Dynamic Loading on Carbon Fiber Wind to HDPE Composite Pipe (CFWHCP)

By

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CERTIFICATION OF APPROVAL

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A project dissertation submitted to the
Mechanical Engineering Program
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(MECHANICAL)

Approved by,

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TRONOH, PERAK
May 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.

MOHD NAQIUDDIN AFIQ BIN ABD AZIZ

ABSTRACT

Carbon fiber composite is regarded as one of the best alternative for light weight and anti-corrosion material. Filament winding is one of the technique for the fabrication of carbon fiber reinforced composite pipe that is cheap and better mechanical properties. Different carbon fiber orientation during the fabrication will have impact to the mechanical properties of the composite and became the focal point of this research. Three different arrangement of tow were used during the fabrication of Carbon Fiber Wind to HDPE Composite Pipe (CFWHCP). The other parameter such as winding angle, winding tension, the number of layers and epoxy content are kept constant to prevent interference in the result. The microstructure of fabricated pipes were tested to calculate the area of void. The results from the test shown that area of void for CFWHP with 4 tows of 12k carbon fiber (1.26382×10^{-8} m^2) is smaller by 53% compared to CFWHCP with 2 tows of 12k carbon fiber plus 4 tows of 6k carbon fiber. Compression test was carried out to approve the hypothesis that different arrangement of tow can affect the mechanical properties of CFWHCP. Subsequently, dynamic impact test was carried out to study how CFWHCP will be affected under the impact and comparison was made between pipes of different tow arrangement and in addition with blank High Density Polyethylene (HDPE) pipe. From the experiment, it can be concluded that CFWHCP with 4 tows of 12k carbon fiber exhibit higher energy absorption, and can withstand higher load compared to CFWHCP with 2 tows of 12k carbon fiber plus 4 tows of 6k carbon fiber. This is due to smaller area of void detected on CFWHCP with 4 tows of 12k carbon fiber thus proven that different orientation of carbon fiber tow during manufacturing can impact the mechanical properties of CFWHCP.

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ABBREVIATION AND NOMENCLATURE

Tow- Untwisted bundle of continuous filaments

CFWHCP- Carbon Fiber Wind to HDPE Composite Pipe

HDPE- High Density Polyethylene

CFRP- Carbon Fiber Reinforce Plastic

ASTM- American Society for Testing and Materials

UTP- Universiti Teknologi PETRONAS

UiTM- Universiti Teknologi MARA

MIC- Microbiologically Induced Corrosion

TCF- Thermoplastic Composite Flowline

API- American Petroleum Institute

LPDE- Low Density Polyethylene

GPP- Glass-Filled Polypropylene

GPE- Glass Polyethylene

SEM- Scanning Electron Microscopy

CHAPTER 1

INTRODUCTION

1.1 Background Study

Steel pipe and pipeline facilities are subjected to corrosion either caused internally or externally. There are industry codes and standards implemented for the pipeline to be protected from the effects of corrosion. However, nonmetallic piping do not undergo the same corrosive effects and require little attention [1]. According to Saudi Aramco News [2], nonmetallic pipe was designed to last for 25 years which is a significant improvement in piping lifespan compared to the conventional carbon-steel pipe.

Composite technologies has matured significantly and widely used by most technical advanced oil and gas companies globally. Fiberglass pipe has been used as a pipeline material in western Canadian oilfields as an alternative to carbon steel pipe which is low resistance to corrosion. Challenges faced in the extraction of hydrocarbon in the North Sea, shallow coast Africa and Gulf of Mexico had initiated the driving force to search for materials that is lightweight, strong, and resistant to corrosion and chemicals. Composites are recognized as the technologies that enable deepwater drilling scenarios because of its ability to stand up to the harsh subsea environment [3].

Carbon fibers had been established as the material of choice where high mechanical load capacity and light weight construction plays a dominant role [4]. Polyethylene is one of the common plastic pipes used in oil and gas industry. It is highly resistance towards corrosion making it suitable to replace the conventional carbon steel. However, the cost of producing carbon fiber reinforced polymer (CFRP) is relatively high compared to carbon steel. To reduce the cost-competitive, filament winding technique is identified as the most efficient and least costly method for the fabrication of composites [5].

In this research, filament winding technique is applied by winding carbon fiber filament using winding machine to High Density Polyethylene Pipe (HDPE). The properties of filament wound CFRP is determined by the angle at which the fiber is laid down. A higher angle will provide greater crush strength while lower angle pattern will provide greater tensile strength [6]. Throughout the research, the winding angle, winding tension, the resin content and the thickness of carbon fiber are made fixed. The manipulated variable is the arrangement of carbon fiber filament tow.

Several tests such as microstructure test, compression test, tensile test and dynamic loading test will be done. The effect of the arrangement of carbon fiber tow to the properties of Carbon Fiber Wind to HDPE Composite Pipe (CFWHCP) is the aim of this research. At the end of this research, the result of collapse mode, energy absorption profile, load-displacement curves and the deformation are expected and discussed.

1.2 Problem Statement

It is estimated 1.372 billion dollar USD is expended annually in the oil and gas production industry due to corrosion by pipeline that is commonly made of carbon steels. It is estimated that 50% of leakage issues that are caused by corrosion [7]. This research serve as initiative for new composite materials that can be used as an alternative to conventional pipeline that is made from carbon steel. To produce such composite materials, several testing must be made such as dynamic loading on the material. This is important to study the mode of failure, energy conservation as well as analyzing the stress-strain curve. According to Paciornik and Almeida [8] voids are distributed among tows of fibers when the fibers are being wound around the mandrel. The existence of void could significantly impact the mechanical properties of the composite. Hence, in this research, carbon fiber tow arrangement were manipulated to study the impact of dynamic loading to the composites for different orientation of carbon fiber tow on CFWHCP.

1.3 Objectives

The aim of this research is to investigate the dynamic loading on Carbon Fiber Wind to HDPE Composite Pipe (CFWHCP) and the effect of different fiber orientation of carbon fiber tow on the mechanical properties of CFWHCP. To achieve this objective, several action must be taken into account which are:

1. To conduct compression test on CFWHCP and dynamic impact test to study the mode of failure under the impact
2. To compare the performance of CFWHCP under quasi static compression test and dynamic impact test for different fiber tow orientation.

All testing are subjected to the standards by American Society for Testing and Materials (ASTM) to ensure that the result of this study is viable and comply with the regulations to be used commercially.

1.4 Scope of Study

The research aim is to study the behavior of CFWHCP in axial and hoop direction subjected to the dynamic load. The importance of this study is to improve understanding on the response to failure of CPWHCP and as part of ongoing effort to made this material as an effective substitute for carbon-steel pipeline for oil and gas application.

To perform this study, the materials will be prepared based on the specification which is 54.7˚ carbon fiber filament wind to High Density Polyethylene tube. The orientation of carbon fiber tow were manipulated to study the effect of different tow orientation to the energy absorption and the failure mode. Then, the mechanical properties of the materials will be validated by tensile test and compression test in hoop and lateral direction. Drop weight impact tests will be performed on CFWHCP by using Instron Dynatup 8250 Impact Tester. All testing are done based on the standard method set by

ASTM. Based on the result of the experiment, the mode of failure development and energy absorption will be analyzed.

The limiting factor of this research is the shortage of capable equipment in Universiti Teknologi PETRONAS (UTP) in which the preparation of CPWHCP was done in SIRIM Berhad in Permatang Pauh, Penang and dynamic testing was performed in Universiti Teknologi MARA (UiTM) in Shah Alam.

CHAPTER 2

LITERATURE REVIEW

This section of the report covers the topic that is related to the background of this research. The objective of the project is investigate the dynamic loading on Carbon Fiber Wind to HDPE Composite Pipe (CFWHCP). Therefore, the use of non-metallic pipeline in oil and gas industry, material properties, filament wind composite techniques, mechanical testing and any relevant information is studied before the commencement on this project to improve comprehension regarding the research.

2.1 Non Metallic Pipeline in Oil and Gas Industry

Corrosion in pipeline systems is one of major issues confronted by many operators in oil and gas industry. In a report by Airborne Oil and Gas [7], it is estimated that 50% of leakage issues in pipeline is caused by corrosion. One of the factors that lead to corrosion is Microbiologically Induced Corrosion (MIC). To encounter this issue, Petronas collaborated with Airborne Oil & Gas [7] to qualify and deliver non-metallic flowlines and risers for hydrocarbon production. This collaboration project yield qualified 6 inch internal diameter Thermoplastic Composite Flowline (TCF) that comprises the requirement of American Petroleum Society (API) including materials testing, prototype testing and fullscale offshore installation testing.

Pipeline plays an important role in oil and gas industries. It helps in large scale fluid transportation for crude oil and natural gas efficiently and more economical compared to other transportation such as rail, truck and tanker in term of flexibility of routes and the large quantities to be moved on. Pipeline used in oil and gas industry used carbon steel as its main material due to its strength and toughness under the water and it is relatively cheap compared to other materials. However, it is limited to the resistivity towards corrosion underwater [9].

2.2 Carbon Fiber

Carbon fiber is a type of material consisting of fibers composed of carbon atoms. It has properties such as high stiffness and strength, light weight, high chemical resistance, high temperature tolerance and low thermal expansion making it highly regarded in a lot of field of industries. Carbon fiber is anisotropic materials making it strength directional. The properties of carbon fiber depend on the layouts of the carbon fibers relative to the polymer. Compared to steel, the fatigue failure of carbon fiber is unpredictable. So, considerable strength safety margins need to be designed to provide the reliability of the materials on the components [10].

2.3 High Density Polyethylene

High Density Polyethylene (HDPE) is widely used in the production of plastic bottles as well as corrosion resistant piping due to its high strength to density ratio. Compared to Low Density Polyethylene (LPDE), HDPE have higher specific strength and higher tensile strength. It is also can withstand high temperature up to 120˚ C [11]. In oil and gas service fields, it was confirms that HDPE able to transport gas at high pressure and resist strong seismic movements with axial elasticity of 1.5%. Mechanical resistance test had been carried out to determine the HDPE pipe exact lifetimes. It is indicated that the lifespan can be more than 50 years which is astounding compared to carbon steel pipe which can lasts up to 20 years of service [12].

2.4 Filament Wind Composite

Filament winding is a fabrication technique mainly used for manufacturing open cylinder such as oil and gas pipelines. The process involves winding filaments under tension over a mandrel. The most common filaments are carbon fiber or glass fiber and are coated with resin as they are wound. Table 2.1 shows the mechanical properties of commercially available fibers [13].

TABLE 2.1 Mechanical Properties of Fibers

Fiber	Elastic Modulus (GPa)	Tensile Strength (MPa)	Tensile Strain (%)
S-Glass	72.5	3447	4.80
R-Glass	86.2	2068	2.40
Carbon	248.0	4550	1.64
Aramid	186.0	3445	1.80

The filament winding process can utilize many different fibers and resins to achieve desired characteristics for the finished component. The end result is an extremely efficient process to create low cost, lightweight, and strong composite materials [14] [15]. According to Cohen [15], there are several parameters of filament winding parameters that affect different strength/stiffness response on composites. Five parameters were studied which are; winding tension, laminate stacking sequence, winding-tension gradient, winding time between layers, and cut-versus-uncut helical. Based on the literature, there are little exposure on the effect of different tow arrangement on the material properties of composites.

2.5 Compression Test

The compressive strength is the capacity of a material or structure to withstand loads tending to reduce size. It can be measured by plotting applied force against deformation in a testing machine. Some materials fracture at their compressive strength limit; others deform irreversibly, so a given amount of deformation may be considered as the limit for compressive load. Compressive strength is a key value for design of structures [16].

2.6 Fiber Volume Ratio

Fiber volume ratio is the percentage of fiber volume in the fiber-reinforced composite material. During the fabrication of polymer composites, fibers are impregnated with resin. The impregnation of resin dependent on the orientation and architecture of the fiber. Voids are often formed in a composite structure and are calculated. Higher fiber volume ratio usually leads to higher mechanical properties of composite. Three methods that can be used to determine fiber volume fractions which are; acid digestion, optic microscopy and resin burning off method. According to Daniel and Ishai [17], fiber volume ratio can be determine by this formula:

$$V_f = \frac{v_f}{v_c}$$

Where v_f is the volume of fibers and v_c is the volume of composites.

2.7 Dynamic Loading Test

A compressive test does not test the behavior of a material in dynamic conditions. It applies a constant rate of strain to a sample. Impact testing was developed as a way to measure the energy absorbed during fracture of a material under severe impact loading conditions. In general, ductile materials can absorb higher amounts of energy than brittle materials [18]. According to Belingardi and Vadori [19], there is lack of models capable of describing the critical transition from a virgin to progressively damaged material up to the complete collapse of composite material. In the research, low velocity impact testing was done on glass fiber composite to study the impact behavior of composite and impact energy absorption of the composite. Hamdan [20] in his research conducted dynamic impact loading tests on several composites such as Glass-Filled Polypropylene (GPP) and Glass Polyethylene (GPE) where the fraction of fiber weight and angle of fiber orientation were manipulated to get energy absorption capacity and collapse mode. Dynamic impact test were carried out using drop hammer. The result of total impact energy dissipated by the specimen of testing is defined by:

$$E = \int_0^{\Delta L} P(S)ds$$

Where P is the instantaneous load and S is the displacement of the specimen. The drop height for the dynamic tests were estimated by formula below:

$$h = \frac{E_{QS}}{mg}$$

Where E_{QS} is the energy absorbed by the specimen during quasi static test, m is the drop mass (kg) and g is the gravitational acceleration.

