BEHAVIOUR OF REINFORCED CONCRETE BEAMS STRENGTHENED EXTERNALLY USING PINEAPPLE LEAF FIBRE (PALF) EPOXY COMPOSITE PLATE

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DEDICATION

It is with my deepest gratitude and warmest affection

that I dedicate this thesis to my lovely

Heavenly Father,

Father and Mother,

for guiding me to be endurance,

for encouragement and days of prayers

to the completion of thesis,

Along with all hard working and respected

Friends and Lecturers

ACKNOWLEDGEMENT

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ABSTRACT

Reinforced concrete (RC) beams are often subjected to deterioration and degradation due to acid attack, overloading, poor construction condition and natural disasters. Repairing and retrofitting of RC beams are needed. The most traditional way to retrofit concrete element is externally bonding of steel plates to concrete. However it is more susceptible to corrosion and hard to install. The retrofitting technique commonly used to replace steel plates is synthetic fibre such as carbon, aramid and glass. Synthetic fibres are expensive and non-biodegradable. Hence, natural fibres are used to replace synthetic fibres towards environmental friendly and sustainable strengthening. The purpose of this research is to study the physical behaviour of pineapple leaf fibre (PALF) treated with different concentration (2%, 5% and 8%) of Sodium Hydroxide, to evaluate the flexural strength of PALF composite plate with epoxy of different volume ratio (0.1, 0.2, 0.3, 0.4) and the effectiveness of PALF-epoxy composite plate to RC beam. The experimental works carried out in the study were alkali (NaOH) treatment, Scanning Electron Microscope (SEM), single fibre test, flexural test of composite plates, and four-point loading test on beams. From the results, the tensile force for fibres treated with 2%, 5% and 8% NaOH decreased 40.8%, 56.3% and 68.2% as compared to untreated fibre. The increase in fibre content of composite samples from 20% to 40% increased the flexural strength by the range of 260% to 460% as compared to neat epoxy. The maximum flexural strength was obtained at fibre volume ratio of 40%. The research found that the beams with PALF-epoxy composite plate increased the flexural strength by 8% as compared to control beam when tested under four point loading system. The beam with PALF-epoxy composite plate has reduced its deflection by 74% at maximum load as compared to the control beam. In terms of crack pattern, PALF-epoxy composite plate has directed the crack to appear at the edge of the plate resulted in diagonal cracking. Hence, it is concluded that the PALF-epoxy composite plate is effective to be used as external strengthening material for retrofitting and rehabilitation of RC beams.

ABSTRAK

Rasuk konkrit bertetulang (RC) sering tertakluk kepada kemerosotan dan degradasi akibat serangan asid, muatan yang berlebihan, keadaan pembinaan yang buruk dan bencana alam. Pembaikan dan pengubahsuaian rasuk RC diperlukan. Cara yang paling tradisional untuk mengubahsuai elemen konkrit ialah ikatan plat keluli di luaran konkrit. Namum ia adalah lebih mudah terdedah kepada hakisan dan sukar untuk memasang. Teknik pengubahsuaian biasa digunakan untuk menggantikan plat keluli adalah serat sintetik seperti karbon, aramid dan kaca. Serat sintetik adalah mahal dan tidak mesra alam. Oleh itu, serat asli telah digunakan untuk menggantikan serat sintetik untuk tujuan pengukuhan dan mesra alam. Tujuan kajian ini adalah untuk mengkaji tingkah laku fizikal serat daun nanas (PALF) dirawat dengan kepekatan yang berbeza (2%, 5% dan 8%) dengan Sodium Hidroksida, untuk menilai kekuatan lenturan plat komposit PALF dengan epoxy jumlah yang berbeza nisbah (0.1, 0.2, 0.3, 0.4) dan keberkesanan plat komposit PALF-epoxy untuk RC rasuk. Kerja-kerja eksperimen dijalankan dalam kajian itu ialah alkali (NaOH) rawatan, Imbasan Mikroskop Elektron (SEM), ujian serat tunggal, ujian lenturan plat komposit, dan ujian muatan empat titik pada rasuk. Daripada keputusan, daya tegangan bagi serat dirawat dengan 2%, 5% dan 8% NaOH menurun sebanyak 40.8%, 56.3% dan 68.2% berbanding dengan serat yang tidak dirawat. Peningkatan kandungan serat dalam sampel komposit dari 20% kepada 40% meningkatan kekuatan lenturan dalam lingkungan 260% kepada 460% berbanding dengan epoxy kawalan. Kekuatan lenturan maksimum telah diperolehi pada nisbah jumlah serat sebanyak 40%. Kajian ini mendapati bahawa rasuk dengan plat komposit PALF-epoxy meningkat kekuatan lenturan sebanyak 8% berbanding dengan rasuk kawalan apabila diuji di bawah system muatan empat titik. Rasuk dengan plat komposit PALF-epoxy telah mengurangkan pesongan sebanyak 74% pada beban maksimum berbanding rasuk kawalan. Dari segi corak retak, plat komposit PALF- epoxy telah mengarahkan retak untuk muncul di pinggir plat dan menyebabkan keretakan pepenjuru. Oleh itu, ia membuat kesimpulan bahawa plat komposit PALF-epoxy berkesan untuk digunakan sebagai bahan pengukuhan luaran bagi pengubahsuaian dan pemulihan rasuk RC.

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LIST OF SYMBOLS

%	Percentage
mm	Millimetre
μm	Micrometre
N/mm^2	Newton per millimetre square
mm/mm	Millimetre per millimetre
kPa	kilo Pascal
MPa	Mega Pascal
Gpa	Giga Pascal
g/cm^3	gram per centimetre cube
Mg^3	Mega gram cube
ºC	Degree Celcius
g	gram
kg	kilogram
N	Newton
kN	Kilo Newton
$kJ\ m^{-2}$	kilo Joules per metre square

LIST OF ABBREVIATIONS

ASTM	American Society for Testing and Materials
b	width
d	thickness
CB	Control beam
FRP	Fibre Reinforced Polymer
GFRP	Glass Textile Reinforced Polymer Composites
h	hour
JFRP	Jute Textile Reinforced Polymer Composite
L	Length
LVDT	Linear Variable Displacement Method
NaOH	Sodium Hydroxide
OPC	Ordinary Portland Cement
P	Load
PALF	Pineapple Leaf Fibre
PALF B1	Beam with Pineapple Leaf Fibre 1
PALF B2	Beam with Pineapple Leaf Fibre 2
PP	Polypropylene
RC	Reinforced concrete
SEM	Scanning Electron Microscope
UMP	University Malaysia Pahang
UTM	Universal Testing Machine
wt	weight

CHAPTER 1

INTRODUCTION

1.1 RESEARCH BACKGROUND

Reinforced concrete (RC) beams are often subjected to problems such as degradation, deterioration, acid attack and seismic retrofits. There are many retrofitting techniques used over years to increase the strength and stiffness of RC beams such as external bonding of steel plates to the structure, fibre reinforced polymer (FRP) sheets, glass fibre reinforced plastics, carbon fibre wrapping, external prestressing and bar reinforcement, and improved external reinforcement techniques (Hemaanitha & Kothandaraman, 2014). Rehabilitation of RC beams using external strengthening method by applying FRP plastic composite to beam is one of the repairing and strengthening methods.

The study of plastic composites has been done since the past decade (Lightsey, 1983). However, synthetic fibres such as carbon, glass, aramid and nylon are usually used for the plastic reinforcement (Erich et al., 1984). These synthetic fibres are expensive and non-biodegradable. In order to find an alternative to replace synthetic fibre reinforced composite, many researchers had turned their intention to natural fibre reinforced composite as external strengthening material in RC beams.

There are many natural fibres that can be used as external strengthening material such as sisal, jute, coir, kenaf, bamboo, oil palm fibre, sugarcane and others. One of the natural fibres that has great potential as external strengthening material is the pineapple leaf fibre (PALF). Due to its high specific strength and stiffness behaviour, and abundantly available in Malaysia, the ability of PALF to be used in natural fibre composite has been studied in the research for its mechanical and physical properties.

The research has been divided into three stages of experimental works, which includes the study of physical properties of PALF, evaluation of the flexural strength of PALF-epoxy composite plate and to study the behaviour of RC beams externally strengthened with the PALF-epoxy composite plate.

1.2 PROBLEM STATEMENT

Reinforced concrete (RC) beams are often subjected to deterioration and degradation due to acid attack, overloading, poor construction condition and natural disasters. Rehabilitation, repairing and retrofitting of RC beams is needed to solve such problem. The most traditional way to retrofit of flexural concrete element over years is externally bonding of steel plates to concrete. Although externally bonding of steel sheets is a good way to increase strength and stiffness of RC structures, it is more susceptible to corrosion and hard to install. Another common retrofitting techniques used is fibre reinforced polymer (FRP) sheets. FRP sheets are made up of continuous fibres and a polymer matrix. The FRP materials have good corrosion resistance and are easy to use and install. However, most fibres used in FRP matrix are synthetic fibre which is expensive, having low melting point which can melt easily, and non-biodegradable. To overcome such problems, natural fibre composite has been introduced and used in FRP matrix because it is renewable, degradable, it has lower density and cost effective than synthetic fibres.

1.3 RESEARCH OBJECTIVES

The objectives of the research are as follows:

i. To study the physical behaviour of pineapple leaf fibre (PALF) treated with different concentration of Sodium Hydroxide (NaOH).
ii. To evaluate the flexural strength of epoxy composite plate reinforced with different volume ratio of pineapple leaf fibre.
iii. To identify the effectiveness of pineapple leaf fibre epoxy composite plate as external strengthening material on RC beams in terms of load-deflection behaviour, crack pattern and failure mode.

1.4 SCOPE OF RESEARCH

The main scope of the research is focused on the behaviour of RC beam externally strengthened with pineapple leaf fibre (PALF) epoxy composite plate.

The pineapple leaf fibre (PALF) is the product extracted from pineapple leaves commonly found in Malaysia. The chemical used to treat PALF was Sodium Hydroxide solution (NaOH) with concentration of 2%, 5% and 8% respectively. The treated PALF was tested under Scanning Electron Microscope to study its physical behaviour. Moreover, the treated fibre with different concentration of NaOH solution was tested for its tensile behaviour through single fibre test.

The binder used for PALF plate fabrication in the research was epoxy resin. A number of PALF composite samples were fabricated using different fibre volume ratio (0.1, 0.2, 0.3 and 0.4) to determine their flexural strength. The dimension of the composite sample was 25 mm x 6 mm x 200 mm in width, thickness and length. The PALF plates were tested under ASTM D790 for flexural test. In order to study the effectiveness of PALF-epoxy composite plate as external strengthening material, the PALF composite plate was fabricated in the dimension of 100 mm x 8 mm in width and thickness and 600 mm in length using hand laying method. The PALF composite plate was then bonded externally to the RC beam and tested under four-point bending system.

A total of three (3) RC beams were prepared. The RC beams were designed as Grade 25. The RC beams were prepared with the dimension of 100 mm x 130 mm in width and height, and 1600 mm in length. One of the beams was used as control beam and the other two beams were externally strengthened with pineapple leaf fibre (PALF) epoxy composite plate at the bottom soffit of the mid-span of beam. The main steel reinforcement bars used were 2H10 at the top and 2H10 at the bottom of the beam and 6 mm of shear bars were used as the shear reinforcement with 300 mm spacing centre to centre. All the beams were tested under four-point bending system.

1.5 RESEARCH SIGNIFICANCE

Researches have been conducted to study the abilities and properties of natural fibres such as coir, bamboo, hemp, sisal, jute, wood fibres and pineapple leaf fibre for structural up-gradation of RC beams. The combination of natural fibres with plastic was investigated for years to find out the alternative to replace synthetic fibres.

This research has the significance to study the ability of pineapple leaf fibres (PALF) in combination of plastic to upgrade the structural performance of RC beams. Development of PALF into composite plates reduces agriculture waste into usable materials, makes good use of locally available materials, reduces environmental problems and generates beneficial income for local economy. Besides, PALF composite plate is a potential material to replace synthetic fibres which are more expensive and non-biodegradable. At the same time, it may have the ability to develop equal or greater properties in upgradation of various engineering structural components especially in civil structures.

CHAPTER 2

LITERATURE REVIEW

2.1 BACKGROUND

Strengthening of a building structure is necessary when the structure is subjected to deterioration due to poor design, increasing loading capacity, change in usage of structure and accident events such as earthquake and wind. Strengthening of structure is important to avoid structural damages. In the past years, externally bonded plates using epoxy adhesions were found to be popular techniques for strengthening of RC beams. This includes gluing steel plates and synthetic fibre reinforced polymer laminates such as carbon fibre reinforced polymer (CFRP) to the surface of the structure. The plates help to carry load from the structures. However, the steel plates and synthetic fibre reinforced laminates contribute to some problems such as corrosion and health hazard issues. Moreover they are expensive and not environmental friendly.

Hence researchers had studied to find an alternative to solve the problem. Green fibres or natural fibres were studied and observed due to their low cost and recyclable nature. Natural fibre composites are found to be more durable, renewable, bio-degradable, and cost effective, compared to synthetic fibre composites (Jauharia et al., 2015). One of the natural fibres that can be used as natural fibre reinforced composite is the pineapple leaf fibre (PALF). The literatures relating to the natural fibre, fibre reinforced polymer (FRP) and strengthening of RC beams are established in this chapter.

2.2 NATURAL FIBRES

Natural fibres are not modern man made synthetic and artificial fibres, such as nylon, acrylic, rayon, glass and carbon, according to International Year of Natural Fibres (2009). Natural fibres can be classified into two categories: plant fibres and animal fibres. Plant fibres consist of abaca, coir, cotton, flax, hemp, jute, ramie and sisal, whereas animal fibres consist of alpaca wool, angora wool camel hair, cashmere, mohair, silk and wool. Plant fibres are classified into seed based, leaf based and fruit based fibres. Seed based fibres are cotton fibres, leaf based fibres are jute, sisal, pineapple, banana, hemp and bagasse whereas fruit based fibres are coir fibres (Nguong, 2013).

Natural fibres are good in thermal insulation due to its low density and cellular structure and have many advantageous properties such as better handling and disposal over synthetic fibres. Natural fibres are low in cost and have good mechanical properties such as good strength to weight ratio, low weight, high corrosion resistance, low thermal expansion, high tensile strength, high compressive strength, high impact strength, high bending strength and high stiffness (Jauharia et al., 2015). However natural fibres have some disadvantages such as poor adhesion between fibres and matrix due to the hydrophilic nature of fibres and low thermal stability (degradation at 200-250 ºC). The advantages and disadvantages of natural fibres are listed in Table 2.1.

The performance of natural fibres is affected by the content of cellulose, lignin, hemicellulose, pectin, waxes and water content. The hemicellulose is netlike structure and bonds with cellulosic fibrils. Cellulose can affect the tensile property, while lignin can affect the stiffness. The performance of natural fibres is also affected by the geometry of cell elements, the angle of helix of fibre and treatment of fibre (Jauharia et al., 2015). Lower microfibrillar angle of fibre and high level of cellulose content provide good strength properties. Generally the synthetic fibres exhibit better mechanical and physical properties than natural fibres, but natural fibres have better specific modulus and elongation at break, in which natural fibres can be considered to be applied in polymer engineering composites (Kabir et al., 2012).

Table 2.1: The advantages and disadvantages of natural fibres

Advantages	Disadvantages
i. Low in cost ii. Good in thermal insulation iii. Better handling and disposal iv. Low thermal expansion v. High tensile strength vi. High compressive strength vii. High impact strength, viii. High bending strength ix. High stiffness x. Renewable xi. Biodegradable	i. Poor adhesion between fibres and matrix due to the hydrophilic nature of fibres ii. Low thermal stability iii. Moisture absorption which can cause the swelling of fibre

Source: Jauharia et al. (2015)

2.2.1 Pineapple Leaf Fibre (PALF)

Pineapple is perennial herbaceous plant commonly found in tropical countries such as Malaysia (Tran, 2006). Pineapple has fruit which has the appearance of hexagonal sections on its outer shell. Its leaves are green and sword shaped.

Pineapple leaf fibre (PALF) is produced in large amount each year. However there is only small portion of PALF is used in energy production (Asim et al., 2015). Pineapple leaf fibre is white, glossy, smooth and has medium length fibre as shown in Figure 2.1. It has soft surface and can maintain its good colour (Py & Lacoeuilhe, 1987). It has high specific strength and stiffness and it is hydrophilic because of its high content of cellulose (George et al., 2001).

PALF consists of pentosans, lignin, pectin, ash content, α-cellulose, fat and wax, antioxidants, nitrogenous matter, degree of polymerization and crystallinity of α-cellulose (Wan Nadirah et al., 2012). It has large amount of α-cellulose (81.27%), low quantities of hemicelluloses (12.31%) and lignin content (3.46%) (Rahman, 2011). The cellulosic content of PALF is higher than other natural fibres such as oil palm frond, coir and banana stem fibres (Khalil et al., 2006). Due to its high compositions of α-cellulose and low micro-fibrillar angle (14 º), it can be reinforced in composite matrix (Lopattananon et al., 2006).

PALF has the density ranges from 1.0-1.6 g/cm^3, modulus ranges from 34.5 to 82.51 GNm^{-2}, tensile strength ranges from 413 to 1627 Mpa, and elongation at breakpoint that ranges from 0.8 to 1.6%. It has diameter that ranges from 20 to 80 μm. In addition, PALF has high elastic and electrical properties. The physical and mechanical properties of PALF is tabulated in Table 2.2. In comparison to the mechanical properties of other natural fibres, PALF has high strength (Asim et al., 2015).

Table 2.2: Properties of pineapple leaf fibre

Diameter (μm)	20 to 80
Density (g/cm^3)	1.0-1.6
Tensile Strength (Mpa)	413-1627
Modulus of elasticity (Gpa)	34.52-82.51
Available Countries	Thailand, Philippines, Malaysia, Brazil

Source: Asim et al. (2015)

Figure 2.1: Pineapple leaf fibre

Source: Asim et al. (2015)

2.3 THERMOSET AND THERMOPLASTIC

Matrix material or resin for composites can be classified into two types: thermoset and thermoplastic. Thermoset resin is a liquid form material that cures and hardens into a designed shape when mixed with catalyst (Khalid & Yatim, 2011). It can be cured with the application of heat. The curing process of thermoset resin makes the polymer to be developed into a three dimensional structure that gives high degree of rigidity. The cross linked structures formed are tough and highly in solvent resistant (Asim et al., 2015). Thermoset resin has high flexibility, strength and modulus (Ticoalu et al, 2010). Examples of thermoset resin are phenolic, polyester and epoxy resins.

Thermoplastic material is a material that soften at a heat range and able to return to their natural properties when cooling. It does not set or cure. A thermoset resin often present in pellet form, it softens and becomes more fluid as heat is applied. The fluidity of the thermoplastic resin allows it to be injected under high pressure from a heat cavity into a cold mould. As the thermoplastic resin is cooled down, it will harden according to the shape of the mould. There is no cross links formed between the polymers. The changes of thermoplastic can be seen physically with the reversible reapplication of heat, this behaviour makes the thermoplastic to be reprocessed for many times. The examples of thermoplastic resin are polyamide, polycarbonate, polyethylene, polypropylene and polyvinyl chloride. Thermoplastics develop more advantages than thermosets when used for matrix composites (Asim et al., 2015). The thermoplastic matrix composites have lower processing cost, design flexibility and easier to be moulded.

