DEVELOPMENT OF HIGH FIBRE VOLUME FRACTION NATURAL FIBRE COMPOSITE

By

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ENDORSEMENT

I, Uwaiz Bin Sallehuddin hereby declare that I have checked and revised the whole draft of dissertation as required by my supervisor.

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I, Uwaiz Bin Sallehuddin hereby declare that all corrections and comments made by the supervisor and examiner have been taken consideration and rectified accordingly.

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DECLARATION

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

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ABSTRACT

Composite materials are generally known as modern environmental friendly material which have much more benefits and competitive advantage compared to traditional material. The application of composite materials is widely used in many large market like transportation, sport, power and energy. Composites are light in weight, compared to most woods and metals. Their lightness is important in automobiles and aircraft, for example, energy or fuel efficiency can be improved as weight reduce. Natural fibre including coir, palm, bamboo and wood fibre are prospective reinforcing materials their use until now has been more empirical than technical. Nowadays various of methods are used to produce composite such as wet hand lay-up, resin infusion, compression molding, filament winding, prepreg, and many more. For this study, closed compression molding is applied to fabricate glass fibre and natural fibre composite. Results show that high fibre volume fraction will contribute high tensile strength for both natural fibre and synthetic fibre. Fibre volume fraction is one of the vital parameter need to be considered in order to produce good composite. For synthetic fibre, fibre volume fraction be determine using acid digestion process or burn-off process. For natural fibre, it totally inapplicable to use burn-off process and it must be treated thoroughly using correct solvent to quantify final fibre volume fraction. Thus, for this study, the most suitable method to find fibre volume fraction of palm fibre is using dichloromethane.

ABSTRAK

Bahan-bahan komposit umumnya dikenali sebagai bahan mesra alam moden yang mempunyai lebih banyak faedah dan kelebihan daya saing berbanding dengan bahan tradisional. Pemakaian bahan komposit digunakan secara meluas dalam banyak pasaran besar seperti pengangkutan, sukan, tenaga dan tenaga. Komposit ringan, berbanding dengan kebanyakan kayu dan logam. Kecerahan mereka penting dalam kereta dan pesawat, contohnya, tenaga atau kecekapan bahan api dapat ditingkatkan seiring menurunkan berat badan. Serat semulajadi termasuk koir, kelapa sawit, buluh dan serat kayu adalah bahan pengukuhan yang prospektif yang digunakan sehingga kini lebih empirik daripada teknikal. Kini, pelbagai kaedah digunakan untuk menghasilkan komposit seperti layul tangan basah, infusi resin, acuan kompresi, penggulungan filamen, prepreg, dan banyak lagi. Untuk kajian ini, pengacuan mampatan yang tertutup digunakan untuk membuat gentian kaca dan komposit serat semulajadi. Keputusan menunjukkan bahawa pecahan volum serat yang tinggi akan menyumbang kekuatan tegangan yang tinggi untuk serat semulajadi dan serat sintetik. Fraksi jumlah serat adalah salah satu parameter penting yang perlu dipertimbangkan untuk menghasilkan komposit yang baik. Untuk serat sintetik, pecahan isipadu serat akan ditentukan menggunakan proses pencernaan asid atau proses pembakaran. Untuk serat semulajadi, ia tidak boleh digunakan sepenuhnya untuk menggunakan proses pembakaran dan ia mesti dirawat dengan sempurna menggunakan pelarut yang betul untuk mengkuantifikasi fraksi jumlah gentian akhir. Oleh itu, bagi kajian ini, kaedah yang paling sesuai untuk mencari pecahan isipadu serat serat sawit menggunakan dichloromethane.

ACKNOWLEDGMENT

The completion of this study could not have been possible without help of some peoples who are expertise in composite field. First and foremost, I would like to wish a very big thank you my supervisor, Dr Mohd Shukur Bin Zainol Abidin for his supervision for two semesters of this research. My deep appreciation I would like to express to staff in composite laboratory which are Mr. Hasfizan and Mr. Shaha for being helpful and tutor in using variety of tools in laboratory. Next, I also thank to my final year project partner, Saiful Majdy for every part of his kindness by helping and giving idea to produce mold and composite fabrication. Finally, I would like to express my full gratitude to post-graduate students or laboratory assistants Mr Sharmendren and Mrs Imee for providing ideas and suggestions and guiding me to conduct matrix digestion experiment.

