DEVELOPMENT OF WIND TURBINE BLADES BASED ON HYBRID BIO-COMPOSITES

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June 2017

Thesis is submitted to
Universiti Sains Malaysia
As partial fulfillment of the graduate with honors degree in
BACHELOR OF ENGINEERING (AEROSPACE ENGINEERING)

DEVELOPMENT OF WIND TURBINE BLADES BASED ON HYBRID BIO-COMPOSITES

ABSTRACT

Bio-composite is a composite material that consist of matrix (resin) and a reinforcement from natural fibres. The purpose of this study is to discuss on the methods and steps to make a research on hybrid composites between glass and natural fibres. This research has lead to the fabricating process of wind turbine blades. In this project, the fabrication process of hybrid bio-composite material using natural fibres were discussed and the mechanical properties will be analysed. The use of hybrid bio-composite material to produce wind turbines are expected to reduce the manufacturing cost of the material used. The material was tested on its tensile, bending and compression properties. The results from tensile, bending, and compression testing were then tabulated and bar charts were plotted to make comparisons based on composite types (GFRP, CFRP, PFRP, CGFRP, and PGFRP). Hybridization of natural fibre composite shows a significant increase in tensile and bending properties such as specific strength and specific modulus. From compression test, the results show minor changes in compressive properties among each type of composite.

ABSTRAK

Bio-komposit adalah bahan komposit yang terdiri daripada matriks (resin) dan diperkukuh daripada gentian semula jadi. Tujuan kajian ini adalah untuk membincangkan kaedah dan langkah-langkah penyelidikan mengenai komposit hibrid antara kaca dan gentian semula jadi. Kajian ini juga akan membawa kepada proses fabrikasi bilah turbin angin. Dalam projek ini, proses fabrikasi bahan bio-komposit hibrid menggunakan gentian asli telah dibincangkan dan sifat-sifat mekanik telah dianalisis. Penggunaan bahan bio-komposit hibrid untuk menghasilkan turbin angin dijangka mengurangkan kos pembuatan bahan yang digunakan. Bahan komposit tersebut akan diuji pada tegangan, lenturan dan sifat-sifat mampatan. Keputusan daripada ujian tegangan, lenturan dan mampatan kemudiannya dijadualkan dan graf bar telah dilukis untuk membuat perbandingan berdasarkan jenis komposit (GFRP, CFRP, PFRP, CGFRP dan PGFRP). Penghibridan komposit serat semula jadi menunjukkan peningkatan yang ketara dalam sifat tegangan dan lenturan seperti kekuatan dan modulus. Daripada ujian mampatan, keputusan menunjukkan perubahan kecil dalam sifat-sifat mampatan antara setiap jenis komposit.

ACKNOWLEDGEMENTS

I wish to express my sincere gratitude to the School of Aerospace Engineering for providing the necessary facilities for the research. I am also very thankful to have a very supportive supervisor, Dr. Mohd Shukur bin Zainol Abidin who had been giving general direction and guidance for the research. Without his help and advice, the research would not achieve what was targeted. I also want to place a sincere thank you to Mr Mohd Shahar bin Che Had and Mr Hasfizan bin Hashim who have been giving technical advises on the fabrication process. Thanks also to En. Fakruruzi Fadzil, who has been guiding me throughout the tensile test, bending test and compression test. I take this opportunity to express thanks to the supervisory committee for providing precious insights and suggestions.

DECLARATION

This work has not previously been accepted in substance for any degree and is not being concurrently submitted in candidature for any degree.

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LIST OF ABBREVIATIONS

ASTM	American Society for Testing and Materials
GFRP	Glass Fibre Reinforced Polyester Composite
CFRP	Coir Fibre Reinforced Polyester Composite
PFRP	Palm Fibre Reinforced Polyester Composite
CGFRP	Coir-Glass Fibre Reinforced Polyester Composite
PGFRP	Palm-Glass Fibre Reinforced Polyester Composite
NFCs	Natural Fibre Composites
CSM	Chopped Strand Mat
RTM	Resin Transfer Molding
VARTM	Vacuum Assisted Resin Transfer Molding

NOMENCLATURE

F^{tu}	:	Ultimate tensile strength, MPa [psi],
P^{max}	:	Maximum load before failure, N [lbf],
σ_i	:	Tensile stress at *i*th data point, MPa [psi],
P_i	:	Load at *i*th data point, N [lbf],
A	:	Average cross-sectional area, mm^2 [$in.^2$],
ε_i	:	Tensile strain at *i*th data point, $\mu\varepsilon$,
δ_i	:	Extensometer displacement at *i*th data point, mm [in.],
L_g	:	Extensometer gage length, mm [in.],
E	:	Modulus of elasticity, GPa [psi].
D	:	Midspan deflection, mm [in.],
r	:	Strain, mm/mm [in./in.],
L	:	Support span, mm [in.],
d	:	Depth of beam, mm [in.],
b	:	Width of beam tested, mm [in.],
σ	:	Stress in the outer fibers at midpoint, MPa [psi],
P	:	Load at a given point on the load-deflection curve, N [lbf],
E_B	:	Modulus of elasticity in bending, MPa [psi],
m	:	Slope of the tangent to the initial straight-line portion of the load-deflection curve, N/mm [lbf/in.] of deflection

CHAPTER 1

INTRODUCTION

1.1 General overview

A wind turbine is a rotating machine which converts the kinetic energy of wind into mechanical energy or electrical power. There are two types of wind turbine which are horizontal axis wind turbine (HAWT) and vertical axis wind turbine (VAWT). The wind turbine provides clean and renewable source of energy for many countries [28]. The size of wind turbine blades can be more than 100 metres in diameter in which strong and lightweight material are required. Conventional materials used here are glass fibre-reinforced polymer (GFRP) and carbon fibre-reinforced polymer (CFRP). However, in order to make a whole wind turbine requires a substantial quantity of these materials which makes the fabrication of wind turbine to be costly. One way to reduce cost is to find a substitute material for glass and carbon fibre such as the natural fibres which are abundant and easy to obtain [11].

