DEVELOPMENT OF CRASH RESISTANCE CAR BUMPERS BASED ON BIO-COMPOSITES AND HYBRIDS

by

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ABSTRACT

Generally, composite material is a material made from two or more constituent materials of different properties. Composite materials are highly utilized in the current era due to their tailored specified properties, such as high strength-to-weight, corrosion resistance, inflammable properties, wear resistance and etc. In this study, mechanical properties of bio composite materials, such as coir, and palm oil fibre, are to be analysed and evaluated thoroughly. Fabrication methods, such as compression moulding and resin film infusion method were used to manufacture the specimens for the test and analysis. Impact test, tensile test, and compression test were carried out simultaneously during analysis and evaluation process. The results from tensile, compression and impact testing were tabulated and plotted into graphs for analysis. Bar charts which include specific mechanical properties were plotted to compare the properties of the composites (GFRC, HPRC, HCRC, PFRC, CFRC). Moreover, hybridization of natural fibre has shown significant increase in tensile and impact testing, whereas for compression testing, no significant change was identified. Eventually, a crash resistance car bumper will be developed based on these bio composite and hybrids.

ABSTRAK

Secara umumnya, bahan komposit adalah bahan yang terdiri daripada dua atau lebih bahan konstituen dengan sifat yang berbeza. Bahan komposit kerap digunakan dalam era semasa kerana memiliki sifat-sifat yang amat berguna, seperti rasio kekuatan-berat yang tinggi, rintangan kakisan, sifat mudah terbakar, tahan lasak dan lain-lain. Dalam kajian ini, sifat-sifat mekanikal yang dimiliki oleh bahan komposit bio, seperti sabut , dan serat kelapa sawit, telah dianalisis dan dinilai dengan teliti. Kaedah fabrikasi, seperti acuan mampatan dan kaedah pemindahan resin telah digunakan untuk menghasilkan spesimen untuk ujian dan analisis. Ujian impak, ujian tegangan dan ujian mampatan telah dijalankan semasa analisis dan penilaian proses. Keputusan daripada tegangan, mampatan dan impak telah dikaji dan diplot sebagai graf untuk analisis. Carta bar yang mengandungi sifat-sifat spesifik mekanikal telah diplotkan untuk dibandingkan antara GFRC, HPRC, HCRC, PFRC, CFRC. Selain itu, hibridisasi serat semula jadi telah menunjukkan peningkatan yang ketara dalam ujian tegangan dan impak, manakala bagi ujian mampatan, tiada perubahan ketara telah dikenalpasti. Akhirnya, bumper kereta telah dihasilkan berdasarkan kepada komposit bio and komposit hibrid.

ACKNOWLEDGEMENTS

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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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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

ASTM	American Society for Testing and Materials
GFRC	Glass Fibre Reinforced Composite
CFRC	Coir Fibre Reinforced Composite
PFRC	Palm Fibre Reinforced Composite
HCRC	Hybrid Coir Fibre Reinforced Composite
HPRC	Hybrid Palm Fibre Reinforced Composite

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

Composite materials in brief are combination of two of more materials of different properties. They are the most widely use materials in the current society due to its vast range of properties [1]. Basically, composite materials are known for their high strength and stiffness, combined with low density. Composite materials are commonly divided into several phases; reinforcing phase provides the strength and stiffness, usually harder, stronger and stiffer than the matrix. Reinforcement is usually in the form of fibre or particulate. In this study, coir, cotton, and palm oil which are easily available in Malaysia were used due to its low cost, as well as its superior mechanical properties such as flexibility, stiffness and modulus compared to glass fibre[1]. However, natural fibres do possess some disadvantages, like poor resistance towards moisture.

In brief, conventional material means the most usually used material. For example, slate is a conventional material for roofing, wool is a conventional material for clothing. However, conventional material is known for posing several disadvantages, especially in material handling. Conventional material is known to be very soft and easily broken. Due to these disadvantages, composite material is designed to meet specific requirements of a particulate object.

Increasing environmental concerns has led to more attention and focus on development of bio-composite. The great potential for using natural fibre reinforced composite lies in their eco-friendliness and wide potential applications for automotive, mobile phone and biomedical industries. Natural fibres such as jute, sisal, coir, hemps, as well as banana and pineapple leaves are generally extracted from renewable sources, fully biodegradable, non-toxic, and can be easily recycled to reduce the materials' carbon footprint[2]. With this, we are able to create a sustainable environment.

