MODE 1 FRACTURE TOUGHNESS OF PALM AND COIR FIBRE REINFORCED COMPOSITE VIA DOUBLE CANTILEVER BEAM TEST

by

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ENDORSEMENT

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

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

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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.

B.Sakthi Sivan

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Date: 11 July 2021

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MODE 1 FRACTURE TOUGHNESS OF PALM AND COIR FIBRE REINFORCED COMPOSITES VIA DOUBLE CANTILEVER BEAM TEST

ABSTRACT

This is a study of the double vacuum bagging (DVB) method employment in the fabrication process of the composite laminate by using natural fibres such as palm and coir fibre. In this world and upcoming world, natural fibres have become the alternative choices of the reinforcement material due to its eco-friendly towards the environment, biodegradability, low density, low cost etc. The purpose of this study is to initiate the application of double vacuum bagging method (DVB) in fabricating the natural fibre reinforced composite. Not only that, fabrication process which able to produce composite material with a higher quality in terms of better surface finishing and mechanical properties is developed in this study. Natural fibres such as palm and coir fibre are used as the reinforcement material in the fabrication process whereas the matrix, EpoxAmite 103 is chosen. Every composite laminate, a minimum of two plies are rolled until the total thickness of a minimum of 3 mm is obtained, then the fibre plies are weighed to calculate the mass of the resin according to the volume fraction. The measured resin is then applied to the fibre plies by the method of wet hand layup. After that, the double vacuum bagging (DVB) method are implanted to the fibre for further compression. At least 5 specimens are cut and loading blocks are attached at the end of the initiation site of the specimen which is required for the double cantilever beam (DCB) test according to the standard of ASTM D5528. As for the ASTM D5045, the number of fibre plies depend on the thickness of the specimen required based on the calculations. Hence, the composite laminate is then cut into the length and width that is required for the compact tension (CT) test according to the ASTM D5045 which will obtain from the calculation as well. A sharp tip crack length is created by using a fresh razor blade. Besides that, this study showed the importance of the vacuum bagging plays a huge important role in the fabrication process where a slight bagging

leakage will affect the mechanical properties of the specimens. Not only that, the uniform vacuum pressure and pressure distribution are important as well as it produces composite laminate with a high quality. The double bagging method used in the study is capable in producing composites with a higher Young's Modulus compared to other method of fabrication process such as resin infusion and wet hand layup. However, the DCB test results were invalid as, it only applicable to unidirectional fibre reinforced specimen while the CT test the energy release rate for the coconut fibre reinforced composite is higher compared to previous study. Further research is required to improve the double vacuum bagging (DVB) method during the fabrication process.

ABSTRAK

Ini adalah kajian pekerjaan kaedah bagasi vakum (DVB) berganda dalam proses fabrikasi lamina komposit dengan menggunakan gentian semulajadi seperti serat sawit dan koir. Di dunia ini dan dunia akan datang, gentian semulajadi telah menjadi pilihan alternatif bahan tetulang kerana mesra alam terhadap alam sekitar, biodegradasi, ketumpatan rendah, kos rendah dan sebagainya. Tujuan kajian ini adalah untuk memulakan penggunaan kaedah bagasi vakum berganda (DVB) dalam membuat komposit bertetulang serat semulajadi. Bukan itu sahaja, proses fabrikasi yang mampu menghasilkan bahan komposit dengan kualiti yang lebih tinggi dari segi kemasan permukaan yang lebih baik dan sifat mekanikal dibangunkan dalam kajian ini. Gentian semulajadi seperti serat sawit dan koir digunakan sebagai bahan tetulang dalam proses fabrikasi manakala matriks, EpoxAmite 103 dipilih. Setiap lamina komposit, sekurang-kurangnya dua perapi dilancarkan sehingga ketebalan minimum 3 mm diperolehi, kemudian serat ditimbang untuk mengira jisim resin mengikut pecahan kelantangan. Resin yang diukur kemudian digunakan pada gentian berplies dengan kaedah lapisan tangan basah. Selepas itu, kaedah bagasi vakum berganda (DVB) diimplan ke serat untuk mampatan selanjutnya. Sekurang-kurangnya 5 spesimen dipotong dan memuatkan blok dilampirkan pada akhir tapak permulaan spesimen yang diperlukan untuk ujian rasuk julur double (DCB) mengikut piawaian ASTM D5528. Bagi ASTM D5045, bilangan gentian optik bergantung kepada ketebalan spesimen yang diperlukan berdasarkan pengiraan. Justeru, lamina komposit kemudiannya dipotong menjadi panjang dan lebar yang diperlukan untuk ujian ketegangan padat (CT) mengikut ASTM D5045 yang akan diperoleh daripada pengiraan juga. Panjang retak hujung tajam dicipta dengan menggunakan pisau cukur segar. Selain itu, kajian ini menunjukkan kepentingan bagasi vakum memainkan peranan penting yang besar dalam dalam proses fabrikasi di mana sedikit kebocoran bagasi akan menjejaskan sifat-sifat mekanikal

spesimen. Bukan itu sahaja, tekanan vakum seragam dan pengagihan tekanan adalah penting serta ia menghasilkan lamina komposit dengan kualiti yang tinggi. Kaedah bagasi berganda yang digunakan dalam kajian ini mampu menghasilkan renjer dengan Modulus Muda yang lebih tinggi berbanding kaedah lain proses fabrikasi seperti infusi resin dan lapisan tangan basah. Walau bagaimanapun, keputusan ujian DCB tidak sah, ia hanya terpakai kepada spesimen bertetulang serat yang tidak disengajakan manakala ujian CT kadar pelepasan tenaga untuk komposit bertetulang serat kelapa adalah lebih tinggi berbanding kajian sebelumnya. Penyelidikan lanjut diperlukan untuk memperbaiki kaedah bagasi vakum berganda (DVB) semasa proses fabrikasi.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

CHAPTER 1 INTRODUCTION

1.1 General Overview

Composite is also known as Fibre-Reinforced Polymer (FRP). It is a combination of two or more materials with different properties. Composites are made up of polymer matrix and reinforcement which is called as fibre.

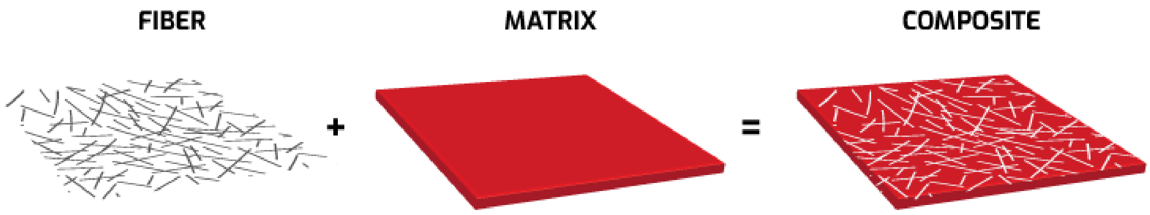


Figure 1.0 above shows the schematic diagram of a composite

Fibre provides strength and stiffness whereas the matrix protects and transfers the load between the fibres. Composites are widely used materials in the current time due to its vast range properties. They are known widely for their high strength and stiffness with low density or weight. They are divided into two parts which are reinforcement and bonding. Reinforcement is usually in the form of fibre or particulate. There are several types of composites such as Ceramic Matrix Composites (CMC), Metal Matrix Composites (MMC) and Polymer Matrix Composites (PMC). These composites are classified according to their matrix compound. In this study, coconut and coir fibres are uses as they are easily available in Malaysia. Not only that, cost of those fibres are low as well as they have superior mechanical properties such as modulus, stiffness and flexibility compared to the glass fibres (Campbell, F.C., 2010). However, natural fibres have its disadvantages such as poor resistance towards moisture.