The demand for composite material has been increasing over the years. More industries, especially aerospace related, are searching for cheaper and higher quality material alternatives. Composite consist of two or more material constituents commonly known as reinforcing phase and a matrix. Rayon, nylon, carbon and glass fibres are common synthetic reinforcing phase [10].

Historically, natural fibres were added to plastics as fillers rather than reinforcing components [29]. The advantage of natural fibres over inorganic materials has traditionally been related with reduced cost, but other attributes include low density, high specific strength-to-weight ratio, low abrasiveness, biodegradability, and the fact that they are produced from a renewable resource [1].

Glass fibre reinforced polymers (GFRPs) are a fibre reinforced polymer made of a plastic matrix reinforced by fine fibres of glass. Fibre glass is a lightweight, strong, and robust material used in different industries due to their excellent properties. GFRP composites are largely used mainly due to a combination of low cost and good mechanical properties. Although strength properties are somewhat lower than carbon fibre and it is less stiff, the material is typically far less brittle [6]. The incorporation of natural fibre with GFRP improves the tensile, flexural and impact strength of the materials [7] and placing the GFRP layers at the ends possess good mechanical strength [8]. The strength properties of natural fibre composites are somewhat lower, because of less stiff and typically less brittle. Reinforcing glass fibre into the natural composites enhanced tensile and flexural properties without any effect on tensile and flexural module. In addition, adding natural fibre with glass fibre improves thermal properties and water resistance of the hybrid composites [9].

1.2 Motivation and problem statements

The usage of fossil fuels to harness the electrical power has caused serious impact on the environment. For years, many have tried to find and develop a clean and renewable source of energy for human consumption. One source of energy is through the harnessing the wind energy. To efficiently harvest the wind energy, a proper design and material selection for wind turbine is necessary. The criteria of an ideal material should have been abundant, readily found and easy processing to reduce cost and maintenance, high strength to weight ratio, high fatigue resistance to withstand cyclic loading, high stiffness to ensure stability of optimal shape, high fracture toughness and able to withstand environmental impacts such as rain, snow, sunlight and lightning. It is difficult to obtain a material with these criteria. In this research, the use of plant based natural fibres to produce a bio-composite able to meet the criteria will be studied. Plant based natural fibre such as coir or coconut fibre is more readily found than any other animal based natural fibre.

Tensile, flexural and compression testing be performed to analyze the mechanical properties of composite with different type of reinforcements, namely the pure E-glass fibre, pure coconut fibre, pure palm fibre, hybrid coconut and E-glass fibres, and hybrid palm and E-glass fibres. One of the hybrid bio-composite will be selected to fabricate the wind turbine blade.

1.3 Objectives of research

In this research, the objectives were as follows,

1. To investigate the combination of hybrid glass-natural fibre.
2. To identify a standard method of producing a composite material from these fibres.
3. To analyse the physical properties of the bio-composite material.
4. To design and fabricate a structural wind turbine from hybrid bio-composite material.

CHAPTER 2

LITERATURE REVIEW

2.1 Composite

A composite material is simply a combination of two or more materials which resulted in a material that has better properties than the individual material components. Composite materials are known for their high strength and stiffness as well as lightweight in comparison to metals or alloys [12]. Composites can be used to make prototypes of variety of shapes at low cost. A composite commonly comprises of reinforcement and matrix. The reinforcements are fibres or particulate. The matrix is mainly from ceramic, metal or polymer. The reinforcement mainly provides the strength and stiffness or the composite material. Usually, the reinforcement is stronger and harder than the matrix [12].

2.2 Fibre

The length of fibre is longer than its diameter where the ratio of length-to-diameter of fibre is called the aspect ratio. Continuous fibre has high aspect ratio with preferred orientation whereas discontinuous fibre has low aspect ratio with random orientation. Continuous fibres are usually unidirectional, woven cloth, or helical winding whilst discontinuous fibres are usually chopped or a random mat. Figure 1 shows the common types of reinforcements. The reason why fibres are used as reinforcement is because their smaller diameter makes them stronger [30]. This is because of lower defects on the small diameter fibre. Therefore, fibres that have smaller diameter would have higher strength. However, the cost is higher for making smaller diameter fibre. Typically, fibres are made from glass, carbon, and aramid. The types of reinforcements determine the properties of the composite. Figure 2 shows the effect of reinforcement types and quantity towards the properties of the composite material.

