MECHANICAL PROPERTIES OF NATURAL FIBRE REINFORCED COMPOSITE BY USING VACUUM ASSISTED DOUBLE BAGGING METHOD

by

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

July 2021

ENDORSEMENT

I, Syazana Husna Binti Othuman Mydin hereby declare that I have checked and revised the whole draft of dissertation as required by my supervisor.

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Date: 11 July 2020

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ENDORSEMENT

I, (Syazana Husna Binti Othuman Mydin) hereby declare that all the corrections and comments made by the supervisor and examiner have been taken in 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 candidate for any other degree.

(Signature of Student)

Date: 11 July 2020

ACKNOWLEDGEMENT

This final year project was a bit hard for me since it needed a lot of strength and time to fabricate the composites laminates and testing processes. However, I manage to finish everything on time due to support and guidance from few people by my sides. First and foremost, I would like to express my gratitude to my final year supervisor, Dr Mohd Shukur Zainol Abidin. he had supported and guided me throughout this one year of project. Although the fabrication work started of late due to the Covid-19 pandemic, the research work and literature review went well with his guidance and briefings. He had given his time and ideas on the study and share a lot of advises during discussions or sudden meetings. Besides that, I would like to thank Dr Aslina Anjang Ab Rahman, who has given me few ideas on my project and share few thoughts during colloquium session during the first semester.

I would like to express my greatest gratitude to the technical staffs in the lab of School of Aerospace and School of Mechanical, who offered guidance and technical assistance throughout my final year project. The technical staffs are Mr Hasfizan Bin Hashim (Assistant Engineer), Mr Mohd Shahar Bin Che Had @ Mohd Noh (Assistant Engineer), Mr Abdul Hisham Bin Sulaiman (Assistant Engineer), Mr Mahmud Bin Isa (Assistant Engineer), and Mr Fakruruzi Fadzil (Assistant Engineer).

Finally, I want to thank all my friends and family members that have been a huge pillar to me, who helped and gave me moral support. The pandemic has dragged the timeline for lab work of my final year project, however, these people helped me to go through it with ease.

ABSTRACT

This is a study of the mechanical properties of natural fibre composites in terms of tensile, compression and flexural manufactured via vacuum assisted double bagging method. Natural fibre composite demands have increased nowadays with its advantages and wide range of applications. The method used to manufacture the composites also plays an essential role in producing a good product. Sadly, studies relating different type of fabrication methods are not diversely done. Thus, this study will give a start up to the fabrication of composite via double bagging method, especially natural fibre composite. In this study, coconut fibre and oil palm fibre are used as the reinforced materials, whereas for the matrix, EpoxAmite 103 with 103 slow harderner is chosen. The fibre volume fraction of the composite laminate is set at constant value, which is 0.4. Based on the ASTM, the total thickness of the laminate should be within 3mm in total. Consequently, for each composite laminate, two fibre plies are rolled by using a rolling machine. The fibre plies are then weighed to calculate the mass of resin needed. The process of fabrication starts with applying resin on the fibre plies by wet hand layup method, followed by double bagging and vacuum process. To ensure the uniform pressure distribution on the laminates, breather is used in between each bagging. This will give a result of laminates with smooth surface and good quality. Since there are three mechanical tests, three batch of double vacuum bagging method is done for each fibre. After the composite is completely cured, each laminate is cut into 5 specimens to be tested for tensile, flexural and compression tests, respectively by using a universal testing machine. Implementation of vacuum assisted double bagging method in this study will gives a better volatile management, lower voids with higher mechanical strength and Young's modulus of the composite produced. However, the maximum load, stress and strain of the composite produced is lower than the previous studies from researchers. Further improvements are needed on the double vacuum bagging method to give a better result in future research.

ABSTRAK

Ini adalah kajian sifat komposit serat semulajadi dari segi tegangan, mampatan dan fleksibel melalui kaedah bagasi berganda yang dibantu vakum. Permintaan komposit serat semulajadi telah meningkat apabila masa berlalu kerana kelebihannya dan pelbagai aplikasi. Kaedah yang digunakan untuk mengeluarkan renang memainkan peranan penting dalam menghasilkan produk yang baik. Malangnya, kajian yang berkaitan dengan pelbagai jenis kaedah fabrikasi tidak dilakukan dengan banyak. Oleh itu, kajian ini akan memberi permulaan kepada fabrikasi serat semulajadi dan serat sintetik melalui kaedah bagasi berganda. Dalam kajian ini, kelapa, sawit, dan serat kaca digunakan sebagai bahan bertetulang, manakala EpoxyAmite 103 dipilih sebagai matrix. Pecahan kelantangan serat lamina komposit ditetapkan pada nilai malar, iaitu 0.4. Berdasarkan ASTM, jumlah ketebalan lamina sekiranya dalam 3mm. Oleh itu, bagi setiap lamina komposit, dua pemerangkap serat digulung dengan menggunakan mesin rolling. Pemberkas serat kemudian ditimbang untuk mengira jisim resin yang diperlukan. Proses fabrikasi bermula dengan menyapu resin pada pemberkas gentian dengan kaedah lapisan tangan basah, diikuti dengan proses bagasi dan vakum berganda. Untuk memastikan taburan tekanan seragam pada komposit, bahan bernafas digunakan di antara bagasi. Ini akan memberi hasil komposit dengan permukaan yang licin dan kualiti yang baik. Oleh kerana terdapat tiga ujian mekanikal, tiga kumpulan kaedah bagasi vakum berganda dilakukan untuk setiap serat. Selepas komposit benar-benar mampat, setiap lamina dipotong kepada 5 spesimen untuk diuji untuk ujian tegangan, fleksibel dan mampatan, masing-masing dengan menggunakan mesin ujian sejagat. Pelaksanaan kaedah bagasi berganda dan vakum dalam kajian ini akan memberikan pengurusan yang lebih baik, lompang yang lebih rendah dengan kekuatan mekanikal dan modulus yang lebih tinggi. Namun, beban maksimum, tekanan dan ketegangan komposit yang dihasilkan adalah lebih rendah daripada kajian sebelumnya

daripada penyelidik. Penambahbaikan selanjutnya diperlukan pada kaedah bagasi vakum berganda untuk memberikan hasil yang lebih baik dalam penyelidikan masa depan.

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LIST OF ABBREVIATIONS

NFRC	: Natural fibre reinforced composite
DVB	: Double vacuum bagging
SVB	: Single vacuum bagging
FVF	: Fibre volume fraction
OPEFB	: Oil palm empty fruit brunch
EFB	: Empty fruit brunch
ASTM	: American Society for testing and materials
SEM	: Scanning electron microscope
CFRC	: Coconut fibre reinforced composite
OPFRC	: Oil palm fibre reinforced composite

LIST OF SYMBOLS

V_f	: Fibre volume fraction (FVF)
FAW	: Fibre areal weight (for each ply)
n	: Number pf plies
t	: Thickness of fibre
ρ_f	: Density of fibre
M	: Mass of fibre
A	: Surface area of fibre
ρ_c	: Density of composite
ρ_m	: Density of matrix
M_m	: Mass of matrix
ρ_m	: Density of matrix
M_f	: Mass of fibre
ρ_f	: Density of fibre
V_f	: Fibre volume friction
M_r	: Mass of resin
M_h	: Mass of hardener

CHAPTER 1 : INTRODUCTION

1.1 Background Study

Each material has a unique mechanical behavior, in which plays a vital role to endure bending, buckling or any vibrations of its purpose. Most of the industry would prefer a material that possess more advantages as compared to disadvantages in its properties. Advance composite has been one of the materials that are popular and common to be used in this industry. High strength fibres are used in common in the aviation and aerospace industries, such as carbon, glass and Kevlar. (Lau, Hung, Zhu, & Hui, 2018) However, there are few issues that arise regarding these fibres, which are its properties that are hard to be recycle, over-strength behaviour and high material cost. Therefore, natural fibres have turned up to replace the synthetic fibre forming natural fibre reinforced composite (NFRC).

