PENCIRIAN SIFAT KOMPOSIT POLIMER BERGENTIAN SEMULA JADI UNTUK APPLIKASI STRUKTUR

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CHARACTERIZATION OF NATURAL FIBRE POLYMER COMPOSITES FOR STRUCTURAL APPLICATION

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Specially dedicated to my beloved mother Wendy Lee Wai Yong, beloved father Liew Moon Fah, sister, brother, lecturers, and friends.

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ABSTRACT

Oil palm fibre which is relatively low cost and abundantly available has the potential as polymer reinforcement in structural applications. This study initially investigated the tensile behaviour of single oil palm fibre and physical properties like diameter, moisture content, moisture absorption and density. Then, the tensile behaviour of natural fibre reinforced polymer composites as a function of fibre volume ratio, fibre length and fibre surface modification was investigated. Lastly, flexural behaviour of reinforced concrete beam strengthened with unidirectional oil palm fibre composite was tested and was compared with reinforced concrete beam strengthened with woven glass fibre composite and ordinary reinforced concrete beam. Oil palm fibre is light but high moisture content, high moisture absorption and large variance of cross section area. The fibre tensile properties are relatively low compare to the literature which may due to degradation problems. The stiffness of the composite is significantly improved when the fibre volume ratio increased. At 10% of fibre volume ratio, the modulus of elasticity is increased up to 150 % compare to neat resin. Higher aspect ratio yield higher tensile strength and modulus of elasticity of the composite. The effect of alkali treatment increases 10% of the tensile strength of the fibres. Oil palm fibre composite could be used as strengthening material for reinforced concrete beam by increasing the flexural strength and stiffness of the reinforced concrete beam while maintaining the ductility of the beams.

ABSTRAK

Gentian minyak kelapa sawit yang kos rendah dan berlambak-lambak di negara ini merupakan bahan gentian yang bepontensi digunakan dalam aplikasi struktur. Kajian ini mengkaji sifat ketengangan gentian minyak kelapa sawit dan sifat fizikal gentian minyak kelapa sawit seperti diameter, kandungan kelembapan, sifat penyerapan kelembapan dan ketumpatan. Kemudian, sifat ketegangan composit polimer bergentian semula jadi dikaji. Antara parameter yang telah dikaji terhadap composit ialah kadaran isipadu gentian, panjang gentian dan modikasi permukaan gentian. Akhirnya, sifat lenturan rasuk konkrit bertulang besi yang diperkuatkan dengan komposit dikaji. Komposit yang terlibat dalam kajian lenturan rasuk termasuk bahan komposit polimer bertulang gentian sintesis – gentian kaca, dan bahan komposit polimer bertulang gentian semula jadi – gentian kelapa sawit. Daripada kajian ini, gentian minyak kelapa sawit adalah bahan yang ringan tetapi kandungan kelembapan yang tinggi, penyerapan kelembapan yang tinggi dan diameter yang perbezaan besar. Sifat ketegangan gentian kelapa sawit adalah rendah berbanding dengan gentian lain seperti gentian kaca mungkin disebabkan masalah pereputan. Keanjalan komposit bergentian kelapa sawit gentian diperbaiki apabila kadaran isipadu gentian bertambah. Gentian kelapa sawit yang lebih panjang menghasilkan composit yang lebih baik dalam sifat ketegangan komposit. Modifikasi permukaan gentian kelapa sawit dengan menggunakan rawatan akali hanya menambahkan daya ketegangan komposit. Komposit polimer bergentian kelapa sawit boleh digunakan bahan penguatan untuk rasuk konkrit bertulang besi dengan menambahkan kekuatan kelenturan dan kekerasan rasuk konkrit bertulang besi pada masa yang sama mengekalkan kemuluran rasuk.

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CHAPTER 1

INTRODUCTION

1.1 General

Natural fibres can be defined as slender threads created by nature. Comparatively, synthetic fibres are created by humans from minerals. Synthetic fibres are extensively used in advanced composites like airplanes, sports gadgets, automotive and infrastructure due to high strength and high performance when combine with plastic material. However, synthetic fibres like glass fibre are usually high cost compare to conventional materials like wood, steel and concrete which limit the use of synthetic fibres in advance applications only. Unlike the synthetic fibres, natural fibres are cheap and available in large quantity and yet environmental friendly[1].

In the past, natural fibres are used in early human civilization in fabric applications. High strength natural fibres like jute, cotton, silk and kenaf are used extensively and directly in one-dimensional products like lines, ropes and cloths. Others natural fibres like oil palm fibres, banana leaf fibres, and rice stalks fibres are residual agriculture product. They are usually disposed into land fill or disposed by open burning.

Environmental issues arise when these materials are in large quantities. Landfill method becomes not economical whilst open burning results air pollution and global warming.

Until recent decade, there is an increasing interest on natural fibres reinforced polymer. The potential of natural fibres replacing synthetic fibres in composite is possible[2]. In general, natural fibres offer high specific properties, low cost, non abrasive, readily available and environmental friendly where no synthetic fibres can surpass these advantages. These advantages attract scientists and technologists especially automobile industry to study on the behaviour of the natural fibres and the characteristic of the natural fibre reinforced composites. However, certain drawbacks such as incompatibility with hydrophobic polymer matrix, the tendency to form aggregates during processing, poor resistance to moisture greatly reduce the potential of natural fibres to be used as reinforcement in polymer[2]. Moreover, no literature is made on the potential of natural fibre composites in structural application. Therefore, a detail study on the characteristic of natural fibre composites is required to investigate the potential of natural fibre composites in structural use.

1.2 Background and Rationale of the Project

Natural fibre reinforced polymer consist of resin as a matrix and natural fibres as reinforcement. Natural fibres are formed in a very complex system and there is an enormous amount of variability in fibre properties, unlike synthetic fibres which is homogenous and constant in physical and mechanical properties. The variability of natural fibres depends upon the origin of the fibres, the quality of plant and location[3]. Hence, it is no doubt that the challenges of the natural fibres use as reinforcement in composite are greater than synthetic fibres.

In the past, the development of fibre reinforced polymeric materials in civil engineering increased rapidly where these materials in civil engineering applications are divided into two categories, structural and non structural. Structural applications are designed to sustain some degree of load like bridge, truss, I-beam, column, repair and rehabilitation applications. While non structural applications are non load bearing and they are designed based on quality guidelines and aesthetic considerations. In Malaysia, the utilizations of fibre reinforced polymeric materials in structural applications are still very low. One of the factors is the high cost of raw materials where mostly are imported from China, Japan, Europe and the United State of America[4]. Can local and low cost natural fibres substitute synthetic fibres in reinforced polymeric materials for structural applications?

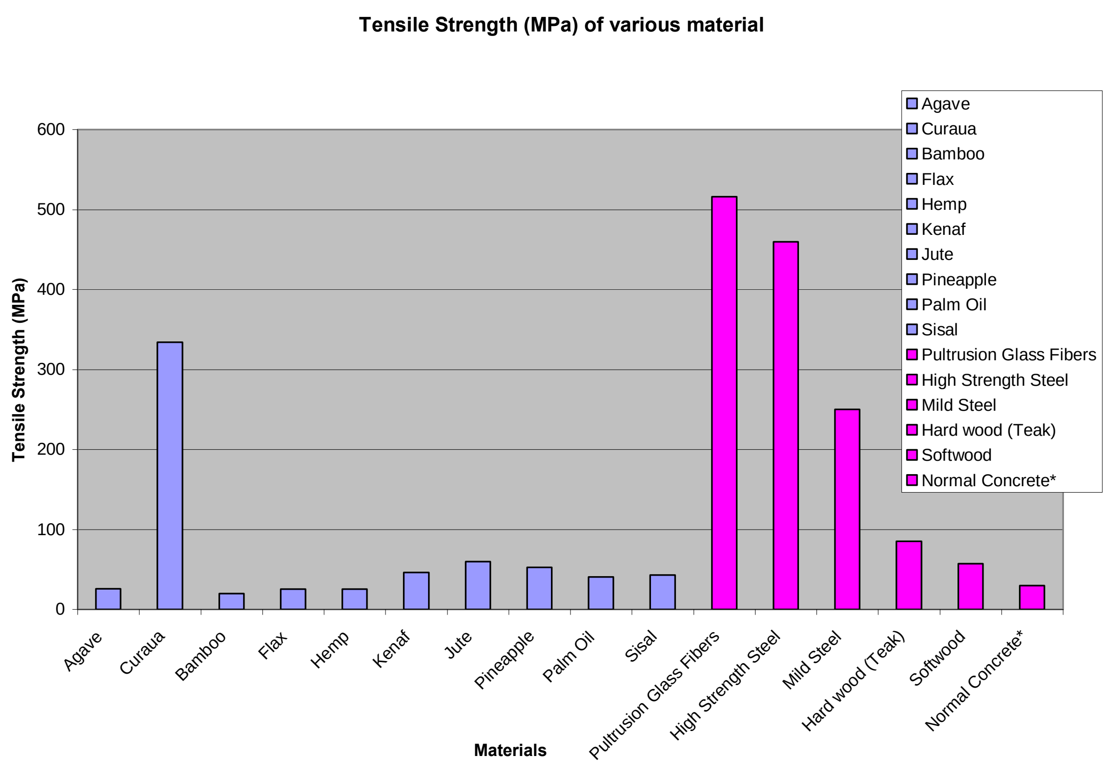
Materials in structural applications must have sufficient mechanical strength and durability to the surrounding environments. Figure 1shows the basic mechanical properties like tensile strength of the natural fibres reinforced composites are compared with the most common materials like FRP, steel, wood, and concrete. Some of the natural reinforced composites materials (like curuau fibres) are comparable to wood, steel and FRP. However, the overall average tensile strength of the natural fibre reinforced composites falls in the range of hardwood and softwood. Therefore, natural fibre reinforced composites can replaced conventional material like timber and wood in structural applications.

The wide variety of natural fibres exhibit different types of behaviour and characteristic. To limit the scope, oil palm fibres and pineapple leaf fibres are employed in this study because it can be obtained locally.

Malaysia, the world's largest palm oil producer, produces more than 15.8 million tonnes of crude palm oil every year[5]. The oil palm fibres are usually treated as residue product and cause environmental problems when disposing them. Oil palm fibres can be extracted from empty fruit bunch and its coirs. Every single empty fruit branch of oil palm yields 400 grams of oil palm fibre and weight of every fresh fruit bunch of oil palm is around 25 kg[6]. About 8.8 million tonnes of oil palm fibres can be produced every year and yet the mesocarp oil palm fibres are not taking into account. The enormous quantity of oil palm fibres is usually disposed by two methods, open burning or land fill[6].

Currently, reports have proved that treated oil palm fibres successful act as reinforcement in composites and durable to environmental attacks[7].

Pineapple leaf fibre is another natural fibre that can be obtained locally and exhibits excellent mechanical properties. The pineapple leaf fibre consists of high cellulose material and is very often associates with excellent mechanical properties. L.Uma Devi et al. study on pineapple leaf fibre composites and the composite exhibit excellent mechanical properties in tensile strength, flexural strength and impact strength. He concluded that the pineapple leaf fibres are good in reinforcing and suitable to be structural applications.



* Compression strength is compared.

Figure 1.1: The tensile strength of natural properties of natural fibre composites and other civil engineering materials.

1.3 Overall Objectives and Scope of the Study

1.3.1 Objectives of the study:

The main objectives of the study are:

1) To characterise the physical and mechanical properties of natural fibre - oil palm fibres.
2) To characterise the tensile properties of unidirectional oil palm fibre composites as a function of fibre volume ratio, fibre length, fibre surface modification.
3) To compare the mechanical behaviour of reinforced concrete beam strengthened with unidirectional oil palm fibre composite, reinforced concrete beam strengthened with woven glass fibre composite and ordinary reinforced concrete beam.

1.3.2 Scope of the study:

The scope of study is established to achieve the objectives and this study will be mainly concentrated on experimental works. To limit the scope, only oil palm fibres and pineapple leaf fibres are employed as natural fibres. The fibres are obtained in fresh condition and require the extraction process.

Synolac 3317AW, unsaturated polyester resin purchased from Cray Valley Company is employed in this study for matrix system. All natural fibre reinforced polymeric material is fabricated using the closed mould-hand lay up system.

All testing methods and procedures are specified according to British Standard and American Society Testing Method.

Firstly, the physical and mechanical properties of oil palm fibres are determined. The physical properties tests include fibre length, fibre diameter, moisture content, moisture absorption and fibre density. Only tensile properties are interested in determining mechanical properties. The tensile properties include tensile strength, strain and modulus elasticity of oil palm fibres.

Due to high efficiency in contributing tensile properties, only unidirectional oil palm fibres composites are interested and tested. Three main factors influence the desired mechanical properties of unidirectional oil palm fibre composites, namely fibre volume fraction, fibre aspect ratio and interfacial shear strength. Fibre volume fraction influence the tensile properties directly, where more fibres are used, the tensile properties are improved. However, the tensile properties may start to decline after the optimum point. The tensile properties are also affected by fibre aspect ratio where high fibre aspect ratio composite usually improve the tensile properties of the composite. Another important factor is interfacial shear strength of oil palm fibres which can be improved by using alkali treatment.

Different fibre volume fraction, fibre aspect ratio and interfacial shear strength of oil palm fibre composites are fabricated and tested under tensile force to determine tensile properties. Comparisons are made and the desired tensile properties of oil palm fibre are used in the structural application.

In this study, the desired tensile properties are used as strengthening material in reinforced concrete beam. A total of three 2000 mm x 150 mm x 250 mm reinforced concrete beams are fabricated. The first beam maintain as control beam while the rest of the beams are strengthened with unidirectional oil palm fibre composite plate and woven glass fibre composite plate. Similar fibre volume fraction is employed for both strengthening material.. The mechanical behaviours of the beams are analysis and discussed.

1.4 Summary

The development of natural fibre composite for structural application is still at infancy stage. Due to the attractive properties like high specific strength and high specific modulus, natural fibre composite rapidly gains popularity in the use of automobile applications and structural applications. Compare to synthetic fibre composite, natural fibres are low cost and abundant in agro base country. The use of natural fibres in composites can reduce the impact of environmental issues.

This study is a preliminary stage to made natural fibre composite as structural application where only mechanical properties is focused. In fact, durability of this new material in structural application is equally important. The use of natural fibre composite in structural application is possible but requires more study and development in future.

CHAPTER 2

LITEATURE REVIEW

2.1 General

The development of natural fibre reinforced polymer composite is still at infancy stage. A strong background of fundamental concept of natural fibre reinforced polymer composite is discusses in the following topics.

2.2 Natural Fibre Reinforced Polymer Composition

2.2.1 Natural Fibres

Natural fibres are threadlike and thick wall cells in plants. They are always long and can be easily extracted from the plants. The fibres usually can be group according to the origins of the plant: seeds, leaf, bast, grass stem and wood. Figure 2.1 shows different types of fibres based on their group.

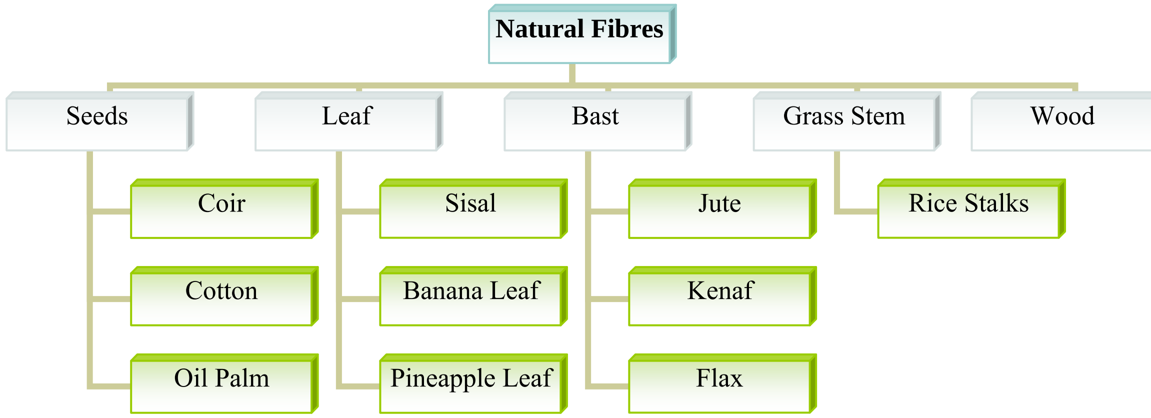


Figure 2.1: Natural fibres based on their group.

The biologists classify this type of plant cell as *Sclenchyma* cells and can be distinguished from other types of cells by its secondary wall layer. Fibres are frequently classified on the basis of vascular tissues as xlary or extraxylary. The preceding one is evolved from tracheids and the latter one occurs in tissues other than xylem. A better classification would divide the fibres into conducting fibres or non conducting fibres. Flax and hemp fibres are classified in extraxylary fibres.

The interest of natural fibre in composites increases dramtically recently due to its advantages over synthetic fibres. Table 2.1 shows the density and the cost of various types of fibres in market[15]. Natural fibres are low cost fibres with low density and high specific properties. They are biodegradable and cause no harm to humans, unlike the synthetic fibres which will cause health problems and environmental pollution[8]. Since most of the fibres are available as agricultural residue, lower environment impact compared to glass fibre production and thus reduce the disposal of agricultural residual via open burning and land fill. However, natural fibres have certain drawbacks that limit the potential of natural fibres and these are discussed more detail in the latter topic.

Table 2.1: The density and the cost of various types of fibres in market.

Fibre	Density	Cost (USD)
Flax	1.45	0.4-0.55
Hemp	1.48	0.4-0.55
Jute	1.4	0.4-0.55
Sisal	1.45	0.4-0.55
Ramie	1.5	0.4-0.55
Pineapple leaf	1.53	0.4-0.55
Cotton	1.55	0.4-0.55
Coir	1.15	0.4-0.55
Kenaf	1.4	0.4-0.55
Softwood	1.4	0.44-0.6
Hardwood	1.4	0.44-0.6
E-glass	2.5	2
S-glass	2.5	2

Natural fibres as mentioned earlier have a thick secondary wall and almost fill in the lumen of the cell. Unlike primary wall which present in all cells, secondary wall only exist in *Sclenchyma* cells. The thicker wall, the chemical composition and the texture of the microfibrils cause the wall to be stronger and resistant to fungal attacks[9].

Like primary wall, the four major components in secondary wall are cellulose, hemicelluloses, pectic substances and lignin. Table 2.2 have summarizes the chemical composition of various types of natural fibres.

Table 2.2: Chemical composition of various types of natural fibres.

Fibres	**Cellulose**	**Hemicellulose**	**Lignin**	**Others**	**Number of refences**
Agave	60-77.6	2.8-5.0	8-13.1	3.6-4	2
Banana	63-64	19	5	11	2
Hemp	57-77	9.0-13	0.8	9.2	1
Kenaf	59-81	-	15-19	2.0-5.0	1
Jute	71.5	13.4	13.1	2	1
Pineapple	70-82	-	5-12.7	1.1	3
Oil Palm	32-65	15-22	11.0-45	2	3
Sisal	65-72	12	9.9-14	10	2

The table indicates that most of the fibres are high percentage of cellulose contain, fibres like kenaf fibres and pineapple leaf fibres have composition of cellulose up to 80%. Therefore, cellulose is the primary component that made the fibres to be strong. Cellulose is composed purely of glucose molecules linked to each other by 1-4 β bonds[1]. The molecules contain from 8000 to 15,000 glucose monomers and are 0.25 to 5 μm long.

This bonding causes the molecules to be flat and ribbonlike and this allows the formation of intermolecular hydrogen bonds. The intermolecular hydrogen bonds lie parallel to each other and form more hydrogen bonds between themselves. The aggregate of the molecular yields the crystalizing product, microfibrils. Cellulose contain hydroxyl group and this cause microfibrils are hydrophilic and it is believed this factor causes the interfacial shear strength of fibres and resins.

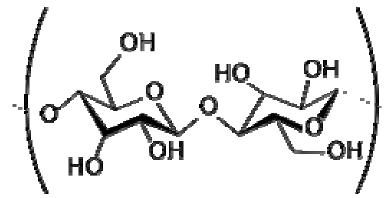


Figure 2.2: Hydroxl groups in cellulose monomer.

Another similar substance is hemicellulose which contains large amount in some natural fibres. Unlike cellulose, hemicellulose is highly branched and has a flat blackbone with 1-4 β bonds from which short side chains edge. Hemicellulose, armophous structure, is effectively gluing and coating the microfibrils together.

About 18% to 35% of the secondary walls may be composed of lignin. Lignin is an amorphous, heterogenous plastic formed by the free radical polymerization of various alcohols. The presence of lignin dramatically alters the nature of the secondary walls in three ways: by forming an extensive crosslinked networks over cellulose microfibrils, provides a stable, resistant and protective coating, and provide a waterproof barier around the microfibrils.

Table 2.2 also shows that the chemical compositions of the fibres are not in certain but in a wide range. This variability depends to the origins of the plants as well as the condition during the formation of the fibres.

Secondary walls have three layers, the outer layer, the central layer and the inner layer (shown in Figure 2.3). The orientation of the microfibrils and the thickness distinguish the position of the layer. The outer layer and the inner are deposited transversely to the long axis of the cell and these layers are rather thin. The central is the thickest layer and the most dominant in contributing mechanical properties. The fibrils are oriented almost parallel to the long axis of the wall.

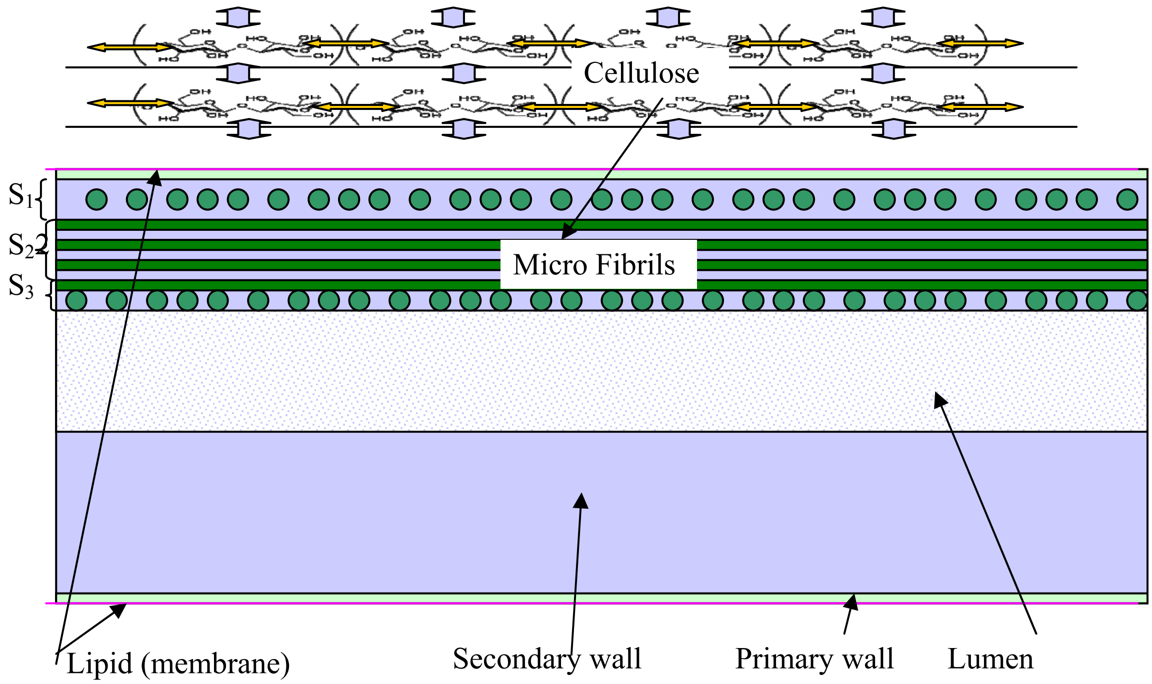


Figure 2.3: Schematic representation of a fibre cell and the micro fibrils.

2.2.1.1 Characteristic of Natural Fibres

Natural fibres are very strong when the fibres are subjected to tension force. Compare with synthetic fibres, natural fibres are in an enormous amount of variability in properties and thus the strength is in wide range whereas the synthetic fibres can be produced with a certain range. Table 2.3 summarizes the basic properties of various natural fibres that have been tested by previous researchers. The natural fibres are compared with commonly used synthetic glass fibres in the industry. Apparently, all natural fibres have lower strength than glass fibres. However, the specific tensile strength and specific modulus of some natural fibres are comparable to or better than glass fibres. These higher specific modulus are one of the major advantages of using natural fibre composites for application wherein the desired properties and also include weight reduction[2].

Table 2.3: Summarizes the basic properties of various natural fibres.

Fibres	**Density (g/cm^3)**	**Tensile Strength (MPa)**	**Tensile Modulus (GPa)**	**Strain**	**Specific Strength**	**Specific Modulus**	**Number of Refences**
Agave	0.74	100-500	1.7-13.2	19-4.8	135-676	2.3-17.8	2
Curaua	1.38	913	30.0	3.9	662	21.7	1
Banana	1.35	540-600	8.0-20.0	3.36	400-444	6-14.8	4
Bamboo	0.9	341-503	19.7-35.9	1.4-1.73	379-559	21.8-40	1
Flax	1.5	343-1035	27.6	2.7-3.2	690-229	18.4	2
Hemp	-	1802-2251	1312-195	1.7-2.3	-	-	3
Kenaf	0.75	377	12.0-28.6	1.3-3.3	503	15.9-38.1	2
Jute	1.24	120-1461	3.75-107	1.2-4.8	97-1178	2.53-86.7	4
Pineapple	1.53	170-640	4.2-6.21	2.4-3	111-418	2.75-4.1	4
Oil Palm	1.03	64-377	0.5-5.25	6.5-25	62-366	0.49-5.1	4
Sisal	1.45	350-635	2.8-9.4	2.0-7.0	241-438	1.9-6.5	5
E-Glass	2.56	3400	72	2.5	1360	28.8	1

2.2.1.2 Oil Palm Fibres

The oil palms (Elaeis) comprise two species of the Arecaceae, or palm family. They are used in commercial agriculture in the production of palm oil. The African Oil Palm Elaeis guineensis is native to West Africa, occurring between Angola and Gambia, while the American Oil Palm Elaeis oleifera is native to tropical Central America and South America.

Mature trees are single-stemmed, and grow to 20 m tall. The leaves are pinnate, and reach between 3-5 m long. A young tree produces about 30 leaves a year. Established trees over 10 years produce about 20 leaves a year. The flowers are produced in dense clusters; each individual flower is small, with three sepals and three petals. The fruit takes five to six months to mature from pollination to maturity; it comprises an oily, fleshy outer layer (the pericarp), with a single seed (kernel), also rich in oil. Unlike other relatives, the oil palm does not produce offshoots; propagation is by sowing the seeds.

The production of palm oil in 2007 is 15.8 million tonnes and 15.9 million tonnes in 2006. Generally, oil palms fibres can be extracted from two important fibrous materials left in palm oil mill, empty fruit branch and coir. Every bunch of empty fruit branch yield oil palm fibres up to 400g. The coir of the oil palm and empty fruit branch are left as waste after the oil extraction and create great environmental problems.

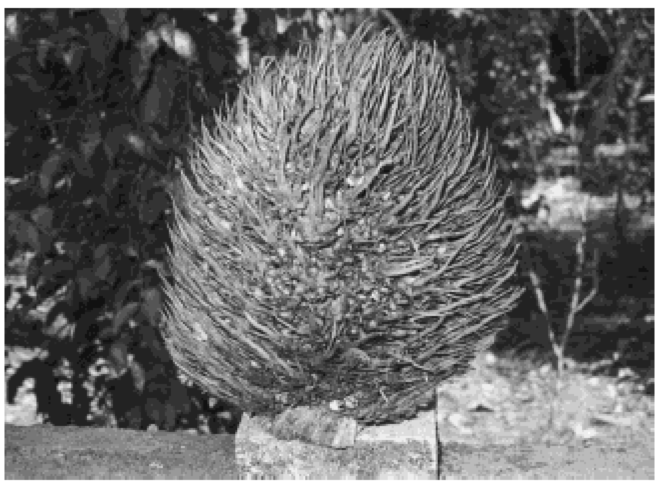


Figure 2.4: Oil Palm Empty Fruit Branch.

2.2.1.3 Pineapple Leaf Fibres

The pineapple industry of Malaysia is the oldest agro-based export-oriented industry dating back to 1888. Though relatively small compared to palm oil and rubber, the industry also plays an important role in the country's socio-economic development of Malaysia, particularly in Johor. In 1997, the industry has contributed RM70.53 million to

Malaysia's export earning. The industry provides employment and also contributes towards the growth of other supporting economic activities such as packaging, transportation and labeling.

Although pineapple can be grown all over the country, the planting of pineapple for canning purposes is presently confined to the peat soil area in the state of Johor which is the only major producer of Malaysian canned pineapple. In other states such as Selangor, Perak, Kelantan, Terengganu, Negeri Sembilan, and Sarawak, pineapple are planted specifically for domestic fresh consumption. The pineapple leaf is left after the extraction of the fruits. Therefore, without any additional cost, the pineapple fibres can be obtained from the industry.

2.2.2 Thermosetting Polyester Resin

Resin is another important element in natural fibre reinforced composite materials. The primary functions are to bind the two materials and transfer the stress between the reinforcing fibres and yet provide a protection for natural fibres from aggressive environment attacks. In general, resins are also named as polymers or plastic. In chemical view, polymers are defined as a large molecule built up by repetition of small, simple chemical units which can be divided into two main groups, namely thermoplastic and thermosets. Table 2.4 shows representative properties of different types of thermoplastic and thermosets resins.

Thermoplastic are solid at room temperature. They soften or melt when heated and re-harden when cooled. The reactions are reversible and do not cross link like thermosets polymers. Themroplastics generally are tough compared to thermosets and are widely used without reinforcement. However, their stiffness and strength properties, although similar to those of thermosets, are low compared to other structural materials. Thermoplastic can be formed into complex shapes easily and economically by process such as injection moulding, extrusion and thermoforming. Thermoplastic are also relatively more susceptible to attack by solvents than thermoset plastic.

While, thermoset plastic are materials that are cured, or hardened into a permanent shape under an elevated temperature by an irreversible chemical reaction known as cross linking. Thermoset plastics are generally brittle and are rarely used without some form of filler or reinforcement. Because of their cross-linked structure, thermosetting plastic have relatively good creep resistance and elevated temperature properties, although modulus and strength decrease with increasing temperature. The most common thermoset resins are epoxy, vinyl esters and polyesters.

Polyesters, the focus of this study, tend to have similar elastic properties like epoxy, but with lower strength characteristic. Polyesters are used extensively as laminating resins, moulding compositions, fibres, films, surface coating resins, rubbers and plasticiers.

Table 2.4: Representative properties of different types of resins.

