INFLUENCE OF WATER ABSORPTION ON THE MECHANICAL PROPERTIES OF JUTE FIBRE BIO-COMPOSITE

by

HEMARAJAN A/L DORAISAMY

Thesis submitted in fulfilment of the requirements for the Bachelor degree of Engineering (Honours) (Aerospace Engineering)

June 2021

ENDORSEMENT

I, Hemarajan A/L Doraisamy hereby declare that I have checked and revised the whole draft of dissertation as required by my supervisor.

(Signature of Student)

Date : 7 July 2021

(Signature of Supervisor)

Name : Dr Aslina Anjang Ab Rahman

Date : 9 July 2021

ENDORSEMENT

I, Hemarajan A/L Doraisamy hereby declare that all corrections and comments made by the supervisor and examiner have been taken consideration and rectified accordingly.

(Signature of Student)

Date : 7 July 2021

(Signature of Supervisor)

Name : Dr Aslina Anjang Ab Rahman

Date : 9 July 2021

(Signature of Examiner)

Name : Dr Mohd Shukur Bin Zainol Abidin

Date : 11 July 2021

DECLARATION

This thesis is the result of my own investigation, except where otherwise stated and has not previously been accepted in substance for any degree and is not being concurrently submitted in candidature for any other degree.

(Signature of Student)

Date : 7 July 2021

INFLUENCE OF WATER ABSORPTION ON THE MECHANICAL PROPERTIES OF JUTE FIBRE BIO-COMPOSITE

ABSTRACT

Bio-composites are increasingly viewed as a renewable alternative to synthetic composites in many applications. However, low durability and rapid degradation of biocomposites in outdoor applications have become a major problem. In particular, wet environments can cause a rapid deterioration in the mechanical properties and efficiency of bio-composites due to moisture absorption. The focus of this work has been to study the mechanical properties of jute fibre bio-composite with and without the influence of water absorption. Distilled water was used to environmentally age the bio-composite samples using the immersion bath technique at room temperature. The studied composite materials used polyester resin as the matrix and were manufactured using wet hand lay-up process. Tensile test and flexural test were conducted on the saturated samples after being immersed for 36.7 $hours^{0.5}$ and 32.6 $hours^{0.5}$, respectively. The tensile test was carried out based on ASTM D 3039 standard, while the flexural test was conducted based on ASTM D 7264 standard. All of the sorption behaviours obtained display a classic Fickian sorption curve. A significant decrement in the mechanical properties of the saturated samples was observed when compared to the standard samples. A reduction of 56.8% in tensile strength, 55.0% in tensile modulus, 31.7% in flexural strength and 47.7% in flexural modulus was shown. This study showed that jute-fibre composites are not suitable for applications in a humid environment, and further modification is needed to improve their moisture absorption properties.

PENGARUH PENYERAPAN AIR TERHADAP SIFAT MEKANIKAL JUTE FIBER BIO-KOMPOSIT

ABSTRAK

Bio-komposit semakin dilihat sebagai alternatif yang boleh menggantikan komposit sintetik dalam pelbagai aplikasi. Walau bagaimanapun, ketahanan yang rendah dan degradasi cepat biokomposit dalam aplikasi luar telah menjadi masalah besar. Khususnya, persekitaran basah boleh menyebabkan kemerosotan pada sifat mekanikal dan kecekapan bio-komposit kerana penyerapan kelembapan. Fokus kerja ini adalah untuk mengkaji sifat mekanik bio-komposit gentian jute dengan dan tanpa pengaruh penyerapan air. Air suling digunakan untuk merendamkan sampel bio-komposit menggunakan teknik rendaman mandian pada suhu bilik. Bahan komposit yang dikaji ini menggunakan resin poliester sebagai matrik dan dihasilkan menggunakan kaedah '*wet hand lay-up*'. Ujian tegangan dan ujian lenturan dilakukan pada sampel, yang masing-masing direndam selama 36.7 jam$^{0.5}$ dan 32.6 jam$^{0.5}$. Ujian tegangan dilakukan berdasarkan standard ASTM D 3039, sementara ujian lenturan dilakukan berdasarkan standard ASTM D 7264. Semua graf penyerapan yang diperoleh memaparkan lengkung Fickian klasik. Penurunan ketara pada sifat mekanik sampel yang direndam dapat diperhatikan jika dibandingkan dengan sampel piawai. Penurunan kekuatan tegangan sebanyak 56.8%, modulus tegangan sebanyak 55.0%, kekuatan lenturan sebanyak 31.7% dan modulus lenturan sebanyak 47.7% ditunjukkan. Kajian ini menunjukkan bahawa jute fiber bio-komposit tidak sesuai untuk aplikasi di lingkungan yang lembap, dan modifikasi harus dilakukan untuk mengurangkan sifat penyerapan kelembapannya.

ACKNOWLEDGEMENT

First and foremost, I would like to express my deepest gratitude and appreciation towards my Final Year Project supervisor, Dr Aslina Anjang Ab Rahman, for her continuous support and guidance throughout the completion of this project. With her help and encouragement, I learned new knowledge and completed this project on time. I would also like to thank my examiner, Dr Mohd Shukur Bin Zainol Abidin, to provide insights after my colloquium presentation, which helped me improve the project.

Besides that, I would like to thank all the technicians and staff involved during this project's completion, especially the composite laboratory technicians, Mr Hasfizan bin Hashim and Mr Mohd Shahar bin Che Had. They shared a lot of knowledge on the fabrication and testing of composites. This research will not succeed without their continuous and supportive work. Next, I would like to convey my utmost appreciation to Mr. Fakruruzi Bin Fadzil, who willingly helped and guided me throughout process of mechanical testing. Furthermore, I would like to express my thankfulness to Ms Athifah Fakhirah Muhammad, who helped me during the Archimedes density testing process and her continuous support throughout the project.