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LIST OF ABREVIATION

ASTM	American Society for Testing and Materials
GFRP	Glass Fibre Reinforced Polymer
PFRP	Coir Fibre Reinforced Polymer
NFRP	Natural Fibre Reinforced Polymer
FVF	Fibre Volume Fraction
HDT	Heat Deflection Temperature

LIST OF SYMBOLS

Ftu	:	Ultimate tensile strength, MPa [psi],
Pmax	:	Maximum load before failure, N [lbf],
σi	:	Tensile stress at *i*th data point, MPa [psi],
A	:	Average cross-sectional area, mm2 [in.2],
Ɛi	:	Tensile strain at *i*th data point, µƐ,
δi	:	Extensometer displacement at *i*th data point, mm [in.],
Lg	:	Extensometer gage length, mm [in.],
E	:	Modulus of elasticity, GPa [psi].
r	:	Strain, mm/mm [in./in.],
d	:	Depth of beam, mm [in.],
T_g	:	Glass Transition Temperature
V_f	:	Volume Fraction
M_f	:	Weight of Fibre
M_c	:	Weight of Composite Specimen
P_f	:	Density of Fibre
P_c	:	Density of Composite Specimen

CHAPTER 1

INTRODUCTION

1.1 General Overview

Composite materials are generally known as modern environmental friendly material which have much more benefits and competitive advantage compared to traditional material. The application of composite materials is widely used in many large market like transportation, sport, power and energy. Composites are light in weight, compared to most woods and metals. Their lightness is important in automobiles and aircraft, for example, energy or fuel efficiency can be improved as weight reduce. Some materials are very strong and heavy like steel, but composites can be design strong and light which the reason why airplanes are made of carbon fibre that provide high strength at the lowest possible weight.

The downside of composites is usually the cost. Although manufacturing process are often more efficient when composites are use, the raw materials are expensive. Composites never totally replace traditional materials like steel, but in many case they are just what are needed. High fibre production cost inhibits high volume deployment; thus, the precursor and processing costs have to be reduced.

Natural fibre including coir, palm, bamboo and wood fibre are prospective reinforcing materials their use until now has been more empirical than technical. In developing countries, they mostly produce low-cost thin element natural fibre for use in housing schemes. This may be returned to that the natural fibres have some drawback such as they are more prone to catching fire, their quality cannot be maintained equally, moisture causes swelling of fibre[1]. Natural fibres require only a low degree of industrialization for their processing and in comparison, with an equivalent weight of the most common synthetic reinforcing fibres, the energy required for their production is small and hence the cost of fabricating these composites are low too.

According to [2] journal, Indonesia and Malaysia(39% of world production) make huge production of oil palm among country in the world. This production is related with the production of biomass which can be regarded as a secondary product at gaining the palm oil. A component of the produced biomass is an empty fruit bunch (EFB) which can be used a source of fibres. Study from[3] stated that oil palm fibre contains a higher percentage cellulose approximately 65% which considered higher compared to coir fibre and sisal fibre. The fibre was found to have a very low ash content. All these factors contribute to better performance of the fibre as reinforcement in polymers.

1.2 Problem Statement

Generally, difference in fibre volume content will affect the mechanical properties of composite material. In previous studies, bio-composites with 30% fibre volume fraction were manufactured in laboratory. The mechanical properties include tensile strength, compressive strength and bending properties were studied. To extend these studies, 50% of fibre volume fraction of bio-composite to be manufactured in laboratory and the tensile strength will be studied.

Composite materials that made up from synthetic fibre such as glass fibre and carbon fibre basically have standard procedure or methods to determine the final fibre volume fraction of the composite. Most prominent methods are burn-off process and acid digestion process. For bio-composite materials, the proper solvent and method have to be conducted in order to remove the matrix without eliminate the natural fibre. This is because natural fibre are very fragile to some solvent and strong acid.

1.3 Research Objectives

Objectives of this research were set as follow:

1. To conduct fabrication process of producing specimen of bio-composite using natural fibre for testing purpose
2. To determine tensile strength of composites by performing tensile test on specimens
3. To study and analyse the tensile strength of reinforced bio-composite material
4. To conduct non-fibre removal process to quantify the actual final fibre volume fraction of composites

CHAPTER 2

LITERATURE REVIEW

2.1 Composite Materials

For general, composite means material that made from two or more distinct material that when combined will give better properties like stronger, tougher and more durable than each would be separately. For this case study, research is conducted specifically on composite material fibre reinforced with polymer. They provide ample scope and receptiveness to design changes, materials and processes. The strength-weight ratio is higher than other materials. Their stiffness and cost effectiveness offered, apart from easy availability of raw materials, make them the obvious choice for applications in surface transportation[4]. In aerospace industry, weight is everything when it comes to heavier-than-air machines, and designers have striven continuously to improve lift to weight ratios since man first took to the air. Composite materials have play major part in contribution to air transportation due to its physical and mechanical properties which suits to the desired feature.

2.2 Fibres

The structural properties of composite materials are derived primarily from the fibre reinforcement. In composite, to enhance properties in the final part such as strength and stiffness, while minimizing its weight, the fibre are held together with matrix resin and contribute to high tensile strength. A fibre has a length that is much greater than its diameter. The aspect ratio of fibre is the length-to-diameter(l/d) ratio which can vary greatly. Continuous-fibre have long aspect ratio and normally have preferred orientation while discontinuous-fibre have short aspect ratio and have random orientation[4]. Because of their small diameter (contain far few defect), fibre produce high tensile strength composites. Generally, the smaller size of fibre diameter, the higher its strength but when the fibre diameter smaller, it cost increases. Moreover, smaller-diameter high-strength fibres have better flexibility and are more manageable to fabrication processes such as weaving or forming over radii. Usually fibre used in laboratory include glass, carbon and aramid which may be continuous or discontinuous.