The comparison of thermoset and thermoplastic is listed in Table 2.3 (Modor Plastics, 2016).

Table 2.3: The comparison of thermoset and thermoplastic

	Thermoset	Thermoplastic
Advantages	i. High resistant to high temperatures ii. High flexibility of design iii. Give good aesthetic appearance iv. High levels of dimensional stability and rigidity v. Cost-effective	i. Highly recyclable ii. High-impact resistance iii. High capability of remoulding iv. Good chemical resistant v. Hard and rubbery surface vi. Easy to be moulded
Disadvantages	i. Unable to be recycled ii. Difficult to finish surface iii. Unable be remoulded or reshaped	i. More expensive than thermoset generally ii. Melt if heated

Source: Modor Plastics (2016)

2.4 THERMOSET FABRICATION TECHNIQUES

There are many methods used for fabrication of natural fibre composites. The most common methods for thermoset matrix composites are pultrusion, injecting moulding (IM), resin transfer moulding (RTM) and hand laying method.

2.4.1 Pultrusion

One of the economy manufacturing methods for composite fabrication is the pultrusion process. Pultrusion is a process to produce continuous length of reinforced polymer composites with uniform cross sections as shown in Figure 2.2. The raw materials include liquid resin mixture that contain the resin, fillers and specialised additives; and fibres. The process involves the pulling of the raw materials through a heated steel curing die by a continuous pulling device. The reinforcement materials (fibres) are in continuous form. These reinforcement materials are wetted out in the resin bath and pulled through the die. Then gelation, which is the hardening of the resin, is done in the heat die and a rigid cured material is formed according to the shape of the die (Nuplex, 2016).

Normally, the fibre volume fractions of fibres are 35-50% (Bakis et al., 2002). Thermosetting resins of polyester, phenolic, epoxy and vynylester are generally used in the pultrusion process (Bakis et al., 2002). Meyer (1985) provides the introduction to the pultrusion process, together with its early evolution, parameters of controlling the pultruded part and the key patents awarded.

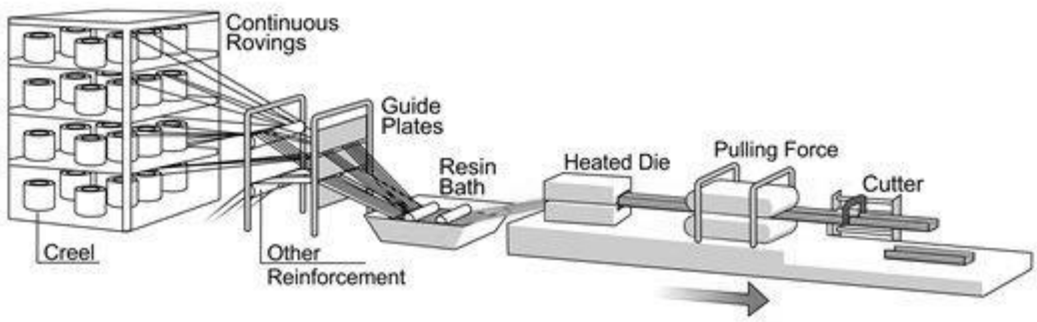


Figure 2.2: The pultrusion process

Source: Nuplex (2016)

2.4.2 Injection Moulding (IM)

Injection moulding is the most common manufacturing process used for fabrication of plastics. The materials used in injection moulding include metals, glasses, elastomers, thermoplastic and thermosetting polymers. It is often used for thermosetting resin. The injection moulding process requires an injection moulding machine, raw plastic material and a mould. The materials are melted in the heated barrel inside the injection moulding machine and then forced into the mould. The materials are then cooled and solidified into the final part. After the product is designed, the mould is made by a mould maker from steel. The alignment of fibre in thermoplastic matrix composites will be more significant with higher fibre contents. Residual stress in thermoplastic matrix composites limits the injection moulding to produce composites of less than 40% fibre content (Asim et al., 2015). The injection moulding machine is shown in Figure 2.3.

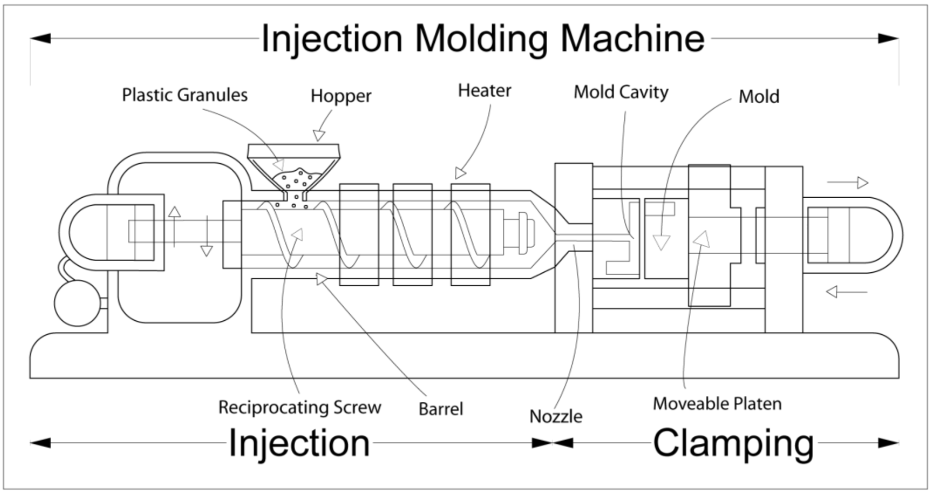


Figure 2.3: Injection Moulding Machine

Source: AV Plastics (2016)

2.4.3 Resin Transfer Moulding (RTM)

Resin Transfer Moulding (RTM) is a common method of moulding using liquid composites. It is used to mould components with large surface area, complex in shape and smooth finish. RTM uses a liquid thermoset resin to saturate a fibre that has been preform placed in a closed mould. Final RTM products should be high in strength and light in weight. The advantages of RTM include low temperature requirement and avoidance of thermomechanical degradation. This moulding is able to reduce material wastage and environment impact. It has the ability to add reinforcements at a point of infusion for greater strength (Thomas, 2013). However compaction under high load is required in the process. RTM needs heavy structured tooling to withstand high hydraulic pressure, and this makes RTM to be high in tooling cost (Asim et al., 2015). Natural fibre composites are less compactible to glass fibre composites according to Francucci et al. (2012). Figure 2.4 shows the resin transfer moulding.

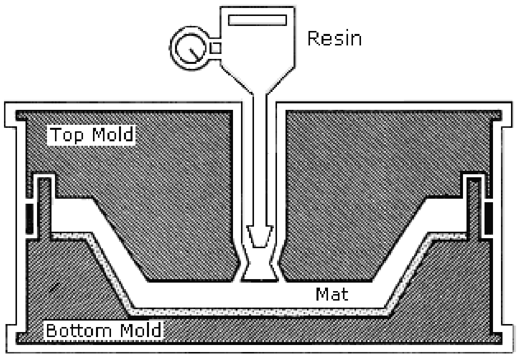


Figure 2.4: Resin Transfer Moulding (RTM)

Source: United States Department of Labor (2016)

2.4.4 Hand Lay-up Method

Hand lay-up or hand laying method is a method used for the production of parts of any dimensions. The most common fabrication method for thermoset composites is hand lay-up method. This method is recommended for the manufacturing of composites that is small and medium in volume. It requires minimal investment in moulds and equipment. The method consists of applying a releasing agent, a gel coat, a layer of liquid thermosetting resin, a layer of reinforcement (fibres) in the mould. Impregnation of reinforcement is done by hand using a brush or roller. The operation is done for each layer of reinforcement to obtain required thickness of the composite. However this method gives only one face of composite to have smooth surface while the other face being rough (Sevkata & Brahimi, 2011).

There are several curing methods available for composites done by hand laying method. The basic curing method is curing at room temperature. Cure can be accelerated by application of heat with heater or oven and by pressure. When heat is applied for cure, the part temperature is ramped up in a small increment and it ramps down to room temperature to prevent distortion or warp caused by contraction and expansion (Johnstona et al., 2015). When this curing is completed and demoulded, some parts go through secondary postcure. They are then subjected to higher temperature than the initial cure to enhance the chemical crosslink density of the composites or parts. The hand lay-up method is shown in Figure 2.5.

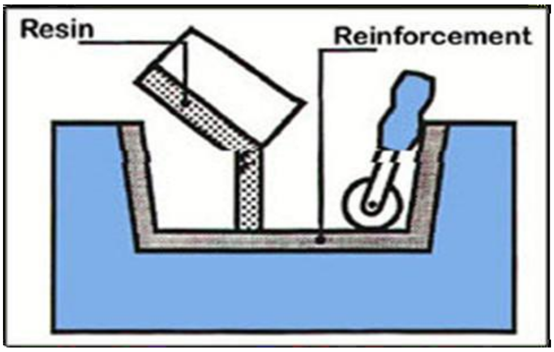


Figure 2.5: Hand lay-up method

Source: Kumar et al. (2015)

2.5 EPOXY RESIN

Epoxy resin is a class of prepolymers and polymers that contain epoxide groups. Epoxy resins are cross linked with themselves by catalytic homopolymerisation or with a range of co-reactants. These co-reactants are often hardeners or curatives. The cross links are referred to as curing. The reaction of resin and hardeners forms a thermosetting polymer with high mechanical properties and chemical resistance. Epoxy has been widely used in electrical components, high tension electrical insulator, structural adhesives and fibre reinforced composites (Amar et al., 2005).

Epoxy resin contains at least two epoxide groups, which are called glycidyl or oxirane groups. Epoxy resins are polymeric or semi-polymeric materials and exist as pure substances. The highly regular structure of epoxy makes it to form crystalline solids. The chemical structure of epoxy is shown in Figure 2.6.

Epoxy resin has advantages that outrun other resins such as polyester and vinly ester in terms of mechanical and adhesion properties. Epoxy has high mechanical properties and resistance of environmental degradation (Suong, 2009). Besides, it is water resistance and develops low shrinkage. It is easy in handling and can be cured in short time. However the epoxy resin has some disadvantages. It is expensive and needs skilled workers to conduct proper mixing procedure. The mixture of epoxy and hardener is critical as correct ratio of mixing is needed to ensure optimal cross linking of the polymers when curing.

When epoxy is compared with polyester and vinyl ester, it is found that the shrinkage in polyester and vinyl ester showed 8% or more, whereas the shrinkage of an epoxy is reduced less than 5% due to little arrangement and with no evolution of volatile by products (Amar et al., 2005). The comparison of the properties of epoxy, polyester and vinylester resin is shown in Figure 2.7, whereas the advantages and disadvantages of polyester, epoxy and vinyl ester are compared as shown in Figure 2.8.

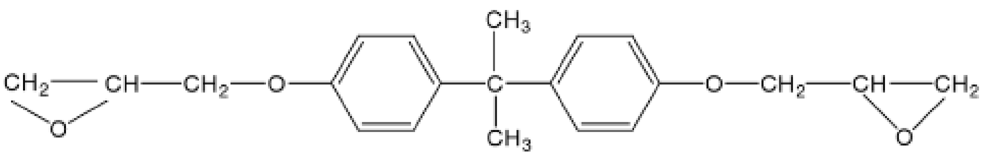


Figure 2.6: Chemical structure of epoxy

Source: Amar et al. (2005)

Properties	Polyester Resin	Epoxy Resin	Vinylester Resin
Density (Mg^3)	1.2–1.5	1.1–1.4	1.2–1.4
Young's modulus (GPa)	2–4.5	3–6	3.1–3.8
Tensile strength (MPa)	40–90	35–100	69–83
Compressive strength (MPa)	90–250	100–200	—
Tensile elongation to break (%)	2	1–6	4–7
Cure shrinkage (%)	4–8	1–2	—
Water absorption 24 h at 20°C	0.1–0.3	0.1–0.4	—
Fracture energy (kPa)	—	—	2.5

Figure 2.7: Comparison of properties of polyester, epoxy and vinyl ester

Source: Amar et al. (2005)

Resin	Advantages	Disadvantages
Polyester	Easy to use Lowest cost of resins available (£1–2/kg)	Only moderate mechanical properties High styrene emissions in open molds High cure shrinkage Limited range of working times
Vinylester	Very high chemical/environmental resistance Higher mechanical properties than polyesters	Postcure generally required for high properties High styrene content Higher cost than polyesters (£2–4/kg) High cure shrinkage
Epoxy	High mechanical and thermal properties High water resistance Long working times available Temperature resistance can be up to 140°C wet/220°C dry Low cure shrinkage	More expensive than vinylesters (£3–15/kg) Critical mixing Corrosive handling

Figure 2.8: Comparison of advantages and disadvantages of polyester, epoxy and vinyl ester

Source: Amar et al. (2005)

2.6 FRP AND NATURAL FIBRE COMPOSITES

Fibre reinforced polymer (FRP) or fibre reinforced polymer composite is a composite material made of polymer matrix and fibres. Composites are made of two or more materials which has significantly different physical and chemical properties. The fibres are strong and stiff while the polymer matrix is weak and less stiff. The combination of polymer matrix and fibres create strong and stiff component but with low density.

FRPs are commonly used in aerospace, automotive and construction industries. The advantages of FRP composites include lightweight, non-corrosive, having high specific stiffness and strength, are easily constructed and have been included in construction and rehabilitation of structures. FRP composites are high in tensile strength, non-magnetic and easy to handle. They also exhibit higher performance, longer lasting and can be used in seismic upgrades, defence systems, space systems and ocean environment. FRP composites are used as reinforcement, formwork and external reinforcement for strengthening (Masuelli , 2013). Besides, there are applications where FRPs are cost effective. This include the use of bonded FRP sheets, plates or composites in repairing and rehabilitation of concrete structures; and the use of FRP fabrics or meshes in thin cement products. The cost of structural rehabilitation is relative higher than the structural cost because it requires high commitment and skills in labour. Hence, usage of FRPs can help to reduce labour cost and the cost of repair materials in long term.

However, the disadvantages of FRPs include poor resistance to fire or high temperatures, limited standard and codes with FRP materials in construction design practice, continued deflection under heavy and sustained loads, requiring high workmanship skill and quality, and difficulty to control the quality of the adhesive layer of FRP composites to concrete surface (Nicolae et al., 2008).

FRP composites have developed greatly in recent years (John & Thomas, 2008). Natural fibres have been used as reinforcing materials in FRP for over years. They are employed in combination with plastics most recently. Many types of natural fibres are used in combination with plastics such as wheat, hemp, kapok, wood fibre, oil palm empty fruit bunch, rice husks, barley, oats, sisal, rye, cane (sugar and bamboo), grass reeds, jute, kenaf, ramie, coir, pennywort, banana fibre, paper-mulberry, flax, pineapple leaf fibre, straw, raphia, and papyrus. These natural fibres are investigated for their properties and abilities as natural fibre polymer composites.

2.6.1 Coir Fibre Reinforced Polymer

The development of fibre composite materials for buildings using coconut coir with low thermal conductivity is a way to solve environment or energy concern. Geethamma et al. (2005) have studied the dynamic mechanical behaviour of natural rubber and its composites reinforced with short coir fibres. Coir fibre–polyester composites were tested as helmets, as roofing and postboxes. These composites, with coir loading ranging from 9 to 15 wt%, have a flexural strength of about 38 MPa. Coir–polyester composites with untreated and treated coir fibres, and with fibre loading of 17 wt%, were tested in tension, flexure and notched Izod impact. The untreated fibres show clear signs of the presence of a weak interface long pulled-out fibres without any resin adhered to the fibres and low mechanical properties were obtained.

Reis (2006) investigated the mechanical characterization (flexural strength, fracture toughness and fracture energy) of epoxy polymer concrete reinforced with natural fibres (coconut, sugarcane bagasse and banana fibres). Fracture toughness and fracture energy of coconut fibre reinforced polymer concrete were higher than that of other fibres reinforced polymer concrete. Flexural strength was increased up to 25 % with coconut fibre only. Bensely et al. (2009) investigated the mechanical properties of coir fibre composites. Scanning electron micrographs obtained were used for to evaluate the interfacial properties of coir/epoxy and compared with glass fibre epoxy. These results indicate that coir can be used as a potential reinforcing material for making low load bearing thermoplastic composites. Figure 2.9 shows the sample of coir fibres polyester composite.

Figure 2.9: Coir fibres polyester composite

Source: Zaman et al. (2009)

2.6.2 Kenaf Fibre Reinforced Polymer

Kenaf fibres are reinforced with polymers to form fibre reinforced composites that can improve the strength of the composites. Nishino et al. (2003) studied the development of bio-composite materials using natural fibres and examined the mechanical properties, moulding conditions, and interfacial bonding. They found that the shape, size and strength of natural fibres depend on the cultivation environment, region of origin and other characteristics which influence the mechanical properties of fibre composites. Akil et al. (2011) immersed kenaf fibre reinforced composite in sea water and the highest reduction rate in tensile modulus was observed, followed by the immersion in acidic rain water and distilled water. Srinivasan et al. (2014) studied the tensile and double shear properties of flax-kenaf hybrid composites and had concluded that hybrid composites are better than mono fibre composites in mechanical properties. Liu et al. (2007) studied the effect of fibre length, fibre content and fibre orientation of kenaf fibre on physical and mechanical properties of kenaf fibre reinforced soy based bio composites.

Figure 2.10: Kenaf fibre epoxy composites

Source: Khalid & Yatim (2011)

2.6.3 Jute Fibre Reinforced Polymer

An investigation has been carried out to study the mechanical properties of jute fibre reinforced composites with polyester and epoxy resin matrices. In the research, the jute fibres length was 5-6 mm. The composites were synthesized at the fibre-resin weight percentages of 18% : 82%. The composites were tested to study their mechanical properties such as tensile strength, flexural strength, impact strength and hardness. The results show that the jute reinforced epoxy composite had better mechanical properties than jute-polyester composite (Gopinath, Kumar, & Elayaperumal, 2014).

The mechanical properties of jute reinforced polyester composite by bleached and control jute composite at different fibre loading was studied. Composite of 60% fibre loading showed that the highest tensile strength of 90.52 ± 8.83 MPa. The highest tensile strength was achieved by the control jute polyester composite (JPH(C)) whereas the bleached jute polyester (JPH (B)) composite showed the highest flexural strength (Dash et al., 1999). Figure 2.11 shows the composite plate made from jute rope.

Figure 2.11: Jute rope composite plate

Source: Ashraful et al. (2015)

2.6.4 Pineapple Leaf Fibre Reinforced Polymer Composites

PALF is being utilised effectively in polymer matrix to develop composites with improved mechanical strength recently. PALF has been combined with thermoset, thermoplastic, biodegradable plastics, and natural rubber.

Pineapple leaf fibre reinforced with polyethylene was studied and the result shows the composite exhibits high performance (Abdelmouleh et al., 2007). Kasim (2015) has studied the effect of PALF loading on the mechanical properties of PALF-Polypropylene composite. The result of PALF/ PP composite with a ratio of 30/70 shows the best mechanical properties compared to other composition ratios. Panyasart (2014) studied the effect of surface treatment on the properties of pineapple leaf fibres reinforced with polyamide 6 composites. The PALF samples prepared are raw, alkaline treated and silane treated. From the results, it could be stated that the alkali treatment is sufficient to improve compatibility and properties of the PALF/polyamide 6 composites at fibre loading of 30 %wt.