Last but not least, I would like to express my heartfelt appreciation to my family for their love and encouragement for me to finish this project. I also wanted to deliver my special thanks to all my friends that assisted me directly or indirectly in completing this project.

TABLE OF CONTENT

LIST OF FIGURES

LIST OF TABLES

LIST OF ABBREVIATIONS

GSM : Gram per Square Meter

UTM : Universal Testing Machine

ASTM : American Society for Testing and Materials

SEM : Scanning Electron Microscopy

PEEK : Polyetheretherketone

PP : Polypropylene

PEI : Polyetherimide

PEKK : Polyetherketoneketone

PPS : Polyphenylene Sulfide

LIST OF SYMBOLS

m_t	: Sample weight at time
m_i	: Initial weight of the sample
D	: Diffusion Coefficient
t	: Initial thickness of the sample
θ	: Slope of the moisture absorption curve
Qs	: Moisture absorption percentage during the saturation phase
S	: Sorption coefficient
Qs	: Molar percentages of water absorption at saturation
Qt	: Molar percentages of water absorption at time
P	: Permeability coefficient
V_f	: Volume fraction
n	: Number of plies used
A_F	: Areal weight of the fibre,
ρ_f	: Density of the fibre
V_v	: Void content
ρ_{comp}	: Density of the composite
m_{comp}	: Mass of the composite
m_f	: Total mass of fibres used
ρ_{matrix}	: Density of resin used

CHAPTER 1

INTRODUCTION

1.1 Overview

Composite materials originated in the mid 20th century as a desirable class of engineering materials that offered great possibilities for modern technology. This is due to the demand for lightweight yet high strength materials in many industries in today's world. A composite material is created by combining at least two materials with significantly different properties. It consists of fibre and matrix. The fibre acts as a reinforcement that provides strength and stiffness to the material while the matrix protects and transfer load between the fibres. There are two types of matrix, which are thermoset matrix and thermoplastic matrix. This combination of fibres and matrix is most likely to produce exceptional qualities such as a great strength-to-weight ratio and corrosion resistance in the material.

In this research, natural fibre is used because it is an excellent alternative to the existing synthetic fibre. Natural fibres are of interest in composite research because of their benefits such as low weight, environmental friendliness and low density. Natural fibre such as jute, kenaf, palm, coir and banana leaves are generally extracted from renewable sources, non-toxic, entirely biodegradable and can be easily recycled to reduce the carbon footprint of materials (Dong et al., 2014). The biodegradability of natural fibre may result in a healthy ecosystem with a low-cost, high-performance material that can meet the industry's economic interests.

However, the application of natural composites is limited to only specific fields due to some material property deficiencies. Examples of the deficiencies of the natural composites are the hydrophilic character, bonding issues with polymer and the temperature limitations in the manufacturing process (Ngo, 2020). The application for natural fibres is focused more on interior application, such as the interior for passenger car, roof tiles and partition boards. Because of the need for high mechanical strength, applications on the exterior are limited.

There are a few mechanisms of water absorption in fibre reinforced polymer composites. They are diffusion, capillary action, and transport of water molecules. The movement of water molecules can happen through microcracks in the matrix of natural fibre composites. Based on the mechanisms of water absorption, there are few cases of diffusion behaviour, which is the Fickian diffusion model, non-Fickian and an intermediate case between the two cases (Muñoz & García-Manrique, 2015).

1.2 Problem Statement

Bio-composites are commonly referred to as a green alternative to synthetic composites in many applications. The environmental condition such as seasons and climates changes represents a variety of temperature and humidity conditions. The overall long-term durability of bio-composites, especially their ability to perform consistently under extreme and changing environmental conditions, remains a major concern (Mohammad Khanlou et al., 2018). The major drawback of natural fibres is their hydrophilic nature, which causes poor interfacial bonding between the fibre and matrix. The hydrophilic characteristic of natural fibres reduces the quality of adhesion between fibres, resulting in swelling and moisture content in the specimen. The weak adherence between hydrophilic fibres and hydrophobic polymeric matrix causes premature ageing through degradation and loss of strength. Natural fibres absorb a lot of moisture, which leads to poor adhesion between the fibres and the matrix (Khalili et al., 2019). Therefore, there is a need to investigate more on how the water absorption may affect the mechanical properties of the natural fibres to better understand their behaviour.

1.3 Research Objective

The objectives of this research are as follows:

1. To manufacture and fabricate Jute fibre bio-composite using the wet hand lay-up method.
2. To measure the water uptake level on the Jute fibre bio-composite.
3. To analyse the tensile and flexural properties of both the immersed and non-immersed bio-composite sample.

1.4 Thesis Outline

This thesis is divided into five chapters that will provide a detailed explanation of the conducted research. The five chapters are the introduction, literature review, methodology, result and discussion and conclusion. Chapter 1 gives a general overview of composite materials and the advantages and disadvantages of bio-composites. Besides that, the problem statement and the research objectives are also defined in this chapter. In chapter 2, all literature related to the topic of this work is presented. The focus is on the properties of the natural fibre and the fabrication method. This chapter also goes through the process of selecting an appropriate matrix. In the third chapter, all the fundamental theories involved in specimen conditioning and fabricating are discussed. Furthermore, the properties of the specimens are also analyzed. Chapter 4 will discuss all the results and discussions obtained from the tensile and flexural testing in this project. Specimen’s void content and fibre volume fraction are also discussed in this chapter as well as the specimen’s absorption curve based on the Fickian diffusion curve. Chapter 5 summarizes all the significant findings from this project. Suggestions and future works that can be carried out to improve the current result is briefly discussed here.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction to composite materials

Composite material is a material that made up of two or more materials differing in composition or form. Although they act together, the constituents retain their identities in the composites as they do not dissolve or merge totally into one other. Composite materials are known for their high strength and stiffness as well as lightweight in comparison to metals or alloys (Campbell, 2010). This allows for a significant weight reduction in the finished parts. Furthermore, composite materials provide better performance and can be shaped into desired features as the designing process is flexible. The most common required materials in a composite are fibre and the matrix. Fibres are discontinuous phase used to carry the load while the matrix is continuous phase act as a binder that holds the fibres together and transmits the load to the fibres.

