EXTERNAL STRENGTHENING OF REINFORCED CONCRETE BEAMS WITH BAMBOO FIBER-VINYL ESTER COMPOSITE PLATE

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DEDICATION

It is my genuine gratefulness and warmest regards that I dedicate this thesis to my sweet and loving parents:

Lim Leong Hock and Chan Siew Cheng

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ABSTRACT

A research has been conducted to investigate the potential application of natural fiber composite (NFC) fabricated by bamboo fiber embedded with vinyl ester resin matrix (BFRCP) in external strengthening of reinforced concrete (RC) beams. In this study, bamboo fiber were obtained from the Forest Research Institute Malaysia (FRIM) which had been treated with 10% of sodium hydroxide (NaOH) for 48 hours. The bamboo fiber has a density of 0.890 g/cm3. In terms of the composite behaviour, the composite plates were tested for physical properties, mechanical properties and thermal properties. The experimental works that carried out in this study were Fourier Transform Infrared Spectroscopy (FTIR), Flexural Test (ASTM D790-03), Tensile Test (ASTM D3039) and Thermogravimetric Analysis (TGA). The BFRCPs were fabricated with different fiber volume ratio (0 %, 10 %, 20 %, 30 %, 40 %) to determine the optimum ratio to be used in strengthening of the reinforced concrete beams. From the composite result, both maximum flexural strength and tensile strength were obtained at the fibre volume ratio of 40 %. The fiber content of composite samples from 10 % to 40 % increased the flexural strength from 104.7 % to 140.9 % compared to the unreinforced neat vinyl ester. Same goes to tensile test, the tensile strength increased from 111.7 % up to 702.7 % with the increases of fiber volume ratio from 10 % to 40 %. The result of FTIR certify that the chemical compositions such as cellulose, hemicellulose and lignin were present in the composite plate and its function were to enhance the adhesion between the fiber and the matrix. The TGA test revealed that the exact thermal decomposition temperature of bamboo fiber - vinyl ester composites was at 320°C. For the structural behaviour, four-point loading tests was carried out to study the behaviour of the RC solid beams as well as RC beams with circular openings. The study shows that the strength of the beam strengthened with bamboo fiber - vinyl ester composite plate increased by 2.0 % in RC solid beam and 77.8 % in RC beam with circular opening when compared to the un-strengthened beams. In the case of cracks, the bamboo fiber-vinyl ester composite plate had diverted the cracks to appear on the edge of the plate for RC solid beam and minimal the propagation of diagonal cracks were traced in RC beam with circular openings. Therefore, it is concluded that the bamboo fiber-vinyl ester composite plate is effectively to be used as an external strengthening material for strengthening of RC beams.

ABSTRAK

Satu kajian telah dijalankan untuk mengenai potensi penggunaan komposit yang diperbuat daripada gentian buluh sebagai gentian semula jadi baru bersama matriks resin vinil ester (BFRCP). Dalam kajian ini, gentian buluh diperoleh dari pihak Institut Penyelidikan Perhutanan Malaysia (FRIM) yang telah dirawat dengan 10% natrium hidroksida (NaOH) dalam masa 48 jam. Gentian buluh mempunyai ketumpatan 0.890 g/cm3. Plat komposit telah diuji dalam segi fizikal, mekanikal dan haba. Kerja-kerja ujikaji yang dijalankan dalam kajian ini adalah Fourier Transform Infra-Merah Spektroskopi (FTIR), Ujian Lenturan (ASTM D790-03), Ujian Tegangan (ASTM D3039) dan Thermogravimetric Analisis (TGA). BFRCPs telah difabrikasi dengan nisbah isipadu gentian yang berbeza (0%, 10%, 20%, 30%, 40%) bagi menentukan nisbah optimum untuk digunakan dalam mengukuhkan rasuk konkrit. Kedua-dua maksimum kekuatan lenturan dan kekuatan tegangan telah diperolehi pada nisbah isipadu gentian 40%. Kandungan serat sampel komposit dari 10% ke 40% telah meningkatkan kekuatan lentur dari 104.7% sehingga 140.9%. Begitu juga dengan ujian tegangan, kekuatan tegangan meningkat dari 111.7% sehingga 702.7% dengan peningkatan nisbah serat sampel dari 10% ke 40%. Keputusan FTIR mengesahkan bahawa kandungan kimia seperti selulosa, hemicellulose dan lignin turut hadir pada plat komposit dan fungsinya adalah untuk meningkatkan lekatan di antara gentian dan matriks. Ujian TGA mendedahkan tepat penguraian haba suhu serat buluh – vinil ester adalah pada 320° C. Ujian empat mata titik beban telah dijalankan untuk mengkaji kelakuan rasuk konkrit pepejal serta rasuk konkrit bukaan bulat. Kajian mendapati bahawa kekuatan rasuk yang diperkuatkan dengan serat buluh - vinil ester plat komposit meningkatkan sebanyak 2.0% pada rasuk konkrit pepejal dan 77.8% pada rasuk konkrit dengan bukaan bulat. Dalam pemerhatian retak, buluh gentian-vinil ester plat komposit telah mengalihkan retak untuk muncul di pinggir plat komposir pada rasuk konkrit pepejal dan memperlahankan penyebaran retak pada rasuk konkrit dengan bukaan bulat. Oleh itu, ia membuat kesimpulan bahawa buluh gentian-vinil ester plat komposit adalah berkesan untuk digunakan sebagai bahan pengukuhan luaran untuk memulihan rasuk konkrit.

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LIST OF SYMBOLS

%	Percentage
N	Newton
mm	Millimeter
N/mm^2	Newton per millimetre square
g/cm^3	Gram per centimetre cube
mL	Milliliter
N	Newton
kN	Kilo Newton
°C	Degree Celsius
g	Gram
mm/min	Millimetre per minutes
mm^2	Millimeter square
MPa	Mega Pascal
a/d	Shear span-to-depth ratio
d	Distance from the support (mm)
l/h	Span-to-depth ratio

LIST OF ABBREVIATIONS

BFRCP	Bamboo Fiber Reinforced Composite Plate
ASTM	American Society for Testing and Materials
BS	British Standard
CFRP	Carbon fiber reinforced plate
FRP	Fiber reinforced plate
LVDT	Linear Variable Differential Transducer
NaOH	Sodium hydroxide
NFRC	Natural fiber reinforce composite
RC	Reinforced concrete
FTIR	Fourier Transform Infrared Spectroscopy
TGA	Thermogravimetric Analysis
UTM	Universal Testing Machine

CHAPTER 1

INTRODUCTION

1.1 RESEARCH BACKGROUND

Fiber reinforced composite plate (FRCP) also known as fiber-reinforced polymer (FRP), can be defined as a combination of two or more constituent materials when combined yield a material with unique properties. The two main constituents are high strength fiber reinforcement and polymer matrix. Its microstructure formation and its composition are primarily affecting the physical and mechanical properties of the fabricated composite plate (Gurunathan et al., 2015). The polymer matrix acts as a stress distributor in the composite to transfers the load while the fiber is dedicated to the stiffness and strength properties. In the past, the use of synthetic fibers such as aramid, glass and carbon have been widely accepted due to their excellent mechanical properties and superior strength-to-weight ratio. Therefore, it has become a promising choice of external strengthening material, particularly in construction industry. However, the problem of synthetic fiber does not address the life cycle sustainability issue. Hence, an alternative use of natural fiber reinforcements has been of interest in a wide variety of applications as their properties can be comparable with the synthetic composites.

Bamboo as Asia's abundant agriculture resources, is one of the advantages of using bamboo fiber as a reinforcing material and its mechanical properties are comparable with steel. Bamboo is a high-intensity orthotropic material along the axial and low-intensity transversal to its fibers. The structure of the bamboo itself is a composite material consisting of long and aligned cellulose fibers immersed in a ligneous matrix. On the basis of earlier reports, bamboo has 60% of cellulose with moderate content of lignin approximately 32% and its micro-fibrillar angle is 2°–10°, which is relatively small. This feature makes the bamboo fiber suitable to be used as fiber reinforcement in a variety of matrix (Tong et al., 2017).

A matrix acts as a binding material which binds the fiber reinforcement together. The matrix can be divided into two types, namely thermoplastics and thermosetting. Thermoplastics are also known as amorphous polymers have special characteristics which can remodel the cured plastic by repeating the heating and cooling process without affecting the configuration of their molecular structure within the temperature range. While the thermosetting polymers are not able to re-hot deformable due to the difficulty in reforming. Most structural engineering applications used thermosetting plastics for applications as the thermosetting plastics are more advance over thermoplastics if they are compared to both. The functional of thermosetting properties included excellent thermal stability at the service temperature, showing low creep, good chemical resistance and relaxation properties. In the fabrication of composite plate, types of thermosetting resins that usually use are: epoxy resin, polyester resin and vinyl esters resin (Das & Nizam, 2014). In this study, vinyl ester was used as the matrix to fabricate the bamboo fiber reinforced composite plate.

Instead of rebuilding after dismantling, most buildings prefer the use of FRP in external enhance due to its high strength, light weight, easy to use and so on. Bamboo fiber with high specific strength, value, light weight and non-hazardous are the attractive features of this material. Therefore, it is possible to reveal the potential use of bamboo fiber-based composites in replacing the non-renewable and costly synthetic fibres.

1.2 PROBLEM STATEMENT

Synthetic fiber reinforcements such as glass, carbon and aramid provided high stiffness and strength-to-weight ratio compared to traditional building materials, such as wood, concrete and steel (Dong et al., 2013). Despite these advantages, the widespread use of synthetic fiber-reinforced polymer-based composites tends to be reduced due to their high initial cost and most importantly, their adverse effects on the environment.

The production of synthetic fiber consumed enormous energy that needed in various stages. Thus, there is an overhead of huge cost. Other than that, the significant amount of carbon dioxide (CO_2) was emitted from manufacturing process. The global warming associated with emission of greenhouse gas and contamination caused by the plastic wastes are among the most serious environmental issues. Hence, the surge of synthetic fiber composite and continuously to threaten the environment, have leads to the development of natural renewable materials and the use of polymer composites.

Natural fiber reinforced composites (NFRC) as a replacement for glass or carbon reinforced polymer composites have recently received considerable attention. Through the different experimental study on mechanical properties of natural fibers, kenaf fiber was considered to be the highest tensile strength of natural fibres (Ku et al., 2011). Natural fibers are non-hazardous, biodegradable and economical in the manufacturing process compared to synthetic fibers. In addition, natural fibers with low density and high specific properties make it better than those of traditional reinforcements. Therefore, the growing concern of the ecological issues and renewable environmentally friendly products in community caused the consideration of using natural bamboo fiber as an alternative material in the polymer fiber composite to replace carbon fiber and glass fiber.

1.3 RESEARCH OBJECTIVES

The aim of this research was to determine the potential use of environmental friendly composite made by bamboo fiber embedded with vinyl ester polymer matrix in external strengthening of reinforced concrete beams. The knowledge gap in the literature review has helped us to set the objectives of this research work as follows:

i. To determine the physical, mechanical and thermal properties of bamboo fibre - vinyl ester composites plate.
ii. To determine the behaviour of RC solid beams both strengthened and un-strengthened with the bamboo fiber- vinyl ester composite plate in terms of load-deflection behaviour, cracks pattern and failure mode.
iii. To determine the behaviour of RC beams with circular openings both strengthened and un-strengthened with the bamboo fiber- vinyl ester composite plate in terms of load-deflection behaviour, cracks pattern and failure mode.

1.4 SCOPE OF STUDY

The bamboo used in this study was grown locally in our own country, Malaysia. For chemical extraction, the preferred concentration of alkaline solution for bamboo treatment was 10% of sodium hydroxide (NaOH) for about 48 hours.

In order to study the effect of bamboo fiber- vinyl ester composite plate on different fiber volume ratios (0 %, 10 %, 20 %, 30 %, 40 %, 50 %), several experiments such as Fourier Transform Infrared Spectroscopy (FTIR), Tensile Test (ASTM D790-03), Flexural Test (ASTM D3039), Thermogravimetric Analysis (TGA) were performed. The ideal volume ratio of BFRCP with optimum strength were then to be used in strengthening RC beams.

All the reinforced concrete beams are of the same size, with a cross-section width of 120 mm, a depth of 300 mm and a length of 1500 mm. All the beams were cast simultaneously with high-strength pre-mixed concrete targeted compressive strength of 30 MPa at 28 days. Main bar with a diameter of 10 mm and shear link of diameter 6 mm were mainly used for all cases involved in this experiment.

Two sets of RC beams were cast in this research. In SET I, three RC solid beams were cast which included one controlled beam and two beams weak in flexural were then be un-strengthened and strengthened with the bamboo fiber-vinyl ester composite plate in the mid-span zone. In SET II, three RC beams with circular openings were cast in which one was controlled beam and two beams weak in shear were then be un-strengthened and strengthened with the bamboo fiber-vinyl ester composite plate on the shear surface of the beam perpendicular to the diagonal crack.

For the reinforced concrete beams with opening, all the specimens have two openings, which is one in each middle of shear span except for the control beam. The shape and size of the opening were in circular with a diameter of 120 mm.

During the four-point loading test, a simply supported method was applied at the bottom part of beams from the end of both sides with a distance of 100 mm while at the same time, two loading points were added to the top of the beams by 500 mm apart from each point. The load-deflection behaviour, cracks pattern and failure mode of the beams were observed and discussed in the following chapter.