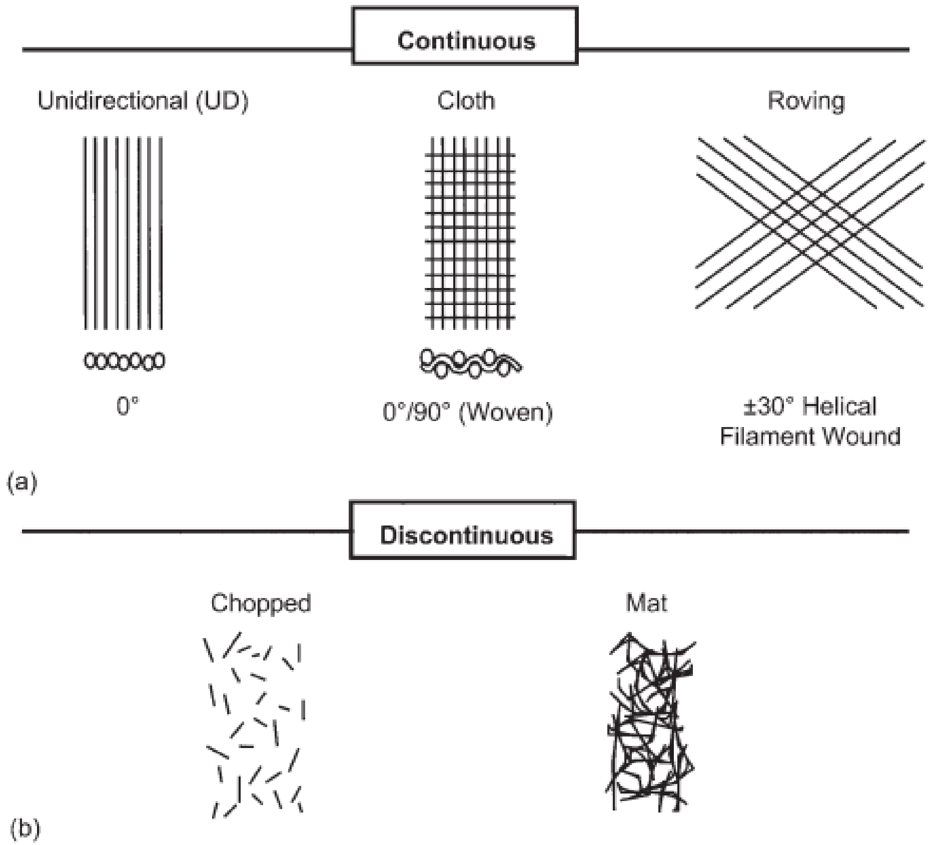


Figure 1: Continuous and discontinuous fibre [12].

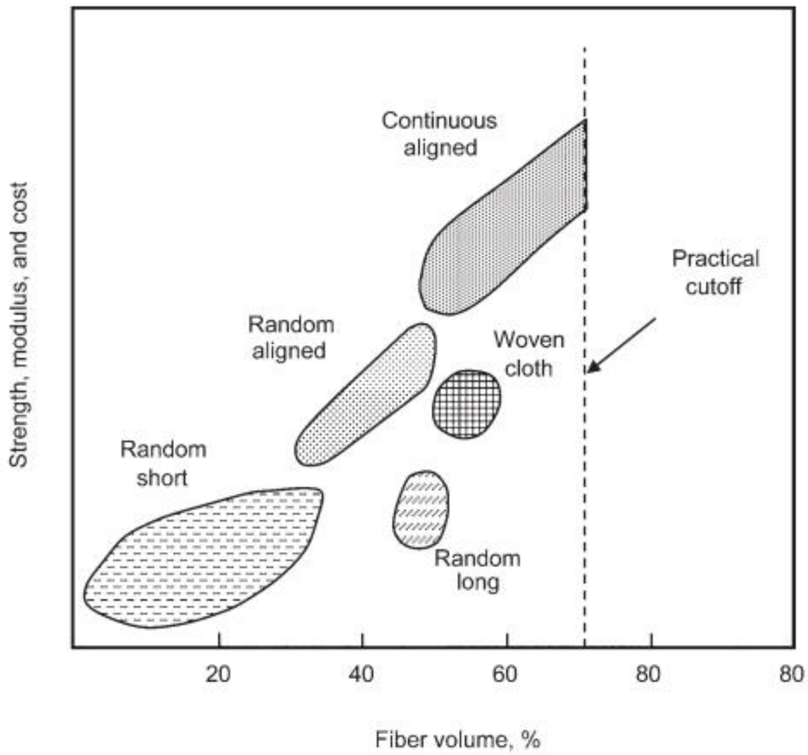


Figure 2: Effect of reinforcement types and quantity on composite performance [12]

2.3 Natural fibre

Natural fibres made of cellulose or plant matter can be extracted from nearly every part of the plant such as the leaf, root, stem or shoot, fruit and bark from different tree species. Fibre can be extracted from a leaf which is fibrous, pliable, strong and green. If the leaf can be wound around a finger without breaking, then it indicates a potential source for making fibre. Table 1 shows fibre extraction parts for various plants. [13]

Table 1: Extraction parts for natural fibre from various plants. [13]

Root	***Stem***	***Branch***	***Leaf***	***Fruit/Seed***
Khus	Bamboo *Kora* grass Jute Hemp Water hyacinth Banana *Kauna* reed Cane palm *Moonj* grass *Sarkanda* *Wagoo* reed *Sikki* grass *Cannabis/ pulla* Wicker *Bhindi* Nettle Flax *Arhar*/Pigeon pea	Willow	Palmyra Palm date Palm coconut Arecanut palm *Sisal* Banana Pineapple Screw pine	Cotton Coir Arecanut

In the recent years, there has been a growing interest in the application of natural fibres as reinforcements for polymer matrices. Natural fibre has good potential as reinforcement in thermoplastic and thermoset polymer composites mainly due to low density and high specific properties of fibres. Natural fibres have the properties, composition, structures and features that are suitable to be used as reinforcements or fillers in polymer composites [14]. Table 2 shows that mechanical properties of various natural fibres.