Fibre can be classified into two categories, which are continuous fibre and discontinuous fibre. The length of a fibre is substantially bigger than its diameter. The length-to-diameter (l/d) ratio is referred to as the aspect ratio, and it varies widely. Continuous fibres have long aspect ratios, while discontinuous fibres have short aspect ratio. Long aspect ratios indicate the desired orientation, whereas short aspect ratios indicate a random orientation. Continuous fibres are frequently used to make laminates by stacking single sheets of continuous fibres in different orientations to achieve desired strength and stiffness. Fibre volume as high as 70% can be achieved by using this type of fibre. Figure 2.1 shows the orientations in continuous and discontinuous fibre (Campbell, 2010).

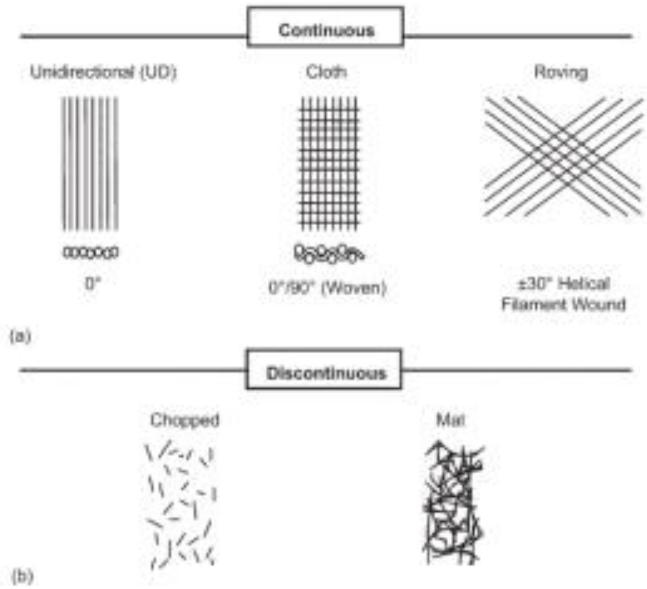


Figure 2.1 : Orientations in continuous and discontinuous fibre (Campbell, 2010).

The matrix provides a medium for binding and holding reinforcements together into a solid. It distributes load to the fibres and is essential in compression loading to prevent premature failure due to fibre micro buckling. It also provides the composite with toughness, damage tolerance, and impact and abrasion resistance (Bunsell & Thionnet, 2018). There are 3 types of composite matrix materials, which are ceramic matrix composites, metal matrix composites and polymer matrix composites. Ceramic matrix composites consist of ceramic fibre embedded in a ceramic matrix. Metal matrix composites are composite materials that made up of at least two constituent parts: a metal and another material of another metal. Polymer matrix composites are made up of a thermoset or thermoplastic matrix.

2.1.1 Jute Fibre

Natural fibres are non-synthetic fibres obtained from various sources such as animals, plants and minerals. The most common type of fibres used is plant fibre. Examples of plant-based fibres are bamboo, jute, hemp, flax, palm, coir, etc. The reinforcement material that was utilized in this investigation was a plant fibre, which is jute. Jute fibre has less resistance to moisture, which makes it a suitable choice for this research. Jute is one of the most commonly used natural fibre as reinforcement in green composites. It is a type of bast fibres from the Tiliaceae family. Jute's scientific name is corchorus capsularis because it is extracted from plants of corchorus. It is a low-cost natural fibre and is currently the bast fibre with the maximum production volume (Singh et al., 2018). Jute may reach a height of 4 to 5 meters in about 3 months. The retting process is used to separate the fibres from the plant's stem. The common types of retting process are mechanical retting, chemical retting, steam retting and water or microbial retting. Following the retting process, the retted fibres are dried in open space or by using any mechanical approach (Charlet et al., 2010). Figure 2.2 shows the illustration of a jute plant and the various types of jute fibre available. Table 2.1 shows the properties of the jute fibre.

(a) (b) (c) (d)

Figure 2.2 : (a) Jute plant; (b) Raw jute fibre; (c) Unidirectional jute fibre; (d) Woven jute fibre (Singh et al., 2018)

Table 2.1 : Properties of jute fibre (Kumar & Srivastava, 2017)

Properties	Values
Density (g/cm^3)	1.3
Elongation (%)	3.5 - 4.5
Tensile Strength (MPa)	393-723
Young's modulus (GPa)	26.5

2.1.2 Matrix

In general, resins can be categorized into two categories, which are thermoset resins and thermoplastic resins. Thermosets are low molecular weight, low viscosity monomers that are converted into three-dimensional cross-linked structures during the curing process. The structures are infusible and insoluble. Examples of thermosets are polyesters, vinyl, esters, cyanate, polyimides and phenolics. Despite the fact that thermosets are often used in composites, one major disadvantage of this type of matrix is that, due to their strongly cross-linked structures, they cannot be reprocessed and will thermally degrade.

Thermoplastic matrix is formed through the polymerization of the monomer unit. It consists of a long linear or branched-chain molecules. Examples of thermoplastics that are still commercially available are Polyetheretherketone (PEEK), polypropylene (PP), polyetherimide (PEI), polyetherketoneketone (PEKK) and polyphenylene sulfide (PPS). The major disadvantage of employing thermoplastics over materials such as metal is their low melting point. In addition, thermoplastics can have poor resistance to organic solvents. They are also susceptible to creep.

Thermoset materials have better mechanical properties such as impact strength and hardness when compared to thermoplastic materials (Dogan & Arikan, 2017). The moisture absorption properties of thermoset are higher than it is in thermoplastic, which makes thermoset to the better choice in this research as we can clearly see how it affects the mechanical properties of the bio-composite. Therefore, thermoset resin, which is polyester resin was chosen to be the matrix in this research.