Energy absorption were determined by integrating the area under force-displacement curve. Hamdan [20] emphasize in his research that increased t/D ratio will increase the energy absorption profile. The volume fraction and fiber orientation also influence the mode of collapse and energy absorption.

CHAPTER 3

METHODOLOGY

3.1 Preliminary Research

The flow of this project starts with definition of problem statement. Numerous literature were studied to rectify the issues that is correlated with the problem statement. The aim of this research is to investigate the dynamic loading impact on different arrangement of tow in CFWHCP. The standard testing methods were studied and gained from ASTM to ensure that the materials were tested by using correct standard. The overall project flow is as Figure 3.1.

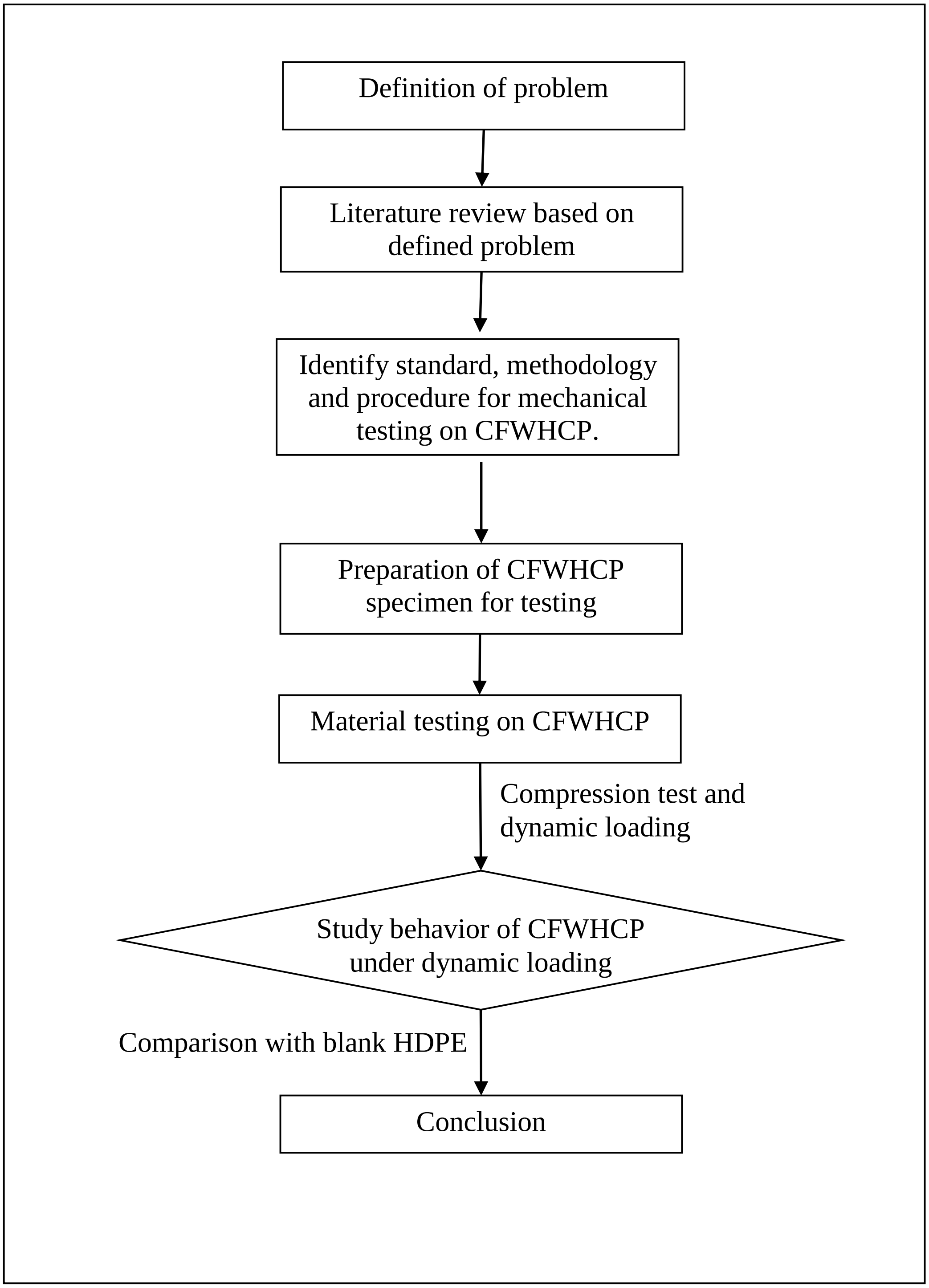


FIGURE 3.1 Overall Project Flow

3.2 Fabrication

The fabrication of CFWHCP was done by applying filament winding technique with reference to previous study by Peters [5]. The fabrication was done using 4-axis, 3-spindle filament winding machine. The flow of machine configuration is as Figure 3.2:

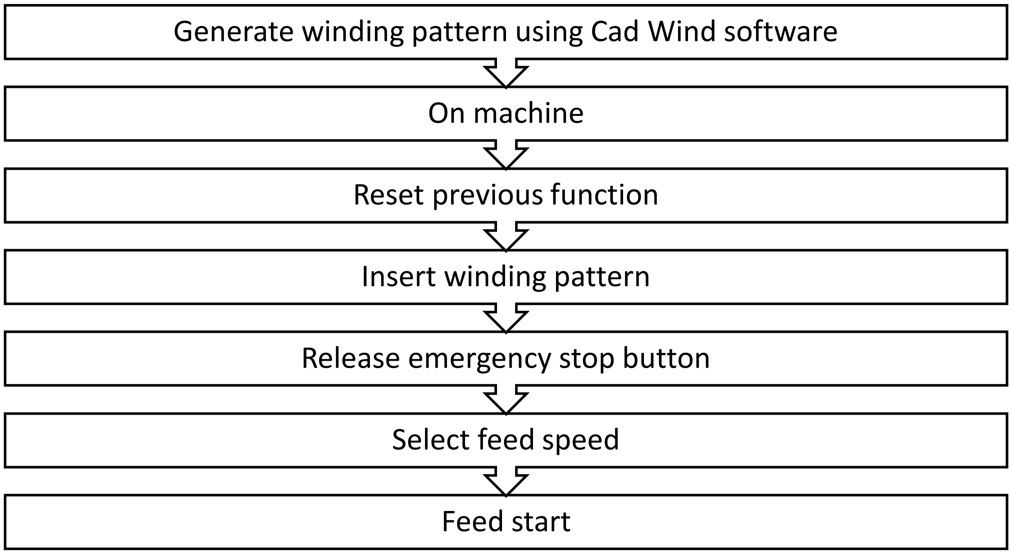


FIGURE 3.2 Flow of Filament Winding Machine Configuration

There are three CFWHCP pipes with different tow arrangement. For each pipe, the carbon fiber was winded with 54.7˚ winding angle on 6 layers arrangement. The epoxy content is comprising of resin with 47% of hardener ratio. Carbon fiber filaments was pre-pregnated with resin bath before winded to the HDPE pipe mandrel. Once the winding finished, the composite pipe was cured in the oven at constant temperature of 90˚C.

The technical specification of composite pipes fabricated is as Table 3.1:

TABLE 3.1 Technical Specification of Fabricated Pipes

Pipe 1	Pipe 2	Pipe 3
Mandrel- HDPE Pipe: Internal diameter- 2” External diameter- 2.375”	Mandrel- HDPE Pipe: Internal diameter- 2” External diameter- 2.375”	Mandrel- HDPE Pipe: Internal diameter- 2” External diameter- 2.375”
Filament- Carbon fiber: 12K fiber 6 tow	Filament- Carbon fiber: 12K fiber 2 tow 6K fiber 4 tow	Filament- Carbon fiber: 12K fiber 4 tow
Matrix: Resin Epoxy	Matrix: Resin Epoxy	Matrix: Resin Epoxy
Winding angle: 54.7˚	Winding angle: 54.7˚	Winding angle: 54.7˚

3.3 Microstructure Test

Microstructure test was employed to characterize the microstructure of fiber-reinforced composite tubes manufactured by filament winding technique. Scanning Electron Microscopy (SEM) machine was used for void characterization. Image processing was employed to detect voids and measure their size [8].

For this testing, samples from Pipe 1 and Pipe 2 were analyzed. The pipe were sectioned and cut for sampling. In this project, the area of interest is the area where the group of fiber tows intersects, as shown in Figure 3.3. This is the area where no-fiber triangles expected to be seen.

FIGURE 3.3 Area of Interest for Sampling

The preparation of the samples followed the standard procedure for microstructure test. Cold mounting method were used for grinding and polishing for the specimen. This is to enable clear mounting since the specimen is already dark in color. The ratio of epoxy resin to hardener is 10:1. The preparation of sample mounting is as Figure 3.4 below:

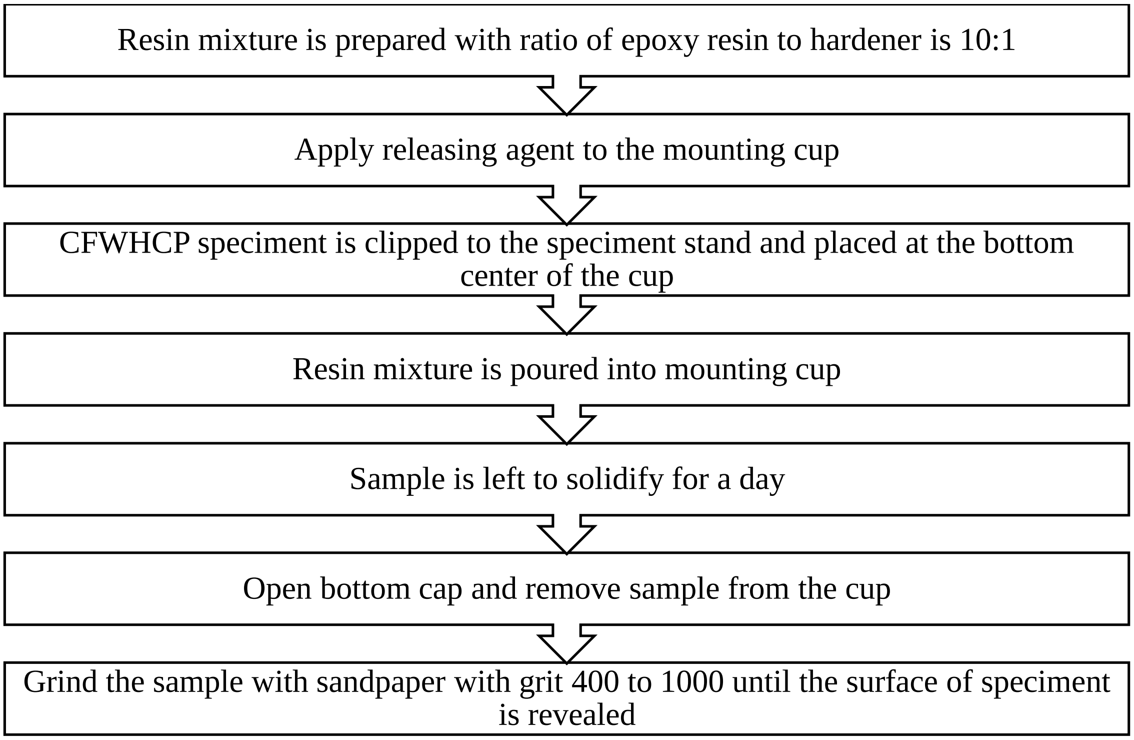


FIGURE 3.4 Sample Preparation Procedure for Microstructure Test

The specimen were made three for each sample to provide adequate data for the test. The digital microscopic structure of specimen were scanned by using Scanning Electron (SEM) Microscope Phenom World Pro X. The technical specifications of SEM machine is as Table 3.2. In latter stage the area fraction of void is calculated. The observation of the void formation in each specimen was taken and discussed.

TABLE 3.2 Technical specifications for SEM machine

	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

3.4 Pipe Boring

The pipe must be bore to achieve D/t ratio of greater than or equal to 9. This is according to Hamdan [20] in his research stating that increased D/t ratio will increase the energy absorption profile. To achieve such ratio, the thickness of HDPE pipe must be trimmed to at least 6mm. The boring process of CFWHCP is made using conventional lathe machine. To ensure that the boring is done uniformly, a clamp device were fabricated. The clamp device is made of carbon steel and enable the bended pipe to be straighten. Figure 3.5 shows the clamp and CFWHCP.

FIGURE 3.5 CFWHCP Clamped by Steel Clamping Device

3.5 Compression Test

Compression tests of CFWHCP were performed on a Universal Testing Machine (UTM) under quasi static experiment. The test were conducted in reference to ASTM standard D-6641. The test were performed under two conditions which is axial and lateral directions where one flat plate moving vertically on the sample until the sample achieved its crushing ability. The compression is set to move at 20 mm per minute. The maximum load given by UTM machine is 50 kN. Figure 3.6 shows the UTM equipment used for this experiment.

FIGURE 3.6 UTM Machine for Quasi Static Compression Test

The tested materials were samples from Pipe 1 and Pipe 2. The data gain from the experiment is the load against displacement curve and compressive stress against strain. The data is then interpreted and analyzed to see the effect of different fiber orientation to the compressive strength of CFWHCP. The finding is then will be used to compare with the finding in dynamic impact test. The result of the experiment will be discussed extensively in Chapter 4.