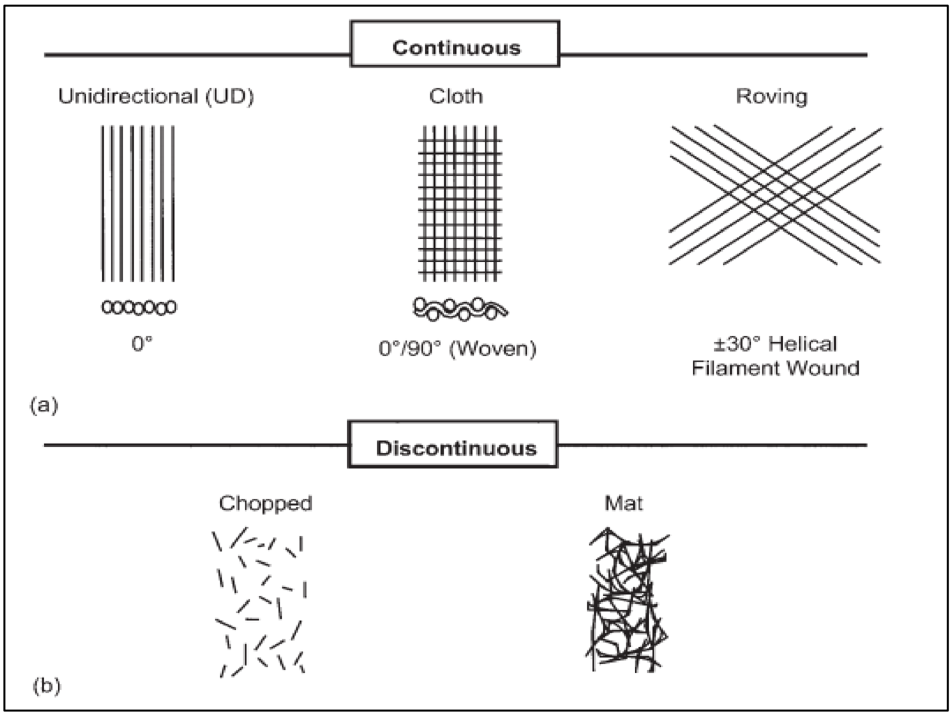

Figure 2.2a : Continuous and Discontinuous Fibre

Table 2.2a : Type of Synthetic Fibre

Type of synthetic fibre	Characteristic
 Glass fibre	• Resistant to oxidation and moisture • Good resistant to solvent, oil and fuel • Very good electrical insulators • Widely used in bathtubs, boats, aircraft, roofing
 Carbon fibre	• Very high stiffness and low density • Very high fatigue strength • Very good corrosion resistance • Used in sporting good, military and aerospace industry
 Aramid fibre	• High tensile strength • Good impact resistance • Poor compressive strength • Used in many civil structure, mechanical structure; helmet

2.2.1 Glass Fibre

Glass fibers, also known commercially as 'fiberglass', are most extensively use reinforcements for polymer matrix composites due to their combination of low cost, high strength and relatively low density[5]. To produce fibre glass, molten glass are pulled through orifices at temperature where the glass has just the right amount of viscosity. Various in diameters, glass fibre can have different composition as shown in Table 2.2.1a.

Table 2.2.1a : Composition of Various Glass Fiber Grades[5]

Designation	Use	Composition
E	Electrical Insulation	55%SiO_2, 11%Al_2O_3, 6%B_2O_3, 18%CaO, 5%MgO, 5%Other
S	High Strength Composites	65%SiO_2, 25%Al_2O_3, 10%MgO (Strength Expensive)
S-2	High Strength Composites	Same as above but less stringent QC
A	Thermal Insulation	72%SiO_2, 1%Al_2O_3, 10%CaO, 3%MgO, 14%K_2O
C	Chemical Applications	65%SiO_2, 4%Al_2O_3, 6%B_2O_3, 14%CaO, 3%MgO, 9%K_2O

The basic raw materials for fiberglass products are a variety of natural minerals and manu-factured chemicals. The major ingredients are silica sand, limestone, and soda ash. The ingredients may include calcined alumina, borax, feldspar, nepheline syenite, magnesite, and kaolin clay, among others. Other ingredients are used to improve certain properties, such as borax for chemical resistance[6]. Commonly fibreglass textile used in as reinforcement material for molded and laminated plastic. Discontinuous fibre cause fibreglass fluffy material, wool and thick usually used in thermal insulation and sound absorption. It is commonly found in ship and submarine bulk heads and hulls(automobile engine compartments) and body panel liners in furnaces and air conditioning units(acoustical wall) and ceiling panels and architectural partitions.