Kumar et al. (2015) studied the mechanical properties of pineapple leaf fibre reinforced epoxy resin composites with pineapple leaf fibre loading of 10%, 20% and 30%. From the results the tensile strength for volume ratio 10%, 20% and 30% was obtained as 26.91 MPa, 35.8 MPa and 65.95 MPa respectively. Hence, it can be concluded that the tensile strength increases as the volume ratio changes from 10% to 30% and maximum tensile strength was seen at 30% volume ratio. The specimens were also subjected to flexural testing for volume ratio 10%, 20% and 30%.The flexural strength obtained as 38.55 MPa, 58.37 MPa and 121.83MPa. The flexural strength obtained was at maximum 30% volume ratio. Figure 2.12 shows the PALF-vinyl ester composite.

Figure 2.12: PALF-vinyl ester composite

Source: Mohamed et al. (2014)

2.7 FACTORS AFFECTING MECHANICAL PROPERTIES OF NATURAL FIBRE COMPOSITES

There are several factors that can affect the mechanical properties of natural fibre composite which include fibre volume ratio and surface treatment which are discussed in the following sub-sections.

2.7.1 Fibre Volume Ratio

Shaikh et al. (2003) indicated that the volume fraction or ratio of natural fibre can affect the composite strength where the composite strength raises linearly with the increase of volume ratio. Different natural fibres will give different effect to the composite structure and some natural fibres can give opposite effect to the composite strength.

Devi et al. (1997) has carried out a research to study the effect of fibre ratio (0.1 to 0.4) to the mechanical properties of PALF reinforced polyester composite. It is found that the tensile strength and Young’s modulus of the composites increased with fibre content. The flexural stiffness and strength of the composite with 30% fibre weight fraction are 2.76 GPa and 80.2 MPa, respectively.The composite specific flexural stiffness is 2.3 times greater than that of neat polyester resin. The impact strength of the composite with 30% fibre content was found to be 24 kJ m^{-2}.

Besides, Kashim et al. (2015) has conducted a study the effect of PALF loading (30% to 70%) on the mechanical properties of pineapple leaf fibre polypropylene (PALF/PP) composite. The mechanical properties of PALF-PP composites were determined through hardness test, tensile test, microstructure analysis and density measurement. It is found that the PALF-PP composite with the fibre volume 0.3 showed the best mechanical properties.

2.7.2 Surface Treatment

The interfacial bonding between fibre and matrix is important to determine the mechanical properties of natural fibre composites. When stress is transferred between the matrix and fibres, good interfacial bonding is important to achieve optimum reinforcement. Interfacial bonding can develop by the mechanisms of chemical bonding, mechanical interlocking, inter-diffusion bonding and electrostatic bonding between the matrix and fibre. One of the best and effective ways to enhance interfacial bonding between fibre and matrix is surface treatment using alkali. Alkali treatment can remove the fibre constituents such as hemicellulose, pectin, wax, fat and lignin; and impurities to improve interfacial bonding. Improvement of fibre strength has been developed using alkali treatment according to Matthews and Rawlings (1999).

The effect of the alkali (NaOH) treatment on the mechanical properties of pineapple leaf fibre (PALF) reinforced high impact polystyrene (HIPS) composites has been studied by Siregar (2010). The concentration of NaOH used in the research was 0%, 2% and 4%. The mechanical properties such as flexural strength, tensile strength, tensile modulus, notched and unnotched impact, flexural modulus, and hardness of short pineapple leaf fibre (PALF) reinforced high impact polystyrene (HIPS) composites were studied and compared. The results show that the PALF treated with 4% NaOH has the highest mechanical properties value as compared to other concentration (Siregar, Salit, Rahman, & Dahlan, 2010).

2.8 EXTERNAL STRENGTHENING OF RC STRUCTURES

Reinforced concrete structures are often subjected to deterioration due to acid attack, corrosion, cracking and accident events. Hence, repairing or retrofitting is necessary to maintain the performance of RC structures. Full replacement of RC structures might cause high costs and interruption of the structure function. So, it is preferred to repair the structure by retrofitting.

The methodologies and techniques to repair and retrofit RC structures can be classified into two: local modification of structures and global modification of structures. Global modification are the structural level retrofitting method to add new structural wall and steel braces, whereas the local modification methods include steel jacket addition, bonding with steel plates and fibre reinforced polymer materials to upgrade the structural strength. The most common method used is steel plate bonding to the RC structures. However, steel plates are often subjected to corrosion and are difficult to handle in construction site. Fibre reinforced polymer (FRP) has been studied and used as replacement of steel plates due to its high corrosion resistance, high specific stiffness, high specific strength and ease of handling and installation than steel plates (Sarker, Begum, & Nasrin, 2010).

FRP composites have been used in success in these years. The retrofitting of RC structures by using external bonded FRP composites has been applied to RC columns, beams, beam-column joints and masonry walls.

2.8.1 RC Beam Strengthening with Synthetic Fibres

Flexural strengthening of reinforced concrete (RC) beams can be done either by external bonding of FRP composites or by insertion of FRP strips or bars into grooves cut into the concrete. Flexural strengthening of RC beams by bonding FRP laminates at the tension face of the beam was first introduced by Meier’s group (Meier, 1997) at the Swiss Federal Laboratories for Materials Testing and Research. After that, many studies (Colalillo and Sheikh, 2009; Saxena et al., 2008; and Choi et al., 2008) have been carried out on flexural strengthening of concrete beams. The studies were to evaluate the effectiveness of FRP on flexural performance of concrete beams or to investigate the effect of various parameters on possible failure modes.

Early research has studied an increase in ultimate strength of concrete beams by 22% due to FRP strengthening. To enhance the shear strength of beams, strengthening scheme with anchoring system can improve the ductility of the retrofitted beam by confining the concrete. This in turn improves the seismic performance of the retrofitted beams. It has also been reported that the shear strength of carbon fibre reinforced polymer (CFRP) retrofitted beams under simulated earthquake loads were enhanced by up to 114% as compared to a similar RC beam without FRP (Colalillo & Sheikh, 2009). Prior to shear failure, FRP materials can stiffen the beams and allowed for relatively elastic behaviour.

An experimental study conducted by Yousif (2012) proved that Carbon Fiber Reinforced Polymer (CFRP) sheets increased the strength and the stiffness of beams when bonded to the web and tension face of the beams. The mode of failure and magnitude of increase are related to the length of CFRP and its load divergence. The results also show that CFRP can be used to increase the strength and stiffness of beams without causing any catastrophic brittle failures with the strengthening technique.

Figure 2.13: Strengthening of RC beams

Source: Sarker et al.(2010)

2.8.2 RC Beam Strengthening with Natural Fibres

The development of Fibre Reinforced Polymer (FRP) materials is not limited to synthetic fibres only, but includes natural fibres to be used in the field of retrofitting and strengthening of concrete elements. Researches have been carried out to study the behaviour of RC beams strengthened with natural fibres such as jute and kenaf.

2.8.2.1 Jute Fibre Reinforced Polymer

Sen and Reddy (2013) conducted a research to study the efficiency of jute textile reinforced polymer composite (JFRP) as flexural strengthening material of RC beams, as compared to carbon textile (CFRP) and glass textile (GFRP) reinforced polymer composites. The experimental works included the study of failure modes, ultimate load, load deflection behaviour and deflection ductility of RC beams bonded externally with JFRP, CFRP and GFRP respectively, wrapped in U configuration in single layer, along the whole length of beam in full wrapping and strip wrapping technique. The RC beam specimens in this research were 140 mm x 200 mm x 1400 mm in width, height and length respectively. The main reinforcements as well as shear links were 8 mm in diameter. The RC beams were categorised into three groups, which were beams without strengthening, beams with full length wrapping and beams with strip wrapping, respectively with JFRP, CFRP and GFRP. The FRP for full length wrapping was applied in single layer, three sided U wraps at the bottom soffit of the beam as illustrated in Figure 2.14. Meanwhile, the FRP for strip wrapping was applied at the bottom soffit of the beam with 62 mm strips and 124 mm spacing, centre to centre, so to achieve 50% of total area strengthening, as shown in Figure 2.15. The results show that JFRP, CFRP and GFRP improved the ultimate flexural strength of RC beams by 62.5%, 150% and 125%, respectively, with full wrapping technique and by 25%, 50% and 37.5% respectively with strip wrapping technique. The beams with full wrapping technique had higher flexural strength than the beams with strip wrapping technique. It is proved that jute textile FRP material has great potential to be used as structural strengthening material.

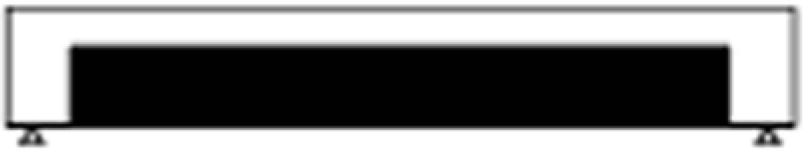


Figure 2.14: Full length wrapping of RC beam with Jute FRP

Source: Sen & Reddy (2013)

Figure 2.15: Strip wrapping of beam with Jute FRP

Source: Sen & Reddy (2013)

Besides, Ashraful et al. (2015) has conducted an experimental research on jute rope composite plate as an alternative of CFRP laminates for flexural strengthening of RC beam. The main reinforcements of beam were 12 mm in diameter and the shear bars were 6 mm in diameter with spacing of 60 mm centre to centre. The dimension of the beam specimens were 150 mm x 250 mm x 2300 mm in width, height and length, respectively. The shear spans were 650 mm. The composite plate with the dimension 100 mm x 8 mm x 2000 mm in width, thickness and length was applied to the bottom soffit of the beam. The results showed that the ultimate load of beam with jute rope composite plate was found to be 58% higher than the control beam. The strengthened beam had reduced deflection at the initial stage. The reinforcement detail of the beam is illustrated in Figure 2.16.

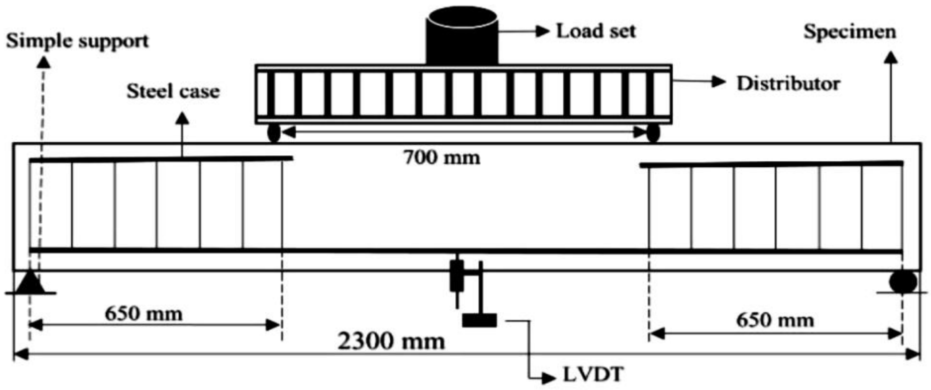


Figure 2.16: Beam reinforcement detail

Source: Ashraful et al. (2015)

2.8.2.2 Kenaf Fibre Reinforced Polymer

Bhutta et al. (2014) conducted an experimental research to study the structural behaviour of RC beams that externally strengthened with various types of kenaf fibre reinforced polymer composite laminates with 50% fibre volume content. A total number of six beams were strengthened with kenaf/epoxy, kenaf/polyester and kenaf/vinly ester composite laminates, meanwhile two beams were not strengthened to serve as control beams. The beam specimens were 100 mm x 130 mm x 1600 mm in width, height and length, respectively. The main reinforcements were 2H8 at the top and 2H10 at the bottom of the beam. The composite laminate (100 mm x 6 mm x 1400 mm in width, thickness and length, respectively) was applied to the bottom soffit of the whole beam. The load deflection, strain behaviour and failure modes of beams were evaluated. The results of the research show that all strengthened beams had improved their maximum flexural strength by 40% and the maximum deflection of beams had reduced by 24%. Moreover, an study conducted by Khalid and Yatim (2011) showed that the RC beam strengthened externally with kenaf fibre reinforced polymer composite (KFRPC) had improved its ultimate load by 41% and the beam deflection had reduced by 29%, as compared to the beam without strenghtening. It is also found that the crack width of beam reduced and started to appear at higher load as compared to the control beam. Hence, the KFRPC plate can improve the flexural strength of RC beam. Figure 2.17 shows the beam details.

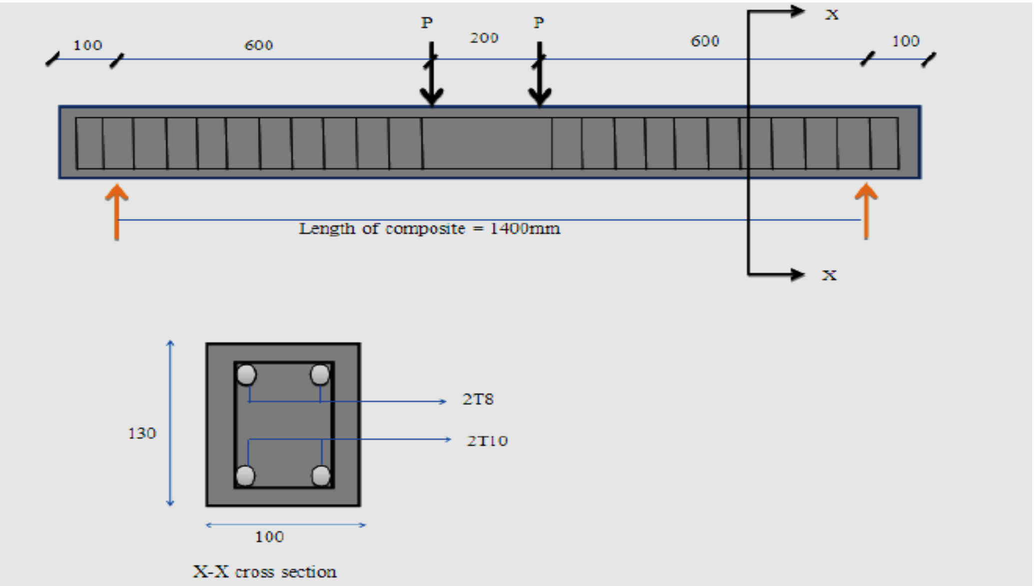


Figure 2.17: Beam dimension

Source: Bhutta et al. (2014)

2.9 FOUR-POINT BENDING TEST

The four-point bending flexural test is a test to provide modulus of elasticity in bending, flexural strain, flexural stress and the flexural stress strain response to the material. Four-point bending test is similar to three-point bending test (Watts, 2016). The major difference of the test is the addition of the 4th bearing that will bring larger portion of the beam to the maximum load or stress.

The test method involves a universal testing machine. The sample such as concrete is placed on the two supporting pins at a set distance apart and on the two loading pins placed at the equal distance around the centre. The loadings are lowered from above until sample fails at a constant rate. The test method is simple and requires minimum sample machining. The maximum stress is directly related to the crack initiation and flexural strength. The schematic of four-point bending test is shown in Figure 2.18.

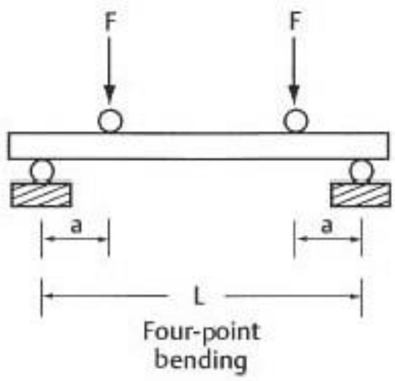


Figure 2.18: Four-point bending test

Source: Brantley et al. (2015)

2.10 SUMMARY

There is a large amount of pineapple leaves dumped as agricultural waste in Malaysia each year. The research of PALF especially in composite materials used for structural strengthening is limited in Malaysia. Based on the literature review, alkali treatment using NaOH is needed to enhance the interfacial bonding of polymer and matrix. The concentration of NaOH can be selected around 4%. The thermoset resin chosen for the research is epoxy resin. For the fabrication of composite plates, the fibre volume ratio range for studying in this research is 0.1 to 0.4. The method of fabrication of composite plate is hand lay-up method. The main reinforcement of the RC beam ranges from 8 mm to 12 mm in diameter, whereas the shear reinforcement ranges from 6 mm to 8 mm. Meanwhile the structural behaviour of RC beam with the application of composite material at the bottom soffit of beam is evaluated by four-point bending test, in terms of load deflection, crack patterns and failure modes.

CHAPTER 3

METHODOLOGY

3.1 INTRODUCTION

This research studied the effectiveness of the PALF-epoxy composite plate to strengthen RC beams in bending and in the tension zone. The methodology of the research covers Scanning Electron Microscope (SEM) test, single fibre test, the flexural testing on mechanical properties of PALF composite samples and four-point bending testing of RC beams.

The experimental work flow of the research is presented in the flowchart as shown in Figure 3.1.

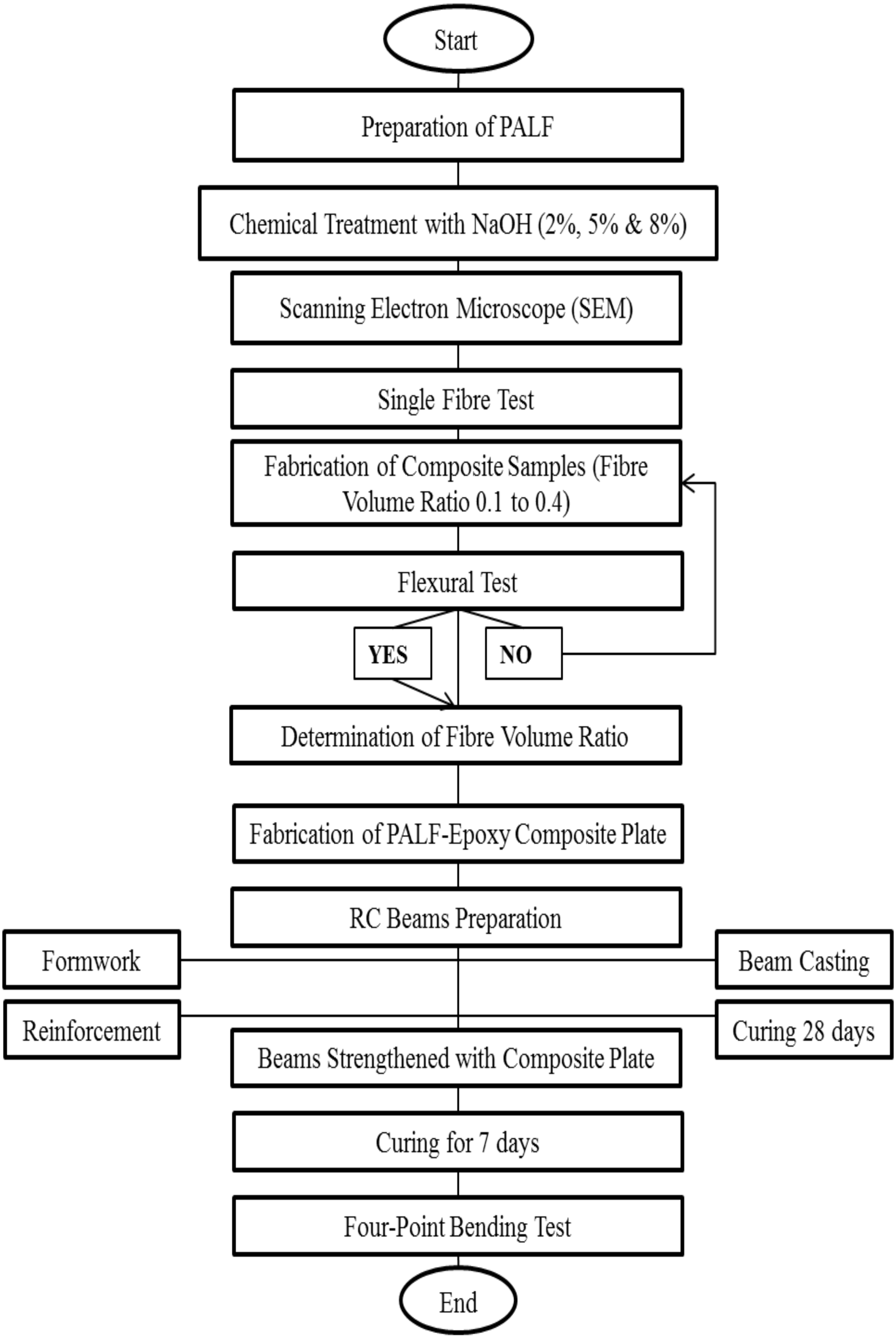


Figure 3.1: Experimental Work Flow of the Research

3.2 MATERIAL PREPARATION

3.2.1 Pineapple Leaf Fibres (PALF)

The pineapple leaf fibres (PALF) used were extracted from the pineapples leaves commonly found in Malaysia. The fibres were obtained from Faculty of Mechanical Engineering, Universiti Malaysia Pahang. The fibres were untreated with any chemical or reagent. The types of PALF used in the research were long fibres, in which the length ranges from 80-100 mm. The density of the PALF is 1.22 g/cm^3.