Usually, hybrid material is a combination of organic and inorganic material. Current example of natural hybrid composites are crustacean carapaces, mollusc shell, diatoms, and etc. The benefits of using hybrid materials include higher flexibility and mechanical strength, a greater temperature range of usability, increased durability, magnetic or redox properties, as well as complex multifunctional domains within the same material[3].

The front and rear of a vehicle should be protected in such a way that a low speed collision should only cause a little damage. For this purpose, car bumpers were invented. In general, car bumpers are used basically to absorb impact during collision, at the same time to minimize the repair cost. Moreover, another function of bumpers is to mitigate injury incurred on pedestrians during impact. Therefore, bumpers are made of flexible material instead of material of high hardness properties. Examples of materials used are foam, plastic, cushion etc. The concept of hybridization has provided much flexibility in tailoring the most suitable composite material to suffice these requirements.

1.2 Motivation and Problem Statements

Car bumpers are designed to sustain impact force and damage. This project will explore the viability of using natural fibre as the replacements for commercially available glass reinforced composites. Majority of modern plastic car bumpers today are made of thermoplastic olefins (TPOs), polycarbonates, polyesters, polypropylene, polyurethanes, polyamides, or blends of these with, glass fibre, for strength and rigidity[4].Therefore, it would be much convenient if bio-composite materials or hybrids are able to surpass the current existing material, eventually providing a better choice for car bumpers manufacturer.

In this thesis, 3 types of testing which are tensile, compression and impact will be performed to analyse the mechanical properties of 5 types of specimens, which are hybrid coir (E-glass + Coir), hybrid palm (E-glass + Palm), pure coir (Polyester + Coir), pure palm (Polyester + Palm) and pure E-glass. Eventually, the most suitable specimen will be selected in the fabrication process of a car bumper.

1.3 Objectives of Research

The research work described in this thesis is performed based on the following objectives:

(i) To fabricate specimen of bio-composites using coir and palm oil for testing purpose.

(ii) To perform tensile, compression, impact, and bending tests on specimens.

(iii) To study and analyse the mechanical properties of coir, palm oil reinforced composite material, as well as identifying the most suitable material for crash resistance bumper

(iv) To fabricate a car bumper based on bio-composites or hybrids

1.4 Thesis Layout

This thesis comprises 6 chapters. Chapter 1 gives a general overview of the definition of composites, bio-composites, and hybrid composite. The functions of car bumpers are discussed as well. Then, the motivation of this project, which is to create a more sustainable environment by replacing plastics with the vast resources of natural fibre, such as coir fibre, palm fibre or even coir. Finally, the objectives of the research are defined.

Chapter 2 reviews all literatures related to this work. The focus is on the fabrication and characterization methodology. Chapter 3 briefly describes all the fundamental theories involved in analysing the properties of the specimens as well as the fabrication and characterization procedures.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction to composite material

In brief, composite material is a combination of two or more materials into another material with better properties. The main advantages of composite materials are their high strength and stiffness, combined with low density, when compared with bulk materials, allowing for a weight reduction in finished part. The reinforcement is usually a fibre or a particulate. Particulate composites tend be much weaker and less stiff than continuous fibre composites, however they are usually less expensive. Continuous fibres have long aspect ratios, which discontinuous fibres have short aspect ratio. Long aspect ratios imply a preferred orientation, whereas short aspect ratio has random orientation. Continuous fibres are often made into laminates by stacking single sheets of continuous fibres in different orientation to obtain desired strength and stiffness properties with fibre volumes as high as 70 percent [1].

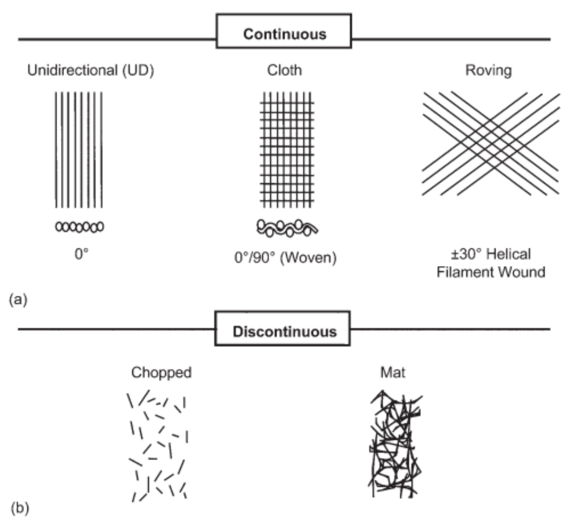


Figure 2. 1: Continuous and discontinuous fibre [1]

Materials can be classified into isotropic or anisotropic. Isotropic is a material having similar properties in all directions. For this type of material, normal loads create only normal strains. For example, aluminium and steel. Anisotropic is a material having no plane of symmetry. Composite materials that do not align with fibre direction belongs to this group. For this type of material, normal loads create both normal strains and shear strains. In short, a material is isotropic if it the properties are independent of direction within the material. For anisotropic material, it has properties very in direction. For example, the moduli are different in each direction ($E0° \neq E45° \neq E90°$).