Typical direction type of fibre glass in laboratory include woven roving, chop strand mats and woven cloth. Woven roving is made from continuous glass fiber roving which are interlaced into heavy weight fabrics. Compatible with most resin systems. Used in most condition to increase the bending and impact strength of laminates. Ideal for multi-layer hand lay-up applications where great material strength is required. Good drapeability, wet out and cost effective. Woven Roving is available in a differences of weaves, weights, widths and finishes to suit a wide range of applications. Chopped strand mat, a random fibre reinforcement designed for use with polyester and vinyl ester resin systems. Uses a styrene monomer soluble binder to hold strands in place, not compatible with epoxy resin systems. Use as basic laminate reinforcement and for gel coat backup to minimize weave print through and pin air bubbles. Chopped strand mat is available in a variety of weights and widths to fit a wide range of applications. Woven fibereglass cloth is produced by conventional textile methods, in virtually any variation. The types of construction are plain weave, twill weave, leno weave, satin weave and unidirectional weave. Woven fibreglass cloth is compatible applied with polyester, vinyl ester and epoxy resins. These fabrics are very regularly used in marine, composite construction and repair. Figure 2.2.1a below shows the example of woven roving, chop strand mats and woven cloth of fibreglass.

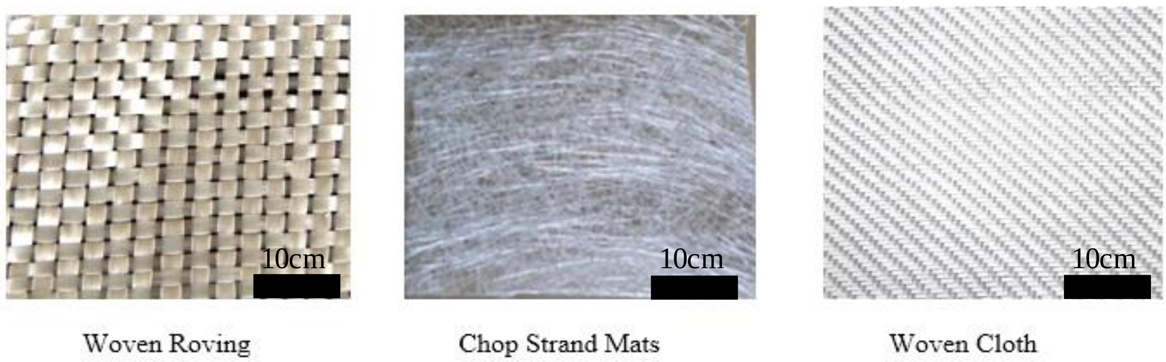

Figure 2.2.1a : Type of Fibreglass in Laboratory

2.2.2 Natural fibre

In simple definition, natural fibres are fibres that are not synthetic or man-made. Their sources can be obtained from animals or plants. In the last few decades, so far the application of natural fibre from both resources, renewable and non-renewable such as oil palm,, sisal, flax, coir and jute to produce composite material gained considerable attention[7]. The good properties and superior advantages of natural fibre over synthetic fibre in term of its relatively low weight, low cost, less damage to processing equipment, good relative mechanical properties such as flexural modulus and tensile modulus natural fibre reinforced polymer matrix catch world attention in various application. Compared to synthetic fibre, natural fibre also improved surface finish of moulded part of composites, renewable resources, flexible during processing, biodegradability and minimal health hazards. From opposite condition, natural fibre is not free from problems and they have remarkable deficits in properties. they have notable deficits in properties. The natural fibre structure consists of (cellulose, hemicelluloses, lignin, pectin, and waxy substances) and permits moisture absorption from the surroundings which causes weak bindings between the fibre and polymer[7].

Characteristic and performance of natural fibre polymer composite(NFPCs) depends on various factor. One of them is chemical composition. The chemical composition of natural fibre play a big role on the characteristics of the composite represented by the percentage of cellulose, hemicellulose, lignin, and waxes. Table 2.2.2a shows the chemical composition of the certain common natural fibres.

Table 2.2.2a : Chemical Composition of Natural Fibres[7]

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

Major production of natural fibres is in South East country such as Malaysia and Indonesia. Large-scale cultivation of natural fibres has come from Latin America. Most commonly natural fibres produce in Malaysia are palm oil fibre, coir fibre, jute fibre and kenaf fibre. This is because the climate and weather are suitable for the plant to live. Some example of common natural fibres are shown in Figure 2.2.2a.

Figure 2.2.2a : Example of Natural Fibres

The average mechanical properties prevent the fibre from using them in high-tech application, but for some reason they can compete with synthetic fibre for others application. From previous research, the advantages and disadvantages of composites using natural fibre [8] are listed below.