Composites can also be in natural or synthetic. As an example, wood is a natural composite where it is a combination of cellulose or wood fibre and a substance called lignin.

The wood fibre gives strength whereas the lignin is the natural glue or matrix which binds and stabilizes them. Other composites such as plywood is man-made composites which is a combination of natural and synthetic materials. Plywood are formed with thin layers of wood veneer that are bonded together with adhesive to form flat sheets of laminated wood which is much stronger than natural wood. A conventional material bring the meaning where a material that is most likely or usually used in a product. As an example, before the advancement of composites, most of the aircraft were manufacture using aluminium alloys for its major structural elements. However, the aluminium alloys which are the conventional material for the aircraft have several disadvantages such as they were heavy and this makes the fuel consumption of the aircraft high.

Hence, composite materials are design to overcome this problem. It can be also tailored to any requirements that is needed during the process of building and aircraft. However, a concern on the environmental health has led the development of natural fibre reinforced composites. There were a lot of interests towards the natural fibre reinforced composites due to its advantages as it is being eco-friendly and easily available in resources. The natural fibre reinforced composites have wide potential of applications in different types of industry such as automotive, biomedical and aerospace industry. Natural fibres such as pineapple leaves, banana, jute and coir are generally extracted from renewable sources. Not only that, they are also fully biodegradable, non-toxic and can be easily recycled as to reduce the materials' carbon footprint (Dong *et al.*, 2014). A cleaner and sustainable environment could be created while reducing the cost of manufacturing a product.

Mode of fracture are divided into three mode which are mode 1, the tension mode and the mode 2, the end notched flexure test. In this study, the test that will be carried out towards the natural fibre reinforced composites is double cantilever beam test (DCB test) and Compact

Tension test (CT test), mode 1 which is the tension mode where it will test the characterize of the interlaminar fracture toughness or critical strain energy release rate (G_{IC}) and critical-stress-intensity factor (K_{IC}) of composites or adhesive in mode 1. Fracture toughness is a macroscopic property of material that indicate the resistance of the materials to propagate a pre-existing flaw. It is a very important property to study as the occurrence of flaws during the process of manufacturing and fabricating is not completely avoidable. Flaws can be existed in the specimen in the terms of voids, cracks, weld defects and etc. An assumption of flaw geometry and size will occur in some of the specimen is a common practices and approach of linear elastic fracture mechanical will be use to design critical components.

1.2 Problem Statements

Since the development of composite materials are mainly in aerospace field, the motive and interest in making a better composite material has move towards as composite materials has superior property such as stiffness to density ratio and exceptional strength. However, there is a huge concern on the environment as the material that are used to produce the composite are mainly the reinforcement or fibre being used which may bring harm to the environment. In the aerospace field, the most used composites are carbon fibre reinforced polymer (CFRP) and glass fibre reinforced polymer (GFRP). These fibres are expensive and difficult to obtain especially the carbon fibre. Hence, it has triggered the interest of the manufactures on searching an alternative reinforcement such as the natural fibre as they are widely known for their availability. Not only that, the cost of natural fibres is way lower compared to the glass and carbon fibre. Not only the cost but also the superior properties as well.

To assure that natural fibres are safe to be used in the aerospace field, quite several studies and experiments have been done to evaluate the properties of the natural fibre reinforced polymer. Hence, research on the mechanical properties for the natural fibre reinforced polymer have been done and it has been proven that it has superior properties. However, macroscopic property of the natural fibre reinforced polymer cannot be neglected. Same as the glass and carbon fibre reinforced polymer, natural fibre reinforced polymer are also exposed to the occurrence flaws. This will made some of the factor in failure of the respective composites. Hence, it is very vital to study and understand the ability of the natural fibre reinforced composites to resist the propagation of the existing flaws.

1.3 Objectives of Research

The studies of this research are based on the following objectives:

(i) Fabricate several types of natural fibre reinforced composites via double bagging method.

(ii) Conduct fracture toughness test via double cantilever beam test (DCB test) and compact tension test (CT test).

(iii) Compare fracture toughness between several types of natural fibre reinforced composites.

(iv) Investigate the fracture toughness of the natural fibre reinforced composites based on ASTM 5528 and ASTM D5045 standards.

CHAPTER 2 LITERATURE REVIEW

2.1 Composite Materials

In common, composite is widely known as Fibre reinforced Polymer (FRP) where composite is a combination or mixture of two or more materials which bring good superior properties compared to the single material component(*Composite Material - Wikipedia*, n.d.). Not only that, composite material is also called as composition material. Each component material which is also known as the constituent material that is used to combine or mixed in the composite material does not lose or downgrade their mechanical properties, but they combine and contribute their properties as to improve the final product. The reinforcement receives support from the matrix whereas the matrix which will be basically in liquid form, as an example like water, epoxy, polyester and etc will surrounds the reinforcement and maintains its relative positions. There have been a huge number of interests towards composite materials due to its advantages of having high strength and stiffness while maintaining a low density compared to bulk materials. Hence, it allows weight reduction in the final parts.

Composites are mostly made up of a polymer matrix reinforced with a fibre such as glass fibre, carbon fibre, palm fibre and etc. Those fibre maybe man-made or natural fibre. However, in aerospace industry, the most common man-made composite materials that are widely used are carbon fibre reinforced polymer (CFRP) and glass fibre reinforced polymer (GFRP) which those composites consist of carbon fibre and glass fibre respectively. The common glass fibre that are used in the glass fibre reinforced polymer (GFRP) is the E-glass fibre whereas in the carbon fibre reinforced polymer (CFRP), the most common carbon fibre that are used is carbon fibres that are about 5-10 micrometers (μm) which is about 0.0002-0.00039 inch (in) or for an alternative, graphite fibre are also being used in the CFRP (Park, 2014). Carbon and glass fibres have several advantages such as high stiffness, high tensile strength, low thermal expansion and etc. However, they are brittle. As for the matrix which is most used are polyester and epoxy, they are tough but lack of strength and stiffness. Hence, the combination of those fibres and matrix makes a composite material with all the benefits as well as few or none of the individual's weakness.