Table 2: Mechanical properties of various natural fibres [16]

	Density (g/cm^3)	Elongation(%)	Tensile strength(MPa)	Young's modulus
Cotton	1.5-1.6	7-8	287-597	5.5-12.6
Jute	1.3	1.5-1.8	393-773	26.6
Flax	1.5	2.7-3.2	345-1035	27.6
Hemp		1.6	690	
Ramie		3.6-3.8	400-938	61.4-128
Sisal	1.5	2.0-2.5	511-635	9.4-22
Coir		30	175	4-6.02
Viscose(cord)		11.4	593	11
Soft wood craft			1000	40
Kenaf		1.5	930	53
Nettle		1.7	650	38
Abaca			430-760	
Oil palm	0.7-1.55	3.2	248	25
Pineapple		2.4	170-1627	60-82
Banana		3	529-914	27-32
Wool		25-35	120-174	2.3-3.4
Spider silk		17-18	875-972	11-13
Twisted & mori silk	1.33	20.57	156.27	3.82
Tussah silk	1.32	33.48	248.77	5.79
E-glass	2.5	2.5	2000-3500	70
Aramid	1.4	3.3-3.7	3000-3150	63-67
Carbon	1.4	1.4-1.8	4000	230-240

2.3.1 Advantages of natural fibres

Compared to conventional reinforcing fibres like glass, carbon and Kevlar, natural fibres have the following advantages [14]:

- Environmentally friendly
- Fully biodegradable
- Non-toxic
- Easy to handle
- Non-abrasive during processing and use
- Low density/light weight
- Compostable
- Source of income for rural/agricultural community
- Renewable, abundant and continuous supply of raw materials
- Low cost

- Free from health hazard (cause no skin irritations)
- Acceptable specific strength properties
- Reduced tool wear
- Reduced dermal and respiratory irritation
- The abrasive nature of natural fibres is much lower compared to that of glass fibres, which offers advantages on processing techniques and recycling [15].

2.3.2 Disadvantages of natural fibre

Nevertheless, natural fibre suffered from the following setbacks [14]:

- Bad compatibility with hydrophobic polymer matrix
- The fibres degrade after being stored for a long time
- High moisture absorption
- Form aggregates during processing [15]
- Low resistance to moisture [15]
- Low thermal stability
- Hygroscopic.

2.4 Polymer matrix

Polymer matrix composites (PMC) are very popular due to their low cost and easy fabrication methods. Use of non-reinforced polymers as structure materials is limited by their low mechanical properties, namely strength, modulus, and impact resistance. Reinforcement of polymers by strong fibrous network allows fabrication of PMCs is characterized in the following [17]:

- High specific strength
- High specific stiffness
- High fracture resistance
- Good abrasion resistance
- Good impact resistance
- Good corrosion resistance
- Good fatigue resistance
- low thermal resistance and
- high coefficient of thermal expansion.

Properties of various polymers will determine the application to which it is suitable. The main advantages of polymers matrix are low cost, easy fabrication, better chemical resistance, and low specific gravity. On the other hand, low strength, low modulus, and low operating temperatures restrain their use [18]. Varieties of polymers for composites are thermoplastic polymers, thermosetting polymers, and elastomers [17].

2.4.1 Types of polymer matrix

Thermoplastics comprises of linear or branched chain molecules that have strong intramolecular bonds but weak intermolecular bonds. They can be reshaped by applying heat and pressure and are either semi-crystalline or amorphous in structure. For example, polyethylene, polypropylene, polystyrene, nylons, polycarbonate, polyacetals, polyamide-imides, polyether ether ketone, polysulfone, polyphenylene sulfide, polyether imide, and so on. Thermosetting polymers have cross-linked structures with covalent bonds on all molecules. They do not soften but decompose on heating. Once solidified by cross-linking process they cannot be reshaped. Common examples are epoxies, polyesters, phenolics, ureas, melamine, silicone, and polyimides. An elastomer is a polymer with viscoelasticity property, generally having considerably low Young's modulus but high yield strain when compared to other materials. Each of the monomers that link to form the polymer is usually made of carbon, hydrogen, oxygen, and silicon. Elastomers are amorphous polymers that exist above their glass transition temperature, so that considerable segmental motion is possible. At ambient temperatures, rubbers are relatively soft and can be deformed. Their main uses are for seals, adhesives, and molded flexible parts. Natural rubber, synthetic polyisoprene, ethylene propylene rubber, epichlorohydrin rubber, silicone rubber, thermoplastic elastomers, polybutadiene, chloroprene rubber, butyl rubber, polysulfide rubber, and so on are some of the examples of elastomers [17].