Resin	Type	Density	Tensile Modulus GPa	Tensile Strength MPa
Epoxy	Thermoset	1.1-1.4	2.1-5.5	40-85
Phenolic	Thermoset	1.2-1.4	2.7-4.1	35-60
Polyester	Thermoset	1.1-1.4	1.3-4.1	40-85
Acetal	Thermoplastic	1.4	3.5	70
Nylon	Thermoplastic	1.1	1.3-3.5	55-90
Polycarbonate	Thermoplastic	1.2	2.1-3.5	55-70
Polyethylene	Thermoplastic	0.9-1.0	0.7-1.4	20-35
Polyester	Thermoplastic	1.3-1.4	2.1-2.8	55-60
PEEK	Thermoplastic	1.3-1.4	3.5-4.4	100
PPS	Thermoplastic	1.3-1.4	3.5	78

2.2.2.1 Characteristic of Unsaturated Polyester

The vast diversity of Polyesters in market shares the common feature of ester link. In general, the unsaturated polyester resins are produced by condensing a glycol with both and unsaturated and a saturated dicaroxylic acid. The unsaturated acid provides a site for subsequent cross-linking whilst provision of a saturated acid reduces the number of sites for cross-linking and hence the cross link density and brittleness of the end the product[2]. Besides that, diluents are added in the resins which can decrease viscosity and thus more workable. Styrene is preferred reactive diluent in general purpose resin due to its low price. Others diluents like methyl methacrylate, vinyl toluene and diallyl phalate are occasionally employed. A number of special materials are mixed in resin to carry out special purpose like improving heat resistance, self extinguishing and ultraviolet stabilizers.

Before applying the resin to the reinforcement, the resin requires a curing system to become rigid. The curing may range from a few minutes to several hours with either ambient temperature or elevated temperature which depends to the curing system adopted. For large hand lay-up structures, curing usually are carried out at room temperature. The curing system consists of two components, peroxides (catalyst) and cobalts (accelerator). The the most common catalyst used in commercial are methyl ethyl ketone peroxide (MEKP) and cyclohexanone peroxide. MEKP is in liquid form whilst cyclohexanone peroxide is in powder form. MEKP is easy to be measured by using a burette but great care must be taken to ensure the liquid is uniformly spread. Whereas cyclohexanone peroxide need to be weighed but it is easier to observed dispersion and spillage. Cobalt naphthenate is generally used as accelerator and mixed in solution of styrene. Polyesters commonly have quantities of 0.5-4.0% of cobalt solution as the accelerator is rather unstable which can cause styrene to be polymerized. The peroxides and accelerator should not be mixed together as the mixture can cause explosion. The polyester starts to gel after mixing according to the right concentration of catalyst and accelerator. The gelation and exothermic reaction indicate cross linking process has occured. It has been recorded a rise of temperature up to 200ºC after the gelation process. The heat is reduced when the glass fibres are applied because the high surface/volume ratio facilitates removal of heat. The hardening is usually accompanied by substantial volumetric shrinkage (~8%). Due to the ease of works, unsaturated polyester resins are very common used in most of the applications.

2.2.2.2 Structure and Properties of Polyester Resin

Synolac 3317AW, unsaturated polyester resin, is the focus of this study is which is purchased from Cray Valley Company. This cloudy pink thermoset resin is tough, high tensile elongation and good water resistance. Table 2.5 summarizes the basic mechanical properties of cured resin without any reinforced materials which is obtained from the supplier. The data shows that this material has a lower strength than most of the natural fibres which is compatible to be used in composites.

Table 2.5: Basic mechanical properties of Unsaturated Polyester.

Barcol Harness	40
Tensile Strength	65 MPa
Tensile Modulus	3600 MPa
Elongation at break	3.8%

Synolac 3317AW is generally used in hand lay-up, spray deposition and machine molding process which is suitable in application like manufacture of water tanks, vehichle bodies, building panels, FRP furniture and similar applications. Like most thermoset resins, Synolac 3317AW requires curing system and it is initiated by adding catalyst into the liquid polyester resin. According to the specification, 2% of MEKP K1 (catalyst) is added into 100g of resin and require 8-11min of curing time.

2.3 Properties of Natural Fibre Reinforced Polymer

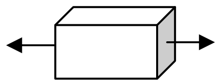
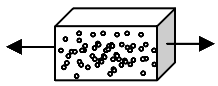
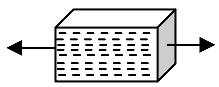
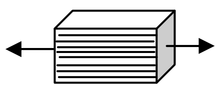
In composite materials definition, the two-phase materials can be classified into three broad categories depending on the type, geometry and orientation of the reinforcement phase namely particulate filler, discontinuous fibres and continuous fibres. Different types of fibres, geometry and orientation of the fibres produced different mechanical properties.

Table 2.6 shows experimental stress strain data for a variety of glass/epoxy systems. Continuous fibres composite lies in the highest bound and are followed by short fibres composite, finally particulate composite. Therefore, it can be concluded that unidirectional fibre composites are the most efficient from the point of view of stiffness and strength. To narrow down the scope, only unidirectional of continuous fibres and discontinuous fibres are the main focus of this study.

Despite the type, geometry and orientation, there are others factors influence the properties of unidirectional natural fibres reinforced polymer. For unidirectional fibre reinforced polymer, the factors may include fibre volume ratio, fibre length, fibre properties, resin properties and interfacial shear strength. Besides that, types of fabrication can also affect the mechanical properties of the composite materials. These factors are further discussed in the latter topics.

Besides the strength of the material, durability of the material is also a major issue. Natural fibres are complex mixtures of organic materials; therefore, they are prone to be attacked by biological organisms and photo degradation. In addition, natural fibres are hydrophilic and can easily absorb moisture which may lead to dimensional variations in long term. Another common issue in composites is the thermal compatibility of fibres and resin which may also influence the performance of the composites material in long term.

Table 2.6: Experimental Stress Strain Data for a variety of Glass/Epoxy Systems.

System (Stress direction)	Filled Shape and Orientation	Strength (x 10^{-3} psi)	Stiffness (x 10^{-6} psi)	Ultimate Strain (%)	Volume Fraction
Neat Resin		10-12	0.3-0.4	4-5	0
Particulate Composite		9-10.5	1.5-1.7	2-2.5	0.5
Short Fibres (Longitudinal)		40	4.5	0.6-1	0.5
Continuous Fibres (Longitudinal)		130-160	6.3-6.8	2	0.5

2.3.1 Tensile Properties of Unidirectional Fibre Composites

Most of the unidirectional fibre reinforced polymer composites are designed to carry longitudinal tension force due to the major reason – high axial tensile strength. In this study, unidirectional natural fibre composites are used in strengthening material for a reinforced concrete beam.

The developments of natural fibre composites are still in infancy stage currently. Most of mechanical properties of natural fibre composites reported in the past are from polymer industry. Table 2.7 summarizes the highest tensile strength that has been tested based on various types of natural fibres. The data collected shows that most of the natural fibres reinforced polymer composites currently under research have less tensile strength than the synthetic glass fibre composites. Though curau fibre reinforced composite achieves outstanding tensile strength with a maximum value of 334MPa, in general, the strength of natural fibres reinforced polymer material is comparatively low.

Fibre volume ratio, fibre aspect ratio, interfacial shear strength of fibre and resins, and fabrication methods are the main factors that influence the mechanical properties.

Fibre Volume Ratio

One of the most important factors affecting composite properties is the amount of fibre it contains. The amount of fibre contains in a composite is usually defined by volume ratio. According to rules of mixture, a property of the composite is equal to the sum of fibre and matrix properties weighted by volume fraction. Fibre usually has better mechanical properties than resin. Therefore, more fibre impart in the composite, theoretically the tensile properties of the composite is improved.

Fibre Length

All natural fibres are discontinuous fibres where one or both end of the fibres within the stress field. Unlike continuous fibre, discontinuous fibre cannot be fully stressed over its entire length unless the fibre length has achieved the effective length. This means that the discontinuous fibre would be less efficient reinforcement. Hence, elasticity of the composite in this study was improved when longer fibre length was used. Besides that, discontinuous fibre would also face larger shear stress concentration at the ends of the fibres. This is due to the sharp edges give rise to stress singularities. This situation is further complicated when localized failure occurs.

Table 2.7: The highest tensile strength that has been tested based on the types of natural fibres.

Fibres	**Plastic**	**Types of Plastic**	**Fibre Loadings %**	**Types of Fibre Treatment**	**Tensile Strength (MPa)**	**Tensile Modulus (GPa)**	**Strain at Break %**	**References**
Agave	HDPE-Petrthene	Thermoplastic	20	NaOH+Silane	26	0.8	-	P.J.Herra-Franco, A.Valadez Gonzalez
Curaua	Randy CP-300	Thermoplastic	70	alkali treated 10%NaOH	334	32	1.74	Alexandre Gomes, Takanori Matsuo, Koichi Goda, Junji Ohgi
Bamboo	Polypropylene	Thermoplastic	-	Untreated	20	2	-	Moe Moe Thwe, Kin Liao
Flax	Bionolle (Biodegradable Polyester)	Thermoplastic	25	Acetate	25.5	1.62	4.8	Massimo Baiardo, Elisa Zini, Mariastella Scandola
Kenaf	Polypropylene (Profax 6501)	Thermoplastic	30	Untreated	46	-	-	M.Zampaloni, F.Pourboghrat, S.A.Yankovich, B.Nrdgers, J.Moore, L.T.Drzal, A.K.Mohanty, M.Misra
Jute	Polyester	Thermoset	45	Untreated	60	7	0.03	T.Munikenche Gowda, A.C.B.Naidu. Rajput Chhaya
Pineapple	Polyester, HSR 8131	Thermoset	30	Untreated	73.5	2.45	4.3	L.Uma devi, S.S. Bhagawan, Sabu Thomas
Palm Oil	Polyester, Crystic 471 PALV)	Thermoset	45	Acetylated	40.5	4.01	4.54	C.A.S.Hill, H.P.S. Abdul Khalil
Pultrusion Glass Fibre	Unsaturated Polyester	Thermoset	50	-	516	40.41	1.36	Jamaludin Bin Mohamad Yatim

Fibre Surface Modification

The common issue in most composite materials is the incorporation of both materials. The composites materials may not exhibit the best performance if both of the materials are incorporated. This issue is highlighted in natural fibre reinforced composites whereas the interfacial shear strength is generally low.

The elementary unit of the fibres is cellulose whereas the cellulose contains three hydroxyl (-OH) ions. These hydroxyl groups not only responsible for the intramolecular and intermorlecular bonding but also causes all natural fibres are hydrophilic in nature. The natural fibres are hydrophilic whereas the resins espeacially polyester is hydrophobic in nature. The imcompatibility of both materials leads to poor wetting of the fibres by the resin and this reduces the interfacial shear strength and thus a reduction of mechanical performances. Researchers believe that this character is the major factor that leads to the low interfacial shear strength. Table 2.8 shows the interfacial shear strength of natural fibres and matrix. The interfacial shear strengths of natural fibres are generally low relative to synthetic glass fibres. To increase the interfacial shear strengths, chemical treatments are considered to optimize the interface of fibres. Types of chemical have been tried and tested will be discussed in the following topic.

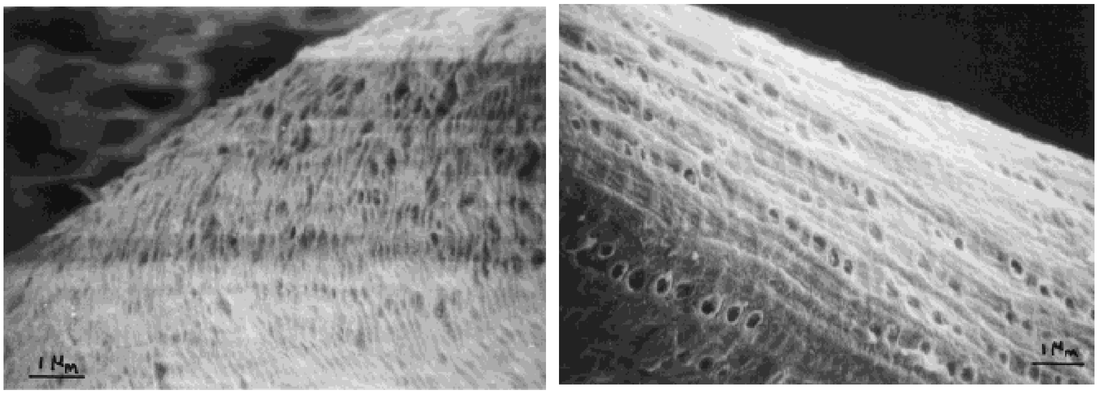
Alkaline treatment is one of the most used and old method to modify the surface of the fibres. This treatment will disrupt the surface of the fibre and remove a certain amount of lignin, wax, and oils that cover the external surface of the cell wall. Besides that, the alkaline may also modify the hydroxl groups in cellulose and introduce new ions to cellulose[14 10]. The reactions are as follows:

$$\text{Fibre-OH} + \text{NaOH} \rightarrow \text{Fibre-O-Na} + H_2O$$

Table 2.8: The interfacial shear strength of natural fibres and matrix

Fibres	Matrix	Interfacial shear strength (MPa)	References
EFB (Oil Palm)	Polyester	1.83	C.A.S.Hill, H.P.S.Abdul
Coir (Oil Palm)	Polyester	1.98	C.A.S.Hill, H.P.S.Abdul
Henequen	HDPE	5.4	P.J.Herrera-Franco, A.Valadez-Gonzalez
Coir (Oil Palm)	Polystrene	1.45	H.P.S.A. Khalil, H. Ismail, H.D.Rozman, M.N. Ahmad
Glass	Vinylester	30	X. Dirand, B. Hilaire, J. P. SoulieF & M. Nardin

M.S.Sreekala et al. investigated the effects of alkaline treatment to the oil palm fibres. The fibres were immersed in 5% of sodium hydroxide solution for 48 hr. the fibres were washed with a few drop of acetic acid to neutralize the residue alkali. The fibres were washed with distilled water and dried. Through SEM examination (Figure 2.5), the surface of the natural fibres becomes rougher where the pits become more obvious and clear. The effect of mercerization become more obvious as the weight of the fibres decreased up to 22-25%. In IR spectra study, alkali treatment may reduce the hydrogen bonding in cellulosic hydroxyl groups and remove the carboxyl groups. The removal of carboxyl groups may present of the fibre surface from traces of fatty acids presents. For thermal stability aspect, this treatment increased the initial degradation temperature up to 350°C compare to untreated takes place at about 325°C. However, the tensile strength of the fibres is reduced. This may due to the bleaching of the oily and wxy materials from the fibre surface. This fact is true as most of the strength of treated fibres decreased drastically after certain optimum NaOH concentration[14 10].



(a) (b)

Figure 2.5: Scanning electron micrographs of oil pam fibres: (a) Untreated oil palm fibre surface and (b) Alkali treated oil palm fibre surface (x400)

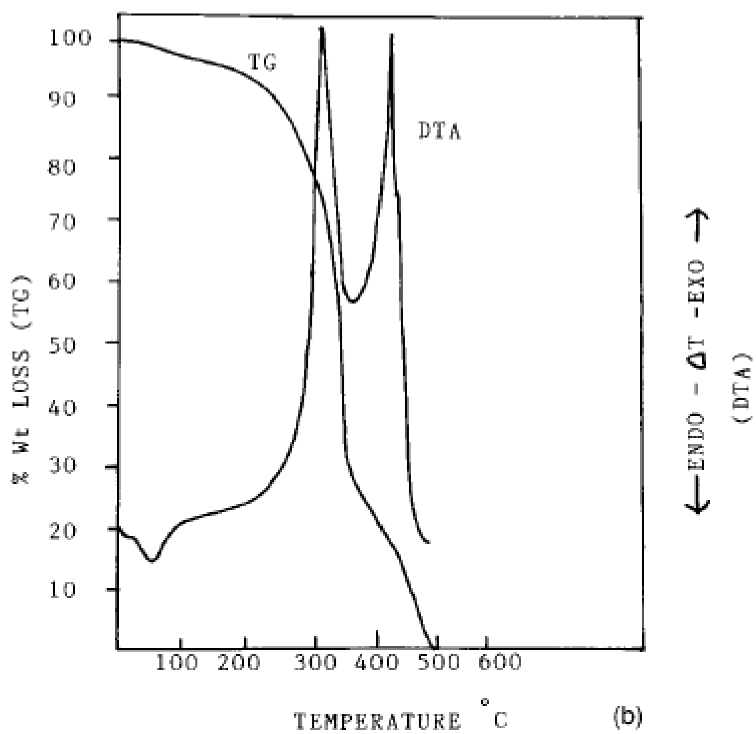


Figure 2.6: TGA and DTA curves of Alkali treated Oil Palm Empty Fruit Brunch Fibres.

2.3.2 Thermal Properties

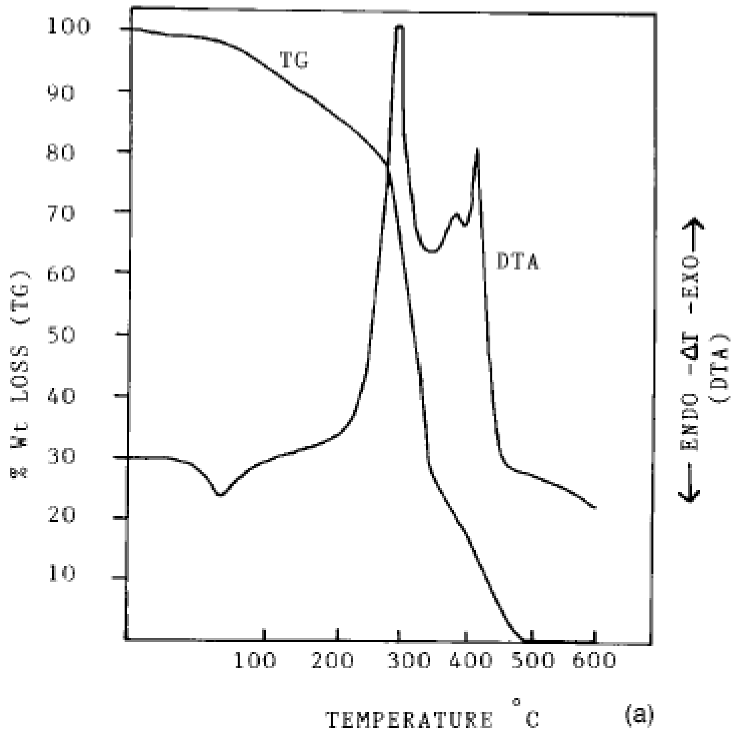


Figure 2.7: TGA and DTA curves of Oil Palm Empty Fruit Brunch Fibres.

Natural fibres are very complex in terms of chemical compounds; as a result, thermal treatment on the fibres will lead to physical and chemical changes[2]. Thermal expansion and thermal degradation are equally important if the thermoplastic materials are used where high termperatures is required. The thermal degradation has been reported by M.S.Sreekala for Oil Palm Empty Fruit Brunch Fibres[6]. The results of Thermal Gravimetric Analysis (TGA) and Differential Thermal Analysis (DTA) are shwon in the Figure 2.7. Below 100°C, 5-8% of weight losses is observed and it is due to the dehydration of the fibres. At about 325°C, major weight losses are found and DTA curves shows major peak in this reqgion. This may due to the thermal depolymerization of hemicellulose and the cleavage of the glucodic linkages of cellulose. The second peak of DTA curves indicates that the fibres are decomposed and formations of charred residue occur. D.Nabi Saheb conclude that temperature more than 200°C may lead to thermal degradation of the fibres and thus lead to porous polymer products with lower densities and inferior properties.

2.3.3 Moisture Content

The nature of the fibres is hydrophilic and the fibres absorb moisture. The moisture content can vary between 5 to 10%. This would lead to dimensional variation in composites and thus affects the mechanical properties. Moisture diffusion in composites may degrade mechanical properties by three different mechanisms. The first involves diffusion of water molecules inside the micro gaps between polymer chains. The second involves capillary transport into the gaps and flaws at the interfaces between fibre and matrix. The third one involves the swelling effects which propagate the microcracks in matrix. In general, moisture diffusion depends on factors such as volume fraction of fibre, voids, viscosity of matrix, humidity and temperature[11]. For oil pam fibres, M.S.Sreekala et al. investigated the water-sorption and conclude that Oil Palm Empty Fruit Brunch showed higher sorption of water than the coil fibres[12]. This absorption of moisture leads to degradation of fibre matrix interface region and creating poor stress transfer efficiencies.

2.3.4 Biodegradation and Photo Degradation

Natural fibres are likely to be attacked by the organism since they can recorgnize the carbohydrate polymers in the cell wall. Besides that, natural fibres when expose to ultraviolet light the properties will undergo photochemical degradation. This is investigated by C.A.S. Hill on the effect of environmental exposure upon the mechanical of coir or oil palm fibre reinforced composites. The primary conclusion shows that treatment on natural fibres shown good retention of mechanical properties during soil or water exposure tests[13].

2.4 Treatment on Natural Fibres

Natural fibres, hydrophilic in nature, exhibit poor compatibility with resins which are hydrophobic. Low interfacial shear strength of natural fibres and resins reduce the overall strength and thus limits the potential of natural fibres as reinforcing agents. This problem is highlighted in most of the researchers that interested in natural fibre reinforced polymer field. Treatment on natural fibres is essential to improve the interfacial shear strength of both natural fibres and resins.

Generally, the treatment can be grouped into physical treatment and chemical treatment. Physical treatment involves surface fibrillation, electric discharge and etc. This method intends to change structural and surface of the fibre and thereby influence the mechanical bonding with resins[14].While, chemical treatments involves modification of hydroxyl groups and introduce new ions that can effectively interlock the matrix. To limit the discussion, chemical treatments are considered here whereby this treatment is easy to apply and low technology is used. Until recently, there are numerous reports related to chemical treatments on different types of fibres. The chemical treatments that have been tried and tested are alkaline treatment, silane treatment, acetylation treatment, benzolation treatment, arcylation and arcylonatrile grafting, maleated coupling agents, permanganate treatment, peroxide treatment, isocyanate treatment, stearic treatment and etc.

Not all the chemical treatments show positive effects, instead some reports indicate that the treatments are inert or show little improvements. Despite improvement of interfacial shear strength, chemical treatments may enhance also the thermal properties, moisture absorption properties, bidodegradation properties.

2.5 Method of Fabrications and Current Applications

The characters of the natural fibre may influence greatly in the fabrication process and its applications. Natural fibres are discontinuous fibres unlike synthetic fibre which can be infinity length. In addition, one of the obstcales addressed by M.Zampaloni et al. is the uneven fibre distribution. The kenaf fibres are difficult to manually separate and visually disperse evenly during fabricating[15]. Therefore, the fabrication method may not applicable in pultrusion, filament winding, and prepreg layup which require consistent fibre length. The oldest fabrication methods in composite is hand layup method is and it is applicable and use widely in research. Besides that, natural fibre composite can be fabricated under mold process like open mold, matched-die, compression molding and transfer molding process. To fabricate simple sections like I beams, tubes and channels, extrusion method is applicable in the industry. Extrusion process involves pushing the material through a die of the desired profile shape and it can be continuous or short pieces.

Recently, interest in commercialization of natural fibre composites has increased espeacially for interior panelling in the automobile industry. DaimlerChrysler Corporation use natural fibre composite in engine and transmission cover for new Mercedes-Benz Travego. They claim that use of natural fibres reduces weight by 10 percent and lowers the energy needed for production by 80 percent, while the cost of the component is five percent lower than the comparable fibreglass-reinforced component.
In construction industry, a Malaysia company, name Fibresit Sdn.Bhd.has made a first move in the natural fibre composites. They claim that their products made of wood fibres (sawdust and rice husks) and 100% of recycled high density polyethylene plastic (pop bottles/detergent containers), are durable and strong and fit to be construction materials which can replace the timber (Figure 2.9).

Figure 2.8: Interior panelling in new Mercedez Benz automobiles.

Figure 2.9: Fibresit site office.

5 failure mode usually occur in reinforced concrete beam, namely concrete crushing, FRP rupture, cover delamination at the end of FRP, interfacial debonding due to flexural crack or shear crack and shear failure.

2.6 Conclusions:

Natural fibres exhibit superior advantages over the synthetic fibres espeacially in cost, environmental aspects and high specific modulus compare to synthetic fibres. However, the drawbacks of the natural fibres include low shear interface strength, thermal stability, water absorption, biodegradation and photodegradation; limit the potential of natural fibre composites in structural use. The drawbacks can be partially overcome by introducing treatments either chemically or physically to the natural fibres. A lot trials and testing have been reported in the last decade and succesful treated fibres should be reviewed and retested before the potential of natural fibre composites utilize in structural application can be concluded.

CHAPTER 3

EXPERIMENTAL PROGRAMME

3.1 General

This chapter discusses and describe a series of experimental programmes to characterize oil palm fibre composite. The experimental programmes include characterization of fibre properties, characterization of oil palm fibre composite and characterization of oil palm fibre composite as strengthening material for reinforced concrete beam.

3.2 Outline of the Experimental Programme

The experimental programmes are divided into three stages to accomplish the objectives of this study.

The first stage is to determine the physical and mechanical properties of the fibres. The physical properties include fibre length, fibre diameter, moisture content of fibre, moisture absorption of fibre and density of the fibre. Only tensile properties are interested in characterization of mechanical property of the fibre. The tensile properties consist of tensile strength, modulus of elasticity and strain.

The second stage of the experimental programme is to determine the mechanical and physical property of the unidirectional natural fibres reinforced polymer composite. The composite is fabricated by employing closed-mould hand lay-up method.

Three important factors affecting the tensile properties of the composite are study. There are fibre volume fraction of the composite, fibre aspect ratio and treated fibre. The fibre is prepared according to different fibre volume fraction and different fibre length. There are several chemical can be successfully treated on the fibre. Only alkali treatment is interested in this study. Before the composite is fabricated, the gelation time of the polyester is adjusted to increase the workability of the fabrication process by controlling the quantity of catalyst.

The tensile test is carried out to determine the tensile properties of the composites. The optimum fibre volume fraction, fibre aspect ratio and treated fibre are determined and the methods of fabricating the desired tensile properties are use in structural application.

The third objective of this study is to prove natural fibre composite can be used as structural applications – strengthening material. Oil palm fibre composite plate is made and it is installed beneath the reinforced concrete beams. The mechanical behaviour of the reinforced concrete beam strengthened with unidirectional oil palm fibre composite plate is compared with ordinary reinforced concrete beam and reinforced concrete beam strengthened with woven glass fibre composite plate.

3.3 Property Test on Natural Fibres

3.3.1 Fibres Extraction

3.3.1.1 Oil Palm Fibres

Oil palm fibres are currently used as wood plastic, medium density fibreboard (MDF), erosion control and landscaping. There are two types of fibres that can be obtained from oil palm plants, namely empty fruit brunch and the coir. In this study, empty fruit brunch fibres are employed and are obtained from Sabutek Sdn. Bhd. The fibres are extracted in factory and are grouped into rectangular bales. It is observed that the oil palm fibres are curly, different direction and entangled. Therefore, the fibres require further process to become straight and aligned in one direction.

Figure 3.1: Empty Fruit Brunch of oil palm fibres.

Combing Process

The oil palm fibres are "comb" using a larger spacer. Then, a finer spacer comb is applied to the fibres. It is observed that the fibre become straighter and aligned in one direction. However, the oil palm fibres are still not as straight as synthetic fibres.

Figure 3.2: Oil palm fibres is obtained in a rectangular bales. The Fibres are curly, different direction and entangled.

Figure 3.3: Processed oil palm fibres after combing process.

3.3.1.2 Pineapple Leaf Fibre

Pineapple leaf fibres are extracted from the leaves by using the simplest and the fastest method, namely Green/Mechanical method. The processes include harvesting, cutting, milling, decortication, cleaning and storing.

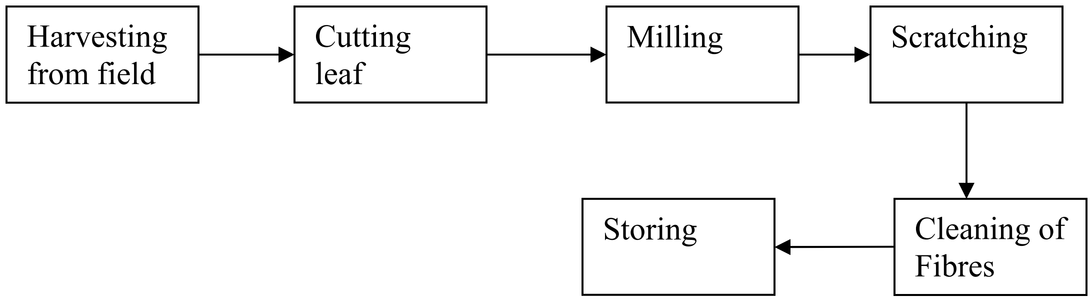


Figure 3.4: Process flow of pineapple leaf fibres in laboratory.

i) Harvesting and Cutting

Pineapple leaves are obtained from the pineapple plant after the fruit is ripe and cut. The leaf is about 45 cm long and 4 cm wide. It is observed that the end of the leaf is white colour and the edge of leaf is red colour with thorn. The rest of the part is light green at the bottom of the leaf to dark green at the tip of the leaf.

Figure 3.5: Pineapple Leaf fibres before cut.

ii) Milling

The leaf is crushed in a smooth roller milling machine. Due to compression action, the moisture in the leaf is partially removed and the leaf is break into small fragments.

However, it can be seen that the fibres remain unbroken. The fibres can be easily visualized in green part while in white part fibre is hardly to discover. The milling process should be repeated several times until the leaf is broken into the finest fragments. However, this process should not be excessive to avoid damaging the fibres.

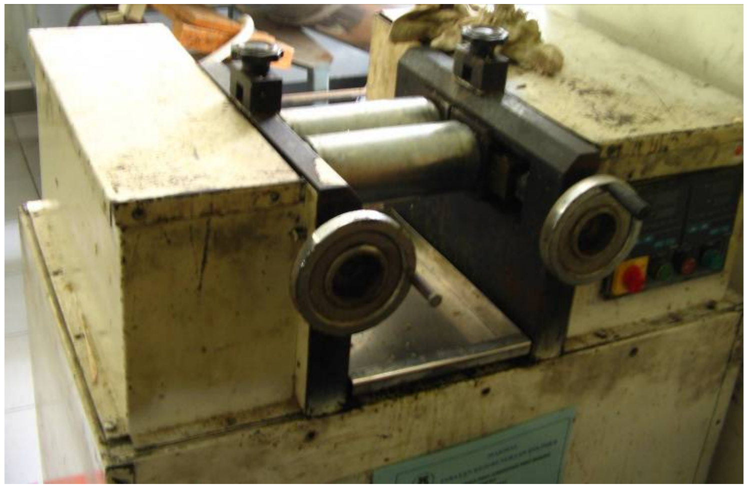


Figure 3.6: Smooth roller milling machine.

iii) Scratching/decortication

At this stage, the fibres can be easily seen and separated from each and others. However, the fibres remain "dirty" and are bundled by the natural adhesion. Thus, a thin blade is used to scratch out the woody tissue. The objective of scratching is to mechanically removed the debris from the fibres and disaggregate the fibre bundles. It is believed that the fibres may suffer from damage during this process and affect the mechanical properties of the composite latter.

iv) Cleaning and Storing

The fibres are brushed to further remove the debris. The fibres are grouped together and are stored in a cool and dry place. To avoid fibres aggregate and entangle, the fibres are laid in one direction.