Polyester resin is a polymer that is simple to use and economical. It is used in many industries such as construction, transportation, marine and aerospace. There are few types of polyester resins: alkyd, vinyl ester, saturated polyester and unsaturated polyester. Today, a vast variety of polyester resins have been developed from various acids, glycols, and monomers, each with unique qualities that may be used for anything from marine boats to fibreglass flat roofs. Advantages of polyester resin include excellent resistance to ageing and weathering and low cost. It also stands up well against high temperature and UV rays. However, polyester resin has a few drawbacks. The shrinkage rate in polyester resin is high and it has a strong styrene smell (*What Is Polyester Resin? - Resin Library*, 2020). Table 2.2 shows the properties of polyester resin.

Table 2.2 : Properties of polyester resin (Shahroze et al., 2018).

Properties	**Values**
Density (g/cm^3)	1.2 to 1.5
Young’s Modulus (GPa)	2 to 4.5
Tensile Strength (MPa)	40 to 90
Compressive Strength (MPa)	90 to 250
Tensile elongation at break (%)	2
Cure Shrinkage (%)	4 to 8

2.2 Wet hand lay-up method

Hand lay-up method has been employed as the method of fabrication in this research. It is considered the simplest and oldest open molding method for fabricating composites (Elkington et al., 2015). The process begins with placing the fibre on the mold, followed by the application of resin by either pouring, spraying or brushing. To densify the lay-up, rollers are used to fully wet the reinforcement with the resin and remove excess resin and entrapped air. The laminate is built up layer by layer until it reaches the desired thickness (Campbell, 2003). Figure 2.3 shows the illustration of the wet hand lay-up process.

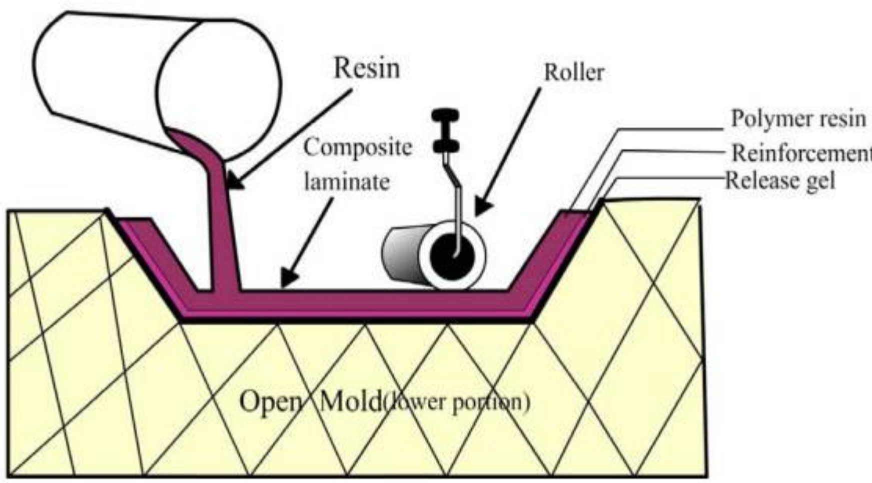


Figure 2.3 : Wet hand lay-up process (*Manufacturing Products for Hand Layup Process*, n.d.)

This method has low-cost tooling, as the only tool required for this method is a roller. A mould may or may not be used, depending on the shape and complexity of the part fabricate. Large products such as large can and large roof can be prepared by this method. However, the production efficiency of this method is low, as this is a fully manual process. The composites that formed from this method will have higher void content as compared to other methods such as vacuum infusion and vacuum bagging, because it is pressed manually using a hand to remove air from the layers of fibre and matrix, which is less effective (Elkington et al., 2015). Void content plays an important role in moisture absorption in composites, as the laminates with high void content will absorb more moisture (Costa et al., 2006). Therefore, hand lay-up method was chosen in this research so that a better understanding of water absorption properties of jute fibre bio-composite can be obtained.

2.3 Moisture Diffusion Behaviour

Moisture is introduced into the composite by diffusion flow along with the fibre/matrix interface or transportation through microcracks and voids. Generally, the water uptake behaviour of the polymeric composites varies from that of Fickian, pseudo-Fickian and non-Fickian (Moudood et al., 2019). There are two phases in the Fickian diffusion model, which are the absorption phase and the saturation phase. During the absorption phase, the absorption curve will be linear until a certain period of time where the absorption rate drops and enter the saturation phase. In the saturation phase, the material's net diffusion activity is zero, causing the curve to have a constant weight growth. In a non-Fickian diffusion model, the diffusion curve does not follow the Fickian law. This behaviour is typically caused by various factors interacting with the Brownian motion of a normal Fickian curve. Figure 2.4 shows the Fickian fit and non-Fickian fit in a weight gain against time graph.

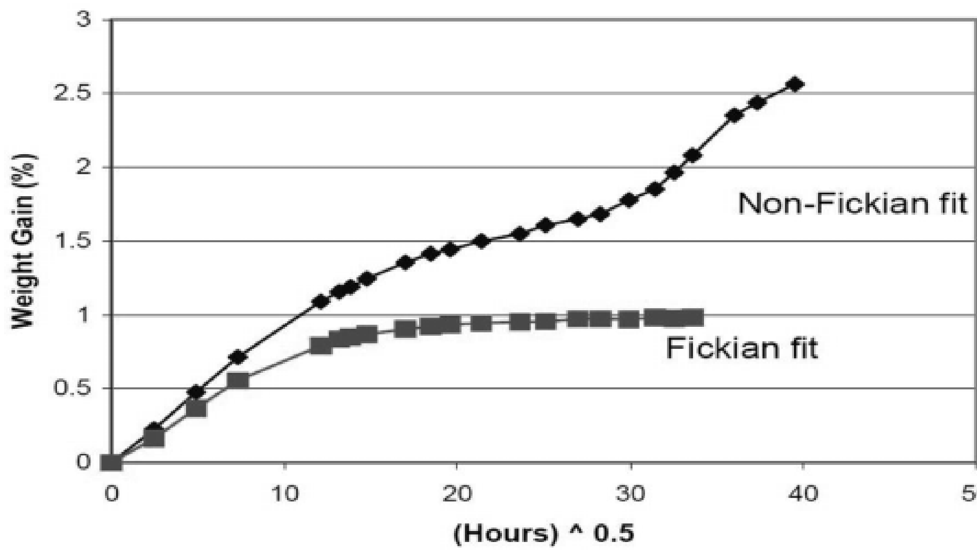


Figure 2.4: Fickian fit and Non-Fickian (Li, 2000)