Besides that, there are several classifications of composites based on their matrix material and reinforcing material structure respectively. There are 3 types of classification composites based on the matrix material which are metal matrix composites (MMC), ceramic matrix composites (CMC) and polymer matrix composites (PMC)(*Classification of Composites [SubsTech]*, n.d.). Metal matrix composites (MMC) are basically composed of metallic matrix such as aluminium, magnesium, iron and etc and dispersed ceramic such as oxides and carbides or metallic phase such as lead, tungsten, molybdenum etc. As for the ceramic matric composites (CMC), it is composed of a ceramic matrix and embedded fibres of other ceramic material(*Ceramic Matrix Composites (Introduction) [SubsTech]*, n.d.) whereas for the polymer matrix composites (PMC) is composed of matrix that are from thermoset such as unsaturated polyester (UP) and epoxy or also thermoplastic such as polycarbonate (PC), polyvinylchloride, nylon and etc with embedded glass, carbon, steel or Kevlar fibres(*Polymer Matrix Composites (Introduction) [SubsTech]*, n.d.). As stated just now, there are also another classification of composites based on the reinforcing material structure such as particulate composites, fibrous composites and laminate composites. Particulate composites are composites that is consist of matrix reinforced by a dispersed phase in the form of particles. Particulate composites are divided into two groups which are composites with random orientation of particles and composites with preferred orientation of particles. There are two types of fibrous composites, short-fibre reinforced composites and long-fibre reinforced composites. Short-fibre reinforced composites are consist of matrix that is reinforced by dispersed phase in the form of discontinuous fibres. Short-fibre reinforced composites are separated in to two groups which are composites with random and preferred orientation of fibres. As for the long-fibre reinforced composites, it is consists of matrix that reinforced by dispersed phase in the form of continuous fibres. It is also divided into two groups which are unidirectional and bidirectional orientation of fibres. Lastly, laminate composites are composites that consists of several layers with different types of fibre orientations which is also called as multilayer or in another word angle-ply composite.

Sandwich structured composite is also one of the class of composite material. This composite is fabricated by attaching two thin but stiff skins to a lightweight but thick core. Usually, the core material that is used will be low in strength. However, its higher thickness provides the sandwich composite with a high bending stiffness and overall low density. The structure of the core would be a honeycomb structure. The traditional way of fabricating or manufacturing the core are expansion, corrugation and moulding which were developed on 1901. Nowadays with the aid of technology, the honeycomb cores are fabricated or manufactured through the expansion and corrugation process from composite materials such as fiberglass which is also known as glass reinforced plastic, carbon fibre reinforced plastic, nomex aramide paper reinforced plastic etc. This sandwich structure composite gives an excellent rigidity at a minimum weight and at a minimal material cost also.

2.2 Fibres or Reinforcement

In a composite materials, fibres or reinforcement provides strength and stiffness to the respective composites. Not only that, fibres can be orientated to provide properties according to the requirement according to the direction of the loads. There are various types of fibres which is compatible to the application and requirements that is needed. There are two major groups of fibres which are natural and man-made fibres. However, those fibres come in various forms which are either continuous or discontinuous.

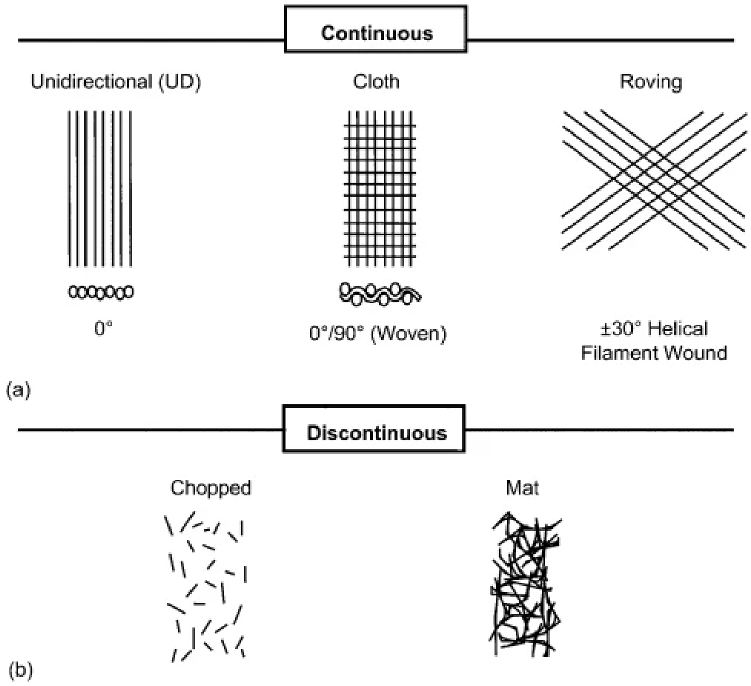


Figure 2.0 shows the types of fibres

As from the Figure 2.0, in the continuous fibre, there are three types of the fibre orientation such as the unidirectional, cloth which is also called as bidirectional and roving whereas for the discontinuous fibre, there are only two types which are chopped, the fibres are not aligned and very far apart and mat where the fibres are not aligned as well but stick or placed very near with the other fibres.

2.3 Natural Fibre

There are various of natural fibre that can be found in this world. These fibres are being produced by the plants, animals and geological process. Natural fibres are also used as a component of composite materials where the orientation of the fibres impact the properties of the respective composite. Not only that, natural fibres are also being used for high tech applications such as composite pars for automobiles. Natural fibres do have advantages as lower density, less skin irritation and better thermal insulation. Natural fibres are unlike glass fibres, they are eco-friendly where those fibres can be broken by the microorganism once it is no longer in use and does not bring any harm to the environment.

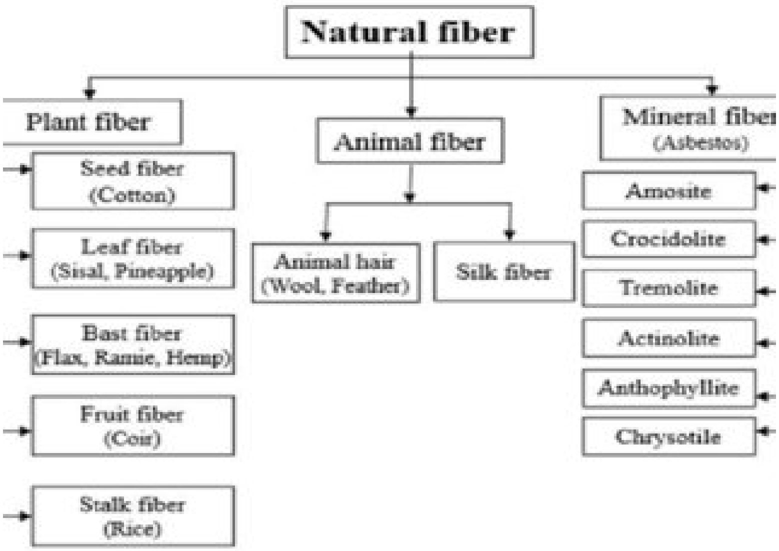


Figure 2.1 shows the types of natural fibres according to their respective sources of extraction.

Based on the figure above (Figure 2.1), natural fibres are divided into three types of fibres which are plant fibre, animal fibre and mineral fibre respectively.

2.4 Plant Fibre

Unlike the animal or mineral fibre, plant fibre is composed of lignin, cellulose, hemi-cellulose, waxes and water-soluble substances. Plant fibres are also known fibre crops that are elongated with thick-walled cells with pointed ends which is consists of cellulose and may or may not contain lignin. Besides that, fibre crops are grown for their fibres as it will be commonly used for making paper, rope and cloth. Fibre crops are very high in length, width, tenacity, uniformity, spinning pliability and flexibility. Fibre crops are also grouped into three groups which are textile fibres, cordage fibres and filling fibres.

Table 2.0 shows composition of natural fibres.