2.5 Fabrication methods

2.5.1 Compression molding

Compression molding is one of the well-known method used to fabricate various shapes of composite. It involves high pressure to compress few matched metal molds to form desired shapes as shown in Figure 3. The reinforcement and matrix is both placed in a metallic mold. Pressure is applied on the compression molder for a certain period. Curing of the composite can be done either at room temperature or at some elevated temperature. After curing, the mold is opened and composite product is removed for further processing [19].

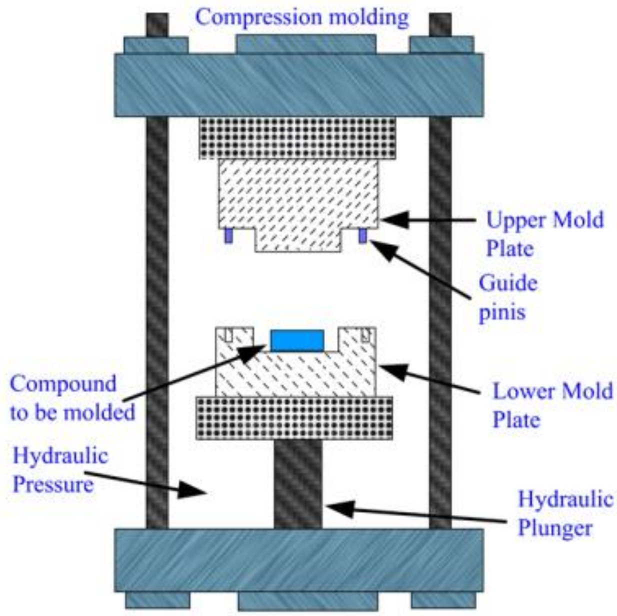


Figure 3: Compression molding set-up [19].

2.5.2 Vacuum bagging

The vacuum bagging molding process uses a flexible and transparent film to fully enclose and compact the wet laminate by utilizing atmospheric pressure. This process uses a vacuum and pump to suck the air out from inside the vacuum bag and compress the part under atmospheric pressure so that the compacting and hardening process take place [2]. Vacuum bagging is an enhanced version of the wet lay-up process and is widely spread in the composite industry because of its clear benefits over this method. Fibreglass, carbon fiber and resin materials being laminated together using the vacuum bag technique are often used. The outer atmospheric pressure caused through the vacuum within the closed system will compress the laminate and excess resin is pumped out of the wet laminate into the bleeder cloth and resin catch pot [21]. Figure 4 shows the vacuum bagging process.

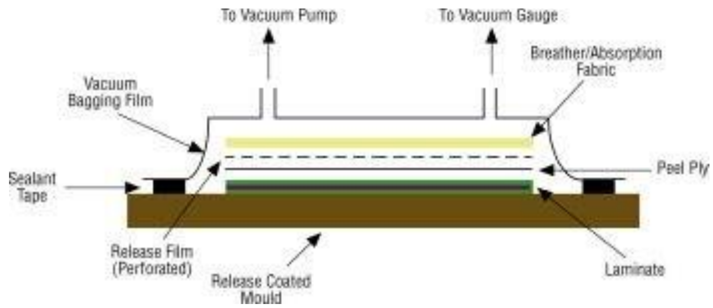


Figure 4: Vacuum bagging process [21]

2.6 Palm/coir based polyester composites

Polymer composites in form of plates were fabricated on pure polyester resin with alkali treated natural fibers as reinforcements under random orientation. For experimentation two set of plates were prepared, one plate with palm fruit fibers and other with coir fibers as reinforcements. The composite plates were made by conventional compression moulding technique. After that these composites were cut using a saw cutter to get the required dimension as per ASTMD specimen standard for testing polymer composites. The tensile test specimens were prepared according to ASTMD 638. For testing the specimen was mounted in the grips of the Instron universal tester with 10 mm gauge length. The stress strain curves w plotted during the test for the determination of ultimate tensile strength and elastic modulus. From the stress-strain curve, a straight line was drawn and from the slope of the line the Young's modulus or elastic modulus was determined. Average of two tests results was taken. The flexural test specimens were prepared according to ASTM D 790. Flexural properties were measured by conducting the three-point bend test on computerized UTM using special attachment. The speed of test was set as 2mm/min at room temperature [22]. Figure 5,Figure 6, and Figure 7 shows the comparison results on percentage elongation, ultimate stress and flexural strength.