The moisture diffusion coefficient is an essential element in Fick's model because it demonstrates the ability of water molecules to penetrate polymer composites. The percentage of moisture absorption in composites can be calculated by using equation 2.1.

$$\text{Moisture absorption (\%)} = \frac{(m_t - m_i)}{m_i} \times 100\ \% \tag{2.1}$$

The weight of the sample at time,t is denoted by m_t and m_i indicates the initial weight of the sample. The diffusion coefficient,D (mm^2/s), can be calculated by using equation 2.2. The initial thickness of the sample is denoted by *t*, the slope of the moisture absorption curve is denoted by θ, and Q_S refers to the percentage of moisture absorption during the saturation phase (Naveen et al., 2019).

$$D = \pi \left(\frac{t\theta}{4Q_S}\right)^2 \tag{2.2}$$

The permeability of polymer composites is determined by the sorption of the fibre. The sorption coefficient,S is an important factor in calculating the permeability coefficient. Equation 2.3 is used to compute the sorption coefficient, where Q_S and Qt are the molar percentages of water absorption at saturation and time,t respectively. Then, by using equation 2.4, the permeability coefficient,P (mm^2/s) which is the combined effect of sorption and diffusion can be calculated (Naveen et al., 2019).

$$S = \frac{Q_S}{Q_t} \tag{2.3}$$

$$P = D \times S \tag{2.4}$$

2.3.1 Effect of absorbed moisture

Exposing the natural fibre composite to moisture will result in degradation of the composite in terms of mechanical properties (Zaki Abdullah et al., 2013). The reason for this degradation is the weakening of the fibre-matrix interface, due to the high moisture content in the fibres and the increased porosity in the microstructure of the composites. Swelling of natural fibres also leads to a decline in stiffness as a result of repeated exposure to water (Akil et al., 2014). A prolonged immersion period results in permanent degradation, such as the formation of micro-cracks, which induces more moisture uptake and therefore a larger plasticizer effect on the polymer (Abdel-Magid et al., 2005).

A study was done by Maslinda et al. (2017) to explore the water absorption behaviour and its influence on the tensile and flexural characteristics of interwoven cellulosic fibres. The water absorption behaviour of these composites is discovered to be non-Fickian. Besides, it is found that hybridization increased the mechanical and water-resistant properties of kenaf, jute, and hemp fibres. In addition, longer water immersion times reduced the tensile and flexural strength of the composites.

In another study, it was found that exposure to water absorption does not negatively affect the mechanical properties of flax fibre composites. The findings imply that swelling of flax fibres in the composite material due to water absorption can have a positive influence on mechanical properties. Despite a drop in flexural properties, the tensile strength of water-immersed specimens is higher than that of dry samples due to greater bonding between the fibre and the matrix (Muñoz & García-Manrique, 2015).

2.4 Tensile Testing

Tensile test is a destructive test that determines the tensile strength and yield strength of a material. It determines the amount of force required to break a plastic specimen or composite, as well as the extent to which the specimen stretches and elongates until a breaking point (Saba et al., 2018). A typical test speed is 2 mm/min. An extensometer or strain gauge may be used to determine the elongation and tensile modulus. A study was done by Khondker et al. (2005) to identify the tensile properties of jute fibre-based thermosetting composites. The tensile strength and tensile modulus obtained from the study were 87 MPa and 5.7 GPa, respectively.

There are few standard test methods used in the tensile test, such as ISO 527-5, ISO 527-4, ASTM D 3039, ASTM D 638, and ASTM C 297. ASTM D 3039 is chosen as the standard test method as it suits this project. In-plane tensile properties of polymer matrix composite materials reinforced by high-modulus fibres are determined using this test method (Nemeth, 1995). Tensile properties such as tensile modulus, tensile strength, and strain at failure of composite laminates were determined. Table 2.3 shows tensile specimen geometry recommendation from ASTM D 3039 test method.

Table 2.3 : Tensile specimen geometry recommendation (Nemeth, 1995)

Fibre Orientation	**Width (mm)**	**Overall length (mm)**	**Thickness (mm)**	**Tab Length (mm)**	**Tab thickness (mm)**	**Tab Bevel Angle, °**
0° Unidirectional	15	250	1.0	56	1.5	7 or 90
90° Unidirectional	25	175	2.0	25	1.5	90
Balanced and Symmetric	25	250	2.5	Emery cloth	-	-
Random-discontinuous	25	250	2.5	Emery cloth	-	-

2.5 Flexural Testing

Flexural testing establishes a material's resistance to flexing or stiffness by measuring the force necessary to bend a plastic specimen or composite. The flexural modulus of a material indicates how much it can flex before permanent deformation. There are two types of flexural test which are the three-point bending test and the four-point bending test. The load in a three-point bending test is concentrated at one place, which is the centre. This type of loading causes the composite structure to flex the most. The load is applied at two points in a four-point bending test, and the maximum flexural stress is distributed across the segment of the composite panel between the loading points. Because the stress is distributed across a broader area, a premature failure can be avoided in this configuration. Based on the reported values, the flexural stress and flexural strain for jute fibre-based thermosetting composites are 137 MPa and 5.6 GPa, respectively (Khondker et al., 2005). Figure 2.5 shows the loading configuration of a 3-point bending test and a 4-point bending test.