3.3.2 Physical Test

3.3.2.1 Fibre Length

Natural fibres are discontinuous fibres, however they are considered fairly long compared with their diameter. The length of the fibres is influenced by the nature of the plant and retting process. Like pineapple leaf fibres, the fibres can be as long as 0.5m but the overall fibres length after retting process can reduce to 0.3m.

The length of the fibres will affect the performance of the composite in terms of strength and workability during composite fabrication. These effects are reported by L.Uma Devi et.al. (1996), where 30% of fibre weight of various fibre lengths are studied. The results showed that 30mm of fibre length produced the highest tensile strength. Their study also discover that long fibres tend to bend or curl during molding and cause a reduction in the effective length of the fibre below optimum length, which results in a decrease of properties.

This test is purposely carried out for oil palm fibres only because the obtained oil palm fibres are in various lengths. The objective of this test is to determine the distribution of fibre length from the primary sampling units. From the results, the optimum fibre length that can be obtained from a bale of oil palm fibres can be determined.

The concept is very simple but the process is tedious. A small sample of the fibres is obtained randomly by hand from the primary sampling units. The fibres are separated and loosened by the comb. Then, every single fibre is measured and the length is recorded according to the range. A distribution of fibre length is plotted.

3.3.2.2 Fibre Diameter

The purpose of this test is to determine the average diameter of oil palm fibre for tensile test of single fibre and study of the influence of fibre aspect ratio of composite. Cross sections of natural fibres are studied by K.Murali Mohan Rao and the diameters of the natural fibres are measured[16]. The study shows that cross section of natural fibres are not in circular shape but are in irregular shape. This shows that the width of the fibres may not be the exact fibre diameter. However, to simplify the measurement, the cross section natural fibre is usually assumed as circular shape. To be more accurate to predict the cross section area, the diameters of the fibres is recorded several times and average diameter is calculated.

ASTM D2130-90, Standard Test Method for Diameter of Wool and Other Animal Fibres by Microprojection is referred to determine the diameter of oil palm fibre[17]. The objective of this test method is for testing wool and other animal fibres for average fibre diameter. The test method describes the detail procedure for measuring the diameter of representative sampling fibres under high magnification of microscope. The observed data are computed to obtain the average fibre diameter and the variation of the fibre diameter.

The apparatus and material in this test include microscope with magnification of 100 x, wedge scale, digital camera and Video Test Structure Software. About 50 fibres are obtained randomly by hand from a bale of oil palm fibres as a representative sample. The fibre is fixed by adhesive along the centreline of a slotted paper tab (Figure) which will be used in tensile test of single fibre. About ten points of image is capture along each fibre and the image is named accordingly. The image is then analyzed by Video Test Structure Software. The fibre image is regarded as diameter only when the fibre is uniformly focused, the edges of the fibre appear as fine line or one edge of the fibre appears as a fine line and the other edge shows as a bright line. If the fibre image is dark borders, the diameter is not recorded because the fibre is not focused correctly. Prior to the analysis the image of wedge scale is captured and calibration is made to Video Test Structure Software. The observed data is recorded and the average diameter of the fibres is calculated.

3.3.2.3 Moisture Content and Moisture Absorption

Natural Fibres are hygroscopic material and this characteristic affects the overall performance of the composite. If the fibres moisture content is high during composite fabrication, the bonding of the fibres and matrix becomes weaker due to poor wetting surface [18] . Therefore, the moisture content should keep to the lowest during the fabrication process.

The objectives of these tests are to determine the moisture content of the fibres before they are dried in an oven and control low moisture content of the fibres before the composite fabrication.

ASTM D2495-07, Standard Test Method for Moisture in Cotton by Oven Drying is referred to determine the moisture content of the fibres. The standard is purposely designed for determining moisture in cotton by oven drying. A few modifications are made to determining the moisture of nature fibres.

The apparatus and material in this test include oven, balance weight with sensitivity of 0.01g, weighing containers and desiccant (calcium chloride). The oven should be thermostatically controlled at a temperature of 105 ± 2ºC with fan-forced ventilation. To avoid the moisture regain during weighing the dried fibres, the balance weight equipped with tight fitting covers and desiccants are placed in the covers.

About 5 grams of oil palm fibres and pineapple leaf fibres are obtained randomly by hand from the primary sampling unit. The specimen is weighed with the containers before the specimen is dried in the oven at a temperature of 105 ± 2ºC for 24 hours. The specimen is placed in the tight fitting covers weighing machine. The weight is recorded when the reading is constant. Then, the tight fitting cover of the weighing machine is opened to allow moisture in the surrounding can be absorbed by the fibres. The weight is recorded as a function of time until the change of the reading is less than 0.1%. A moisture absorption versus time graph is plotted. All procedures are repeated for three specimens of oil palm fibres and pineapple leaf fibres.

3.3.2.4 Fibre Density

The objective of this test method is to determine the density of natural fibres. Density of natural fibres can be determined a few methods, like buoyancy method, sink float method and density gradient method. Only buoyancy method is employed in this study. The sample weight in air divided by the sample volume is equal to the fibres density. The sample volume is the difference weight of the sample in air and water divided by the water density at a temperature.

The apparatus include thermometer, stirrer, balance, balance stand, suspension wire and distilled water. 5 gram of oven dried fibres is obtained randomly by hand. The suspension wire is weighed in the air first. Then, the weight of suspension wire plus the sample is weighed. The suspension wire plus the sample is then immersed in the water and the weight is recorded. The weight of the suspension wire is weighed in the water. The temperature of the distilled water is recorded. The procedures are repeated for at least three samples. The average density is calculated and standard deviation is calculated.

3.3.3 Mechanical Test -Single Fibre Tensile Test

The objectives of this testing is to measured the properties of fibres of longitudinal modulus, tensile strength and ultimate tensile strain.

Due to no relevant standard on tensile test of natural fibres, the standard for synthetic fibres, ASTM D3379-75 and single fibre making testing procedures for papermaking are referred. Besides that, the latest reports about tensile test on natural fibre are referred.

The method describes in ASTM D3379-75 is recommended for fibres with an elastic modulus greater than 23GPa. The reported values of elastic modulus of oil palm fibres and pineapple leaf fibres are less than the specified. Figure shows the fibre specimen mounted on slotted paper tab.

The length of the fibres should be more than 2000 times of the nominal filament diameter. Both nominal diameters of natural fibres are in range of 0.4-1.0mm. The length of the fibre is at least 1m and this may not be applicable because the maximum length of the fibre is around 0.4m. Therefore, this approach may need to be revised.

The concept of testing tensile properties of fibres is easy to understand. The fibre is mounted along the centreline of a slotted paper and axial alignment is accomplished without damaging the fibre. The objectives of slotted paper are to maintain the axial alignment and to avoid damaging the end fibre. After the specimen is fixed to the test machine, the paper is cut to allow for filament elongation. The fibre is tested until breakage at a constant cross head rate. Load displacement curve is plotted. The strength of the fibres is simply the maximum load divided by the average cross sectional area.**Error! Bookmark not defined.** The strain of the fibres and modulus of fibres cannot be directly obtained from the test. To determine the elastic modulus of the fibre, the measured load displacement curves must be corrected for the system compliance. System compliance can be determined by testing various gage lengths of fibres in same testing system. A graph apparent compliance (displacement over load) versus fibre gage length is plotted. The system compliance is apparent compliance when zero gage length.

In this study, Instron Universal Testing Machine with a capacity of 100N in Material Laboratory of Faculty of Mechanical, Universiti Teknologi Malaysia was set up for the test. A pair of self tightening roller grips with a capacity 1kN was employed to hold the slotted paper. The grips are originally designed to test thin and flexible specimen. The specimen is tightened automatically by the spring pressure once the specimen is put in the grips. To ensure no grips occur at the end tabs of the specimens, the slotted paper is marked at the end near the grips and slippage is monitored for all specimens. The slipped specimens are rejected and at least three successive specimens are tested for different gage length. The cross head rate in this study is 1mm/min.

The specimen is prepared one week before testing to ensure the adhesive is set. The adhesive in this testing is Araldite Rapid where the content is epoxy. In this study, 25cm, 50cm and 75cm gage length is employed. Before tensile test is carried out, the specimens are kept in desiccators to maintain low moisture content. The humidity and the temperature during testing are maintained constant. The average fibre tensile strength, modulus elasticity and strain are calculated. An idealized stress strain curve is drawn after correction is made from system compliance.

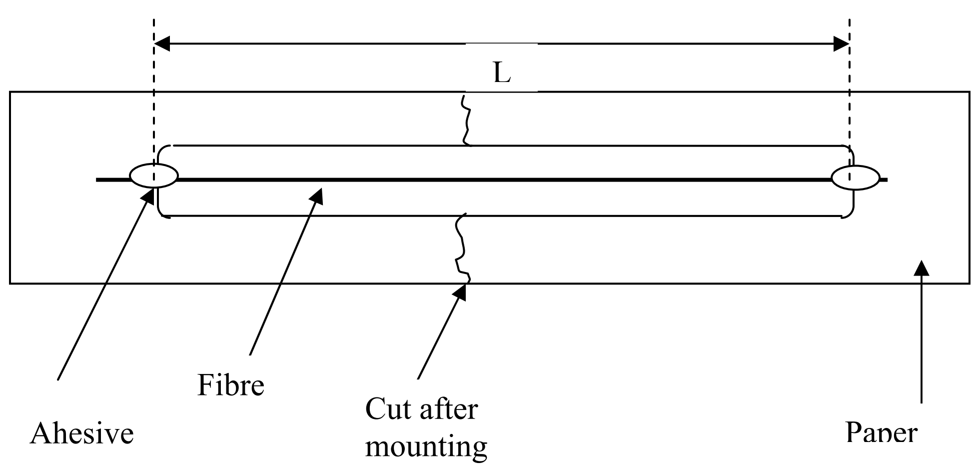


Figure 3.7: Schematic of single fibre test specimen.

3.4 Property Test on Natural Fibre Reinforced Composite

3.4.1 Material Preparation

3.4.1.1 Fibres

The extraction process of oil palm fibres and pineapple leaf fibres are discussed in previous chapter. Pineapple leaf fibres and oil palm fibres are all extracted by manual. Due to time constraint, only oil palm fibres are employed in all composite testing. Pineapple leaf fibres are only employed in fibre volume fraction test.

i) Fibre Volume Fraction

In this test, oil palm fibres are prepared according to different fibre volume ratio. Theoretically, the tensile properties of the fibres are improved when fibre volume ratio increase. However, reports have found that the optimum fibre volume ratio may reach due to poor wetting surface of the fibres. In this study, 0.05, 0.1, 0.15, 0.2 and 0.3 of fibre volume ratio are employed in fibre volume fraction test. All oil palm fibres are maintained 15cm long.

ii) Fibre Length

The objective of this test is to investigate the influence of fibre length in composite. Report shows that increase of fibre length improve the tensile properties of the composite. However, the increase of fibre length may cause low workability and affect the straightness of fibre, thus degrade the tensile properties of the composite. In this study, 50mm, 100mm and 150mm long fibres are made to study on the influence of fibre length in composite.

iii) Fibre Treatment

Alkaline treatment is one of the most used and old method to modify the surface of the fibres. This treatment will disrupt the surface of the fibre and remove a certain amount of lignin, wax, and oils that cover the external surface of the cell wall. The fibres are immersed in 2% by weight of sodium hydroxide solution for 2 hr, 4hr and 8hr. The fibres are washed with distilled water and dried in oven at temperature 105°C.

3.4.1.2 Resin

Synolac 3317AW is employed in this study due to its general used in hand lay-up, spray deposition and machine molding process. The manufacturer specification indicates that it is suitable in application like manufacture of water tanks, vehicle bodies, building panels, FRP furniture and similar applications.

i) Setting Time Test

The workability of resin is influenced by the setting time. Therefore, it is very important to design a suitable setting for the resin to avoid early set. The setting time is influenced by curing system with either ambient temperature or elevated temperature. The curing system initiated by adding the catalyst, MEKP and the amount of catalyst affect also the curing time.

BS 2782-8, Methods of Testing Plastic, Part 8: Other Properties, Method 835B: Determination of gelation time of polyester resin (manual method) is referred to determine setting time of resin as a function of amount of catalyst. The apparatus include container, stirring rod, timing device and thermometer. 0.5% of catalyst is mixed in the resin and the timing device is started once the catalyst is mixed. The stirring rod is stirred by moving the rod one complete revolution of the diameter container about every 15s until gelation occurs. The procedures are repeated for 1%, 2% and 3% of catalyst. The graph of gelation time as a function of catalyst amount is drawn.

Figure shows the setting time of polyester versus percentage of catalyst amount. An increasing rate of setting time of polyester is observed when less amount of catalyst is mixed. 2 % to 3 % of catalyst will cause polyester suffer from high temperature and shrinkage problem. The amount of catalyst should not be less than 0.7% as specified by the manufacturer. 0.9% of catalyst by volume is decided in this study which yields an hour of setting time of polyester.

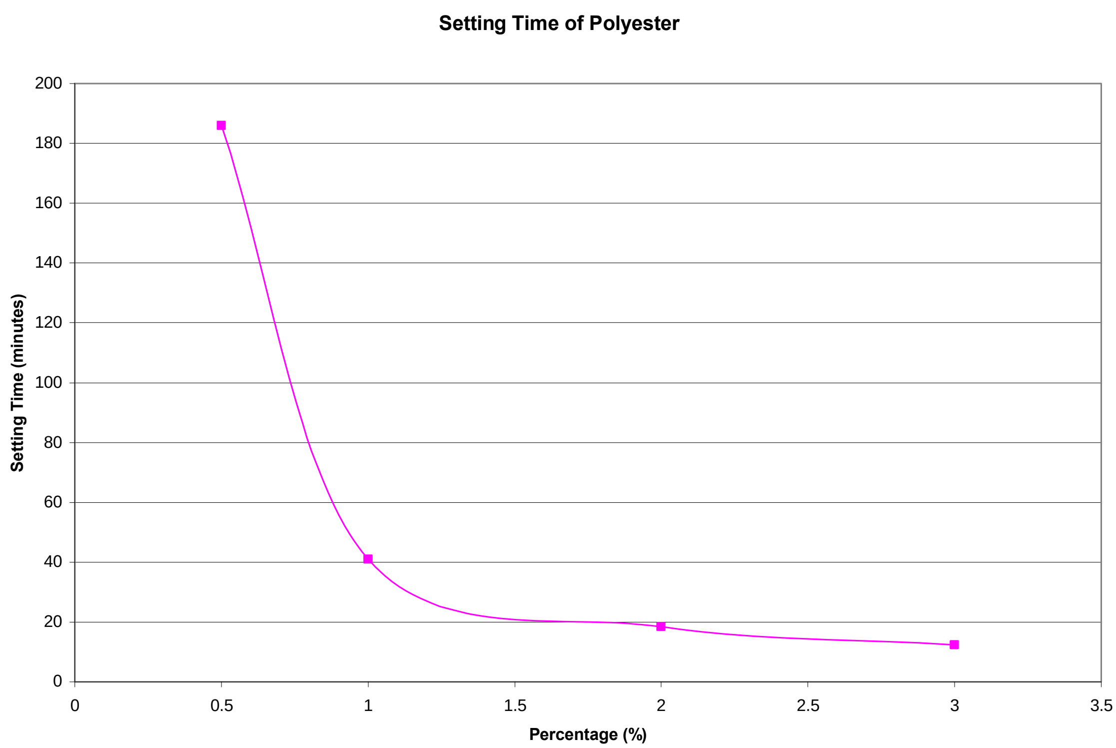


Figure 3.8: Setting time of polyester versus percentage of catalyst amount

3.4.1.3 Closed Mould - Hand Lay-up System

Steel mould is built for fabricating natural fibre composite. In the early stage, open mould system is made and several attempts to made natural fibre composite were carried out. However, the product of open mould system does not have good surface due to the irregularities of the fibres. Figure 3.9 shows the steel mould in an early stage and the product of the composite.

Open-mould system is then modified to close-mould system to achieve a better surface of the natural fibre composite. The fibres are compressed to the desired thickness by screw. The close-mould product successfully achieves the smooth surface of the composite. 4 close moulds are made to fabricate natural fibre composite plate. The dimension and configuration of the close-mould are shown in Figure 3.10 and 3.11. The dimensions of composite plate are 90 x 360 x 6 mm.

A layer of wax is applied to the mould before the fabrication process. The reason is this layer of wax can decrease the adhesion of the composite with the steel mould and thus increase the ease of mould removal.

Figure 3.9: Open steel mould is made and the product of open-mould system.

Figure 3.10: A close-mould system and the product of close-mould natural fibre composite.

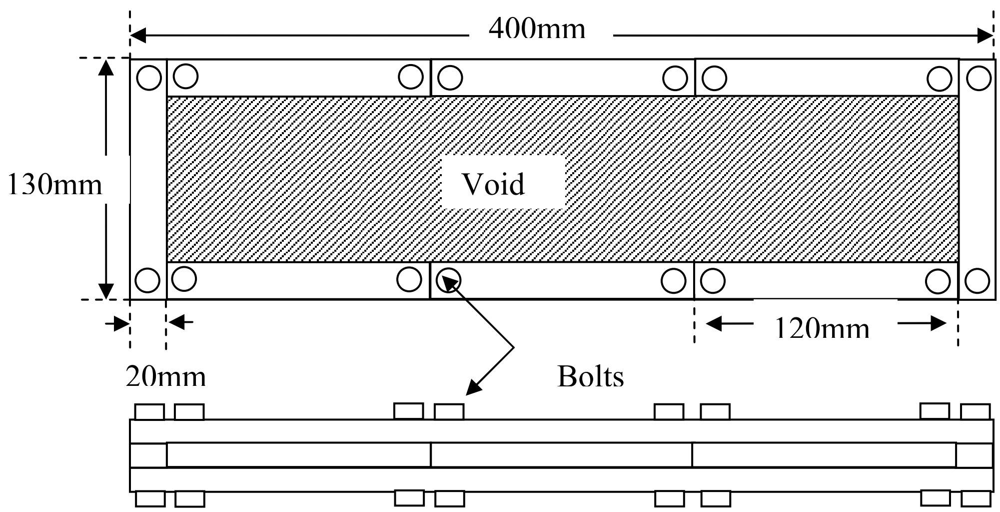


Figure 3.11: Plan view and side view of the close mould system.

3.4.2 Fabrication of Composite and Polyester

Unidirectional natural fibres composite and woven glass fibre composite are fabricated by close-mould system. While the dog bone shape polyester is fabricated by open mould system.

To make unidirectional oil palm fibre composite, the extracted oil palm fibres are oven dried at 105 ± 2ºC for 24 hours and cut to the desired length. The fibres are weighed according to the fibre volume ratio. To maintain homogeneity, the fibres are arranged systematically according to the weight. Firstly, the weighed fibres are divided into two groups where each group represent a layer. The first layer of the fibres is further divided into 5 small groups. Three small groups are laid accordingly as shown in the figure. Then, the other two small groups are laid between the gaps of the previous small groups. The procedures are repeated for the second layers. Both layers are separated before the fabrication.

The resin is measured according to the desire volume and the catalyst is measured for 0.9% by volume of the resin. The resin is mixed with catalyst and the mixture is stirred. A quarter of mixture is poured to the mould to ensure the mould surface is wetted. Then, the first layer of the fibres is laid gently without disturbing the fibres orientation. Then another quarter of mixture is poured to wet the fibres. Trowel is used to remove the air. Another quarter of mixture is poured before laying the second layer of the fibres. The last quarter of mixture is poured before the mould is closed and screwed. The composite plate is removed from the mould after 24 hours. The procedures are repeated for all specimens.

The procedures of fabrication of woven glass fibres composite are similar to unidirectional oil palm fibres. The only difference is the procedures of laying woven glass fibres where the fibres are laid directly.

The dog bone shape of polyester is fabricated by open mould system. 0.9% by volume Catalyst is mixed with the resin and poured into the mould. The dog bone shape of polyester is obtained after 24hours.

All composite plate and polyester are tested under tensile test at least after 7 days of composite fabrication to ensure the resin is fully cured and hardened.

Figure 3.12: The sequence of laying the fibres before composite is fabricated.

3.4.3 Tensile Test

To obtain a valid tensile property from a tensile test is a challenge. However, the basic principles can be easily understood through simple mechanics theory. Moreover, it is very important to understand the background theory of the tensile test before the actual test is conducted to reduce the amount of trial test.

Figure 3.13 shows a straight-sided specimen. The basic principle of a tensile test is transformation of tension force from the machine to the grips and from the grips, the shear stress are transfer to both side of the tab length. From the tab lengths, the shear stress is uniformly distributed to the gage length. To avoid failure at the grips, sufficient shear strength at the end tabs is required. The surface of grips areas of the samples were first roughened by applying smooth grinding to provide a good bonding with the tabs. Adhesive material, like epoxy is used which has strong adhesive properties.

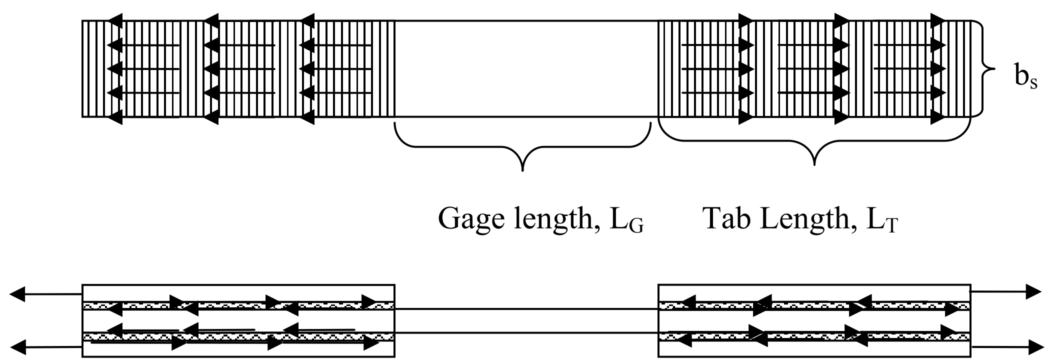


Figure 3.13: Straight-sided specimen.

A gage length can be defined as the longitudinal length of the predicted failure region. For mechanical strain gage, gage length is the maximum distance of the strain gage where the region will receive distance changes related to stress. The gage length will directly influence the accuracy of stress and strain. The shorter the gage length, determination of the actual state of stress at a point is more accurate, provided the instruments have enough sensitivity. As shown in figure 3.14, the stress from the test is not the actual maximum stress but an average stress. Therefore, a long gage length will be inaccurate to measure the strength of the material.

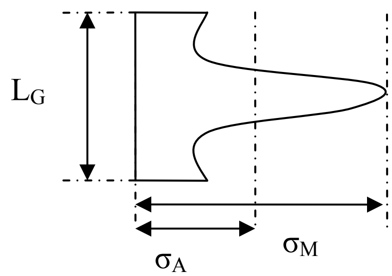


Figure 3.14: A strain gage with base length L measures an average physical property related to the stress, σ_A.

The width of the gage length will influence the amount of load subjected to the specimen. The larger the width of the gage length the larger the load need to archive failure in the gage section. However, the load required can be very high until exceed the shear strength of the bonding and material. In most cases, the minimum width of the gage section is controlled by the size of the strain gage.

Two standard procedures mainly on unidirectional fibres are referred to test tensile properties of natural fibre composites. There are American Standard ASTM D 3039/D 3039M-00 (2006) and British Standard BS EN ISO 527-5:1997. Table 1 summarizes the basic requirements for testing materials mainly on unidirectional fibres reinforced polymer.

Both standards recommend almost similar points on the coupon tensile test where minimum of 5 straight sided specimens for each test condition is required. The width of the straight sided specimen is 15mm and an overall length should more than 250 mm. The preferably tab material for the specimen is continuous glass fibre reinforced matrix materials with a length more than 50 mm.

In this study, the fibre composite plate is cut into straight sided specimens with a dimension of 20 x 250 x 6 mm (Figure 3.15). Each test condition is prepared with at least 3 specimens. The grips area of the specimen is roughened to provide a good bonding surface for the tabs. Woven pultruded GFRP plates with 6.35mm thickness are employed as the tab material. The bonding agent is Araldite Rapid epoxy resin, which has tensile strength of 94N/mm^2. After applying the epoxy, the tabs and samples are fixed by G-clamped.

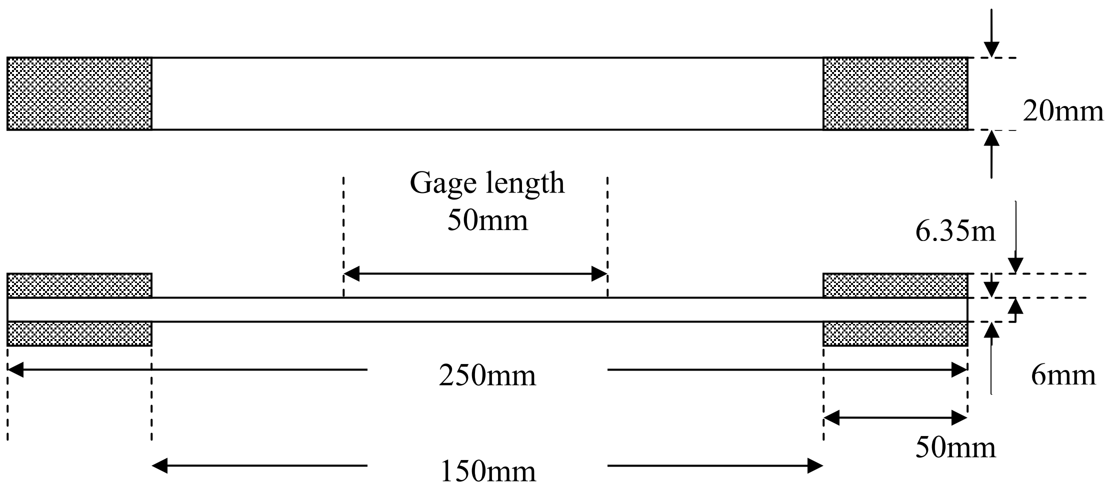


Figure 3.15: Straight sided specimen size and configuration.

Figure 3.16: Straight sided specimen size of oil palm fibre composite.

Table 3.1: Basic requirement suggested by ASTM 3039 and BS EN ISO 527-5 for unidirectional tensile properties.

	ASTM D 3039	BS EN ISO 527-5:1997
Scope	- fibre reinforced composites for continuous and discontinuous fibres which the laminate is balanced and symmetric with respect to the test direction	- fibre reinforced thermosetting and thermoplastic composites specifically for completely unidirectional fibres - reinforcements covered include carbon fibres, glass fibres, aramid fibres and other similar fibres
Sampling	Test at least five specimens per test condition unless valid results can be gained through the use of fewer specimens	Minimum of five specimens for the properties considered
Shape	Straight sided	Straight sided
Geometry		
Width	15 mm	15 mm
Overall length	250 mm	250 mm
Thickness	1 mm	1 mm
Tab length	56 mm	≥ 50 mm
Tab Thickness	1.5 mm	0.5 to 2 mm
Tab Material	Continuous E-glass fibre reinforced polymer matrix materials	Preferably cross-ply or fabric glass fibre laminate
Speed of Testing		
Constant Head Speed Test	2 mm/min	2 mm/min

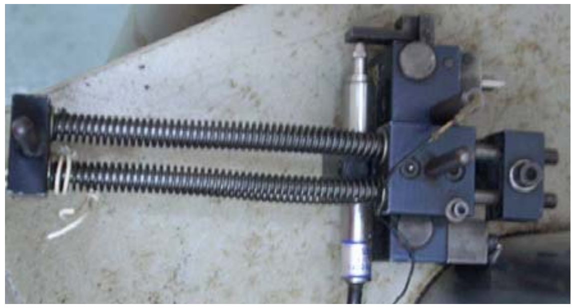


Figure 3.17: Extensometer with 50 mm gage length.

The samples are placed in room temperature at 25±2ºC and 70±5% relative humidity after 24 hours for conditioning. The thickness and width of gauge region of the samples are measured for three points using digital calliper with sensitivity of ± 0.01mm. The average value of width and thickness is calculated and recorded.

50mm long of extensometer is placed at the gauge area to measure longitudinal strain. The tensile tests are carried out by using DARTEC Universal Testing Machine, which generated via servo-hydraulic and computerised control system with a capacity of 250kN. The samples are carefully placed into the grips of and aligned to avoid non axial stress. The hydraulic pressure generated top and bottom grips are set to 500psi ($3.5N/mm^2$), which is enough for the tensile test without damaging the end tabs. The result is obtained and graph stress versus strain is plotted by using Microsoft Excel. The ultimate tensile strength, modulus of elasticity and strain is calculated. The average value is computed for each test condition.

Figure 3.18: DARTEC Universal Testing Machine, with a capacity of 250kN and hydraulic grips.

3.5 Flexural Test on Reinforced Concrete Beam Strengthening with Oil Palm Fibre Composite Plate

The use of FRP laminate and steel plate for rehabilitation of beams and slabs started 20 years ago. Currently, carbon fibre reinforced polymers (CFRP) sheets are the most studied material in strengthening reinforced concrete structure due to its high tensile strength, low weight and durable. The concept of strengthening RC beam is simple where the tension zone of the RC beam is improved by the FRP laminate or steel plate. The effect of strengthening on tension zone should not exceed the capacity of the beam. The strengthened RC beam should maintain the ductility of the RC beam.

This study investigates the potential of natural fibre reinforced composite use as the strengthening material. For comparison purpose, ordinary reinforced concrete beam as control beam and reinforced concrete beam strengthened with woven Glass Fibre Reinforced Polymer plate are employed.

3.5.1 Specimen Preparation

A total of 3 specimens of reinforced concrete beams are prepared. The first beam is control specimen, and the other two beams are strengthened with woven GFRP plate and unidirectional oil palm fibre reinforced polymer plate.

3.5.1.1 Reinforced Concrete Beam

Normal concrete mixture for 25MPa is employed in the reinforced concrete beams. The slump concrete is designed to have 30-60mm. The concrete mixture is designed according to the standard specified by Department of Environmental, British. The concrete mixture proportions are presented in Table. Trial mix is done and concrete cube test is carried out before casting reinforced concrete beams.

Table 3.2: Proportion of Concrete Mixture of Grade 25.

Material	Coarse Aggregate	Fine Aggregate	Cement	Water
Proportion (kg/m^3)	1132	637	460	230

* Maximum size of aggregate is 20 mm.

All steel use in this study is mild steel which has 250MPa yield stress. 8 mm diameter mild steels are used in reinforcing bars and 6 mm diameter link are used in reinforced concrete specimens. The arrangement of the reinforcement in beam is shown in the Figure 3.22. The size of the specimen beam is 2000 x 200 x 150 and three formwork moulds are made to cast the beams.

The reinforcement bars are placed in the formwork and hang by steel wire to maintain 25mm distance of the reinforcement bar from the cover. The concrete mixture is placed in the concrete and compaction is done to avoid honey comb. Six concrete cubes with size 150 x 150 x 150 mm are prepared to determine strength at 7 days and characteristic strength at 28 days. Proper curing is provided to the RC beams where wet mats are covered to the RC beams after removal of the formwork at the 7 days after casting. The concrete cubes are immersed in water after the removal of formwork.