Fiber	Cellulose (wt%)	Hemicellulose (wt%)	Lignin (wt%)	Waxes (wt%)
Bagasse	55.2	16.8	25.3	–
Bamboo	26–43	30	21–31	–
Flax	71	18.6–20.6	2.2	1.5
Kenaf	72	20.3	9	–
Jute	61–71	14–20	12–13	0.5
Hemp	68	15	10	0.8
Ramie	68.6–76.2	13–16	0.6–0.7	0.3
Abaca	56–63	20–25	7–9	3
Sisal	65	12	9.9	2
Coir	32–43	0.15–0.25	40–45	–
Oil palm	65	–	29	–
Pineapple	81	–	12.7	–
Curaua	73.6	9.9	7.5	–
Wheat straw	38–45	15–31	12–20	–
Rice husk	35–45	19–25	20	14–17
Rice straw	41–57	33	8–19	8–28

Based on the table above (Table 2.0), the most substances that is held by the natural fibres is cellulose or in another it can be said that natural fibres have a high percentage of cellulose as it gives better strength towards the fibres. Plant fibre are very eco-friendly and biodegradable. Plant fibre are also low in cost and density compared to synthetic fibre. However, plant fibre would not be suitable to be used as reinforcement right after harvesting as the moisture in the fibre would decrease the interfacial boding between the fibre and matrix. Hence, many research has been done and found out that chemical treatment is needed to be done to the fibre as to enhance the interfacial bonding and wettability of the natural fibre.

2.4.1 Palm Fibre

In Malaysia, oil palm is the largest commercial plantation. Hence, a lot of palm fibre could be obtained from Malaysia. In palm fibre, there are various type of palm fibre. Palm fibre is produced from the oil palm's vascular bundles in the Empty Fruit Bunch (EFB). EFB is considered as waste products after Fresh Fruit Bunch (FFB) have been processed. Palm fibre is not only produced from EFB but also from other parts of the palm tree (Figure 2.2) (*Oil Palm Fibre*, n.d.). Since palm fibre is one of the natural fibres, it is 100% natural, environmentally friendly, biodegradable and non-hazardous. Palm fibre are very low in moisture and cost.

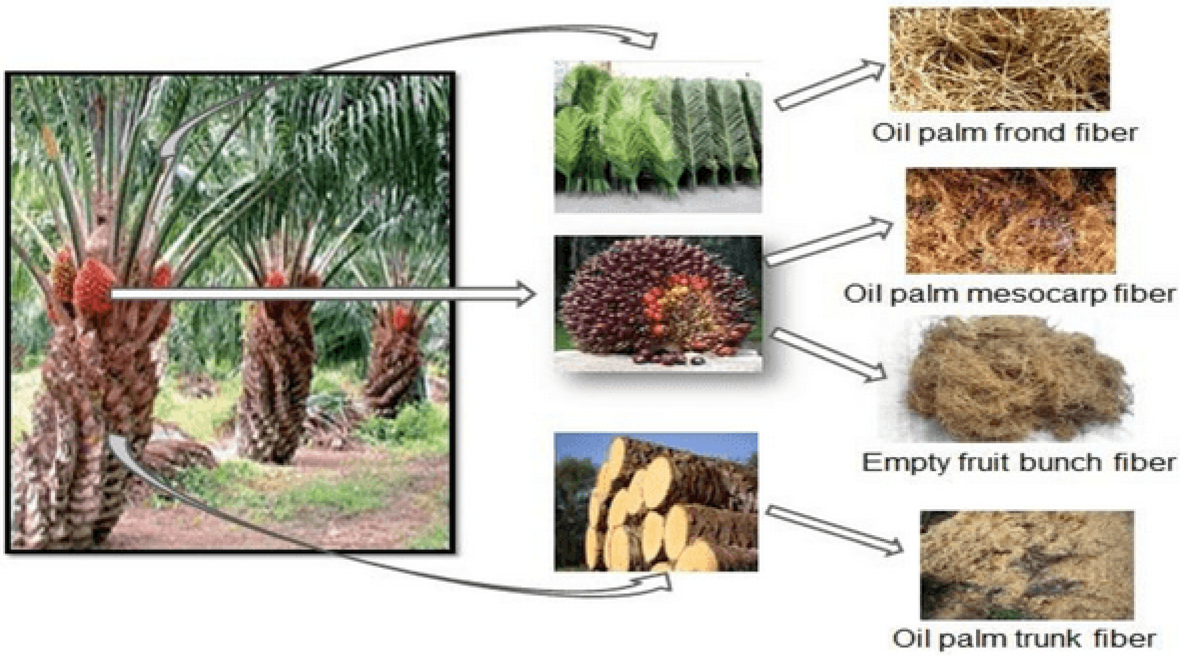


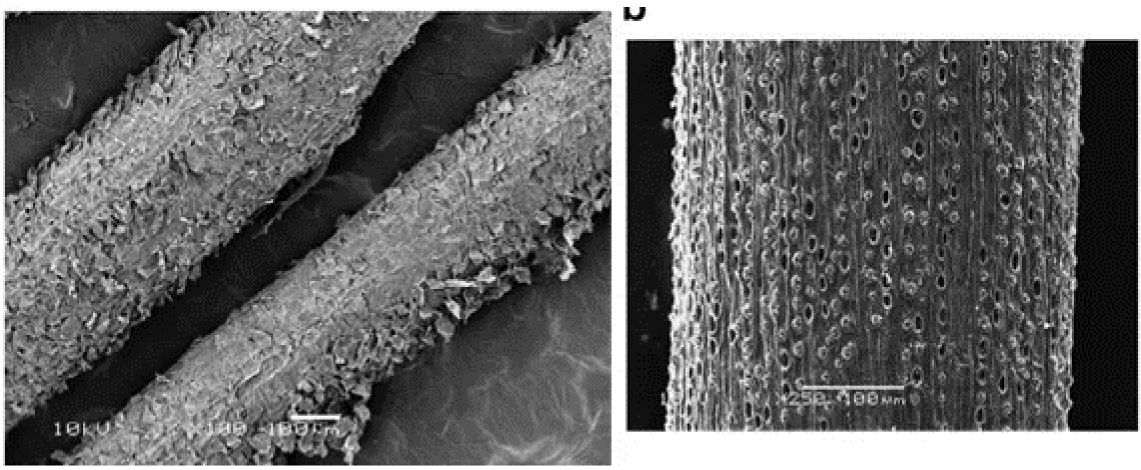
Figure 2.2 shows the sources of palm fibre

Table 2.1 shows the specific characteristics of palm fibre.

Length (mm)	20-250
Diameter (µm)	100-1000
Density (g/cm^3)	0.9-1.2
Specific Modulus	Approximately 7
Thermal Conductivity (W/m K)	0.083

Tensile Strength (MPa)	58-203
Elongation at Break	5-10%

Mechanical properties of natural fibre are determined by structure, micro-fibrillar angle, chemical composition, cell dimensions and defects. Even though palm fibre is a natural fibre but it has some good mechanical properties compared to synthetic fibre (Table 2.1). Palm fibre has good and higher thermal insulation properties compared to carbon fibre. Not only that, palm fibre tensile strength is higher than steel. As palm fibre is a natural fibre, some chemical treatment is needed and one of the treatments that can be done to the palm fibre is alkaline treatment. It is a main and vital treatment to the palm fibre. The huge modification that is done by this treatment is the disruption of hydrogen bonding within the network structure by increasing the surface roughness (Figure 2.3). Aqueous sodium hydroxide (NaOH) is utilized to remove the lignin, wax and oils from the cell walls. Thus, this treatment often affected the cellulosic fibril, degree of polymerization and the extraction of lignin as well as the other non-cellulosic compounds (Manalo et al., 2015).