2.1.1 Natural Fibre

Natural fibre is defined as fibrous plant material produced as a result of photosynthesis. These fibres are sometimes referred to as vegetable, biomass, photomass, phytomass, agromass, or photosynthetic fibres. Another general term would be lignin and cellulose containing fibre. Natural fibres also include hair, feather, wool, and silk fibres [5].

The use of composite materials dates from centuries ago, and it all started with natural fibres. Natural fibres are known for having lower durability and lower strength than glass fibres. However, recently developed fibre treatments have improved these properties considerably [6].

Advantages of natural fibres [6]:

- Low specific weight, which results in a higher specific strength and stiffness than glass. This is a benefit especially in parts designed for bending stiffness.
- It is a renewable resource, the production requires little energy, CO_2 is used while oxygen is given back to the environment.

- Producible with low investment at low cost, which makes the material an interesting product for low-wage countries.
- Friendly processing, no wear of tooling, no skin irritation
- Thermal recycling is possible, where glass causes problems in combustion furnaces.
- Good thermal and acoustic insulating properties

Disadvantages of natural fibres [6]:

- Lower strength properties, particularly its impact strength
- Variable quality, depending on unpredictable influences such as weather.
- Moisture absorption, which causes swelling of the fibres
- Restricted maximum processing temperature.
- Lower durability, fibre treatments can improve this considerably.
- Poor fire resistance
- Price can fluctuate by harvest results or agricultural politics

2.1.2 Matrix

A fibre-reinforced composite (FRC) is a high-performance composite material made up of 3 components – the fibres as the discontinuous or dispersed phase, the matrix acts as the continuous phase, and the fine interphase region of the interface. The matrix is basically a homogeneous and monolithic material in which a fibre system of a composite is embedded. It is completely continuous. The matrix provides a medium for binding and holding reinforcements together into a solid. It offers protection to the reinforcements from environmental damage, serves to transfer load, and provides finish, texture, color, durability and functionality [7].

There are 3 types of composite matrix materials: Ceramic matrix composites, which consist of ceramic fibre embedded in a ceramic matrix. Metal matrix composites are composite materials that contain at least 2 constituent parts, a metal and another material of another metal. The metal matrix is reinforced with the other material to improve strength and wear. Polymer matrix composites can be divided into 3 subtypes, namely, thermoset, thermoplastic, and rubber. Polymer is a large molecule composed of repeating structural units connected by covalent chemical bonds.

2.2 Fabrication process

2.2.1 Manufacturing of compression moulded PLA based bio-composite [8]

In this paper, bio-composites were manufactured using jute, cotton and flax fibres as reinforcement of PLA matrix applying compression moulding method. Compression moulding method is schematically shown in Figure 4.2.1 below. First, the PLA pellets are placed between two thermos-heated plates at temperature of 185℃. A universal test machine Servosis ME -404/100 +PCD -1065 with a limit load of 900kN was used to apply 2MPa pressure. A 0.5mm thickness uniform film is obtained.

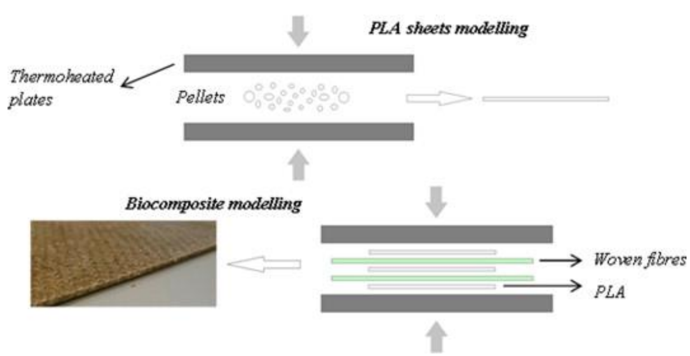


Figure 2. 2: Scheme of compression moulding process [8]

Then, the matrix films are stacked alternatively with woven piles. The stacked piles are placed between thermos-heated plates. After pre-heating, pressure was applied using same universal test machine[8].