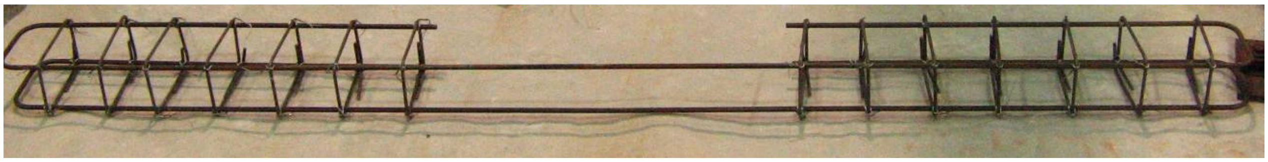


Figure 3.19: Arrangement of reinforcement bar for the beam.

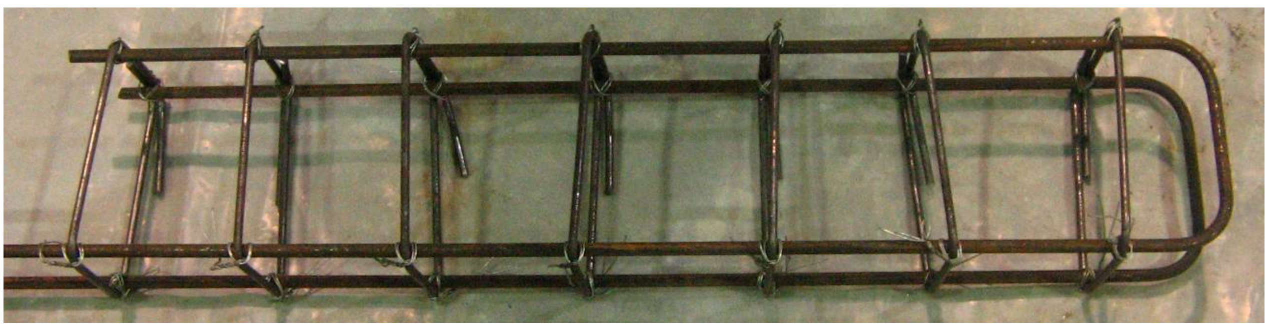


Figure 3.20: Shear link and anchorage bar.

Figure 3.21: Wooden formwork for reinforced concrete beam.

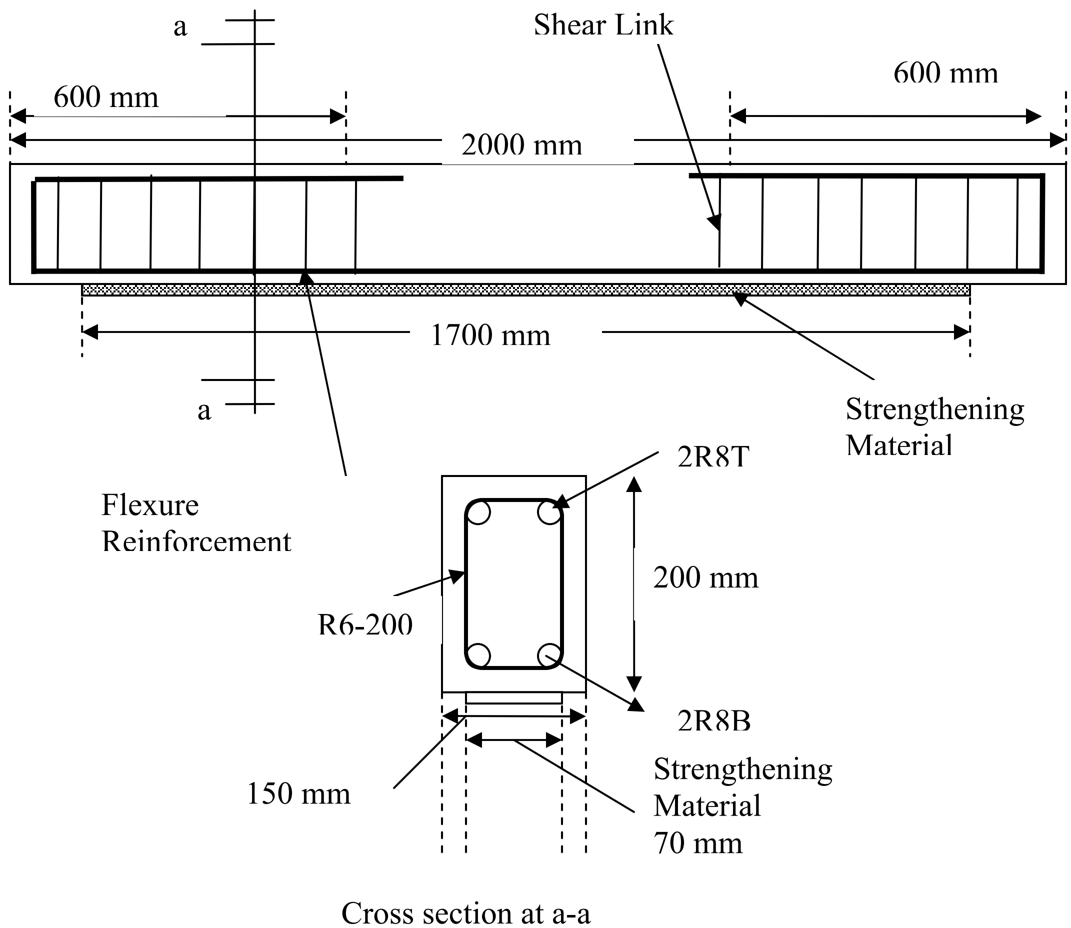


Figure 3.22: Longitudinal and cross section of the reinforced beam.

The dimensions of the specimens represent a model of approximately ½ scale of an actual RC beam designed and constructed. The beams fall into a category of slender beams with a span to depth ratio of 10. The failure mode of the ordinary RC beam is expected to fail in flexure mode.

The minimum reinforcement for flexure in tension zone is used where a total area of steel is 0.33 percent. Two 8 mm diameter of the plain steel reinforced bar with a total steel area of 101 mm^2 are used to resist tension force. Seven steel shear links with 6 mm diameter are made and placed at 100mm from the support to the first loading point. Shear reinforcement is provided to prevent any shear failure at the concrete beams. The capacity of bare reinforced concrete beam is 3.75 kNm where ultimate loading is 12.5kN.

3.5.1.2 Reinforced Concrete Beam with Natural Fibre Composite Plate and Glass Fibre Composite Plate

Two reinforced concrete beams are strengthened with natural fibre composite plate and glass fibre composite plate. Both composite plates are prepared under closed mould hand lay-up method similar to the fabrication procedures of coupon test. Size 2000 x 130 mm of steel mould is made to fabricate 1900 x 90 x 6mm of composite plate. After removal of the mould, the composite plate is cut and trimmed to have a straighter edge. The final size for composite plate is 1700 x 70 x 6 mm.

Figure 3.23: Steel mould is made to fabricate composite plate

Before applying the strengthening material at the bottom of the beams, the surface of the beams are roughened by compressed-air hammer to provide a better bonding surface. The area of the roughened surface is enlarged about 10mm bigger than the composite plate to ensure the adhesive is covered at all edges of the strengthening material. The surface of concrete is cleaned by air pump to remove any irregularities and loose particles.

The adhesive used for strengthening beam in this study is hand-mixed epoxy. The adhesive is applied evenly on the prepared concrete surface and the composite by a spreader. The composite plate is placed on the bottom of the beam and G-clamp is clamped to ensure the plate is fully bonded.

Figure 3.24: The bottom surface of the concrete beam is roughened to provide better bonding.

3.5.2 Four Point Bending Test Setup

The specimens are tested under a four point load system using a hydraulic jack. The tests are conducted on a self-reacting frame built-up with steel channel sections, which is anchored and erected on strong floor. A 0.29kN and 900mm load spreader is used to transfer the load from the hydraulic jack to the beams. The level of applied load is measured by a 100kN load cell through computerised TDS-303 data logger. The four point bending test is set up as shown in figure.

To measure the deflection of the beams, three LVDT are used where two LVDT are placed directly under the forces and one LVDT is placed at the middle point of the beam.

Four PL-60-11 types of TML strain gauge with lead wire are installed at the top of every beam and side surface of every beam. The top strain gauge is to measure the strain of the compressive concrete. The side strain gauges are to measure the strain of the cross section reinforced beam. Prior to the test, every strain gage is tested with insulation resistance to ensure the strain gage is functioned.

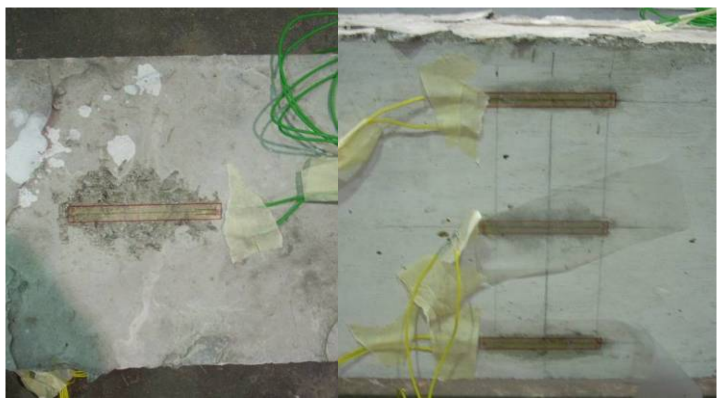


Figure 3.25: Four strain gauge are installed at top of the beam and side beam.

Two PI-2-50 types of TML displacement transducers are installed at the composite plate to measure the strain of plate. Dummy plates PIF-11 are used to maintain the gauge length when mounting the PIF-21 jig to the composite plate. Before testing, the TML displacement transducers are calibrated. A displacement transducer is connected with a data logger and fixed on a Perspex. The opening of the displacement transducer is moved and the reading from the data logger is recorded. The distance of the opening is measured by a calliper with an accuracy of 0.01mm. The procedures are repeated for next distance. A constant is obtained from the actual displacement and the transducer readings.

Figure 3.26: Dummy plates PIF-11 are used when mounting the PIF-21 jig to the composite plate.

Figure 3.27: Two PI-2-50 types of TML displacement transducers are installed at the middle of composite plate.

The specimens are marked to indicate loading, support positions, transducers positions and the spreader positions. The specimens are arranged and placed at the correct position prior to the testing. The readings of strain gauge, LVDT and displacement transducers are recorded once the beams are subjected to 1kN from the hydraulic jack. The specimens are tested until the subjected load start to reduce and large displacements are found at middle of the beams. The displacement transducers are taken out when the displacements exceed 25mm. The stress strain curve is plotted and the ultimate moment is compared for all the beams by using Microsoft Excel.

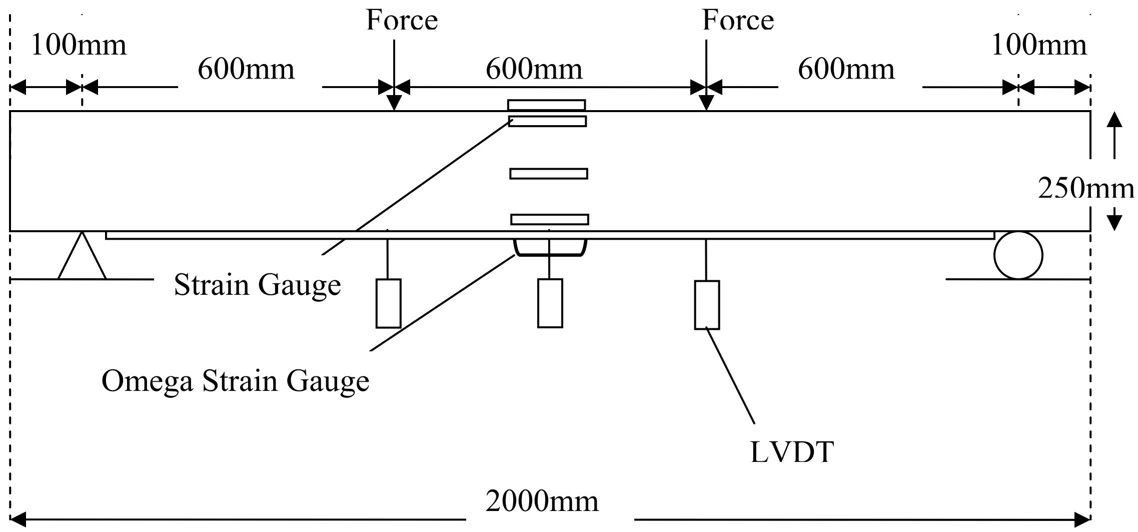


Figure 3.28: Setup and Position of the instrumentions.

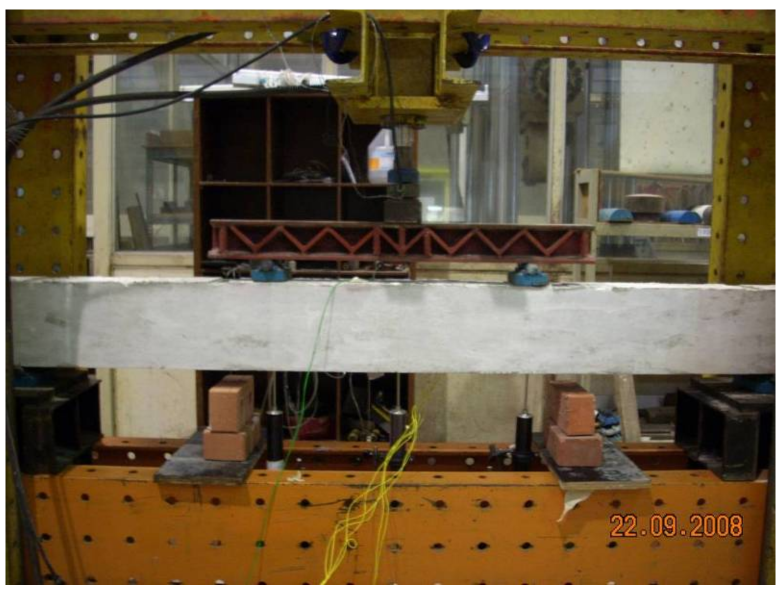


Figure 3.29: Flexural test on control beam.

3.6 Conclusions

The experimental programme was carried out according to the relevant standards and recommendation by the researchers. Few conclusions could be withdrawn as :

1) Fibre extraction were done by using mechanical method as explained in this chapter.
2) Physical test and tensile test of oil palm fibre and pineapple leaf fibre were successfully conducted. The test methods and procedures were discussed in detail.
3) Oil palm fibre reinforced polymer composite was fabricated under closed mould - hand lay-up method after several trial and error.
4) The tensile test of composite and resin was carried out according to the standards.
5) Three reinforced concrete beams were tested under four point loading.

CHAPTER 4

RESULTS

4.1 General

This chapter presents the overall result of experimental work of the study. These include physical test and tensile test of natural fibres, tensile test of natural fibre reinforced composite and flexural test of strengthened reinforced concrete beams.

4.2 Property Test on Natural Fibres

The physical test and tensile test were carried out to characterize the physical and tensile properties of oil palm fibres and pineapple leaf fibres. The physical properties included fibre length, fibre diameter, moisture content, moisture absorption and fibre density. Tensile properties obtained from single fibre tensile test consist of ultimate tensile strength, modulus of elasticity and strain.

4.2.1 Physical properties

Oil palm fibres were light brown in colour and curly while pineapple leaf fibres were golden in colour and straight. All physical test and tensile test were carried out to oil palm fibres. Only density test and moisture absorption and moisture content were carried out for pineapple leaf fibres.

Figure 4.1: Oil Palm Fibres and Pineapple Leaf Fibres after Oven-Dried.

4.2.1.1 Fibre Length

This test was purposely carried out for oil palm fibres because the obtained oil palm fibres were in various lengths. The result of this test was used to determine the minimum oil palm fibre length can be extracted for composite used.

A small sample of oil palm fibres was obtained randomly by hand from the primary sampling units. The fibres were separated and loosened by a comb. Every single fibre length was measured using ruler. The fibre was pulled until it was straight when measurement was made. The length was recorded according to 6 ranges where the difference of every range is 5cm. Results from the measurement are shown in Table 4.1. About 764 fibres were measured in this test. The results show that most of the fibres lengths are within 0 to 5 cm range. The frequency of fibres decreased drastically when fibres length increases (Figure 4.2). This indicates the oil palm fibres required further process to ensure the composites have adequate minimum fibre length.

The minimum fibre length used in composite influences the amount of works. Low frequency fibre length range which has long fibre will cause long time for extraction process. While high frequency fibre length which yield a lot short fibres may cause the deduction of mechanical properties of composite. To determine the minimum fibre length for composite, oil palm fibre length distribution curve was drawn and shows in Figure 4.3.

After considering the amount of works to process the fibres, minimum fibre length selected in this study is 15 cm which yield about 15% from the primary unit.

Table 4.1: Number of Oil Palm Fiber Length.

Fiber length range (cm)	Frequency
0 to 5	276
5 to 10	270
10 to 15	148
15 to 20	44
20 to 25	25
25 to 30	0
30 to 35	1
Total	764

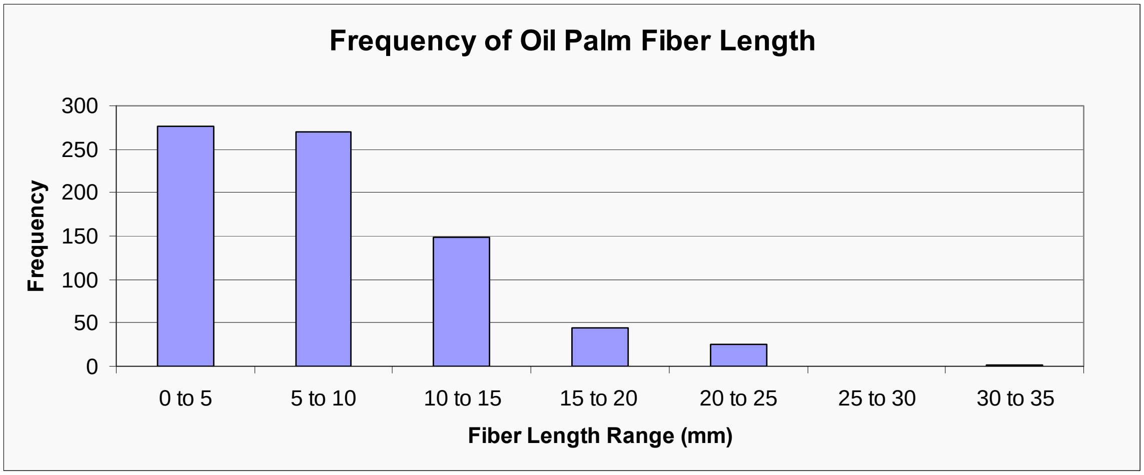


Figure 4.2: Frequency of Oil Palm Fibre Length.

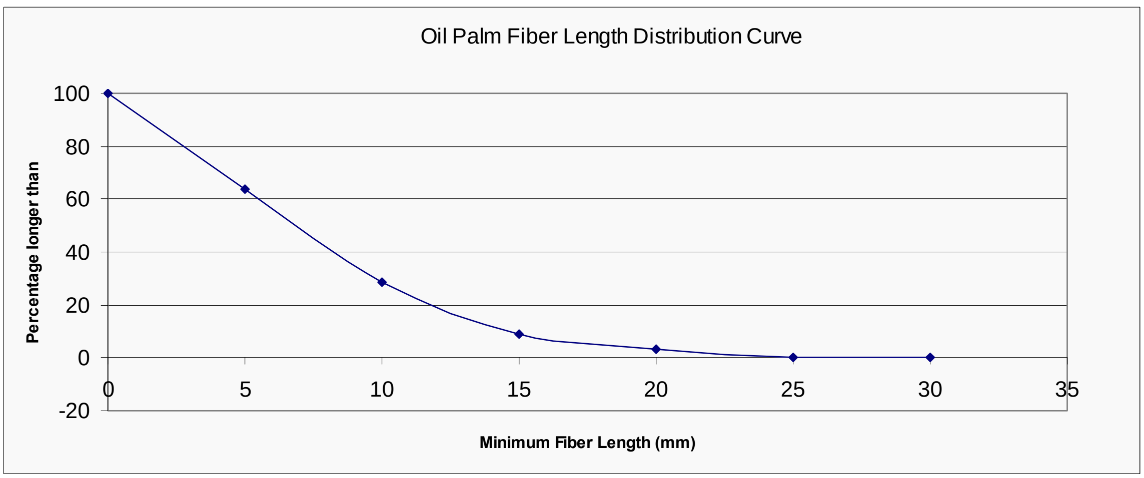


Figure 4.3: Oil palm fibre length distribution curve.

4.2.1.2 Fibre Diameter

This test was carried out to determine the average diameter of oil palm fibre for single fibre tensile test and the study of the effect of fibre aspect ratio of composite. The image of the fibre was captured under microscope with 100x magnification. Then, the widths of the fibres were measured by using Video Test Structure Software which has the accuracy of 0.001 mm. The images of the fibres are shown in Figure 4.4 and Figure 4.5. Some defects were found in some of the fibres where there can be classified into splitting, branch, and knob. The measurement was made only for fibre without defects. About 500 images were captured and about 450 measurements of the fibre width were carried out. The shape of the fibre is assumed to be prismatic and circular. Therefore, the width of the fibres is assumed as the fibre diameter.

The results are statistically presented in Table 4.2 and Figure 4.6. The average diameter of the fibre is 0.448 mm. The standard deviation is ±0.171mm with 90% of confidence level. The coefficient of variance is 38.2% which is considerably high. The maximum fibre diameter is 0.808 mm while the minimum fibre diameter is 0.236mm.

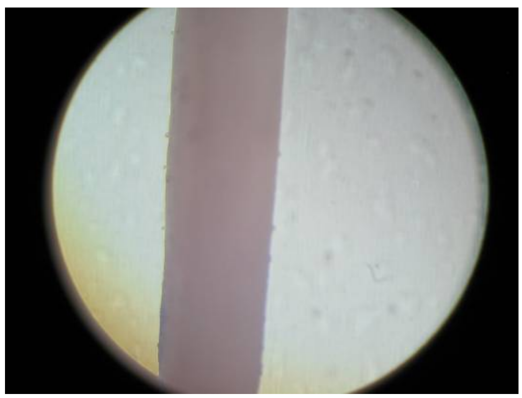


Figure 4.4: The image of oil palm fibre under 100x magnification.

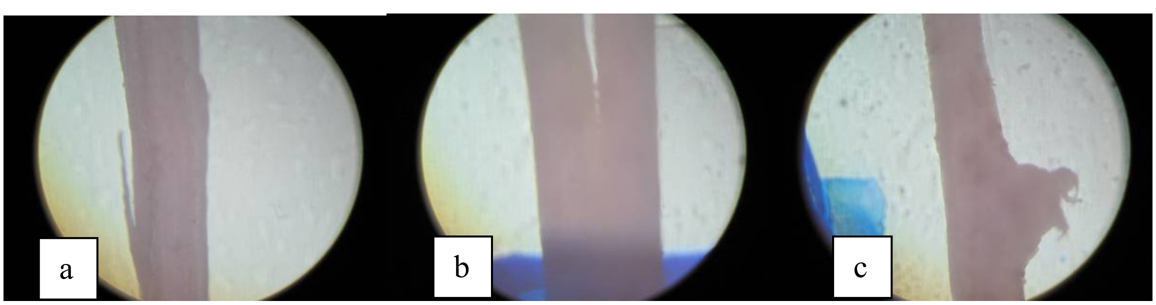


Figure 4.5: Defects of Oil Palm fibre, (a) branch (b) split (c) knob.

Table 4.2: The diameter of oil palm fibre.

Mean	Max	Min	SD*	COV (%)
0.448	0.808	0.236	0.171	38.22

(*) 90% confidence level.

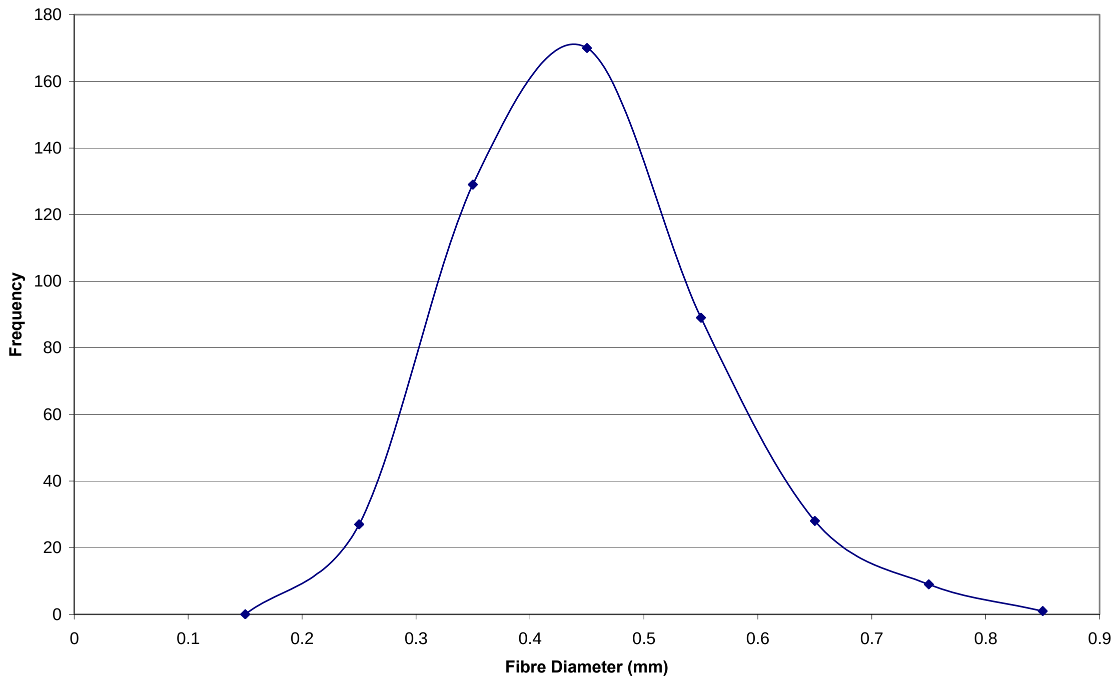


Figure 4.6: Distribution of oil palm fibres diameter.

4.2.1.3 Moisture Content and Moisture Absorption

High moisture content of natural fibre reduces the bonding of fibres and matrix due to poor wetting surface. The moisture content should maintain to the lowest during the fabrication process. Three specimens from each type of fibres were recorded for moisture content and moisture absorption tests.

In moisture content test, the specimen was weighed with the containers before the specimen was dried in the oven at a temperature of 105 ± 2ºC for 24 hours. After oven dried, the specimen was placed in the tight fitting covers weighing machine. The weight was recorded with an accuracy of 0.01g until the reading was constant. The specimen was placed in the oven again. The procedures were repeated until the weight of the specimen was constant to ensure the fibres were totally dried.

The result of the moisture content is shown in Table 4.3. It is found that the pineapple leaf fibres have higher moisture content than the oil palm fibres. However, the coefficient of variance of pineapple leaf fibres is smaller. This shows that the moisture in pineapple leaf fibres is more even than the oil palm fibre.

Table 4.3: Moisture Content of Pineapple Leaf Fibres and Oil Palm Fibres.

Specimens	Average	SD	COV
PLF	18.36291	0.085198021	0.00464
OPF	17.48257	0.128473496	0.007349

PLF: Pineapple leaf fibres

OPF: Oil Palm Fibres

In moisture absorption test, the dried specimens from moisture content test were reused. The tight fitting cover of the weighing machine was opened to allow moisture in the surrounding absorbed by dried fibres. The humidity around the test specimens was recorded as 50±5%. The weight was recorded as a function of time until the changes of the reading was less than 0.1%. The absorbed moisture was recorded and presented in Table 4.4. The absorbed moisture from the surrounding is approaching the original moisture content after three hours. Oil palm fibres absorbed more moisture from the air. A graph of moisture absorption versus time is shown in Figure. The figure shows that the absorbed moisture for both fibres increased in a decreasing rate. After about an hour, the moisture absorption process for both fibres almost reached saturation point. This could be a disastrous to the composite during fabrication.

Table 4.4: Moisture Absorption of Pineapple Leaf Fibres and Oil Palm Fibres.

Specimens	Average	SD	COV
PLF	13.7224699	0.31317929	0.022822
OPF	14.0625581	0.56081091	0.03988

PLF: Pineapple leaf fibres

OPF: Oil Palm Fibres

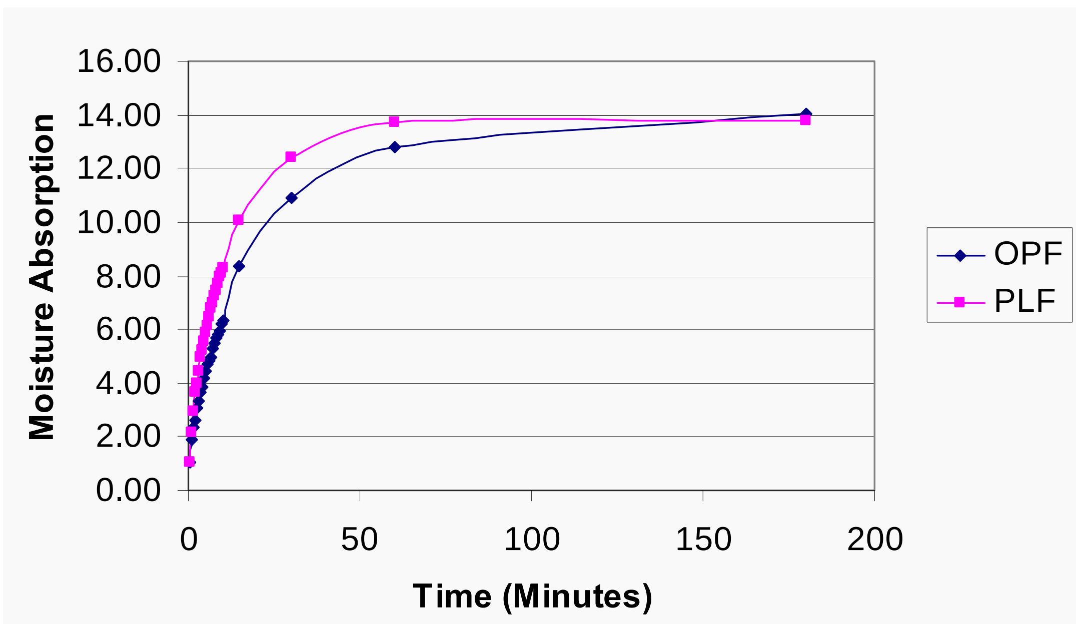


Figure 4.7: Moisture absorption versus time of oil palm fibres and pineapple leaf fibres.

4.2.1.4 Fibre Density

The fibre density of pineapple leaf fibres, oil palm fibres and oil palm fibres are presented in Table 4.5. The density of both natural fibres is lighter than glass fibres. Oil palm fibres exhibited the lowest density which is the lightest. During the density test, the weight of the oil palm fibres immersed in water was difficult to measure. Due to porosity, oil palm fibres required longer time to eliminate entrapped air. Therefore, it is not surprised that the coefficient of variance of oil palm fibres is much higher.

Table 4.5: Fibre density of Pineapple Leaf Fibres, Oil Palm Fibres and Glass Fibres.