The pineapple leaf fibres were washed with tap water at room temperature in order to remove impurities in the fibres. After washing, the fibres were dried in oven at temperature of 70 ºC for 24 hours before further chemical treatment process. Figure 3.2 shows PALF.

Figure 3.2: Pineapple Leaf Fibre (PALF)

3.2.2 Epoxy Resin- DER331

The type of resin used to bind the fibres in the research was epoxy resin DER311. It was a liquid epoxy resin made from the product of epichlorohydrin and bisphenol A, and it was transparent in colour. The density of the epoxy resin was 1.16 g/cm^3. The epoxy resin was mixed with hardener before the fabrication of composite samples with the ratio of 2:1. The hardener used was JOINTMINE 905-3S. The epoxy resin was used for the fabrication of composite samples. The epoxy and its hardener are shown in Figure 3.3.

Figure 3.3: Epoxy DER-331 and harderner

3.2.3 Epoxy Resin- Sikadur 30

The type of epoxy resin to bind composites onto the surface of concrete beams was Sikadur 30. Its density was 1.65 kg/litre. It contained two parts, in which Part A was white in colour and Part B was black colour. Part A and B were mixed with the volume ratio of 3:1. It was used to bond the PALF composite plates with RC beams for four-point bending test.

Before the application of Sikadur 30 on the beams, the concrete surface was cleaned and free of standing water. Proportion one part of Part B to three parts of Part A by weight was mixed thoroughly until uniform in colour (grey). The mixed Sikadur 30 was applied onto the concrete and plate with a trowel. The thickness of the epoxy was 3 mm. The epoxy was then left to be cured for 7 days to reach its design strength. Figure 3.4 shows the concrete applied with Sikadur 30.

Figure 3.4: Concrete applied with Sikadur 30

3.3 TREATMENT OF PALF

Alkali treatment method was selected for surface treatment of the fibres. The treatment was important to remove the surface impurities and to develop fine fibre structure modifications. In this research, the alkali used was Sodium Hydroxide (NaOH). NaOH treatment can remove the waxes, lignin, hemicellulose and alkali soluble compounds found on the surface of fibres. This treatment reduced the hydrophilic tendency of the fibres and hence created better fibre resin adhesion (Mwaikambo & Ansell, 1999).

3.3.1 Treatment of PALF with Different Concentration of NaOH

In order to study the physical behaviour of PALF, after the PALF were cleaned, the fibres were alkali-treated with three levels of NaOH concentration (2%, 5% and 8%) respectively. The NaOH pellets were dissolved with distilled water. The PALFs were soaked in NaOH solution with 2%, 5% and 8% concentration at 30 ºC for an hour. After NaOH treatment, the fibres were washed and rinsed with distilled water for several times. The fibres were then dried in an oven at 70 ºC for 24 hours. The PALFs that had treated with 2%, 5% and 8% of NaOH solution were used in SEM test and single fibre test. Figure 3.5 shows the NaOH pellets used for chemical treatment. The fibres treated with 2%, 5% and 8% of NaOH solution are shown in Figure 3.6.

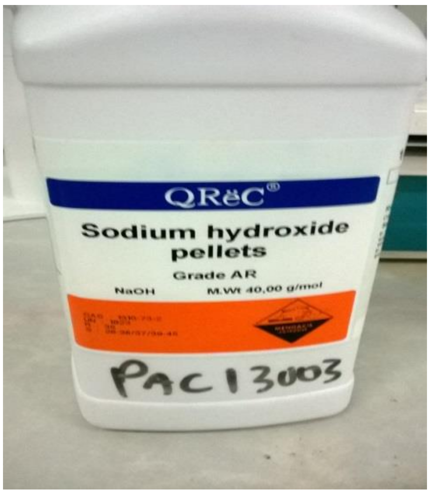


Figure 3.5: Sodium Hydroxide Pellet

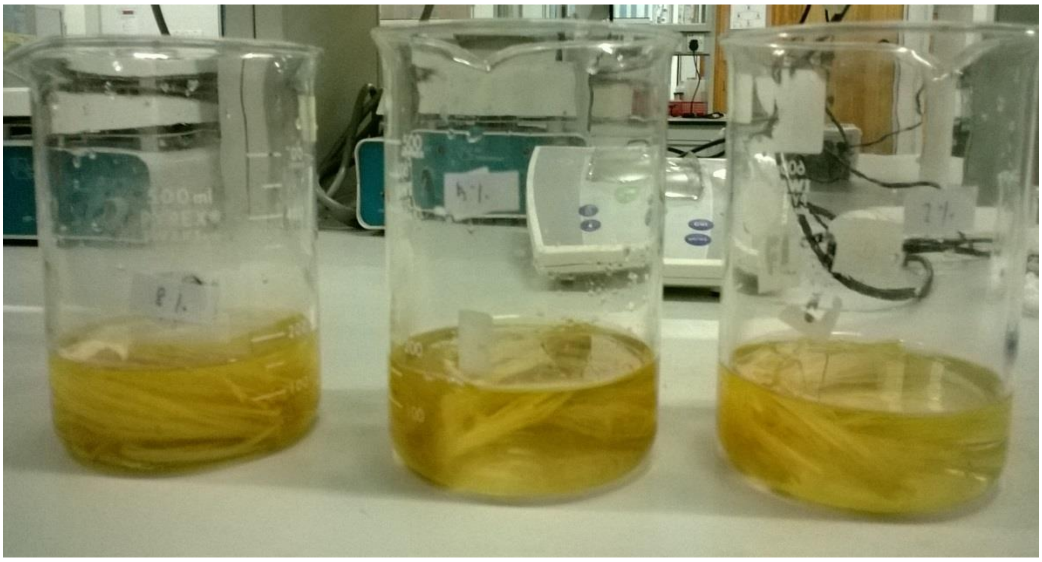


Figure 3.6: The fibres treated with 2%, 5% and 8% of NaOH solution (from right)

3.3.2 Treatment of PALF for PALF-Epoxy Composites

The pineapple leaf fibres (PALF) were soaked in 4% of Sodium Hydroxide (NaOH) solution at 30 ºC for an hour for cleaning, bleaching and enhancing the adhesion between fibre and matrix. The ratio of the fibres to the NaOH solution was 1:20 (w/v). After the alkali treatment, the fibres were washed and rinsed with tap water several times, and then dried in oven at 70 °C for 24 hours. The treatment was used for the fabrication of PALF composite samples and plates. The process of treatment and drying is shown in Figure 3.7.

(a) (b)

Figure 3.7 (a): The fibres were soaked in NaOH solution; (b) The fibres were dried in oven at 70 °C

3.4 FABRICATION OF PALF COMPOSITE PLATES

3.4.1 Fabrication of PALF Composite Samples with Different Fibre Volume Ratio

PALF-epoxy composite samples having different fibres content were prepared by varying the fibre volume ratio from 0.1 to 0.4 in order to study the effect of fibre volume on the composite mechanical properties. The composite samples sized 25 mm wide x 6 mm thick x 200 mm long. The composition of PALF-epoxy composite is presented in Table 3.1.

Table 3.1: The composition of PALF-epoxy composite

PALF volume ratio	Epoxy resin volume ratio
0.1	0.9
0.2	0.8
0.3	0.7
0.4	0.6

Neat epoxy resin plate (without fibre) was fabricated to serve as control plate. PALF-epoxy composite samples with fibre volume ratio of 0.1, 0.2, 0.3 and 0.4 were fabricated by hand laying technique. A total number of two (2) composite samples were fabricated for each fibre volume ratio and one sample of neat epoxy plate was prepared.

For the fabrication of composite samples, epoxy was mixed thoroughly with hardener with ratio of 2:1 by weight. The pineapple leaf fibres with 0.1 volume ratio was calculated and weighed before the composite fabrication. The calculation of fibre and resin by weight is shown in Equation 1 and 2 respectively.

Fibre weight= Composite sample volume x PALF density x Fibre volume ratio (Eq. 1)

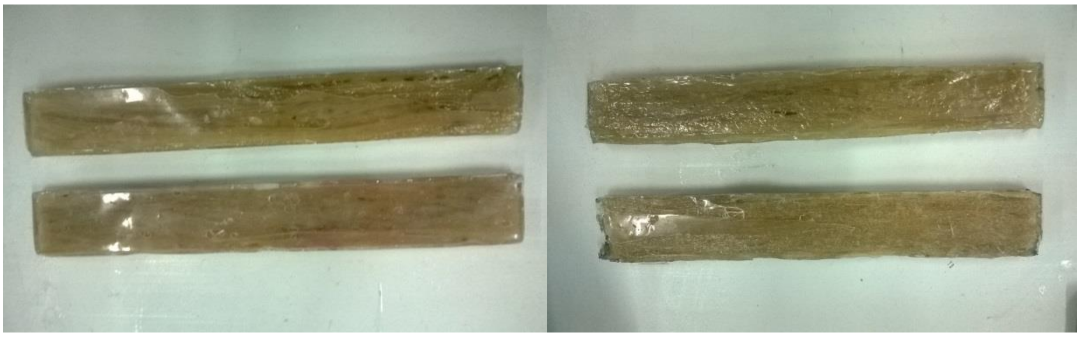
Resin weight= Composite sample volume x Epoxy density x Resin volume ratio (Eq. 2)

The calculations of composite samples are summarised in Table 3.2.

Table 3.2: Calculation of fibre weight and resin weight by fibre volume ratio

Fibre (%)	Epoxy resin (%)	Fibre weight (g)	Resin weight (g)	Epoxy weight (g)	Hardener weight (g)
Neat	100	0	34.80	11.60	23.20
10	90	3.66	31.32	10.44	20.88
20	80	7.32	27.84	9.28	18.56
30	70	10.98	24.36	8.12	16.24
40	60	14.64	20.88	6.96	13.92

A layer of lamination paper was laid at the bottom of the mould for easy detachment of fabricated composite. At the beginning, a thin layer of epoxy resin was applied on the mould. The fibres were separated into three layers and one of the layers of PALF was first laid on the adhesive by hand. The resin was laid again followed by the second layer of fibre. The steps were continued until all three layers of fibres were laid. The final step was compressing the plate using weight made of steel. The plate was compressed under load for one day. The whole process was repeated for fibre volume ratio 0.1 to 0.4. The composite plates with fibre volume ratio of 0.1 to 0.4 are illustrated in Figure 3.8.



(a) (b)

(c) (d)

Figure 3.8: Composite samples with fibre volume ratio (a) 0.1; (b) 0.2; (c) 0.3; (d) 0.4

3.4.2 Fabrication of PALF Composite Plates

The mould used to fabricate PALF-epoxy composite plate was Perspex mould as shown in Figure 3.9. The size of the glass mould is 100 mm x 8 mm x 600 mm in width, thickness and length.

Figure 3.9: Perspex mould

Initially fibres were treated with 4% of NaOH solution, washed and dried at 70 ºC in an oven. Fibres with fibre volume ratio of 0.3 and epoxy resin were prepared. Fibre volume ratio of 0.3 was chosen as the optimum tensile strength and flexural strength were both obtained at this fibre volume ratio (Devi, Bhagawan, & Thomas, 1997). A layer of releasing agent, Vaseline was spread over the bottom of the mould to ensure the composite plate can be removed easily when it hardened.

A layer of epoxy resin mixed already with hardener was then laid before the fibres were placed into the mould as illustrated in Figure 3.10. It was ensured that the epoxy resin filled the entire bottom surface of the mould. Then, a layer of fibre was laid uniformly and unidirectional onto the resin inside the mould by hand as shown in Figure

3.11. The fibres were arranged in straight line. Epoxy resin was then laid again onto the fibres carefully and flattened. It was ensured that the resin penetrated between the fibres. Then the process was repeated for laying the second and third layer of fibres. After three layers of fibres were laid onto the mould, a lamination paper was placed on the top of the mould, and steel weight was placed onto the fibres to ensure the plate with smooth surface and constant thickness and to remove air bubbles. After the composite had fully dried, it was taken out from the mould and then placed in an airtight bag. A total number of two (2) plates were fabricated. A completed PALF-epoxy composite plate is shown in Figure 3.12.

Figure 3.10: A layer of epoxy mixed with hardener was laid at the bottom of mould

Figure 3.11: A layer of fibre was laid onto the epoxy adhesive

Figure 3.12: PALF composite plate

3.5 PREPARATION OF BEAM SPECIMENS

Three (3) RC beams with a dimension of 100 mm x 130 mm x 1600 mm in width, depth and length, respectively were cast. The beams were Grade 25 RC beams.

3.5.1 Formwork

The formwork used in the experiment was made out of plywood. A formwork layout was proposed to cut the plywood. The three formworks were constructed and placed in dry condition. Oil was spread over the plywood formwork before concrete was poured. Figure 3.13 illustrates the formwork.

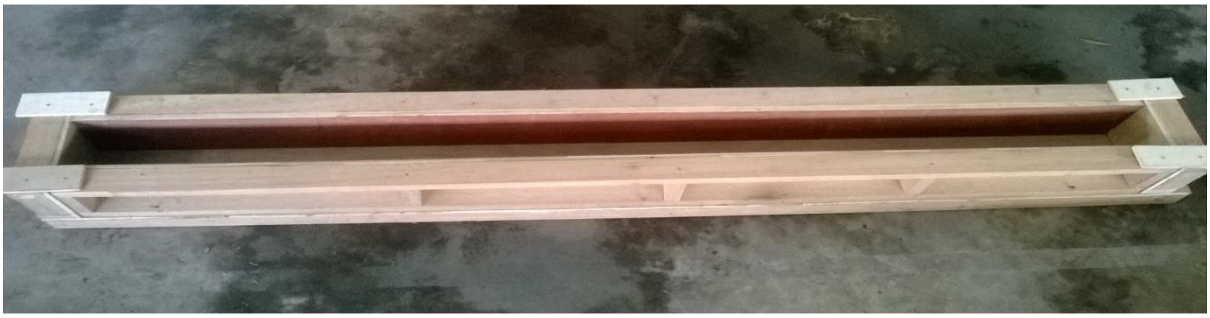


Figure 3.13: Formwork

3.5.2 Internal Reinforcement Steel Bars

The internal steel reinforcements used were mild steel bars of 6mm and 10mm in diameters. 2H10 were used as the main reinforcement at the top and bottom of the beam while 6 mm steel bars were used as the shear links with 300 mm spacing, centre to centre. The steel bars were cut using steel bar cutter and were bent using bar bending machine. The steel bars were tied using steel wire to form steel frame before concrete pouring. Figure 3.14 shows the internal steel reinforcement bar of the beam.

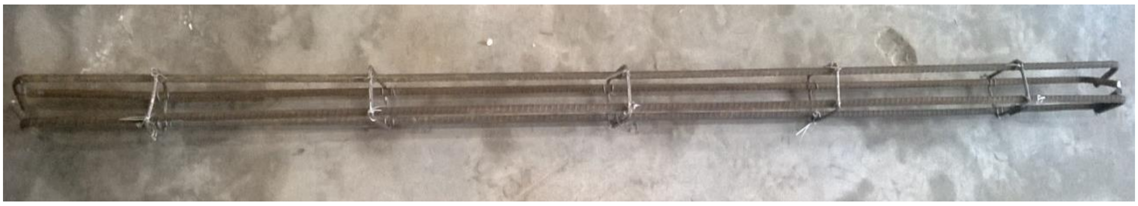


Figure 3.14: Steel reinforcement bar of beam

3.5.3 Concreting and Casting

Readily mixed fresh concrete was sponsored by a concrete batching plant and transported by a concrete mixing transport truck as shown in Figure 3.15. The beams were designed to achieve 25 N/mm^2 of compressive strength. The Grade 25 concrete was then poured into the formwork. A concrete vibrator was used to compact the concrete to prevent honeycomb issue in the beams as shown in Figure 3.16. The surface of the concrete was smoothened and finished with the trowel hand tool. The concrete was also poured into fifteen (15) moulds of cubes for compressive strength testing at 3, 7 and 28 days.

Figure 3.15: Fresh concrete was supplied by a concrete mixing transport truck

Figure 3.16: Fresh concrete was vibrated using a vibrator

3.5.4 Curing

All the beams were covered with wet gunny bags after casting. All the beams were allowed to be cured continuously for 28 days. The beams were left indoor to prevent moisture lost due to hot environment and strong winds. At the end of curing, the RC beams were removed carefully from the formwork and painted with white paint as shown in Figure 3.17 so that cracks can be seen easily during tests. Gridlines were drawn for better examination of cracks during four point bending test.

Figure 3.17: Beams painted with white paint

3.6 SCANNING ELECTRON MICROSCOPE (SEM)

In order to study the physical behaviour of PALF especially the surface morphology of fibres after surface treatment, the fibres were observed using Scanning Electron Microscope (SEM). The surface conditions of fibre treated with different concentration of NaOH were examined. The formation of hollows or voids inside the fibres microstructures were observed through SEM images taken.