1.5 RESEARCH SIGNIFICANCE

The increase in environmental concerns has leads to an interest in replacing synthetis fiber with natural fiber as an alternative in RC beams strengthening purpose. The production of synthetic fiber caused negative impact to the human body and the environment while derived of natural fibers from renewable resources do not require a lot of energy to deal with and it is totally biodegradable.

The study also intends to investigate the potential use of this method as a structural engineering solution to improve the bending performance of reinforced concrete beams. Besides, beams with opening will always reduce the ultimate strength from the original by 50 %. In order to solve this problem, it is possible to restrict stress distributed on the beams using bamboo fiber-vinyl ester composite plate (BFRCP) due to the openings in web.

Hence, the importance of this research contributed experimental result and evidences about the behaviour of solid RC beams and RC beam with circular opening strengthened with BFRCP in term of load-deflection, cracks pattern and failure mode tends to prove the effectiveness use of BFRCP in strengthening purpose.

In addition, natural fibers with low density and high specific properties make it better than those of traditional reinforcements. Therefore, the inherent characteristics of natural fibers can meet the requirements of the global market, especially in weight reduction concerned by industries. Natural fiber can be potentially replace the non-renewable synthetic fibers.

CHAPTER 2

LITERATURE REVIEW

2.1 INTRODUCTION

In this chapter, summary gaps were determined from the previous research. The method of strengthening and improving the performance of natural fiber composite plate with different types of natural fibers is proposed.

2.2 NATURAL FIBER

Fibers are classified into natural and man-made fibers. Natural fibers are divided into three types based on their origin which from plants, animals and minerals. Plant fibers are divided into six types (bast, leaf, seed, straw, grass and wood). These fibers can be in the form of hairs (cotton, kapok), hard fibres (coir, sisal), and fibre sheaves (flax, hemp, jute). Plant fiber is classified according to its utility such as primary and secondary. Plants to be used as fibres for primary utilities include hemp, jute and kenaf while the byproducts of plants such as coir and pineapple are belong to the secondary group (Faruk et al. 2012). Figure 2.1 shows the fiber classification chart.

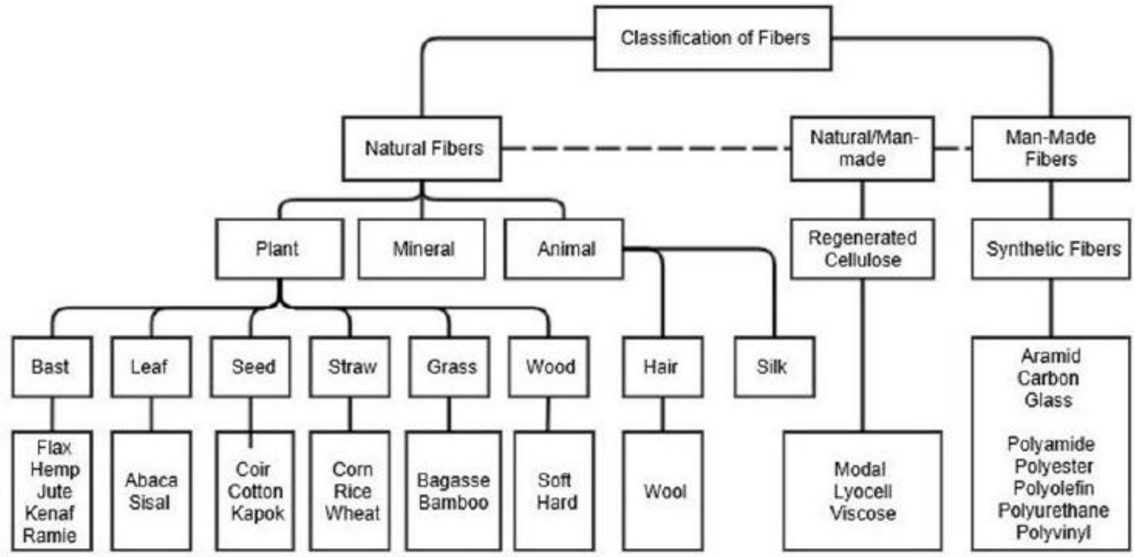

Figure 2.1: Fiber classification chart

Source: Ramamoorthy et al.(2015).

In plant fiber, lignocellulose (cellulose, hemicellulose and lignin) is the main chemical composition that partially determine the physical properties of the fibres. The amount of these components are differ from plant to plant. Cellulose is the strongest and stiffest component of the fibre. The enhancement efficiency of the composite plate was greatly contributed by cellulose content. It means that, natural fibers with higher cellulose content have a better mechanical properties as well as load carrying capacity. From the Figure 2.2 and Figure 2.3, pineapple fiber gives a higher cellulose content and mechanical properties than the others. Owing to low density, low cost, renewability and sustainability of natural fibres, these fibres are preferred reinforcements in several applications (Ramamoorthy et al. 2015).

Fibre	Cellulose (wt%)	Lignin (wt%)	Hemicellulose (wt%)	Wax (wt%)
Bast				
Flax	71.0	2.2	18.6 – 20.6	1.7
Hemp	70.2 – 74.4	3.7 – 5.7	17.9 – 22.4	0.8
Jute	61.0 – 71.5	12.0 – 13.0	13.6 – 20.4	0.5
Kenaf	31.0 – 39.0	15.0 – 19.0	21.5	–
Ramie	68.6 – 76.2	0.6 – 0.7	13.1 – 16.7	0.3
Leaf				
Abaca	56.0 – 63.0	7.0 – 9.0	20.0 – 25.0	3.0
Curaua	73.6	7.5	9.9	–
Henequen	77.6	13.1	4.0 – 8.0	–
Pineapple	70.0 – 82.0	5.0 – 12.0	–	–
Sisal	67.0 – 78.0	8.0 – 11.0	10.0 – 14.2	2.0
Seed/Fruit				
Coir	36.0 – 43.0	41.0 – 45.0	0.15 – 0.25	–
Cotton	82.7	–	5.7	0.6
Oil Palm	65.0	–	29.0	–
Grass				
Bagasse	55.2	25.3	16.8	–
Bamboo	26.0 – 43.0	21.0 – 31.0	30.0	–
Straw				
Rice	41.0 – 57.0	8.0 – 19.0	33.0	8.0 – 38.0
Wheat	39.0 – 45.0	13.0 – 20.0	15.0 – 31.0	–
Others				
Rice Husk	35.0 – 45.0	20.0	19.0 – 25.0	14.0 – 17.0

Figure 2.2: Chemical composition of natural fibres

Source: Ramamoorthy et al. (2015)

Fibre	Density (g/cm^3)	Tensile Strength (MPa)	E-Modulus (GPa)	Elongation at break (%)
Bast				
Flax	1.5	345 – 1100	27.6	2.7 – 3.2
Hemp	–	690	30 – 60	1.6
Jute	1.3 – 1.4	393 – 773	13.0 – 26.5	1.2 – 1.5
Kenaf	–	930	53.0	1.6
Ramie	1.5	400 – 938	61.4 – 128.0	1.2 – 3.8
Leaf				
Abaca	1.5	400	12.0	3.0 – 10.0
Curaua	1.4	500 – 1150	11.8	3.7 – 4.3
Pineapple	–	413 – 1627	34.5 – 82.5	1.6
Sisal	1.4	468 – 640	9.4 – 22.0	3.0 – 7.0
Seed/Fruit				
Coir	1.1	131 – 175	4.0 – 6.0	15.0 – 40
Cotton	1.5 – 1.6	287 – 800	5.5 – 12.6	7.0 – 8.0
Oil Palm	0.7 – 1.55	248	3.2	25.0
Grass				
Bagasse	1.25	290	17	–
Bamboo	0.6 – 1.1	140 – 230	11 – 17	–

Figure 2.3: Physical and mechanical properties of natural fibres

Source: Ramamoorthy et al. (2015)

2.2.1 Bamboo Fiber

Bamboo, generally common in Asian countries, yet has not been extensively investigated by researchers. It is a long fleshy plant which technically comes under grass family but the appearance is never like grass. It is soft towards the centre and hard towards its periphery. It is mainly planted in Asian countries and constitutes about 65% of the total bamboo resources found in the world. Globally, the area occupied by bamboo is expected to be 36 million hectares or an average of 3.2 percent of the total forest area if bamboo outside forest area is included. Out of these 36 million hectares, 24 million hectares of bamboo forest, constituting about 4.4 percent of the total forest area are occupied in Asia itself (Lobovikov et al., 2007).

Roslan et al., (2015) found out that the high strength of bamboo in fiber direction is due to the longitudinally alignment of its fiber to its body while at the same time this is attributed by its polylamelate wall structure that consists of alternating broad and narrow layers with different fibrillary orientation. Furthermore, high cellulose and lignin content and relatively small micro-fibril angle of bamboo plant contribute to this high strength of bamboo fiber.

Table 2.1: Comparison of the physical and mechanical properties in natural fibers

Natural Fiber	Density(g/cm^3)	Ash(%)	Lignin(%)	Pentosans(%)	Cellulose(%)	Tensile Strength(Mpa)
Banana	1.35	-	5	-	65	500
Rice Husk	7	17	20	-	35	7
Kenaf	1.45	2-5	15-19	22-23	44-57	930
Sugarcane	1.25	-	15	25	55	290
Palm Oil	1.45	-	19	-	65	200-250
Bamboo	0.6-1.1	1.7-5	21-31	15-26	26-43	140-230

Sources: John and Anandjiwala (2008); Mathew et.al. (2006)

Bamboo fibers are often referred to as natural glass fibers because their high strength relative to their weight comes from longitudinally aligned fibers in their bodies (Okubo et. al., 2004). The attractive properties of bamboo in which the tensile strength of bamboo is relatively high and can reach 370 MPa that makes it to become as an alternative to steel in tensile loading (Thwe et.al., 2003).

Mechanical analysis is the behaviour of materials under load. The mechanical properties provided mainly by the cellulose content are influenced by many factors such as fiber length, fibers volume fraction, fiber aspect ratio, fiber-matrix adhesion or fiber configuration. Several papers have been published on the study of bamboo fiber reinforced composites reported that mechanical properties of bamboo vary because of the different testing methods used and the samples tested (Vasoya et.al., 2007).

Navdeep et al., (2015) investigated seven different fiber reinforcement polymer composites were fabricated by hand layup method using short coconut, short bamboo and short glass fiber binding with urea formaldehyde. The different mechanical properties like density, tensile strength, hardness, flexural strength and percentage elongation of specimens were calculated and compare with pure urea formaldehyde resin. Tensile strength of composites is increases with 20 wt% of glass fiber. Flexural strength is increases with 10 wt% of bamboo fiber. The percentage elongation was increases in 20 wt% of coconut.

Krishnaprasad et al., (2009) studied the effect of microfibrils loading to the composite behaviour. Composite materials based on hydroxybutyrate (PHB) and bamboo microfibers were prepared with various microfibre loads. It was found that the tensile strength and impact strength of the composites increased with the increases of the loading of the bamboo microfibers, and then decrease with the further increase of microfiber loading.

Table 2.2: Mechanical properties of PHB and its composites with bamboo microfibrils.

Sample	**Impact Strength (kg/m^2)**	**Tensile Strength (Mpa)**	**Elongation at break (%)**	**Young Modulus (Mpa)**
PHB pure	593	10.90	1.94	1044
PHB 5	953	9.73	2.28	1256
PHB 10	991	11.05	2.25	1388
PHB 20	748	12.05	1.70	1824
PHB 30	510	11.17	0.96	2165

Source: Krishnaprasad et. al., (2009)

2.3 Fiber Surface Treatments

Natural fibers are usually treated before being used as a reinforcing material for composites. This is mainly to improve the compatibility between the fiber and the matrix by removing the impurities and reducing the fiber hydrophilicity. The interfacial properties between the fiber and the resin play an important role in the mechanical properties of the fiber composite. Cellulose fibers which are polar make it to absorb moisture easily as hydroxyl groups interact with water molecules through hydrogen bonding. Adhesive properties of hydrophobic non-polar matrices due to the hydrophilic nature of the cellulosic fibres led to poor fiber matrix interface and poor composite properties (Mohanty et al. 2005). Waxy substances and other impurities on the fiber surface contribute to poor surface wetting and also affect the fiber matrix bonding, as a strong fiber matrix interface is important for good composite mechanical properties (Mohanty et al. 2001).

Through chemical modification, the hydroxyl groups in the fiber can also be activated and introduce new groups that can interact with the matrix. Treatment that are commonly to be used to improve the reinforcement potential of cellulosic fibres will be alkali treatment and silane treatment.

Table 2.3: Fiber Surface Treatment Methods

Technique	**Characterization**
Alkali treatment	Usually suitable only for short fibers as short fiber with large total surface area can only easily to react with NaOH solution. The fibers will be soaked in NaOH solution for about 3 to 4 hours. The fibers are then washed repeatedly to remove residue of NaOH on fiber surface and dried in an oven.
Silane treatment	In this method, silane functioned to improve the fiber surface quality by chemically reacted with the hydroxyl groups in fiber. The fiber is immersed in a 3: 2 alcohol aqueous solution with pH $\approx$ 4 about 2 hours. It then dried with oven after flushing with water.