Specimens	Average (g/mm^3)	SD	COV
OPF	1.0762	0.119047	0.11062
PLF	1.5880	0.249204	0.156927
GFRP	2.4075	0.002206	0.000916

4.2.2 Tensile Properties of Oil Palm Fibre

The single fibre tensile test was carried out for oil palm fibre only. ASTM D 3379 was referred and Hookean behaviour was assumed for the tested fibre.

A typical load versus elongation of single fibre tensile test was presented in Figure 4.6. This graph cannot represent the true behaviour of oil palm fibre under tensile test because the elongation of this test was not the true elongation of the fibre.

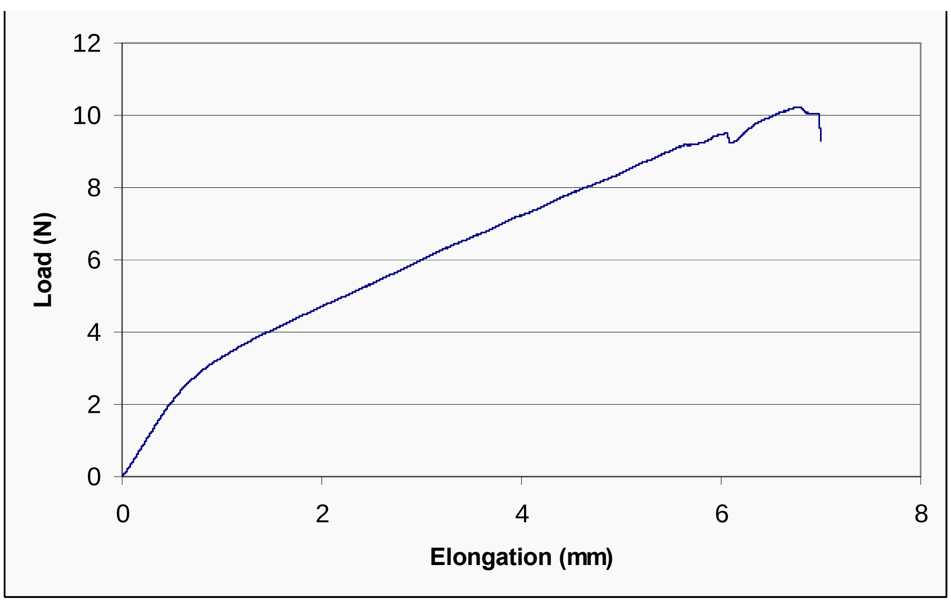


Figure 4.8: Typical load versus elongation of single fibre tensile test of oil palm fibre.

The ultimate strength of the fibre was calculated from the maximum load over the cross sectional area of the fibre. In this study, cross sectional of oil palm fibre was assumed to be circular section where width of the fibre was the fibre diameter. The diameter of the fibre was measured under microscope with 100x magnification.

To determine the elastic modulus of the fibre, the measured load displacement curve must be corrected for the system compliance. The measured compliance was the sum of the fibre and system compliances. Therefore, the true elongation of the fibre under stress was the measured compliance minus the system compliances. The system compliance included the displacement of the grip system and end tab where the stiffness of the system was assumed to be small and linear under force. The system compliance was obtained as the zero gage length intercept by plotting the graph of apparent compliance versus fibre gauge length fibre graph. Figure shows the relationships of apparent compliance versus fibre gauge length from single fibre testing test. From the graph, it shows the system compliance was 0.16mm/N which every 1 Newton produce 0.16 mm in every single fibre test.

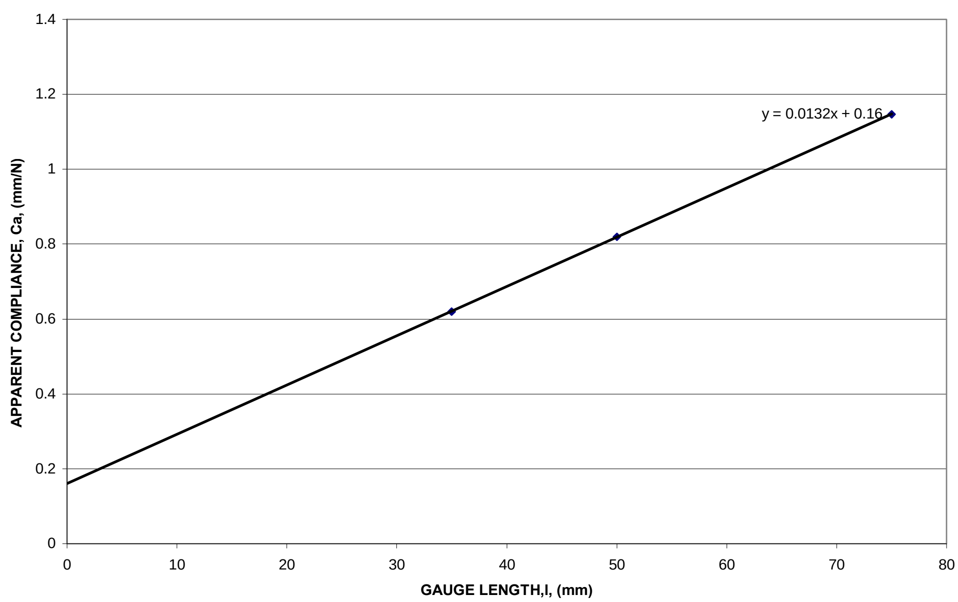


Figure 4.9: Relationships of apparent compliance versus fibre gauge length from single fibre testing test.

The fibre ultimate strength, strain at break and modulus of elasticity of each gauge length were calculated according to the ASTM D 3379 and presented in Table 4.6. The average value of fibre ultimate strength, strain at break and modulus of elasticity were calculated and shows in the table. The average fibre ultimate tensile strength was 58.30±5.91 MPa and fibre modulus of elasticity was 12.08 ±0.019 MPa. The strain at break of the fibre was 12.22±1.221 %. Coefficient of variance of modulus elasticity of the fibre was rather smaller than the ultimate tensile strength and strain at break of the fibre. This means that the stiffness of oil palm fibre is quite constant but the ultimate strength and strain at break of the fibre have large variance.

Table 4.6: Tensile Properties of oil palm fibre in various gauge length according to ASTM D 3379.

Gage length	Average Ultimate Strength (MPa)	MOE (MPa)	Strain At Break (%)
35	64.94	478.18	13.58
50	53.58	476.66	11.24
75	56.37	477.68	11.80
Overall	58.30	477.51	12.21
SD	5.92	0.78	1.22
COV	0.10	0.00	0.10

A typical stress versus strain curve of oil palm fibre after correction of system compliance was presented in Figure 4.10. Initially, the behaviour of oil palm fibre shows linearity. After 0.5% of strain, curvature was observed where the fibre elongates in an increasing rate when load increases. This happens because the weak primary cell wall collapses and decohesion of cells occurs[6]. At ultimate tensile stress, the oil palm fibre failed in a brittle behaviour where the fibre broke in sudden.

From the graph, non-linear behaviour of oil palm fibre was observed and similar behaviour was reported by Sreekala (1997). Therefore, linear assumption until strain at break in calculating modulus of elasticity was inappropriate. Initial of modulus of elasticity of oil palm fibre was preferred and the value was obtained by measuring the initial tangent stress strain curve at the origin.

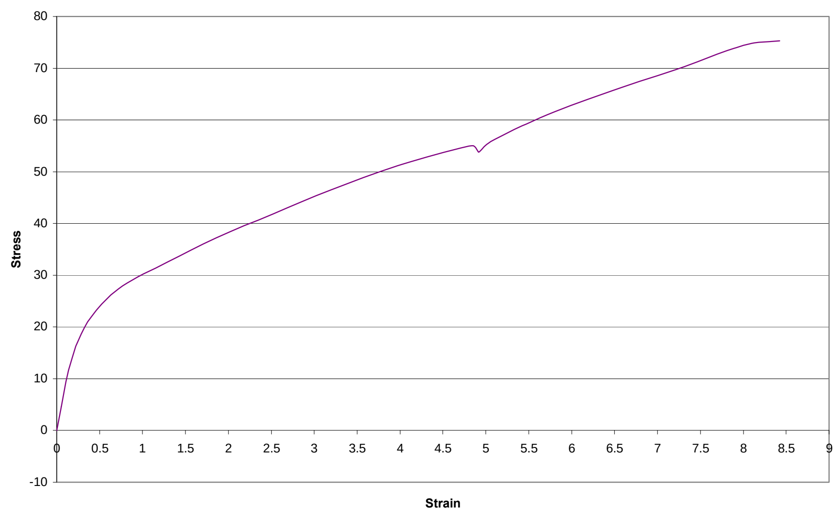


Figure 4.10: Typical stress versus strain of single fibre tensile test of oil palm fibre.

4.3 Tensile Properties of Composite and Resin

This chapter presents the result of tensile properties of oil palm fibre reinforced polymer composite, resin and woven glass fibre reinforced polymer composite. Tensile properties of oil palm fibre reinforced polymer composite are compared as a function of fibre volume ratio, fibre length and fibre surface modification. The tensile properties include ultimate tensile strength, strain at break and modulus of elasticity. Ultimate tensile strength is stress of the sample at the moment of rupture and it is measured as ultimate force per unit area. The strain at break is strain when the sample fractures. Modulus of elasticity is referred to the initial tangent stress strain curve at the origin.

4.3.1 Tensile Properties of Oil Palm Fibre Reinforced Polymer Composite

Oil palm fibre reinforced polymer composite was fabricated as a function of fibre volume fraction, fibre length and surface modification. About 3 samples were successfully tested for all condition and the tensile properties were calculated and presented in this chapter.

4.3.1.1 Fibre Volume Fraction

0.05, 0.10, 0.15, 0.20 and 0.30 of fibre volume fraction of oil palm fibre reinforced polymer composite was made in this study. Three samples were successfully tested for every condition and the results of the tensile properties are calculated and statistically presented. Figure 4.11 shows the appearance of different fibre volume fraction composite. As shown in Figure 4.11, 0.05 of fibre volume fraction of oil palm fibre reinforced polymer composite was more transparent and less fibre. The transparency of the composite decreased when the fibre volume ratio increased.

Figure 4.11: The appearance of different fibre volume fraction composite.

The tensile properties of different fibre volume fraction were presented in Table 4.7 and Figure 4.12, 4.13 and 4.14. The properties were statistically presented where mean, standard deviation and coefficient of variance are presented in every specimen condition. From the results, the highest ultimate tensile strength was 0.05 fibre volume fraction. The ultimate tensile strength of the composite decreased when more oil palm fibres were added in composite where low tensile strength was observed at 0.10 of fibre volume ratio composite. However, the ultimate tensile strength of 0.15 fibre volume ratio composite was improved about 7% when comparing with 0.10 of fibre volume ratio. The ultimate tensile strength of the composite decreased after 0.15 of fibre volume ratio.

Table 4.7: Tensile properties of different oil palm fibre volume fraction composite.

Specimen		Ultimate Tensile Strength (MPa)			Strain At Break (%)			MOE (GPa)		
		Mean	SD	COV	Mean	SD	COV	Mean	SD	COV
Fibre Volume	0.05	36.30	3.63	0.10	2.27	0.49	0.22	1.497	0.366	0.244
	0.10	29.38	1.53	0.05	1.21	0.02	0.02	2.542	0.054	0.021
	0.15	31.50	2.55	0.08	1.30	0.06	0.04	2.358	0.192	0.081
	0.20	28.59	0.71	0.02	1.09	0.01	0.01	2.170	0.003	0.001
	0.30	29.24			1.36			2.308		

The highest strain at break of the composite was found in 0.05 fibre volume fraction where 2.27% was observed. Strain at break of 0.10, 0.15, 0.20 and 0.30 of fibre volume fraction is in the range of 1.36 to 1.09. It was rather low than 0.05 fibre volume fraction.

The modulus of elasticity of the composite was improved when fibre volume fraction was increased. The highest modulus of elasticity of the composite was 2.542 GPa in 0.1 fibre volume fraction of composite. The modulus of elasticity decreased when the fibre volume fraction reached 0.15.

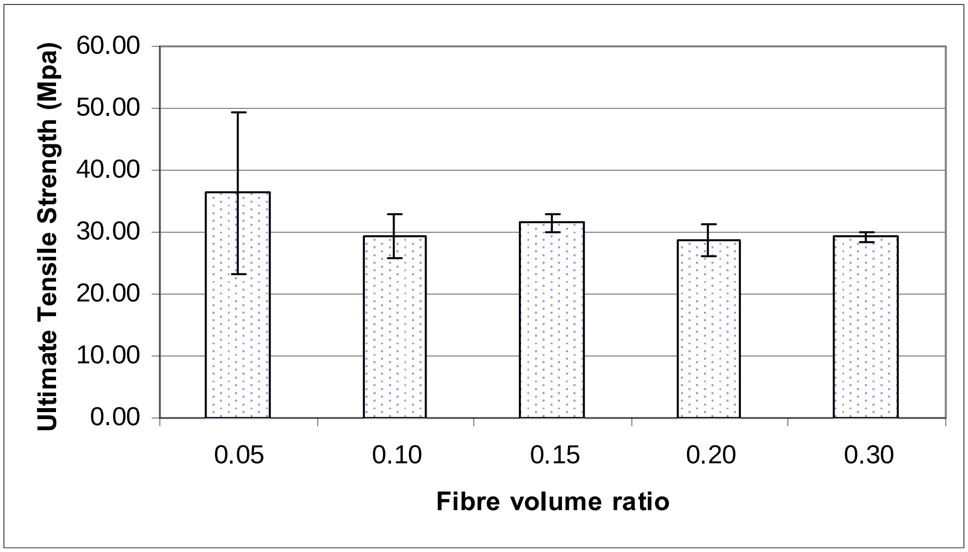


Figure 4.12: Bar chart of ultimate tensile strength versus fibre volume ratio.

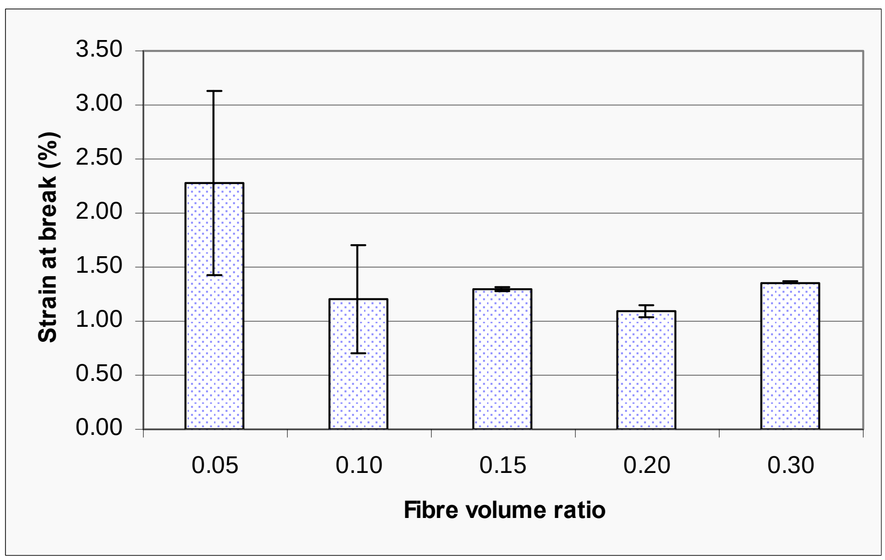


Figure 4.13: Bar chart of strain at break versus fibre volume ratio.

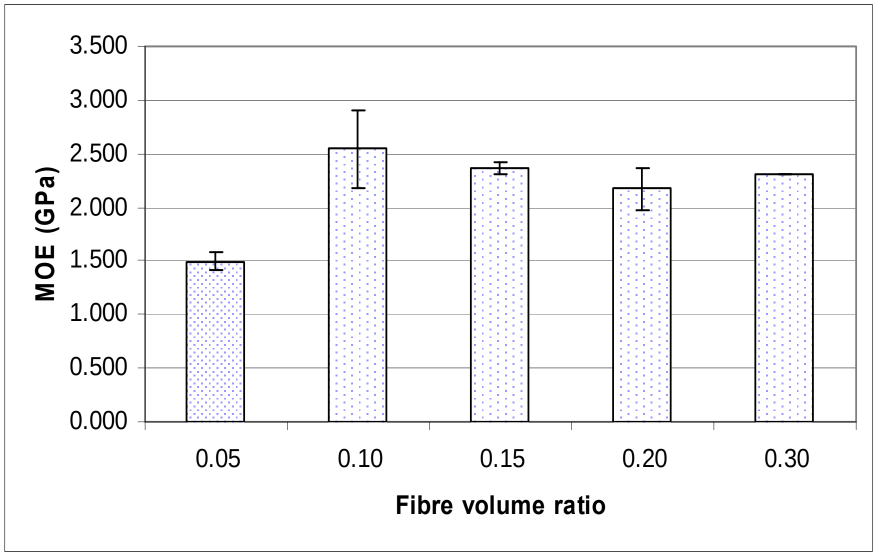


Figure 4.14: Bar chart of modulus of elasticity versus fibre volume ratio.

The tensile stress versus strain of the composite with different fibre volume ratio was shown in Figure 4.15. Linear elastic was found in tensile behaviour of the composite until strain at break. However, strain hardening was found in 0.10 and 0.15 of fibre volume fraction of the composite. All composite failed in brittle manner where the composite fracture after the ultimate tensile strength.

Mode of failure was observed for successfully tested oil palm fibre reinforced polymer composites. All successful tested composite showed transverse matrix cracking, fibre pulled-out and fibre debonding. The fibres were remain unbreak after the ultimate tensile stress as shown in Figure4.16. A few specimens failed near the end tab may due to bending stresses caused by misalignment (Figure 4.16 a).

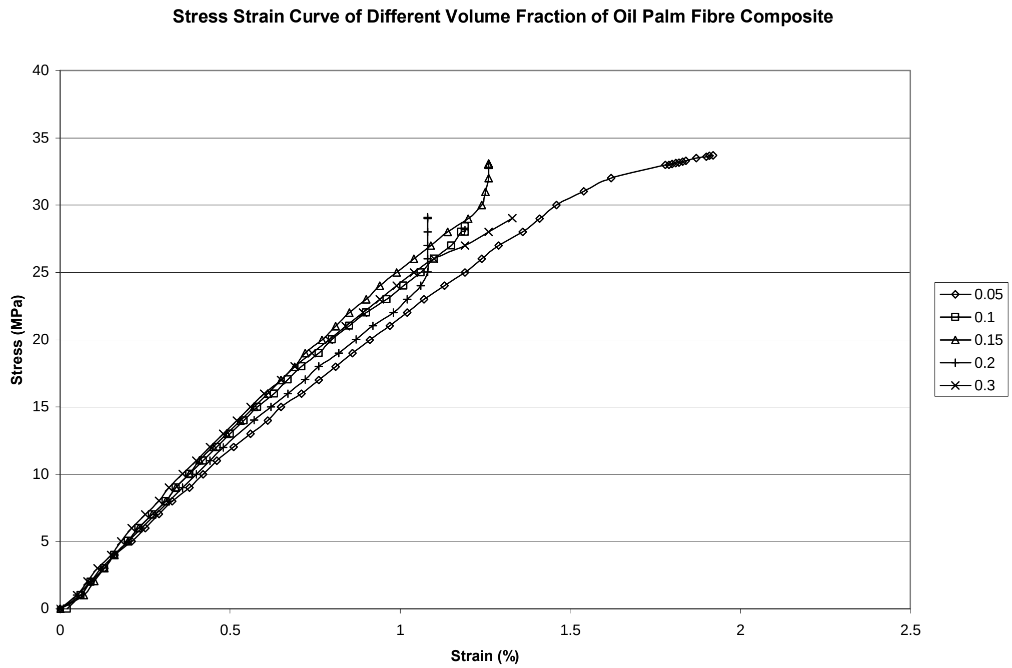


Figure 4.15: Stress strain curve of different volume fraction of oil palm fibre composite.

Figure 4.16: Typical failure pattern of unidirectional composites under longitudinal tension, a) fracture near tab, b) and c) fracture in gage length.

4.3.1.2 Fibre Length

Three different fibre length composites were fabricated to investigate the effect of fibre length in composite. At least three specimens were successfully tested in three different fibre lengths composite. Table 4.8 and Figure 4.17, 4.18 and 4.19 show the tensile properties of three different fibre lengths composite.

Table 4.8: Tensile properties of different oil palm fibre length composite.

Specimen		Ultimate Tensile Strength (MPa)			Strain At Break (%)			MOE (GPa)		
		Mean	SD	COV	Mean	SD	COV	Mean	SD	COV
Length	5	28.15	0.64	0.02	1.49	0.04	0.02	1.951	0.162	0.083
	10	24.77	3.47	0.14	1.15	0.21	0.18	2.183	0.126	0.058
	15	31.50	2.55	0.08	1.30	0.06	0.04	2.358	0.192	0.081

As shown in Figure 4.17, the highest ultimate tensile strength of the composite was the longest fibre composite. Generally, increase of fibre length in the composite, increase of ultimate tensile strength was observed in the study. However, a slightly decrease of ultimate tensile strength was found in 10cm fibre length composite.

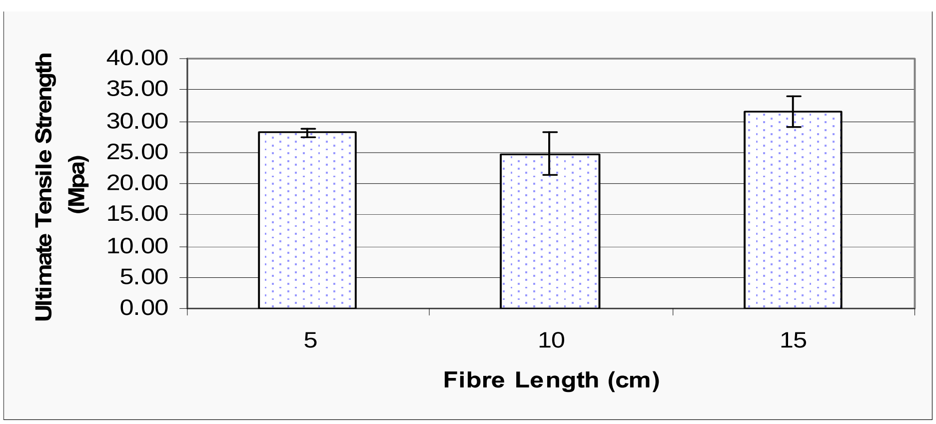


Figure 4.17: Bar chart of ultimate tensile strength versus fibre length.

Strain at break of different fibre length composite shows in Figure 4.18. Increase of fibre length in the composite, decrease of strain at break was observed in the study. Similar to ultimate tensile strength, a decrease of strain at break was found in 10cm fibre length composite but an increase was found in 15 cm fibre length composite.

Obviously, modulus of elasticity of the composite in this study was improved when fibre length was increased in the composite. This may due to the increase of efficiency in transferring stress from resin to fibre. Further explanation is discussed in discussion.

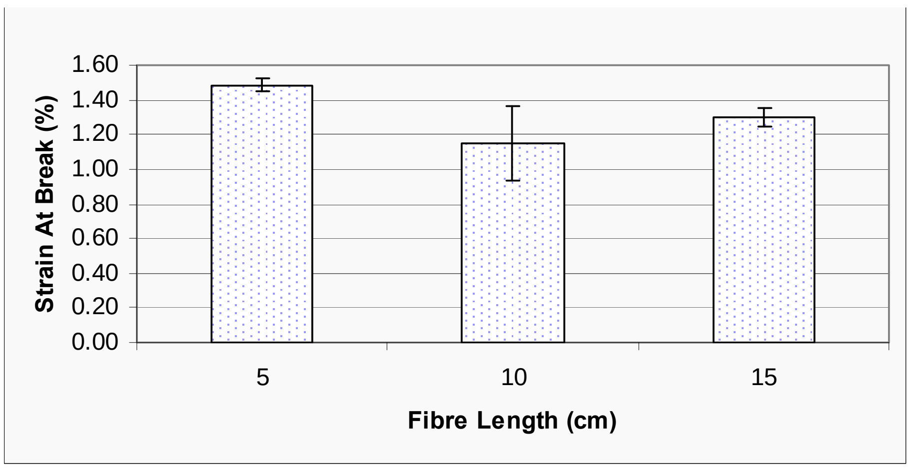


Figure 4.18: Bar chart of strain at break versus fibre length.

The tensile stress versus strain of the composite with different fibre volume ratio was shown in Figure 4.20. Linear elastic was found in tensile behaviour of all composite until strain at break. All composite failed in brittle manner where the composite fracture after the ultimate tensile strength.

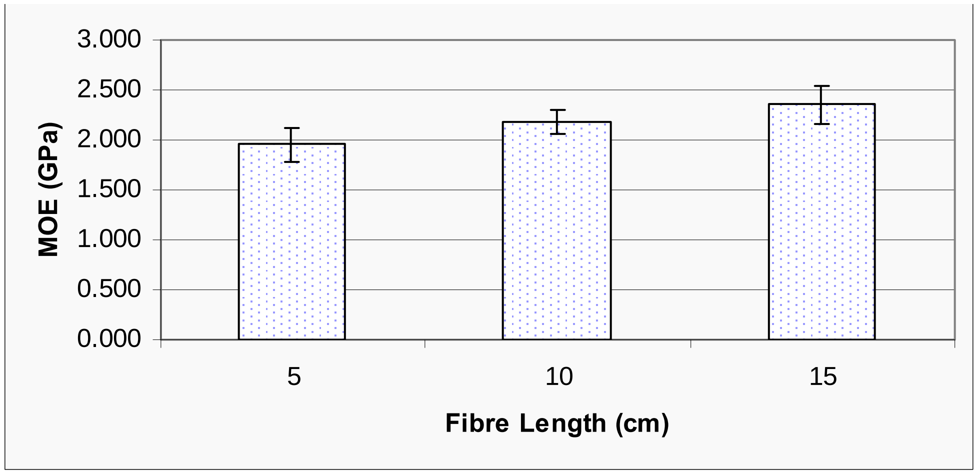


Figure 4.19: Bar chart of modulus of elasticity versus fibre length.

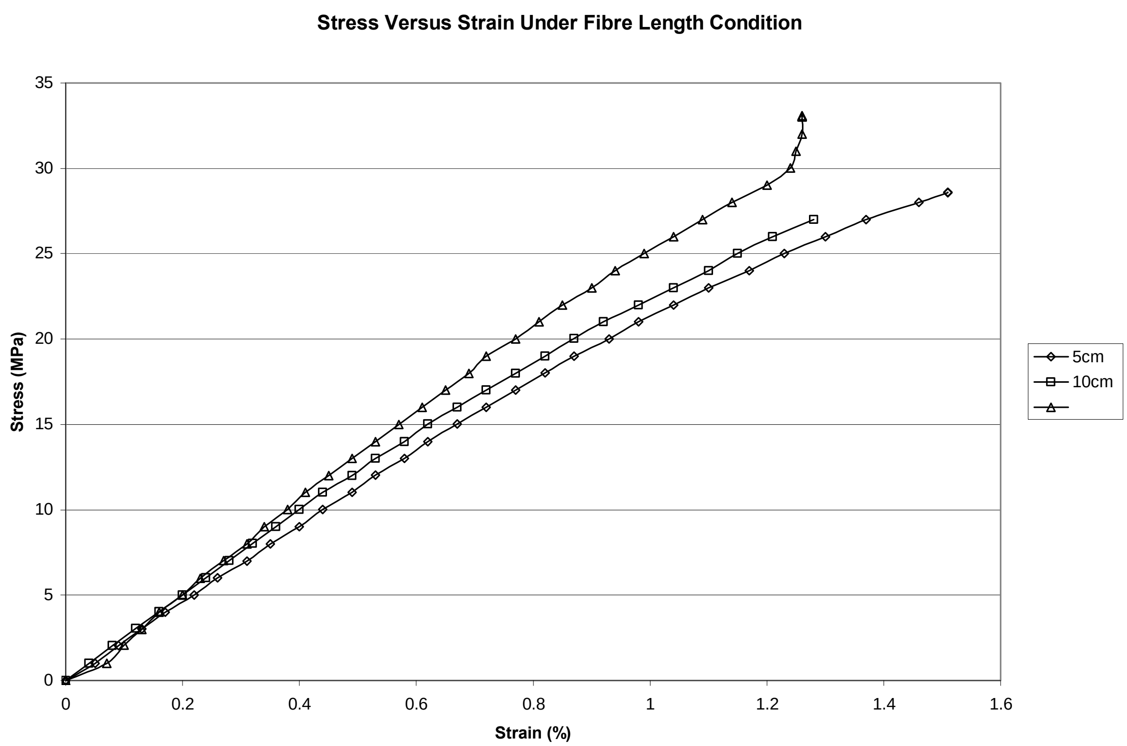


Figure 4.20: Stress strain curve of different fibre length of oil palm fibre composite.

4.3.1.3 Fibre Treatment

In this study, oil palm fibre was immersed in 2% of sodium hydroxide as a function of time. The alkali solution causes disruption of the fibre surface and removal of lignin and wax. Besides that, new ion was introduced to replace hydroxyl groups in the fibre. Thus, it was believed alkali solution could provide better wetting fibre surface for matrix adhesion. Tensile properties of the composite are presented in Table 4.9, Figure 4.21, Figure 4.22 and Figure 4.23.

Generally, ultimate tensile strength of the composite was found higher than untreated composite. In the beginning of the treatment, lower tensile strength was found than the untreated composite. However, the effect of the treatment started to improve ultimate tensile strength of the composite after 4 hours of treatment. Ultimate tensile strength of the composite decreased after 8 hours of alkali treatment.

Table 4.9: Tensile properties of fibre composite as a function of alkali treatment hours.

Specimen		Ultimate Strength (MPa)			Strain At Break (%)			MOE (GPa)		
		Mean	SD	COV	Mean	SD	COV	Mean	SD	COV
Alkali	0	31.50	2.55	0.08	1.30	0.06	0.04	2.358	0.192	0.081
	2	25.29	0.75	0.03	1.12	0.10	0.09	2.296	0.081	0.035
	4	32.84	0.41	0.01	1.71	0.03	0.02	2.035	0.164	0.081
	8	30.52	4.78	0.16	1.53	0.55	0.36	2.352	0.082	0.035

Strain at break of the composite was found improved after 4 hours of alkali treatment. In the beginning, of the treatment the strain at break of the composite was lower than untreated fibre composite. However, after 4 hours of treatment strain at break of the composite was increase. However, after 8 hours of treatment, strain at break of composite decrease.

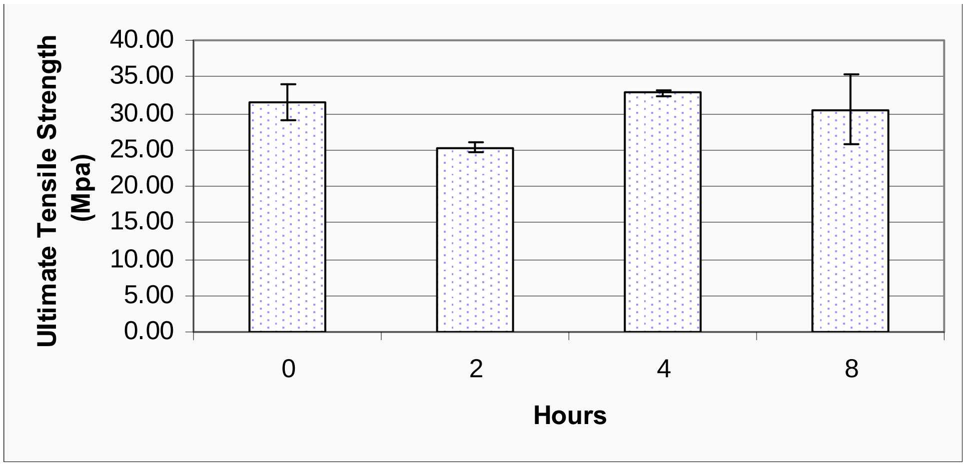


Figure 4.21: Bar chart of ultimate tensile strength versus fibre length in alkali treatment study.

