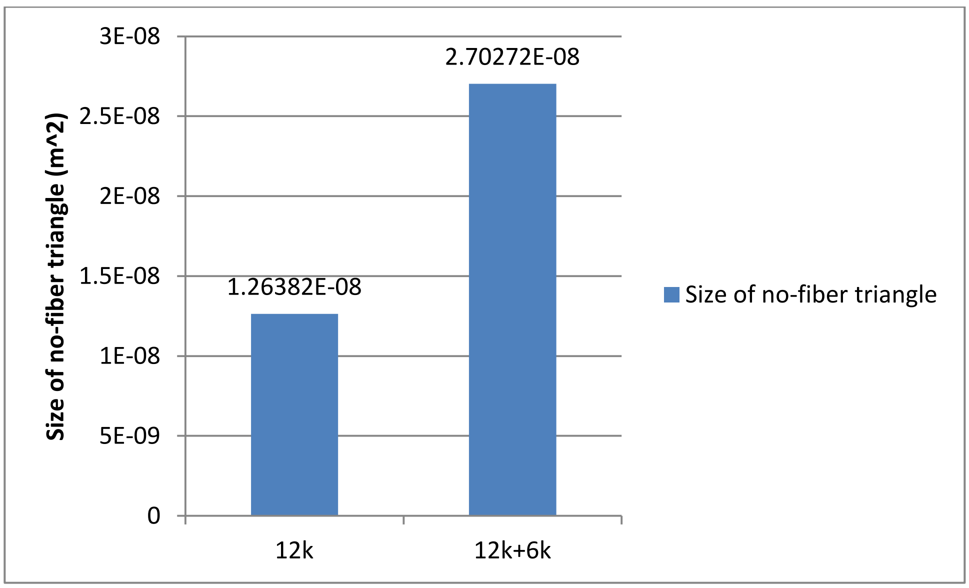

Figure 36: Comparison of the size of no-fiber triangle with different fiber arrangements

4.2 Tensile Properties

The failure of composites can be viewed as any property changes which makes the component unacceptable structurally or functionally. The tensile properties are found to compare the properties of FRP having same size fiber tows with different sizes of fiber tows.

Figure 37 and 38 shows the tensile graphs for CFE samples, which indicate the samples are brittle. Figure 39 illustrates the tensile test graph for HDPE which shows the ductility of HDPE.