2.2.2 Bond characterization of adhesively bonded joints made with the resin infusion (RI) process [9]

In a resin infusion process, the sample should be cleaned to avoid and deficiency inside the bond between substrate and the fibre reinforced polymer (FRP) plates. The dry plate preform is placed on the mould and fixed by applying the spray adhesive. Subsequently, the peel ply and flow medium are placed on the plates. The flow medium is used to aid the resin to distribute all over the bond area. To take off the disposable parts, a peel ply layer is arranged between the flow medium and vacuum bag. Then, the whole system is covered by a specific plastic bag in order to produce vacuum condition. The vacuum bag can be sealed around with vacuum sealant tapes. The inlet and outlet tubes are located at the start and at the end point of the mould to supply resin and remove the air. Inlet tube is attached to resin house, while the outlet tube is attached to vacuum hose, as shown in Figure 4.2.2.

The vacuum pulls the resin down through the flow medium, plate preform and the interface between the FRP and the mould (substrate). Therefore, the epoxy can saturate the dry fibres and bond them together as well as to the substrate. When the resin covers all the area, the inlet tube (resin supply) is closed and the bonded area is kept under the vacuum condition until the resin is cured under ambient temperature. The excessive resin is trapped in a resin trap tank before it flows to the vacuum pump.

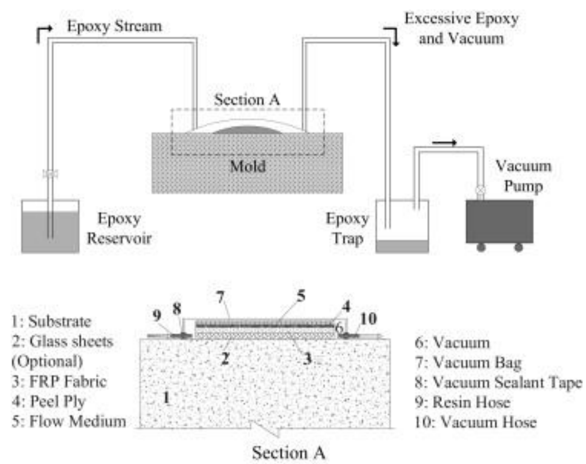


Figure 2. 3: Scheme of resin infusion process [9]

The presence of the vacuum minimizes the formation of dry spot areas on the cured FRP which leads to higher quality of the composite. Therefore, the vacuum pressure has an important role on the performance of the RI system. Although 78—98 kPa pressure is reasonable to produce the vacuum, it depends on the substrate porosity, higher vacuum pressure is necessary. If sufficient pressure is not used, the composite may be of low fibre volume fraction with some unsaturated spots on the plates[9].

2.3 Characterization

2.3.1 Tensile test - Tensile testing composite ASTM D3039 [10]

ASTM D3039 is used to measure the force necessary to break a polymer composite specimen. Tensile tests produce a stress-strain graph, which is used to determine the tensile modulus. Moreover, it is recommended to test specimens at temperature that simulate the intended end use environment [10].

Specimens are placed in the grips of a Universal Test Machine at a specified grip separation and pulled until failure. The test speed however can be determined by the material specification or time to failure (1 to 10 minutes). A typical test speed is 2 mm/min. An extensometer or strain gauge is used to determine elongation and tensile modulus [10].

The most common specimen is a constant rectangular cross section with 25mm in width × 250mm in length.

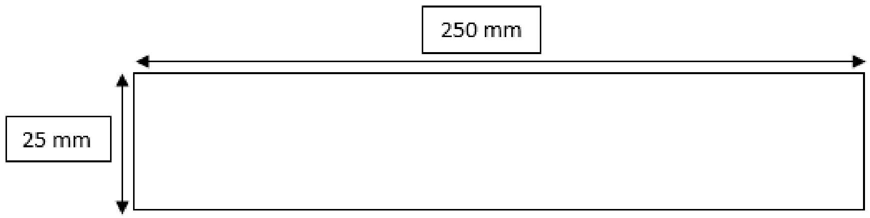


Figure 2. 4: Tensile test specimen

2.3.2 Compression Test - Compression Properties ASTM D695, ISO 604 [11]

ASTM D695 is used to measure compressive properties of a material. Compressive properties can be described as the behaviour of a material when it is subjected to a compressive load. For compression testing, loading is at a relatively low and uniform rate. Compressive strength and modulus are the common values generated by the test.

The specimen is placed between compressive plates parallel to the surface. The specimen is then compressed at a uniform rate. The maximum load is recorded along with stress-strain data [11].