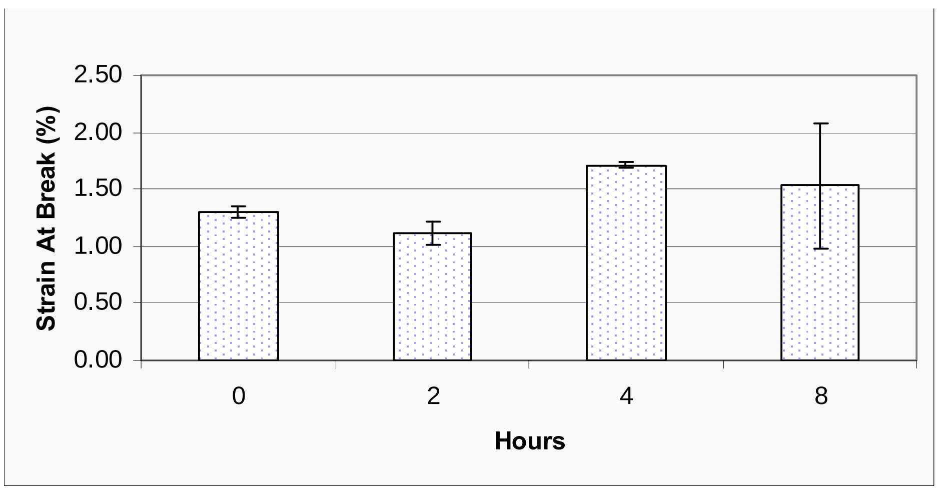


Figure 4.22: Bar chart of strain at break versus fibre length in alkali treatment study.

Mean while, modulus of elasticity of the composite was decreased after the treatment in all specimens. After 4 hours of treatment, the composite showed the lowest modulus of elasticity. Typical stress strain curves as a function of treatment hours were shown in Figure 4.24. Linear elasticity was found in all composite and brittle failure was observed in all specimens.

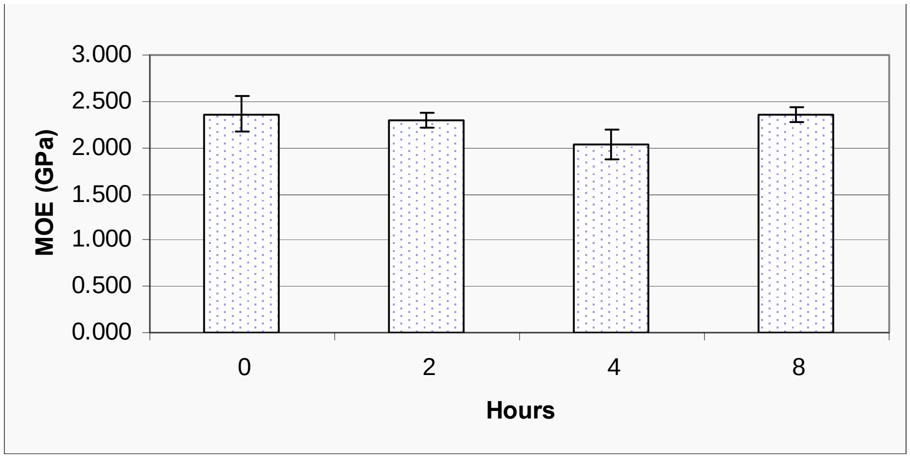


Figure 4.23: Bar chart of modulus of elasticity versus fibre length in alkali treatment study.

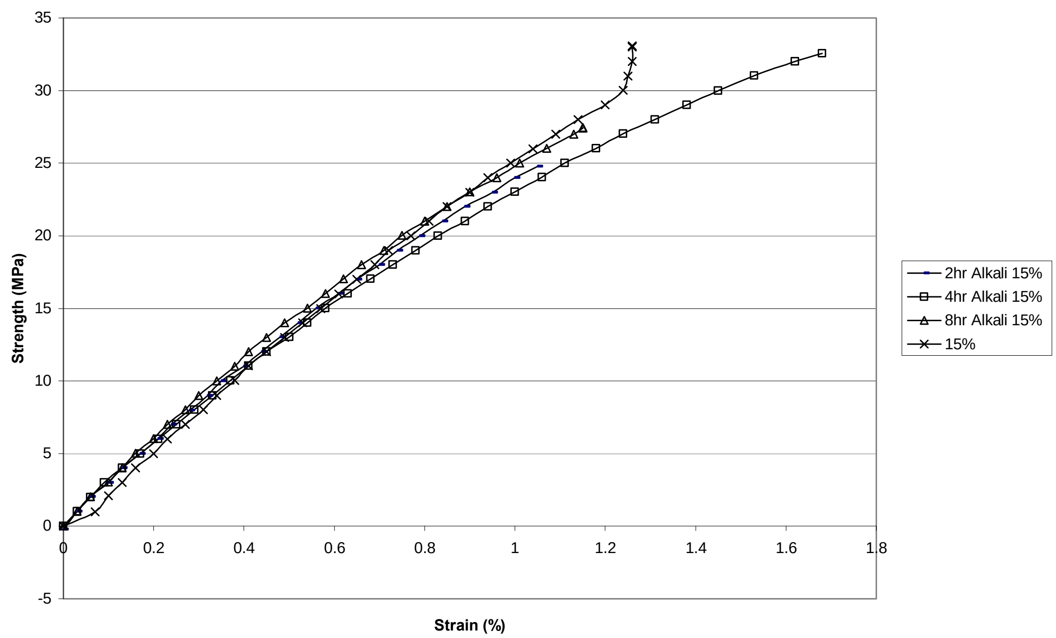


Figure 4.24: Stress strain curve of oil palm fibre composite as a function of treatment time.

4.3.2 Tensile Properties of Glass Fibre Composite

15 % by fibre volume ratio of woven glass fibre was obtained and fabricated using closed mould – hand lay-up system. Like oil palm fibre, coupon woven glass fibre composite was prepared and tested. The tensile properties of glass fibre composite are shown in Table 4.10 in statistical form. The average ultimate tensile strength was 48.55 MPa and strain at break was 1%. Modulus of elasticity of the composite was 48.76 GPa. Small coefficient of variance was obtained in all tensile properties.

Typical stress strain curve of glass fibre composite was shown in Figure 4.25. Linear elastic behaviour was observed in glass fibre composite. Transverse matrix cracking was found initially and fracture of the composite was observed at ultimate tensile strength.

Table 4.10: Tensile properties of woven glass fibre composite.

Tensile Properties	Mean	SD	COV
Ultimate Tensile Strength (MPa)	48.55	0.71	0.01
Strain At Break (%)	1.00	0.04	0.04
MOE (GPa)	48.760	0.269	0.006

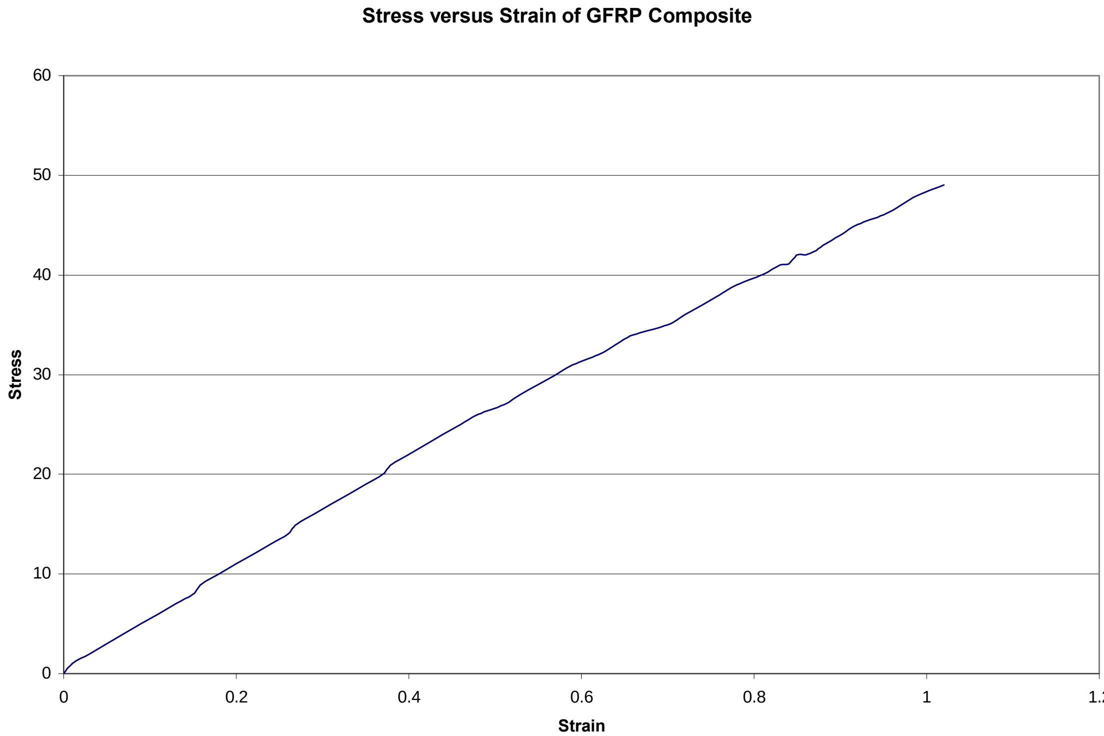


Figure 4.25: Typical stress strain curve of woven glass fibre reinforced polymer composite.

4.3.3 Tensile Properties of Resin

0.9% of catalyst was added into polyester and the mixture was poured into a dog bone shape mould. The tensile properties of the resin were tested. The tensile properties of the resin are shown in Table4.11 in statistical form. The average ultimate tensile strength was 38.44 Mpa and strain at break was 3.84%. Modulus of elasticity of the composite was 0.999 GPa. Large coefficient of variance was obtained in ultimate tensile strength and strain break.

Typical stress strain curve of resin was shown in Figure 4.26. Linear elastic behaviour was observed in resin. Brittle behaviour was found at the ultimate tensile strength. The resin experienced explosive failure in gage length.

Table 4.11: Tensile properties of polyester resin.

Tensile Properties	Mean	SD	COV
Ultimate Tensile Strength (MPa)	38.44	13.02	0.34
Strain At Break (%)	3.84	0.85	0.22
MOE (GPa)	0.999	0.088	0.088

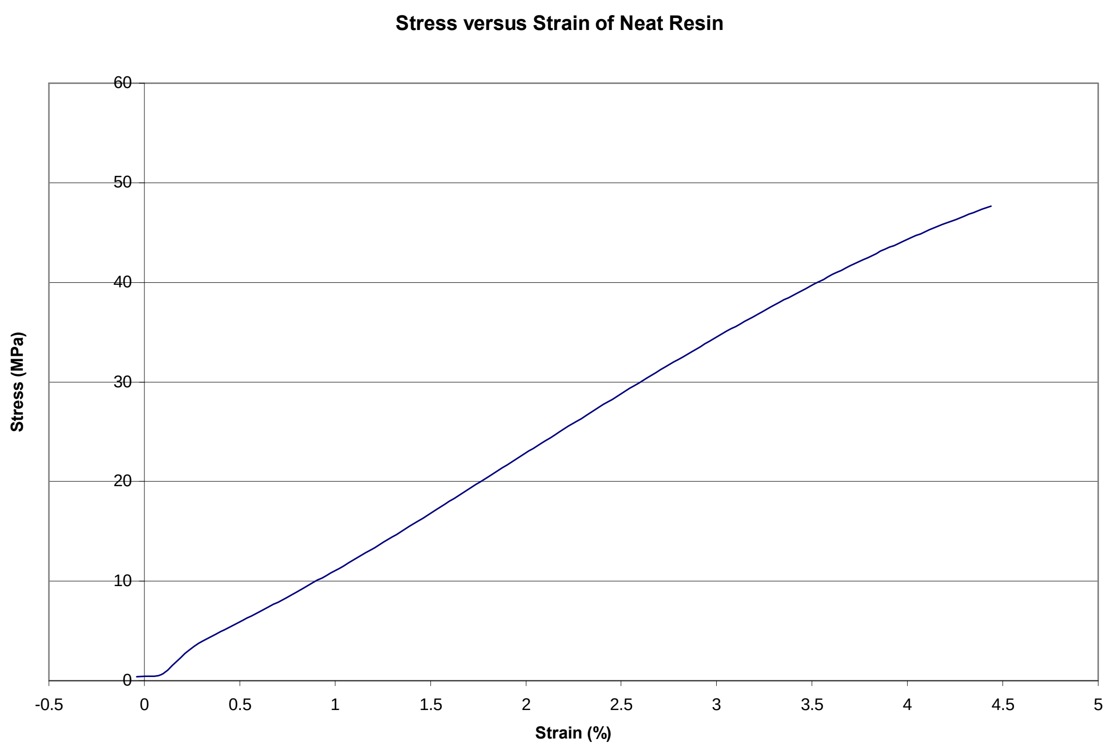


Figure 4.26: Typical stress strain curve of polyester resin.

4.4 Flexural Property of Strengthening Reinforced Concrete Beams

Three reinforced concrete beams were made and two of the beams were strengthened with natural fibre reinforced polymer composite and glass fibre reinforced polymer composite. Four point bending test was carried out to test flexural behaviour of the beam specimens. Ultimate bending load, mid-span deflections, longitudinal cross-sectional strains, compressive strain of concrete surface and tensile strain of composite surface were reported.

4.4.1 Compressive Strength of Concrete

Six concrete cubes were prepared to ensure the characteristic of the compressive strength of the concrete reached 25MPa. The compressive strength of the concrete were tested on 7 days and 28 days. Wet curing was applied to the concrete cubes by immersing the cubes in water after removal of the form works. Average compressive strength of the concrete was 18.01MPa at 7 days and 27.81MPa at 28 days. Non-explosive failure was found in all concrete cube.

Table 4.12: Compressive strength of concrete.

	Strength (MPa)		
Specimen	Mean	SD	COV
7 days	18.01	0.82	0.05
28 days	27.81	1.65	0.06

Figure 4.27: Longitudinal cracks were found on tested concrete cubes at 28 days.

4.4.2 Control Specimens

Flexural test were tested for control specimens to verify the effects of the strengthened beams. Three LDVT instruments were employed to measure deflection of the beam when subjected to load. 100kN load cell was employed to measure the applied load. Load versus displacement graph was shown in Figure 4.28. From the graph, linearity was found until it reached 10kN load. The stiffness of the beam started to decrease after the applied load reached 10kN. Decreased of beam stiffness may due to small crack at the tensile zone of the beam. The first visible flexural cracks were found when 10kN load was applied. When applied load reached 22 kN, the displacement of the beam started to increase in an increasing rate. Small load applied to the beam caused the beam to deflect largely. This occurred because the reinforcement bar of the steel had reached yielding point. The beam behaved in a ductile manner before it failed. Ultimate load of control beam was 24.4kN. Large flexural crack was found under the applied load after the beam failed.

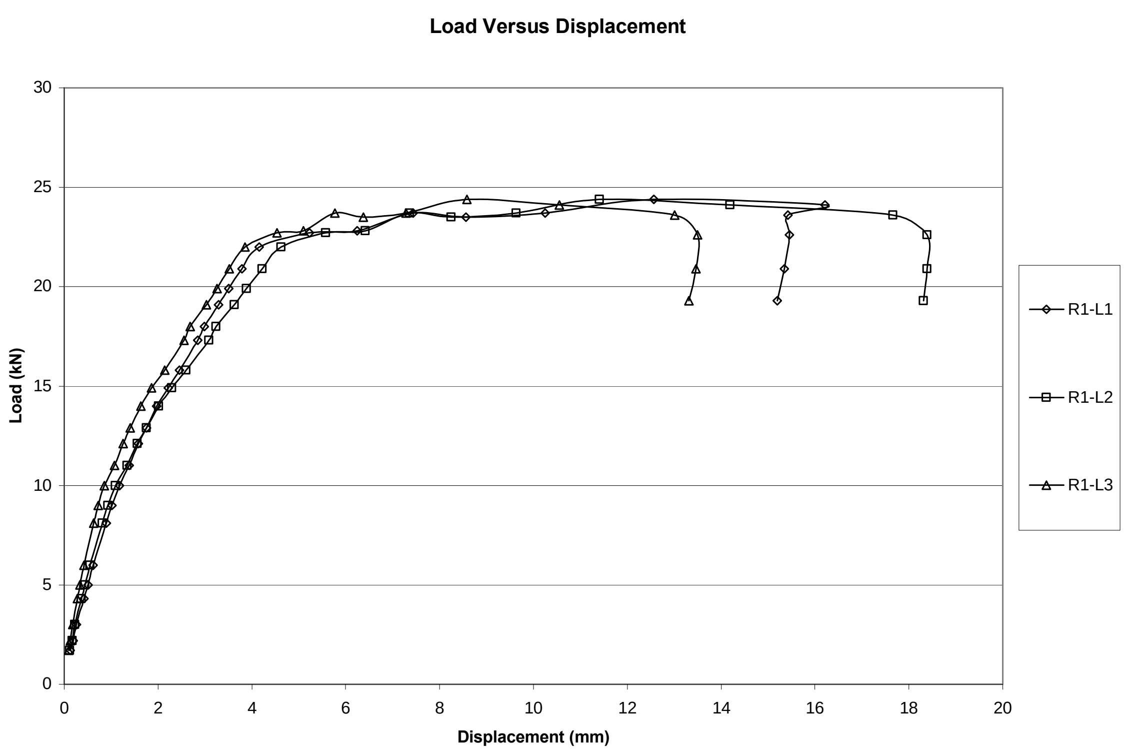


Figure 4.28: Load-displacement curve of control beam.

Figure 4.29: Large flexural crack was found under the applied load after the control beam failed.

Figure 4.30: Flexural cracks were observed in control beam.

Three strain gauges were installed at the side surface of the concrete beam. The locations of the strain gauges were 25mm, 100mm and 175mm from the top surface of the beam respectively. Figure 4.31 shows the result of development of strain in the mid span cross section beam under various applied load. At 14kN applied load, the measured strain was linear in depth of the beam. As the load reached ultimate load, non linear was observed and the neutral axis started to move from mid depth to bottom surface of the beam. Non-linear was observed can be due to cracks that reduced the strain. This was proved as the tensile strain of the concrete at ultimate load was reduced compare to tensile strain at 14kN.

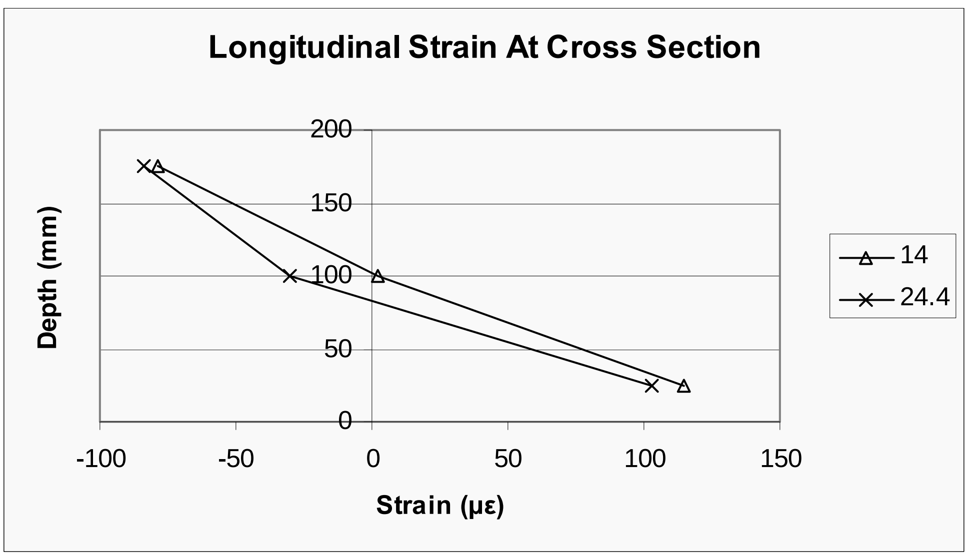


Figure 4.31: Longitudinal strain in the mid span cross section control beam under various applied load.

In Figure 4.32, load versus compressive strain of the concrete beam at the top surface was shown. Non linear was observed in the figure where the compressive strain increases in a decreasing rate. The ultimate compressive strain of the concrete beam remained lower than the designed strain as specified in British Standard which was 3500 με. This was important to indicate that the beam was still under reinforced and no crushing failure in compression concrete would occur.

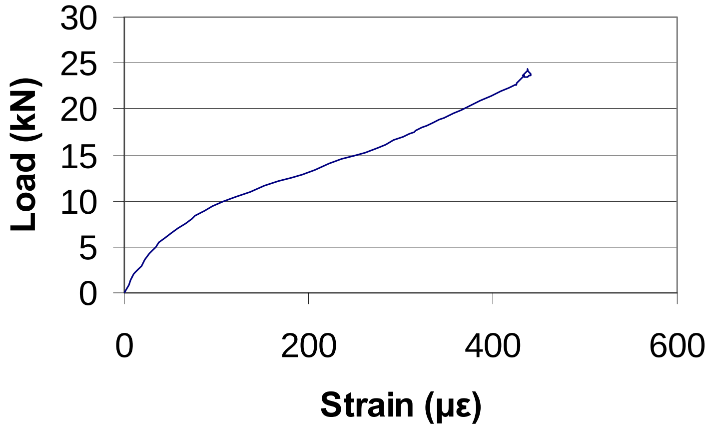


Figure 4.32: Load versus compressive strain of the concrete beam at the top surface.

4.4.3 Reinforced Concrete Beam strengthened with Glass Fibre Composite Plate

15% by volume fraction of woven glass fibre were fabricated using close mould hand lay-up system to strengthen the concrete beam. The surface of the bottom beam was roughened to increase bonding between the composite plate and concrete. Epoxy, the adhesive, was employed in this study. Load versus displacement graph of reinforced concrete beam strengthened with glass fibre reinforced polymer composite plate (RC-GFRP) was shown in Figure 4.33. Linearity was found until it reached 12kN load. Stiffness of the beam started to decrease after the applied load reached 12kN. The decreased stiffness was due to visible crack at the tensile zone of the beam. When applied load reached 34 kN, the displacement of the beam started to increase in an increasing rate but the applied load increased in a slower rate. The beam continued to take load until it reached ultimate load which was 43.4kN. It was observed that more flexural cracks were found in RC-GFRP beam than control beam. No ductility was found after the ultimate load can be due to the debonding of GFRP plate in the end of beam.

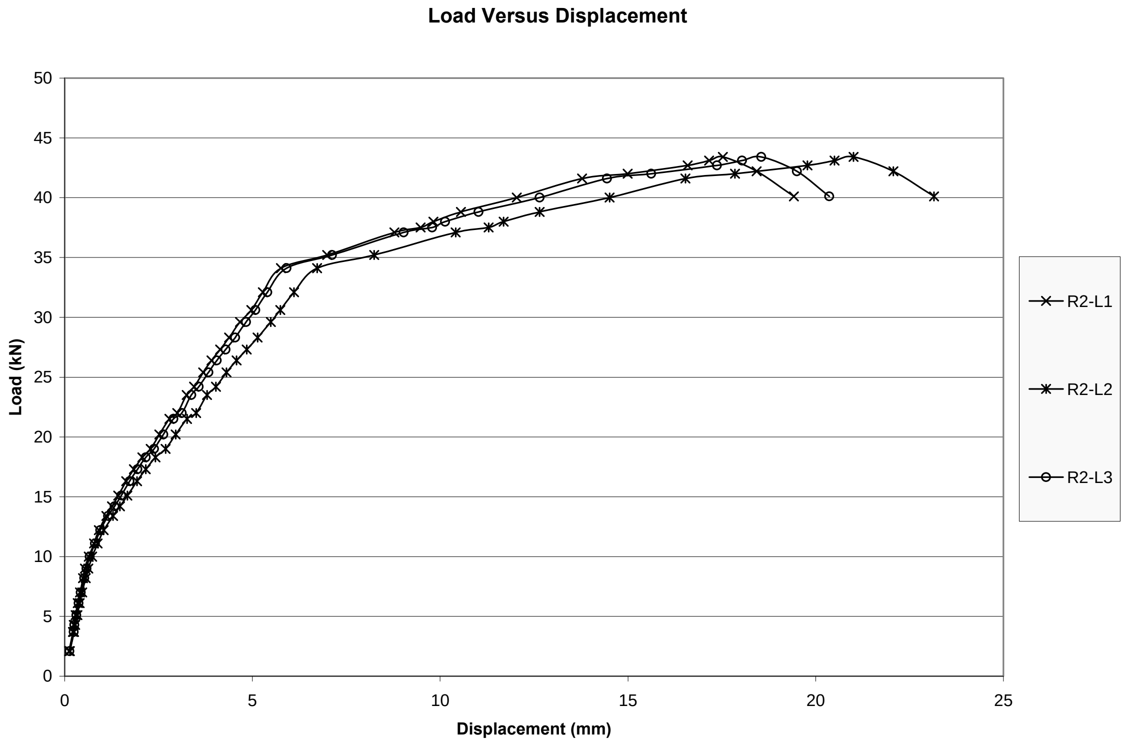


Figure 4.33: Load-displacement curve of RC-GFRP beam.

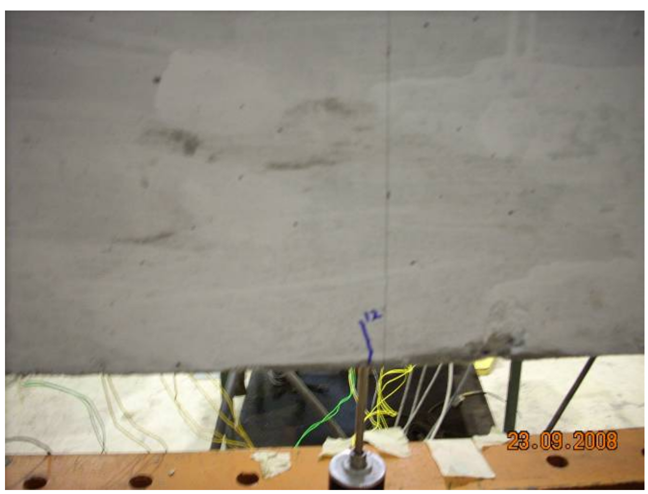


Figure 4.34: Initial crack was found at 12kN of applied load in GFRP-RC beam.

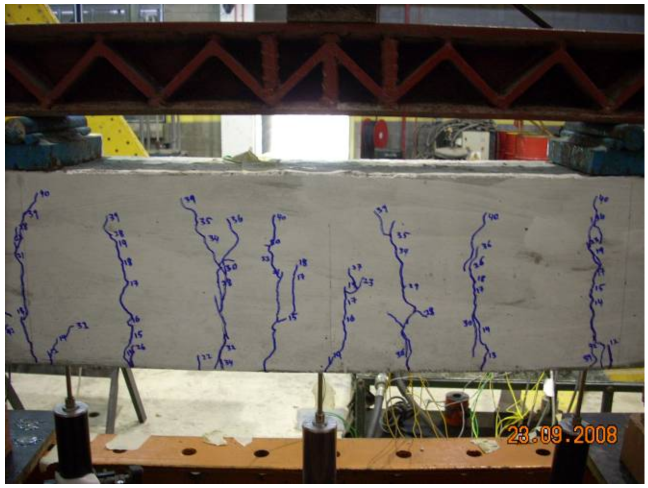


Figure 4.35: Flexural cracks were observed in GFRP-RC beam.

Figure 4.36: GFRP plate end interfacial debonding was observed after ultimate load.

Like control beam, three strain gauges were installed at the side surface of the concrete beam. The locations of the strain gauges were 25mm, 100mm and 175mm from the top surface of the beam respectively. Figure 4.37 shows the result of development of strain in the mid span cross section beam under various applied load. At 14.2kN applied load, the measured strain was linear in depth of the beam. The neutral axis at 14.2kN was not in the middle of the cross section beam. As the load reached ultimate load, non linear was observed and the neutral axis started to move from mid depth to top surface of the beam.

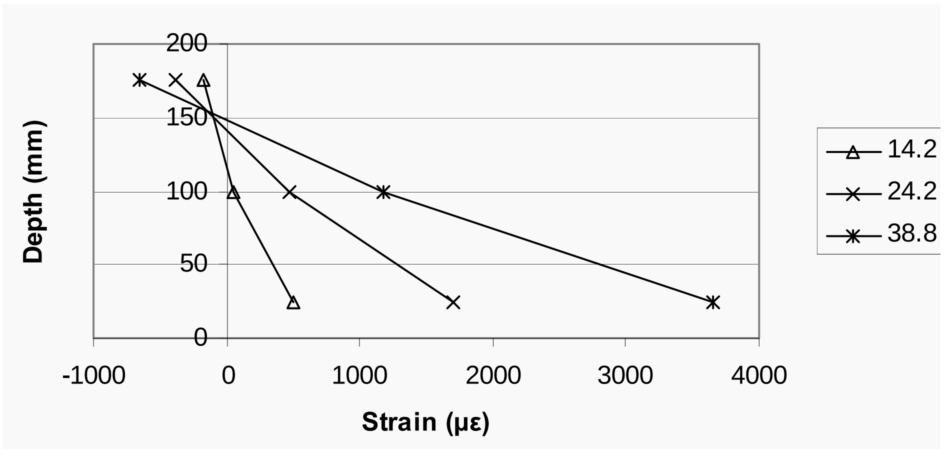


Figure 4.37: Longitudinal strain in the mid span cross section RC-GFRP beam under various applied load.

Figure 4.38 shows load versus compressive strain of the concrete beam at the top surface. Like control beam, non linear curve was found where the compressive strain increases in a decreasing rate. The ultimate compressive strain of the concrete beam remained lower than the designed strain as specified in British Standard which was 3500 με.

Figure 4.39 shows load versus tensile strain of glass fibre reinforced polymer composite at the bottom of the beam. Non linear curve was found where the tensile strain of the composite increases in a decreasing rate. At 35kN applied load, the fluctuated tensile strain of the composite was observed and this can be due to the uneven stress transfer from the beam to the plate. More cracks appeared and propagated causes the uneven stress transfer.