Source: Mantia and Morreale (2011)

2.3.1 Alkaline Treatment

Alkali treatment, also known as mercerizing process, is one of the most commonly used chemical treatments for natural fibers. It is a simple chemical treatment, coupled with an effective low-cost process and minimal environmental effects in modifying the surface of the fiber by destroying the internal hydrogen bonds to create roughness surface. The crystallinity, unit cell structure and orientation of fibrils will change through the treatment process (Colom and Carrillo 2002). This alkaline treatment was able to eliminate large amounts of hemicellulose, lignin, wax and oil on the outer fiber surface. Added aqueous NaOH to natural fiber will ionized hydroxyl group to alkoxide natural fibers (Gurunathan et al., 2015). The process of alkali treatment improved the tensile strength properties of natural fiber due to the stronger bonding properties between the fibers and the matrix (Nitta et al., 2013)

The tensile properties of sisal fibers after alkali treatments are shown in Table 2.4. Several authors have succeeded in enhancing the mechanical and chemical properties of natural fiber reinforced composites by alkaline treatment. (Valadez-Gonzalez et al. 1999; Mwaikambo and Ansell 2002; Alvarez et al. 2003). Alkali treatment changes the surface morphology and crystalline structure. Increasing surface roughness in fiber may improve the interlocking resistance with resin, thereby enhancing the properties of the composite material through the strong fiber matrix bonding.

Table 2.4: Alkali effect on tensile properties of sisal fibre

Treatment	Tensile strength (g/tex)	Young's Modulus ($x10^3$ /tex)	Elongation (%)
Untreated	30.7	1.18	2.5
Alkaline	31.7	0.53	7.5
Alkaline + thermal	27.6	0.70	4.7
Acetic acid + alkaline	9.3	0.39	2.6

Source: Yang et al. (1996)

2.4 THERMOPLASTIC AND THERMOSET

Thermosets cured by chemical reaction when cross-linking molecules form strong bonds. The curing is not reversible and the production of thermosetting material are heat-resistant, solvent resistance and good toughness. Thermoset plastic composites superior over thermoplastic, because it has a high mechanical strength. Uncured thermoset resin will be in liquid form, and their viscosity lower than thermoplastic which makes production of composite to be easy with a variety of processing methods on room temperature. Unsaturated polyester, vinyl ester and epoxy resins are the thermosetting materials that commonly used in composite applications. Among these, epoxy resins are more severe and have better chemical and temperature resistance than unsaturated polyester resins. Therefore, epoxy is commonly used in high performance applications such as aircraft, boats and wind turbine blades (Meier et al. 2007).

Thermoplastics are solid at room temperature. Above the melting points, they melt and can be remolded or recycled. In this process there are no chemical reactions, and only a change in the physical state of the polymer. These plastics cannot be used for high temperature applications, because the polymer will soften when heated. They are also vulnerable to the influence of high pressure. Most commonly used thermoplastic in composite materials are based on non-renewable resources, namely, polypropylene, polyamide, and so on. Plastics from renewable sources such as polylactic acid has recently been discovered for large-scale commercial non-composite applications.

2.4.1 Vinyl Ester

Vinyl ester resin with density of 1.05 g/cm3, is becoming increasingly important for fiber reinforced composites (Vignesh. M et al., 2014). Vinyl ester is one of the preferred resins for the production of FRP plates when the hand laying method is selected. Good adhesion characteristics of vinyl esters and room temperature curing have been the advantages of vinyl ester compared to others. They combine the excellent mechanical, chemical, solvent resistant in epoxy resins with properties found in unsaturated polyester resins. Figure 2.4 shows the chemical structure of the vinyl ester resin.

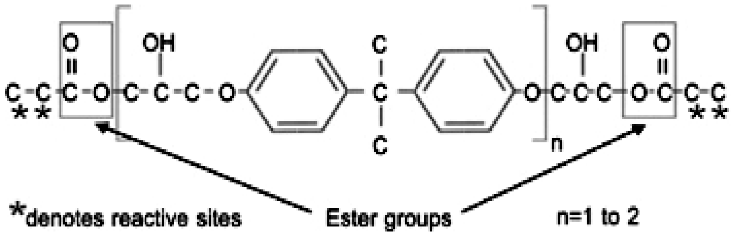

Figure 2.4: Chemical structure bonding of vinyl ester

Source: Vignesh. M et al. (2014)

Epoxy properties are better than vinyl esters and polyesters if three common types of resins are compared. However, the other two resin types are more economical than epoxy resins (Das & Nizam, 2014). Figure 2.5 shows the comparison of the stress versus strain. The results show that the highest yield point and load capacity belong to the epoxy.

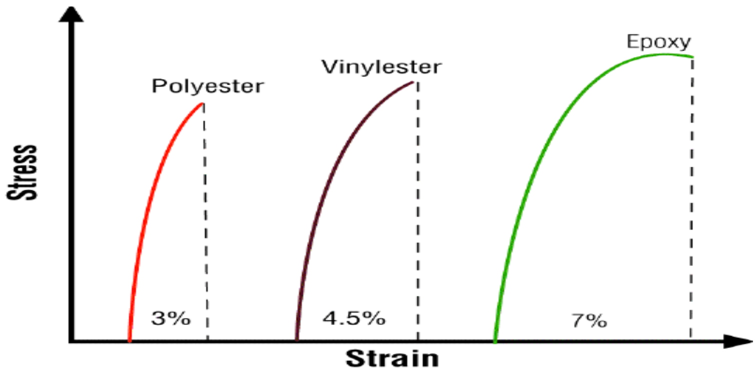

Figure 2.5: Comparison of stress versus strain

Source: Das & Nizam, (2014)

2.5 NATURAL FIBER REINFORCED COMPOSITE (NFRC)

At the request of environmental safety, several natural fiber reinforced polymer composites (NFPCs) had brought into the competitive market. Compared with synthetic fiber composites, NFPC provides a wide range of advantages. These advantages include high strength to weight ratio, high temperature strength and high creep resistance and high toughness (May-Pat et al., 2013). These advantages can also be its light weight, high durability and design flexibility.

Shalwan et al. (2013) found that in order to obtain excellent performance of fiber reinforcement composite, the main factor will be the composite used. NFPCs with jute fibers are added in PLA (polylactic-acid) shown better mechanical properties for about 75.8% of tensile strength than a pure matrix in this case. However, a negative impact in 16% reduced tensile strength showed with additional of flax fibers. In contrast, PP composites improved strength with the combination of hemp, kenaf and cotton.

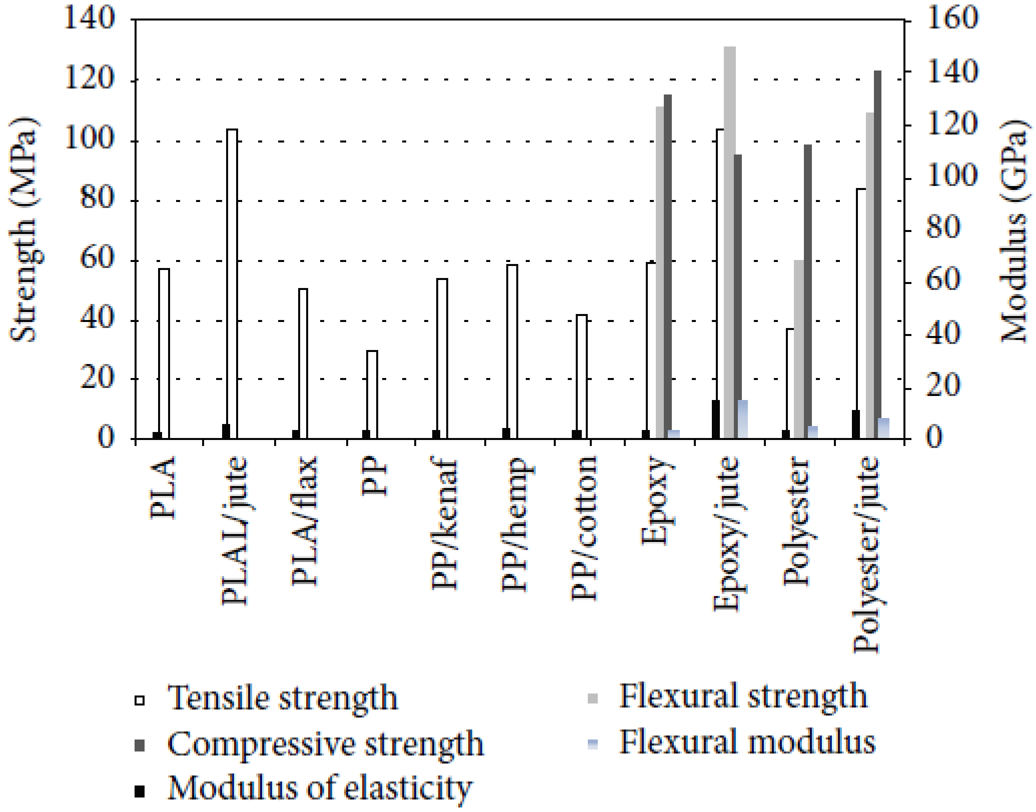

Figure 2.6: Comparison for excellent performance of natural fiber composite (NFC)

Source: Shalwan et al. (2013)

2.6 FIBER VOLUME RATIO

The fiber volume fraction is the percentage of fiber volume in a fixed volume of fiber reinforced composite which means when load increases fiber, resin matrix reduction in weight. For example, if the fiber composite plate filled with 20% of fiber loading, then the polymer resin was filled the remainder of 80%. Mechanical properties of natural fiber composite plate under the influence of fiber content percentage. The mechanical properties increased with the increasing of fiber loading due to the increasing of cellulose content in the NFRC.

According to Dilli et al. (2014), the maximum fiber loading content for Calotropis gigantea fruit fiber occurred with 0.35 volume fraction of fiber. Figure 2.7 shows the result of testing bio-composite plate with variation of 0.5 volume fraction for each sample. Referring to the figure, reinforced polyester performed better than unreinforced polyester. Tensile strength increases with the increase of fiber volume fraction.

However, different fiber types affect the result of optimum fiber fraction content in natural fiber composite plate. Snake glass fiber has the optimum volume fraction of fiber for 0.25 (Sathishkumar et al., 2012) while pineapple leaves fiber optimum fiber loading content of 0.30 shows the best result compared to other variation (Kasim et al., 2015).

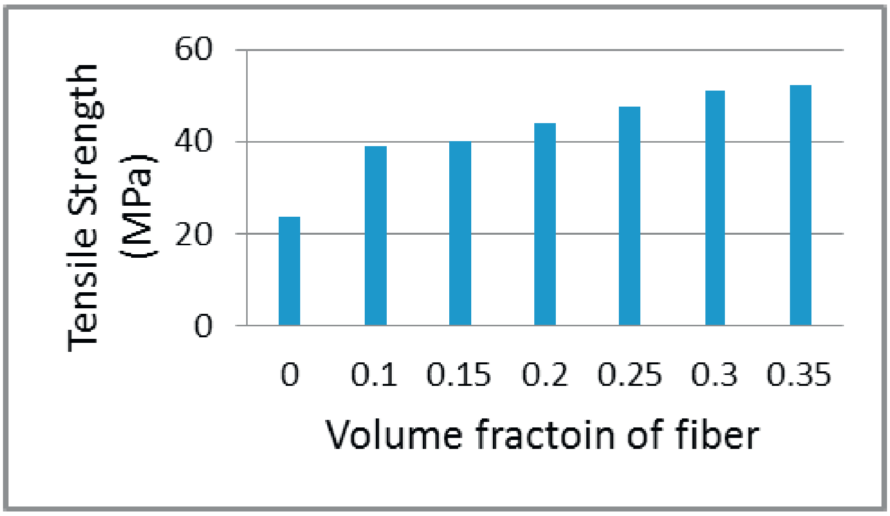

Figure 2.7: Effect of volume fraction of fiber towards tensile strength in composite plate.

Source: Dilli et al. (2014)

2.7 MECHANICAL PROPERTIES TEST

The mechanical analysis is to study the behaviour of the material under applied load. In this research, the samples were fabricated according to ASTM standard and performed two of the mechanical test:

i. Flexural test on fiber plate (ASTM 790-03)
ii. Tensile test on fiber plate (ASTM 3039)

2.7.1 FLEXURAL TEST ON FIBER PLATE (ASTM 790-03)

Five identical samples were prepared for each volume fraction of fibre according ASTM D 790 M-86 with the dimension of 25 mm x 3 mm and length 100 mm to test under three point loading test (Prasad and Rao , 2011).

In this present study, it is observed that the flexural strength of all fiber reinforced composites increases with the increase in fiber volume ratio. The results shown that jowar fiber can have better strength once the fiber volume ratio beyond 0.34 due to stronger bonding of jowar fibre with polyester matrix. The flexural strength of jowar fibre composite is 35% and 4% higher than those of sisal and bamboo composites, respectively at this volume fraction of fibre (Prasad and Rao,2011). The great properties in jowar fiber composites makes it have also been compared with those of hemp and kenaf fiber polyester composites from the literature (Sarifah and Martin, 2004) Ultimate flexural strength and modulus of of fibers at 0.4 volume fraction are listed in Table 2.4 for comparison. While Figure 2.8 indicated the effect of volume fraction of fibre on mean flexural strength for fibers.

Table 2.4: Flexural Properties of fibers at 0.4 volume fraction of fiber.