A number of research have been done on the properties and fabrication method of natural fibres in order to replace the conventional materials. As comparing to synthetic fibre, natural fibres are extracted from the nature, which saves energy and is sustainable to the environment. Natural fibres constituents can be found abundantly in the nature that makes it a renewable source and has a relatively lower material cost as compared to synthetic fibres. Hence, natural fibre composite demand has increased from day to day due to its advantages and wide range of applications.

This research allows a learning process on NFRCs properties and performances in a closer extend. In this paper, the major topic is on the fabrication and behaviour of natural fibre composites upon mechanical test. There are many methods to fabricate a composite such as lay-up processes, vacuum bagging, curing, filament winding, liquid molding resin film infusion and pultrusion.

1.2 Problem Statement

In general, natural fibre is biodegradable, low costs and low densities, with acceptable specific strengths and moduli, which eventually leads to low weight. NFRCs are good in thermal and insulation, which is an advantage in this industry. The manufacturing industry has neglected the advantages of natural fibre reinforced composite (NFRC) and consider synthetic fibre as it is an easier option since it has been used for decades. Synthetic fibre is familiar with its better mechanical properties and wide range of applications; however, natural fibre has better properties as compared to synthetic fibre in terms environmentally friendly and sustainability development concept.

Vacuum assisted double bagging method is not diversely explored in the fabrication of fibre, either synthetic or natural fibre. By all these reasons, this research study is begun in order to study more on natural fibre constituents, properties, behaviour, and introducing double vacuum bagging method to the manufacturing industry. The functions of DVB method is compression and compaction. Fibre volume fraction (FVF) of NFRC that is in the range of 50 to 60% will increase the FVF of composite, which eventually gives a higher voids percentage and leads to lower the strength of NFRCs produced (Pickering, 2016). Therefore, the NFRC fabricated in this research work will have a constant FVF of 0.4 and the mechanical behaviour of the composite will be observed.

A number of researchers have discovered better ways to manufacture or produce NFRCs with higher strength and mechanical properties. Natural fibre has been used as reinforced materials to enhance the ductility and toughness of materials produced. As the percentage of natural fibre increases, the mechanical properties of materials are proven to be improved. Addition of natural fibre with different percentages has improved the properties of composites in terms of compressive, flexural, and splitting tensile strength (M.A. Othuman Mydin, 2014). This has broadened the purpose of this study to diversely analyse the behaviour of natural fibre composites in terms of tensile, compression and flexural.

1.3 Objectives

1) To fabricate a composite by using natural fibre and resin as its constituents.
2) To perform tensile, flexural and compression tests on the fabricated composite accordance with the standard of ASTM D3039 and ASTM D790 by using universal testing machine.
3) To analyze and explore the mechanical strength of natural fibre composite in terms of tensile, compression and flexural.

1.4 Chapter Overview

There are five chapters in this paper and each chapter consists of different aspects that grows gradually starting from literature review to analysis and discussion phase of the study. This is the first chapter (Chapter 1) of this paper which includes a background study, problem statement and objectives of the study. It is considered as the starting phase where a proper and detail research is done to have a better idea on the title, objectives, and the manufacturing process that will be used to fabricate natural fibre composite which is the vacuum assisted double bagging method.

Chapter 2 will be covering the literature review from several research papers found online. The literature review topics include the reinforcement material (plant fibre especially palm and coconut fibre), matrix (thermoset and thermoplastic), properties of tests conducted in this paper (tensile, flexural and compression test) and the double bagging method. Chapter 3 is the methodology chapter that explain a detailed procedure of the pre-fabrication process, the whole fabrication process, and the post-fabrication process. The pre-fabrication process consists of the preparation of materials for the fabrication and the preparation of the fibres and matrix required. The fabrication processes include material handling and procedures to manufacture the composites. Post-fabrication comprises of specimen's preparation and details on the tests that will be conducted.

Chapter 4 take in the result and discussion of all the tests taken place. Based on the literature review, comparison of results will be made with other researchers. Verification and justification will review the quality of the results of this study. Finally, chapter 5 will conclude the findings from this study and further recommendations are written in this chapter for improvements in future evaluations. List of references will be provided at the end of this paper.

CHAPTER 2 : LITERATURE REVIEW

2.1 Plant Fibre

Natural fibers origin from the nature and can be achieved through different mechanical and chemical process. It can be found in various colors, sizes, and shapes. There are three main categories of natural fibers as can be seen in the figure below.

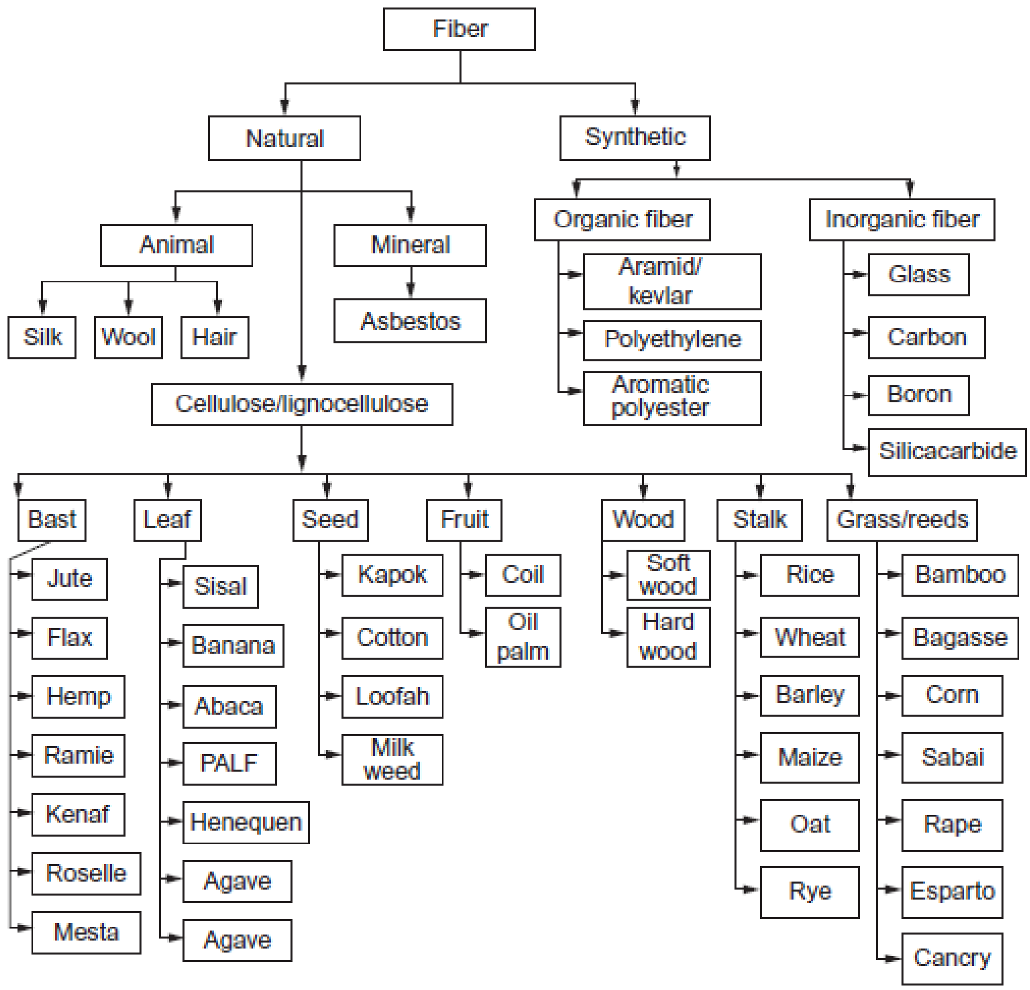

Figure 2.1: The hierarchy of fibre categories (Faris M. AL-Oqla, 2017)