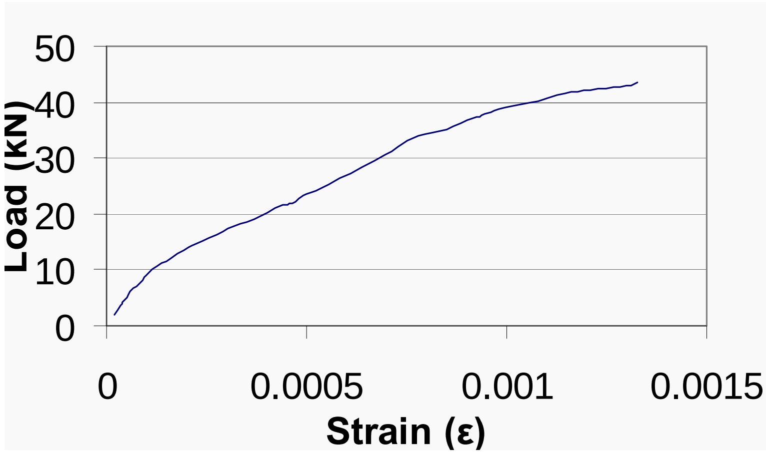


Figure 4.38: Load versus compressive strain of GFRP-RC concrete beam at the top surface.

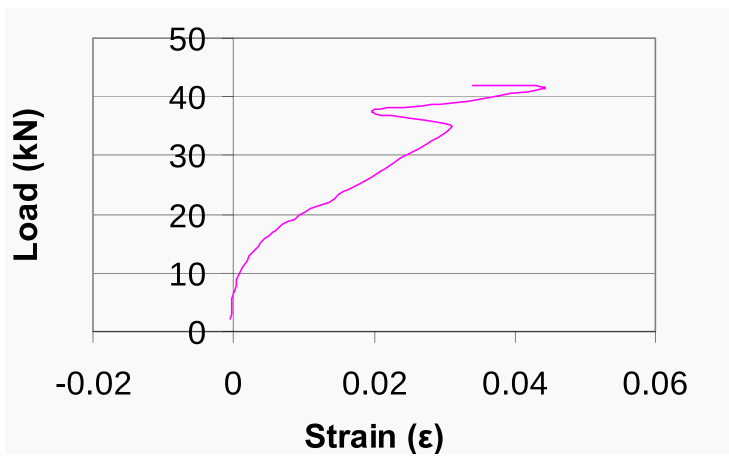


Figure 4.39: Load versus tensile strain of GFRP composite plate at the bottom of the beam.

4.4.4 Reinforced Concrete Beam strengthened with Oil Palm Fibre Composite Plate

The main objective of the study was to investigate the potential used of oil palm fibre composite plate as strengthening material in reinforced concrete beam. Like glass fibre reinforced polymer composite, 15% by volume fraction of oil palm were also fabricated using close mould hand lay-up system to strengthen the concrete beam. The surface of the bottom beam was roughened to increase bonding between the composite plate and concrete. Epoxy, the adhesive, was employed in this study. Load versus displacement graph of reinforced concrete beam strengthened with oil palm fibre reinforced polymer reinforced (RC-OPFRP) was shown in Figure 4.40. Linearity was iniatially found until it reached 11kN load. Then, stiffness of the beam started to decrease due to flexural cracks. The first flexural crack was found when 11kN load was applied. The beam reached ultimate load which was 26.6 kN and dropped to 22kN due to the fracture of oil palm fibre reinforced polymer. The beam behaves ductile after the decreased load. The number of flexural cracks was less than RC-GFRP but more than control beam.

Like control beam and RC-GFRP beam, three strain gauges were installed at the side surface of the concrete beam. The locations of the strain gauges were 25mm, 100mm and 175mm from the top surface of the beam respectively. Figure 4.43 shows the result of development of strain in the mid span cross section beam under various applied load. At 14.2kN applied load, the measured strain was not linear in depth of the beam. However, linearity was observed when the load was 20.4kN. The can be due to the malfunction of the third strain gauge in the beginning of the load. The neutral axis at 14.2kN was not in the middle of the cross section beam. As the load reached ultimate load, non linear was observed again and the neutral axis move from 130mm depth to bottom surface of the beam.

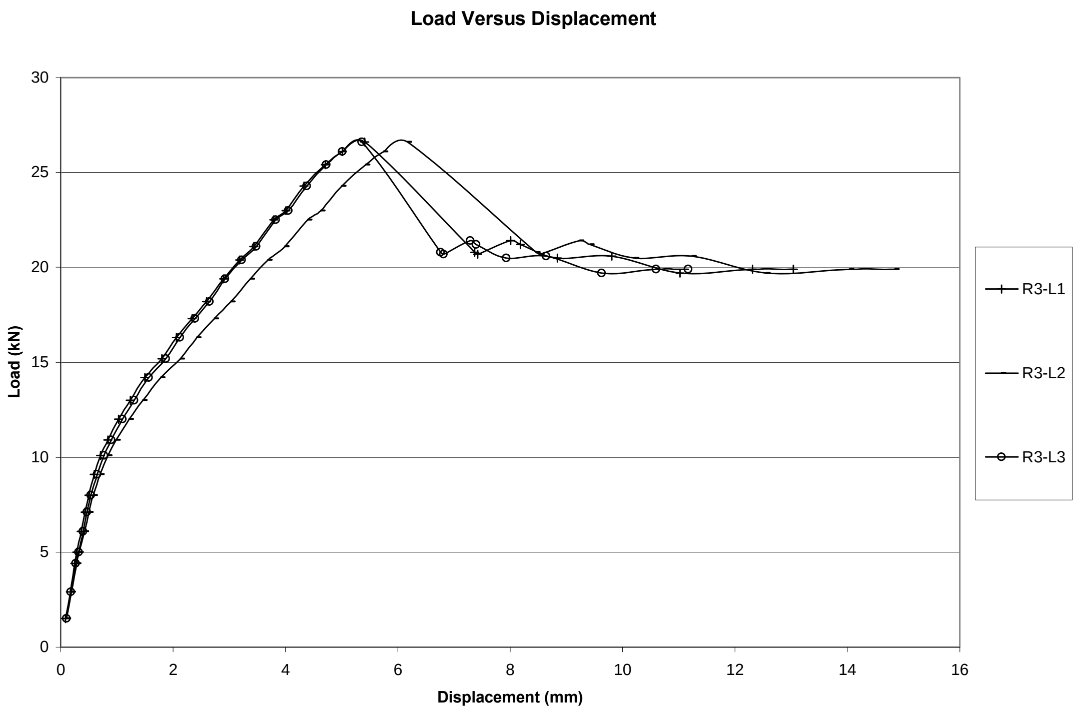


Figure 4.40: Load-displacement curve of RC-OPFRP beam.

Figure 4.41: Fracture of oil palm fibre reinforced polymer composite at ultimate tensile strength.

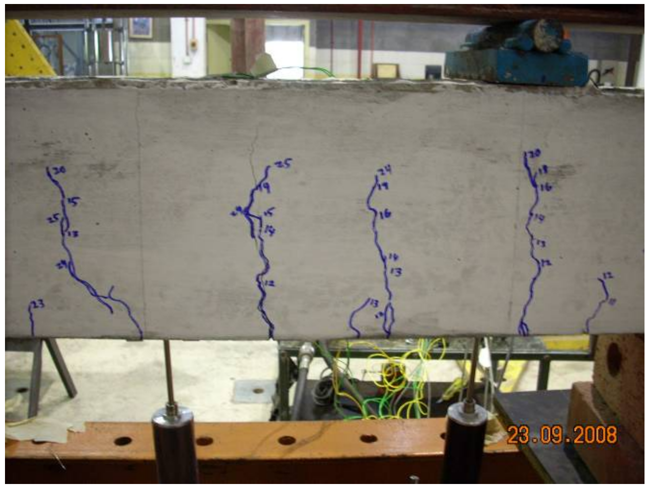


Figure 4.42: Flexural cracks were observed in OPFRP-RC beam.

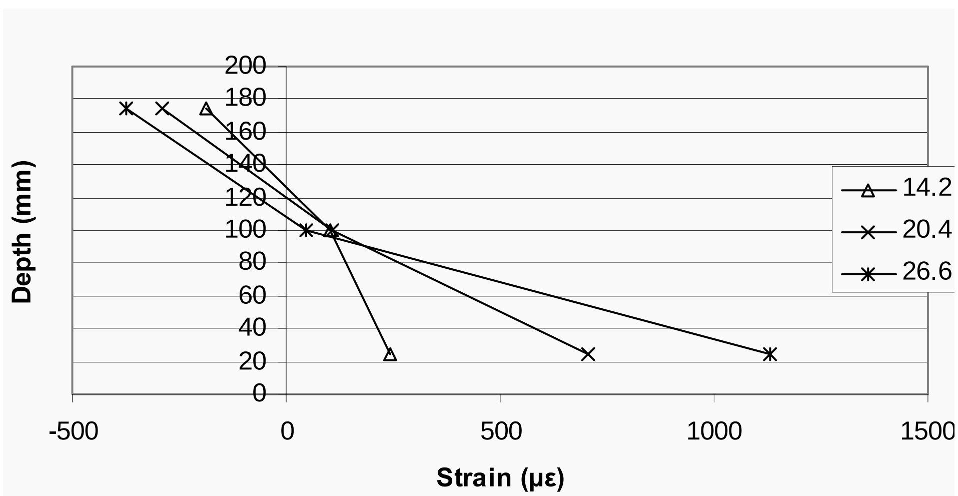


Figure 4.43: Longitudinal strain in the mid span cross section RC-OPFRP beam under various applied load.

Figure 4.44 shows load versus tensile strain of oil palm fibre reinforced polymer composite at the bottom of the beam. Non linear curve was found where the tensile strain of the composite increases in a decreasing rate after 11kN. Due to malfunctioning of strain gauge at the top reinforced concrete beam, the results was not recorded.

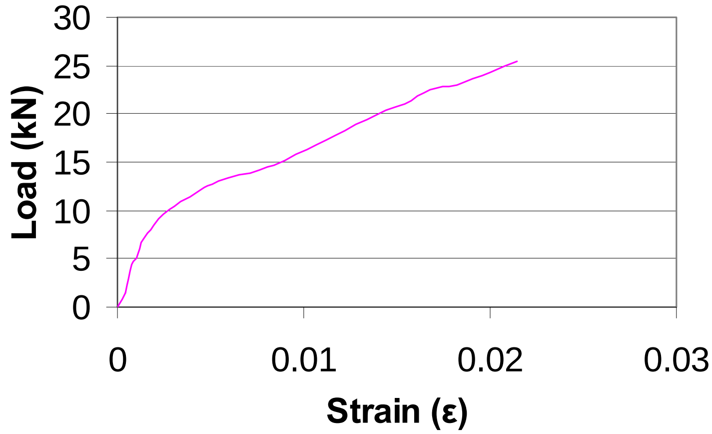


Figure 4.44: Load versus tensile strain of GFRP composite plate at the bottom of the beam.

4.5 Conclusions

The results of the experimental works were presented in this chapter. A few conclusions could be withdrawn as:

1) The physical test carried out in this study proved that the oil palm fibre was light, high moisture content, high moisture regain, large variance in with fibre diameter.
2) Oil palm fibre obtained in this study is generally low strength, low modulus and high strain at break compare to synthetic fibre.
3) When fibre volume fraction increased, modulus of elasticity of oil palm fibre reinforced polymer composite was improved but tensile strength of the composite was decreased.
4) Increased of fibre length in composite generally improve the tensile properties of oil palm fibre reinforced polymer composites.
5) 4 hours of alkaline treatment could increase the tensile strength of oil palm fibre reinforced polymer but degrade the elasticity of the composite.
6) Oil palm fibre reinforced polymer composite and Glass fibre reinforced polymer composite increase the stiffness and ultimate load of ordinary

reinforced concrete beam. Both ordinary reinforced concrete beam and beam strengthened with oil palm fibre reinforced polymer composite showed ductility after reaching the ultimate load. However, no ductility was found in the beam strengthened with glass fibre reinforced polymer composite.

CHAPTER 5

ANALYSIS AND DISCUSSION

5.1 General

This chapter discusses the analytical aspect of experimental results of natural fibre, oil palm fibre reinforced composite and reinforced concrete beam strengthened with natural fibre composite plate. The physical and tensile properties of the natural fibre were characterized and were compared to the literature. The effect of oil palm fibre in reinforcing polymer were discussed by comparing typical stress strain diagram of oil palm fibre, oil palm fibre reinforced polymer composite and resin. Mathematical models were used to validate the test results of natural fibre reinforced composite as a function fibre volume fraction and fibre length. The effect of alkali was discussed in detail and comparison was made with other literatures. The flexural behaviour of ordinary reinforced concrete beams were compared with the beams strengthened with composite plates. Comparison between theoretical predictions and experimental results were made.

5.2 Characterization of Natural Fibres

Physical properties and tensile properties of natural fibres were discussed and compared with literature. The physical properties included fibre length, fibre diameter, moisture content, moisture absorption and fibre density. The tensile properties included ultimate tensile strength, strain at break and modulus of elasticity.

5.2.1 Physical Properties

5.2.1.1 Fibre Length

Natural fibre in nature is discontinuous fibre in most fibre reinforced polymer composite applications. The method of fabricating the discontinuous fibre composite and the mechanical properties of the discontinuous fibre composite were affected by the fibre length. The obtained oil palm fibre from Sabutek Sdn. Bhd. was generally shorter than 5 cm. However, some of the fibre was 30cm long in the test. Generally short fibres in the primary units may be caused by the extraction process. Therefore, further investigation was required to examine original oil palm fibre length.

5.2.1.2 Fibre Diameter

The diameter of oil palm fibre found in this study was compared with the other literatures. In general, the oil palm fibre diameter can be range from 0.213-0.811 mm. The study observed that the cross section of oil palm fibre was not circular at all. There is lumen in the cross section of the oil palm fibre instead of compact cross section was found. M.Sreekala describe that the cross section of oil palm shows a lacuna-like portion in the middle[6]. 0.113 mm lumen width was reported by Sabutek Sdn.Bhd[19]. Therefore, the oil palm fibre is tube like fibre where the true cross sectional area of the fibre require measurement on the outer diameter and inner diameter.

Table 5.1: Diameter of Oil Palm Fibre (Empty Fruit Brunch)

Author	Diameter (mm)
Hill and Khalil	0.408 (0.081)
K.M.M.Rao	0.811
Sabutek Sdn. Bhd.	0.213
From test	0.448 (0.171)

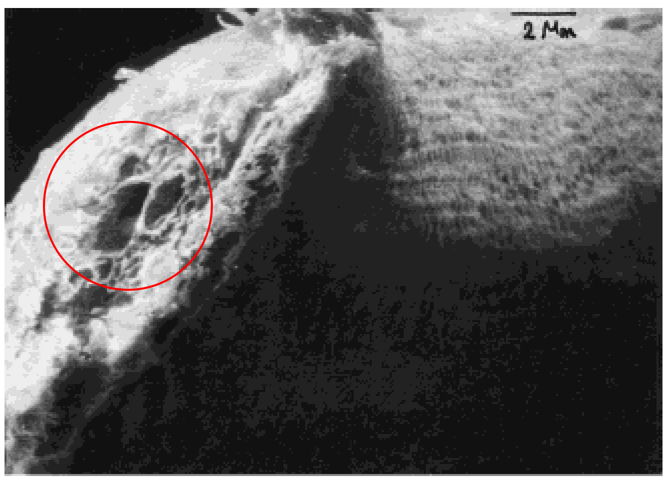


Figure 5.1: Lumen was found in the cross section of oil palm fibre [6].

5.2.1.3 Moisture Content and Moisture Absorption

The present of moisture content in natural fibre could be disastrous in terms of strength and durability for composite. Poor wetting surface for hydrophobic resin may cause interfacial shear bond and thus lower the strength of the composite. In long term effects, high moisture content in fibre can cause problems in dimensional stability of the composite. Therefore, the moisture content should be maintained to the lowest by oven dried. Table 5.2 shows the moisture content of other types of natural fibres. This study found that oil palm fibre and pineapple leaf fibre have higher moisture content than other natural fibre. However, in general, moisture content in natural fibres is deadly high for polymeric composite. This can be due to the hydrophilic character in natural fibres. High content cellulosic material which has hydroxyl groups in micro fibril tends to absorb the moisture in the air. Therefore, it is not surprised that the moisture regain in oil palm fibre and pineapple leaf fibre almost approach the original moisture content in this study.

Table 5.2: Moisture content of various fibres.

Types of Fibre	Moisture Content
Vakka	12.09
Date	10.67
Bamboo	9.16
Oil Palm*	17.48
Palm	12.08
Coconut	11.36
Pineapple leaf *	17.48

* Determine in this study.

5.2.1.4 Fibre Density

Fibre density is an important parameter in natural fibre reinforced polymer composite especially in automobile industry and aerospace industry to reduce weight of the composite application. The density of natural fibre in this study was determined by using Buoyancy method and was compared with the literature. Various types of natural fibre density are show in Table 5.3. The measured density of oil palm fibre and pineapple leaf fibre in this study is similar to the density measured by other author. In general, density of all natural fibres is smaller than synthetic fibre - glass fibre.

Table 5.3: Density of different type of natural fibres.

Fibers	Density (g/cm^3)
Agave	0.74
Curaua	1.38
Banana	1.35
Bamboo	0.9
Flax	1.5
Kenaf	0.75
Jute	1.24
Pineapple	1.53
Pineapple*	1.58
Oil Palm	1.03
Oil Palm*	1.07
Sisal	1.45
E-Glass	2.56

* Determine in this study.

5.2.2 Tensile Properties of Oil Palm Fibre

The role of fibre in composite is to act as reinforcement in polymeric material. Hence, tensile properties of natural fibre influence directly to the mechanical properties of the composite. Table 5.4 shows tensile properties of various natural fibres. The tested oil palm fibre tensile properties in this study are lower than the reported results. This can be due to biodegradation problem as the oil palm fibre in this study was stored in high humidity area. Among the natural fibres, tensile properties of hemp, flax and jute was comparable to the synthetic fibre. In general, natural fibres have lower tensile properties than synthetic fibre. When compare with resin, most of the natural fibres have higher strength, modulus of elasticity and strain at break. This means that the present of natural fibre in resin could improve the tensile properties of the composite.

The stress-strain curve of oil palm fibre in this is compared with the reported stress-strain curve by other researcher. Similar behaviour is found in both stress-strain curve of oil palm fibre. Initially, the behaviour of oil palm fibre shows linearity. After 0.5-1% of strain, curvature was observed where the fibre elongates in an increasing rate when load increases. At ultimate tensile strength, the oil palm fibre failed in a brittle behaviour where the fibre broke in sudden.

Table 5.4: Density of different type of natural fibres.

Fibers	Ultimate Tensile Strength (MPa)	Modulus of Elasticity (GPa)	Strain at Break (%)	Number of Refences
Agave	100-500	1.7-13.2	19-4.8	2
Curaua	913	30.0	3.9	1
Banana	540-600	8.0-20.0	3.36	4
Bamboo	341-503	19.7-35.9	1.4-1.73	1
Flax	343-1035	27.6	2.7-3.2	2
Hemp	1802-2251	1312-195	1.7-2.3	3
Kenaf	377	12.0-28.6	1.3-3.3	2
Jute	120-1461	3.75-107	1.2-4.8	4
Pineapple	170-640	4.2-6.21	2.4-3	4
Oil Palm	64-377	0.5-5.25	6.5-25	4
Oil Palm*	58.3	0.5	12.21	-
Sisal	350-635	2.8-9.4	2.0-7.0	5
E-Glass	3400	72	2.5	1
Polyester	65	3.6	3.8	1

* Determine in this study.

(a) (b)

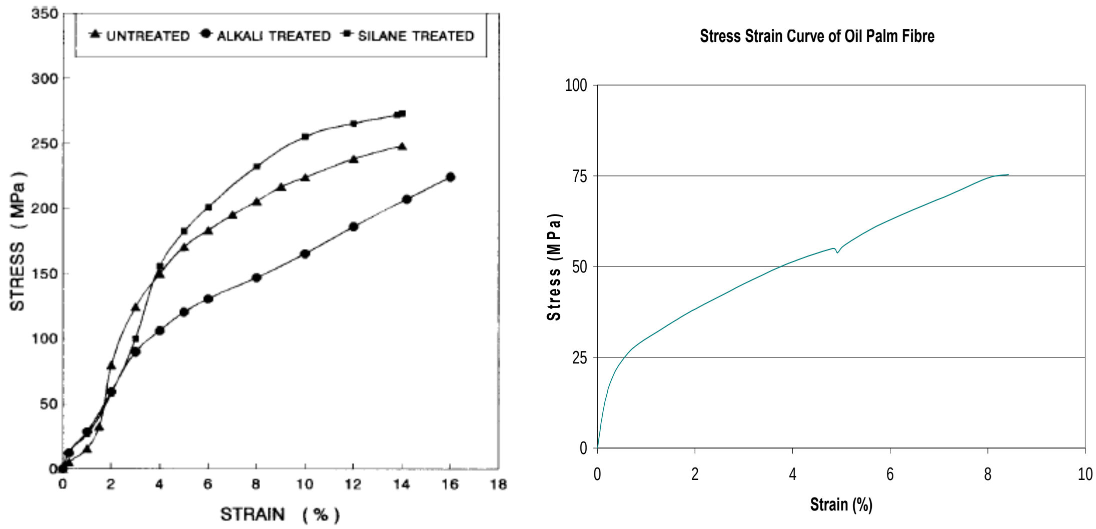


Figure 5.2: a)Stress-strain curve of treated and untreated oil palm fibre reported by M.S.Sreekala and b) a)Stress-strain curve of untreated oil palm fibre reported in this study.

5.3 Characterization of Tensile Behaviour of Natural Fibre Reinforced Composite

Tensile behaviour of natural fibre reinforced composite is influenced by the fibre itself, fibre volume fraction, fibre length and surface modification. The effect of these factors in fibre reinforced polymer composite are explained and discussed. Mathematical model is used to predict some of the behaviour of the composite.

5.3.1 Effect of Oil Palm Fibre in Reinforcing Polymer

In this chapter, the effect of oil palm fibre in reinforcing polymer was discussed in micromechanics scale. The failure mechanisms and processes on a micro mechanical scale were discussed to prove the reinforcing effect of oil palm fibre in polymer. The composite behaviour is governed by two main components, namely fibre and matrix. The mixture of two components will produce composite which has the behaviour influenced by the two main components.

To elaborate the effect of oil palm fibre in composite, typical stress strain curves of oil palm fibre, oil palm fibre reinforced polymer composite and resin were presented in Figure 5.3. In this case, 0.15 of fibre volume fraction of oil palm fibre reinforced polymer composite was employed for the discussion. Factors like orientation, curvature, fibre length and surface of the fibre influence the overall composite mechanical performance. However, to simplify the discussion, the fibre was idealized and was treated as straight and long fibre.

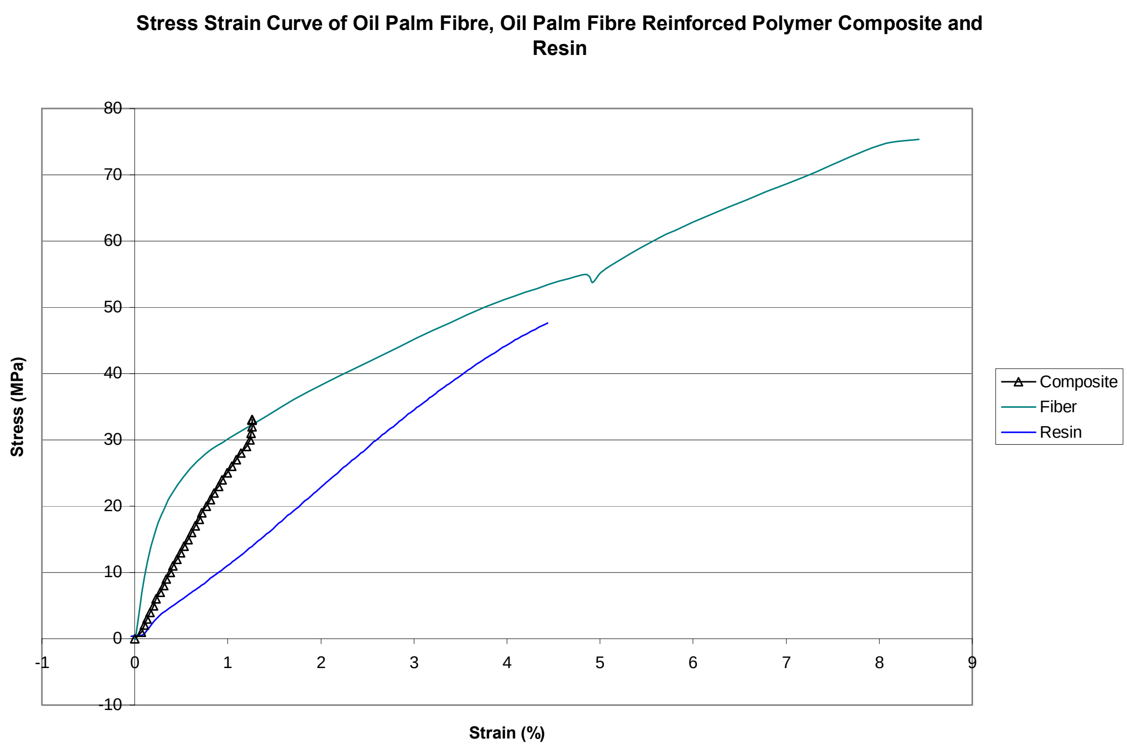


Figure 5.3: Stress-strain curve of oil palm fibre, oil palm fibre reinforced polymer composite and resin.

The figure shows that oil palm fibre has higher ultimate tensile strength and higher strain at break than the resin. Because of this factor, the composite generally failed before the ultimate tensile strength of oil palm fibre and resulted in generally low tensile strength. The stiffness of the composite was improved due to higher initial stiffness of oil palm fibre. Due to lower stiffness of oil palm fibre after 1% of strain than the resin, the resin started to carry more loads than the oil palm fibre. The composite reached its ultimate tensile strength when the resin fracture transversely and left some fibres remain unbroken.

The sequence of micromechanics failure was illustrated in Figure 5.4. Prior to the failure, resin transfer the tensile stress to oil palm fibres. When stiffness of oil palm fibre drop below the resin, resin started to absorb load and caused small cracks. Matrix transverse cracking propagated very fast and caused composite failure. The fibres experienced fibre pulled out and debonding. Some fibre was broken but mostly remained unbroken.

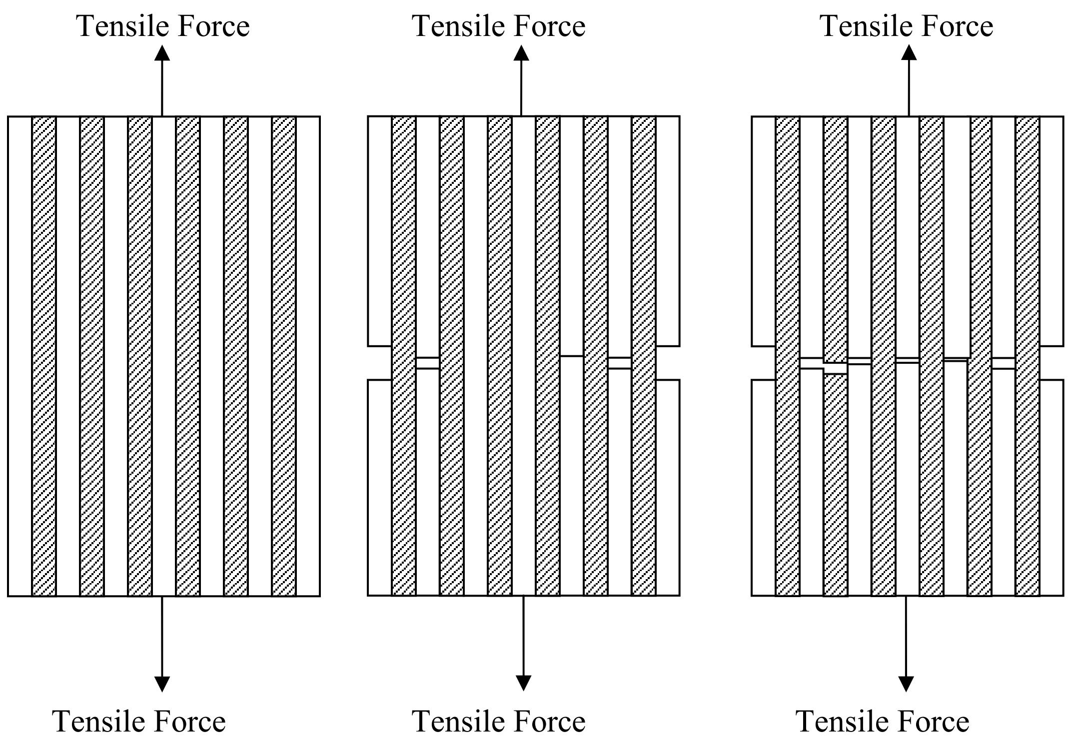


Figure 5.4: Sequence of micromechanics failure in composite.

5.3.2 Effect of Fibre Volume Fraction in Composite

Figure 5.5 shows the effect of tensile properties of oil palm fibre reinforced polymer composite as a function of fibre volume ratio. In general, lower ultimate tensile strength and lower strain at break of the composite were found when comparing with the resin. This can be due to the nature characteristic of oil palm fibre. As discussed before, oil palm fibre in this study is generally low tensile strength and high strain at break of oil palm fibres. The composite generally failed before the ultimate tensile strength of oil palm fibre. In addition, the fibres are not straight and form curvature in the composite. The effect of curvature can produce local stress perturbations which tent to promote fibre debonding and other local failure[20]. Besides, void contains in composite may also lead to severe internal stress concentrations in the material and causes the composite to fail easily. Significant improve was found in modulus elasticity of the composite when compare with resin. The stiffness of the composite started to improve when 0.1 of fibre volume fraction of oil palm fibre was employed in the composite.

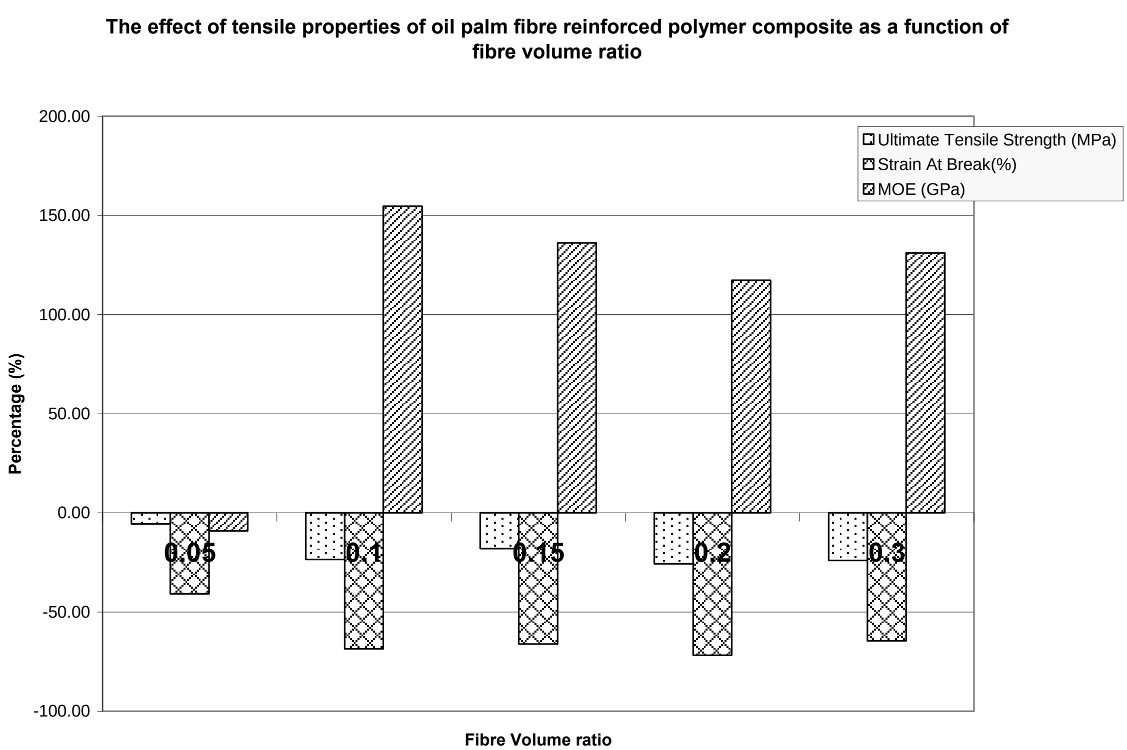


Figure 5.5: The effect of tensile properties of oil palm fibre reinforced polymer composite as a function of fibre volume ratio.