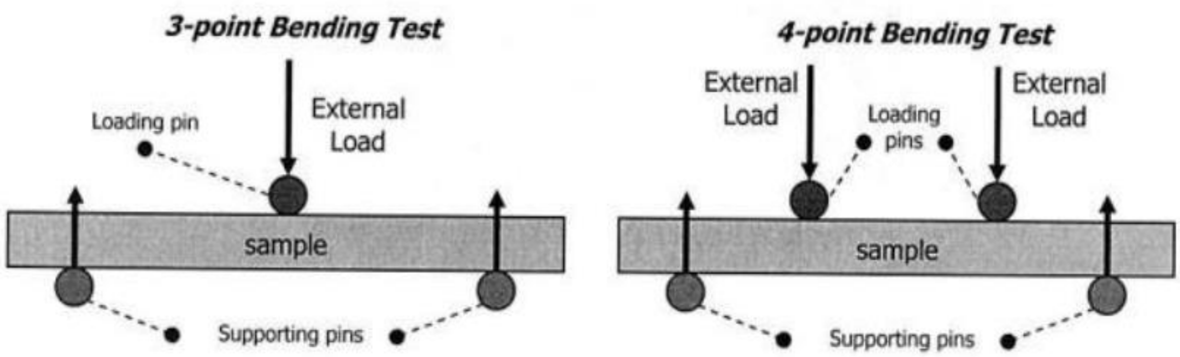


Figure 2.5 : 3-point bending test and 4-point bending test loading configuration (*(PDF) Failure Mechanics of Multi Materials Laminated Systems Review Analysis-Based Project*, n.d.).

The standard test methods that are commonly used in the flexural test are ASTM C78, ASTM D7264, ASTM D6272 and ASTM D790. The standard test method that is used in this project is ASTM D7264. This test method determines the strength properties and flexural stiffness of polymer matrix composites. Parameters such as flexural strength, maximum flexural stress, maximum strain, flexural modulus of elasticity and flexural secant modulus of elasticity can be determined in this testing. For ASTM D7264 test method, the standard span-to-thickness ratio is 32:1. Next, the specimen's standard thickness and the standard width is 4 mm and 13 mm, respectively. For this method, the specimen length should be about 20 % longer than the support span (International, 2007). Figure 2.6 indicates the support span,L in fixed specimen support and rotatable specimen support.

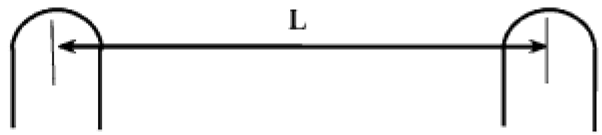


FIG. A1.1 Markings on Fixed Specimen Supports

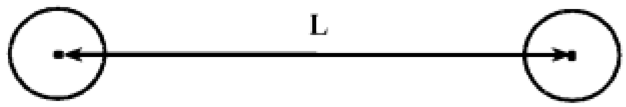


FIG. A1.2 Markings on Rotatable Specimen Supports

Figure 2.6 : The support span of fixed specimen support and rotatable specimen support (International, 2007).

CHAPTER 3

METHODOLOGY

3.1 Overview

In this chapter, the process flow of this project will be discussed. Furthermore, all the details and steps involved in fabricating, conditioning and testing the specimens will be described. Firstly, a suitable reinforcement material and matrix is decided based on the title of this project. Then, the specimens are manufactured by using a desirable manufacturing method. The specimens are then cut with dimensions based on the ASTM selected for the tests that are planned. Next, specimens conditioning is done as a changing variable in this project. After that, mechanical tests are done for both the conditioned and non-conditioned specimens. Finally, the results obtained from the tests are compared and analyzed. Figure 3.1 shows the overall flowchart for the methodology of this project.

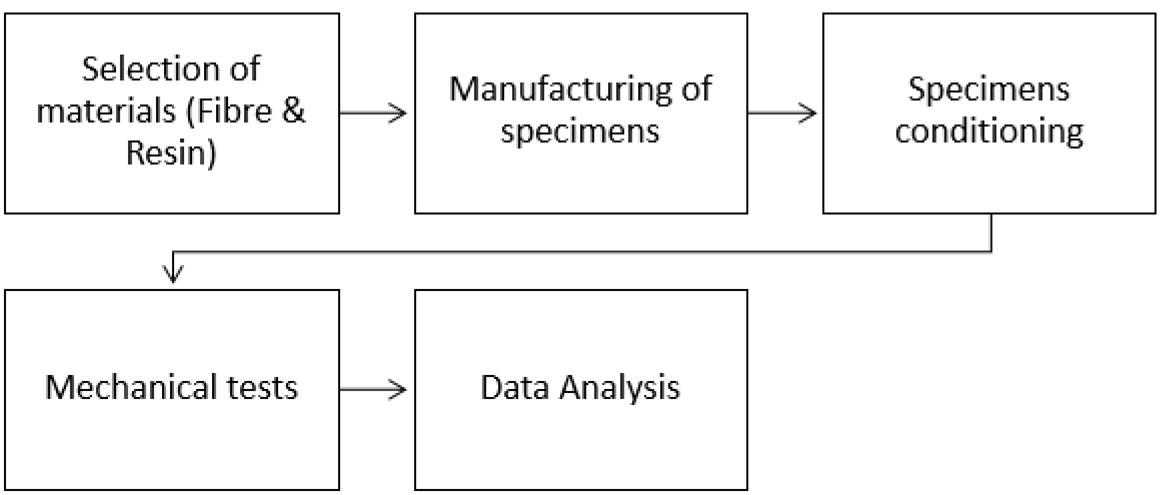


Figure 3.1 : Flowchart for the methodology of this project

3.2 Materials

3.2.1 Plain Weave Fibre

The fibre that is used in this project is jute fibre. The woven jute fibre fabric supplied by MazhuCity Textile Co. Ltd from Guangzhou China. Figure 3.2 shows the woven jute fabric that is used in this project. The properties of the woven jute fabric are shown in Table 3.1.