(A) (B)

Figure 2.3 shows the images of Scanning Electron Microscope (SEM) for untreated palm fibre (A) and treated palm fibre (B) respectively.

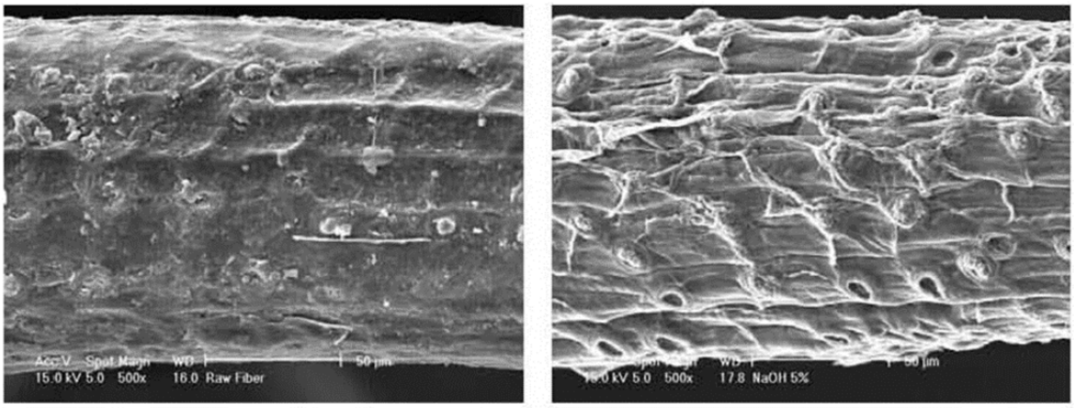
2.4.2 Coconut Fibre

Coconut fibre is a by-product of coconut coir processing and is potentially to be used as one of the most important resources in the development of biodegradable polymer composites. Coconut fibre is the tissue surrounding the seed of the coconut palm which is thick, lightweight and has a great abrasion resistance. Coconut fibre is extracted from the fibrous outer cover of the fruit of the coconut plant which is mainly consist of cellulose and lignin. Compared to other plant fibres, coconut fibre has the lowest percentage of cellulose which is around 36 – 43 %. However, the amount of the lignin is twice which is around 41 – 45 % (*Coconut Fibre*, n.d.). Not only that, in general, coconut fibres are hydrophilic in nature as they are obtained from ligno-cellulose which contain strong polarized hydroxyl groups. Hence, coconut fibres are less compatible with hydrophobic thermoplastics such as polyolefins and thermoset polymer matrix.

Table 2.2 shows the mechanical properties of coconut fibre.

Properties	Value
Density (kg/m^3)	1200
Elongation at Break (%)	30
Tensile Strength (MPa)	175
Young's Modulus (GPa)	4 – 6
Water Absorption (%)	130 - 180

From the Table 2.2, coconut fibre has lower tensile strength compared to palm fibre but higher elongation at break than palm fibre. Since the coconut fibre has a low decomposition rate which it takes around from 20 to 30 years, it has become a huge advantage in making the durable product as stated by Lee (2018). Since coconut fibre is also one of the plant fibre, chemical treatment has to be done to the fibre which is same as the treatment that were done to the palm fibre, alkaline treatment. Same as the palm fibre, this treatment is done to increase the surface roughness of the coconut fibre and the micropores will be more visible (Figure 2.4). The coconut fibre which has been treated with the treatment tends to improve its tensile strength by reducing the absorption of water.



(A) (B)

Figure 2.4 shows the images of Scanning Electron Microscope (SEM) for untreated coconut fibre (A) and treated coconut fibre (B) respectively.

2.4.3 Flax Fibre

Flax fibre is classified as natural, cellulose, bast and multi-cellular fibre. It is also considered as a heavy fibre compared to other natural fibres. Flax fibre is also known as linen fibre. Hence because it has the most linen textile materials that are of light construction. Since it has thick linen materials, it would be very uncomfortable to wear. Flax fibre is abstracted from the stalk of the flax plant and cultivated in cold and humid condition. Flax fibre is relatively smooth, straight and lustrous. However, it is difficult to prepare and spin into yarn. The overall structure of the flax fibre is that it consists of thick and regular fibre with a subdued luster. There will be cross making in the flax fibre which is also known as nodes that provides the characteristics microscopic appearance for the flax fibre. As for the microstructure for the flax fibre, there will be flax fibre cell that is covered with a wax film. The cell walls of the flax fibre are build-up of spiralling fibrils which are composed of cellulose polymers. Hence, the flax fibre cell is more sturdily compared to cotton cell as the flax fibre cell walls is thicker. Flax fibre has greater tenacity compared to cotton. Based on the Table 2.3, flax fibre has higher specific tensile strength compared to E-glass fibre. Not only specific tensile strength, but also flax fibre is lighter compared to E-glass fibre.

Table 2.3 shows the mechanical properties of E-glass fibre and flax fibre respectively.

Property	E-glass	Flax fibres
Diameter (μm)	8–14	10–80
Density (g/cm^3)	2.56	1.4
E-modulus (GPa)	76	50–70
Tensile strength (GPa)	1.4–2.5	0.5–1.5
Specific E-modulus (Gpa/g·cm^{-3})	30	36–50
Specific tensile strength (GPa/g·cm^{-3})	0.5–1	0.4–1.1

2.5 Advantages and Disadvantages of Natural Fibres

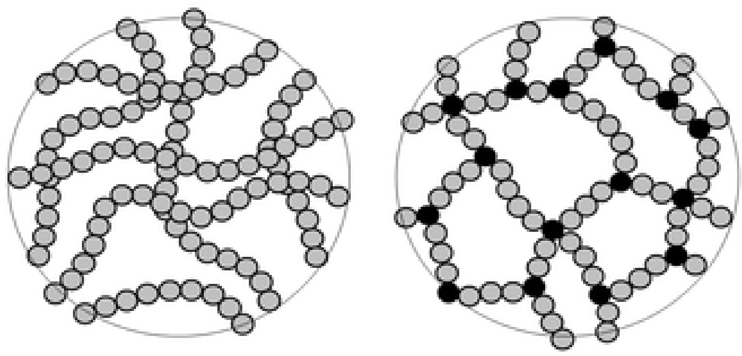
There are advantages as well as disadvantages for natural fibres compared to other conventional reinforcement. Firstly, the advantage of the natural fibres is that they are mainly low in cost and affordable compared to synthetic fibre such as glass and carbon fibre. Natural fibres do have continuous supply of raw materials as they are easy to be obtained from the environment. It could be also become a huge potential source of income for the agriculture community. Natural fibres are also renewable unlike synthetic fibre. Natural fibres are environmentally friendly and non- toxic as it is biodegradable. Natural fibres do not cause skin irritation unlike glass fibre. However, natural fibres have low resistance to moisture as well poor fire resistance. Not only that, natural fibres do have bad compatibility with hydrophobic polymer matrix.