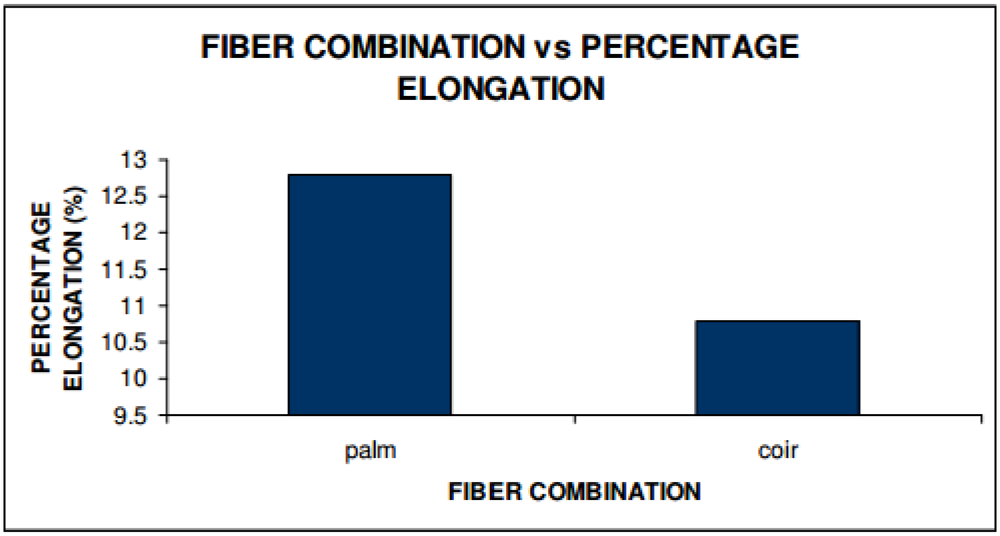


Figure 5: Comparison of effect of fiber combination on percentage elongation [22]

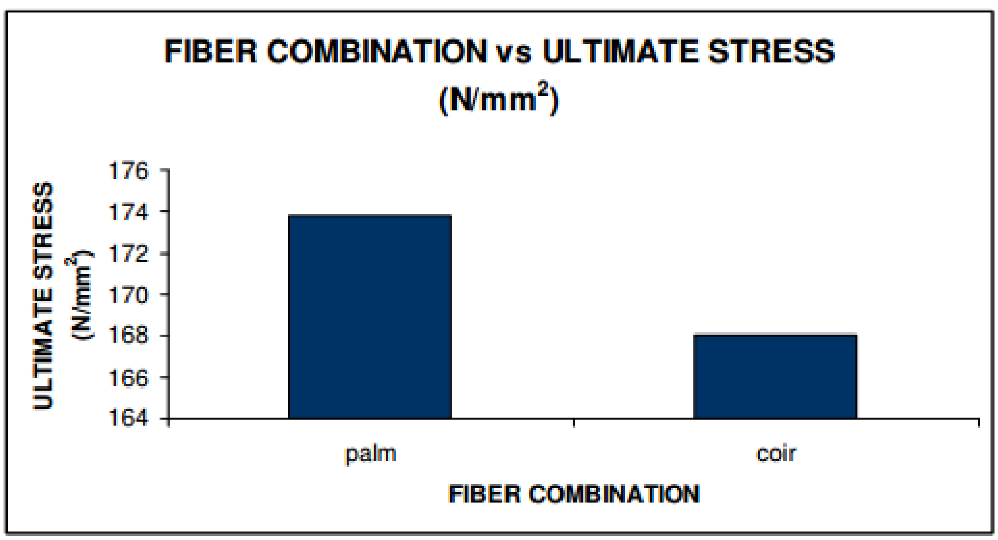


Figure 6: Comparison of effect of fiber combination on ultimate stress [22].

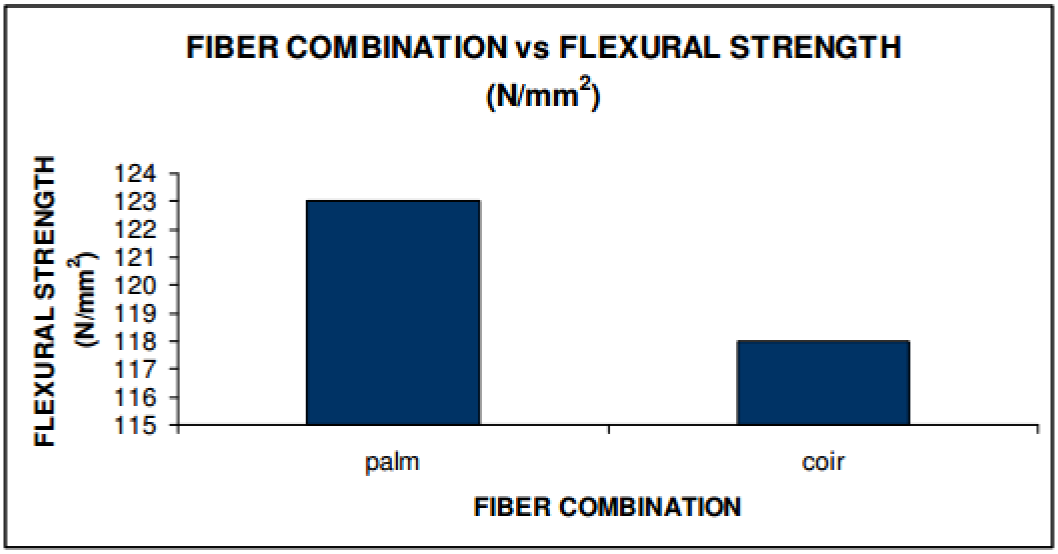


Figure 7: Comparison of effect of fiber combination on flexural strength [22].

2.7 Hybrid composites from coir fibres reinforced with woven glass fabric.

Coir nonwoven mats were used as a core material for sandwich composites. Glass fiber woven roving was used as a skin layers. Woven glass fiber mats were used as a skin material due to their low WA, high stiffness, and high strength to weight ratio [23]. Figure 8 shows the arrangement of coir and glass mat samples to be tested. Table 3 shows that tensile properties of coir and glass hybrid composite whereas Figure 9 shows the flexural properties.