The experimental result of fibre volume ratio in oil palm fibre reinforced polymer composite was compared with mathematical model. "Rule of mixtures" was employed to explain the effects of fibre volume ratio in composite. Basically, the rule of mixture explains that a property of the composite is equal to the sum of fibre and matrix properties weighted by volume fraction. Hence, for perfectly bonded fibres, the average longitudinal stress in composite is given as:

$$\sigma_c = \sigma_f \nu_f + \sigma_m \nu_m \qquad \text{(E/1)}$$

Where σ_c = Tensile stress of composite

σ_f = Tensile stress of fibre

σ_m = Tensile stress of matrix

ν_f = Fibre volume ratio of fibre in the composite

ν_m = Fibre volume ratio of fibre in the composite

Meanwhile, the average longitudinal modulus of the composite is given as:

$$E_c = E_f \nu_f + E_m \nu_m \qquad \text{(E/2)}$$

E_c = Modulus of elasticity of composite

E_f = Modulus of elasticity of fibre

E_m = Modulus of elasticity of matrix

The equations above were used to predict the ultimate tensile strength and longitudinal modulus of the composite due to fibre volume ratio. In the prediction of the composite strength, the tensile stress of the fibre was used at the strain at break of polyester because strain at break of the polyester was lower than the oil palm fibre,. Figure 5.6 shows the comparison of ultimate tensile strength of composite of experimental results and theoretical model as a function of fibre volume ratio. It was found that the rule of mixture is not valid in prediction of tensile strength of the composite. This can be due to the factors like curvature, void content and variance of fibre strength. However, the trend of experimental results of modulus of elasticity of the composite was valid in the theory of rule of mixtures (Figure 5.7). Increase of fibre volume ratio in composite, improvement in modulus of elasticity of the composite was observed. However, the prediction was lower then modulus of elasticity. This can be due to lower value of modulus of elasticity of oil palm fibre was used.

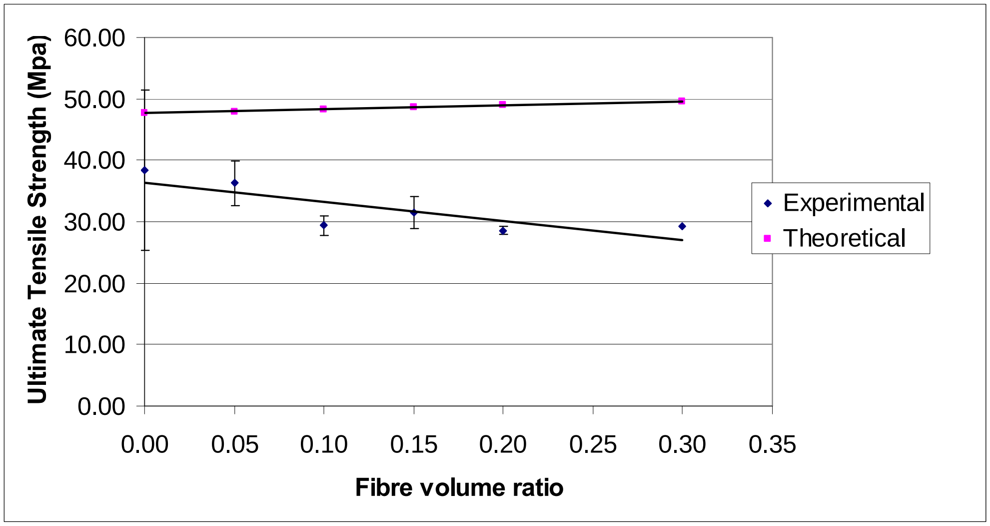


Figure 5.6: Comparison of ultimate tensile strength of composite of experimental results and theoretical model as a function of fibre volume ratio.

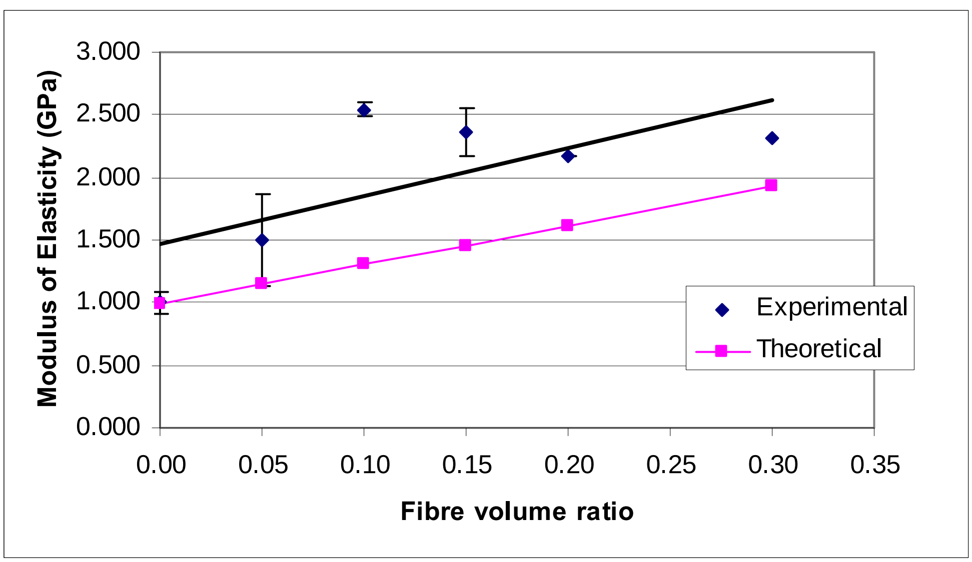


Figure 5.7: Comparison of ultimate tensile strength of composite of experimental results and theoretical model as a function of fibre volume ratio.

5.3.3 Effect of Fibre Length in Composite

Figure 5.8 shows the effect of tensile properties of oil palm fibre reinforced polymer composite as a function of fibre length. Tensile properties of 10cm and 15 cm fibre length composites were compared with 5 cm fibre length composite. Improvement or decrease effect was presented in percentage. Modulus of elastic of the composite was significantly improved when longer fibre was used. 20% of increment in modulus elasticity was found when 15cm fibre length was used in composite when comparing with 5cm fibre length composite. However, strain at break and ultimate tensile strength decreased when longer fibre was used.

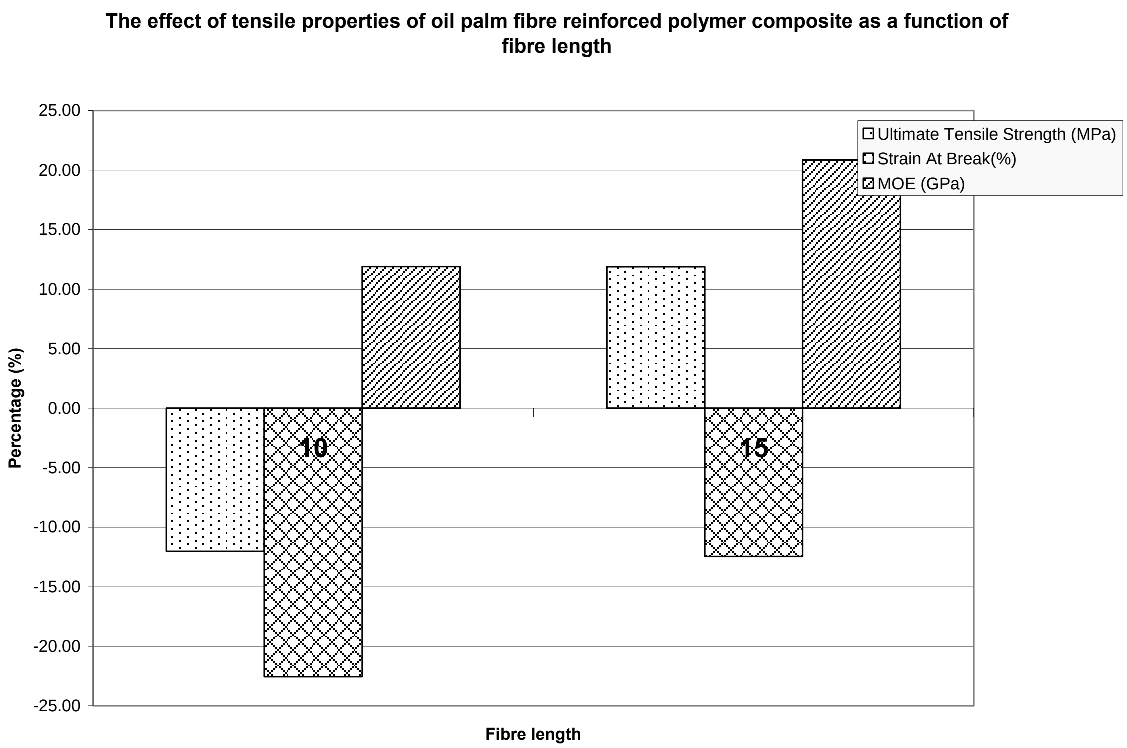


Figure 5.8: The effect of tensile properties of oil palm fibre reinforced polymer composite as a function of fibre length.

Cox explained behaviour of the discontinuous fibre by using a circular fibre confined by resin[20] as shown in Figure 5.9. Initially, both fibre and matrix are in elastic and perfectly bonded. The shear stress is transferred from matrix to the fibre and this causes tensile stress in fibre. For continuous fibre which is very long, maximum tensile stress approaches $E_f\varepsilon$, where E_f is modulus elasticity of the fibre and ε is composite strain. However, unlike continuous fibre, discontinuous fibre is cannot be fully stressed over its entire length unless the fibre length has achieved the effective length. This means that the discontinuous fibre would be less efficient reinforcement. Hence, elasticity of the composite in this study was improved when longer fibre length was used.

According to Figure 5.9, discontinuous fibre would also face larger shear stress concentration at the ends of the fibres. This is due to the sharp edges give rise to stress singularities. This situation is further complicated when localized failure occurs.

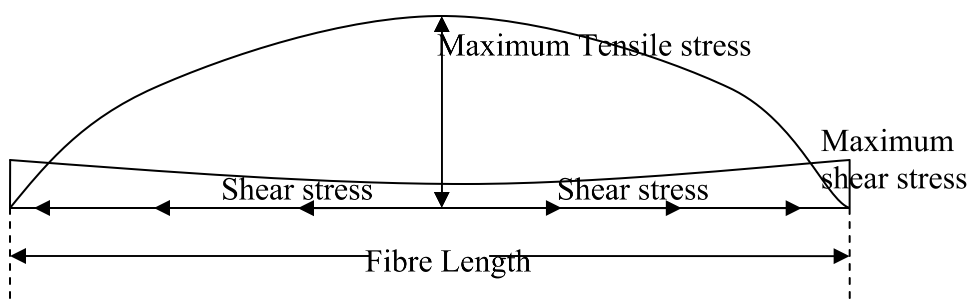


Figure 5.9: Stresses in a discontinuous fibre.

5.3. 4 Effect of Fibre Treatment in Composite

As discussed earlier, discontinuous fibre would face higher interfacial shear stress than the continuous fibre due to the rise of stress singularities in the edge of the fibre. Hence, in the past, researchers have tried to modify the fibre surface for better wetting surface by chemical treatment. Alkali treatment was employed in this study to investigate the effect of surface modification. Figure 5.10 shows the effect of tensile properties of oil palm fibre reinforced polymer composite as a function of treatment hour. The tensile properties of treated fibre composites are compared with untreated fibre composite. It was found that only ultimate tensile strength and strain at break was improved in 4 hours alkali treatment.

Alkaline treatment disrupts the surface of the fibre and removes certain amount of lignin, wax, and oils that cover the external surface of the cell wall. Besides that, the alkaline may also modify the hydroxyl groups in cellulose and introduce new ions to cellulose[21]. The reactions are as follows:

$$\text{Fiber-OH} + \text{NaOH} \rightarrow \text{Fiber-O-Na} + H_2O \qquad \text{(E/3)}$$

It is noted that in the beginning of the treatment, alkaline treatment disrupts the surface of the fibre and causes some damage to the fibre. When the fibre was treated longer, alkaline may modify the hydroxyl groups in cellulose which helps to decrease the hydrophilic behaviour of the fibre. However, due to much damage in fibre, the ultimate tensile strength of the fibre was decreased again when the longer treatment is provided. Further research is required to investigate the effect of alkaline treatment on natural fibre.

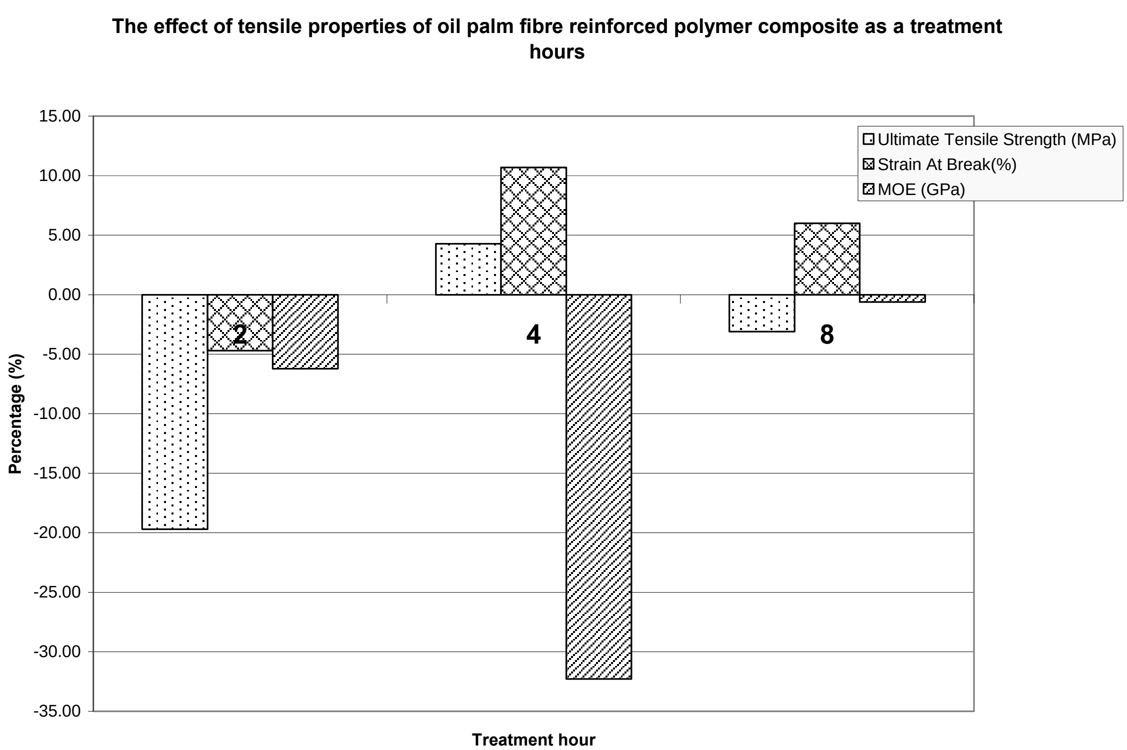


Figure 5.10: The effect of tensile properties of oil palm fibre reinforced polymer composite as a function of treatment hour.

5.4 Characterization of Flexural Behaviour of Strengthening Reinforced Concrete Beam

Flexural test were carried out for ordinary reinforced concrete beam and reinforced concrete beams strengthened with natural fibre reinforced polymer composite and glass fibre reinforced polymer composite. Ultimate bending load and mid-span deflections of the beams were compared. In addition, the beams were deigned using standards and were compared with the experimental results.

5.4.1 Load-Deflection Behaviour and Ultimate Capacity of the Beams

Table 5.5 shows first crack load and ultimate load of various beams. The ultimate load of the beam was increased by 10% when oil palm reinforced polymer (OPFR) composite was used as strengthening material. Meanwhile, glass fibre reinforced polymer composite (GFRP) improved the flexural strength about 70% of the beam. Both OPFRP and GFRP delayed the first crack of the beams.

Table 5.5: First crack load and ultimate load of various beams.

Beam specimens	First Crack Load (kN)	Ultimate load (kN)
Control Beam	10	24.4
RC-GFRP	12	43.4
RC-OPFRP	11	26.6

Load versus displacement graph of three beams were presented in Figure 5.11. The control beam behaved in ductile manner after the ultimate load is reached. Beam strengthened by oil palm reinforced composite (OPFRP- RC) behave almost similar to the control beams. Using oil palm reinforced composite as strengthening material, the beam slightly increases the stiffness of the ordinary beam. The applied load drops in sudden when the beam reaches the ultimate load due to the fracture of the composite plate. However, the ductility of the beam is maintained after ultimate load is reached.

This shows that oil palm fibre has the potential to use as strengthening material which could increase ultimate load and stiffness of the beam while maintaining ductility. Meanwhile, beam strengthened with glass fibre reinforced polymer composites (GFRP-RC) behaves totally different from the control beam. GFRP-RC beam increased the stiffness of the beam initially until 34kN. Then, the stiffness of the beam decrease drastically where large deflection is found. The beam reaches its ultimate strength when the composite plate is slightly debonded at the end of the plate. No ductility of GFRP-RC beam is observed after the ultimate load.

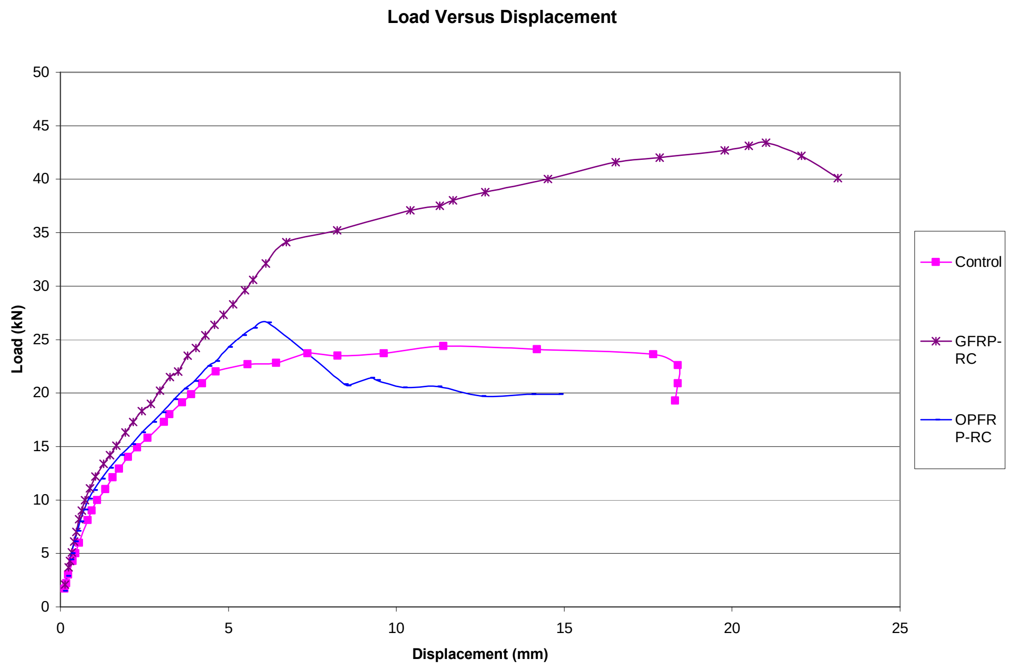


Figure 5.11: Load versus displacement of the beams.

5.4.2 Comparison between Theoretical Predictions and Experimental Results

Theoretical predictions of ultimate limit state were done to the beams by referring to BS 8110 and ACI 440.22-02.

For simplification, parabolic stress block was modified to rectangular stress block as in the standard. The maximum usable compressive strain in the concrete is 0.0035. Since concrete is designed for compression purpose and weak in tension, the tensile strength of the concrete is neglected. Upon to the adhesive layer, no slippage between composite and concrete surface is assumed which means the bonding of composite plate was perfectly bonded. Since the adhesive layer is very thin with slight variations with in its thickness, the shear deformation within the adhesive layer neglected. The FRP reinforcement has a linear elastic stress strain relationship to failure. Linear strain development at the middle cross section of the beam was assumed whereby a plane section is assumed before loading and after loading. No safety is considered in the calculations.

The calculation process used in this study to achieve the ultimate strength should satisfy strain compatibility and force equilibrium and should consider the governing mode of failure. The procedures require trial and error of two equations. Firstly, obtain the depth to the neutral axis by computing the stress level in each material and checking internal force equilibrium. Then, the assumed depth of the neutral axis is used to check the strain level in each material. The procedures are repeated until both strain developments and force equilibrium are satisfied. The procedure of the calculations of was shown in Appendix.

Table 5.6 shows the theoretical and experimental results of ultimate load in various beams. It was found that all theoretical design was underestimate the actual experimental load. This can be due to the underestimate of material properties like steel. In addition, the discrepancy of the assumptions may also result to the lower value of ultimate load.

Table 5.6: Theoretical and Experimental results of ultimate load in various beams.

Beam specimens	Theoretical	Experimental	Experimental/Theoretical
Control Beam	13.45	24.4	0.55
RC-GFRP	30.80	43.4	0.71
RC-OPFRP	24.14	26.6	0.91

5.5 Conclusions

The results of the experimental works were discussed in this chapter. A few conclusions could be withdrawn as:

7) Oil palm fibre was light, high moisture content, high moisture regain, large variance in with fibre diameter.

8) Oil palm fibre obtained in this study is generally low strength, low modulus and high strain at break compare to synthetic fibre when comparing with the results of other literature.

9) The trend of modulus of elasticity of oil palm fibre reinforced polymer composite due to fibre volume ratio could be explained by rule of mixture where a property of the composite is equal to the sum of fibre and matrix properties weighted by volume fraction.

10) Increased of fibre length in composite generally improve the tensile properties of oil palm fibre reinforced polymer composites because the increased fibre length improved the efficiency of transferring stresses and reduce shear stress.

11) Alkali treatment could disrupt the surface of the fibre and replace hydroxyl ions with new ions. This caused 4 hours of alkaline treatment increase the tensile strength of oil palm fibre reinforced polymer but degrade the elasticity of the composite.

12) Oil palm fibre reinforced polymer composite and Glass fibre reinforced polymer composite increase the stiffness and ultimate load of ordinary

reinforced concrete beam. Both ordinary reinforced concrete beam and beam strengthened with oil palm fibre reinforced polymer composite showed ductility after reaching the ultimate load. However, no ductility was found in the beam strengthened with glass fibre reinforced polymer composite.

CHAPTER 6

CONCLUSIONS AND RECOMMENDATIONS

6.1 General

The studies of natural fibre reinforced polymer composites structural application particularly in civil engineering had not been done extensively. This study comprises of determining the physical and tensile properties of natural fibre. Tensile properties of oil palm fibre reinforced composite as a function of fibre volume fraction, fibre length and surface modification was investigated. Lastly, natural fibre reinforced polymer composites used as strengthening material in reinforced concrete beam was tested and compared with ordinary reinforced concrete beam and reinforced concrete beam strengthened with glass fibre reinforced polymer composite.

6.2 Physical and Tensile Properties of Natural Fibre

The tested physical properties of natural fibre include fibre length, fibre diameter, moisture content of fibre, moisture absorption of fibre and density of the fibre. The average diameter of oil palm fibre is 0.448mm and the standard deviation (SD) for 90% confidence level is ±0.171mm. Coefficient of variance of fibre diameter is 38.22% which is considerably high. Due to hygroscopic behaviour, moisture content of oil palm fibre is high and comparable with wood. Surprisingly, moisture regain of oven-dried oil palm fibre is approaching the original moisture content after exposing the fibre in air for three hours. This indicates the fabrication process should be done in a low humidity area to avoid moisture absorption and provide good wetting fibre surface. The density of oil palm fibre and pineapple leaf fibre are lower than glass fibre reinforced polymer which means oil palm fibres are lighter.

The oil palm fibre tensile strength and modulus of elasticity in this study are rather lower than the literature. The lower ultimate strength and modulus of elasticity may be due to biodegradation of fibre as the obtained fibres were stored in improper place.

6.3 Tensile Properties of Oil Palm Fibre Reinforced Composite

The results show ultimate strength and strain at breaks of all composites are lower than the neat resin. However, the modulus of elasticity of the composite, one of the important parameters for structural composite, is higher than neat resin about 150 % for 10% fibre volume ratio. This indicates that increase of fibre volume fraction improves the elasticity. The lower ultimate strength than the neat resin is caused by low interfacial shear strength. Due to this factor, failure mechanism of the composite shows fibre pulled out and matrix cracking. It is also observed that the fibre not break at ultimate tensile strength of the composite which could be due to higher strain of fibre at ultimate strength.

In the study of fibre length effect, the test results show increased of ultimate tensile strength and modulus elasticity of the fibre increase when longer fibre is used. Increased of fibre length in composite generally improves the tensile properties of oil palm fibre reinforced polymer composites because the increased fibre length improves the efficiency of transferring stresses and reduce shear stress.

Alkali treatment could disrupt the surface of the fibre and cause damage to the fibre initially. Later, alkali treatments replace hydroxyl ions with new ions and modify the hydroxyl groups in cellulose which helps to decrease the hydrophilic behaviour of the fibre . The tested results finds that 4 hours of alkaline treatment increase the tensile strength of oil palm fibre reinforced polymer but degrade the elasticity of the composite. Therefore, alkali treatment is not a good chemical treatment to improve interfacial shear strength of oil palm fibre.

6.4 Flexural Properties of Reinforced Concrete Beam Strengthened with Oil Palm Fibre Reinforced polymer composites

The ultimate load of reinforced concrete beam is increased by 10% when 15% of fibre volume fraction of oil palm fibre reinforced composite is used as strengthening material. Meanwhile, 15% of fibre volume fraction of glass fibre reinforced polymer composite improves the flexural strength about 70% of the beam.

Beam strengthened by oil palm reinforced composite (OPFRP- RC) behaves almost similar to the control beams. Using oil palm reinforced composite as strengthening material, the beam slightly increases the stiffness of the ordinary beam. The applied load drops in sudden when the beam reaches the ultimate load due to the fracture of the composite plate. However, the ductility of the beam is maintained after ultimate load is reached. This shows that oil palm fibre has the potential to use as strengthening material which could increase ultimate load and stiffness of the beam while maintaining ductility.

Meanwhile, beam strengthened with glass fibre reinforced polymer composites (GFRP-RC) behaves totally different from the control beam. GFRP-RC beam increased the stiffness of the beam initially until 34 kN. Then, the stiffness of the beam decreases drastically where large deflection is found. The beam reaches its ultimate strength when the composite plate is slightly debonded at the end of the plate. No ductility of GFRP-RC beam is observed after the ultimate load.

In conclusion, the oil palm fibre reinforced polymer composite could strengthened the reinforced concrete beam by means of improving stiffness, increasing ultimate load, delaying cracking and maintaining the ductility of the beam.

6.5 Recommendations for Future Studies

Recommendations for future studies are made upon to the conclusions of this study.

1) A study on performance of natural fibre reinforced polymer composite under various weather conditions is required. Biodegradation, photo-degradation and hygrothermal effect could cause degradation of the performance of the material.
2) Different type of natural fibre in reinforcing polymeric composite is required to find out the best performance of natural fibre reinforced polymer for structural applications.
3) Other mechanical property tests are suggested to carry out in oil palm fibre reinforced polymer composites.
4) Fibre extraction process required further study as fibre is the most crucial component of the composite.

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Appendix

Calculation of Strengthening Beam OPFRP-RC Capacity

Properties

c =	25	mm
$ø$ =	8	mm
$ø_l$ =	6	mm
h =	200	mm
b =	150	mm
f_{cu} =	28	N/mm2
$\varepsilon_{ult\ cc}$ =	0.00127	
γ_m =	1	
A_s =	100.544	mm2
f_y =	250	N/mm2
d=	165	
f_{frp} =	31	N/mm2
$\varepsilon_{y\ st}$ =	0.00122	
$\varepsilon_{ult\ frp}$ =	0.013	
E_{frp} =	2300	MPa
t_{frp} =	7	mm
b_{frp} =	80	mm
A_{frp} =	560	mm2
ε_{cc} =		
ε_{st} =		
ε_{frp} =	0.013	

Trial 1
Internal Force Equilibrium

$$Fc = Ft + Fcom$$

$$\frac{0.67\,(f_{cu})(b)s}{\gamma_m} = \frac{f_y(A_s)}{\gamma_m} + E_{frp}(\mu_{frp})(A_{frp})$$

$$\frac{(0.67)(28)(150)S}{1} = \frac{(250)(100.544)}{1} + (2300)(0.013)(560)$$

$$= 25136\ \text{N} + 16744$$

$$S = \frac{41880}{2814} = 14.9\ \text{mm}$$

$$x = 16.5\ \text{mm}$$

Strain Development

$$\varepsilon_{st} = \varepsilon_{cc}\,(d-x)/x$$

$$= 0.0035\,(8.97801)$$

$$= 0.03142 > \varepsilon_{y\ st} = 0.00122$$

The steel has yielded.

ε_{frp} = ε_{cc} (d-x)/x
= 0.0035 11.3062
= 0.03957 > $\varepsilon_{ult\ frp}$ = 0.013
Exceed the strain at break of composite

Trial 2

Internal Force Equilibrium

Fc = Ft + Fcom

$$\frac{0.67\,(f_{cu})(b)s}{\gamma_m} = \frac{fy(As)}{\gamma_m} + E_{frp}(\mu_{frp})(A_{frp})$$

$$\frac{(0.67)(28)(150)S}{1} = \frac{(250)(100.544)}{1} + (2300)(0.013)(560)$$

= 25136 N + 16744

$$S = \frac{41880}{2814} = 14.9 \text{ mm}$$

x = 16.5 mm

Strain Development

ε_{st} = ε_{cc} (d-x)/x

= 0.00145 (8.97801)

= 0.01302 > $\varepsilon_{y\ st}$ = 0.00122
The steel has yielded.

ε_{frp} = ε_{cc} (d-x)/x
= 0.00145 9.18966
= 0.013 = $\varepsilon_{ult\ frp}$ = 0.013
Equilibrium to the strain at break of composite
Composite fail first.

Moment Capacity

M capacity = Fst As (d-s/2)
= 7.2432 kNm
F = 24.144 kN