2.6 Matrix

In a composite material, the other constituent is the matrix. The function of matrix in a composite material is to hold the fibre together and distribute the load evenly throughout the fibre. There are several types of matrixes that are used in composite material such as thermoset, thermoplastic, rubber and biodegradable matrixes. Usually, matrix in the composite material would be in liquid form.

2.6.1 Thermoset Matrix

Thermoset or also known as thermosetting polymer is a polymer that is obtained by an irreversibly process of hardening or in another word curing, a soft solid or viscous liquid prepolymer which is also called as resin. Usually, heat is generated by the reaction of the resin with a curing agent such as hardener and catalyst. Hence, heat is not necessarily needed to be apply externally. Thermoset matrix has a rigid 3D structure with the cross-linking of covalent bonds between the molecules (Figure 2.5). the cross-linkage in the thermoset matrix happens during the curing process and it will be not soft after the temperature has been rise. The cross-linkage which is the three-dimensional networks of bonds in thermoset matrix that provides strength to the matrix. Thermoset matrix is suitable for high temperature applications since their shape as the strong covalent bonds between the polymer chain cannot be broken down easily. The common thermoset matrix that are used in manufacturing composite materials are epoxy, polyester and vinyl ester.



(A) (B)

Figure 2.5 shows the images of individual linear polymer chains (A) and polymer chains which have been cross linked to give a rigid 3D thermoset polymer (B) respectively.

2.6.2 Thermoplastic Matrix

Thermoplastic or also known as thermosoftening plastic which is a plastic polymer material that becomes pliable or moldable at certain elevated temperature and solidifies upon cooling. Thermoplastic do have high molecular weight. The polymer chains in thermoplastics are connected by an intermolecular force which weaken rapidly with increased temperature, yielding a viscous liquid. At this state, thermoplastics can be reshaped and used to produce parts which are from different polymer processing techniques such as injection moulding, compression moulding, extrusion and calendaring. Thermoplastics are different from thermosets as thermoplastics can form irreversible chemical bonds during the curing process unlike thermosets. Thermoplastics are high in ductility and impact resistance. However, the usage of thermoplastics are lower compared to the usage of thermosets due to its high viscosity.

2.7 Fabrication Method

There are numerous ways of fabricating composite components. Even though there are numerous ways of fabricating composite materials, the selection of method depends on the materials, part design and end-use application. Some of the methods have been borrowed from different industry such as injection moulding from plastic industry. Fabricating composite materials typically involves some form of moulding as to shape the resin and reinforcement. There are different methods that does not require moulding such as hand lay-up and resin infusion methods.

2.7.1 Double Vacuum Bagging (DVB)

This method was proposed by the Naval Air Warfare Center as to replace the single vacuum bagging (SVB) method. Mehrkam (1993) found that double vacuum bagging (DVB) of wet hand lay-up technique could reduce the content of void and increase shear strength in the composite. The DVB was first used in the 1980s as to reduce the porosity and increase mechanical properties.

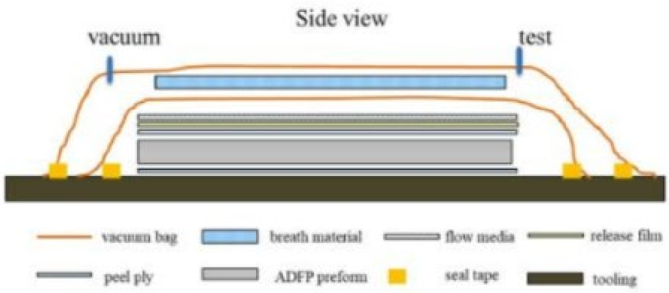


Figure 2.6 shows the setup of double vacuum bagging (DVB).

The laminate was place in the DVB setup and the condition of the vacuum compressing the laminate. The pressure that being applied at the first or inner vacuum bag is lower compared than the pressure applied at the second or outer vacuum bag. Hence, because the outer bagging is to compact the composite whereas the inner bagging is to extract the volatiles such as the trapped air, ambient moisture and solvent (Gardiner, 2010a). Not only that, the lower pressure in the inner bagging is able to pull the matrix throughout the fibre. The breath material which is placed in between the inner and outer bagging (Figure 2.6) function as to separate the two bagging from sticking each other and prevent them to function as one bagging (*Double-Bag Infusion: 70% Fiber Volume? | CompositesWorld*, n.d.).

A huge pressure difference in the resin infusion method between the vacuum bagging and resin inlet will cause variation in the thickness of the composites. However, the pressure in the bagging will decrease as the resin inlet will cause the pressure to increase during the resin flow to the composite. The thickness of the composite that is close to the resin feed will increase as the bagging around the resin inlet will be loosen. As the purpose and uses of the second bagging which is the outer bagging will compact the composite. Thus, the application of DVB in the resin infusion method is to maintain the thickness of the composite throughout the curing process.

2.8 Standard Tests

2.8.1 Fracture Toughness test – ASTM D5528

This test is used to determine the Mode 1 interlaminar fracture toughness, G_{IC}. This test is designed to characterize the critical value of G for delamination growth as a result of an opening load or displacement as well as the energy release rate which is the loss of energy, dU in the respective test specimen per unit of specimen width for an infinitesimal increase in delamination length, da for the delamination growing under a constant displacement (ASTM D5528-01, 2014). In the mathematical form it is written as,

$$G = \frac{1}{b}\frac{dU}{da} \qquad \text{Equation 2.1}$$

Where:

U = total elastic energy in the test specimen

b = specimen width

a = delamination length

This test involves by using the double cantilever beam (DCB) specimen (Figure 2.7) by tensile test. Based on Figure 2.7, the specimen consists of a rectangular, uniform thickness, unidirectional laminated composite specimen containing a non-adhesive insert in the midplane as the delamination initiator. Forces are applied to the DCB specimen by the loading blocks which are attached to one end of specimen by a strong glue. The loading blocks are attached precisely and accurately so that it could be placed correctly in the testing machine. The ends of the DCB specimens are opened by controlling either the opening displacement or the crosshead movement while the load and delamination length are recorded. The Mode 1 interlaminar fracture toughness is calculated utilizing a modified beam theory or compliance calibration method (Ayatollahi et al., 2002).

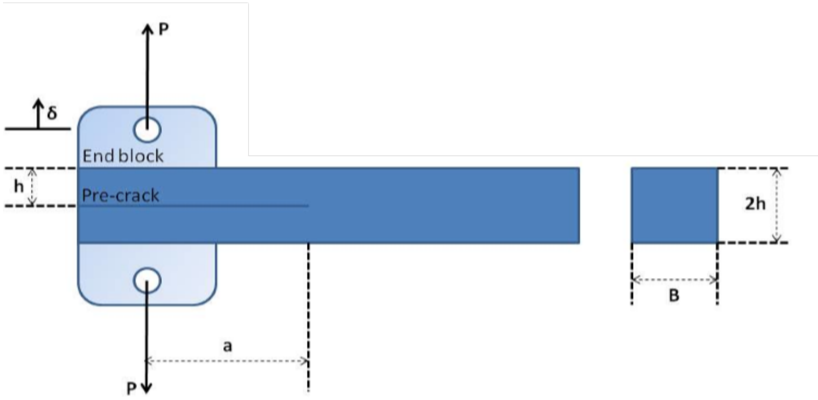


Figure 2.7 shows the double cantilever beam (DCB) specimen.