Specimens can be either blocks or cylinders. For ASTM, the typical blocks are as shown in Figure 2.5 [12]. For compression testing, 2 sets of specimens are prepared: one with gauge length of 38 mm and another with gauge length of 10 mm.

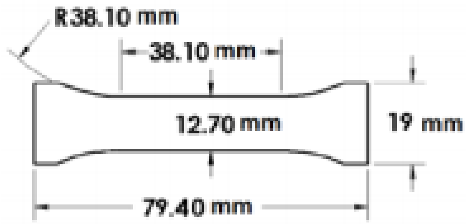


Figure 2. 5: Compression test specimen [12]

2.3.3 Impact test - Izod Impact (Notched) ASTM D256, ISO 180

Izod impact test is a single point test that measures a material's impact resistance from a swinging pendulum. Izod impact is defined as the kinetic energy required to initiate a fracture and continue the fracture until the specimen is broken. This test is usually used for quick quality control check to determine if a material meets specific impact properties [13].

The specimen is clamped into the pendulum impact test fixture with the notched side facing the striking edge of the pendulum. The pendulum is released and allowed to strike through the specimen. If breakage does not occur, a heavier hammer is used until failure occurs [13].

Specimen size during impact testing is as follows:

Standard ASTM size: 64 x 12.7 x 3.2 mm

Preferred thickness: 6.4 mm instead of 3.2 mm because it is less likely to bend or crush.

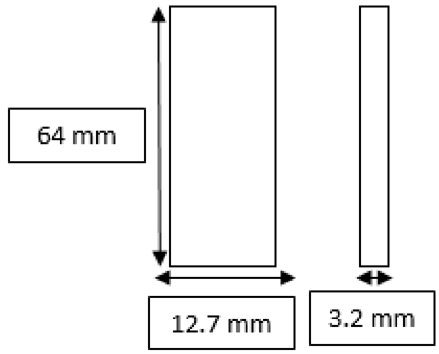


Figure 2. 6: Impact test specimen size

2.3.4 Thermal, mechanical, and physical properties of seaweed/sugar palm fibre reinforced thermoplastic sugar palm Starch/Agar hybrid composites [14]

The aim of this research is to identify the effect of sugar palm fibre (SPF) on the mechanical, thermal, and physical properties of seaweed/thermoplastic sugar palm starch agar composite. Obtained results indicated that the hybrid composites display improved tensile and flexural properties accompanied with lower impact resistance. The highest tensile (17.74 MPa) and flexural strength (31.24 MPa) was obtained from hybrid composite with 50:50 ratio of seaweed/SPF [14].

Density

Density determination balance (XS205 Mettler Toledo) was used to measure the density of materials. Five measurements were conducted at 27 °C and the average value was computed [14].

Tensile Testing

Tensile tests were conducted according to ASTM D-638 at the temperature of 23 ± 1 °C and relative humidity of 50 ± 5%. The tests were carried out on five replications using a Universal Testing Machine (INSTRON 5556) with a 5 kN load cell; the crosshead speed was maintained at 5 mm/min [14].

Impact Testing

Izod impact tests were conducted according to ASTM D256 at a temperature of 23 ± 1 °C and relative humidity of 50 ± 5%. The unnotched samples were prepared with dimensions of 60 mm (L) x 13 mm (W) x 3 mm (T). The tests were performed on five replications using a digital INSTRON CEAST 9050 pendulum impact tester. The impact strength was calculated based on the impact energy and cross section area of the specimen as shown in equation below:

$$\text{Impact strength} = \text{Impact energy (J)/area (mm}^2\text{)}$$

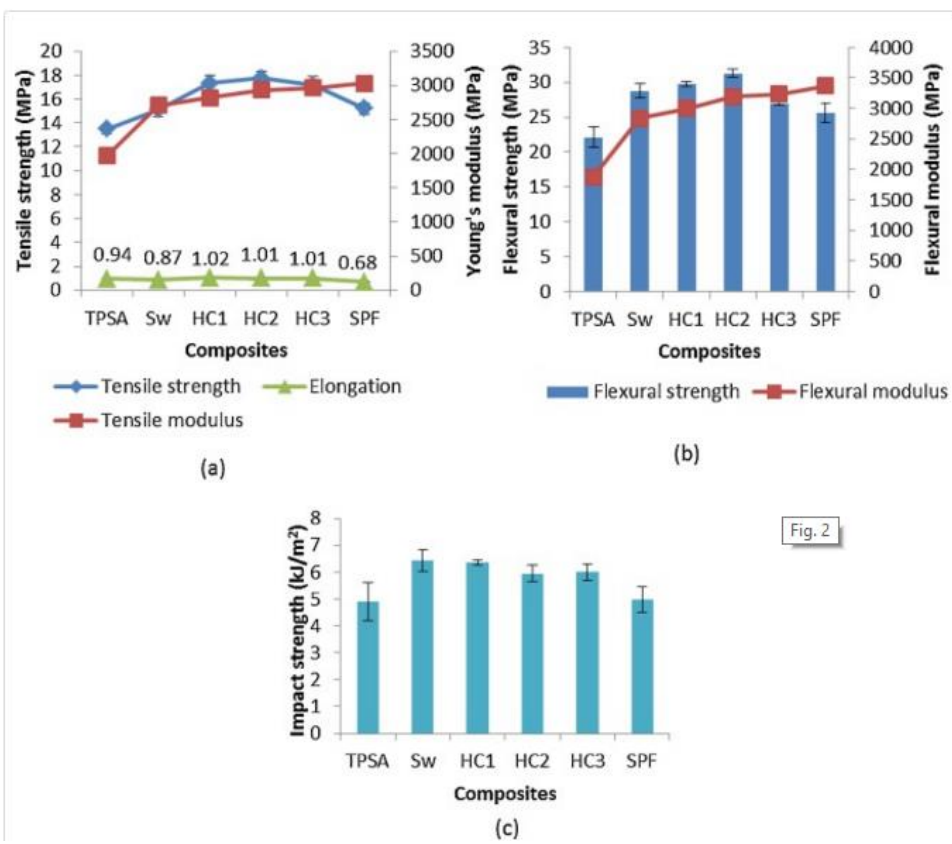


Figure 2. 7: Mechanical properties of Sw/SPF hybrid composites [14]

2.3.5 Coir Polyester Composite - A Study on Impact Strength Characteristics of Coir Polyester Composites

The aim of this research is to study the energy absorption capability of coir polyester composites. Experiments were conducted on specimens with both untreated and treated with 5 % NaOH solutions. The specimens of 2 mm, 3 mm, 4 mm, 5 mm and 6 mm thicknesses with fiber volume fraction of 10 %, 15 %, 20 %, 25 % and 30 % were tested to study the variation of their impact strength with variation in specimen thickness and fiber volume fraction respectively.

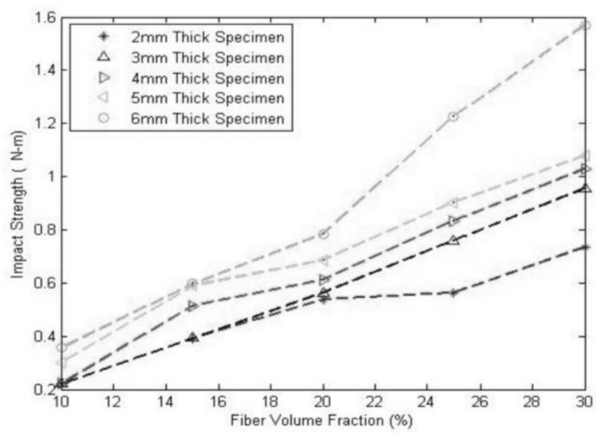


Figure 2. 8: Variation of impact strength of untreated coir reinforced polyester composites with fiber volume fraction

It is observed that as the thickness and fibre volume fraction of both treated and untreated coir polyester composite specimen increases the impact strength also increases. Untreated coir polyester composite of 30% fibre volume fraction yielded its highest impact strength of 1.570 N-m. Similarly treated composite specimens also yielded its peak impact strength of 1.275 N-m at its 30% fibre volume fraction.

CHAPTER 3

METHODOLOGY

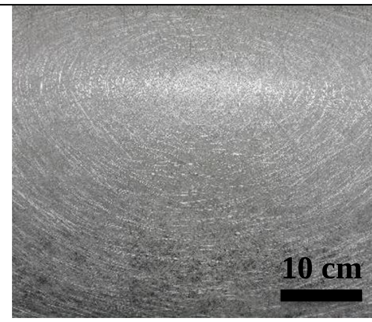
This chapter presents all the equations applied during certain calculations of results as well as the methods applied throughout fabrication and testing and analysis processes.