3.7 SINGLE FIBRE TEST

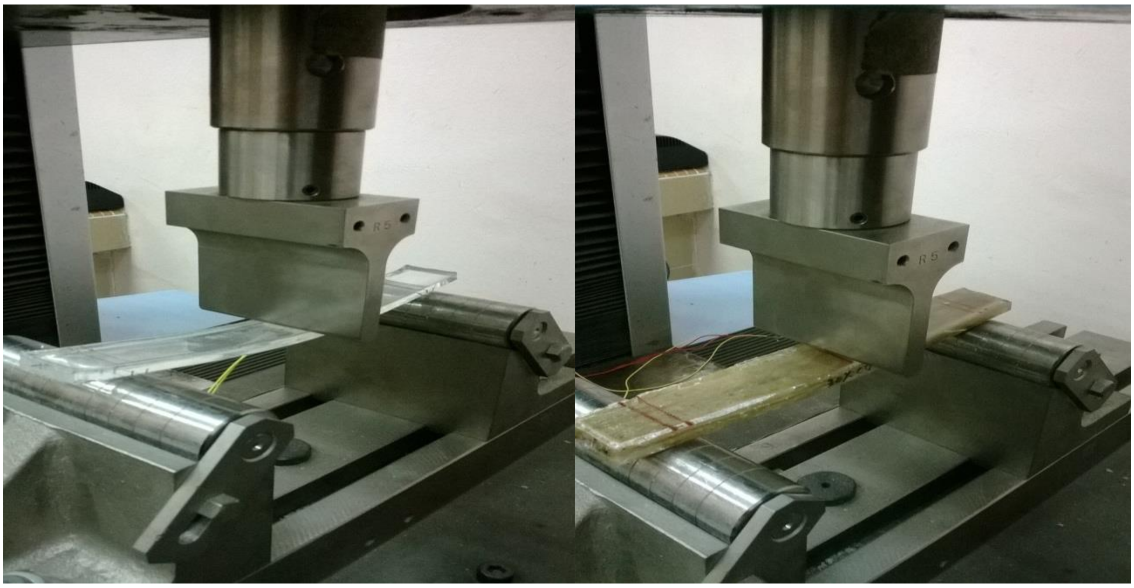
Single fibres were selected at random from the untreated and NaOH (2%, 5% and 8%) treated fibres. The test was carried out according to ASTM D3822-01.

Three (3) samples of untreated and treated fibres with (2%, 5% and 8%) NaOH were prepared. The fibres were tested using Universal Testing Machine (UTM). The single fibres were mounted to the jaws of clamps of UTM machine without stretching and the distance between the clamps was adjusted. The gage length was 20 mm for each sample. Each of the sample weighed 20 g. The samples were ensured to be straight within the jaws and lied on the line of action. The samples were tested under speed 1mm/min until the fibres reached the ultimate load. Figure 3.18 shows the fibre sample tested under UTM machine.

Figure 3.18: Single Fibre Test using UTM machine

3.8 FLEXURAL TEST OF PALF COMPOSITE SAMPLES

The flexural strength of PALF-epoxy composite sample was determined with flexural test accordance to ASTM D790. The fabricated composite samples were tested for flexural test using Universal Testing Machine (UTM) as illustrated in Figure 3.19. The crosshead speed was set 5mm/ min. The samples had span-to-depth ratio greater than 16. The type of loading system was three point bending system. The composite sample was centred on the supports. The gage length of the composite sample was 160 mm, in which the support was 20 mm from each side of the edge to the support. The loading nose was adjusted to be midway between the supports. Load was applied to the composite samples at the specified cross head rate until the plate samples ruptured. The strain of the composite plates was measured by strain gage pasted under the sample in contact with it at the centre of the support span as shown in Figure 3.20 in order to read the crack width of the sample.



(a) (b)

Figure 3.19: (a) Neat epoxy sample was tested with UTM; (b) Composite sample was tested with UTM

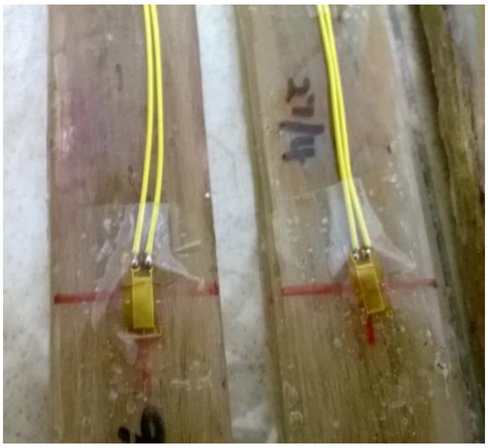


Figure 3.20: Strain gages were pasted at the bottom and midway of composite plate

3.9 FOUR POINT BENDING TEST

The RC beams were tested to failure under four-point bending in a loading frame, known as Magnus's frame. The load was applied with increasing static load until beam failure. A total of three beams were tested, where one beam served as control beam and two beams were externally strengthened with PALF composite plates as mentioned in Section 3.4.2. The beam specimens are listed in Table 3.3.

Table 3.3: Beam specimens for four point bending test

Beam Specimens	
CB	Control Beam
PALF B1	Beam 1 strengthened with PALF composite plate
PALF B2	Beam 2 strengthened with PALF composite plate

The mid-span of the beam was measured and marked. The PALF composite plates were bonded to the bottom soffit at mid span of the beam as shown in Figure 3.21. Strain gages were attached to the plate at least one day before the test in order to read the strain values. The application of strain gages is depicted in Figure 3.22.

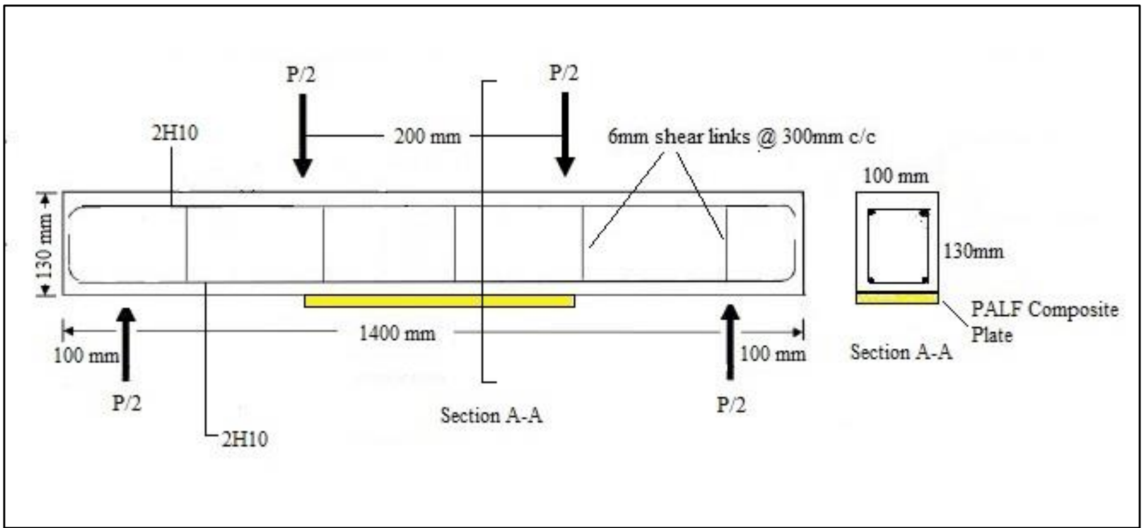


Figure 3.21: Schematic diagram of four-point bending test

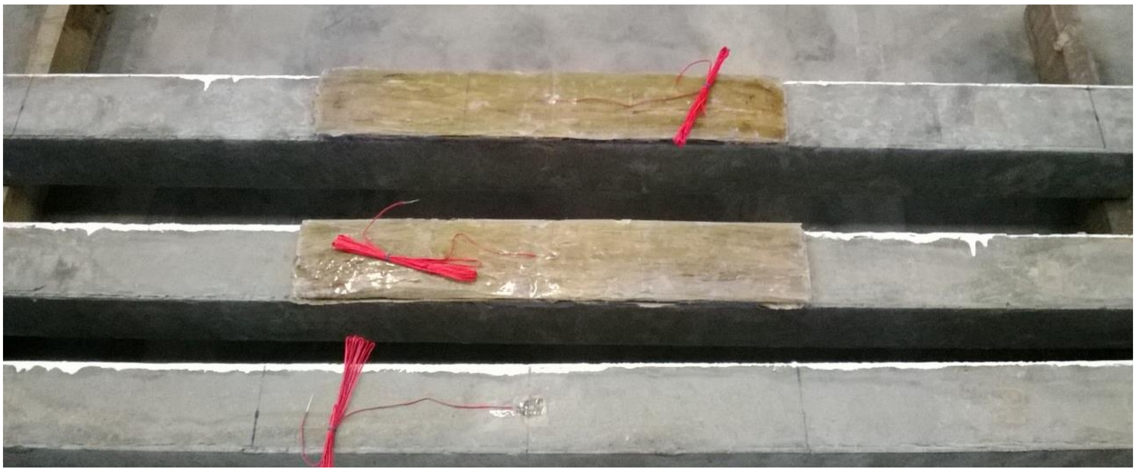


Figure 3.22: Composite plates together with strain gages were attached to mid-span bottom soffit of the beam

During the test, the deflection of beam was determined by placing the Linear Variable Differential Transducers (LVDT) on the centre of the beam soffit as illustrated in Figure 3.23. Data logger was used to record and collect data during the test. The cracks appeared on the beams were marked using a marker pen.

Figure 3.23: Four-point bending test

3.10 SUMMARY OF METHODOLOGY

The summary of methodology is shown in Table 3.4.

Table 3.4: Summary of methodology

<table>
<tr><th colspan="3">Test</th><th>SEM</th><th>Single Fibre Test</th><th>Flexural Test of Composite Samples</th><th>Four Point Bending Test</th></tr>
<tr><td rowspan="12">Number of Samples</td><td rowspan="4">Concentration of NaOH</td><td>0%</td><td>1</td><td>2</td><td colspan="2" rowspan="4">(4% NaOH treatment)</td></tr>
<tr><td>2%</td><td>1</td><td>2</td></tr>
<tr><td>5%</td><td>1</td><td>2</td></tr>
<tr><td>8%</td><td>1</td><td>2</td></tr>
<tr><td rowspan="5">Fibre Volume Ratio</td><td>0</td><td rowspan="8"></td><td rowspan="8"></td><td>1</td><td rowspan="5">(0.3 Fibre Volume Ratio)</td></tr>
<tr><td>0.1</td><td>2</td></tr>
<tr><td>0.2</td><td>2</td></tr>
<tr><td>0.3</td><td>2</td></tr>
<tr><td>0.4</td><td>2</td></tr>
<tr><td rowspan="3">Beam</td><td>CB</td><td rowspan="3"></td><td>1</td></tr>
<tr><td>PALF B1</td><td>1</td></tr>
<tr><td>PALF B2</td><td>1</td></tr>
<tr><td colspan="3">Total Number of Samples</td><td>4</td><td>7</td><td>9</td><td>3</td></tr>
</table>

CHAPTER 4

RESULT AND DISCUSSION

4.1 INTRODUCTION

The results obtained from experimental work are discussed in this chapter. This includes concrete cube test, Scanning Electron Microscope (SEM), single fibre test, flexural test of composite samples and four-point bending test. Comparison was made in each test with their respective control specimens.

4.2 PHYSICAL TESTING

4.2.1 Scanning Electron Microscope (SEM)

The effect of the surface treatment on pineapple leaf fibres was studied by the examination of the fracture surface of the fibres with Scanning Electron Microscope (SEM). SEM showed the surface topology of untreated and treated fibres.

The untreated fibres contained a lot of impurities such as dust as shown in the red circle in Figure 4.1. NaOH treatment removed the impurities from the surface of the fibres and also partial removed the hemicellulose, lignin and other soluble materials (Matthews & Rawlings, 1994) (Mwaikambo & Ansell, 1999). This is because hemicellulose and lignin were soluble in NaOH solution (Samal & Ray, 1998), these components dissolved during NaOH solution treatment and washed out when rinsed with water. It is shown that the fibre surface of treated fibres in Figures 4.2, 4.3 and 4.4 were clean and rougher than the untreated fibre. In addition NaOH treatment made the fibre soft due to the inter fibril region likely to be less dense and less rigid that makes the fibres able to rearrange along the direction of loading.

Moreover, it was observed that there were increasing presences of voids inside the fibres with increasing concentration of NaOH treatment. The voids appearance in fibres treated with 8% NaOH (Figure 4.4) were higher than the fibres treated with 2% (Figure 4.2) and 5% (Figure 4.3) of NaOH. This is due to high NaOH solution concentration removed more amounts of internal constituents or compounds on the surface of fibres. The interfacial adhesion between matrix and fibre increased by the use of treated fibres in composites (Jayabal et al., 2011).

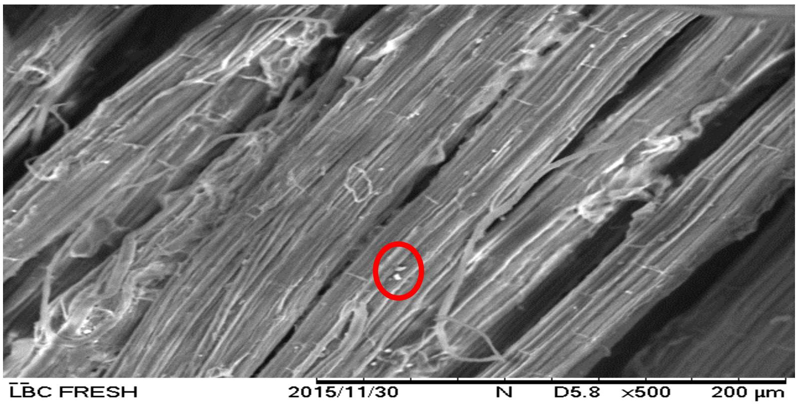


Figure 4.1: SEM of untreated PALF

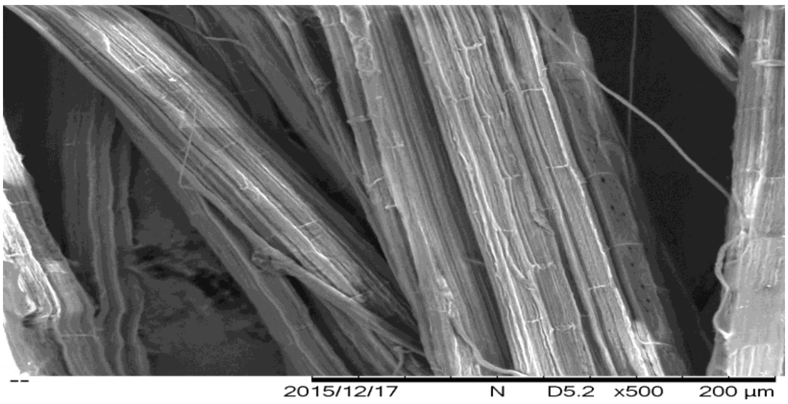


Figure 4.2: SEM of PALF treated with 2% of NaOH solution

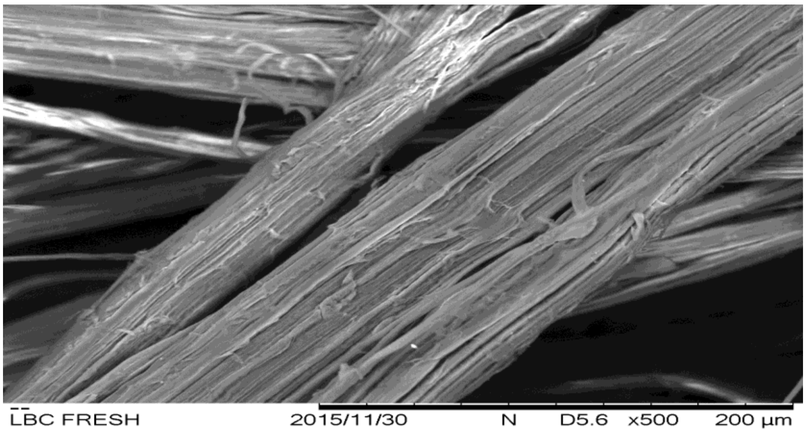


Figure 4.3: SEM of PALF treated with 5% of NaOH solution

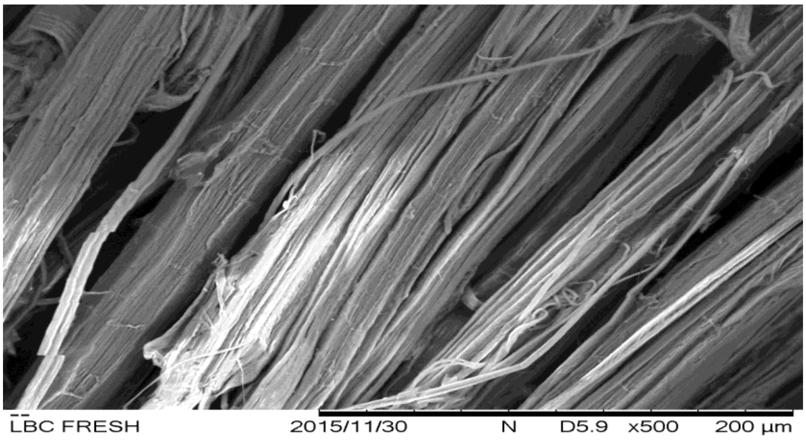


Figure 4.4: SEM of PALF treated with 8% NaOH solution

4.3 MECHANICAL TESTING

4.3.1 Single Fibre Test

Table 4.1 summarises the maximum tensile force the untreated fibres and treated fibres (with 2%, 5% and 8% of NaOH) could sustain. It is shown that the tensile strength of PALF decreased as the concentration of NaOH increased. The average maximum tensile force for fibres treated with 2%, 5% and 8% of NaOH solution decreased by 40.8%, 56.3% and 68.2% as compared to the untreated fibre. Meanwhile the average maximum tensile force of fibres treated with 5% of NaOH decreased by 26.2% as compared to fibres treated with 2% of NaOH and the average maximum tensile force of fibres treated with 8% of NaOH decreased by 27.2% as compared to fibres treated with 5% of NaOH. It is apparent that the tensile strengths of alkali treated fibres were lower than those of untreated fibres. This is possibly due to the removal of hemicellulose, lignin or other binding materials had caused the inter fibril region to be less rigid and less dense, and the fibres became soft, hence the fibres sustained less stress. Increasing concentration of NaOH for fibre treatment removes more binding materials in fibre, thus the tensile force of treated fibres decreased. Another possible reason is due to the remaining NaOH inside the fibres which interrupt the rearrangement of fibrils and this affected the load sharing and stress development in the fibres (Payae & Lopattananon, 2009). The average maximum tensile force of PALF is shown in Figure 4.5.