Table 2.2.2b : Advantages and Disadvantages of natural fibre

ADVANTAGES	DISADVANTAGES
Friendly to environment	Poor compatibility with hydrophobic polymer matrix
Fully biodegradable	Store for a long time can cause fibre degradation
Non-harmful	Hygroscopic (absorb moisture)
Easy to manage	Form aggregates during processing
Non-abrasive during processing and use	Low thermal stability
Low density/light weight	
Compostable	
Source of income for rural/agricultural community	
Renewable, abundant and continuous supply of raw materials	
Cheap	
Acceptable specific strength properties	
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	

The application of natural fibre reinforced polymer composites (NFPCs) are growing rapidly in various engineer field. The different types of natural fibres such as jute, hemp, kenaf, oil palm, and bamboo reinforced polymer composite have received considerable vital parts in different automotive applications, structural components, packing, and construction. NFPCs also applied in electric and electronic industries, aerospace, sport and recreation equipment, boats, machinery office products and many more. Some of the example of natural fibres and its application are shown in Table 2.2.2b.

Table 2.2.2c : Example of Fibre and its Application[7]

Fibres	**Application**
Hemp fibre	Construction, textile, paper & packaging, cordage, electrical, manufacture notes and manufacture of pipes
Oil palm fibre	Building materials such as windows, door frames, structural insulated panel building systems, siding, fencing, roofing, decking
Wood fibre	Window frame, panels, door shutters, decking, railing systems, and fencing
Flax fibre	Window frame, panels, decking, railing systems, fencing, tennis racket, bicycle frame, fork, seat post, snowboarding, laptop cases
Rice husk fibre	Building materials such as building panels, bricks, window frame, panels, decking, railing systems, and fencing
Bagasse fibre	Window frame, panels, decking, railing systems, and fencing
Sisal fibre	In construction industry such as panels, doors, shutting plate, and roofing sheets; also, manufacturing of paper and pulp
Stalk fibre	Building panel, furniture panels, bricks, and constructing drains and pipelines
Kenaf fibre	Packing material, mobile cases, bags, insulations, clothing-grade cloth, soilless potting mixes, animal bedding,
Cotton fibre	Furniture industry, textile and yarn, goods, and cordage
Coir fibre	Building panels, flush door shutters, roofing sheets, storage tank, packing material, helmets, brushes and brooms, ropes and yarns for nets, bags, and mats, padding for mattresses, seat cushions
Ramie fibre	Use in products as industrial sewing thread, packing materials, fishing nets, and filter cloths
Jute fibre	Building panels, roofing sheets, door frames, door shutters, transport, packaging, geotextiles, and chip boards

2.3 Matrix

Polymer matrix composites (PMCs) most commercially produced by using polymer matrix material often called a resin solution. Depending upon the starting raw ingredients, there are many different polymers. The most common are recognize as polyester, vinyl ester, epoxy, phenolic, polyimide, polyamide, polypropylene, polyether ether ketone, and others. Low cost and simple fabrication method make PMCs very popular. The polymer matrix has three main function which are to hold fibre together, distribute load between fibres and protect fibre from environment. Reinforcement of polymers by strong fibrous network permits fabrication of PMCs is the reason why it has many advantages[9].

Table 2.3a : The Advantages and Disadvantages of Polymer Matrix Composites (PMCs)

ADVANTAGES	DISADVANTAGES
High specific strength	low thermal resistance
High specific stiffness	high coefficient of thermal expansion
High fracture resistance	
Good abrasion resistance	
Good impact resistance	
Good corrosion resistance	
Good fatigue resistance	
Low cost	

Polymer matrix have different in properties that will determine the application to which it is appropriate. The main pros of polymers as matrix are low cost, easy processability, good chemical resistance and low specific gravity. On the other side, the use is limited because of low strength, low modulus, and low operating temperatures. Most commonly used polymers for composites are thermoplastic polymers, thermosetting polymers, elastomers, and their blends.

2.3.1 Thermoplastic Polymers

Thermoplastics consists of linear or branched chain molecules having strong intramolecular bonds but weak intermolecular bonds. They can be reshaped by application of heat and pressure and are either semi crystalline or amorphous in structure. Thermoplastic resins have linear chains with no cross-linked and it cause weak secondary bonds bridge between the thermoplastic chains which provide some mechanical stiffness & strength. The chain structure of thermoplastic is shown in Figure 2.3.1a. Thermoplastics derive their strength and stiffness from the inherent properties of the monomer units & the very high molecular weight. Due to the change orientation of carbon atoms along the chain, the long chains will coil into a complex, random configuration. This is known as an 'amorphous polymer'