Composite	Volume Fraction	Ultimate Flexural Strength (MPa)	Flexural Modulus (Gpa)
Plain Polyester	0.00	55.08	1.54
Jowar	0.41	134.00	7.87
Sisal	0.40	99.50	2.49
Bamboo	0.40	128.50	3.70

Source: Prasad and Rao (2011)

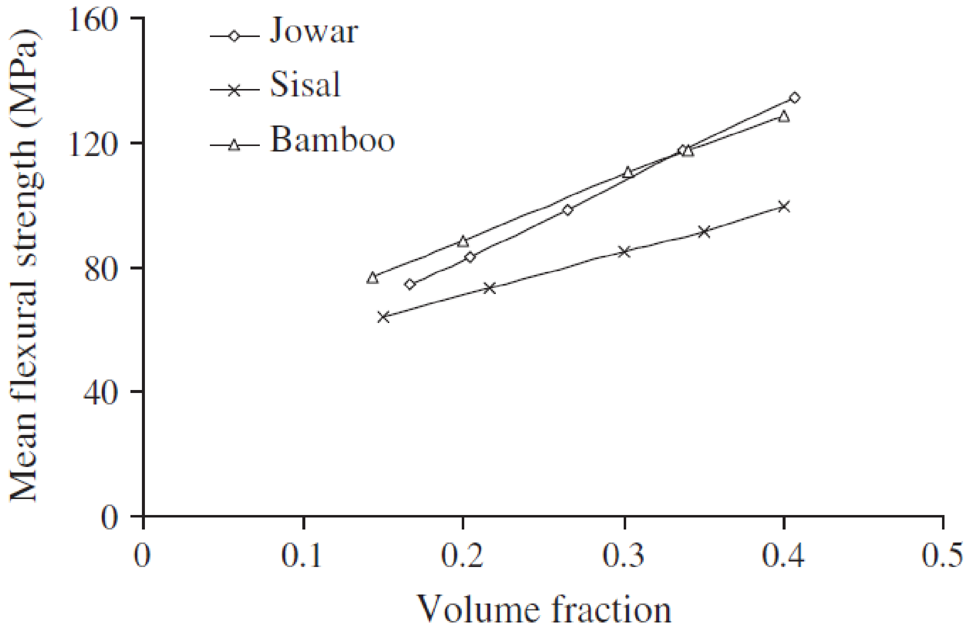

Figure 2.8: Effect of volume fraction of fibre for Jowar fibre reinforced composites in comparison to sisal and bamboo fibre composites in flexural test.

Source: Prasad and Rao (2011)

2.7.2 TENSILE TEST ON FIBER PLATE (ASTM 3039)

Table 2.5 lists the ultimate tensile strength and modulus of three different fiber types at 0.40 volume fraction of fibre while Figure 2.9 shows the mean tensile strength of three fibers with different volume fraction of fibre for jowar fibre reinforced composites in comparison to sisal and bamboo fibre composites. Unidirectional composite samples were fabricated according to ASTM D 638-89 with a dimension of 12.5 mm x 3 mm, length 160 mm to measure the tensile properties (Prasad and Rao, 2011).

In this study, the researcher shown that the tensile strength of fiber composites increased in the sequence of sisal jowar and bamboo with the increasing of fiber volume fraction. The tensile strength of jowar is almost equal to bamboo's tensile strength when increasing the fiber volume fraction and it is about 2 times strength of sisal. However, in this research, it shows that bamboo fiber composite has the highest tensile strength compared to jowar, sisal and plain polyester composite.

Table 2.5: Tensile Properties of fibers at 0.4 volume fraction of fiber.

Composite	Volume Fraction	Ultimate Tensile Strength (MPa)	Tensile Modulus (Gpa)
Plain Polyester	0.00	31.5	0.63
Jowar	0.40	124.0	2.75
Sisal	0.40	65.5	1.90
Bamboo	0.40	126.2	2.48

Source: Prasad and Rao (2011)

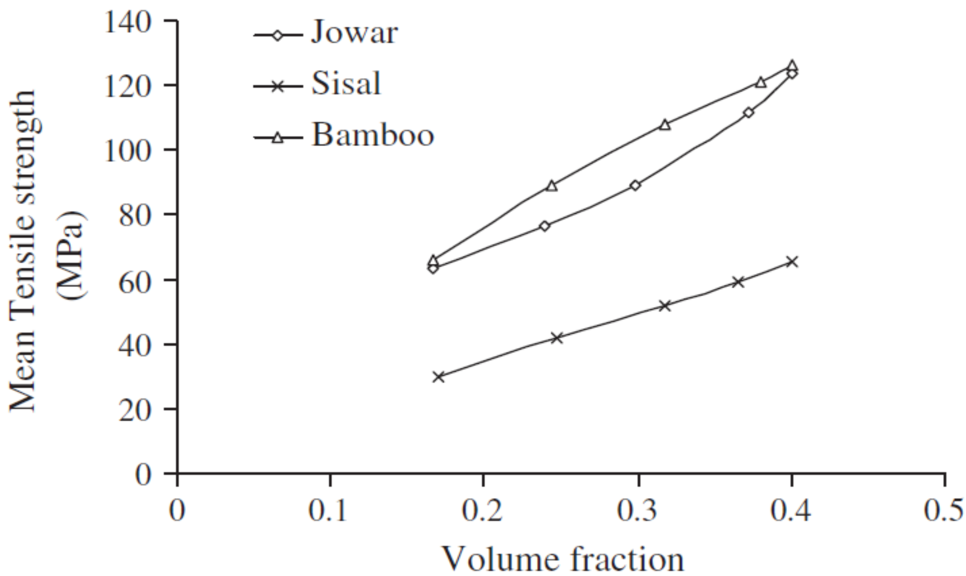

Figure 2.9: Effect of volume fraction of fibre for jowar fibre reinforced composites in comparison to sisal and bamboo fibre composites in tensile test.

Source: Prasad and Rao (2011)

2.8 RC BEAM STRENGTHENING EXTERNALLY USING FRP

Reinforced concrete beams can be strengthened externally by several methods such as using synthetic fiber or natural fiber. Factors that influencing the strength of the fiber-reinforced plate include the type of fiber, the number of layers and the reinforcement scheme. In this section, the use of synthetic and natural fiber in the past of the research were discussed.

2.8.1 Natural Fiber

Alam et al. (2015) has researched the potential use of jute rope composite plate in strengthening the flexural zone of RC beam. Jute rope composite plate was fabricated in dimension of 2000 x 100 mm in length and width, with thickness of 8 mm and attached at the concrete beam as shown in Figure 2.10 for setup and test. The result of load versus deflection of beams for control and strengthened beam shown in Figure 2.11. From the graph, strengthened beams has the higher yield point and it begin to fail when the limit load of about 130 kN. The ultimate load of strengthened beams is higher than the controlled beam in 75%. Jute It can be concluded that the jute rope composite plate was efficiently in beam strengthening purpose.

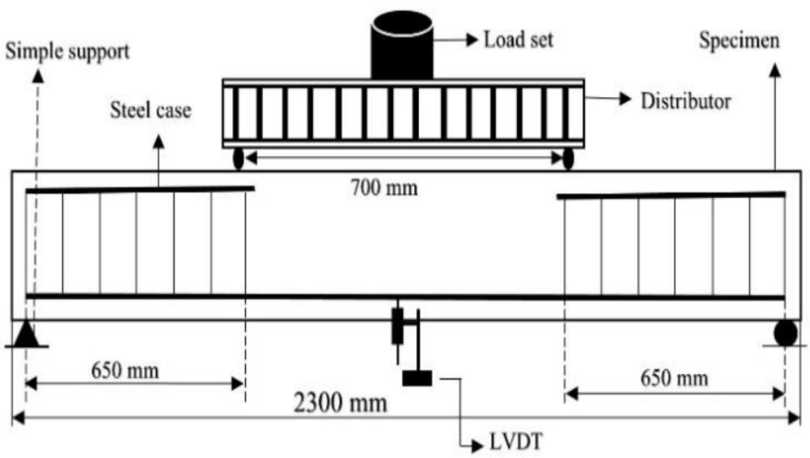

Figure 2.10: Three point loading Test.

Source: Alam et al. (2015)

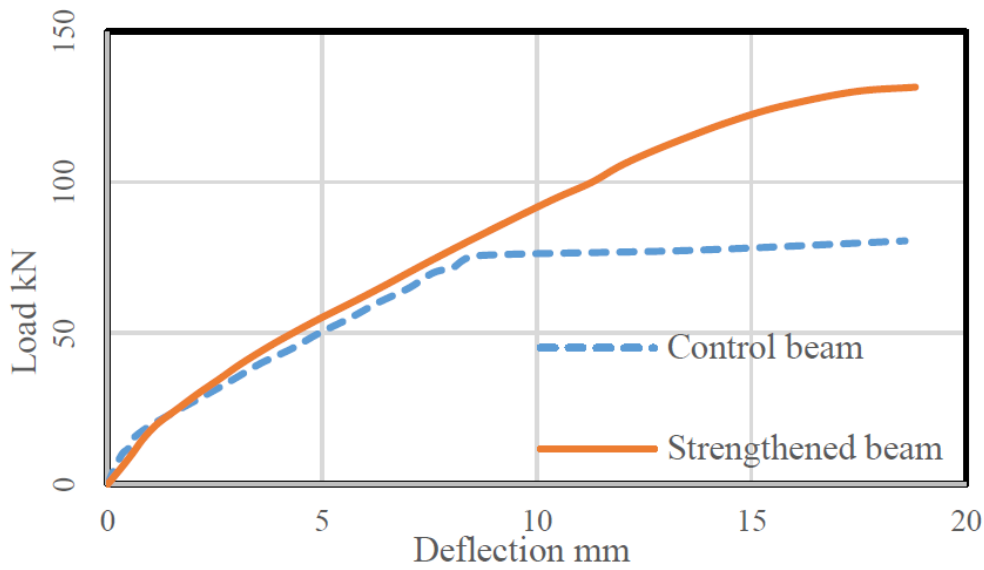

Figure 2.11: Load-deflection curve

Source: Alam et al. (2015)

2.8.2 Synthetic Fiber

Raju and Mathew (2013) researched on synthetic fiber to retrofit RC beam. All sides of the RC beams were wrapped by fiber with epoxy as polymer matrix. In this study, fiber used were: carbon, glass, steel, polypropylene and coir. Experimental results are shown in Figure 2.12 and Figure 2.13. Full wrapping method reduces the deflection of the beam and an increase in carrying capacity. In addition, the results also showed that, compared with other samples, deflections of the CFRP seemed to have the lowest deflection and the highest load capacity. Overall results found, RC beams with strengthening perform better than the controlled beam. However, this method is consider expensive and un-environmental friendly because if compared with other methods used, this full wrap method needed huge amount of FRP.

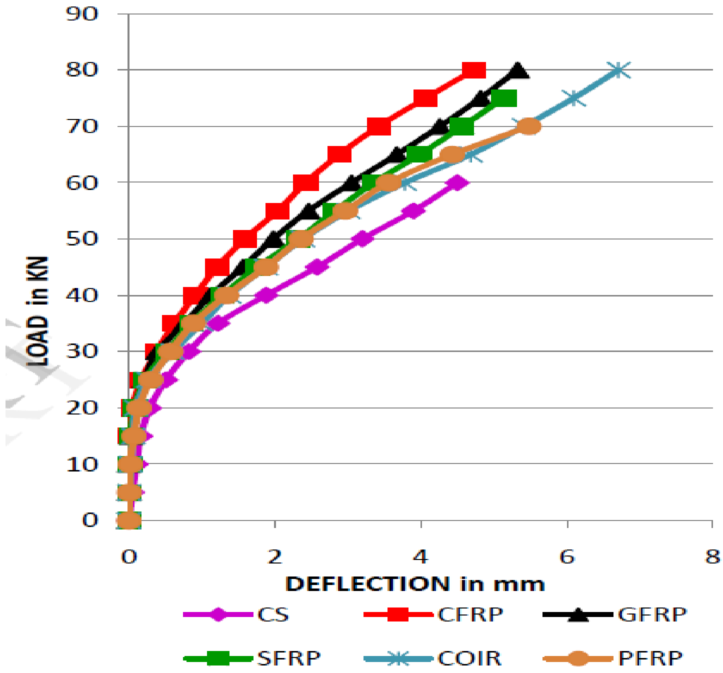

Figure 2.12: Comparison of different fiber sheet and control specimen in terms of deflection

Source: Raju and Mathew (2013)

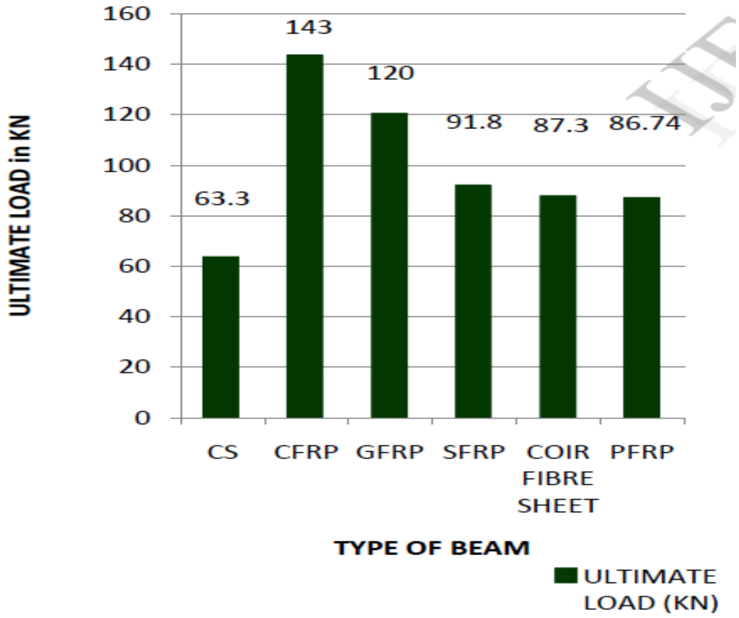

Figure 2.13: Comparison of different fiber sheet and control specimen in terms of ultimate load

Source: Raju and Mathew (2013)

2.9 BEHAVIOUR OF RC BEAMS WITH OPENINGS

Campione and Minafòhad, (2012) investigated the effect of circular openings on RC beams at low shear span-to-depth ratio, a/h is equivalent to 0.27. twenty small-scale RC beams with or without circular openings in flexure were tested under four-point loading test. In this study, the parameters were the layout of reinforcement and the openings location.