Table 4.1: Maximum tensile force for PALF treated with different NaOH concentration

Percentage treatment (%)	Maximum Tensile Force (N)		Average Maximum Tensile Force (N)
	1	2	
0	137.43	114.64	126.04
2	63.83	85.38	74.61
5	47.87	62.26	55.07
8	29.33	50.86	40.09

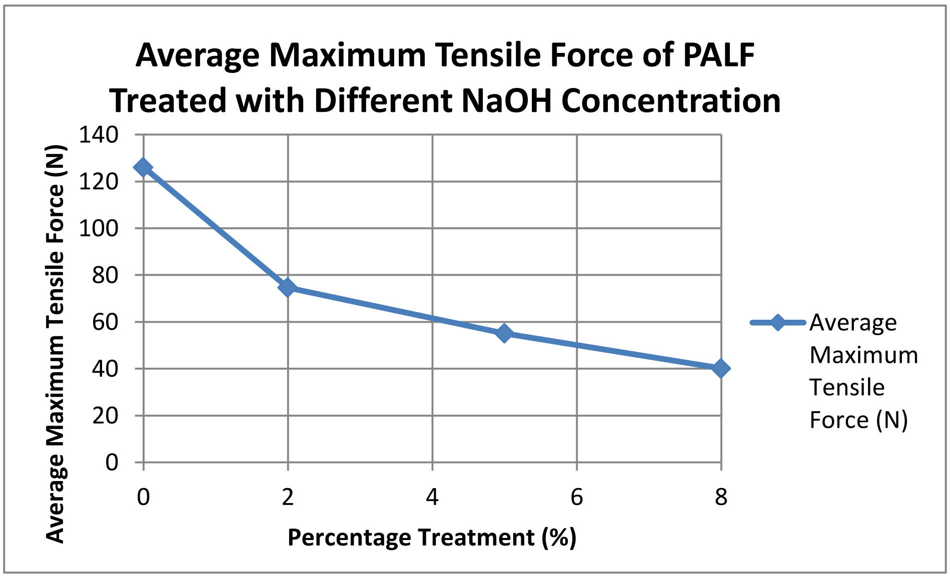


Figure 4.5: Average maximum tensile force of PALF treated with different concentration of NaOH

4.3.2 Flexural Test of PALF Composite Samples

The flexural test was conducted onto a neat epoxy resin sample and a total of eight samples of composite with fibre volume ratio of 0.1, 0.2, 0.3 and 0.4. All the composite samples were tested until failure and ruptured at the middle of the sample. The values of the load obtained were recorded until the maximum strain. Maximum strain was obtained at the point where first crack of the composite happened. The crack made the strain gages to be torned. The load values were continued to be recorded until the maximum load of the composite sample was obtained at the failure point. Figures 4.6 to 4.10 show the graphs of load versus strain curve for each sample respectively. Table 4.2 shows the load at maximum strain of each composite sample and Table 4.3 shows the maximum load of composite samples.

From the graph in Figure 4.6, the neat epoxy sample shows ductile behaviour. The neat epoxy sample undergoes extensive plastic behaviour at strain range of 5 to 17 mm/mm and 21 to 27 mm/mm. The load increases until it reaches the ductile fracture load of 202.71 N. During the experimental work, the neat epoxy sample broke into half at the peak or fracture load. It was observed that the deflection of the neat epoxy sample was large with increasing of load and broke suddenly at fracture point.

As for the composite plates with 0.1, 0.2, 0.3 and 0.4 fibre volume ratio, all the graphs show linear relationship. The value of load increases proportionally with increasing of strain. The graphs also show that the composite plates have a small region of elastic behaviour and a large region of ductile behaviour, so they can be said as ductile materials. Besides the composite plates have large strain values around 3000 mm/mm while the neat epoxy has only strain values of 27 mm//mm. This shows that the pineapple leaf fibres composite have higher ductility than the neat epoxy plate.

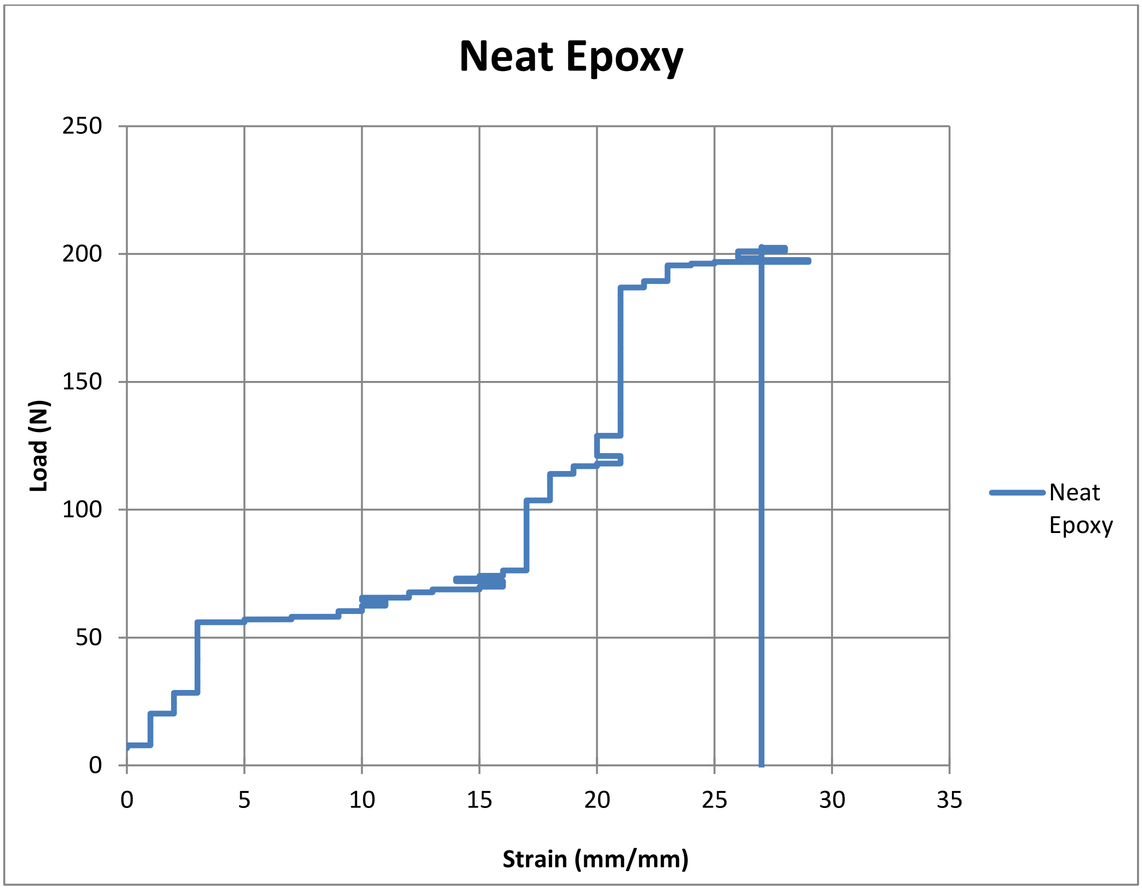


Figure 4.6: Load versus strain curve of neat epoxy composite samples

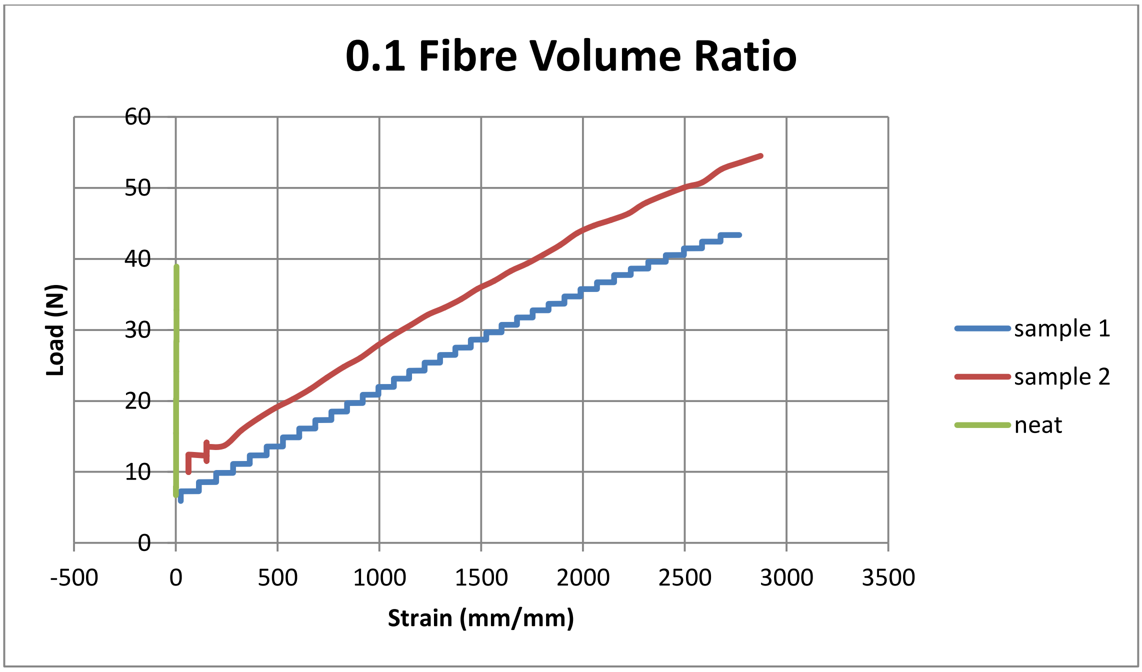


Figure 4.7: Load versus strain curve of composite samples with 0.1 fibre volume ratio

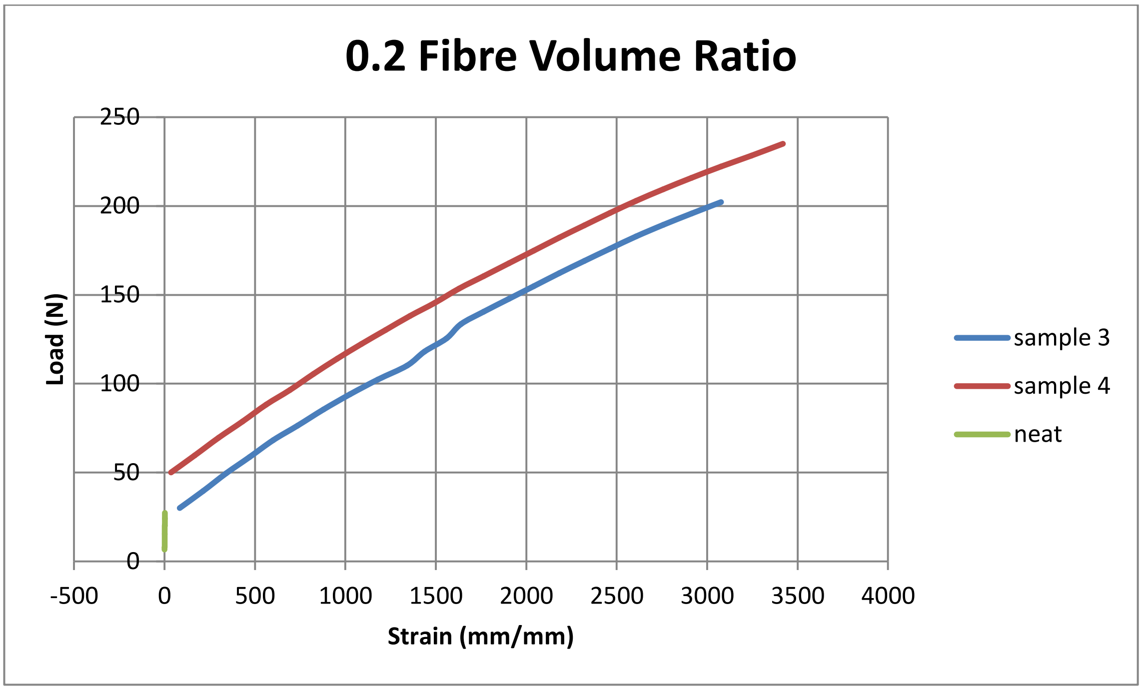


Figure 4.8: Load versus strain curve of composite samples with 0.2 fibre volume ratio

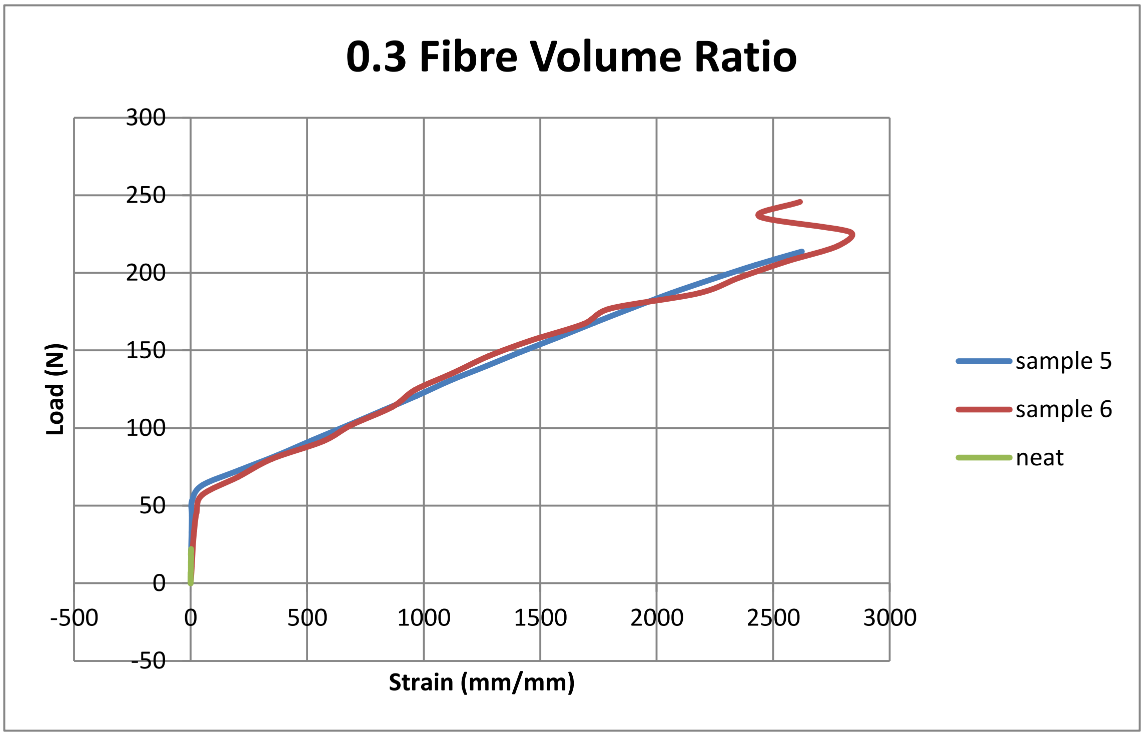


Figure 4.9: Load versus strain curve of composite samples with 0.3 fibre volume ratio

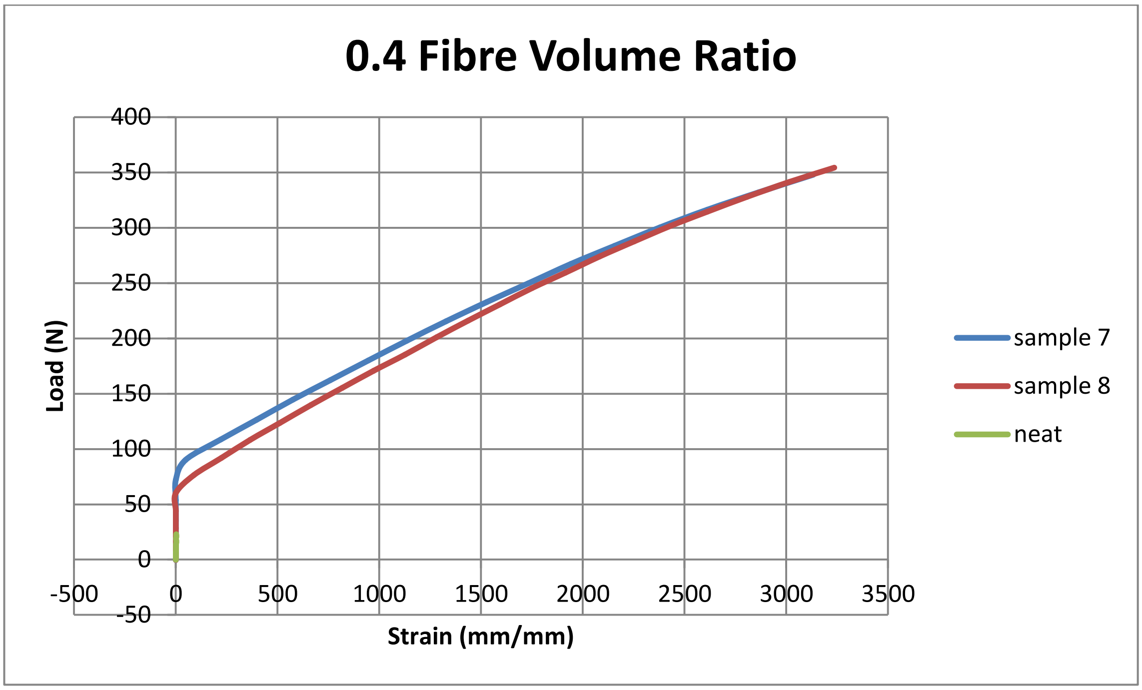


Figure 4.10: Load versus strain curve of composite samples with 0.4 fibre volume ratio

Table 4.2 shows the load at maximum strain of composite samples with different fibre volume ratio. The average load at maximum strain of neat epoxy was 202.71 N. The average load at maximum strain of composite samples with 0.1, 0.2, 0.3 and 0.4 fibre volume ratio are 48.93 N, 218.57 N, 229.76 N and 351.35 N, respectively. The average load value of composite samples with 0.1 fibre volume ratio decreases by 75.9% as compared to neat epoxy sample. Meanwhile the average load value of composite samples with 0.2 fibre volume ratio increases by 7.8% as compared to neat epoxy sample and 346.7% as compared to the value of 0.1 fibre volume ratio. The average load value of composite samples with 0.3 fibre volume ratio increases by 13.3% as compared to neat epoxy sample and 5.1% as compared to the value of 0.2 fibre volume ratio. The average load value of composite samples with 0.4 fibre volume ratio increases by 73.3% as compared to neat epoxy sample and 52.9% as compared to the value of 0.3 fibre volume ratio. The ultimate load at maximum strain of 351.35 N is achieved by the composite samples with 0.4 fibre volume ratio. This indicates addition of fibres can make the composite more ductile (Devi et al., 1997).

Table 4.2: Load at maximum strain of samples with different fibre volume ratio

Fibre Volume Ratio	**Load at Maximum Strain (N)**		
	1	**2**	**Average**
Neat	202.71	-	202.71
0.1	43.35	54.50	48.93
0.2	202.17	234.97	218.57
0.3	213.76	245.76	229.76
0.4	347.87	354.28	351.35

Table 4.3 shows the maximum load and flexural strength of composite samples reinforced with different fibre volume ratio. The maximum stress occurred at the mid span of the composite sample when the homogeneous elastic material was tested with three-point system. The flexural strength is calculated using Equation 3.

$$\text{Flexural strength} = \frac{3PL}{2\mathrm{b}d^2} \qquad \text{(Eq.3)}$$

where L is the support span; b, the width of the specimen; d, the thickness; and P, the maximum load.