3.1 Material

Palm oil fibres and coir fibres were used as the natural fibre reinforcement for the composites. The coir fibres and oil palm fibres were supplied by Green Tree Garden & Landscape Nursery and United Palm Oil Industries Sdn. Bhd. respectively. The density of coir fibre is 1.2 g/cm^3, whereas for oil palm fibres is 1.0 g/cm^3. The fibre glass used throughout this project is chopped strand mat (CSM) with a density of 2.5 g/cm^3. CSM is utilized in this project because of its randomly distributed characteristics, which is similar to that of natural fibres. Polyester resin was applied as recommended by the technical staff. The polyester resin was mixed with hardener at a ratio of 1:100 to obtain the matrix for the composites.

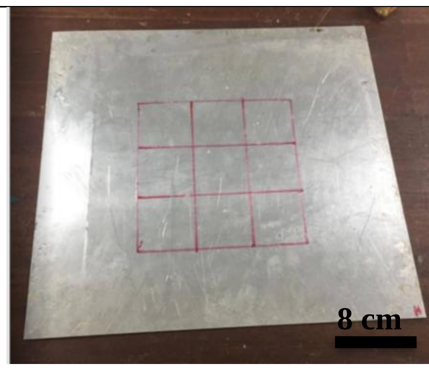
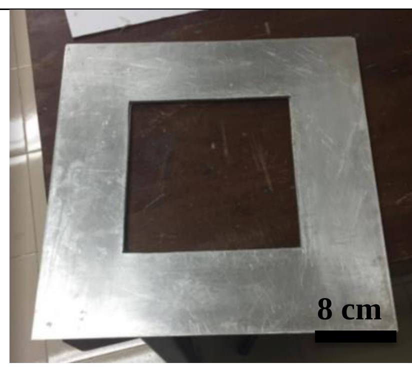
Table 3. 1: Lists of materials

Material	Image
Coir fibre	

Oil palm fibre	
Chopped strand mat glass fibre	
Polyester resin	
Hardener	

DOLPHIN Superior polyester putty	
Scotch Spray Mount repositionable adhesive	
Gel coat with hardener (MEKP)	
Gel coat colour dye	
Plasticine	

Table 3. 2: List of apparatus

Apparatus	Image
Ratchet toolbox	
Aluminium base	
Aluminium mould	

Einhell water jet cutting machine	
KENNEDY Ratchetting bar clamp	

3.2 Fabrication Process

3.2.1 Natural fibre separation

Clean natural fibres were handpicked and separated from impurities, such as sand and leaves. These impurities may cause inconsistent density of the specimen, as well as affecting the results of the tests.

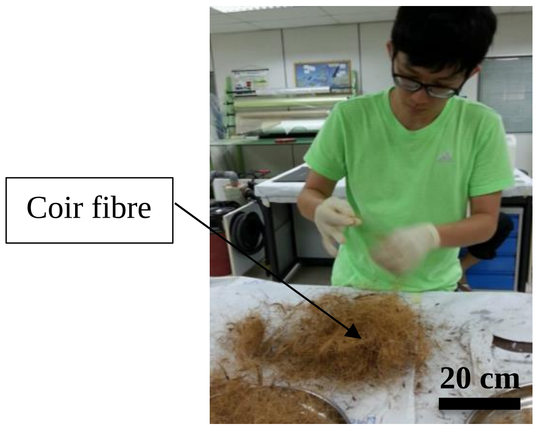


Figure 3. 1: Fibre separation

3.2.2 Allocation of fibre

Separated fibres were then weighted using electronic weighing balance before being allocated on designated plate with area of 160 mm × 160 mm. The total mass of the natural fibre was divided by 4 as 4 plies of fibre sheets will be used. To evenly distribute the mass of the fibre, the mass of each ply of fibre was divided by 9, to be allocated on the designated squares as shown Figure 3.3 and 3.4. For instance, the total mass of coir to be used in CFCR is 27.65 g. This amount will be divided by 4, which makes it 6.92 g per ply, then divided by 9 making it 0.768 g per square grid.