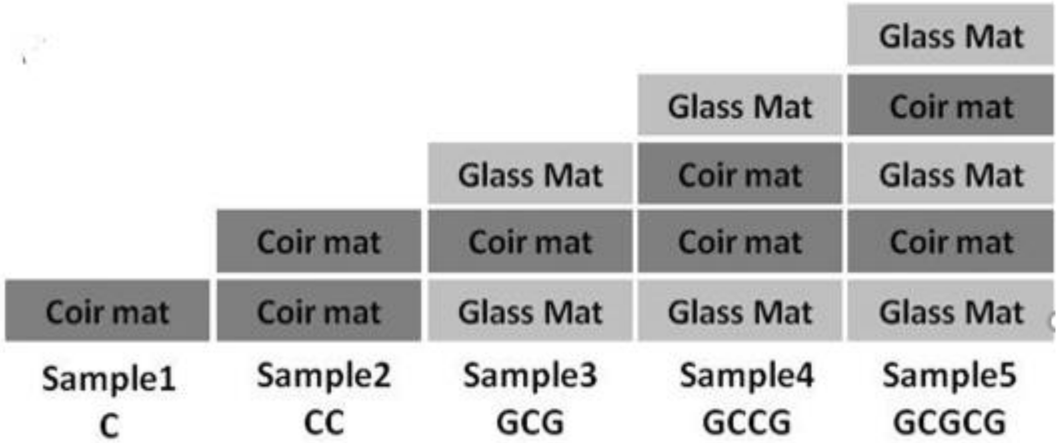


Figure 8: Coir/glass mat arrangement [23].

Table 3: Tensile properties of sample [23].

Samples	Thickness (mm)	Break Load (kN)	Displn cement (mm)	Percent Elongation (%)	Tensile Strength (MPa)
C	3.7	0.239	0,130	0.261	4.2
CC	7.8	0.862	0.170	0.340	8.2
GCG	5 2	4.279	0.634	1.268	69.2
GCCG	8.4	4.973	0.592	1.185	43.3
GCGCG	8.9	10.701	0.661	1.322	70.0

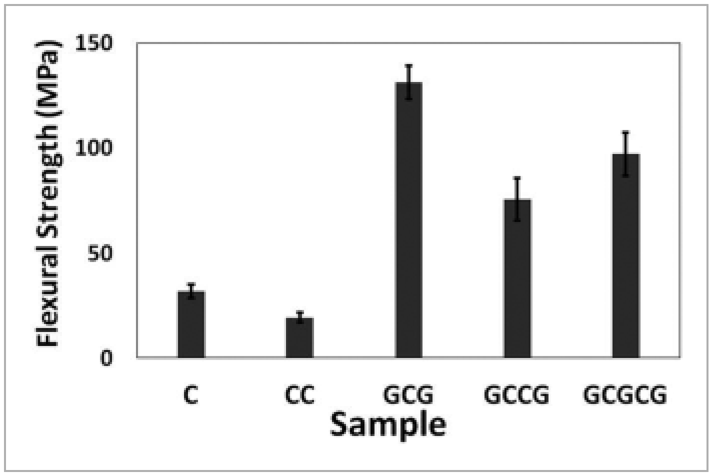


Figure 9: Flexural strength along coir/glass composite [23].

2.3 Characterization

2.3.1 Tensile test

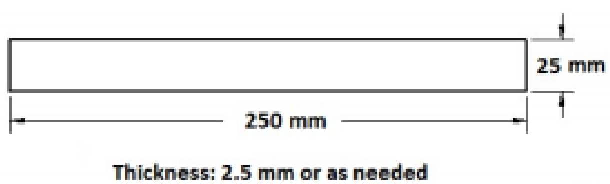


Figure 10: Tensile test specimen [3].

Tensile properties such as tensile modulus, tensile strength, and strain at failure of composite laminates were determined according to ASTM D3039 (2008). An extensometer (Instron 2630-100 series clip on type) was used for the displacement measurement with a constant cross head speed of 2 mm/min. A total of 5 specimens were tested.

2.3.2 Compression test

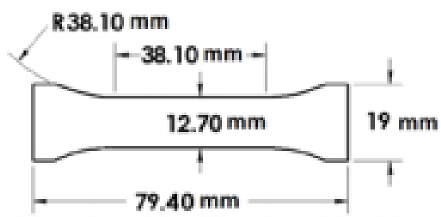


Figure 11: Compression test specimen [3].

Properties in compression were determined by static compression tests according to with ASTM D695 (1996). Loading of the specimen was applied as a constant displacement control of 1.3 mm/min. A strain gage wass placed in the centre of the specimen to measure the strains during testing. A total of 5 specimens were tested.