Table 4.3: Maximum load and flexural strength of composite samples with different fibre volume ratio

Fibre Volume ratio	Maximum Load (N)			Flexural Strength (MPa)
	1	2	Average	
Neat	202.71	-	202.71	54.06
0.1	186.06	189.73	187.90	50.11
0.2	602.70	871.76	737.23	196.59
0.3	932.84	976.17	954.50	254.53
0.4	1142.44	1122.12	1132.28	301.94

The table shows that the flexural strength increased with the increase of PALF content. In the case of pure epoxy, the flexural strength is 54.06 MPa. The flexural strength value of the PALF-epoxy composite is found to be less than the neat resin at low weight fraction (0.1) of the fibre. The flexural strength of composite with fibre volume ratio of 0.1 is 50.11 MPa, which decreased 7% as compared to the neat epoxy. This is because at low fibre volume ratio, the fibres act as flaws (Devi, Bhagawan, & Thomas, 1997). The flexural strength of the composite with 0.2 fibre volume ratio increased 292% as compared to composite with 0.1 fibre volume ratio. The flexural strength of the composite with 0.3 fibre volume ratio increased 30% as compared to composite with 0.2 fibre volume ratio. Meanwhile the flexural strength of the composite with 0.4 fibre volume ratio increased 19% as compared to composite with 0.3 fibre volume ratio. In addition, the increase in fibre volume ratio of 0.2, 0.3 and 0.4 increased the flexural strength by 263%, 371% and 459% respectively as compared to the neat epoxy. The maximum flexural strength was obtained at fibre volume ratio of 0.4 or 40%. The maximum flexural strength of PALF-epoxy composite sample is 351.94 MPa. The results of the flexural test are plotted in Figure 4.11.

The optimum fibre volume ratio for best flexural strength is 0.4. However the fibre volume ratio of 0.3 was chosen and used in the composite plate fabrication for bending test. This is due to the findings and reports by researchers (Kashim et al., 2015); (Devi et al., 1997); (Khalid & Yatim, 2011) stating that the fibre volume ratio for best tensile and flexural strength is 0.3. On the other hand, Kasim et al. (2015) found out that the fibre volume ratio of 0.3 exhibited the best mechanical properties than other fibre volume ratio. Figures 4.12 to 4.14 show the composite samples after flexural test.

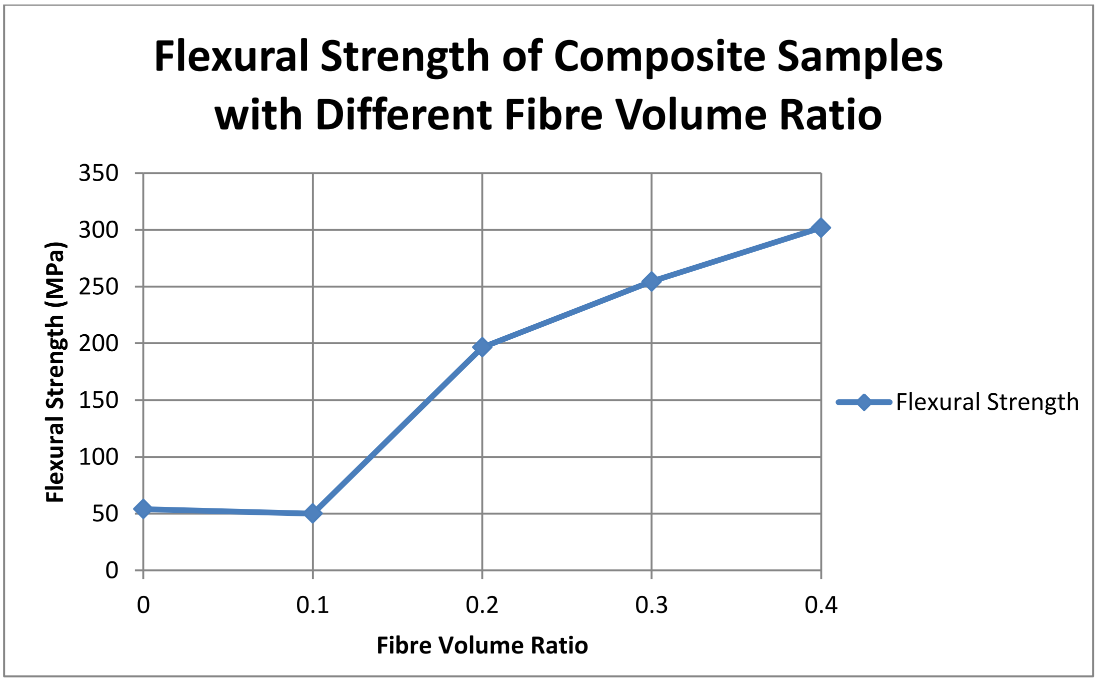


Figure 4.11: Flexural Strength of Composite Samples with Different Fibre Volume Ratio

Figure 4.12: Neat epoxy sample after flexural test

Figure 4.13: Top view of composite sample after flexural test

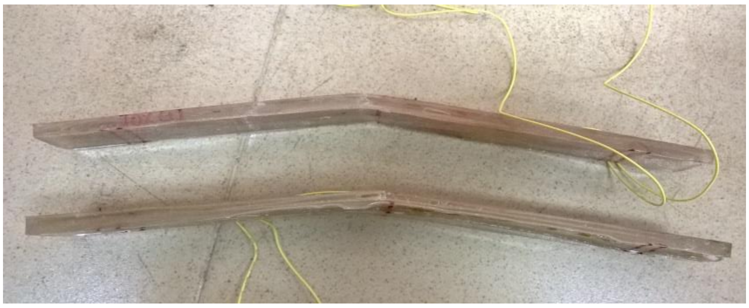


Figure 4.14: Side view of composite sample after flexural test

4.3.3 Concrete Cube Compression Test

The concrete cube compression test was conducted using a compression testing machine to determine the targeted compressive strength of the concrete beam. A total of fifteen (15) hardened cubes with dimension (breadth x depth x length) of 150 x 150 x 150 mm were tested at 3, 7 and 28 days. The compressive strength of the cube samples is presented in Table 4.4.

Table 4.4: Compressive Strength of Cube Samples at 3, 7 and 28 days

Sample	**Weight (kg)**	**Sample Age (days)**	**Load (kN)**	**Compressive Strength (MPa)**	**Average Compressive Strength (MPa)**
A1	7.78	3	412.01	18.31	17.94
A2	7.85	3	423.78	18.84	
A3	7.70	3	392.74	17.46	
A4	7.55	3	391.24	17.39	
A5	7.70	3	397.89	17.68	
A6	7.55	7	506.98	22.53	24.05
A7	7.70	7	513.57	22.83	
A8	7.85	7	524.88	23.33	
A9	7.85	7	552.68	24.56	
A10	7.85	7	606.99	26.98	
A11	7.70	28	722.28	32.10	31.74
A12	7.75	28	694.80	30.88	
A13	7.75	28	748.63	33.27	
A14	7.61	28	705.27	31.35	
A15	7.73	28	699.21	31.08	

From the result, the average compressive strength reached at 28 days was 31.74 MPa. Hence, the design mix satisfied the required compressive strength of 25 MPa at 28 days. The concrete cube compressive strength is illustrated in Figure 4.15.

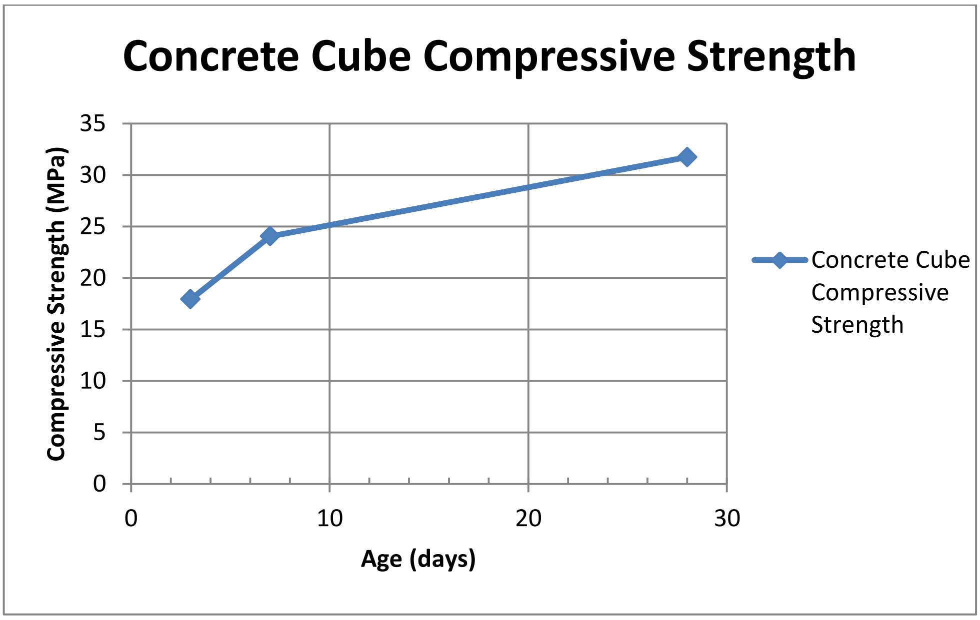


Figure 4.15: Compressive strength of cubes samples at 3,7 and 28 days

4.3.4 Four-Point Bending Test

Four-point bending test was carried out to determine the beam strength when externally strengthened with pineapple leaf fibre epoxy composite plate. The ultimate load, load behaviour, crack patterns and mode of failures were recorded up to failure throughout the experimental testing.

4.3.4.1 Ultimate Load

The ultimate load of control beam and beam strengthened with PALF composite plate are listed in Table 4.5. The ultimate load of the control beam can achieved is 14.98 kN, whereas the ultimate load of the beam specimens 1 and 2 strengthened with PALF-epoxy composite plates were 16.15 kN and 15.98 kN, respectively. The first beam with PALF-epoxy composite plate increased the strength by 8% and the second beam increased the flexural strength by 7%, as compared to control beam.

The strengthening using natural fibre such as kenaf fibre in RC beam (Khalid & Yatim, 2011) should achieve an improvement in strength of 41%. Hence, the strengthening improvement in PALF-epoxy RC beam should be higher than 8%. The strengthening using PALF-epoxy composite plate only can achieve improvement in strength at maximum 8% in this study. This is possibly due to insufficient application of epoxy resin Sikadur 30 to bind the PALF composite plates with the RC beams. Although the thickness of Sikadur 30 is mentioned to be less than 3 mm according to the manuals, the thickness of Sikadur 30 should be at least 5 mm for better bonding due to the thickness of the composite plate.

Table 4.5: Comparison of ultimate load of beam specimens

Specimen	**Ultimate load (kN)**	**Percentage of Strengthening (%)**	**Strengthening Ratio**
Control Beam	14.98	-	-
Beam with PALF Plate 1	16.15	8	1.08
Beam with PALF Plate 2	15.98	7	1.07

4.3.4.2 Load Deflection Behaviour

The load deflection curves of the beams are illustrated in Figure 4.16 and the deflection corresponding to the ultimate load are presented in Table 4.6.

From the load deflection curve of the beam specimens as depicted in Figure 4.16, it is shown that the control beam approaches the elastic region at the beginning of the four point bending test until it reaches the yield point of 13.31 kN at 6.09 mm deflection. After that the beam approaches the plastic region until it reaches the ultimate strength and undergoes necking phase until the fracture point. The beam with PALF composite plate 1 undergoes similar behaviour as the control beam. It approaches elastic region until the yield point of 14.32 kN at 5.13 mm deflection, develops plastic behaviour till ultimate strength, continued with necking phase until beam fractured. As for the beam with PALF composite plate 2, the beam approaches the elastic region and reaches the ultimate load which is also the yield point at 15.98 kN at 5.59 mm deflection, followed by significant decrease of load around 3 kN. This is probably because of the debonding of the composite plate has reduced the ability of the composite plate to sustain the load and resist deflection. Then the load increases from 13.52 kN at 5.93 mm and the beam undergoes uniform plastic elongation in the plastic region, necking and finally the load deflection relationship ended at the fracture point.

Overall, it is shown that the beams with PALF composite plate have steeper slope compared to the control beam. It indicates that the PALF composite plates have better stiffness as compared to control beam, and hence the composite plates can resist the deformation of RC beam. The comparison of ultimate load, percentage of strengthening, deflection and percentage of deflection reduction of the beam specimens are tabulated in Table 4.6.

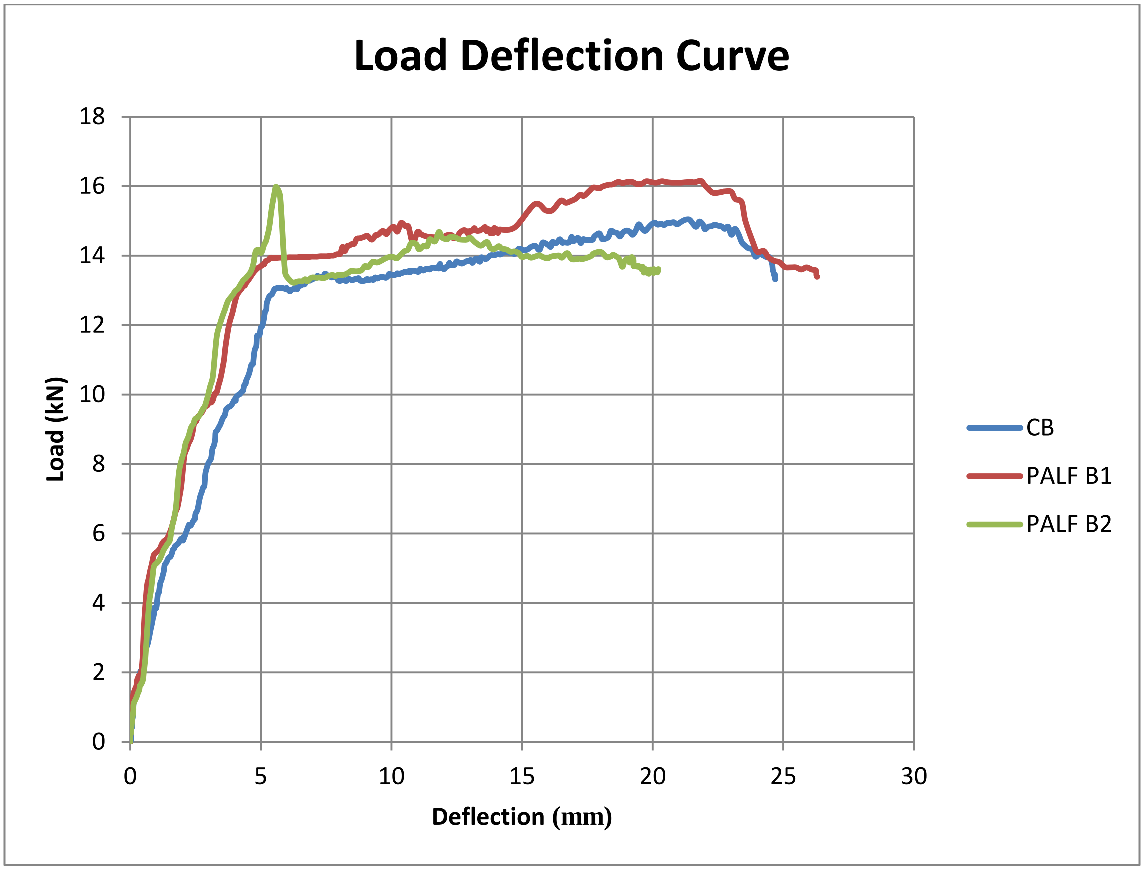


Figure 4.16: Load deflection curve of beam specimens

The deflection at ultimate load of control beam is 21.79 mm whereas the deflection at ultimate load of beam with PALF composite plate 1 and 2 achieve 20.35 mm and 5.59 mm respectively. Beam with PALF composite plate 1 has reduced deflection at mid span of 7 % meanwhile the beam with PALF composite plate 1 has reduced deflection of 74 % as compared to the control beam. The beams strengthened with PALF composite plates give lower deflection as compared to the control beam.

Table 4.6: Comparison of ultimate load and deflection of beam specimens

Specimen	Ultimate load (kN)	Percentage of Strengthening (%)	Deflection at Ultimate Load (mm)	Percentage of Deflection Reduction (%)
Control Beam	14.98	-	21.79	-
Beam with PALF Plate 1	16.15	8	20.35	7
Beam with PALF Plate 2	15.98	7	5.59	74

4.3.4.3 Crack Patterns

The cracks pattern of each beam specimen was analysed by observing the cracking pattern produced during and after beam testing. The cracks were observed and marked on the beam throughout the test.

4.3.4.3.1 Control Beam (CB)

Figure 4.17 and Figure 4.18 show the crack pattern of the control beam. When load was applied to the control beam, cracks started to appear starting from the soffit of the beam and became widen when load increased as the bottom surface of beam was weak in tension. The first crack of the control beam appeared at the mid span of the beam. The first crack happened at the load of 5.72 kN. Cracks started to appear continuously as load increased. Two vertical flexural cracks appeared at 7.18 kN left and right beside the first crack. The appearance of cracks and propagation of cracks continued to the point load as load increased. It was observed that large amount of crack propagation around 13kN of load. The cracks continued until the failure of the RC beam. The cracks happened at the middle of the tension zone. All the cracks were vertical flexural cracks.

Figure 4.17: Overview of crack pattern on control beam

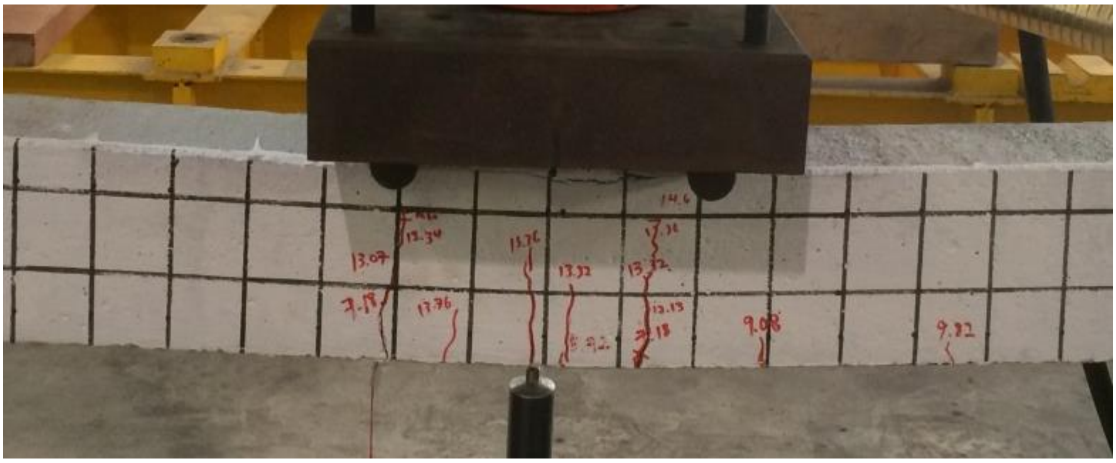


Figure 4.18: Flexural cracks on control beam

4.3.4.3.2 Beam with PALF 1 (PALF B1)

Figure 4.19 and Figure 4.20 show the crack pattern of the first beam strengthened with PALF composite plate. The first cracks appeared at the load of 9 kN which can be seen at both end sides of the plate. The cracks at both end sides continued to extend and penetrate and became wider as load increased. At the load around 13.4 kN the cracks had penetrated towards the neutral axis of the beam in diagonal direction. The cracks appeared to be shear failure cracks. However there were very little of flexural cracks appeared at the mid span of beam at the same time. As the load continually increased, the cracks widen and two main diagonal shear cracks can be seen clearly at the both end sides of the beam. There was also extension of secondary cracks from the main crack, in which the cracks penetrated the beam in diagonal direction. It was observed at the end of the test, that the width of the main cracks was enlarged as shown in Figure 4.20. It can be said that the PALF-epoxy composite plate resisted all the tensile stress in the mid-span and directed the cracks in the flexural zone to the end of the plate. Hence, the cracks in the mid span of the beam were lesser than the control beam.