3.6 Dynamic Impact Test

Impact tests are categorized into either low or high velocity. In this project, low velocity impact test is used where the velocity of dropped hammer is made constant to be at 3.5ms-1. The test was employed to study the mode of failure in velocity impact and the energy absorption of CFWHCP before its fail.

Dynamic impact test was done in reference to ASTM standard test method for measuring the damage resistance of fiber-reinforced polymer matrix composite to a drop-weight impact event designation standard ASTM D7136. The test was done using impact tester machine, Instron Dynatup 8250 (Figure 3.7). The technical specification of the machine is detailed in Table 3.3.

FIGURE 3.7 Instron Dynatup 8250 for Dynamic Impact Test

TABLE 3.2 Technical Specification of Instron Dynatup 8250

Impact Energy	0.6 to 303 J (gravity driven) 16.2 to 840 J
Impact Velocity	1 to 3.66 m/s (gravity driven) 3.66 to 13.41 m/s (pneumatically assisted)
Load Range	5, 10, 25, 50, 75, 100 lbs.
Temperature	40°C to 55°C

The drop weight was kept constant through all the experiment with mass of 46 kg and the velocity of drop weight is measured to be within range of 3.8 to 4.0 ms^{-1}. The test was done to samples from Pipe 2, Pipe 3 and blank HDPE pipe axially and laterally. Sample from Pipe 2, Pipe 3 and HDPE pipe was labelled A, B and C respectively. The testing for axial and lateral impact was done on two samples from each pipe. The details of the samples are as in Table 3.4.

TABLE 3.4 Technical Details of Samples

Sample	Impact Direction	Length (mm)	Diameter (mm)	Thickness (mm)	Mass (g)
A1	Lateral	90.03	55.39	6.03	116.80
A2	Lateral	90.33	54.70	6.24	124.04
A3	Axial	90.17	54.76	6.35	121.42
A4	Axial	89.95	54.83	6.00	119.30
B1	Lateral	90.50	55.70	6.59	132.56
B2	Lateral	90.30	56.79	6.56	134.34
B3	Axial	90.10	55.61	6.13	133.32
B4	Axial	90.42	55.57	6.80	135.25
C1	Lateral	89.93	54.42	4.03	71.42
C2	Lateral	89.96	54.87	4.40	73.00
C3	Axial	89.71	54.54	4.82	72.34
C4	Axial	90.02	54.78	4.43	72.68

CHAPTER 4

RESULT AND DISCUSSION

The main objective of this research is to investigate the dynamic loading on Carbon Fiber Wind to HDPE Composite Pipe (CFWHCP). To fulfil the main objective, several action must be taken into account which are:

1. To construct a prototype of CFWHCP with different arrangement of carbon fiber tow.
2. To conduct dynamic impact test on CFWHCP and study the mode of failure under the impact and energy absorption during impact.

4.1 Fabrication of CFWHCP

The fabrication of CFWHCP was done by applying the filament winding technique. Filament winding technique is a process where the carbon fiber filament were winded under tension around HDPE pipe as the mandrel. The fabrication was done using by locally engineered 4-axis filament winding machine in SIRIM Permatang Pauh. The carbon fiber filaments were coated with synthetic resin as they wound. The filament winding pattern selected was helical winding.

The control variable of the fabrication are the wind angle, the resin content, the tensional stress and the wound thickness. The wind angle was kept constant at 54.7˚. The epoxy content is comprising of ratio of 47% hardener to the amount of resin.

The manipulated variable in the process of the fabrication of CFWHCP was the size of tow. While the number of tow was kept constant at six, the size of tow was varied from 12K to 6K. This is important as throughout the research, the effect of the size of tow will be studied in related with the mechanical properties, the impact of dynamic loading and the mode of failure and energy absorption of the composite. Once the HDPE pipe was completely covered by the carbon fiber, it was cured in the oven at constant temperature of 90˚C.

4.2 Microstructure Testing of CFWHCP

The mechanical properties of material are strongly influenced by its microstructure. Microstructure test was done to identify the microstructure properties of two different arrangement of carbon fiber tow. Along with the continuation of this research, these properties will be made the variable to see the effect of different tow arrangement in related to the result of dynamic impact loading.

From the result of microstructure test, it can be observed that Pipe 1 with tow arrangement comprising of six 12K carbon fiber had smaller void in comparison to Pipe 2 that consist of 2 tow of 12K plus 4 tow of 6K carbon fiber. Figure 4.2 shows the existence of void for Pipe 1 which comprises of 6 tow of 12K carbon fiber and void for Pipe 2 which comprises of 4 tow of 12K carbon fiber and 4 tow of 6K carbon fiber. Figure 4.3 shows the difference of area of void between Pipe 1 and Pipe 2 in which area of void on Pipe 1 is smaller 53% than Pipe 2.

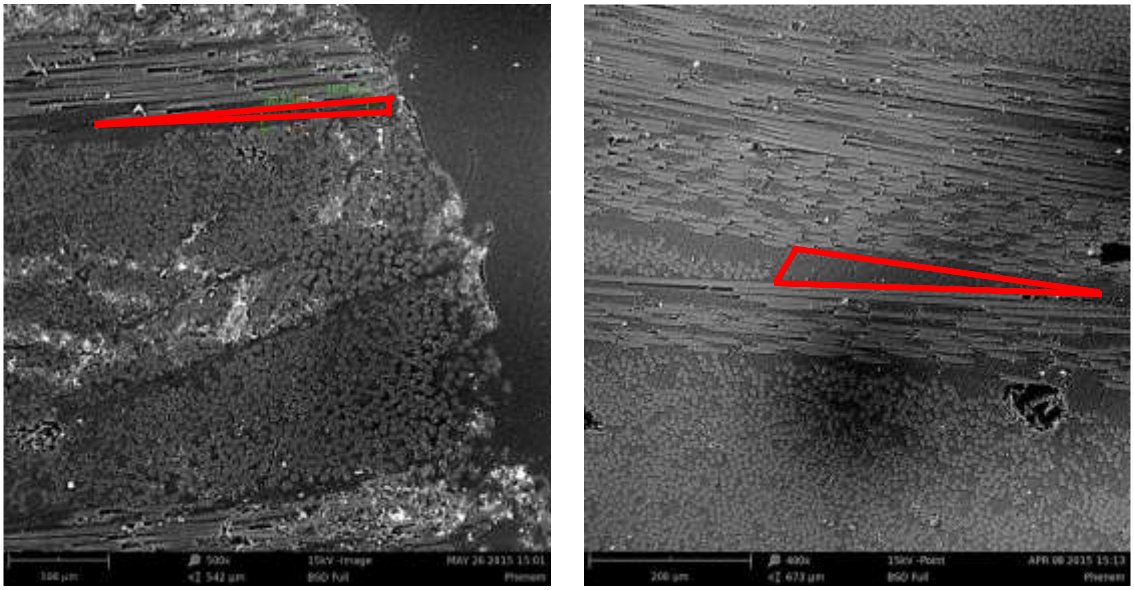


FIGURE 4.1 Void appearance in microstructure of CFWHCP. Pipe 1 (left) and Pipe 2 (right)

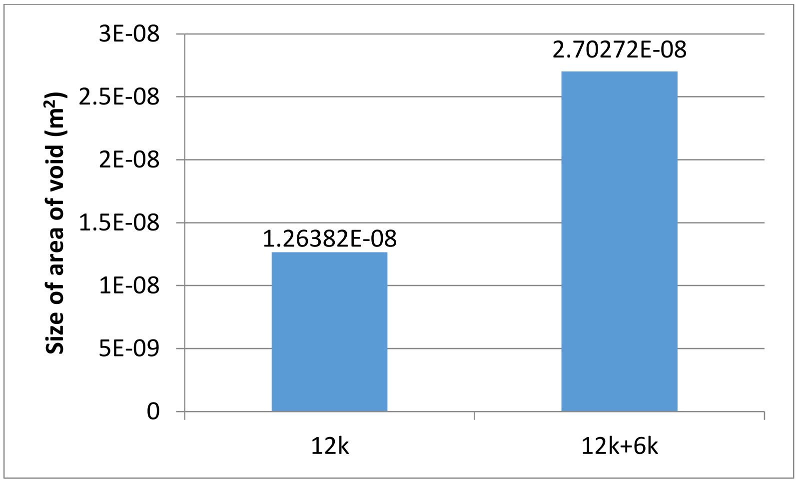


FIGURE 4.2 Area of void on CFWHCP. Pipe 1 (12k) and Pipe 2 (12k+6k)

4.3 Compression Test

Table 4.1 shows the compression test results performed on samples from Pipe 1 and Pipe 2 in lateral position. Pipe 1 is the CFWHCP fabricated with fiber orientation of 6 tow of 12k carbon fiber while Pipe 2 is the CFWHCP of 2 tow 12k carbon fiber and 4 tow 6k carbon fiber. These samples have been tested using two flat plate where one moving plate moved in vertical direction compressing the sample until it crushed. From the table, sample from Pipe 1 exhibit higher load resistance compared to Pipe 2. The energy absorption for Pipe 1 also higher compared to energy absorption by Pipe 2.

Table 4.2 shows the compression test result for axial position. From the table, the result achieved also same as result for lateral position where samples from Pipe 1 exhibit higher load resistance compared to Pipe 2. The energy absorption for Pipe 1 also higher compared to energy absorption by Pipe 2.

TABLE 4.1 Quasi Static Compression Test (Lateral Direction)

Sample	Final Height (mm)	Max Load (kN)	Energy Absorption (kN.m)
Pipe 1	57	7.97	87×10^6
Pipe 2	53	5.91	69×10^6

TABLE 4.2 Quasi Static Compression Test (Axial Direction)

Sample	Final Height (mm)	Max Load (kN)	Energy Absorption (kN.m)
Pipe 1	82	43.13	113×10^6
Pipe 2	79	37.78	99×10^6

4.4 Dynamic Impact Test

The dynamic impact test was done in lateral and axial direction of the tested sample. This section will detailed on the analysis of data and the result of the dynamic impact on CFWHCP and HDPE pipe.

4.4.1 Lateral Impact on CFWHCP and HDPE Pipe

Figure 4.3 until Figure 4.14 present the graph of load against displacement and graph of load against time experienced by tested samples. These samples have been tested using the drop hammer of 46kg mass at 3.9ms-1 velocity and 1.00m heights in lateral direction. As can be seen, the recorded load and displacements show a steady rise in load until a peak value is reached. This is followed by sudden drop in value of load indicating the pipe failure. The continuous fragmentation then occurred until the carbon fiber collapsed.

Figure 4.15 and Figure 4.16 shows the comparison of performance of CFWHCP and HDPE pipe under lateral dynamic load. From the graph, it can be seen that sample B1 which has 6 tow of 12k carbon fiber peak the highest load at 14.9kN, compared to sample A1 and A2 which has mixture of 2 tow of 12k and 4 tow of 6k fiber tow. The ability to withstand higher load proves that sample from Pipe 3 is tougher compared to Pipe 2 which also proves the microstructure test. Comparison also made with blank HDPE pipe which remarked with sample C1 and C2. From Figure 4.15, HDPE pipe exhibit lower absorption of load compared to CFWHCP.

Citing from Richardson and Wisheart [21], the mode of failure for CFWHCP Pipe 2 is type III failure which is fiber failure. Fiber failure usually occurs under high stresses and indentation effect where the continuous fiber breaks under progressive crushing. It was observed that the samples from Pipe 3 exhibit different mode of failure which is type II failure. Type II failure is delamination failure which is the failure due to crack at resin rich area. Richardson and Wisheart explained that delamination failure is caused by bending-induced stress. Figure 4.17 shows the image of fiber fragmentation from sample A1 and B1 respectively. Fracture in fiber from sample A1 is more obvious compared to fiber from sample B1 showing that the load that can be withstand by sample B1 is higher compared to sample A1.