2.8.2 Fracture Toughness test – ASTM D5045

As for ASTM D5045 is used to measure the plain-strain fracture toughness and strain energy rate of plastic materials. This test method is also designed to characterize the toughness of plastic in the terms of the critical-stress-intensity factor, K_{IC} and the energy per unit area of crack surface or critical strain energy release rate, G_{IC} at fracture initiation. The two various testing geometries are covered by two methods which are single-edge-notch bending (SENB) and compact tension (CT). A state-of-plain at the crack tip is required at specimen. Not only that, the thickness of the specimen should be sufficient as to ensure the stress state. It is also important as the crack at the specimen must be sufficiently sharp to ensure a minimum value of toughness could be obtained. These test methods are involved by loading a notched specimen that has been pre-cracked, in either tension or three-point bending. As for the K_{IC} value, it is calculated from the load by equations that have been established based on the elastic stress analysis on type of specimens described in test methods respectively. The validity of determining the K_{IC} value by these test methods depends on the establishment of a sharp-crack condition at the tip of the crack. To determine the G_{IC} value, it requires the determination of the energy derived from the integration of the load versus load-point displacement diagram.

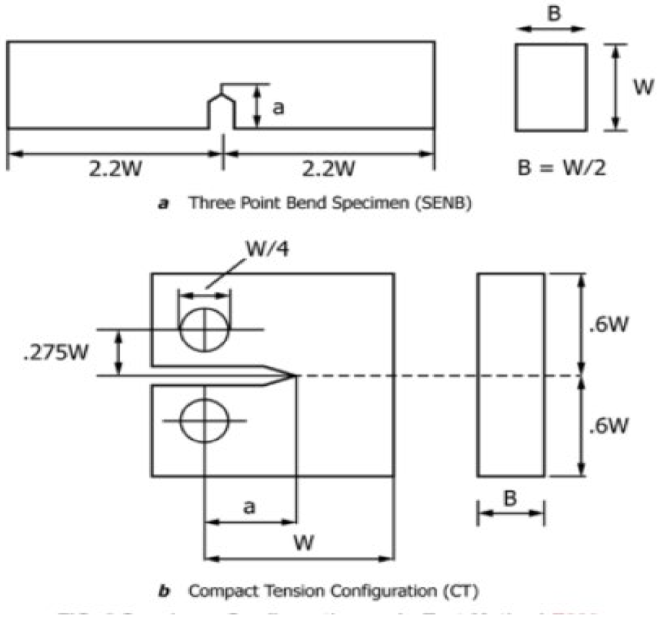


Figure 2.8 shows the specimen configuration for test methods respectively.

Based on Figure 2.9, the specimen width, W is twice the specimen thickness, B. In mathematical form it is written as W = 2B. As for the crack length, a, it is selected in such a way that $0.45 < \frac{a}{W} < 0.55$. In order to consider the results are valid according to the test methods, the size criteria must be satisfied as:

$$B, a, (W - a) > 2.5\,(K_Q/\sigma_y)^2 \qquad \text{Equation 2.2}$$

Where

K_Q = condition or trial K_{Ic} value.

σ_y = yield stress of the respective material for the temperature and loading rate of the test.

However, the criteria require that B must be sufficient to ensure the plan strain as well as (W -a) to avoid excessive plasticity in the ligament. The standard nominal ratio, $\frac{W}{B}$ for the specimens are 2 but if the (W – a) is too small and non-linearity in loading, then ratio could be increase to a maximum of 4 is only permitted for the ENB specimens. The sharp crack in the specimens could be crated by using a fresh razor blade and tapping.

CHAPTER 3

METHODOLOGY

In this chapter, the flow of the research, the process and the techniques that are implemented in this investigation will be described. Materials such as the matrix and natural fibre that are used as the main reinforcement in the laboratory session will be introduced in the first part of this respective chapter, followed by the procedures in producing the natural fibre reinforced composites (NFRC) and the testing of the specimens. The figure below shown is the flow chart of the research study.

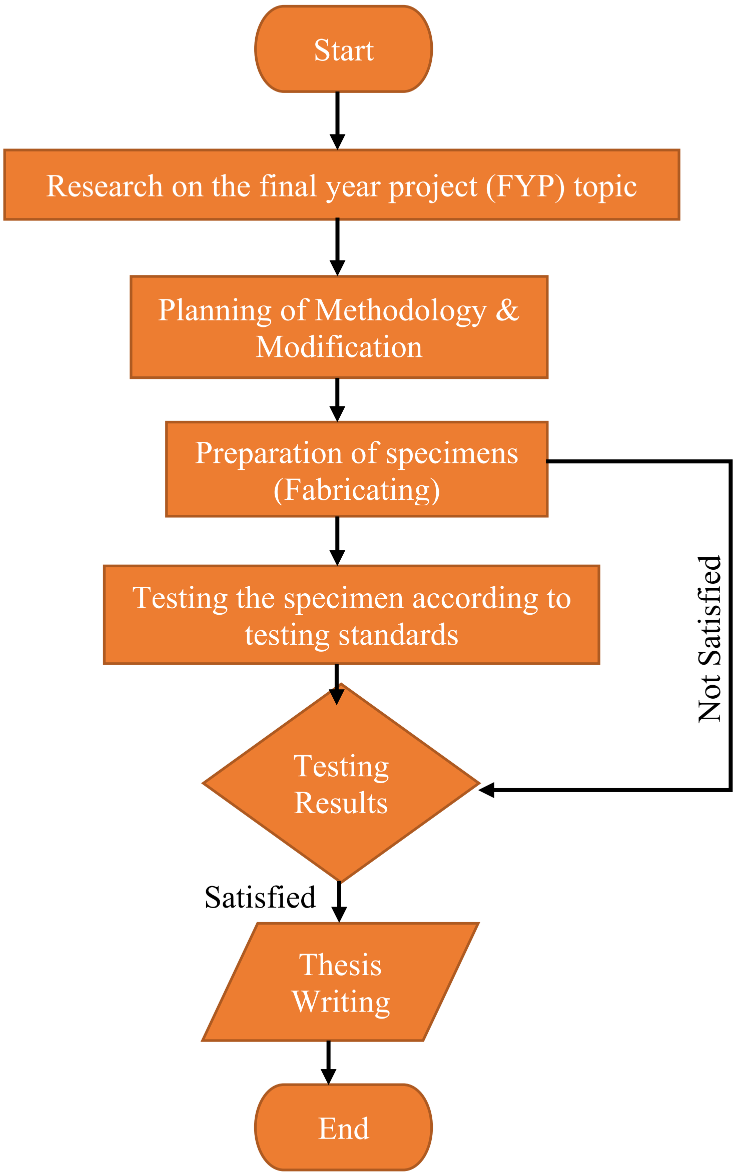


Figure 3.0 shows the flow chart of the final year project (FYP).

Hence, the flow chart below shows the process of fabricating the specimens according to testing standards respectively.