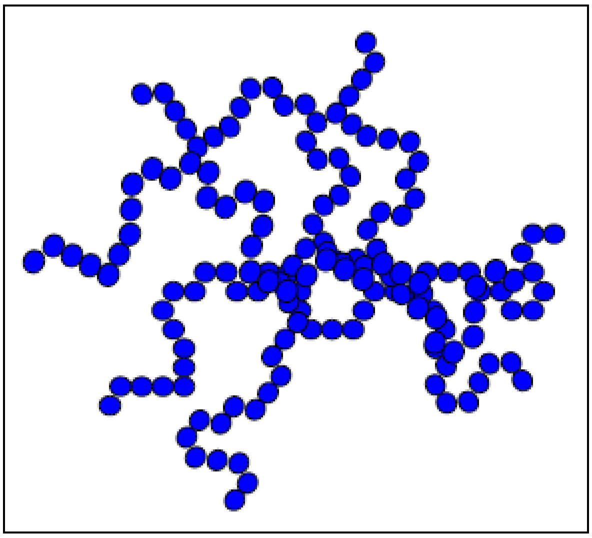

Figure 2.3.1a : Thermoplastic chain structure

2.3.2 Thermosets Polymers

Thermosets are cross-linked polymers that have a three-dimensional network structure with covalent bonds linking the chains. In order to produce thermosets, a liquid resin consisting of monomers and oligomers (several monomer units joined together) is mixed with a liquid hardener, which can be another resin or catalyst. Resin and hardener react in a condensation process that joins the monomers and oligomers into long polymer chains and forms cross-links between the chains. The chain structure of thermosets is shown in Figure 2.3.2a. They resist rotation and sliding of the chains under load when cross-links are formed and will provides thermosets with better strength, stiffness and hardness than thermoplastics.

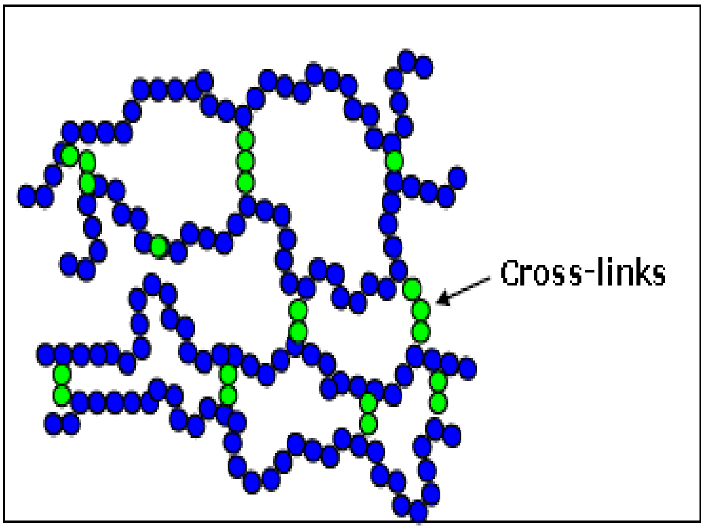

Figure 2.3.2a : Thermosets chain structure

2.3.3 Elastomers

An elastomer is a polymer with the characteristic of viscoelasticity, generally having remarkable low Young's modulus and high yield strain compared with other materials. Each of the monomers that link to form the polymer is commonly made of carbon, hydrogen, oxygen, and silicon. Elastomers are amorphous polymers existing above their glass transition temperature, so that considerable segmental motion is possible[9].

Thermoset, thermoplastic and elastomer have different application in composite technology due to their different properties. The advantages and disadvantages of three matrix are shown in Table 2.3.3a

Table 2.3.3a : Advantages and Disadvantages of Polymer Matrix

Thermoplastic	Thermoset	Elastomer
Advantages		
•Non-reacting; no cure required •Rapid processing •High ductility •High fracture toughness •High impact resistance •Absorbs little moisture •Can be recycled	•Low processing temperature •Low viscosity •Good compression properties •Good fatigue resistance •Good creep resistance •Highly resistant to solvents •Good fiber wetting for composites	•Low processing temperature •High ductility & flexibility •High fracture toughness •High impact resistance
Disadvantages		
•Very high viscosity •High processing temperature (300-400ºC) •High processing pressures •Poor creep resistance	•Long processing time •Low ductility •Low fracture toughness •Low impact resistance •Absorb moisture •Limited shelf life •Cannot be recycled	•Long processing times •Poor creep resistance •Low Young's modulus •Low tensile strength

Temperature properties are often described by two properties, heat deflection temperature (HDT) and glass transition temperature (T_g). HDT is a measure of the ability of the polymer to resist deformation under load at elevated temperature. Definition of HDT is simply the temperature required to deflect a polymer by a certain amount under heat and load. The stress applied to the polymer is usually 0.46MPa (66psi) or 1.8MPa (264psi)[10]. The higher the HDT then the greater is the temperature needed to cause permanent distortion of a polymer when under load. The glass transition temperature, Tg, is used more often than the HDT to describe the softening of polymers at elevated temperature. Table 2.3.3b shows temperature properties examples of thermoset and thermoplastic resin.