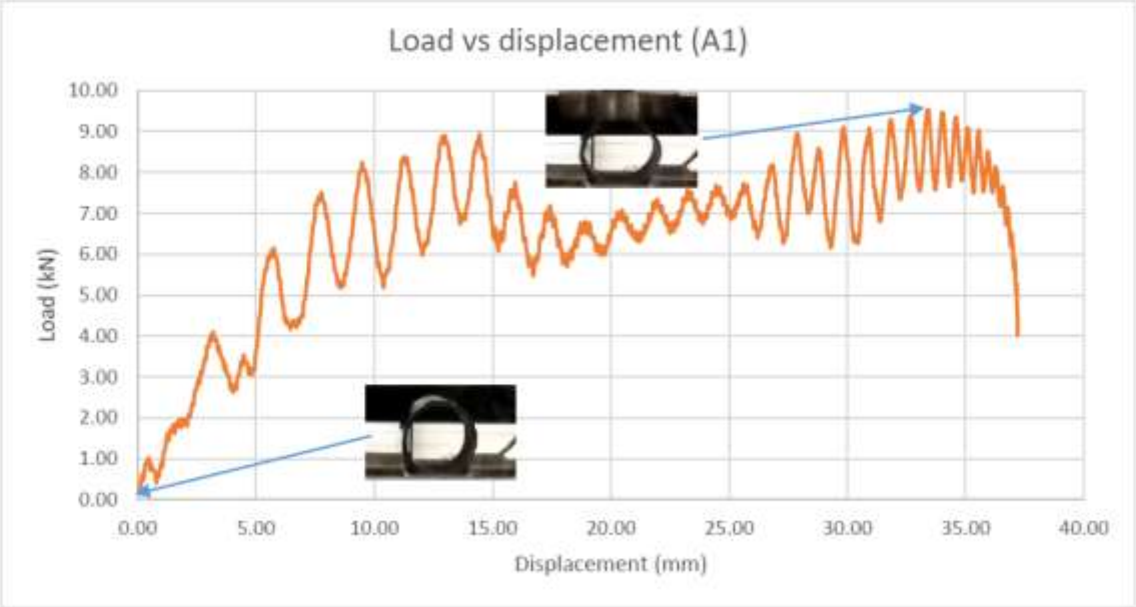


FIGURE 4.3 Load vs Displacement for Sample A1

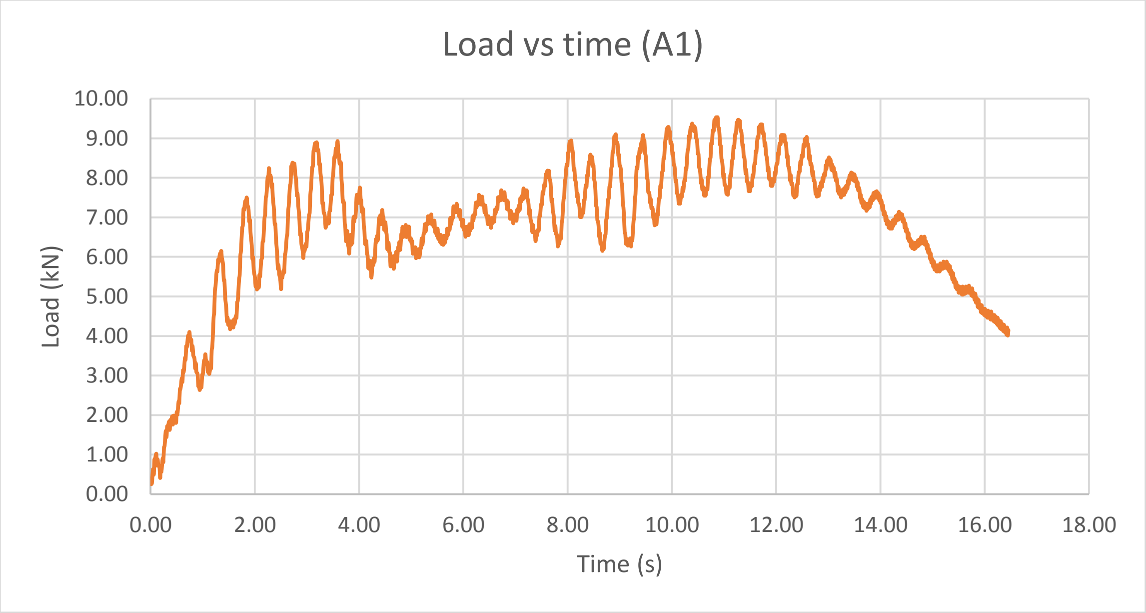


FIGURE 4.4 Load vs Time for Sample A1

FIGURE 4.5 Load vs Displacement for Sample A2

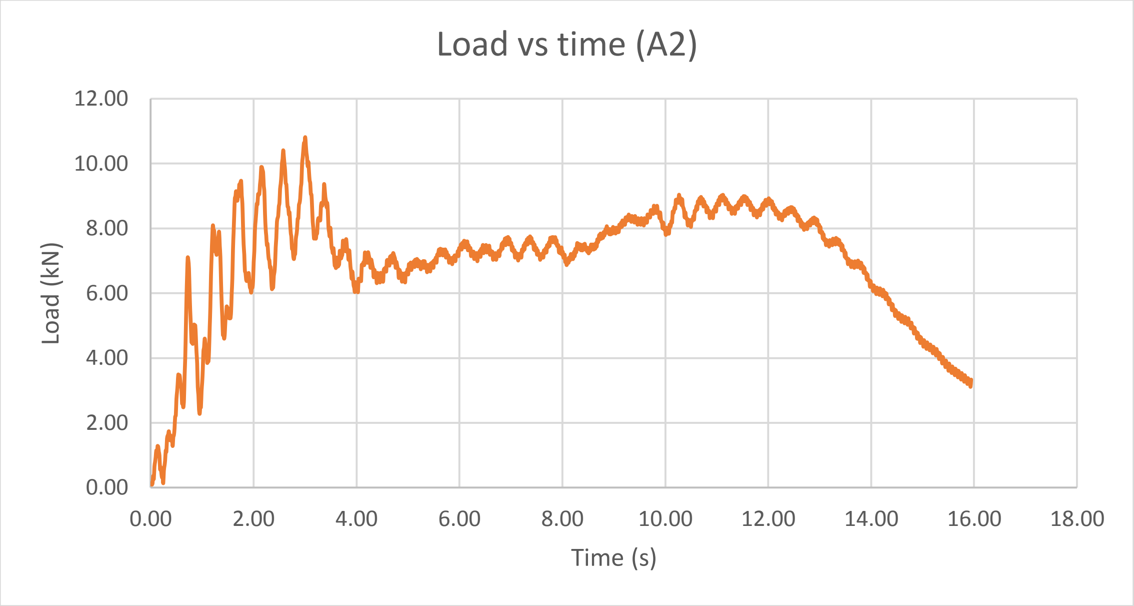


FIGURE 4.6 Load vs Time for Sample A2

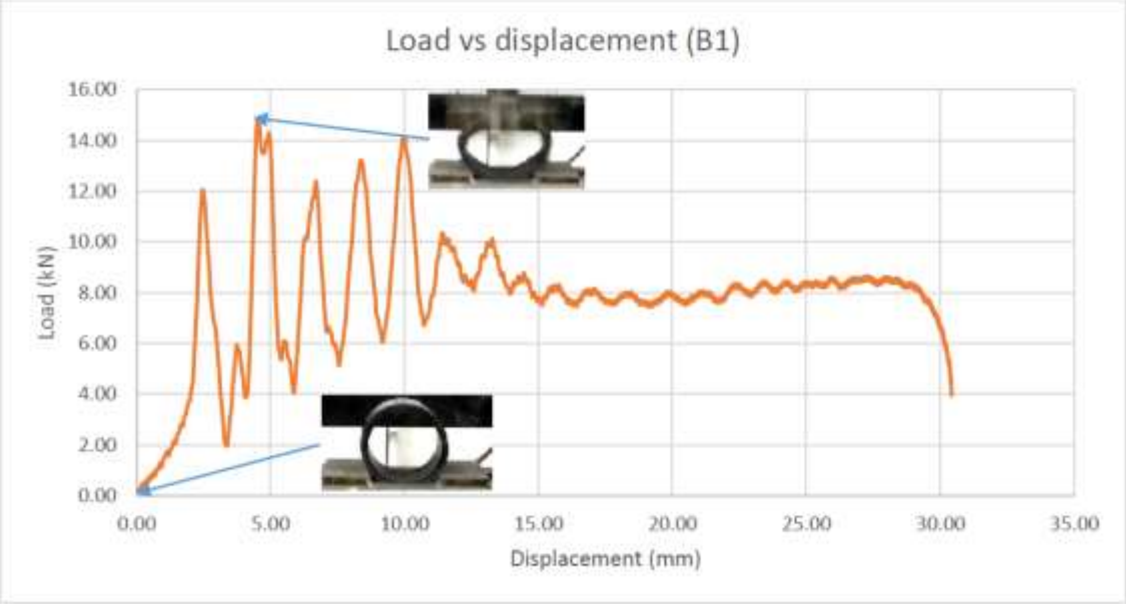


FIGURE 4.7 Load vs Displacement for Sample B1

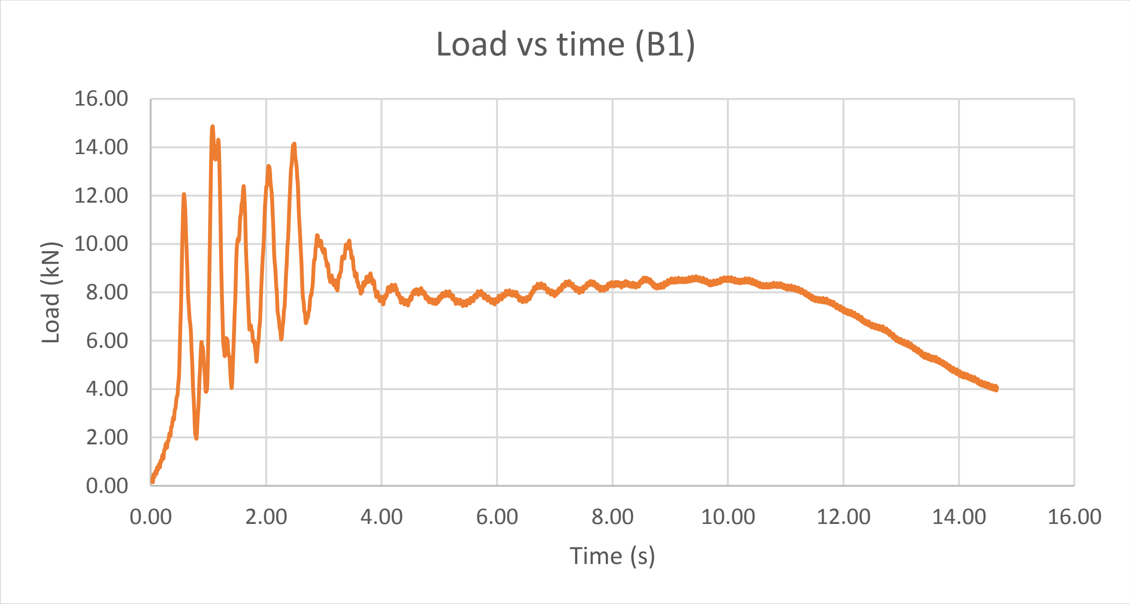


FIGURE 4.8 Load vs Time for Sample B1

FIGURE 4.9 Load vs Displacement for Sample B2

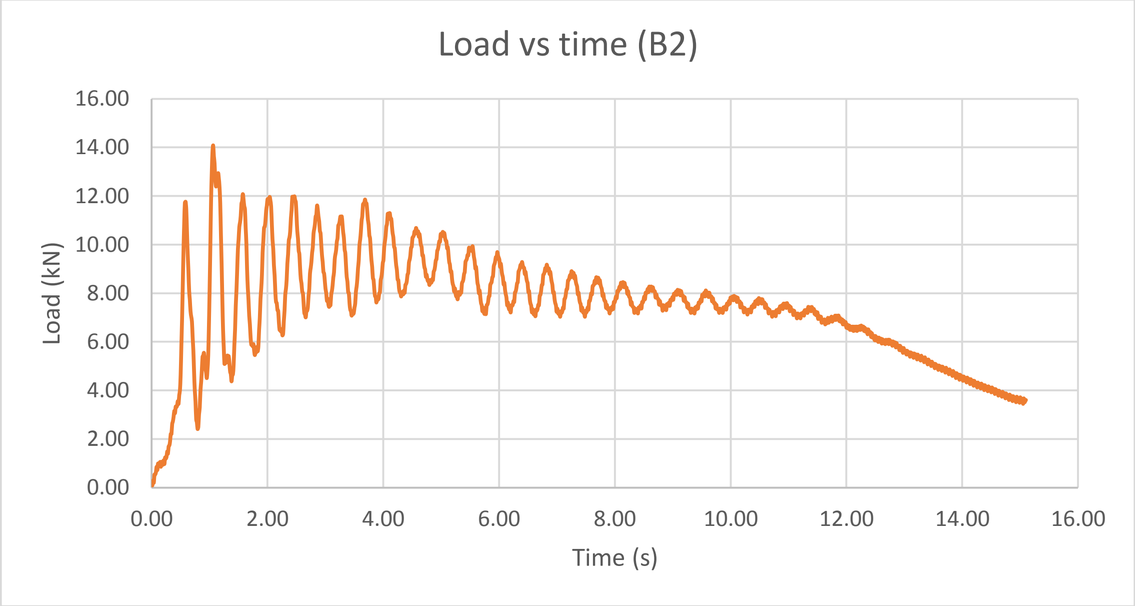


FIGURE 4.10 Load vs Time for Sample B2

FIGURE 4.11 Load vs Displacement for Sample C1

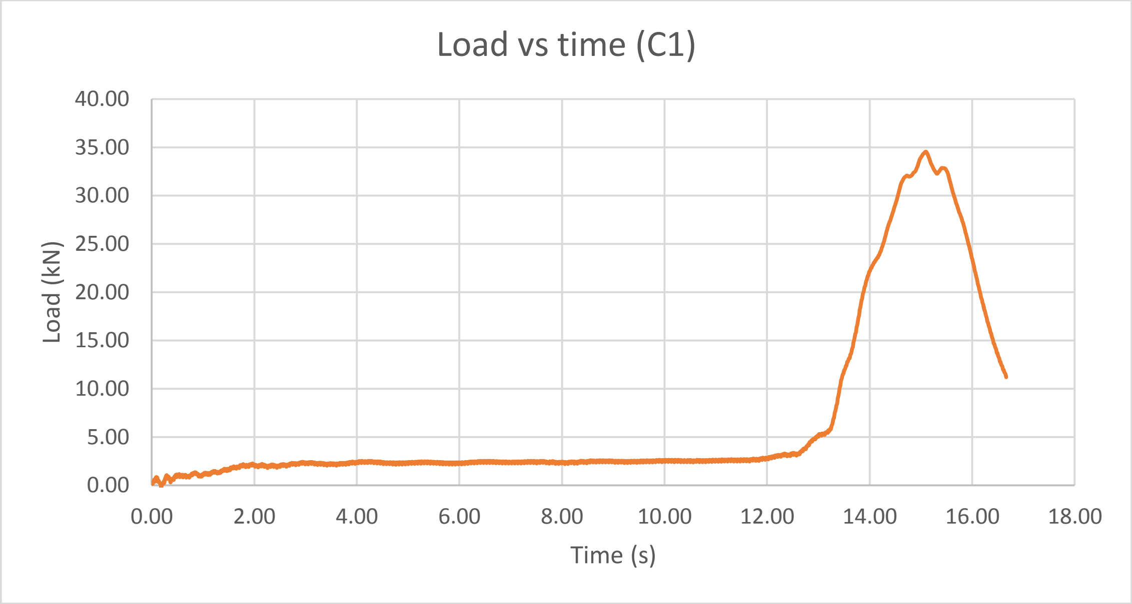


FIGURE 4.12 Load vs Time for Sample C1

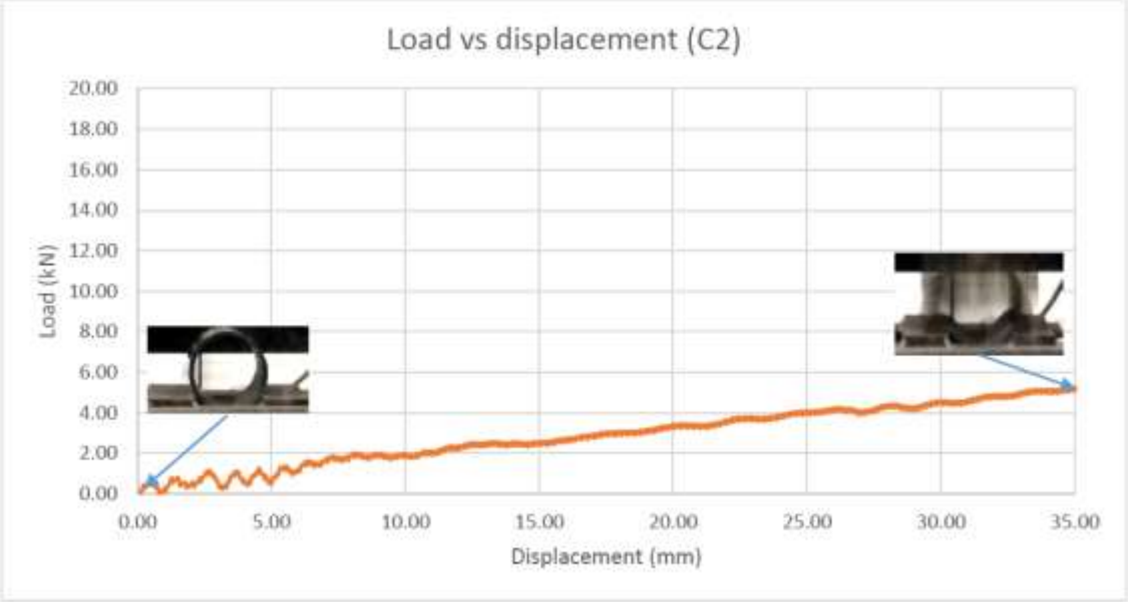


FIGURE 4.13 Load vs Displacement for Sample C2

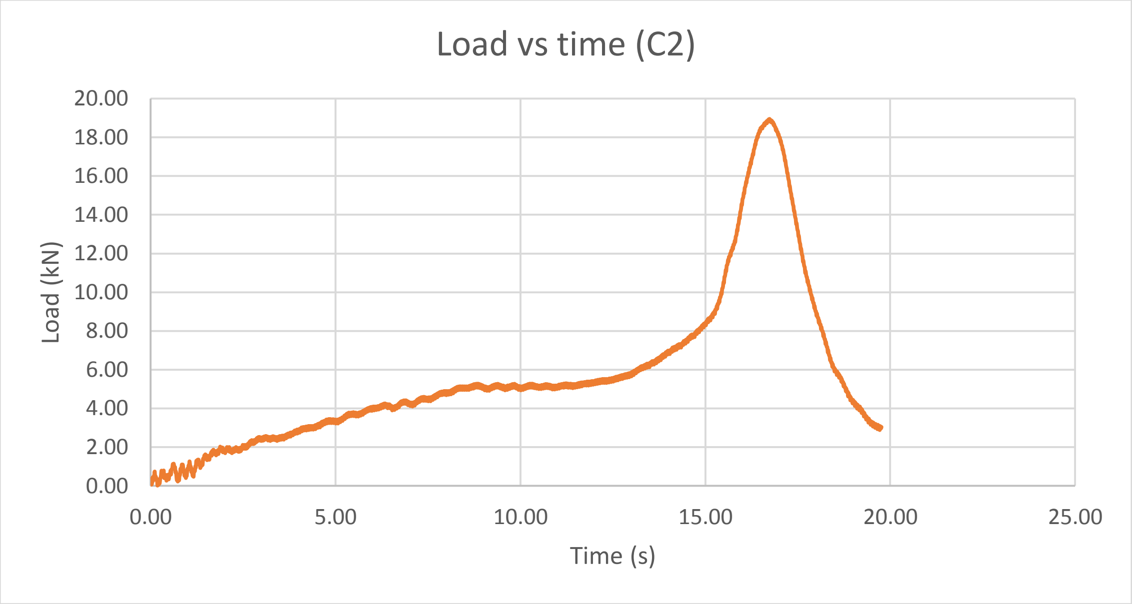


FIGURE 4.14 Load vs Time for Sample C2

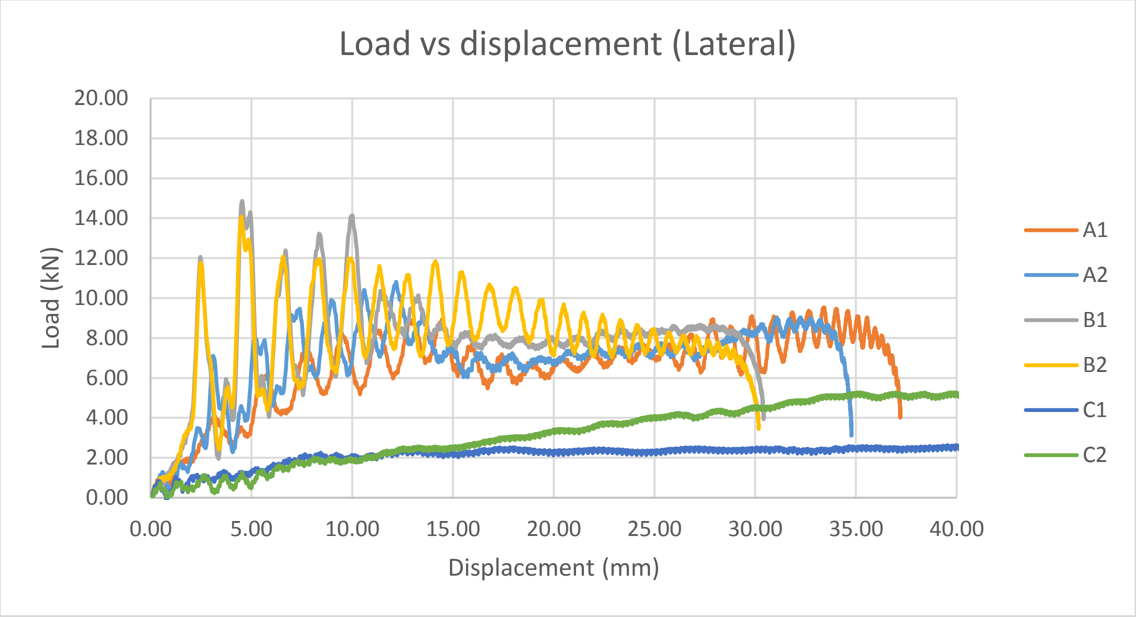


FIGURE 4.15 Load vs Displacement Graph Comparison between Samples

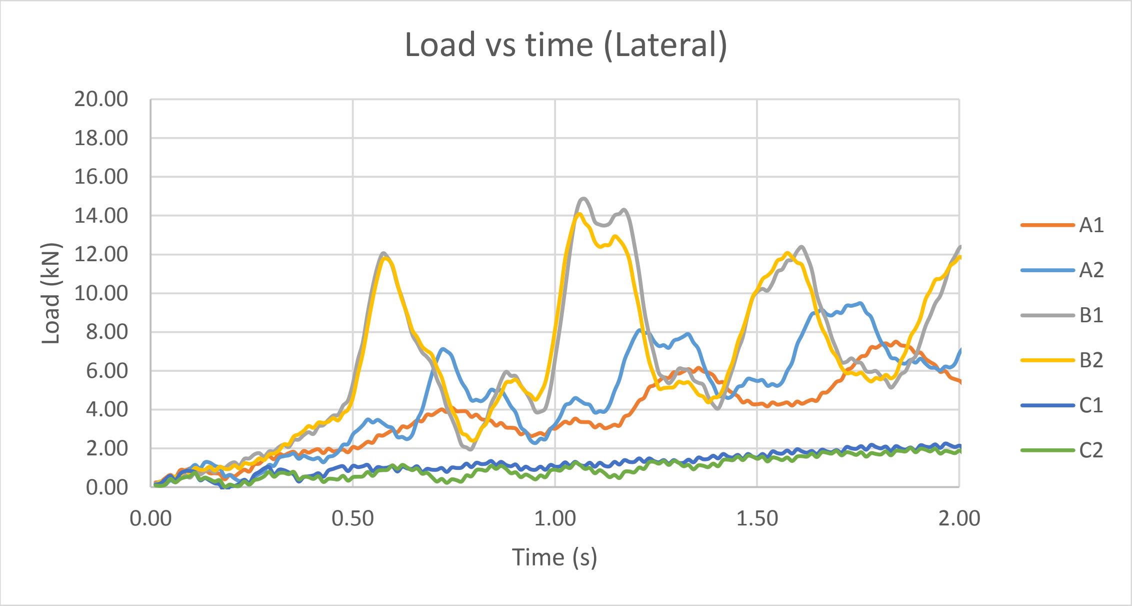


FIGURE 4.16 Load vs Time Graph Comparison between Samples

FIGURE 4.17 Appearance of Fiber Fracture on Sample A1(left) and Sample B1 (right)

4.4.2 Axial Impact on CFWHCP and HDPE Pipe.