First, animal fibers are natural fibers found from animal's part consisting of proteins such as silk, hair wool, feathers, and other uncommon sources. Secondly, mineral fibers are generally asbestos. Thirdly, plant fibers are based of natural cellulose or lignocelluloses fibers that contain macroscopic particles. These particles are obtained from specific technologies that include crushing of wooden material picked from filaments or long elements, which are obtained from strong and dense leaves of wild tropical plants. The other option to acquire plant fibers is by performing chemical treatments on vegetable matrix, where they will be extracted. There are several classifications of plant fibers such as bast fibers, leaf, seed-hair, and fruit fibers. Among all three categories of natural fibers, plant fibers are given the domain due to its wide range of choices and variations.

Plant fibres have a hierarchical structure of few components starting from the molecular level (at the cell wall), individual cells, and cellular arrays. At molecular level, the cell wall is composed of cellulose, hemi-cellulose, lignin, and pectin. Individual cells are known as microfibrils or ultimate fibres in engineering with a hollow core, and cellular arrays are known as fibre bundles or technical fibres. The basic chemical structure of cellulose in all plant fibres is similar. However, they vary in the degree of polymerization, while the cell geometry of each type of cellulose changes respectively with fibres. These factors contribute to diverse properties of the plant fibres.

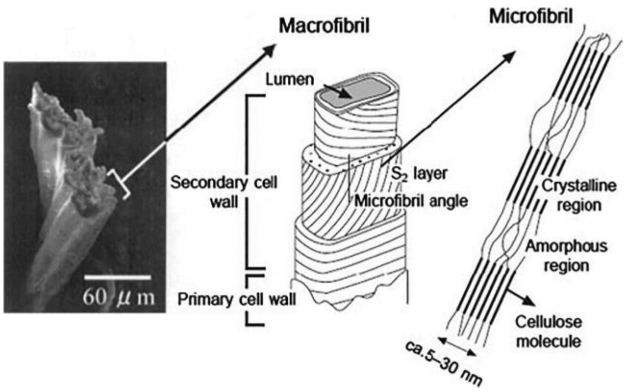

Figure 2.2: Schematic representations of macro-fibril and micro-fibril of natural plant (Kin-tak Lau, 2017)

The mechanical and material properties can create issues for a NFRC. There are several major factors that influence reinforcing efficiency of fillers in a matrix such as fibre dispersion, orientation, length distribution, and matrix adhesion.

2.1.1 Coconut Fibre

Coconut trees usually grown very well in the coastal region in the wet tropical regions such as India, Sri Lanka, Philippines, Indonesia, Malaysia, Vietnam, Hawaii Islands, Solomon Islands and areas same as these. Coconut is the seed of palm species called as *Cocos nucifera*, where its fibre is taken from the coconut shell. It is famous for high oil content which is a main usage of the food and dairy industry. In common, coconut tree has a life span of approximately 80 years. It is usually grown in the soil with high content of alluvial or loam which locks the soil moisture and in general, coconut tree grows very well in saline moisture soil, with light wind, well-distributed rainfall, high humidity, and moderate climate. The total productivity in the world has increased from 35 million t to more than 45 million t (dry weight) today. The palms flower every month, and the fruit will be ripe in 1 year after 3 to 5 years after planting. In every stage of maturity, it will have fruits and a mature tree is estimated to produce more than 50 coconuts per year. A coconut would weigh around 1.2 kg per nut, where the husk would weigh 300 to 400 gms. The husk consists of about 30% textile quality fibre and the remaining are small fibres and small fragments of fibres. The main purpose in these fibres is for ropes, carpets, furnishings, floor matting, wall decorative etc. (Basu S. S., 2017)

There are several factors that determine the quality of coconut fibres: rainfall, humidity, soil moisture, variety of seedlings, fibre extraction. A good fibre quality is obtained from the green coconut husk when it is in natural hydrated state. The fibre will be in a white color, softer and easy for chemical treatment. Since the main product of coconut is copra, dehusking will be done after the coconut husk reach full maturity after 9 months where the fibre is fully matured and at this stage the fibre will be dehydrated and changed into brown colour. Then, raw fibres are retted conventionally in backwater for a timeline of 6 to 12 months to soften it. Besides the conventional method, chemical retting has been proposed recently by using a combination of sodium sulfide (Na_2S), sodium carbonate (Na_2CO_3) and sodium hydroxide (NaOH). This method will improve the fibre properties and the treatment would be done in 2 hours. (Basu G. M., 2015)

Figure 2.3: Raw coconut fibre (Basu S. S.)

Figure 2.4: Retted coconut fibre (Basu S. S.)

A study is done to compare the physical and mechanical properties of coconut fibre with two other fibres which are jute and sisal. Figure 2.5 shows the details on the properties of these fibres. Based on the figure, it can be said that coconut fibre is much thicker than jute and sisal. The diameter and length of coconut fibre are in and average values of 183 μm and 320mm respectively. The linear density of coconut fibre is also higher as compared to jute and sisal. It is stated that coconut fibre has a higher linear density and lower length to diameter ratio, which indicates it to be suitable for coarse textile applications. In terms of mechanical properties, the breaking tenacity and initial modulus of coconut fibre seems to be lower than the other fibres. This might be affected by the low degree of crystallinity.

Property parameter	*Coconut*	*Jute*	*Sisal*
Physical parameters			
Diameter (μm)	320[a] (50.5)	60 (32.1)	190 (36.9)
Length (mm)	183[b]	60[c]	770
Length–diameter ratio	750	1000	4052.6
Linear density (tex)	59.2	3.8	29.67
True density (g cm^{-3})	1.40	1.48	1.45
Apparent density (g cm^{-3})	1.17	1.23	1.2
Bulk density	0.43	0.48	0.45
Mechanical behavior			
Breaking tenacity (cN/tex)	11.25 (54)	33.2 (45.7)	28.2 (40.05)
Breaking extension (%)	21.5 (51)	1.8 (41.3)	2.76 (48.01)
Initial modulus (cN/tex)	200	1900	1100
Specific work of rupture (mJ/tex-m)	13.4	2.8	4.41
Flexural rigidity (mN-mm^2)	1100	22.1	284.1
Coefficient of friction	0.35	0.45	0.56
Moisture relationship			
Moisture regain at 65% RH (%)	11.7	13.5	10.92
Longitudinal swelling (%)	0.6	0.07	0.08
Transverse swelling (%)	15	25	15
Water imbibition (%)	58	92	64
Vertical wicking length after 24 h (mm)	2	7	17
Electrical properties			
Mass specific resistance (Ω-kg m^{-2})	4.0	1.83	2.96

[a]Range 100–795 μm;
[b]Range 44–305 mm;
[c]Modal value of filament.
Figure in parentheses indicates coefficient of variation of the corresponding parameter.