The result shown that the first crack and failure mode are largely influenced by the opening location. Their studied result concluded that the first cracking load and failure mode primary depend on the location of the opening. When solid beams tested under four point loading test, the initial flexural crack occurred at about 20% of the maximum load applied and the diagonal crack obviously seen at average load of 60% of ultimate load while for beams with openings at shear zone showed a reduction of load- carry capacity in the range of 19-30%. The researchers also found that vertical stirrups increased the ultimate load by about 15% in the beam with openings. However, horizontal stirrups is not efficiently for RC beams with openings. All specimens failed in diagonal crack or concrete support failure.

Figure 2.14: Specimens with openings in the shear-span after testing

Source: Campione and Minafò (2012)

2.9.1 OPENING CLASSIFICATIONS

The classification of openings determined the failure mode and cracks pattern in RC beams. Classification of reinforced concrete beams with openings can be based on opening's shape, size and location.

2.9.1.1 Shape

Prentzas (1968) studied the type of opening's shape such as rectangular, circular, trapezoidal, triangular, diamond and even irregular shapes. The researcher found out that although there are many shapes of opening available, but the rectangular and circular are the most common one in practice. Normally the circular openings are used to facilitate service piping such as power supply, plumbing, etc. While rectangular shapes are usually made for air conditioning pipes, so they can be passed through rectangular beams. There are two types of failure in circular section of beams caused by the reduction in shear strength, which were beam-type failure and frame-type failure.

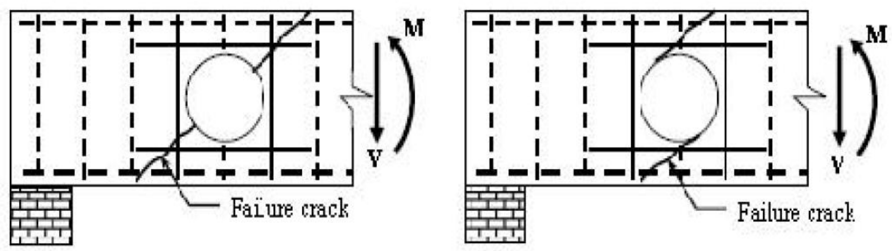

Figure 2.15: Beam-type failure and frame-type failure.

Source: Prentzas (1968)

2.9.1.2 Size

Somes and Corley(1947) considered the circular opening is large when its diameter exceeds 0.25 times the depth of the web. According to Mansur and Tan (1999) have considered that the essence of classifying an opening as either small or large would influence the structural response of the beam. If the usual beam theory can be keep applied on the beam, then the opening can be consider as small opening, otherwise the opening is considered as large if the normal beam-type behaviours are no longer applied.

Mansur (2006) indicated that to clarify the opening is small the diameter of opening should not exceed than 50% of the overall depth of the beam. Many researchers have been dealing with the opening size, whether it is small or large opening, but currently there is without any clear-cut demarcation line or definition.

The hinges form in the chord members at a distance of h/2 from the vertical faces of the opening can be also used to classify the size of an opening as either small or large. The length of opening I_0 is less than or equal to h_{max}, it may be defined as a small opening. For large openings, $I_0 > h_{max}$. However, Aykac and Yilmaz proved that while compared to the triangular openings, the beam with circular openings presented a good ductile flexural behaviour. (Mansur , 2006)

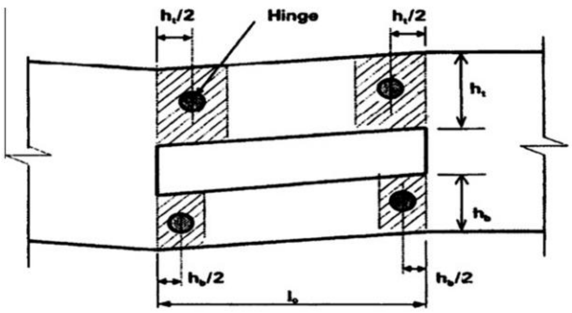

Figure 2.16: Forming of hinge in RC beam with opening.

Source: Mansur (2006)

2.9.1.3 Location

Nilesh's (2013) contributed the guidelines to select the location of web openings. The researcher proved that the most critical position of was near to the support and the optimum location of openings in the span of the beams were in the flexure zone which is the mid-span of beam. When the condition of multiple openings are used in the same section of beam, the distance between these two openings should not less than 0.5D. In a similar way, an opening location should not nearer than 0.5D to any concentrated loads.

Yang et al. (2006) concluded that the optimum location for web openings in the span of beam greatly rely on the relative proportion of bending moment and shear forces. Generally, the openings give a magnificent impart on the shear resistance rather than the bending resistance. An analysis was developed by Miguel and Neto (2014) to demonstrate how the location of the web openings can affect the shear loading path by considering four distance values of the web openings measured from the support. He proved that for the short span beams, it would cause a greater reduction of load capacity if the openings were placed near to the support. For long span beams, it was more affected when the openings situated in the middle of span. Ashour and Rishi (2000) observed that when failures happened in the beam with openings, it was majorly caused by the location of the openings, but not the reinforcement arrangement.

2.9.2 External Strengthening Around the Openings Using FRP Materials

Chin et al.(2012) tested six reinforced concrete beams with large square opening placed in the shear region, at a distance 0.5 d and 0 d away from the support. The inclusion of openings in the shear region resulted a great reduced in the beam capacity, which approximately in the range of 69 % to 74 %. The control beams were failed in shear mode as observed. The diagonal constituted at the corners of openings and leads to yielding reinforcement eventually as well as concrete cover crushed.

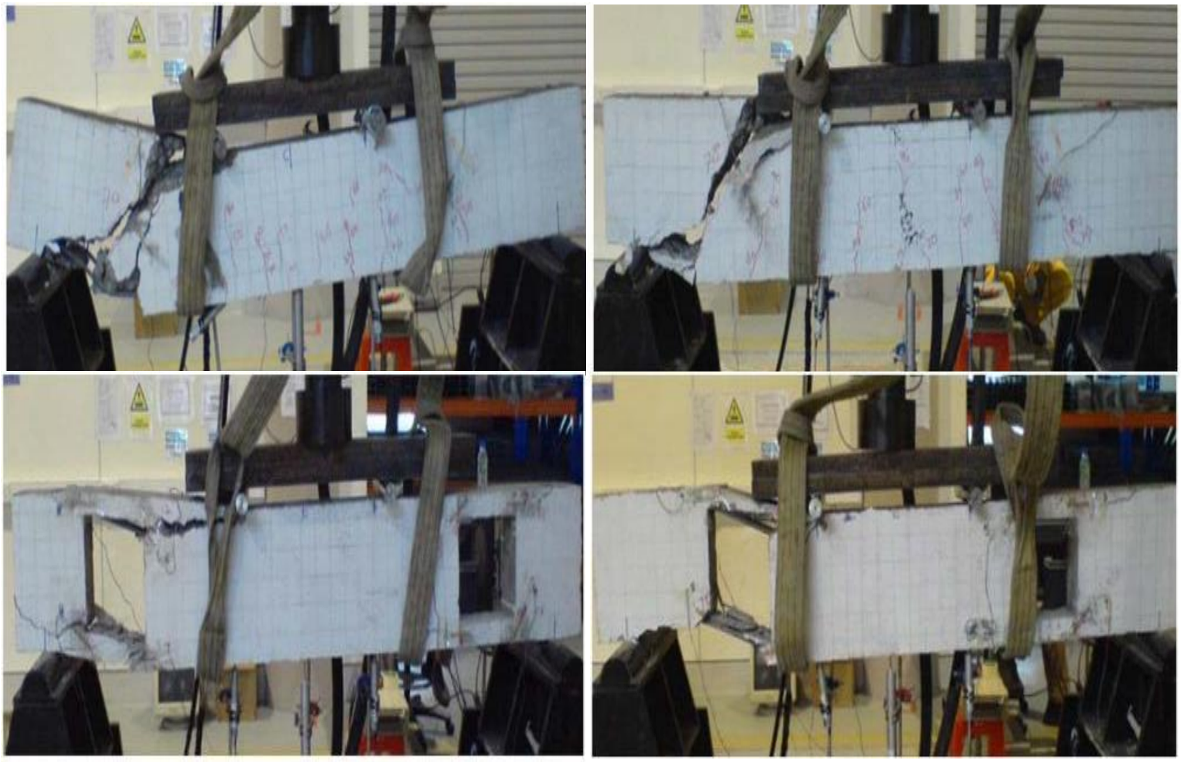

Figure 2.17: Cracks pattern and failure mode of control beam and un-strengthened beams with rectangular openings

Source: Chin et al. (2012)

The implemented strengthening configurations were full wrapping system around the openings. The presence of CFRP laminates effectively disrupted the path of crack propagation which required a higher energy to distract the cracks into flexural cracks along the mid-span. The beam strength regain respectively to approximately 54% of the original structural capacity of beams.

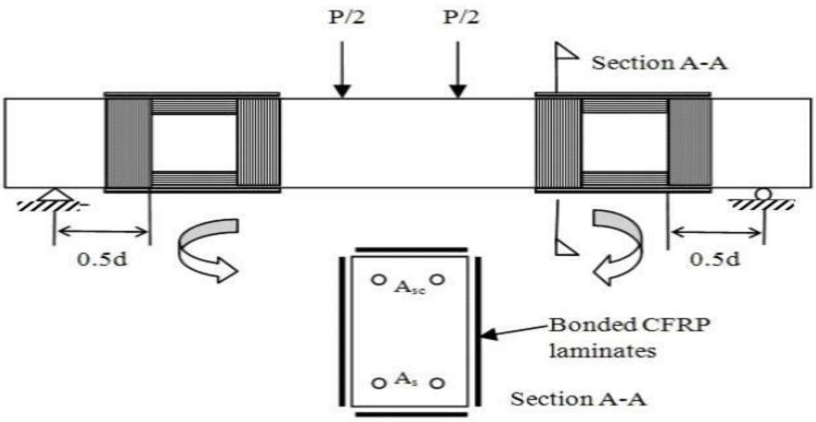

Figure 2.18: CFRP strengthening configuration by Chin et al.

Source: Chin et al. (2012)

Figure 2.19: Cracks pattern and failure mode of strengthened beams with rectangular openings

Source: Chin et al. (2012)

2.10 SUMMARY

Through an extensive literature review, it has been observed that although the literature is rich in the study of mechanical behaviour of natural fiber reinforced composites, however information about using NFCP in RC strengthening are still lacking. To date, even though there were numerous extensive theoretical studies and experimental studies had been done regarding strengthening of RC beam using natural fiber reinforced such as jute and kenaf, but rarely research has looked into the externally strengthening of RC beam using bamboo fiber in form of composite plate. Besides, there were few of studies included opening in RC beams yet does not involved opening at shear zone and most of the researchers focuses on rectangular opening but not circular opening. Hence, the potential use of natural reinforced composite plate in strengthening RC beams were studied in this research.

CHAPTER 3

METHODOLOGY

3.1 INTRODUCTION

This chapter outlines the procedures for conducting this research which include the preparation and application of bamboo fiber reinforced composite plate (BFRCP), preparation of specimens and laboratory testing. Figure 3.1 shows the flow chart of methodology throughout the research.