Figure 4.18 until Figure 4.29 present the graph of load against displacement experienced by tested samples. These samples have been tested using the drop hammer of 46kg mass at 3.9ms-1 velocity and 1.00m heights in axial direction. As can be seen, the recorded load and displacements show a steady rise in load until a peak value is reached. This is followed by sudden drop in value of load indicating the pipe failure. The continuous fragmentation then occurred until the carbon fiber collapsed.

Figure 4.30 and Figure 4.31 shows the comparison of performance of CFWHCP and HDPE pipe under lateral dynamic load. From the graph, it can be seen that sample B4 which has 6 tow of 12k carbon fiber peak the highest load at 117.45kN, compared to sample A3 and A4 which has mixture of 2 tow of 12k and 4 tow of 6k fiber tow. The ability to withstand higher load proves that sample from Pipe 3 is tougher compared to Pipe 2 which also proves the microstructure test. Comparison also made with blank HDPE pipe which remarked with sample C3 and C4. From Figure 4.30, HDPE pipe exhibit lower absorption of load compared to CFWHCP.

Same as in lateral testing, the mode of failure for CFWHCP Pipe 2 is type III failure which is fiber failure. It was also observed that the samples from Pipe 3 exhibit different mode of failure which is type II failure which is delamination failure which is the failure due to crack at resin rich area. However, compared to lateral impact result, the failure is too minimal to be observed by naked eyes. Figure 4.32 shows the image of fiber fragmentation from sample A3 and B4 respectively.