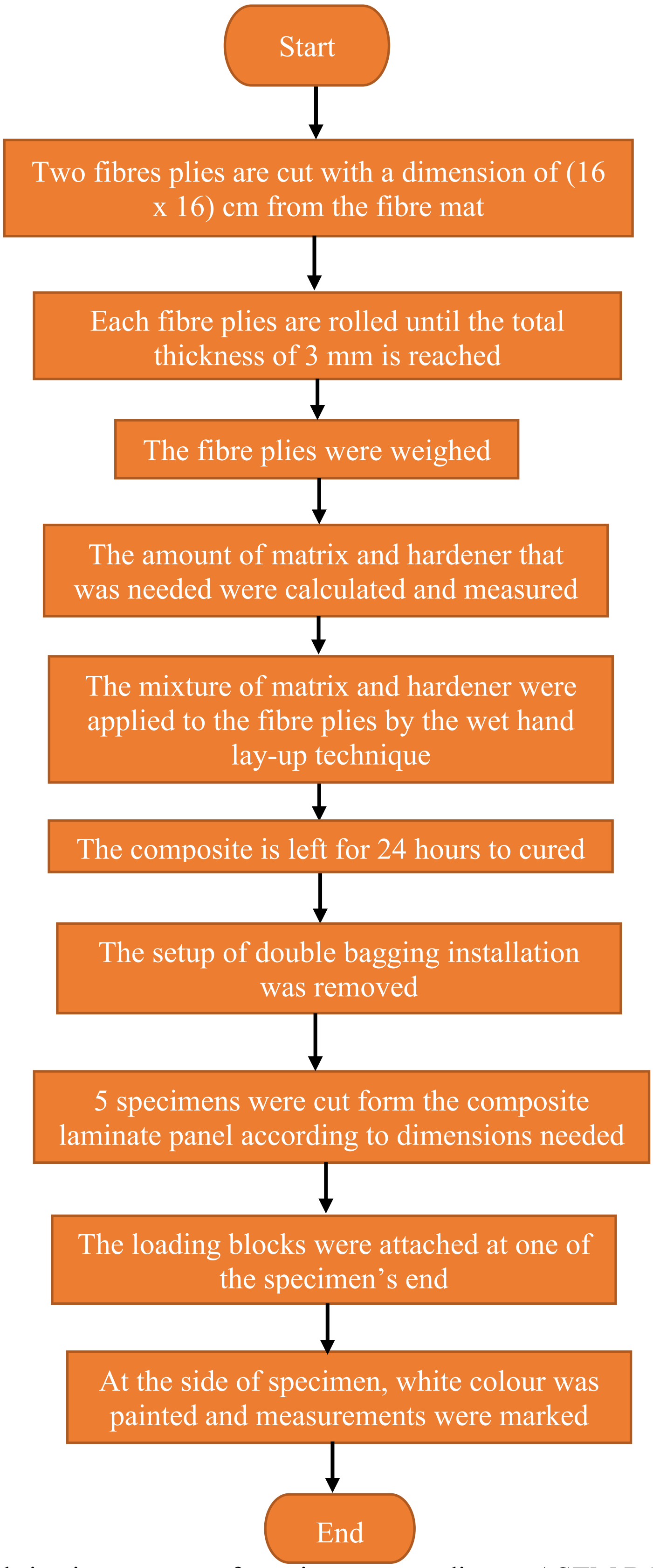


Figure 3.1 shows the fabrication process of specimens according to ASTM D5528 standards.

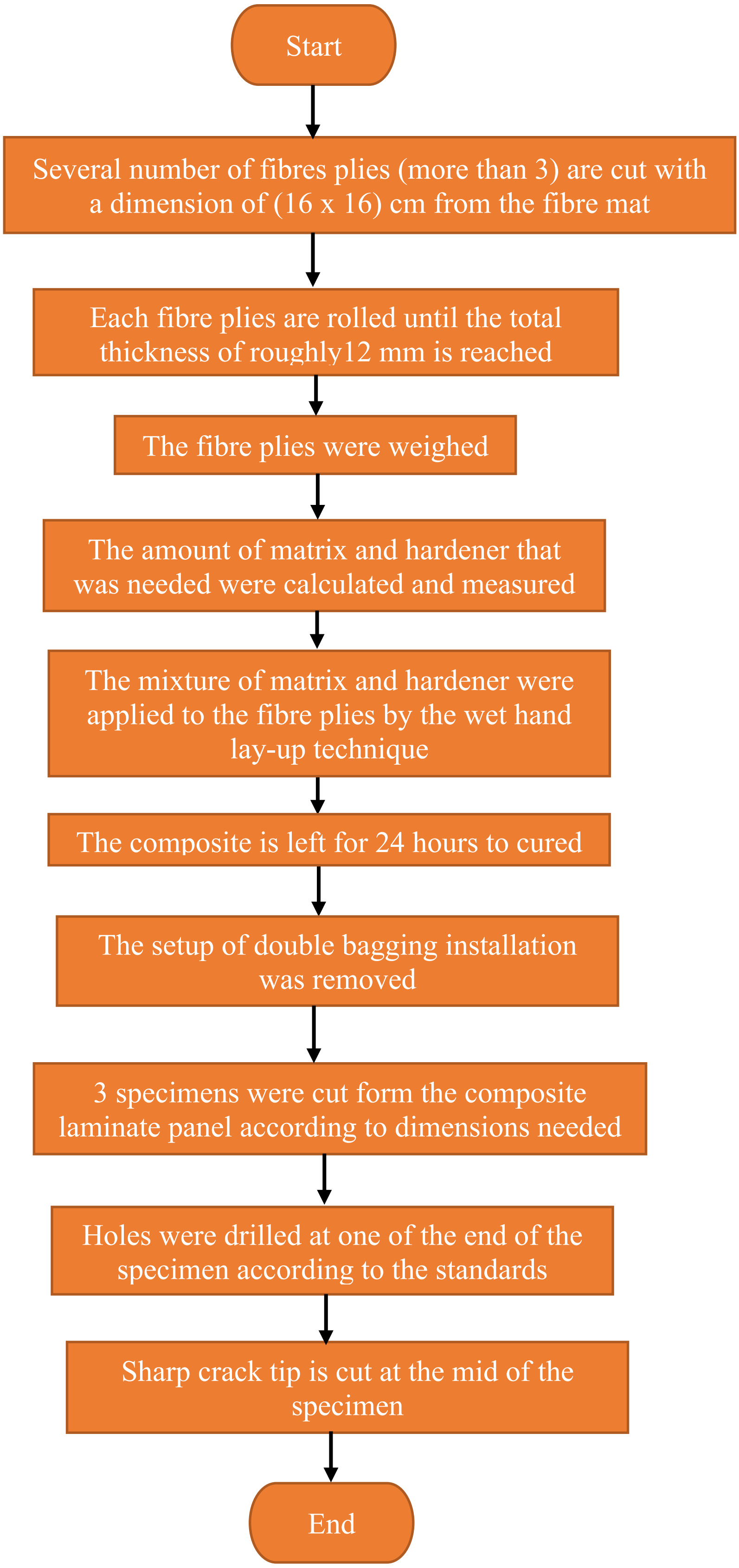


Figure 3.2 shows the fabrication process of specimens according to ASTM D5045 standards.