Figure 2.5: Properties of coconut, jute and sisal fibre in terms of its properties (G.K. Bhattacharya, 2009)

2.1.2 Oil Palm Fibre

Oil palm tree or *Elaeis guineensis*, is a type of tree that have been growing in the wild and originates from West Africa. It has been one of the main sources of vegetables oil in the industry. Oil palm tree is divided into three constituents, which are oil palm frond, empty fruit bunch, and oil palm trunk. Over years, the cultivation of oil palm has expanded greatly as the demand for oil has increased. Among all three constituents, only oil palm frond gives (Basu S. S.)out most of the fibres production as compared to the other two. Oil palm empty fruit bunches (OPEFBs) are already available in the palm-oil mills. In Malaysia, there is an estimation targeted round 4.43 million t (dry weight) empty fruit bunches (EFBs) are available annually.

Presently, 65% of the oil palm is incinerated, while the bunch ashes are used back as fertilizer at the plantation. However, the incineration process is harmful to the environment as it emits white smoke with fly ash. Although Malaysia is known as the largest producer for palm oil, at the same time, significant amount of oil palm waste is created here.

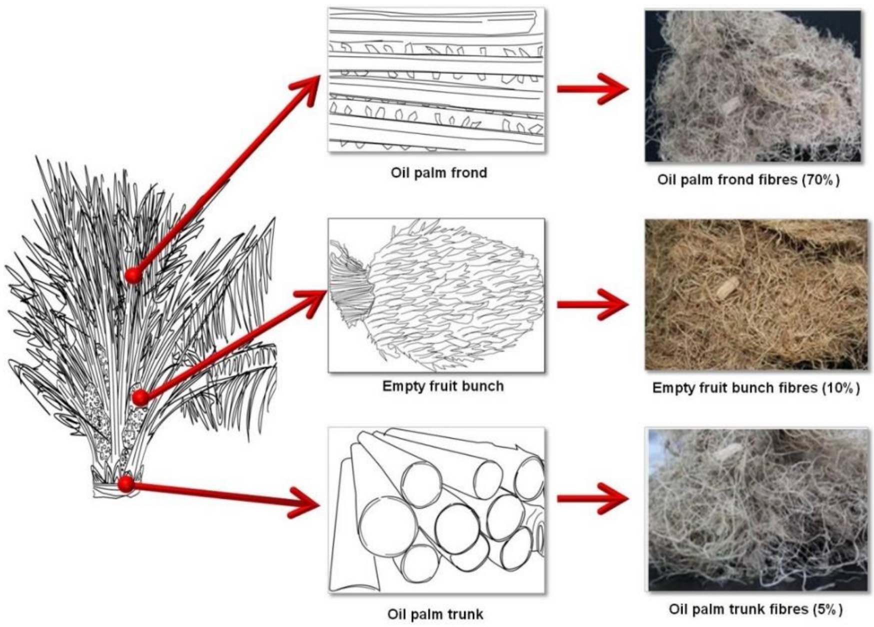

Figure 2.6: The compositions of an oil palm tree (H.P.S. Abdul Khalil, 2012)

A study was done on a suitable method to get rid or use EFB properly. First, pretreating is done to remove the residual oil from the EFB by using chemical such as sodium hydroxide (NaOH). Yet, pretreating has reduced the mechanical and physical properties of the fibre produced. John *et al.* has stated reason behind the downfall of this method. Based on the findings, at such high concentrations of alkali, the lignocellulose sisal and oil palm fibres undergo degradation, which eventually reduces the tensile strength. Other than that, chemical treatment on these fibres results in superior tensile properties which gives a better interaction between fibre and rubber matrix (Ridzuan R., 2002).

A research study was done by treating EFB with maleic anhydride (MAH) which by Fourier transform infrared (FRIR) analysis (Rozman H.D., 2001). In this research study, it is found that the composites possessed a higher flexural and impact properties with treatment of MAH. Based on this study, the flexural strength of the composite increases as the percentage on EFB increased. Moreover, higher strength is found in the fibres that is treated with isocyanate as comparing to untreated fibres. It can be concluded that the percentage of EFB and isocyanate-treated fibres have the same outcome on the tensile and flexural modulus.

2.2 Matrix (Thermoset, Thermoplastic)

Matrix is an important component in a fibre-reinforced composite. It protects the surface of the fibres from any mechanical impact and transfers the load to fibres. Matrix selection depends on the reaction it gives to natural fibres, which is limited since natural fibre degrade fast. There are two main categories of matrix, which are thermoset and thermoplastic.

2.2.1 Thermoset

Thermoset is a type of matrix made up from synthetic materials. It can be heated up to be strengthen, however it must be done within a limit. If it exceeds the limit, the damage will be irreversible. Thermoset cannot be reheated or remolded into its initial state. In short, the changes of thermosets are permanent. Thermosets include epoxies, polyimides, bismaleimides, polyesters, vinyl esters, cyanate esters and phenolics. Epoxy has been a dominant resin used for low and moderate temperatures. Figure 2.7 shows the characteristics and advantages of some thermosets (Campbell, 2010). The usage of thermoset has a vast of advantages. First and foremost, thermosets will retain their shaped and strength in place when heated. The product of thermoset is permanent and suitable for the large and solid shapes.

Polyesters	Used extensively in commercial applications. Relatively inexpensive, with processing flexibility. Used for continuous and discontinuous composites.
Vinyl Esters	Similar to polyesters, but are tougher and have better moisture resistance.
Epoxies	High-performance matrix systems for primary continuous-fiber composites. Can be used at temperatures up to 250–275 °F. Give better high-temperature performance than polyesters and vinyl esters.
Bismaleimides	High-temperature resin matrices for use in the temperature range of 275–350 °F with epoxy-like processing. Requires elevated-temperature postcure.
Cyanate Esters	High-temperature resin matrices for use in the temperature range of 275–350 °F with epoxy-like processing. Requires elevated-temperature postcure.
Polymides	Very-high-temperature resin systems for use at 550–600 °F. Very difficult to process.
Phenolics	High-temperature resin systems with good smoke and fire resistance. Used extensively for aircraft interiors. Can be difficult to process.

Figure 2.7: Characteristics of thermosets (Campbell, 2010)

Thermosets are brittle and have an excellent strength. Since it is permanent, it would not lose neither it shapes nor the strength at high operating temperatures. Other than that, thermosets cost lower than other type of matrix in terms of tooling and setup. It has a high resistance towards corrosion with high dielectric strength (Matrix, n.d.).

2.2.2 Thermoplastic

Thermoplastics are the exact opposite of thermosets. It is melted and flow during processing it, however unlike thermoset, it does not form any crosslinking reactions. The main bonding is a weak secondary bond. At the same time, thermoplastics has a high molecular weight, which cause it to have a high magnitude of viscosity. Since thermoplastics do not crosslink during the processing, they can be reformed, remolded and reprocessed by simply reheating it. However, there is a certain limit a thermoplastic can be reprocessed. Processing temperatures are close to the polymer degradation temperatures, which will lead the resins to eventually degrade, and in some cases, it may crosslink (Campbell, 2010).