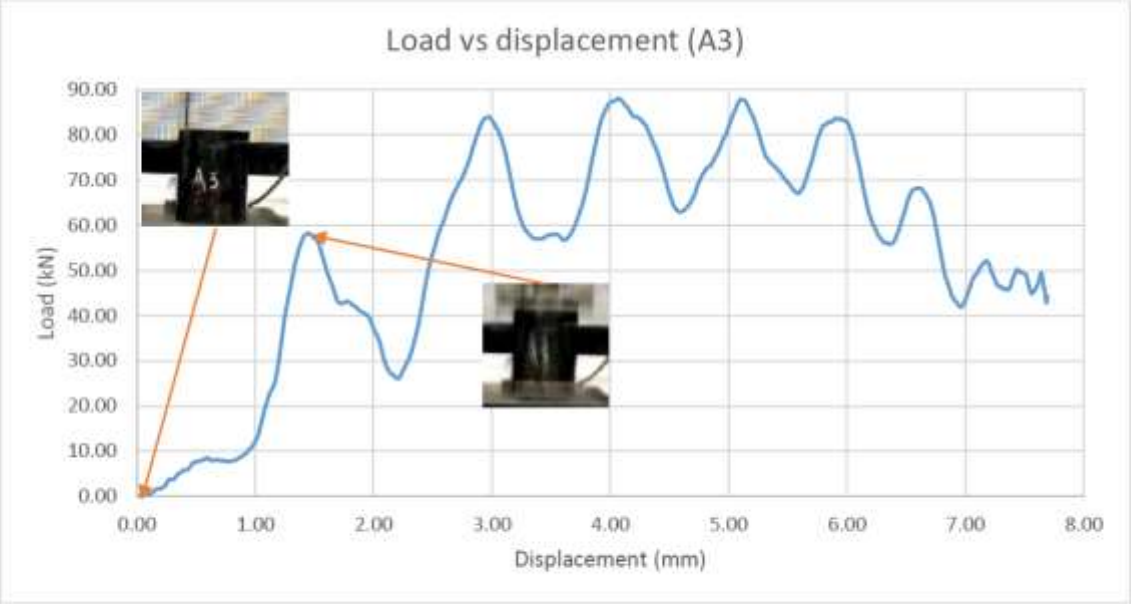


FIGURE 4.18 Load vs Displacement for Sample A3

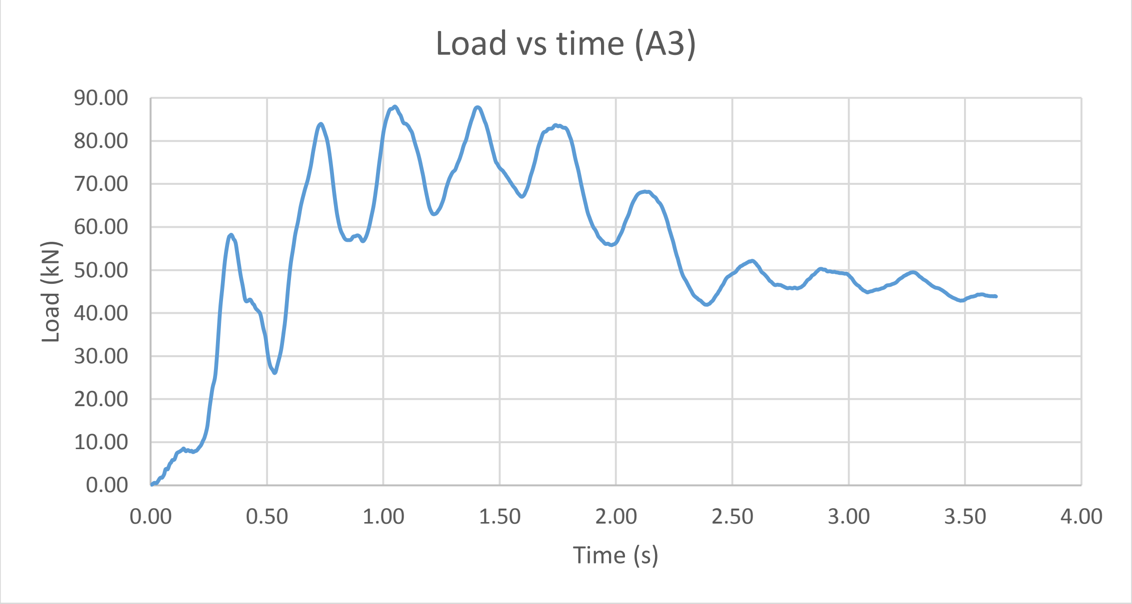


FIGURE 4.19 Load vs Time for Sample A3

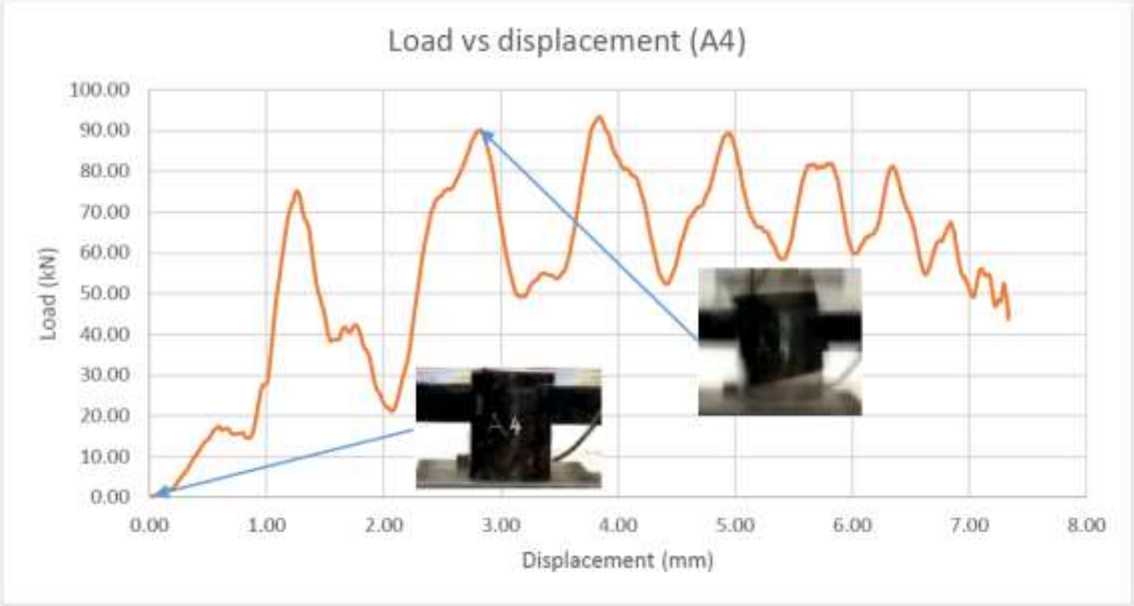


FIGURE 4.20 Load vs Displacement for Sample A4

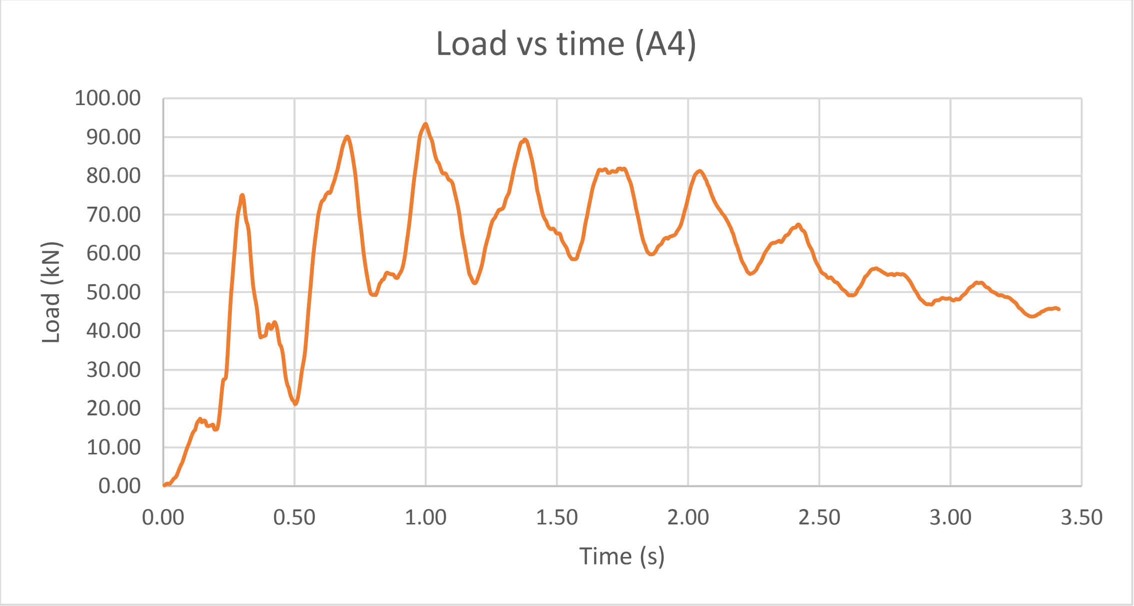


FIGURE 4.21 Load vs Time for Sample A4

FIGURE 4.22 Load vs Displacement for Sample B3

FIGURE 4.23 Load vs Time for Sample B3

FIGURE 4.24 Load vs Displacement for Sample B4

FIGURE 4.25 Load vs Time for Sample B4

FIGURE 4.26 Load vs Displacement for Sample C3

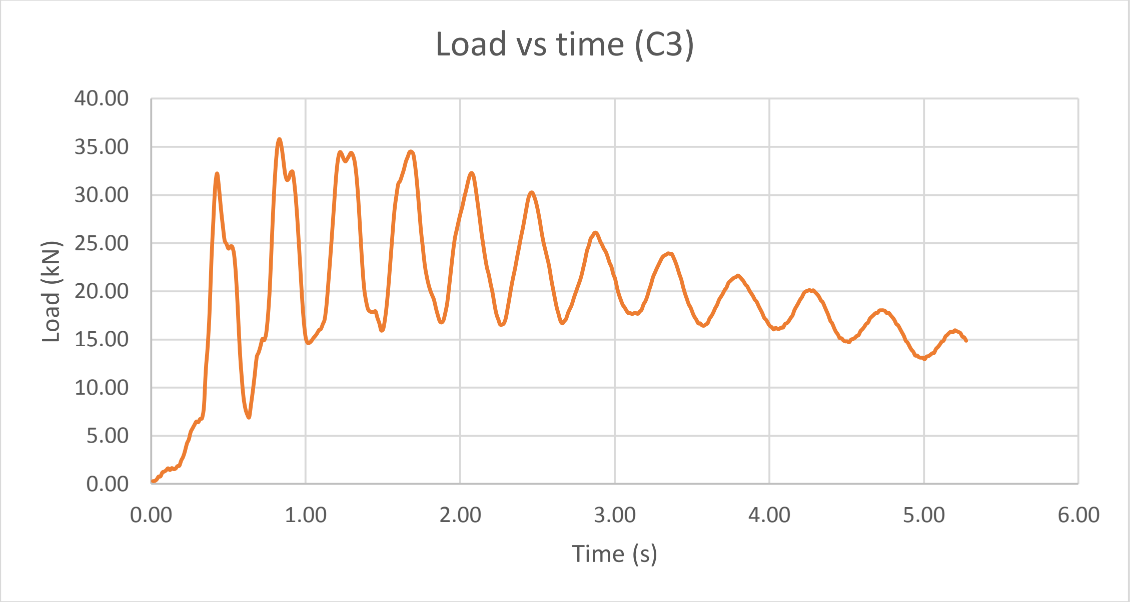


FIGURE 4.27 Load vs Time for Sample C3

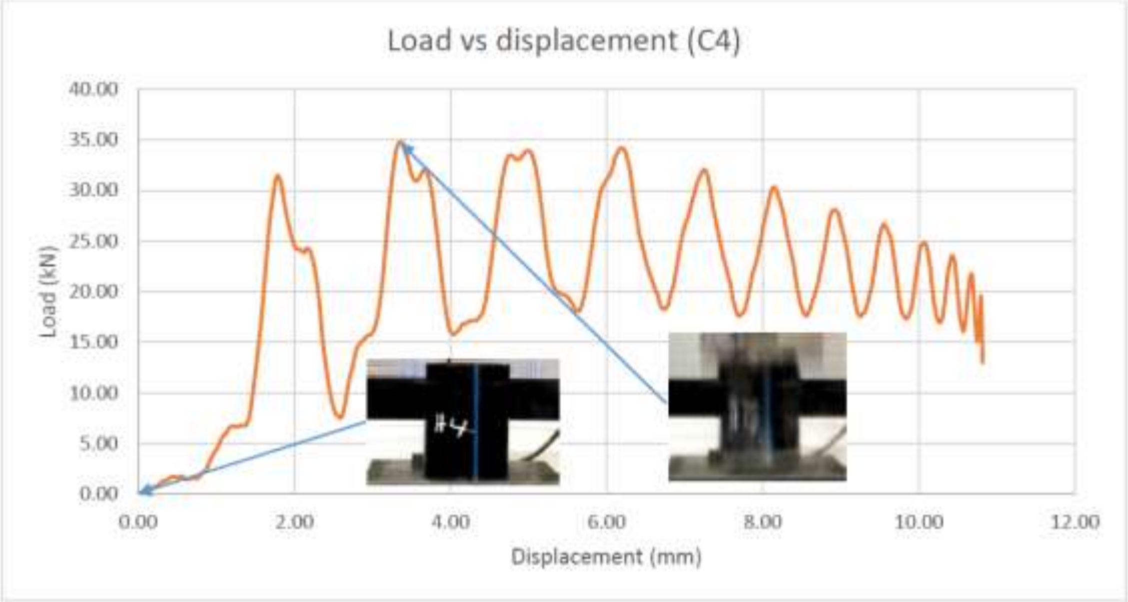


FIGURE 4.28 Load vs Displacement for Sample C4

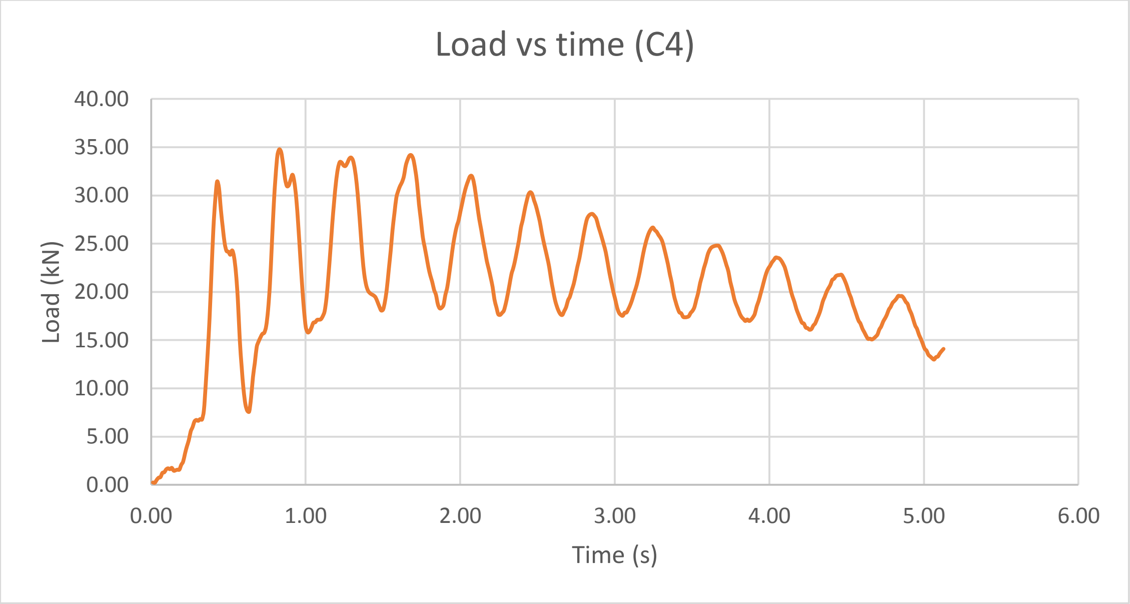


FIGURE 4.29 Load vs Time for Sample C4

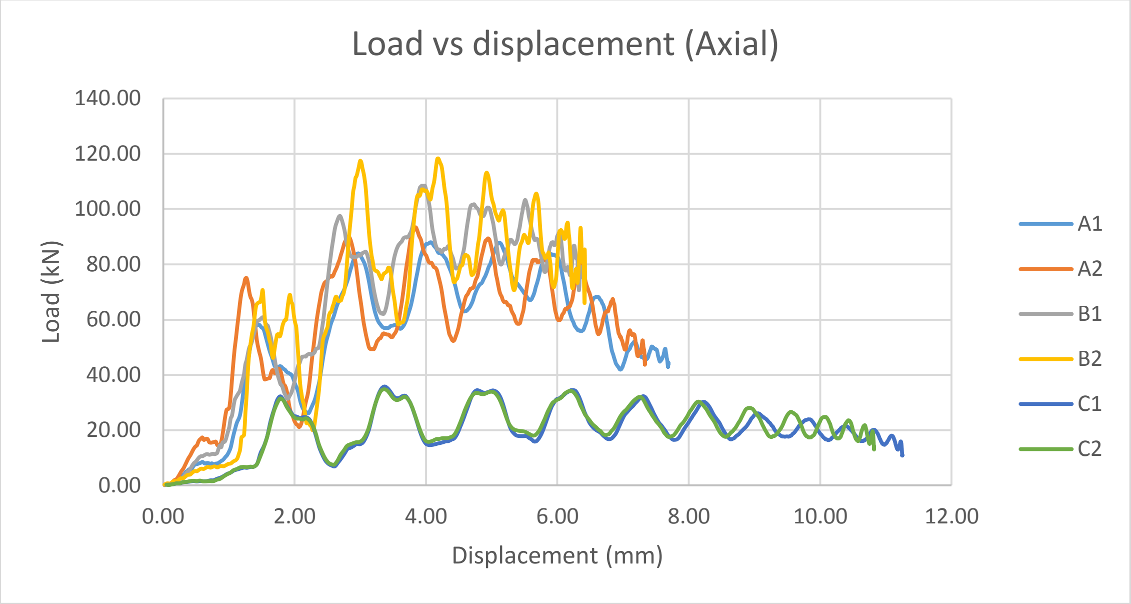


FIGURE 4.30 Load vs Displacement Graph for Comparison between Samples

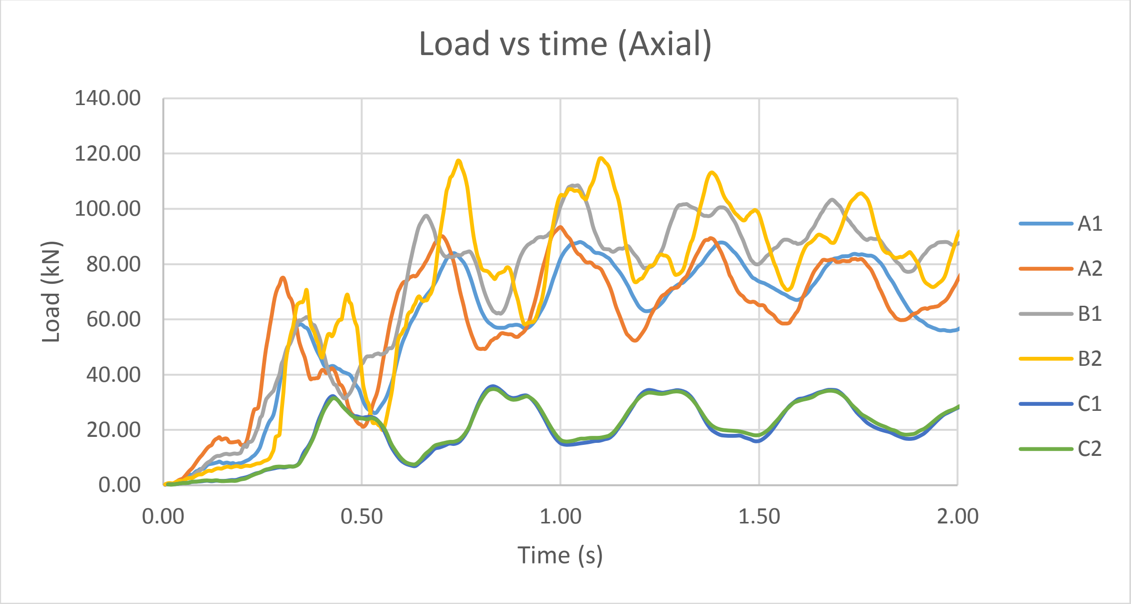


FIGURE 4.31 Load vs Time Graph for Comparison between Samples

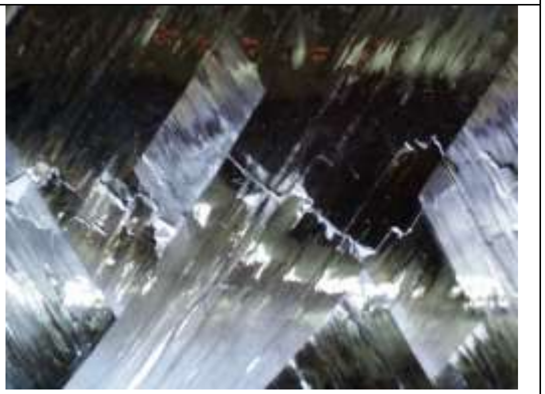
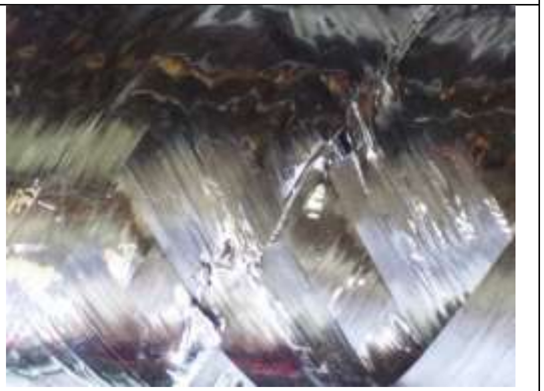
FIGURE 4.32 Appearance of Fiber Fracture on Sample A3 (left) and Sample B4 (right)

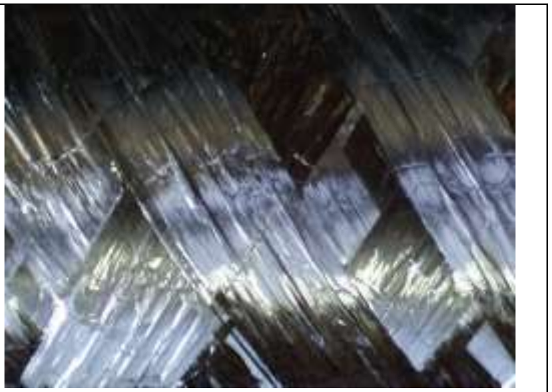
4.4.3 Summary of Dynamic Impact Test

Table 4.1 shows the summary of maximum load, mean load, energy absorption capacity and failure mode under dynamic impact on each samples. In lateral direction, the highest maximum load is on sample B1 and the highest mean load is also on sample B1. The highest total energy absorbed during the impact is from sample B2 proving that it can withstand higher load compared to other samples. The failure mode is ranging from 1-4, where 1 is the lowest level of fatality on the sample and 4 is considered as total failure according to Richardson and Wisheart [21]. From the table, HDPE pipe has the lowest level of failure mode whereas the failure level of other samples are maximum at Level 3.

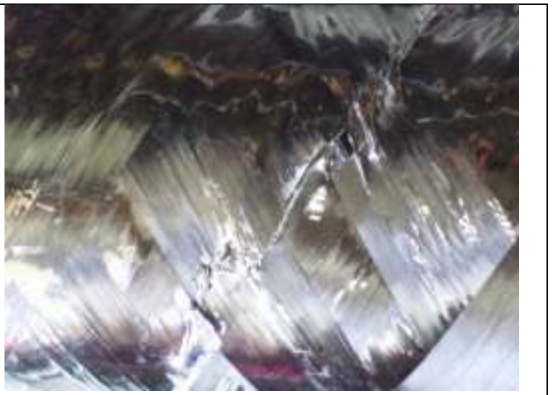
In axial direction, the highest maximum load is on sample B4 and the highest mean load is on sample B3. The highest total energy absorbed during the impact is from sample B3 proving that it can withstand higher load compared to other samples. The resulting impact saw that sample B3 and B4 has the lowest level of failure mode compared to sample A while sample C is completely fail under the impact.

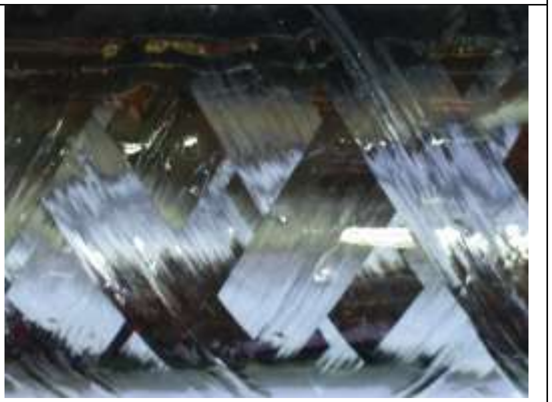