3.2 RESEARCH METHODOLOGY

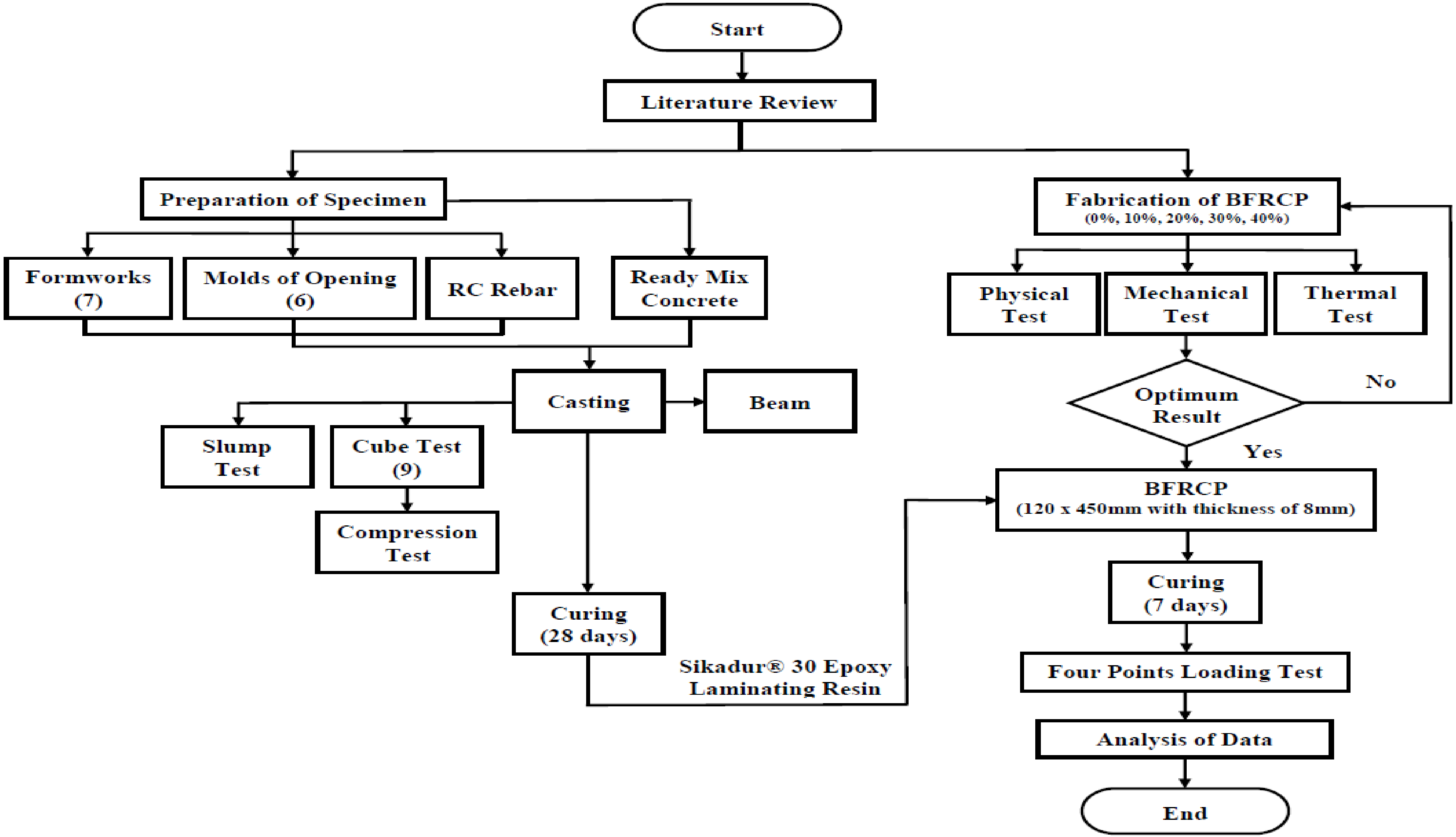

Figure 3.1: Research Methodology Flow Chart

3.3 PREPARATION OF MATERIALS

This section lists the materials required in this study. The function and preparation of each materials are described in detail below.

3.3.1 Bamboo Fiber

In this research, bamboo fiber was obtained from Forest Research Institute Malaysia (FRIM). The flexibility of the bamboo fiber as well the mechanical properties of the natural composite plate are mainly due to the lignin and pectin of the fiber. Thus, alkaline treatment is needed to reduce or eliminate the lignin content of the fiber. This treatment also has an effect on other components of the bamboo microstructure such as hemicellulose and pectin (Varinder et al, 2013). Therefore, the fiber were dried and treated with 10% of sodium hydroxide for about 48 hours. The bamboo strip were then separated into monofilaments through a mechanical process. The fiber has a density of 0.890 g/cm3. The internode will likely reduce the mechanical properties of the composite plate making it to be weak. Hence, the fibers were cut into desired length by avoiding the internodes part.

Figure 3.2: Processed individual bamboo fiber

3.3.1.1 Fiber Treatment

The extracted fibres were thoroughly washed by immersing them into water tank to remove impurities on the fiber surface. An indicator paper was used to ensure that the pH value of bamboo fiber was neutralised into the optimum range of 5-6 pH. The fiber was then dried in an oven with a temperature of 60°C for 24 hours. In addition, finer individual fiber were made through manual separation to prevent thick fiber that may cause voids during the fabrication of the composite plate. This method of extraction resulted in less fiber damage. After the fiber were removed from the oven, the samples were then placed into the desiccator for 24 hours and ready to be used.

Figure 3.3: Soaking of bamboo fiber in warm water

Figure 3.4: Bamboo fiber drying process

3.3.2 Vinyl Ester with Cobalt Accelerator and Hardener MEKP

The function of Vinylester Bisphenol.A as the matrix polymer in composite plate was considered in this study. The vinyl ester was present at a density of 1.05 g/cm 3. The cobalt accelerator and hardener methyl ethyl ketone peroxides (MEKP) were mixed gently with the vinyl ester gently during the fabrication of the composite plate. The proportion of Vinyl ester to MEKP and cobalt used are 100: 2: 0.1 ratio. The mixed procedure must be carried out by means of vinyl ester, which is first blended with cobalt and stirred for 5 minutes then followed by the addition of MEKP for 5 minutes in sequence. The addition of cobalt and MEKP directly at the same time is strictly not allowed.

Figure 3.5: Matrix polymer. (Vinyl Ester, Cobalt Accelerator, Hardener MEKP)

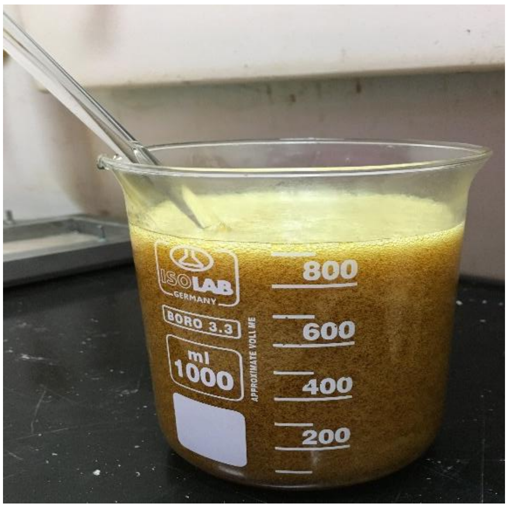

Figure 3.6: Ready used vinyl ester

3.3.3 Sikadur® 30 Epoxy Laminating Resin

Sikadur®-30 was used in this experimental study to provide an efficient structural adhesive bonding between bamboo fiber-vinyl ester composite plate (BFRCP) and the concrete surface. It provides excellent advantages, such as the strong adhesion, excellent adhesion to many substrates and offered high mechanical properties as lists in Figure 3.7. In addition, it is easy to mix and handle by using a shovel and impregnation roller.

Sikadur®-30 has been divided into two parts, which are resin parts A and B. Part A is in white colour and the curing agent B part is in black colour. The ratio of part A and part B used in mixing was 3:1 by weight. A minimum mixing time of ten minutes was needed. A mixing spindle attached to a slow speed electric drill (max. 600 rpm) was used until the mixture became smooth and became uniform light grey in colour with a 70 minute pot life after a well mixing. Seven days curing period were needed before proceed with testing to achieve the ultimate strength.

Sikadur®-30 was applied according to the product data sheet provided, it must be protected from rain for at least 24 hours after application. In order to maintain its shelf life, it must be sealed and undamaged in dry conditions at a temperature of + 5 ° C to + 25 ° c. Table 3.1 summarizes the mechanical properties of Sikadur®-30.

Table 3.1: Mechanical properties of Sikadur®-30 epoxy laminating resin

Sikadur®-30 Mechanical Property	Value	
Tensile Modulus of Elasticity	11200 N/mm^2	(7 days at +23°C)
Flexural Modulus of Elasticity	9600 N/mm^2	(7 days at +23°C)
Compressive Strength	85-95 N/mm^2	(7 days at +35°C)
Tensile Strength	26-31 N/mm^2	(7 days at +35°C)
Shear Strength	18 N/mm^2	(7 days at +23°C)

Figure 3.7: Sikadur® 30 Epoxy Laminating Resin

3.4 FABRICATION OF BAMBOO FIBER-VINYL ESTER COMPOSITE PLATE (BFRCP)

In this present study, the hand lay-up method was adopted for composite fabrication and the fabrication of composite plate were carried out at room temperature. Stainless steel moulds were used in casting the BFRCP plates. Five different fiber volume ratios of BFRCP including 0 %, 10 %, 20 %, 30 %, 40 % were fabricated.

Various sizes of BFRCP were fabricated and tested in each of the experimental testing. For flexural test, the BFRCP were in a dimension of 12.7 x 127 mm, and 4 mm thick plate; for tensile test, it were in size of 25 x 250 mm, and a thickness of 3 mm while the plate strengthening at soffit of flexural zone and shear zone of RC beam were in 120 x 450 mm, with thickness of 10 mm.

The mould releasing agent (honey wax) was applied surrounding the mould and Teflon paper was put underneath the bottom part of the mould to avoid adhesion between the composite plate and the mold. The required amount of bamboo fiber and vinyl ester are then weighed and measured using an electronic balance. Thereafter, the cobalt and MEKP were measured and added successively. When cobalt and MEKP were added, the mixture was gently mixed for about 5 minutes to avoid the formation of bubbles.

The vinyl ester resin and the bamboo fibers were arranged across the mould uniformly and layer by layer according to sequence. At first, a thin layer of vinyl ester was poured to the steel mould and followed by a layer of unidirectional bamboo fibers. After that, the second layer of resin was coated on the previous surface of bamboo fibers for interfacial bonding. Another layer of bamboo fibers were then placed over on the previous layer later. These steps were repeated until the thickness of the plate considered in this study were obtained. The final step of the fabrication were compression of the composite plate after the required thickness of plate had been achieved. The composite was subjected on the top part of the mould to form a smooth surface and remove trapped air bubbles during the curing process.

The fabricated BFRCP were cured at room temperature for 24 hours to achieve complete curing. Afterwards, the plates were post- cured in oven with the temperature of 110°C for about 4 hours and the desiccator for 24 hours. The BFRCP was then proceed with testing. Figure 3.6 to Figure 3.8 show the materials and methods used in BFRCP fabrication.

Figure 3.8: Stainless steel moulds for composite fabrication

Figure 3.9: Application of mould releasing agent (honey wax)

Figure 3.10: Fabricating composite plate with hand lay-up method

3.5 PREPARATION OF SPECIMENS

A total of six reinforced concrete beams (RC beams) were prepared and cast in this research. From these six RC beams, two were used as the controlled beam, two beams were in soild and the other two beams had circular openings of diameter 120 mm at the shear zone. The preparation work of specimens were carried out in Concrete Laboratory, Faculty of Civil Engineering (FKASA). The preparation of beam samples types was summarized in Table 3.2.

Table 3.2: Beams preparation

Beam Specimen	Beam Dimension (B x H x L) (mm)	Without Opening	With Circular Opening (120mm)	Strengthen in Flexural Zone	Strengthen in Shear Zone
1	120 x 300 x 1500	Control Beam			
2	120 x 300 x 1500	✓			
3	120 x 300 x 1500	✓		✓	
4	120 x 300 x 1500	Control Beam			
5	120 x 300 x 1500		✓		
6	120 x 300 x 1500		✓		✓

3.3.1 Formwork Preparation

Figure 3.11 shows the formwork for reinforced concrete solid beams and Figure 3.12 shows the formwork for reinforced concrete beams with circular openings. In this study, timber formworks were prepared for concrete beams casting as it is reusable, economic, easy to available in FKASA laboratory and lightweight compared to steel and aluminium formwork.

The fabrication and assemble of formwork must be good to ensure no leakage of concrete during casting. A total of seven beams were cast simultaneously with an approximately constant rectangular section of 120 x 300 mm and length of 1500 mm. A layer of release agent (mould oil) acts as a lubricant oil was coated on the inner surface of the formwork to prevent adhesion between formwork and concrete after hardening as well to ease the formworks demolition work.

Figure 3.11: Formwork for reinforced concrete solid beams

Figure 3.12: Formwork for reinforced concrete beams with circular openings

3.3.2 Steel Reinforcement

Figure 3.13 shows the arrangement of reinforcement bars in reinforced concrete (RC) solid beam and Figure 3.14 shows the arrangement of reinforcement bars in reinforced concrete (RC) beams with cicular openings.

The reinforcement bars used in this experimental study were ribbed steel bars and ligatures. All reinforced concrete beams had the same compression and tension steel reinforcement. The size of deformed steel bars used was 10 mm of diameter with a nominal cross section area of A = 78.5 mm^2, while the steel stirrups used were 6 mm diameter with a nominal cross section area of A = 28.3 mm^2 . The steel stirrups were placed at a consistent interval of 100 mm centre to centre along the beam length. However, steel stirrups were not be provided in certain area where there is an existing opening or BFRCP.

Badly corroded or damaged steel shall not be used, as it may cause structural damage. The length and shape of bars were prepared according the draft by bending and cutting machine. Individual reinforcing bar were tied up using tying wire at the intersection point between the rebar and the links to form a reinforcement cage. Additionally, clear cover of average 25 mm were cast and inserted at the bottom, top and vertical sides of the beams to provide a sufficient distance between the steel bar and concrete surface in avoiding steel reinforcements from corrosion.