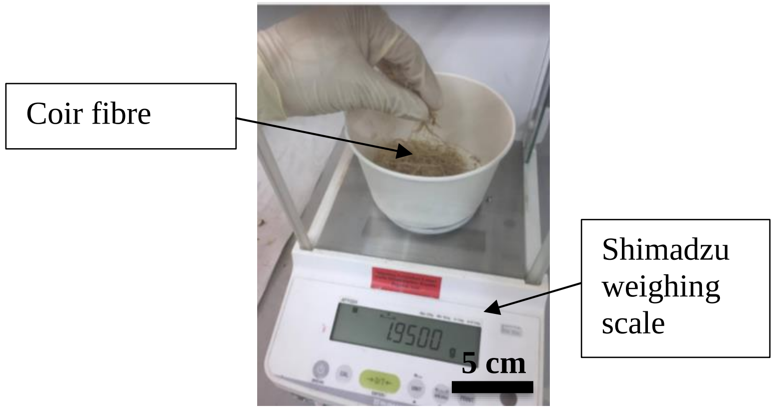


Figure 3. 2: Natural fibre being measured

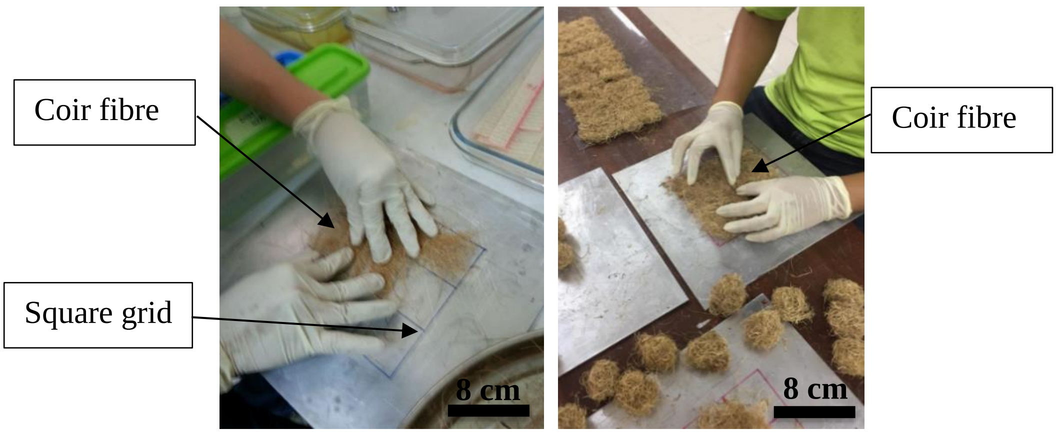


Figure 3. 3: Fibre allocated on aluminium plate with area of 150mm × 150mm

Fibre volume fraction and fibre content estimation

Below are the calculations for the weightage of several types of configurations: glass fibre reinforced composite (GFRC), coir fibre reinforced composite (CFRC), oil palm fibre reinforced composite (PFRC), hybrid coir reinforced composite (HCRC) and hybrid oil palm fibre reinforced composite (HPRC).

Volume of composite $= 160\text{mm} \times 160\text{mm} \times 3\text{mm}$

$= 76800\ mm^3$

Volume of matrix = 70% of total volume

= 53760 mm^3

Mass of matrix = Density of polyester ×Volume of Matrix

= 1.37 $\frac{g}{cm^3}$× 53.76 cm^3

= 73.65g

Calculation for various configurations

GFRC

Fibre content = 30% ×76800 mm^3

= 23040 mm^3

Mass of fibre = 2.5$\frac{g}{cm^3}$ × 23040 mm^3

= 57.6 g

CFRC

Coir content = 30% ×76800 mm^3

= 23040 mm^3

Mass of coir = 1.2 $\frac{g}{cm^3}$ × 23040 mm^3

= 27.65 g

PFRC

Oil palm content = 30% ×76800 mm^3

= 23040 mm^3

Mass of oil palm = 1.0 $\frac{g}{cm^3}$ × 23040 mm^3

= 23.04 g

HCRC

Fibre content = 15% ×76800 mm^3

$= 11520\ mm^3$

Mass of fibre $= 2.5\ \frac{g}{cm^3} \times 11520\ mm^3$

$= 28.8\ g$

Coir content $= 15\% \times 76800\ mm^3$

$= 11520\ mm^3$

Mass of coir $= 1.2\ \frac{g}{cm^3} \times 11520\ mm^3$

$= 13.83\ g$

HPRC

Fibre content $= 15\% \times 76800\ mm^3$

$= 11520\ mm^3$

Mass of fibre $= 2.5\ \frac{g}{cm^3} \times 11520\ mm^3$

$= 28.8\ g$

Oil palm content $= 15\% \times 76800\ mm^3$

$= 11520\ mm^3$

Mass of oil palm $= 1.0\ \frac{g}{cm^3} \times 11520\ mm^3$

$= 11.52\ g$

3.2.3 Fibre drying and rolling

Upon fibre allocation, the fibres are dried by placing in the oven at approximately 50 ℃ for at least 5 hours. The purpose of drying the fiber is to extract moisture from the fiber to prevent the water from affecting the results, as well as enhancing the curing process. The fibre sheet was placed on a plastic paper, then being rolled into a much thinner sheet of fibre. The roller is available in the workshop of School of Aerospace