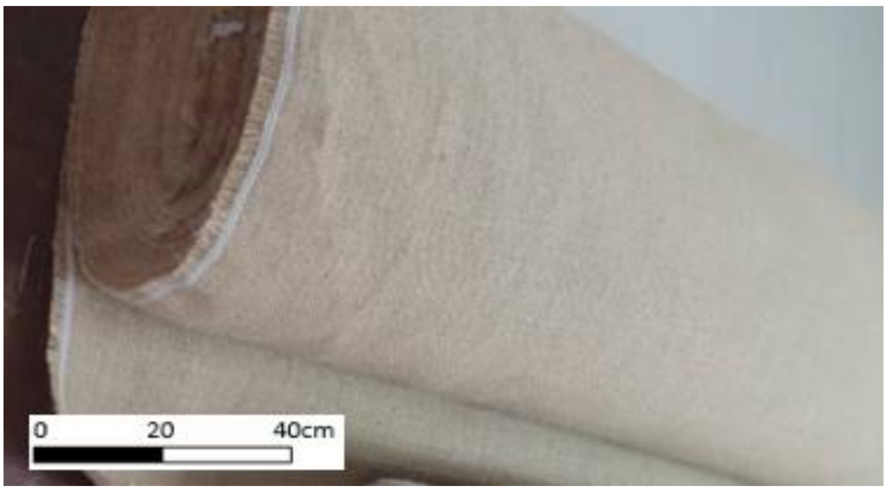


Figure 3.2 : Woven Jute Fibre Fabric from the aerocomposite lab

Table 3.1 : Properties of the woven jute fibre fabric

Specifications	**Values**
Density	1.5 g/cm^3
Thickness (1 ply)	1.0 mm
Fabric Weight (GSM)	480 g/m^2

3.2.2 Matrix

Polyester resin is chosen as the matrix in this project. Polyester resin is a type of thermoset resin. The resin used was General Purpose 9509W polyester resin supplied by Castmech Technologies Sdn. Bhd. This resin is suitable for hand lay-up process in fabricating composites. The hardener that was used with the polyester resin is AKPEROX A50, which is a general purpose MEKP curing agent. Figure 3.3 shows the General Purpose 9509W polyester resin while figure 3.4 shows the AKPEROX A50 hardener. The specifications of General Purpose 9509W polyester resin is shown in table 3.2.

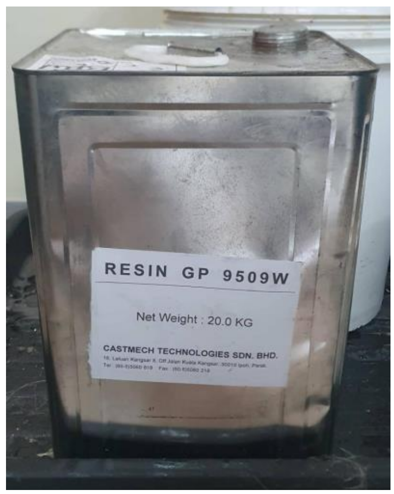


Figure 3.3 : General Purpose 9509W polyester resin

Figure 3.4 : AKPEROX A50 Hardener

Table 3.2 : Specifications of the General Purpose 9509W polyester resin

Properties	**Values**
Density	1.11 g/cm^3
Solid content	60 - 70 %
Gel time	8 – 11 mins

3.3 Manufacturing Process

3.3.1 Fibre preparation

The woven jute fibre fabric is cut into a dimension as shown in figure 3.5. A total of 6 fibre sheets was cut by considering the specimen thickness needed according to the ASTM standard for tensile testing and flexural testing.

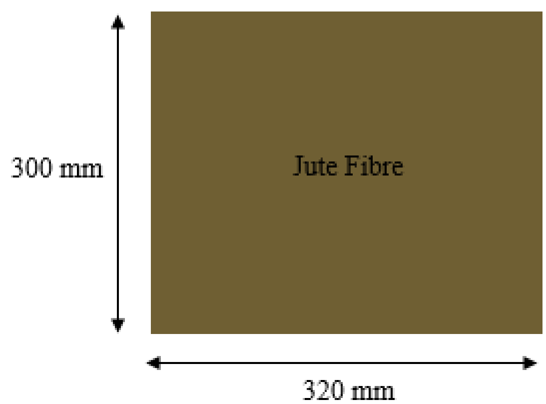


Figure 3.5 : Dimension of jute fibre for fabrication

3.3.2 Resin preparation

The resin solution is prepared by adding hardener to the polyester resin. The fibre is weighed and the amount of resin needed is calculated using ‘mass of fibre : mass of matrix’ ratio of 1:2. The mass of hardener used is 3% of the mass of resin used. For this project, 248g of polyester resin is weighed and mixed well with 8g of hardener. After the mixing process, the resin are ready to be use for fabrication.

3.3.3 Wet hand lay-up process

The manufacturing method that is used in this project is the wet hand lay-up method. The process is done on an open, clear glass surface to produce a flat surface composite. Firstly, releasing agent is applied on the glass surface to ease the composite-removing process once it is cured. The releasing agent used was the Mold Release by TR Industries. Three layers of jute fibre sheets are stacked on top of each other, with resin applied to every layer. The resin was spread evenly using cardboard to ensure every area is wetted with resin before proceeding with the next layers. After the resin is fully applied, the composites are then let to cure for 24 hours. Figure 3.6 shows the composite after the wet hand lay-up process.