Table 2.3.3b : Temperature Properties of Matrix

	Glass Transition Temperature (°C)	Melting Temperature (°C)
Thermoplastics		
Polyetheretherketone (PEEK)	140	245
Polyphenylene sulfide (PPS)	75	285
Polyetherimide (PEI)	218	220
Polycarbonate (PC)	150	155
Thermosets		
Polyester	110	-
Vinyl ester	120	-
Epoxy	110 – 220	-
Phenolic	100-180	-
Bismaleimide	220	-
Polyimide	340	-
Cyanate ester	250-290	-

2.4 Compression Molding

Compression Molding is a major manufacturing process for natural fibre reinforced polymer composite alongside sheet molding and resin transfer molding. Due to its suitability for high volume production, repeatability and more recently production of great surface finish, compression molding has been used in various industry since 1940's[11]. Compression molding perform a closed mold process with high pressure application to form a desired shape. In this process, two matched strong metal molds are used to manufacture composite products. As shown in Figure 2.4a, two matched mold where the upper mold is movable used to apply pressure and the lower mold is stationary used to place specimen and sustain pressure. Fibre and matrix are reinforced together in the metal mold, then heat and pressure are applied as relevant with the requirement of the composite in a particular period. Curing process can be carried out either at room temperature or at raised temperature depends on the composite product. After curing, mold is opened and composite product is removed for further processing.

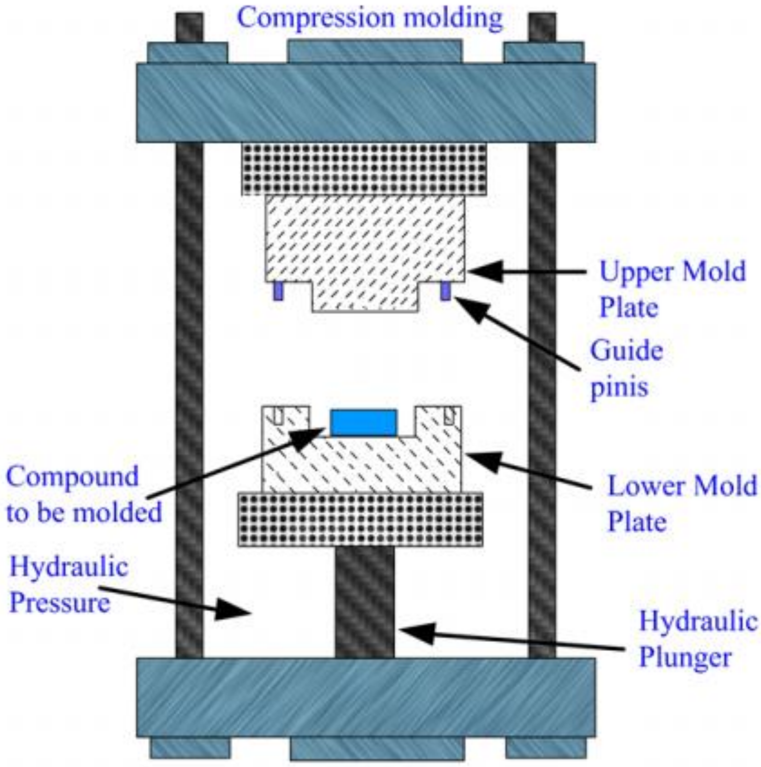

Figure 2.4a : Compression Molding Method[12]

Generally, every process to fabricate composite products has their pros and cons. For compression molding, the advantages and disadvantages[12] of using this method are listed below.

Table 2.4a : The Advantages and Disadvantages of Compression Mold Fabrication Method

ADVANTAGES	DISADVANTAGES
Production rate is high as the mold cycle time is in few minutes	Due to expensive machinery and parts, the initial capital investment associated with compression molding is high
Good surface finish with different texture and styling can be achieved	The process is suitable for high production volume. It is not economical for making a small number of parts or for prototyping applications
High part uniformity is achieved with compression molding process	It is a labour intensive process
Good flexibility in part design is possible	Sometimes secondary processing (trimming, machining) of product is required after compression molding
Extra features like inserts, bosses and attachment can be molded in during the processing	Sometimes uneven parting lines are there
Raw material wastage is minimum	Size limitation
Maintenance cost is low	
Residual stresses are absent or negligible in the molded component	
Twisting and shrinkage in product is reduced therefore dimensional accuracy is good	

2.5 Tensile Test

The main purpose of tensile test is to create the stress-strain diagram. Tensile test decides the strength of a material subjected to a simple stretching operation. Generally, standard dimension test specimens are pulled slowly (static loading) and at uniform rate in the testing machine while stress and strain is defined in equations below.

$$\varepsilon = \frac{\delta}{L_o} \tag{2.5.1}$$

ε = strain of material L_o = original length

δ = changes in length

$$\sigma = \frac{P}{A_o} \tag{2.5.2}$$

σ = stress of material A_o = original cross-sectional area

P = applied force

For this project, tensile test is specified for polymer matrix composite specimen. The standard used is referred in ASTM D3039 and the machine used is Universal Testing Machine (UTM). For ASTM D3039, the test speed can be defined by the material specification or time to failure which most commonly 1 to 10 minutes. Test speed for standard test specimen that typically used is 2mm/min (0.05inch/min). An extensometer or strain gauge is required to determine the elongation and tensile modulus. The size of specimen that usually tested is rectangular cross section with 25mm wide and 250mm long[13]. The used of sand papers at the both end of the specimen are recommended as for stronger grip. The testing is conducted inside the controlled thermal environment the same as it would be at ambient temperature.