TABLE 4.3 Summary of Dynamic Impact Test

Sample	Impact direction	Maximum Load (kN)	Mean Load (kN)	Total Energy (kN/mm)	Failure Mode	Post Impact Picture
A1	Lateral	9.532	6.782	180.56	3 (Fiber Mode)	
A2	Lateral	10.816	7.001	199.08	3 (Fiber Mode)	

B1	Lateral	14.863	7.577	230.68	3 (Fiber Mode)	
B2	Lateral	14.083	7.367	231.31	3 (Fiber Mode)	

C1	Lateral	14.546	6.732	19.11	4 (Penetration)	
C2	Lateral	08.951	5.710	68.32	4 (Penetration)	

A3	Axial	88.009	54.470	620.29	3 (Fiber Mode)	
A4	Axial	93.374	57.862	676.98	3 (Fiber Mode)	

B3	Axial	108.45	73.369	985.96	1 (Matrix Mode)	
B4	Axial	118.321	73.119	972.55	1 (Matrix Mode)	

C3	Axial	35.804	19.336	215.22	4 (Penetration)	
C4	Axial	34.786	20.714	223.96	4 (Penetration)	

CHAPTER 5

CONCLUSION AND RECOMMENDATION

From microstructure test done, it can be concluded that the void found on the microstructure of specimen with four 12K carbon fiber tow had smaller void compared to 2 bundle of 12K plus 4 bundle of 6K carbon fiber. According to Paciornik and Almeida [8], the existence of void had significant impact to the mechanical properties of composites. To prove the theory, dynamic impact test was conducted to study the toughness property of CFWHCP.

Dynamic impact test was conducted to CFWHCP. In this test, the failure mode and load against displacement curves was studied. From the result, it can be conclude that Pipe 3 which is CFWHCP with 4 tow of 12k carbon fiber are able to withstand higher load compared to Pipe 2 which is CFWHCP with 2 tow of 12k carbon fiber plus 4 tows of 6k carbon fiber. This result supports the quasi-static testing done on similar pipe. The justification of this result is due to the smaller area of void existed on Pipe 3 compared to Pipe 2.

The energy absorption profile also studied based on the result of dynamic test. This test was done to each sample as well as blank HDPE pipe without the winding of carbon fiber composite for comparison. The comparison of energy absorption profile shows that Pipe 3 absorbs higher energy compared to Pipe 2 before fragmentation occur.

As for recommendation in future research, failure mode should be done by proper testing instead of simple observation. This will improve the knowledge on how the initiation of fragmentation to the composites propagate during the collapse. Moreover, higher mass should be used to properly see the failure mode of the composites since the drop mass used in this experiment is not enough to fail the composite.