There are few advantages of thermoplastics. One of it is thermoplastics can withstand higher processing temperature; for fabrication in the autoclaves, presses or bagging that require high temperatures, thermoplastics are suitable. Thermoplastics do not need refrigeration and has a low moisture absorption. Since thermoplastics can be reprocessed, they can be applied in forming and joining applications that involves reheating (Campbell, 2010). However, for this study, thermoplastics were not used as thermosets are lower in costs and this study do not involve reheating or higher temperature fabrication process.

2.3 Test properties

In this fabrication process, all specimens were made based on the ASTM for each test (tensile, flexural, and compression) and ASTM for the void. ASTM D3039 (ASTM, Standard Test Method for Tensile Properties of Polymer Matrix Composite Materials, 2014) is for tensile test, ASTM D790 (ASTM, Flexural, 2014) is for flexural test and ASTM D2734 is for the void.

2.3.1 Tensile test

ASTM D3039 is specifically used for plastics reinforced particles or short fibres. It is one of the basic tests done to certify a material tensile properties. The specimens will be in rectangular shape with a uniform cross-section. Greater lengths are recommended for the specimens since it will reduce bending stress. The testing will be done by using a universal testing machine with a suitable grip as shown in Figure 2.8. Extensometers will be used to measure the strain produced during the test. The result from a tensile test will includes failure mode, tensile stress, tensile strength, ultimate tensile strain and modulus (McEnteggart, 2021).

Figure 2.8: Tensile test setup (McEnteggart, 2021)

2.3.2 Flexural test

ASTM D790 is a commonly used specifications in the plastics industry. This test mainly determines the flexural strength and modulus of reinforced and unreinforced plastics. These parameters will show the stiffness of the materials and shows its behaviour. Based on ASTM D790, the test uses a universal testing machine with a three-point bend fixture to bend the materials and acquire related data for the calculations (Thackeray, n.d.).

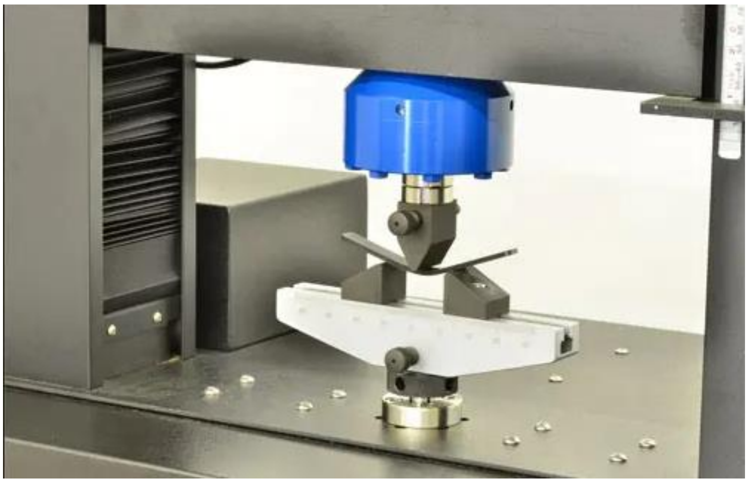

Figure 2.9: 3-point bend test setup (Thackeray, n.d.)

2.3.3 Compression test

Compression test is usually done by referring to the most common standard ASTM D695. However, this study will be done by using a different measurement for the specimens based on previous final year project. Therefore, compression test will be conducted based on one gauge length of 8mm on a universal testing machine.

2.3.4 Mechanical properties of coconut fibre

Tensile properties of coconut fibre composite could be found in an experimental study on the mechanical properties of coconut fibre reinforced lightweight foamed concrete. Foamed concrete is good in compression, however, weak in tension and tends to get brittle. This weakness can be overcome by adding coconut fibre to study the behavior the fibre-matrix composite after crack and improving its toughness. Different volume fraction of fibre ranging from 0.2% to 0.4% were used in the experimental work to produce specimens for compression, flexural and splitting tensile loading (M.A. Othuman Mydin, 2014). The results of the tests are shown in figure 2.10, 2.11 and 2.12. Addition of coconut fibre in the foamed concrete significantly increased the toughness and mechanical properties.

The results of the test showed that the compressive, flexural and splitting tensile strength of the foamed concrete increases with the fibre volume fraction of the coconut coir fibre in the concrete mix. Figure 2.13 shows the microstructure of three foamed concrete mixes with different percentage of coconut fibre through scanning electron microscope (SEM) observation. As the pore size becomes smaller, the mass density and compressive strength increases with comparable percentage. The coir fibre functions to reduce the amount and size of the pores in the materials. It also helps to produce more uniform distribution of the air voids. Hence, it will prevent bubbles from merging with each other and gives a uniform coating on each of bubbles (M.A. Othuman Mydin, 2014).

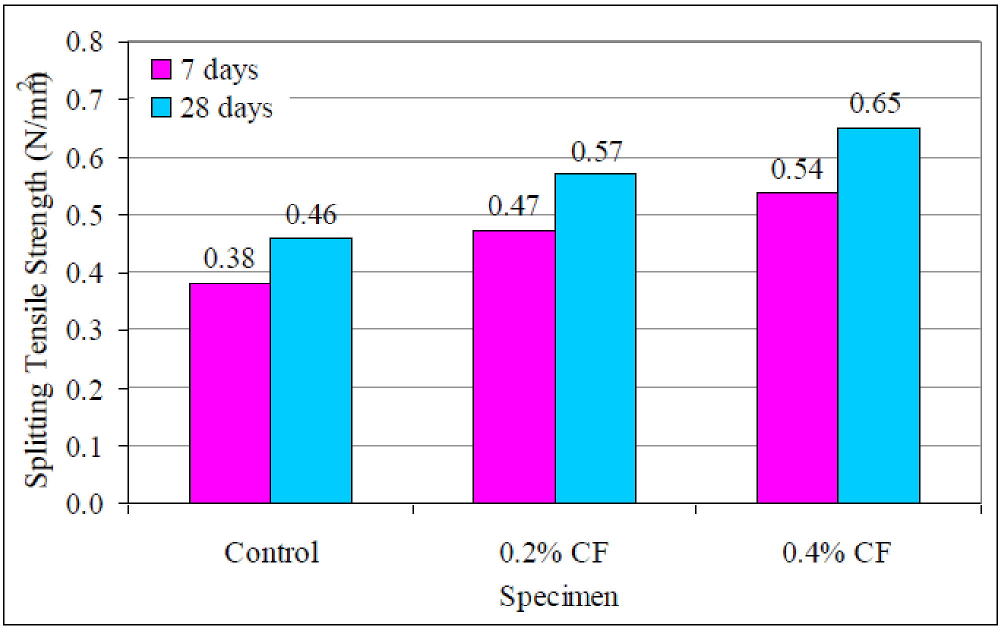

Figure 2.10: Splitting tensile strength at 7 and 28 days (M.A. Othuman Mydin, 2014)