Figure 4.19: Overview of crack pattern on beam with PALF 1

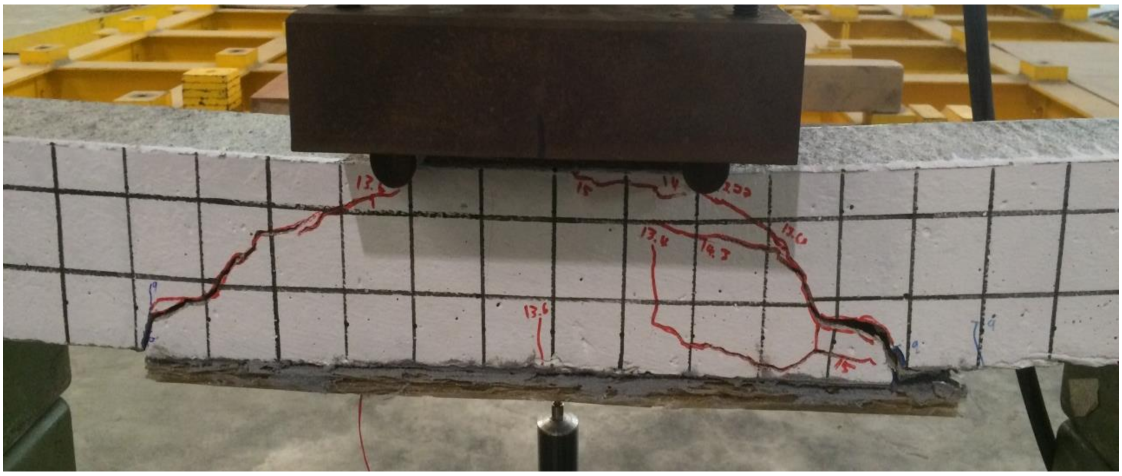


Figure 4.20: Shear cracks at the both end sides of the plate

4.3.4.3.3 Beam with PALF 2 (PALF B2)

Figures 4.21 to 4.22 show the crack pattern of the second beam strengthened with PALF composite plate. The first crack appeared at the load of 10 kN and followed by increasing of shear cracks as load increased. At the load of 13 kN, the cracks extended and penetrated through the neutral axis of the beam in diagonal direction. More cracks were developed and obvious at the left end side of the plate. Whereas there were only very little flexural cracks developed at the same time. As the load continually increased, the cracks widen and a main diagonal shear crack can be observed clearly at the left end side of the beam. There was also extension of secondary cracks from the main crack, in which the cracks were developed in diagonal direction. The main crack width of the beam was large at the end of the test with the peeling of PALF-epoxy composite plate from the concrete surface as shown in Figure 4.22. The plate had the ability to carry and transfer the load to the region without the plate. Hence the flexural cracks were lesser in the mid span of the beam. The appearance of diagonal shear crack at the left end of the plate was possibly due to the plate end interfacial debonding. The right end of the plate was still bonded to the concrete and hence could withstand more loads.

Figure 4.21: Overview of crack pattern on beam with PALF 2

Figure 4.22: Diagonal shear cracks on the both end sides of the plate

4.3.4.4 Mode of Failure

The mode of failure of beam was observed at the end of the plate. The mode of failure of the control beam and beam strengthened with PALF composite plate were analysed and summarised in Table 4.7.

Table 4.7: Failure mode of beam specimens

Specimen	Failure Mode	Sequence of Failure Mode	Remarks
Control Beam	Flexural	i. Vertical flexural cracks ii. Crushing at compression face	Failure of ordinary RC beam
Beam with PALF	Flexure to Shear	i. Shear cracks ii. Rupture of composite plate	Material Failure

The cracks developed on the control beam were all vertical flexural cracks. The length of cracks increased as the load increased. The width and also the length of the cracks increased as the load increased as shown in Figure 4.23. It was observed there was a little crushing at the mid span top of the beam. The flexural cracks were developed at the middle tension zone of the beam and the greatest crack width developed at the tension face of the beam. It can be said that the failure mode of the control beam was flexural failure.

Figure 4.23: Failure mode of control beam

The cracks developed on the first beam with composite plate, PALF B1 were mainly shear cracks which penetrated the beam in diagonal direction away from the strengthened area. The main cracks developed at both ends of the composite plate and had great crack width at the end of the bending test. The beam failed in shear. At the end of the test, it was observed that the end of the plate had ruptured and debonded from the beam (Figure 4.24) as the adhesive layer was thin. This reduced the bonding or adhesion between the plate and beam. The similar situation happened to the second beam with composite plate, PALF B2. A main shear crack appeared in diagonal direction at the left end side of the plate and penetrated the neutral axis of the beam, followed by great crack width at the tension face of the beam. The beam also failed in shear. At the end of the test, the plate end interfacial debonding occurred due to insufficient adhesion of the plate and the beam (Figure 4.25).

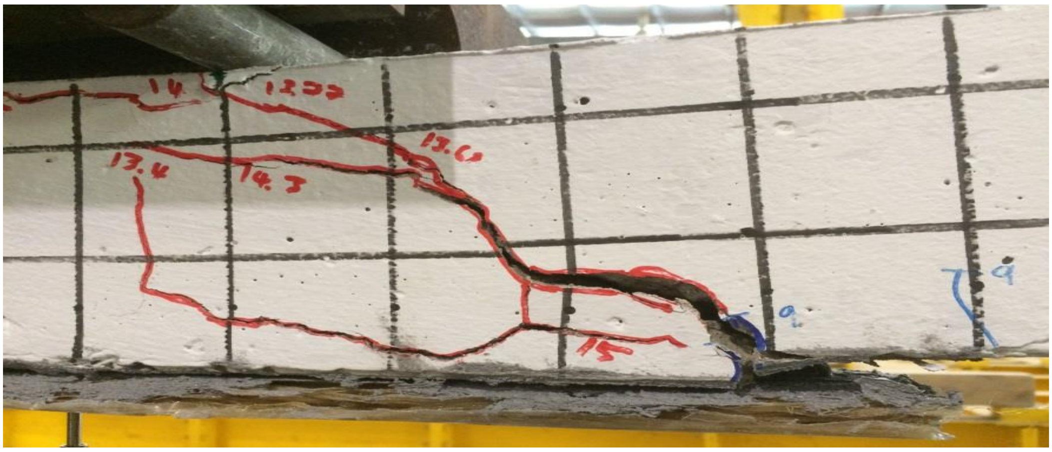


Figure 4.24: The plate end interfacial debonding of PALF B1

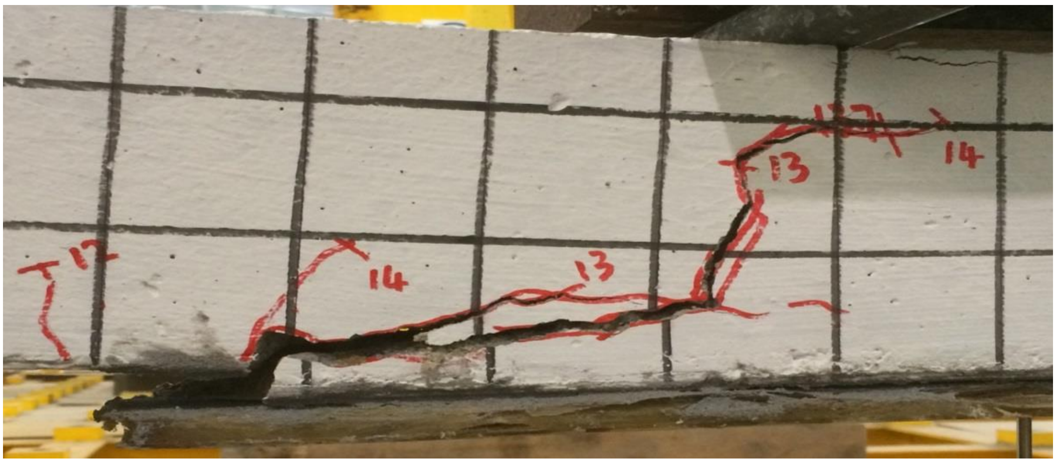


Figure 4.25: The plate end interfacial debonding of PALF B2

CHAPTER 5

CONCLUSION AND RECOMMENDATION

5.1 INTRODUCTION

This chapter discusses the conclusion and recommendation of the research. The research had investigated the structural behaviour of reinforced concrete beam externally strengthened using pineapple leaf fibres (PALF) epoxy composite plate. Recommendations are stated for future research to enhance the understanding towards external strengthening method of reinforced concrete structures using natural fibre composite plate.

5.2 CONCLUSION

Based on the results obtained, the research found that pineapple leaf fibre composite plate is effective to be used as external strengthening material for reinforced concrete beam. The research can be concluded as follows:

i. The increasing of NaOH concentration for alkali treatment of pineapple leaf fibres increase the formation of pores in fibres due to the removal of internal constituents on fibre surface. The formation of pores is the highest in fibres treated with 8% of NaOH. Treated fibres enhance the interfacial adhesion between the matrix and the fibre.
ii. The maximum flexural strength of PALF-epoxy composite plate was obtained at fibre volume ratio of 0.4. The maximum flexural strength of PALF composite plate is 301.94 MPa. The flexural strength of composite 0.4 fibre volume ratio increased 459% as compared to neat epoxy and 19% as compared to 0.3 fibre volume ratio.

iii. PALF-epoxy composite plate is effective to be used as external strengthening material in terms to increase the strength of RC beams. PALF-epoxy composite plate has higher load capacity compared to control beam. Strengthening of PALF-epoxy composite plate has increased the beam strength by 8% as compared to the control beam. The beam strengthened with the plate develops lower deflection by 74% as compared to control beam. In terms of crack patterns, the cracks appeared on the control beam are flexural cracks whereas the cracks on beam with composite plate are shear cracks. Hence, the failure mode of the control beam is flexural failure whereas the failure mode of beam strengthened with the composite plate is flexure to shear failure. The PALF-epoxy composite plate has higher ability to resist tensile stresses in mid-span of beam and reduce the flexural cracks at the region that is strengthened with the plate.

5.3 RECOMMENDATIONS FOR FUTURE RESEARCH

Future works to study the effectiveness of PALF composite plates as strengthening material is still on-going. There are some recommendations for the future research:

i. Application of PALF combination with other polymer such as polyester, polypropylene as external strengthening material.
ii. Fabrication of PALF composite plate with other fabrication method such as press moulding method instead of hand laying method to increase precession of PALF composite plate fabricated.
iii. Research on the effect of PALF-epoxy composite plate thickness to mechanical properties of beam.
iv. Application of PALF composite plate on deep beams, slabs or other RC structures should be considered.
v. Research regarding to repair damaged or cracked beams with PALF composite plate.
vi. Research on the effect of PALF composite plate length to mechanical properties of RC beams, especially the type of failure mode of the composite plate.

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APPENDIX A

CONCRETE MIX DESIGN

PAMIX SDN. BHD. (Company No. 261694-H)
A-9,2nd & 3rd Floor, Pusat Komersial Kuantan perdana,
Jalan Tun Ismail, 25500 Kuantan, Pahang Darul Makmur,
Tel : 09-5172810/2813/2819/2820 Fax : 09 - 5172821/2806

CONCRETE MIX DESIGN COMPUTATION & SUMMARY

Reference Standard : For Specifying Production And Compliance Creteria
(MS523: 1993 / BS 5328 / JKR 20800 - 132 - 23 (Sec D :2005)

1	1.1	Characteristic Strength (**OPC**)	Specified **25 N/mm2 at 28 days** below which 5 % of test results may be expected to fall	
	1.3	Designed Standard Deviation	4.0 N/mm2	
	1.4	Designed Margin	1.64 * = 7.0 N/mm2	
	1.5	Target Mean Strength	**32.0 N / mm2**	
	1.6	Cement Type	OPC	
	1.7	Cement Source	PAHANG CEMENT	
	1.8	Aggregate Type : Coarse	Graded Granite	
		: Fine	Natural / Manufacturing Sand	
	1.9	Free Water / Cement Ratio Specified	0.53	
2	2.1	Specified Slump (**NORMAL**)	**75 +/- 25 mm**	
	2.2	Maximum Aggregate Size	20 mm	
	2.3	Type of Concrete	Ordinary	
	2.4	Free Water Content	160	Kg/m3
3	3.1	Cement Content (**OPC**)	300	Kg/m3
	3.2	Cement Content ( )	-	Kg/m3
	3.3	Maximum Cement Content	-	Kg/m3
	3.4	Minimum Cement Content	-	Kg/m3
4	4.1	Relative Density of Aggregate	2.6	
	4.2	Concrete Density	2306	Kg/m3 (Average)
	4.3	Total Aggregate Content	1846	Kg/m3
5	5.1	Grading of Fine Aggregate	BS 882 C or M Limit	
	5.2	Proportion of Fine Aggregate	44.0%	
	5.3	Fine Aggregate Content	813	Kg/m3
	5.4	Coarse Aggregate Content	1033	Kg/m3

6 6.1 **SUMMARY – NORMAL MIX PER CUBIC METRE**

Mix (Mpa)	Slump (mm)	Cement (OPC) (Kg/m3)	20mm granite (Kg/m3)	Sand (Kg/m3)	Water (Kg/m3)	A/C Ratio	W/C Ratio
25	**75 ± 25**	**300**	**1033**	**813**	**160**	**6.15**	**0.53**

7 **ADMIXTURES**

Mighty 40RA (RETARDAR) at	500	ml / 100 kg of OPC @	**1.5**	lit / m3
Mighty 150M (PLASTICIZER) at	0	ml / 100 kg of OPC @	**0.0**	lit / m3

8 REMARKS **: MIX CODE P254**

Mohd Faisal Bin Ali
Sr. QA/QC Executive

Date : ***07/01/2016***

APPENDIX B

DELIVERY ORDER OF READY MIX CONCRETE

PAMIX SDN BHD (Company No. 261694-H)

OFFICE ADDRESS : A-9, 2nd & 3rd Floor, Pusat Komersial Kuantan Perdana, Jalan Tun Ismail, 25000 Kuantan, Pahang Darul Makmur.

TEL. NO : 09-5172810, 5172813, 5172819, 5172820 FAX NO : 09-5172821

GST NO. : 001201274880

SERIAL NO: C **464692**

PLEASE PLACE ALL ORDER TO :
TEL : 09-5172820
FAX : 09-5172821

Customer :
PAMIX S/B

Delivery Order No. : RMC

Date : 23.02.2016

Account No :

Deliver To :
UMP GAMBANG

Delivery From Plant No : BT 12 JLN GAMBANG

Grade	Max. Aggregate Size (mm)	Specified Slump (mm)	Total Order (Cu. Metre)	This Load (Cu. Metre)	Progress Total (Cu. Metre)
P254A	20MM	75+/-25	1.20	1.20	1.20
	Cement Type O.P.C		Admixture Type 40RA	Water Added At Site (Litres)	0
Truck No.	Driver's Name	Batchers Name	Batching Time	Arrival Time	Time Left
CDK 458	HALIM	ZUL C.A	11:40		

Remarks,

Goods received in accordance with the standard conditions of sale and delivery

Batcher's Signature

Company's stamp and signature

Name : Tan Khye fang

IC No : 920117-07-5172

1. Interest of 1.5% per month shall be charged on any overdue invoices.
2. All cheques must be crossed and drawn to order of Pamix Sdn Bhd.
3. No receipt is valid unless issued on the Company's official receipt.
4. Any discrepancies in this delivery order must be notified to us upon receipt of goods otherwise this delivery order deemed to be in order and accepted as correct.

APPENDIX C

PRODUCT INFORMATION OF EPOXY RESIN DER331

Product Information

D.E.R.™ 331™
Liquid Epoxy Resin

Description

D.E.R.™ 331™ Liquid Epoxy Resin is a liquid reaction product of epichlorohydrin and bisphenol A.

Introduction

D.E.R. 331 Epoxy Resin is the most widely used general purpose liquid epoxy resin. It is recognized as the standard from which many variations have been developed.

A wide variety of curing agents is available to cure liquid epoxy resins at ambient conditions. The most frequently used are aliphatic polyamines, polyamides, amidoamines, cycloaliphatic amines and modified versions of these curing agents. Curing may also be done at an elevated temperature to improve selected properties such as chemical resistance and glass transition temperature. If anhydride or catalytic curing agents are employed, elevated temperature cures are necessary and long post-cures are required to develop full end properties.

Typical Applications

This product is suitable for use in applications such as:

- Adhesives
- Casting and Tooling
- Civil Engineering
- Composites
- Automotive Coatings
- Can and Coil Coatings
- Marine and Protective Coatings
- Photocure Industrial Coatings
- Potting and Encapsulation

Typical Properties

Property(1)	Value	Method
Epoxide Equivalent Weight (g/eq)	182 – 192	ASTM D-1652
Epoxide Percentage (%)	22.4 – 23.6	ASTM D-1652
Epoxide Group Content (mmol/kg)	5200 – 5500	ASTM D-1652
Color (Platinum Cobalt)	75 Max.	ASTM D-1209
Viscosity @ 25°C (mPa*s)	11000 – 14000	ASTM D-445
Hydrolyzable Chloride Content (ppm)	500 Max.	ASTM D-1726
Water Content (ppm)	700 Max.	ASTM E-203
Density @ 25°C (g/ml)	1.16	ASTM D-4052
Epichlorohydrin Content (ppm)	5 Max.	DowM 101321
Shelf Life (Months)	24	

(1) Typical properties, not to be construed as specifications.

APPENDIX D

PRODUCT INFORMATION OF HARDERNER

EPOCHEMIE

An associate company of Yun Teh Industrial Co., Ltd

Product Data Sheet
LIT/0508-905-3S

JOINTMINE 905-3S

INTRODUCTION

JOINTMINE 905-3S is a modified cycloaliphatic amine of low viscosity, low color and room temperature curing agent. It imparts good resistance to abrasion, moisture and chemical resistance. It has also low in toxicity than aliphatic amine and exhibit high gloss film and ideal for solventless free floor coating, self-leveling flooring and tank lining.

CHARACTERISTICS

- Low viscosity and transparent liquid
- Good working pot life
- Good chemical resistance
- High gloss and good color stability

APPLICATIONS

- Self-leveling floor coating
- High solid coating
- Chemical tank coating
- Water resistant tile grout

PACKING

Jointmine 905-3S available in 200kg net per drum

STORAGE CONDITIONS

At least 12 months from the date of manufacture in the original sealed container at ambient temperature. Store away from excessive heat and humidity in tightly closed containers.

SPECIFICATION

Amine value (mg KOH/g)	300 ± 20
Viscosity (BH type @25°C, cPs)	200 ~ 400
Color (Gardner)	<2
Equivalent Wt (H)	95

BASIC FORMULATION

Mix ratio (with EEW=190 epoxy resin) = 50 phr

TYPICAL PROPERTIES

Pot life (100g @25°C)	75 mins
Hardness (Shore D)	85
Thin film set time (@25°C)	5 hours

PHYSICAL PROPERTIES

Compressive Strength (JIS K6911)	1000kg/cm²
Bending Strength (JIS K6911)	800kg/cm²
Tensile Strength (JIS K6911)	700kg/cm²

Epochemie International Pte Ltd., No.1, Woodlands Terrace, Singapore 738471
Tel : 65-67565680 Fax : 65-67560760, email : epochemie@pacific.net.sg