REFERENCES

[1] J. J. Baron and M. Peters, "Reinforced Composite Pipelines- Best Management Practices," in NACE Northern Area Western Conference, Alberta, 2010.

[2] "Aramco ExPats Corporation," Saudi Aramco, 2 January 2009. [Online]. Available: http://www.aramcoexpats.com/articles/2009/01/nonmetallic-pipe-used-for-hydrocarbons/. [Accessed 14 February 2015].

[3] "Composites World," Gardnerweb.com, 1 January 2014. [Online]. Available: http://www.compositesworld.com/articles/the-markets-oil-and-gas-2012. [Accessed 14 February 2015].

[4] T. Rehberg, M. Schad and M. Green, "Non-Metallic Composite Repair Systems for Pipes and Pipelines," 3R International, no. 1, pp. 42-46, 2010.

[5] S. T. Peters, Composite Filament Winding, ASM International, 2011.

[6] P. d. Bakker, "GW Composites: The industry leader in carbon fiber and fiberglass rods and tubes," GW Composites, [Online]. Available: http://gwcomposites.com/production-processes/filament-winding/. [Accessed 1 April 2015].

[7] "Airborne Oil and Gas," Airborne International, 2013. [Online]. Available: http://airborne-oilandgas.com/related-case-pipe-solutions/. [Accessed 31 January 2015].

[8] S. Paciornik and J. Almeida, "Digital Microscopy and Image Analysis Applied to Composite Materials," Revista Matéria, vol. 15, no. 2, pp. 172-181, 2010.

[9] A. Standard, Standard for Seamless Carbon Steel Pipe for High Temperature Service, New York: ANSI/ASME, 2002.

[10] J. M. Corum, R. Batiste, K. Liu and M. Ruggles, Basic Properties of Reference Crossply Carbon Fiber Composite, Tennessee: Oak Ridge National Laboratory, 2000.

[11] M. L. Berins, SPI Plastics Engineering Handbook of the Society of the Plastics Industry, Society of the Plastics Industry Inc, 2000.

[12] M. Domaneschi, "Experimental and Numerical Study of Standard Impact Tests on Polypropylene Pipes with Brittle Behavior," Journal of Engineering Manufacture, vol. 226, no. 12, p. 2035–2046, 2012.

[13] E. S. Erdiller, Experimental Investigation for Mechanical Properties of Filament Wound Composites Tube, Turkey: Middle East Technical University, 2004.

[14] T. Johnson, "Filament Winding- The Basics," About.com, 2015. [Online]. Available: http://composite.about.com/od/equipment/a/Filament-Winding-The-Basics.htm. [Accessed 11 February 2015].

[15] D. Cohen, "Influence of Filament Winding Parameters on Composite Vessel Quality and Strength," Composites Part A, vol. 28, no. A, pp. 1035-1047, 1997.

[16] C. W. Jr., Materials Science & Engineering an Introduction, Utah: John Wiley & Sons, 2003.

[17] I. M. Daniel and O. Ishai, Engineering Mechanics of Composite Materials, Oxford: Oxford University Press, 2006.

[18] P. Gninga, M. Tarfaouia, F. Collombetb, L. Riouc and P. Daviesc, "Damage Development In Thick Composite Tubes Under Impact Loading and Influence on Implosion Pressure: Experimental Observations," 29 January 2005. [Online].

Available: http://www.sciencedirect.com/science/article/pii/S1359836804001398. [Accessed 17 February 2015].

[19] G. Belingardi and R. Vadori, "Low Velocity Impact Tests of Laminate Glass-fiber-epoxy Matrix," International Journal of Impact Engineering, vol. 27, pp. 213-229, 2002.

[20] H. Ya, Impact Loading of Composite Plastic Pipes, Manchester: Manchester University, 2006.

[21] M. W. Richardson and M. J. Wiheart, "Review of Low-Velocity Impact Properties of Composite Materials," Journal of Composites, vol. 27A, pp. 1123-1131, 1996.

[22] J. R. Davis, Tensile Testing, 2nd Edition, Ohio: ASM International, 2004.

APPENDICES I FABRICATION OF CFWHCP

APPENDIX 1.1 Carbon fiber is pre-pregnated into resin bath

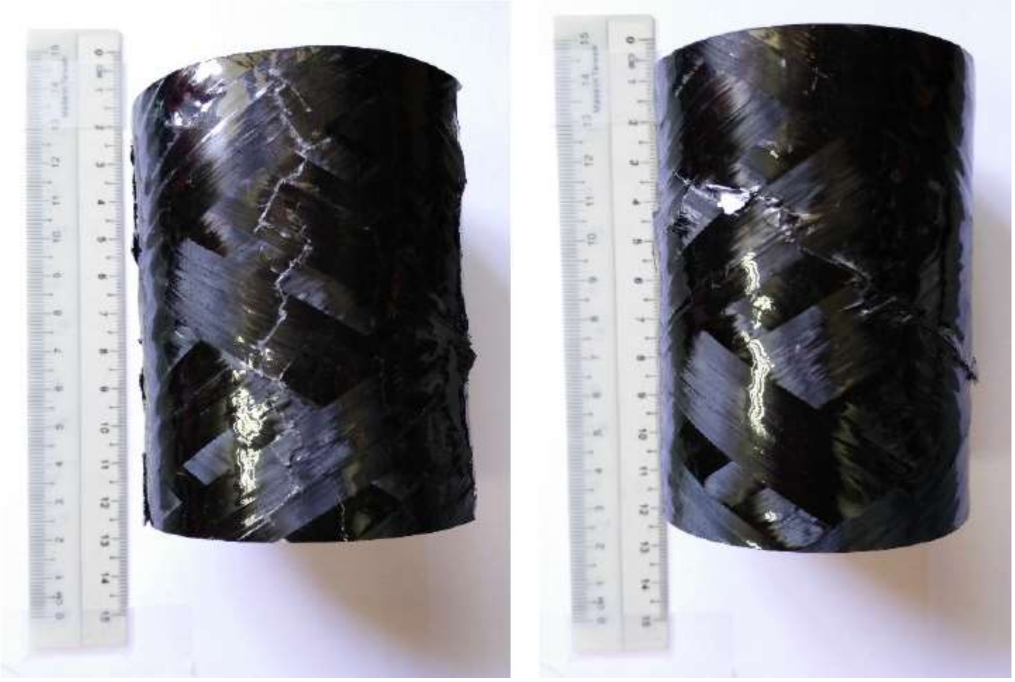
APPENDIX 1.2 Carbon fiber is laid with uniform bandwith

APPENDIX 1.3 Pre-installed CAD for wind pattern

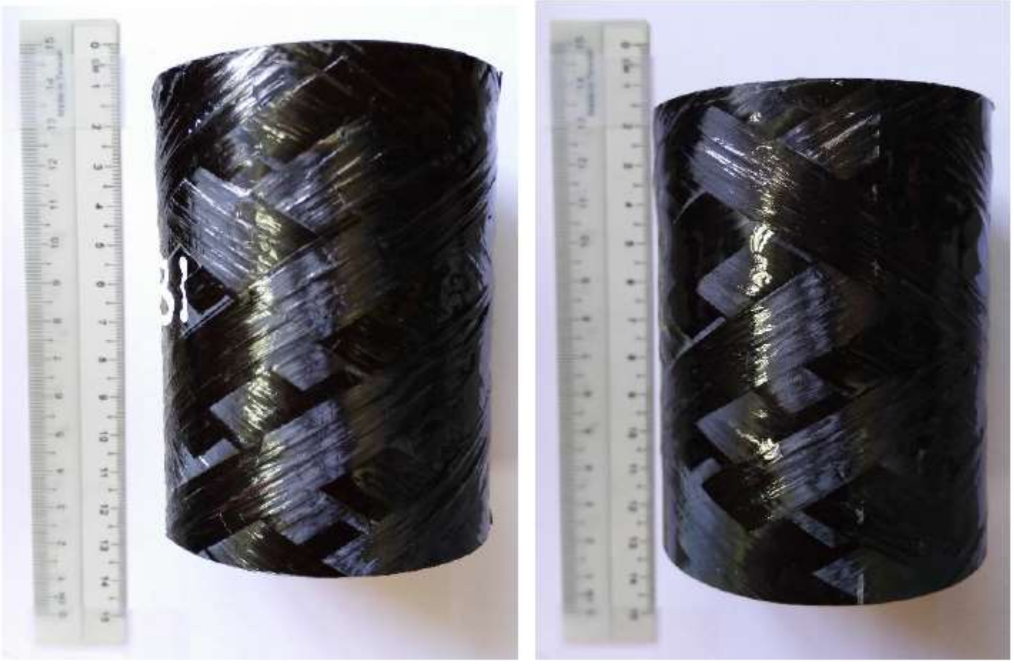
APPENDIX 1.4 Carbon fiber is wind to HDPE pipe

APPENDIX 1.5 Result of carbon fiber winding pre heated

APPENDICES II POST IMPACT OF DYNAMIC LOADING



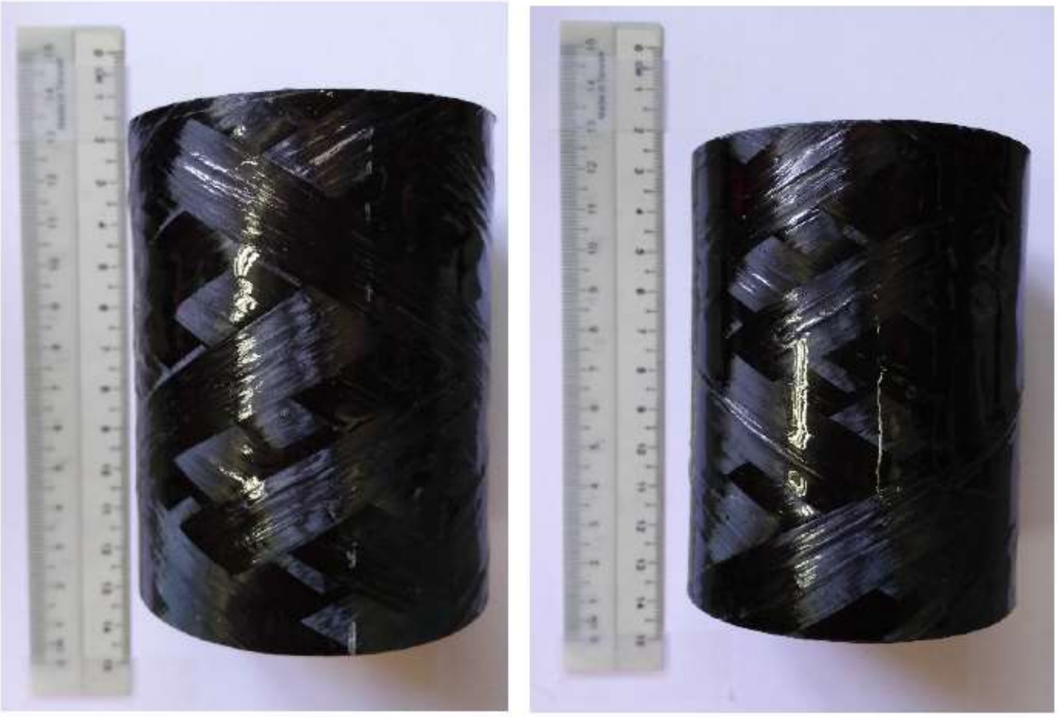
APPENDIX 2.1 Post Impact for Sample A1 and A2



APPENDIX 2.2 Post Impact on Sample B1 and B2

APPENDIX 2.3 Post Impact on Sample C1 and C2

APPENDIX 2.4 Post Impact on Sample A3 and A4



APPENDIX 2.5 Post Impact on Sample B3 and B4

APPENDIX 2.6 Post Impact on Sample C3 and C4

APPENDICES III SAMPLE OF DATA

Operator Name	Naqiuddin UTP					
Lot ID	SET A (AXIAL) 46kg					
Date/Time	08-08-15 00:24					
Channel	1					
Index	Time	Raw Data	Load	Energy	Velocity	Deflection
#	ms	A/D Counts	kN	J	m/s	mm
6804	0	516	-0.075545	0	4.225585	0
6805	0.004882813	521	0.113318	0.00039	4.225631	0.020633
6806	0.009765625	527	0.339953	0.005066	4.225655	0.041266
6807	0.014648438	532	0.528815	0.014029	4.225656	0.061899
6808	0.01953125	532	0.528815	0.02494	4.225648	0.082532
6809	0.024414063	530	0.45327	0.035071	4.225644	0.103165
6810	0.029296875	538	0.75545	0.047541	4.225628	0.123798
6811	0.034179688	549	1.170948	0.067415	4.225573	0.144431
6812	0.0390625	560	1.586445	0.09586	4.225475	0.165063
6813	0.043945313	565	1.775308	0.13054	4.225344	0.185695
6814	0.048828125	564	1.737535	0.166777	4.225206	0.206326
6815	0.053710938	574	2.115261	0.20652	4.225049	0.226957
6816	0.05859375	588	2.644076	0.255611	4.224844	0.247587
6817	0.063476563	615	3.663934	0.320674	4.224558	0.268215
6818	0.068359375	619	3.815024	0.397807	4.224209	0.288842
6819	0.073242188	616	3.701706	0.475324	4.223857	0.309467

APPENDIX 3.1 Sample of Data Iteration for Dynamic Impact Test (Sample A1)