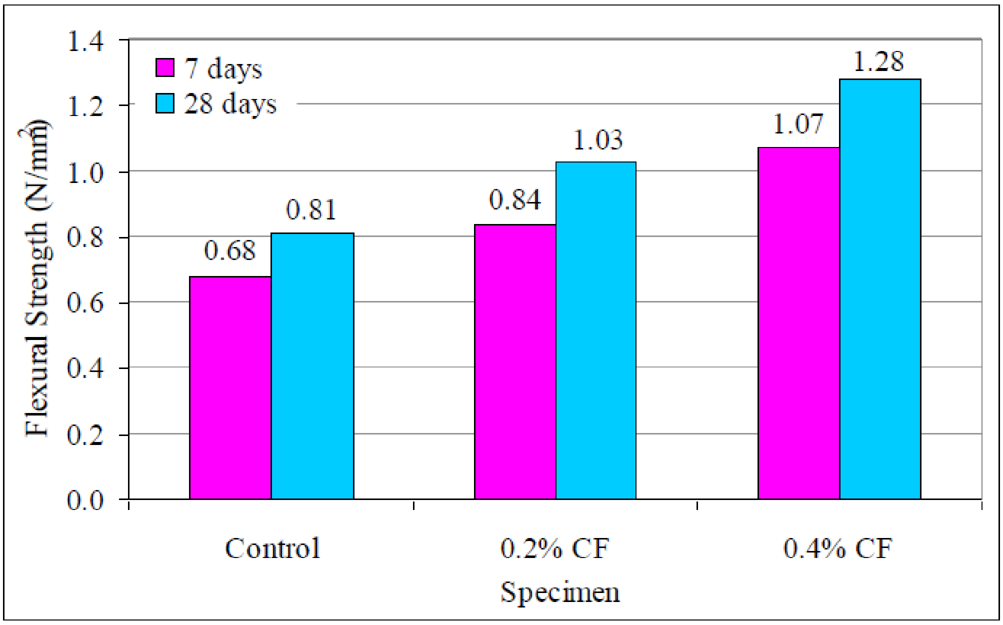

Figure 2.11: Flexural strength at 7 and 28 days (M.A. Othuman Mydin, 2014)

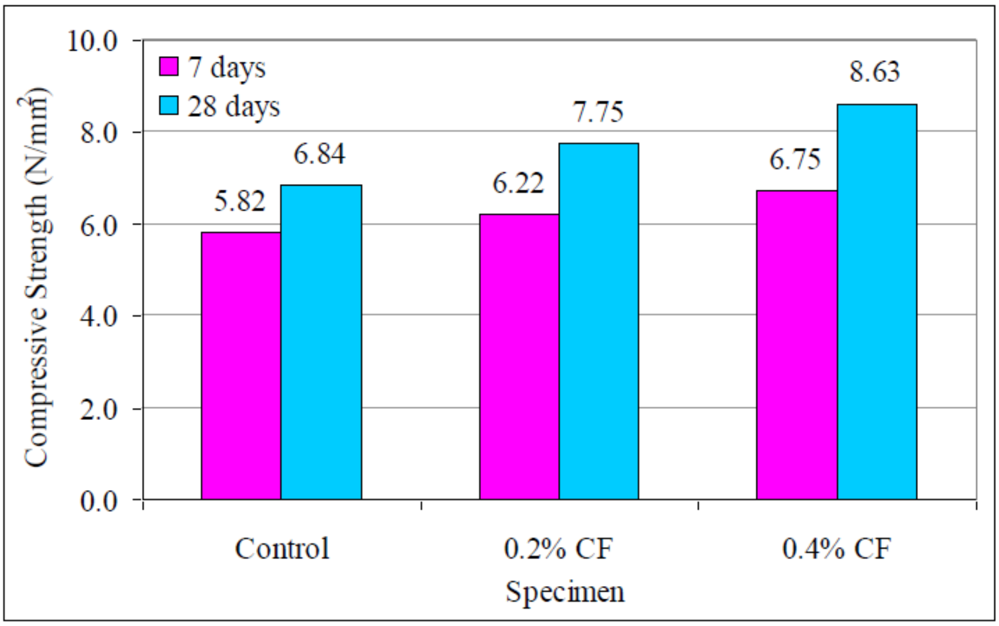

Figure 2.12: Compressive strength at 7 and 28 days (M.A. Othuman Mydin, 2014)

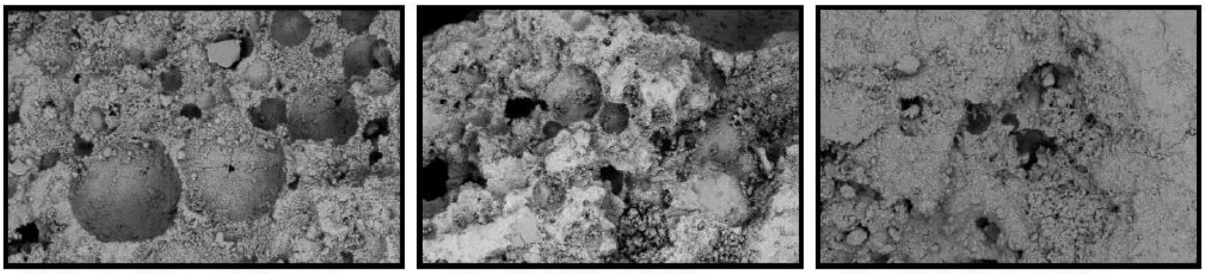

Figure 2.13: Comparison of formation of pores with normal foamed concrete (control) with foamed concrete with different percentage of coir (Magnification level 40x) (M.A. Othuman Mydin, 2014)

2.3.5 Mechanical properties of oil palm fibre

The tensile properties, Young's modulus and gel content of oil palm fibre were analyzed in a study concurrent to the reduction in the elongation at break of the composites. Morphological studies showed that there is an improvement in adhesion between fibre and polymer matrix is achieved by grafting OPEFB fibre with MA (Ratnam C.T., 2007). Electron-beam irradiation was used to improve the properties of the composite. It is verified that usage of reinforcement with carbon fibres (CFs) increases the tensile strength of the matrix approximately by 300% and Young's modulus by more than 500%. Figure 2.14 and 2.15 shows the effect of percentage OH of EFB on tensile strength and tensile modulus respectively.

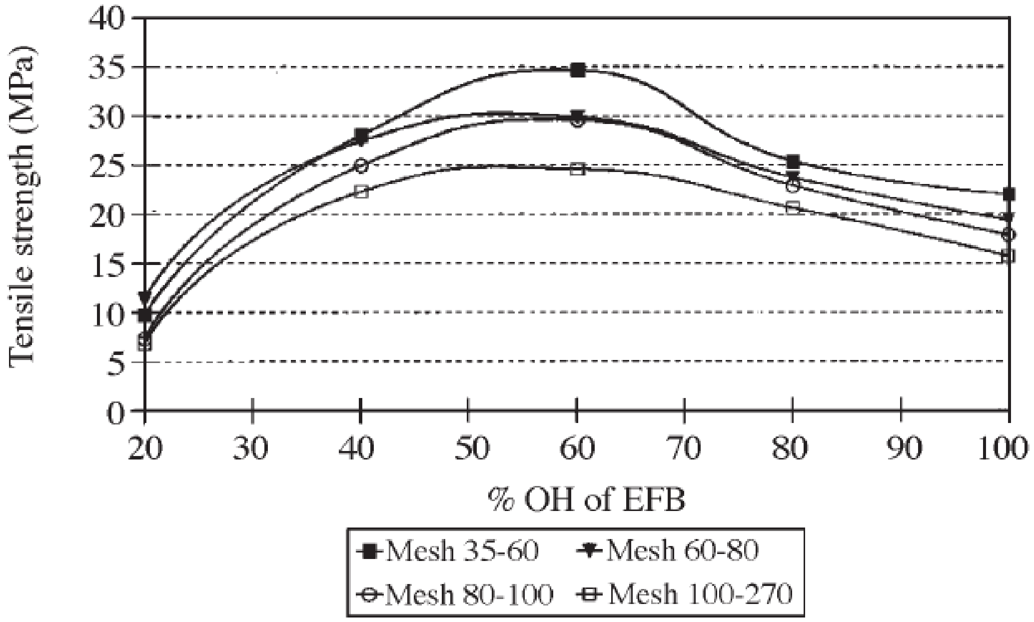

Figure 2.14: Effect of percentage OH of EFB on tensile strength (Rozman H.D., 2001)