2.6 Fibre Volume Fraction(FVF)

Fibre volume fraction(FVF) or fibre volume ratio is percentage of fibre volume in the whole composite polymer reinforced product. When polymer composite is produced, fibre and resin are impregnated together with appropriate volume of both elements. Several investigation[14],[15] prove that the fibre volume fraction is one main parameter in determination the mechanical properties of composite. In order to determine fibre volume fraction, there are some methods that are compatible with certain fibre. In ASTM D3171, typically method used to digest epoxy resin are matrix digestion using nitric acid, sulphuric acid with hydrogen peroxide, ethylene glycol with potassium hydroxide and matrix carbonization in a nitrogen-purging furnace or burn-off process. According to ASTM D2584, the equation to find out fibre volume fraction is shown as below.

$$V_f = \frac{\rho_m \times W_f}{\rho_m \times W_f + \rho_f \times W_m} \tag{2.6}$$

V_f = Fibre volume fraction

W_f = Weight of fibre

W_f = Weight of matrix

ρ_f = Density of fibre

ρ_m = Density of matrix

CHAPTER 3

METHODOLOGY

3.1 Materials

In this project, mainly material used to fabricate reinforced composite product are oil palm fibre (natural fibre) and Chop Strand Mat E-Glass fibre (synthetic fibre). The density of palm fibre is 1.09g/cm^3[16] . The density of fibre glass chop strand mat is 2.5g/cm^3[8]. Both fibre are discontinuous type and have random distribution of fibre. The table below shows all materials used to fabricate composite.

Table 3.1a : List of Materials

Oil Palm Fibre	
Glass Fibre Chop Strand Mat	

<table>
<tr><td>Epoxy Resin</td><td>
</td></tr>
<tr><td>Hardener</td><td>
</td></tr>
<tr><td>Release Mold Wax</td><td>
</td></tr>
</table>

3.2 Fabrication Process

3.2.1 Mold Fabrication

Closed mold compression method was chosen to fabricate the composite because the aim thickness is 3mm for both fibre composite which compression mold is the most appropriate method. The mold must be square shaped with size 160mm x 160mm. Thus, first step is to produce a strong metallic mold. The material used is aluminium square tube to form square frame and steel plate as a base. Figure 3.2.1a and Figure 3.2.1b show them respectively.

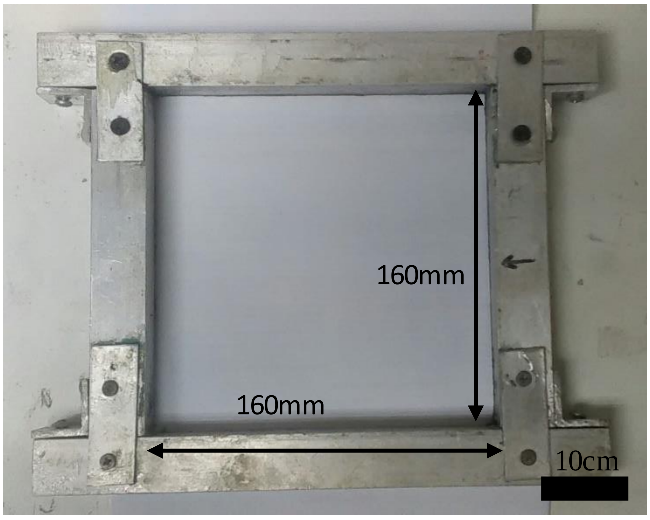

Figure 3.2.1a : Aluminium Square Tube

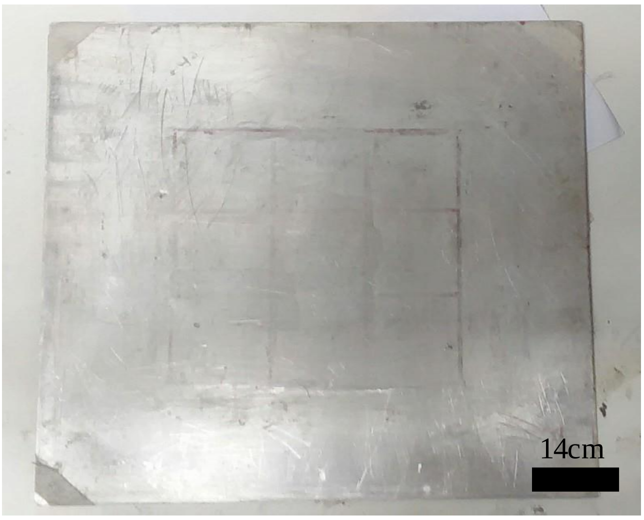

Figure 3.2.1b : Steel Plate