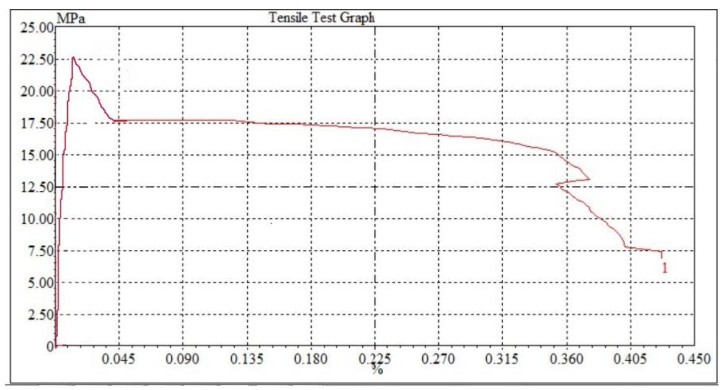

Figure 37: Tensile test graph for 12k CFE

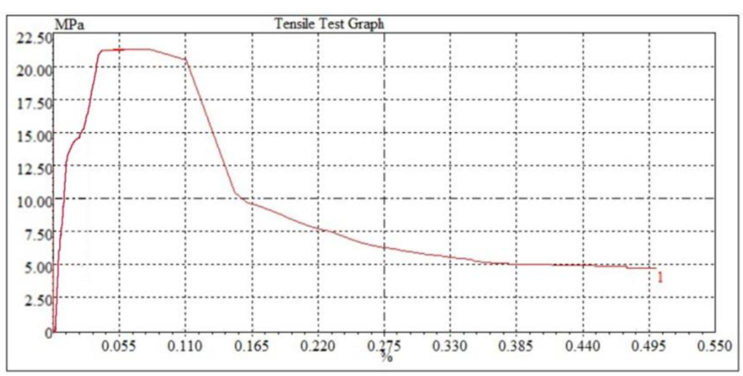

Figure 38: Tensile test graph for 12k + 6k CFE

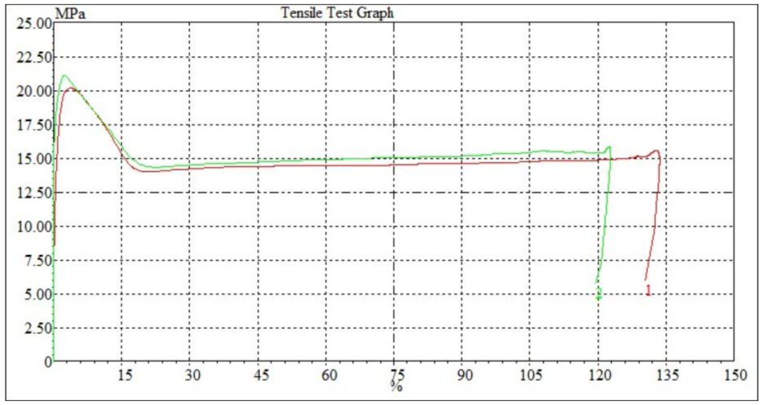

Figure 39: Tensile test graph for HDPE

Figure 40 and 41 demonstrates the comparison of tensile strength and elastic modulus for each sample. Table 8 summarizes the overall comparison for the two parameters of mechanical analysis. It can be seen that samples with 12k fiber tows have higher tensile strength and elastic modulus as compared to 12k and 6k fiber tows for the CFE sample. This indicates that samples with higher fiber content will have higher tensile strength compared to those with lower fiber content. HDPE sample has lower tensile strength and maximum stress compared to both the CFE samples. HDPE can be increased in its tensile strength if it is reinforced with CFE.