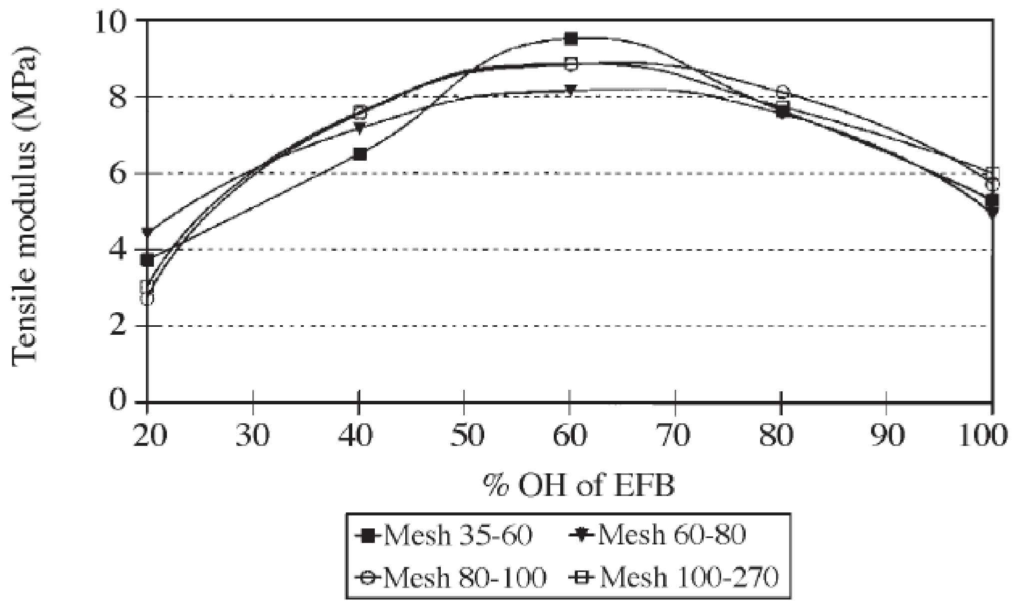

Figure 2.15: Effect of percentage OH of EFB on tensile modulus (Rozman H.D., 2001)

A study was done to study the flexural strength of oil palm fibre flexural strength and modulus. The results shows that the flexural strength of glass fibre increases with fibre loading. The addition of OPEFB fibre with 0.55 fibre volume fraction gives the hybrid composites with good flexural properties (M.S. Sreekala, 2002). The flexural modulus of glass/PF composites decreases with over 40 wt.% glass fibre loading. Figure 2.16 shows the variation in flexural strength for hybrid glass and OPEFB fibre. Hybridization of lower quantities glass fibre and OPEFB fibre produces composites with sufficient modulus as show in the figure (0.24:0.76).

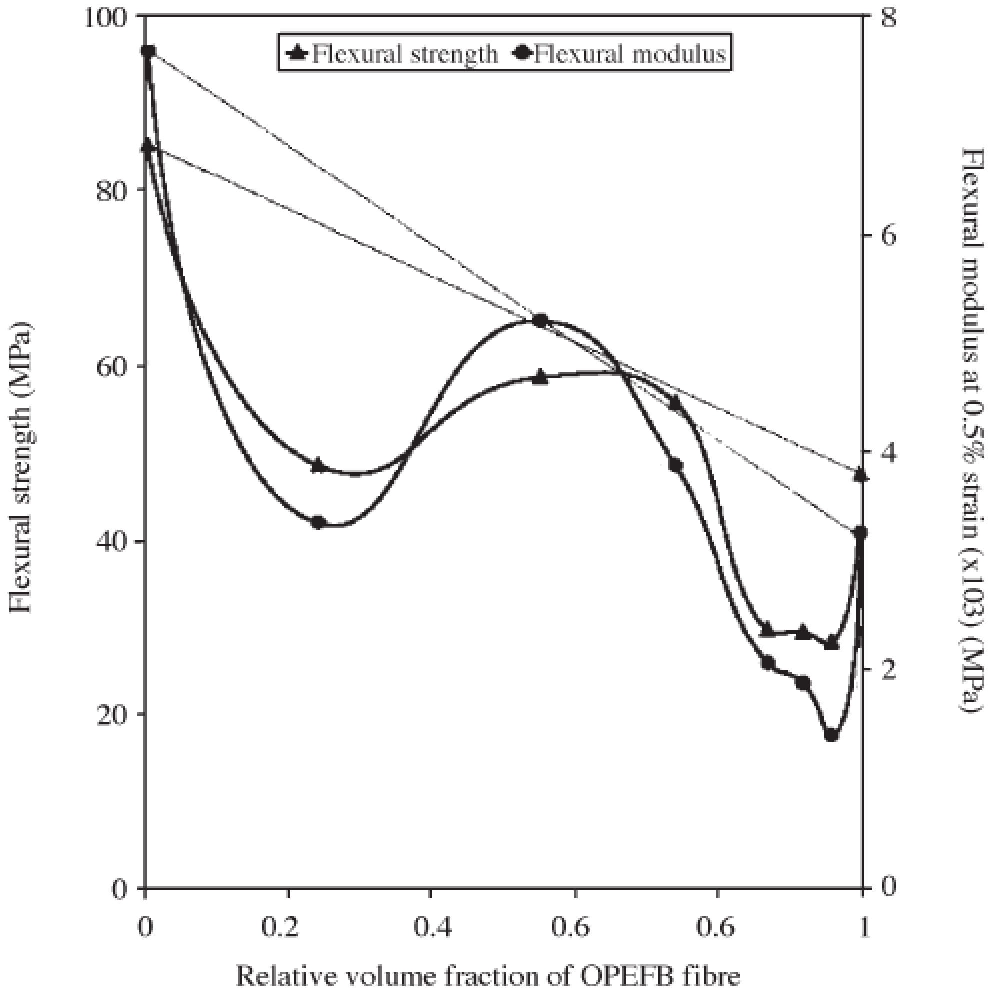

Figure 2.16: Variation in flexural strength of hybrid glass and OPEFB fibre (M.S. Sreekala, 2002)

2.4 Vacuum assisted double bagging method (DVB)

There are many methods to fabricate a composite such as lay-up, vacuum bagging and curing. In this work, double vacuum bagging method is precisely chosen to fabricate the NFC. Previously, single-vacuum-bag (SVB) process was used and now it has been replaced with double-vacuum-bag (DVB) method. The double bagging method was developed years ago by a Naval Air Warfare Centre, Warminster in conjunction of repairing aircraft parts. DVB is developed and consider as a superior to the SVB due to the enhanced management of volatile compound and offers exceptional void management. Thus, DVB is considered as a technique for volatile management in composite fabrication using a common molding equipment. This equipment was designed and built at the NASA Langley Research Centre; hence the concept of DVB was first introduced in 1990.