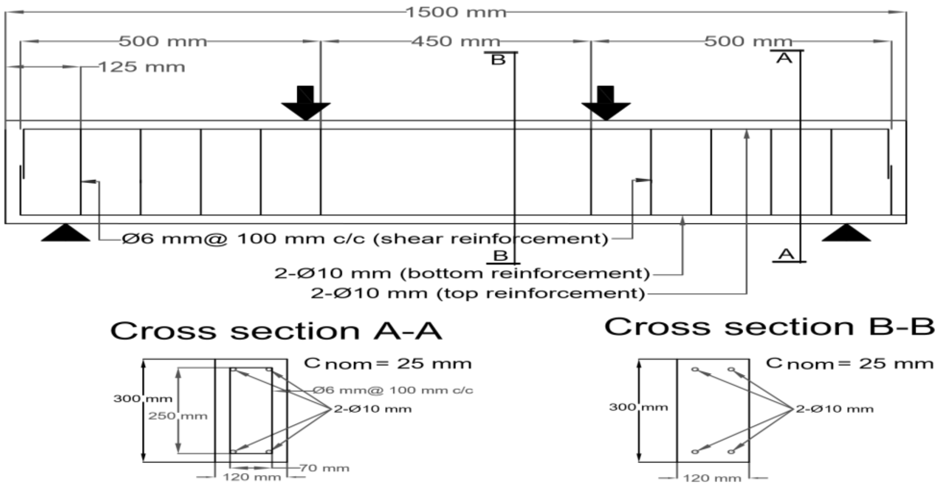

Figure 3.13: Arrangement of reinforcement bars in solid RC beam

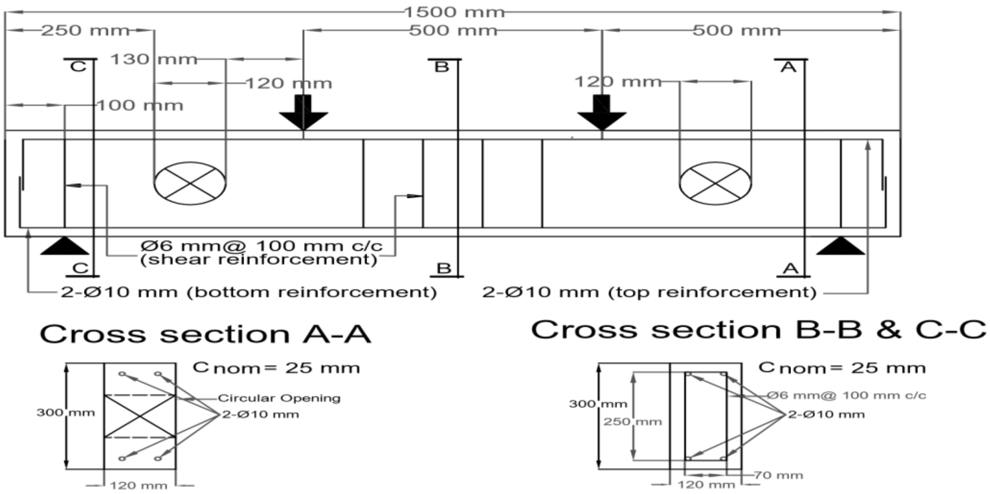

Figure 3.14: Arrangement of reinforcement bars in RC beam with circular opening

3.3.3 Concrete

The concrete used was high strength ready mixed concrete supplied by PAMIX Sdn Bhd as shown in Figure 3.15. It was designed for 28 days with compressive strength of 30 N/mm^2. The water cement ratio was 0.52. Fine sand as fine aggregate was used. The coarse aggregate was 20 mm granite crushed aggregates.

Figure 3.15: Ready mixed concrete from PAMIX Sdn Bhd.

3.3.4 Mould of Opening

In this experimental study, two RC beams with circular openings were cast to determine the shear failure. The openings were created using polystyrene sheets as it does not have any adhesion to the concrete surfaces when curing, so that it can be removed easily if compared with using PVC pile as opening's mould.

The polystyrene sheet was cut into cylinder shape with a height and diameter of 120 mm. The cylinder shape were then attached to the both end sides of formwork with distance of 250 mm from the inner length of formwork to the outer line of cylinder mould. Figure 3.16 and Figure 3.17 shows the mould of circular openings.

Figure 3.16: Circular openings

Figure 3.17: RC beams with circular openings

3.4 CONCRETING

Concreting works were carried out in Concrete Laboratory, Faculty of Civil Engineering (FKASA). A total of $1m^3$ ready mixed concrete with grade G30N from mixer truck was sponsored by PAMIX Sdn. Bhd.

3.4.1 Casting

Prior to the concrete casting, all the necessary checking have to be done. The formwork were cleaned with air compresses to make sure there are no debris that would interfere the quality of concrete surface. When there were any gaps or holes within the inner surface of the formwork, rectification can be done by sealant to avoid any leakage during concrete placement. The formwork had to be stable enough to restrict the vibration when concrete vibrating and the weight of fresh concrete when casting. A layer of mould oil was applied before and the arrangement of steel reinforcement was inspected to ensure it was according to the drawing draft. In addition, all relevant equipment and tools to handle concrete pouring are ready. The grade and amount of the concrete which stated in delivery order have been checked upon delivery of concrete. The slump test and sampling of 9 cubes with the standard dimension mould of 150 mm x 150 mm x 150 mm has been done in advanced. Figure 3.18 shows the tools for slump test and cube test.

Figure 3.18: Tools for slump test and cube test

Figure 3.19 and Figure 3.20 shows the preparation and casting work. The concrete casting steps began by placing at the corner of the formwork. The concrete vibrating were then took place to avoid void and honeycomb. The vibration were vertically inserted and removal within 5 seconds for 30 seconds to avoid excessive vibration. Excessive vibration tends to drive the finer aggregates to the top and coarses aggregates assembly to the bottom. Hence, segregation happened. In order to achieve a smooth surface and a high concrete strength, the contact between the formwork and the vibrator must be avoided because it might loosen the formwork and afftected the quality of the concrete.

Figure 3.19: Preparation works before casting

Figure 3.20: Beams Casting

3.4.2 Curing

By referring the Figure 3.21 and Figure 3.22, curing process were then be carried out to develop a good strength performance in concrete. The formworks of beams were dismantled after 24 hours of casting. The concrete surfaces were covered by wet gunny bags and periodically wetting. The process repeated for 28 days in order to reach the ultimate strength. After 28 days of moisture-curing, the beams surface were cleaned and painted with white color. Systematic guidelines were drawn to give a clear vision on appeared crack during the experiments. The nine concrete cubes were demoulded and put into the water tank for curing purpose immediately after 24 hours of casting.

Figure 3.21: Completed beam casting.

Figure 3.22: Beam curing process

3.7 BFRCP STRENGTHENING SYSTEM

To achieve the objective in this study, all the beams were strengthened with BFRCP in both flexural and shear zone. The beams were tested under four point loading to determine the load deflection behaviour and crack pattern.

3.7.1 BFRCP STRENGTHENING CONFIGURATION

By referring the Figure 3.23, BFRCP with the dimension of 120 mm x 450mm, and thickness of 10 mm were to strengthen the flexural zone of the RC beams externally. Two different BFRC configurations were implemented in this experimental study which were in the flexural zone and shear zone.

For RC solid beams, the BFRCP was pasted at the mid-span soffit of beam. While for RC beams with circular openings, the BFRCP were bonded on the surface of the beam in which perpendicular to the crack for effective strengthening purpose.

Before bonding the composite plate onto the concrete surface, the required region of the concrete surface was roughed and then cleaned with air blower to remove all dirt and debris. This step is important in order to improve the bonding between the concrete beam and composite plate. Components A and B of Sikadur® 30 must be mixed evenly for approximately 5 minutes before use. When the BFRCP was bonded to the corresponding position was uniformly pressed out to the sides from the middle of the plate to ensure that all Sikadur® 30 are evenly distributed to form a better bond with a uniform thickness of 3 mm. After 7 days of curing, the beam specimen were ready for testing.

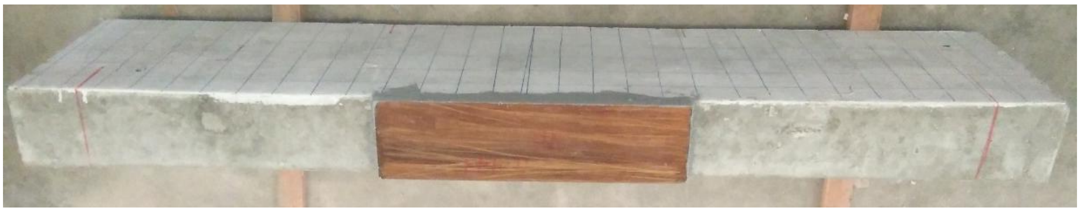

Figure 3.23: BFRCP bonded at the mid-span soffit of RC solid beam

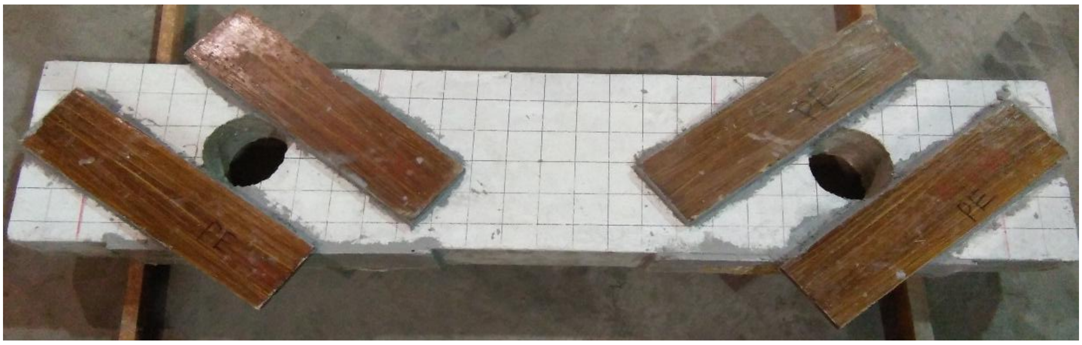

Figure 3.24: Surface strengthening with BFRCP for RC circular openings beam.

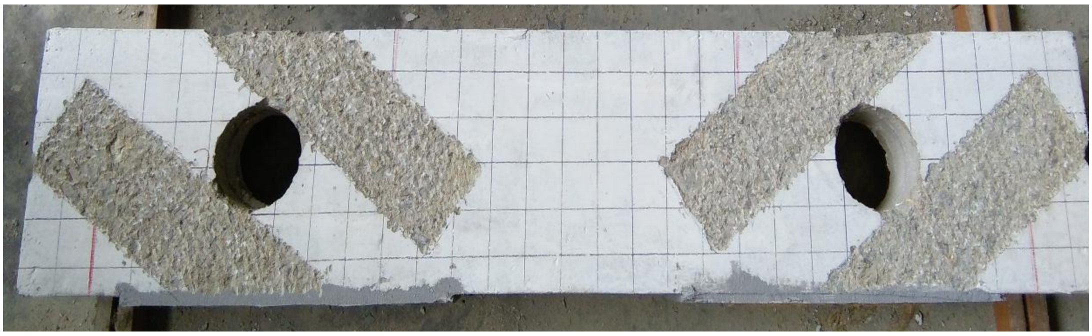

Figure 3.25: Roughed concrete surface

Figure 3.26: Strengthening procedure

3.7 COMPOSITE BEHAVIOUR

The behaviour of bamboo fiber reinforced composite plate were studied by conducting physical properties test, mechanical properties test and thermal properties test.

3.7.1 Physical Properties Test

The poor adhesion between the matrix and fiber leads to poor ability in transferring stress from the matrix to the fiber. In order to increase the quality of the fiber-matrix interface in composite materials, surface modification of fibers is required to achieve maximum compatibility and thereby provided a good adhesion. In this study, physical properties test was carried out to evaluate the surface morphology in the composite plate.

3.7.1.1 Fourier Transform Infrared Spectroscopy (FTIR)

Fourier Transform Infrared Spectroscopy (FTIR) is an analytical technique that uses infrared scanning to test the samples and observe the molecules structure of the composite in the wavelength range of 4000 to 400 cm^{-1}, at a resolution of 4 cm^{-1}.

Solid samples were usually shaved to be thin enough to get a good spectrum sample material. The first step is to collect the background spectrum to subtract from the test spectrum and ensuring that all the actual samples were analysed. The samples were then analysed LTI's fully-computerized Fourier Transform Infrared Spectroscopy system which produced an absorption spectrum showing unique chemical bonds and molecular structure of the sample samples. This profile is in the form of an absorption spectrum showing the peak represented high concentration of the components. The outcome in absorbance form can be also simply converted to light transmittance as they are just reverse of each other.

Figure 3.27: Shaved BFRCP for FTIR test

3.7.2 Mechanical Propertied Test

Mechanical test is a study of the behaviour of a material under loading. The following tests were carried out on the specimens.

i. Flexural properties test
ii. Tensile properties test

3.7.2.1 Flexural Strength Test (ASTM D790-03)

Figure 3.28 shows the conducted of flexural strength test using Universal Testing Machine Equipment with a capacity of 5 kN. The composite samples were prepared in accordance standard ASTMD790-03 with fiber ratios from 0% to 40% in order to determine the optimum fiber loading of bamboo fiber reinforced composite plate (BFRCP). The size of composite plates for flexural test were in the dimension of 127 x 12.7 mm, and 4 mm thick.

Three point loading was used in this test where the load imposed to the mid-span of the samples until it failure. The ultimate load was recorded and the stress-strain graph can be obtained from the test.

Figure 3.28: Flexural test for composite plate

3.7.2.1 Tensile Strength Test (ASTM D3039)

Figure 3.29 shows the conducted of tensile test using Universal Testing Machine Equipment with a capacity of 5 kN. The composite samples were prepared in accordance standard ASTM D3039 with fiber ratios from 0% to 40%. The optimum fiber volume ratio was chosen and fabricated to strengthen the RC beams. The stainless steel moulds for tensile test were fabricated into a dimension of 250 x 25 mm, and thickness of 3 mm.

A uniaxial load was applied at the ends of composite with a test speed of 5mm/min. The sample fractures at the ultimate tensile strength. The ultimate load was recorded and the stress-strain graph can be obtained from the test was recorded.