Figure 3.6 : Composite after the wet hand lay-up process

3.3.4 Specimen preparation

After the composites are dried completely, they are then cut into dimensions based on ASTM D3039 for the tensile testing specimens and ASTM D7264 for the flexural testing specimens. For tensile testing, the samples should have a length of 250mm and a width of 25mm. For flexural testing, the length and the width of the specimens are 175mm and 13mm, respectively. A circular saw machine and band saw machine was used to cut the composites into the required sizes. Figure 3.7 shows the cutting process using a circular saw machine and band saw machine. After the cutting process, the specimens were surfaced-finished by using sandpaper to smoothen out the edges. Figure 3.8 shows the samples for tensile testing after the cutting and sanding process.

(a) (b)

Figure 3.7: Cutting process of the samples a) Circular Saw Machine and b) Band Saw Machine

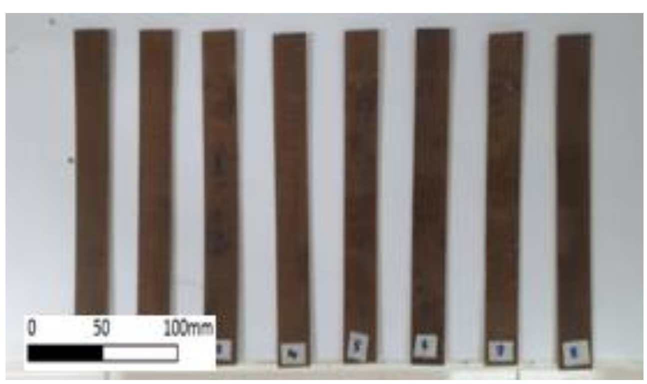


Figure 3.8 : Tensile testing samples

3.3.5 Tabs preparation

Tabs are manufactured to be fixed at both ends of the tensile testing samples to give a better grip for the testing machine. Two layers of jute fibre and polyester resin are used to fabricate the tabs using the hand lay-up method. After that, they are cut into a length of 56mm and a width of 25mm. The tabs are then pasted on both sides of both ends of the samples using three-second glue. Figure 3.9 shows the tabs for tensile samples, and figure 3.10 shows the tensile samples after fixing the tabs.

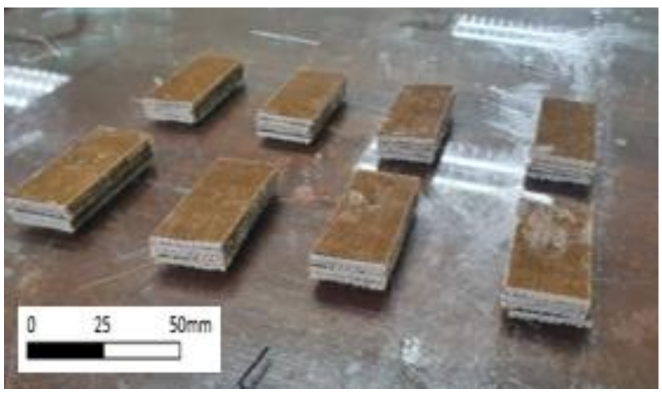


Figure 3.9 : Tabs for tensile samples

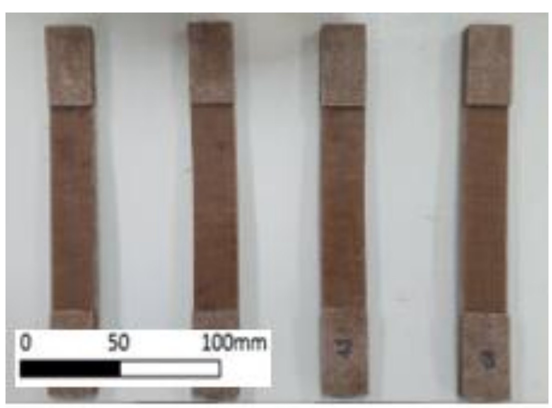
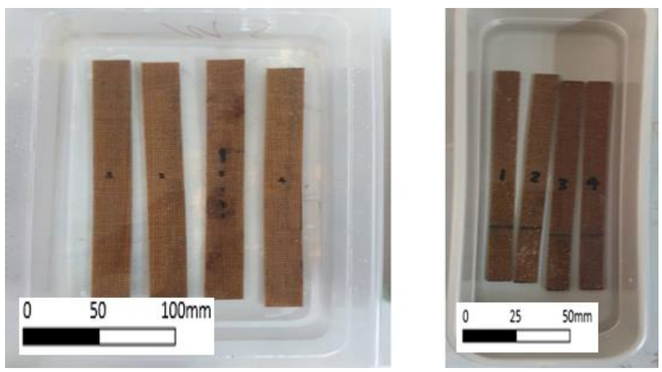


Figure 3.10 : Tensile samples after fixing the tabs

3.4 Specimen Conditioning

For this project, distilled water is used as the immersion liquid for the immersion process of samples. Four samples for tensile testing and four samples for flexural testing are immersed in two separate containers, as shown in figure 3.11. The moisture uptake set-up was done based on ASTM D5229. The initial mass of the samples is measured using Shimadzu ATY224 high precision analytical balance, as shown in figure 3.12. After the samples are immersed, their mass is measured and recorded every day until they reach a saturation point. The moisture uptake of the samples was then calculated using equation 2.1.



(a) (b)

Figure 3.11 : Immersion of the samples (a)Tensile testing samples (b)Flexural testing samples

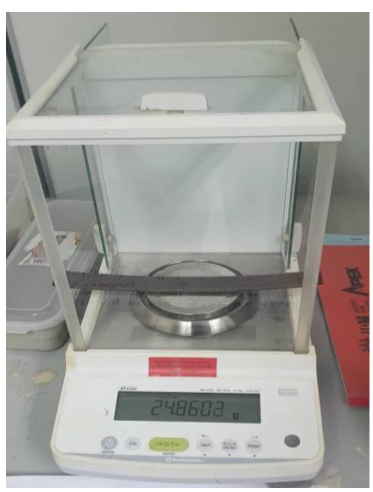


Figure 3.12 : Measurement of sample's mass using the analytical balance