2.3.3 Flexural test

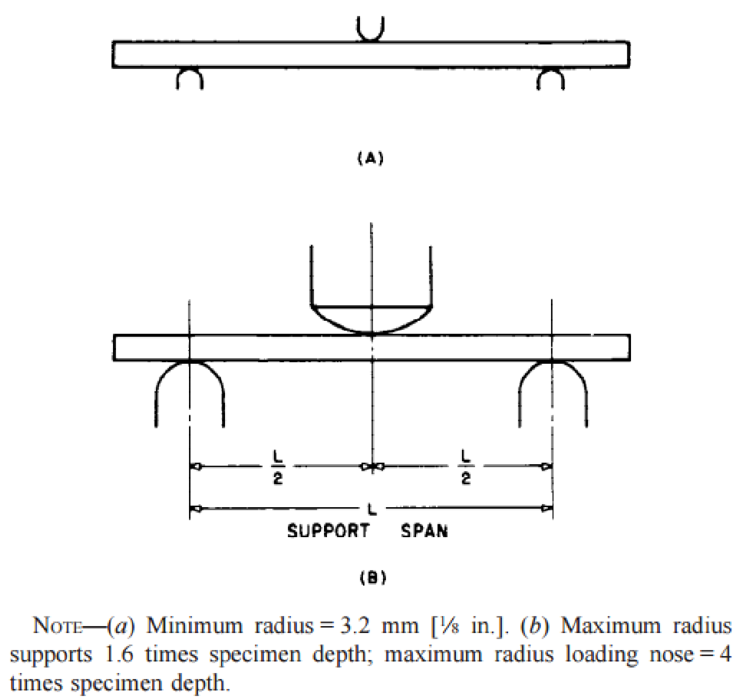


Figure 12: Allowable range of loading nose and support radii [4]

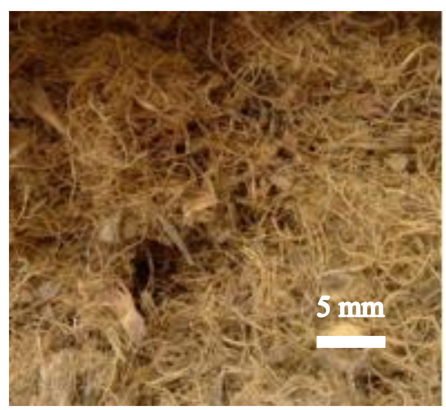
For each composite, flexural testing was performed on five normalized specimens according to ASTM D790-03.23 The flexural tests were conducted using an Instron model 8821S (Instron, USA) universal testing machine equipped with a homemade system. The crosshead speed was set at 2 mm/min. The flexural properties reported are the average of five samples.

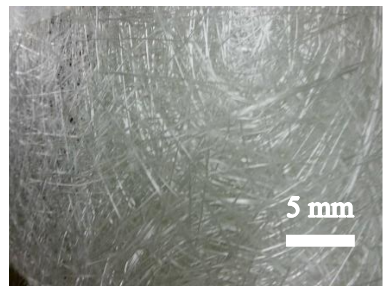
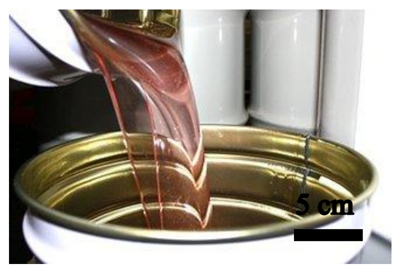
CHAPTER 3

METHODOLOGY

3.1 Material

The reinforcements used for the research are coir, palm and Chopped Strand Mat (CSM) E-glass fibres. The density of coir, palm and CSM E-glass fibres are 1.2gcm^{-3}, 1.0 gcm^{-3}, and 2.5gcm^{-3} respectively. CSM E-glass is chosen to help in making comparison on the mechanical properties of pure coir, pure palm, pure E-glass, hybrid coir-glass and hybrid palm-glass composites. The random distribution and alignment of fibres in CSM E-glass are similar to natural fibres. As such, CSM E-glass is the most suitable baseline material.

Materials	Figure
Oil Palm Fibre	

Coir Fibre	
CSM Glass Fibre	
Polyester Resin	
Luperox DDM-F Polyester Hardener	

Pigment (Orange, Red, and Black)	
Plaster Cement	
Polycor GP-H Gel Coat	

3.2 Fabrication process of composite specimen

3.2.1 Natural fibre preparation

Both raw coir and raw oil palm fibre contains dusts and particles. The dusts and particles would later affect the mechanical properties of the composite material produced. Therefore, the dusts and particles must be rid of manually. Figure 13 shows the dusts and particles being manually separated from the fibre.

Figure 13: Manual separation of dust and particle from natural fibre

The natural fibre may contain moisture which would hinders the curing process of polyester resin. Hence, fibres that had been cleaned were placed in the oven for 5 hours at 55 °C. Figure 14 shows the natural fibres placed in the oven.

Figure 14: Natural fibres placed in the oven for 5 hours at 55 °C.

3.2.2 Natural fibre sheets making

The dimension of the metal mold used for compression molding is 160 mm × 160 mm × 3 mm. 30% of fibre and 70% of polyester resin will be used for the composite sample. Calculations were made to find the mass of polyester, coir fibre, oil palm fibre and glass fibre for each composite specimen: glass fibre reinforced polyester composite (GFRP), coir fibre reinforced polyester composite (CFRP), oil palm fibre reinforced polyester composite (PFRP), hybrid coir-glass fibre reinforced polyester composite (CGFRP) and hybrid oil palm-glass fibre polyester composite (PGFRP).

Calculations:

Volume of composite = 160 mm × 160 mm × 3 mm

= 76800 mm^3

Volume of polyester = 76800 mm^3 × 0.7

= 53760 mm^3

Mass of polyester = 53760 mm^3 × 1.39 g/cm^3 ÷ 1000