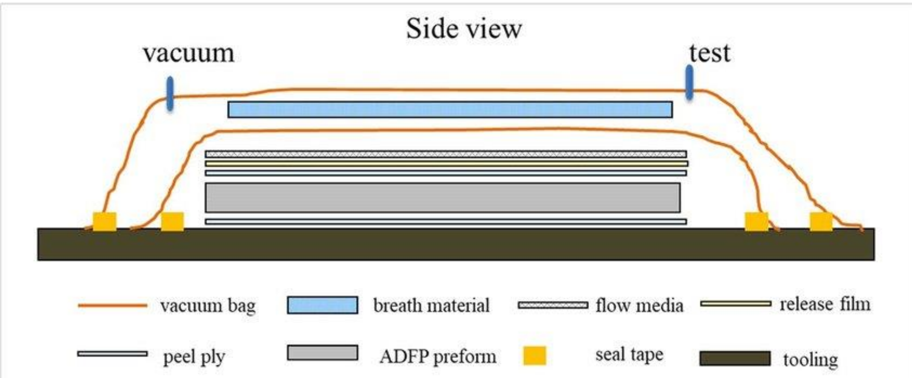

Figure 2.17: Double vacuum bagging setup (Ya-Nan Liu, 2019)

The above figure shows a simple setup of the DVB. As the name goes, DVB has two main bagging to be setup. The composite layup will be applied with appropriate amount of resin by using wet hand-layup method. The composite will then be placed in between two PTFE peel ply, topped with a metal plate, a breath material, and a bag sealed with sealant tape. Another breath material is placed on the first bagging. Next, the second bagging is placed and sealed with the sealant tape. Each bagging is connected to a vacuum pump. For a better output, the molding area should be cleaned first to avoid any sharp specimens' leftover or dirt create any holes through the bagging.

2.5 Fibre Volume Fraction

Fibre volume fraction (FVF) is a method to determine the content of fibre and strength of the composite. The simplest way to calculate the FVF of the natural fibre is by including the fibre volume over the composite volume. The formula to calculate FVF will include the thickness, mass and density of fibre. The equation is as below:

$$V_f = \frac{FAW \times n}{t \times \rho_f} \qquad \text{Equation 2.1}$$

$$t = \frac{M}{A \times \rho_c} \qquad \text{Equation 2.2}$$

Substituting Equation 2.2 into Equation 2.1 giving:

$$V_f = \frac{FAW \times A \times \rho_c \times n}{M \times \rho_f} \qquad \text{Equation 2.3}$$

Where:

V_f	Fibre volume fraction (FVF)
FAW	Fibre areal weight (for each ply)
n	Number pf plies
t	Thickness of fibre
ρ_f	Density of fibre
M	Mass of fibre
A	Surface area of fibre
ρ_c	Density of composite

The derivation of equation for FVF is as shown above. From the final equation, it can be concluded that the thickness and areal weight of fibre affects the accuracy of FVF. The other parameters will stay constant for the same set of specimens; however, the thickness will vary due to irregular surface of the specimen. An alternation equation will be implemented as shown below, where the accuracy of the FVF depends on the density of composite.

$$V_f = \frac{\rho_c - \rho_m}{\rho_f - \rho_m} \qquad \text{Equation 2.4}$$

Where:

ρ_m	Density of matrix

CHAPTER 3 : METHODOLOGY

In this chapter, the flow of the research work will be, the technique and type of mechanical testing are described. First, the materials that are used will be mentioned such as the fibre, matrix and DVB materials. Next, fibre and matrix preparation will be covered following with the DVB installation. In general, to fabricate the NFC composite, wet hand-layup method is used to apply the matrix before installing the DVB. After the fabrication process is completed, the specimens are let to be cured for 24 hours, followed by cutting the specimens based on the ASTM for each mechanical test. The test will be carried out and the results obtained are then discussed in the next chapter. The workflow of this study is shown as in figure below.

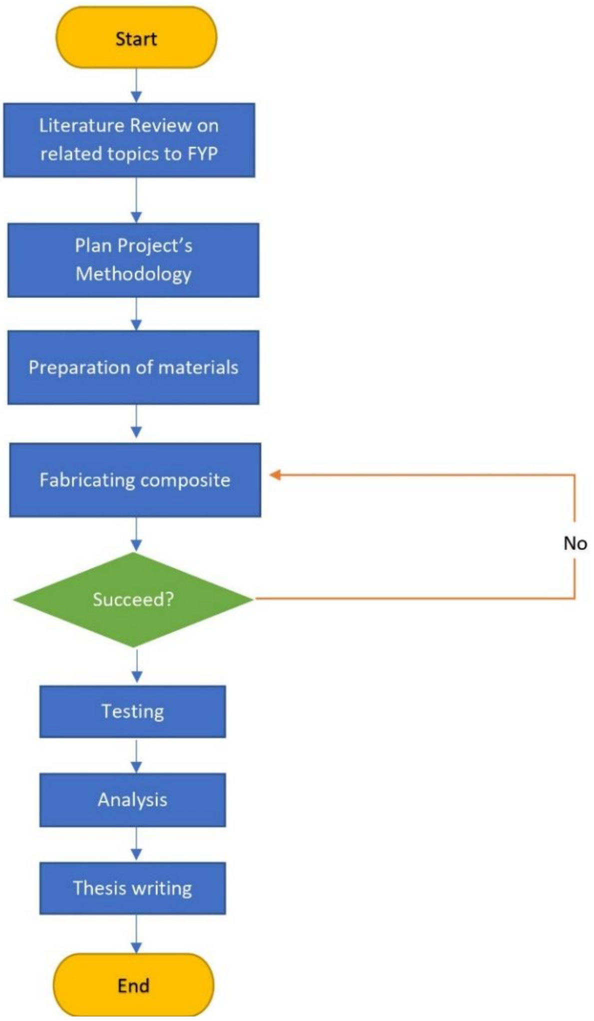

Figure 3.1: The workflow of this research work

3.1 List of material

The materials used for the fabrication process are coconut fibre, palm fibre, epoxy, harder and materials and equipment needed for DVB installation. The materials used are divided into three categories, which are the fibre, matrix and double vacuum bagging materials.

3.1.1 Fibre

The main materials used as fibre are coconut fibre and palm fibre. The natural fibres are purchased from Heng Huat Group, which a company that manufacture natural fibre located in Sungai Jawi, Penang. Based on the company website, Heng Huat company is one of the leading companies that manufacture and supply natural fibre in Malaysia. The coconut fibre is extracted from the fibrous outer cover is coconut plant, which is called coconut husk while the are still in white or brown colour. Heng Huat produces coconut fibre that has less than 3% impurities (Heng Huat Group, n.d.). Table 3.1 shows the specification of the coconut fibre.

Table 3.1: Specifications of coconut fibre

Coconut fibre Specifications	
Length	> 50mm
Moisture content	< 15 %
Impurity	< 3%
Packing	Tightly strapped bales
Quantity	1 x 49 HC (17-18 metric tons)
Density	1200 kg/m^3

Next, palm fibre is produced from the palm vascular bundle found in the EFB as mentioned in previous chapter. The palm fibre is 100% natural and biodegradable. It contains lignin that acts as a binder in compressed materials. The palm and coconut fibre are produced in large quantities and self-designed by the company's production lines (Heng Huat Group, n.d.). Table 4.2 shows the specifications of oil palm fibre.