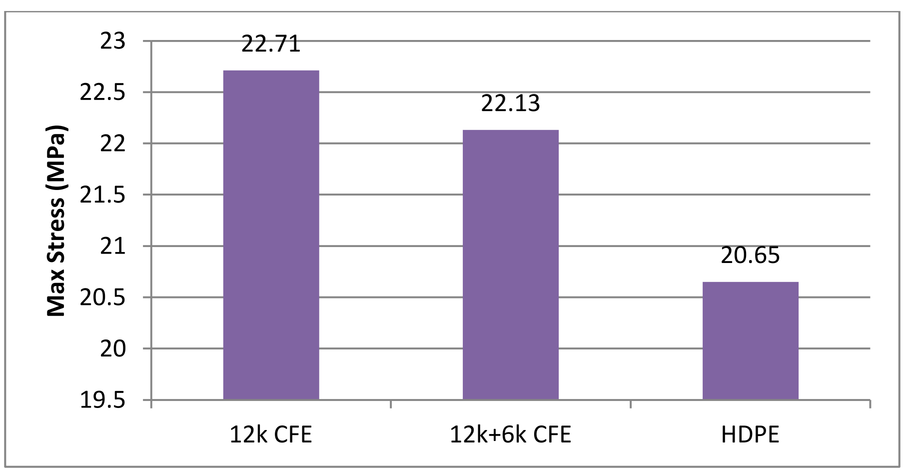

Figure 40: Tensile Strength Comparison

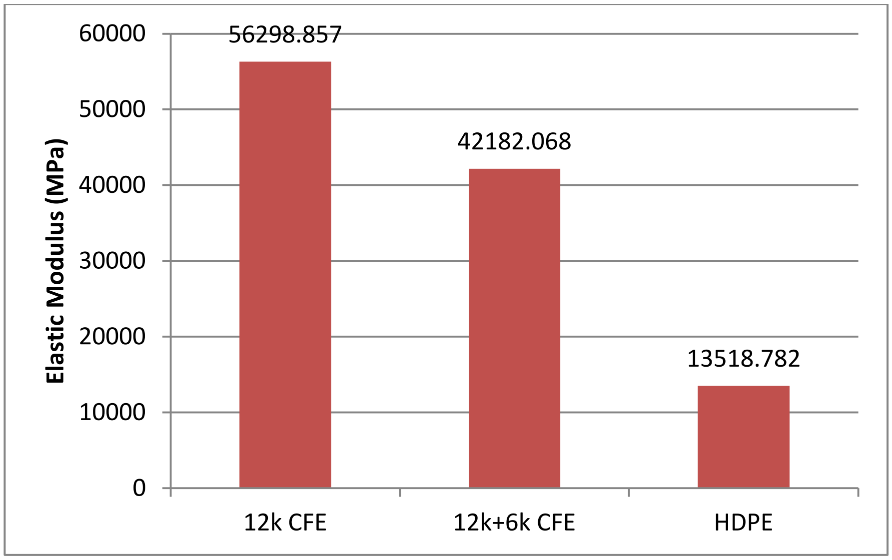

Figure 41: Elastic Modulus Comparison

Table 8: Comparison of mechanical properties of samples

Sample	Tensile Strength (MPa)	Elastic Modulus (MPa)
12k CFE	22.71	56298.857
12k+6k CFE	22.13	42182.068
HDPE	20.65	13518.782

Figure 42 shows the difference of the samples after tensile test for CFE and HDPE. The fracture in Figure 42 (a) indicates that it is brittle while in Figure 42 (b) shows the effect of ductility to the fracture of the sample.

a) b)

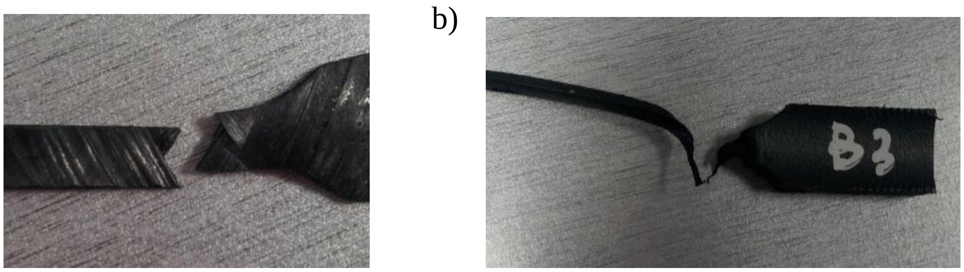

Figure 42: (a) Sample fracture of CFE composite (b) Sample fracture of HDPE

CHAPTER 5

CONCLUSION AND RECOMMENDATION

5.1 Conclusion

As a conclusion, the required composites of Carbon Fiber Wound to HDPE Composite Pipe (CFWHCP) were successfully fabricated according to the winding angle of 57° and other specifications.

- SEM analysis showed the no-fiber triangle area of 12k and 6k CFE to be bigger than CFE with 12k fiber tow only. This is due to the lower fiber content in 12k and 6k CFE.
- 12k CFE has the highest tensile strength and modulus values, which are 22.71 MPa and 56298.857 MPa respectively. 12k and 6k CFE has lower tensile strength and elastic modulus compared to 12k CFE.
- HDPE has the lowest tensile strength and modulus values, which are 20.65 MPa and 13518.782 MPa respectively.

Hence it is observed that the different size of fiber tow with the maintained number of tows and bandwidth size has reduced the original properties of tensile strength and elastic modulus. The area of no-fiber triangle also has increased.

5.2 Recommendations

For recommendation, the author would like to propose:

- Further research with FRP with more than 6 fiber tows with different size of fiber tows (12k and 6k) to fill in the no-fiber triangle as compared to the 12k fiber tow sample.
- Further research on the impact of combining FRP and HDPE to its mechanical properties.
- Further research regarding the adhesive that will strengthen the adhesion between the FRP and HDPE liner.

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