Figure 3.29: Tensile test for composite plate

3.7.3 Thermal Properties Test

The thermal test was conducted to determine the degradation temperatures of natural composite plate. In this study, thermogravimetric analysis (TGA) was carried out to determine the thermal stability and crystallization in bamboo fiber reinforced composites plate.

3.7.3.1 Thermogravimetric Analysis (TGA)

The thermal stability and degradation temperature of composite plates were analysed with Thermogravimetric Analysis (TGA). An average weight of 5 to 10 mg sample weight as shown in Figure 3.30 were prepared to test using Perkin Elmer Pyris-7 TGA equipped with Perkin Elmer thermal analysis software. High quality nitrogen atmosphere (99.5%) at a temperature from 50 to 800 °C and a heating rate of 10 min °C were required in conducting this test.

Figure 3.30: TGA testing samples

3.9 LABORATORY TESTING

In this study, the behaviour of RC beams were investigated to analysis the load deflection behaviour and cracks pattern. In terms of concrete strength, slump test and compressive test were carried out to ensure the strength achieved the targeted minimum requirement.

3.9.1 Slump Test

Slump test were carried out to measure the consistency of plastic concrete and detecting changes in workability. The test was conducted in accordance to reference standard, BS EN 12350: Part 2 (2009). There are three types of slumps which is true slump, shear slump, and collapse slump. Figure 3.31 shown the example of shear slump and the method to measure the slump.

Figure 3.31: Slump test.

3.9.2 Compression Test

Compression test of cured specimen was conducted immediately after the removal of specimens from curing water tank, with three hardened concrete specimens shall be used in the measurement of concrete strength at the designed age. The standard used for compression test are BS 1881: Part 116 (1983).

In compression test, concrete specimens were subjected to the compression load at the specified rate. The specimen were tested to its failure and the maximum load achieved were recorded.

Figure 3.31: Compression test

3.9.3 FOUR-POINT LOADING TEST

Four point loading test were conducted to determine the behaviour of RC beams both strengthened and un-strengthened condition with BFRCP. This test was conducted using a Magnus Frame with a capacity ranges of 300 kN to 500 kN as shown in Figure 3.32. The optimum fiber volume ratio of 40 % was used to fabricate the composite plates and bonded it using Sikadur® 30 resin to the soffit of the beam at the mid-span zone for solid beams and at the surface of beam which is perpendicular to the cracks for beams with openings. The bonded BFRCP was fully cured for 7 days before proceed for experimental testing.

The four point test comprises of two loading points and two support points. The load imposed vertically downward until the beam failure. Linear variable displacement transducers (LVDT) was installed at the mid span of solid RC beams and shear zone of RC opening beams to determine the deflection of the beam. The LVDT that attached to the tested beams was connected to a data logger to obtain the deflection value throughout the testing. The crack propagation and crack load were marked on the beam surface for recording purpose. The test lasted until the beam failed and then the results obtained are compared with the control beam.

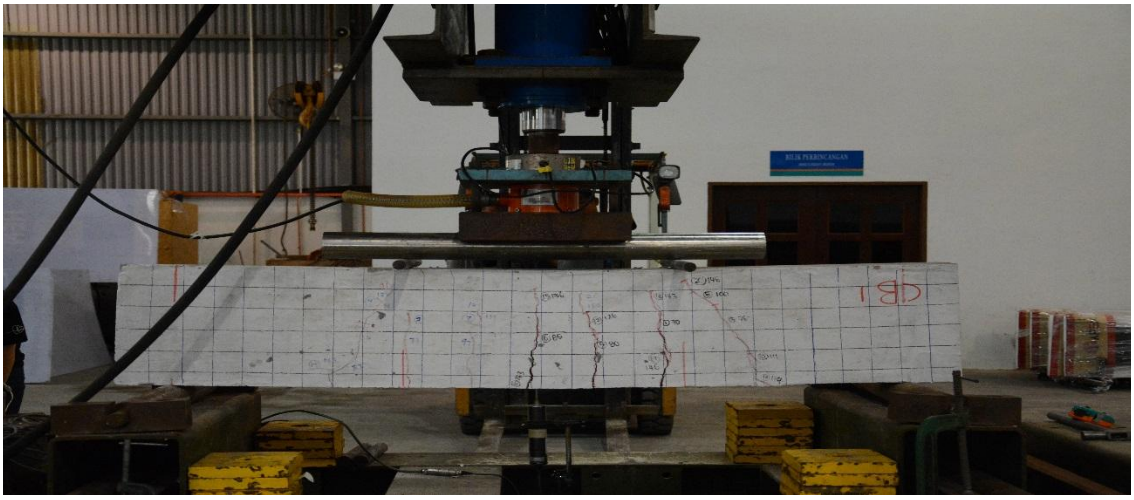

Figure 3.32: Setup of four-point loading test

3.10 SUMMARY

Table 3.3: Fabricated composite plate

Experimental Tests		Fiber Volume Ratio					Total
		0%	10%	20%	30%	40%	
Composite testing	Flexural Test	5	5	5	5	5	30
	Tensile Test	5	5	5	5	5	30
Beams strengthening	Four-Point Loading Test					10	10

Table 3.4: Summary of beams specimens

Beam Specimen	**Beam Dimension (B x H x L) (mm)**	**Classification**	**Strengthening Method**
1	120 x 300 x 1500	Control Beam	
2	120 x 300 x 1500	Without Opening	-
3	120 x 300 x 1500		Strengthen in Flexural Zone
4	120 x 300 x 1500	Control Beam	
5	120 x 300 x 1500	With Circular Opening (120mm)	-
6	120 x 300 x 1500		Strengthen in Shear Zone

Table 3.5: Outline of experimental tests included

Specimens	**Experimental Tests**	
Bamboo Fiber Composite Plate	Physical Properties	Fourier Transform Infrared Spectroscopy (FTIR)
	Mechanical Properties	Flexural Test (ASTM D790-03)
		Tensile Test (ASTM D3039)
	Thermal Properties	Thermogravimetric Analysis (TGA)
Strengthened RC Beams with BFRCP	Four-Point Loading Test	

CHAPTER 4

RESULTS AND DISCUSSION

4.1 INTRODUCTION

In this chapter, all the experimental data obtained were discussed. The test were divided into two parts which include to determine the behaviour of composite plate based on physical, mechanical as well the thermal properties and structural behaviour under four-points loading test.

4.2 FRESH AND HARDENED PROPERTIES OF CONCRETE

The properties of ready mixed concrete was studied by performing slump test and compression test to ensure the quality of the concrete is acceptable and the targeted concrete strength is achieved at 28 days. The proportions in concrete materials, for example, cement, water and aggregates required are set to meet the specific strength, workability, durability as listed in BS 5328.

4.2.1 SLUMP TEST

From the observation of Figure 4.1, the slump result obtained was as a true slump, which recorded at a height of 85 mm. A true slump indicated that high workability of the mixes. Targeted slump was in the range of 75 ± 25 mm. Hence the concrete quality is acceptable.

Figure 4.1: Slump test

4.2.2 COMPRESSION STRENGTH

This test was specifically conducted to obtain the compressive strength of the cured concrete after 3, 7 and 28 days. 9 cubes were divided equally and tested in 3 different days to ensure that the targeted strength was achieved with a minimum compressive strength of 30 MPa at 28 days. According to the results listed in Table 4.1, in all the cases, it can be concluded that the mean compressive strength of the cubes at 3 and 7 days are 26.0 N/mm^2 and 29.9 N/mm^2, respectively. In addition, the mean compressive strength was over-achieved at days 28 and recorded at 39.1 N/mm^2 as shown in Figure 4.2. Thus, the design mix satified the required strength.

Figure 4.2: Compression test

Table 4.1: Result of compressive strength test

Sample	Weight (kg)	Sample Age (days)	Load (kN)	Compressive Strength (N/mm^2)	Average Compressive Strength (N/mm^2)
C1	7.8	3	596.1	26.5	
C2	7.8	3	566.8	25.2	26.0
C3	7.8	3	588.6	26.2	
C4	7.8	7	637.0	28.1	
C5	7.8	7	647.9	28.8	29.9
C6	7.8	7	731.9	32.5	
C7	7.8	28	791.6	35.2	
C8	7.8	28	863.5	38.4	39.1
C9	7.8	28	982.7	43.7	

Figure 4.3 illustrates the development of average compressive strength versus sample age for 9 cubes. In the first 3 days, the graph shows a steep slope which indicated that the compressive strength of the cubes achieved high early strength. The rate of strength development started to reduce after 3 days and the difference in terms of the strength gained between 7 and 28 days was about 9.2 N/mm^2 which is approximately to 30.8 %. The compressive strength reached a peak of 39.1 N/mm^2 at 28 days.

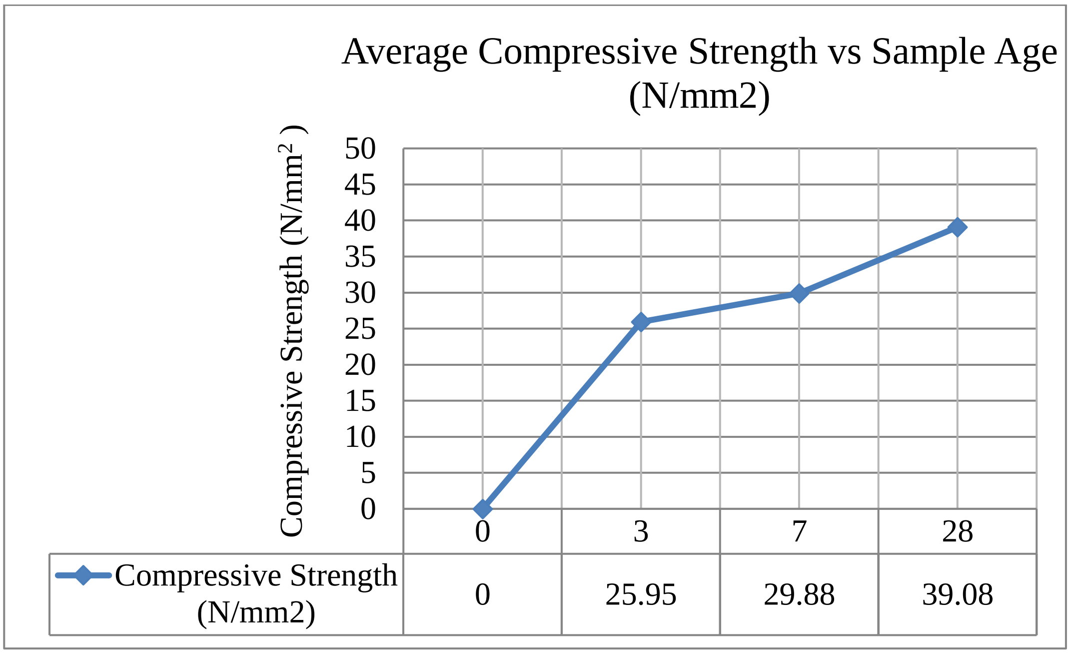

Figure 4.3: Graph of compressive strength versus days

4.3 BEHAVIOUR OF BAMBOO FIBER- VINYL ESTER COMPOSITE PLATE

Fabricated bamboo fiber –vinyl ester composite plate were subjected to various testing such as physical, mechanical and thermal properties tests to obtain the optimum strength of fiber volume ratio. The optimum fiber volume ratio will be chosen for composite plate strengthening in reinforced concrete (RC) beams.

4.3.1 PHYSICAL PROPERTIES TEST

In this study, physical test was conducted to examine the ability of BFRCP to absorb light at each wavelength to demonstrate the presence of chemical compositions such as cellulose, hemicellulose and lignin in the fiber composite plate. Fourier Transform Infrared Spectroscopy (FTIR) in the hydrogen bonds analysis was included for this section.

4.3.1.1 FOURIER TRANSFORM INFRARED SPECTROSCOPY (FTIR)

Plant cell walls are consist essentially of cellulose, hemicellulose, and lignin in a ratio of 4:3:3 and the mechanical as well as the physical properties of the fibers are mainly influenced by these chemical compositions. For example, a higher tensile strength and a higher thermal stability are obtained for fibers that contain more crystalline cellulose (Matheus, et al., 2014).

Hydrogen bonds are considered to be responsible for various properties of native cellulose, lignin and of course, natural fiber itself. Thus, the closer the cellulose chains, the greater the interaction between the adjacent chains, resulting in more and stronger hydrogen bonds which can lead to greater packing of chemical chains to obtain a higher mechanical and thermal properties (Matheus, et al., 2014).

The result of FTIR spectra for bamboo fibers were studied and is plotted in Figure 4.4. It can be observed that there is a strong broad band at around 3431.9 cm^{-1}, which is assigned to different O–H stretching modes, and another two bands at around 3028.5 cm^{-1} and 2927.5 cm^{-1} demonstrating the spectrum of cellulose.

The bands at the range of 1723.4 cm^{-1} to 1030.8 cm^{-1} are assigned to C=C, C–O stretching or bending vibrations of different groups present in lignin. Hemicelluloses can form a linkage between cellulose and lignin or it can also be in the form of lignin-carbohydrate complexes by ether bonds (Matheus, et al., 2014). The bands at 1178.9 cm^{-1} to 994 cm^{-1} are characteristic of C–H, C–O deformation, bending or stretching vibrations of many groups in lignin and carbohydrates. Wavenumbers that below to 662 cm^{-1} are considered C-OH out-of- plane bending that do not indicate any chemical compositions. Thus, the result certify that the chemical compositions such as cellulose, hemicellulose and lignin were present in the composite plate and its function were to improve the adhesion between the fiber and the matrix.

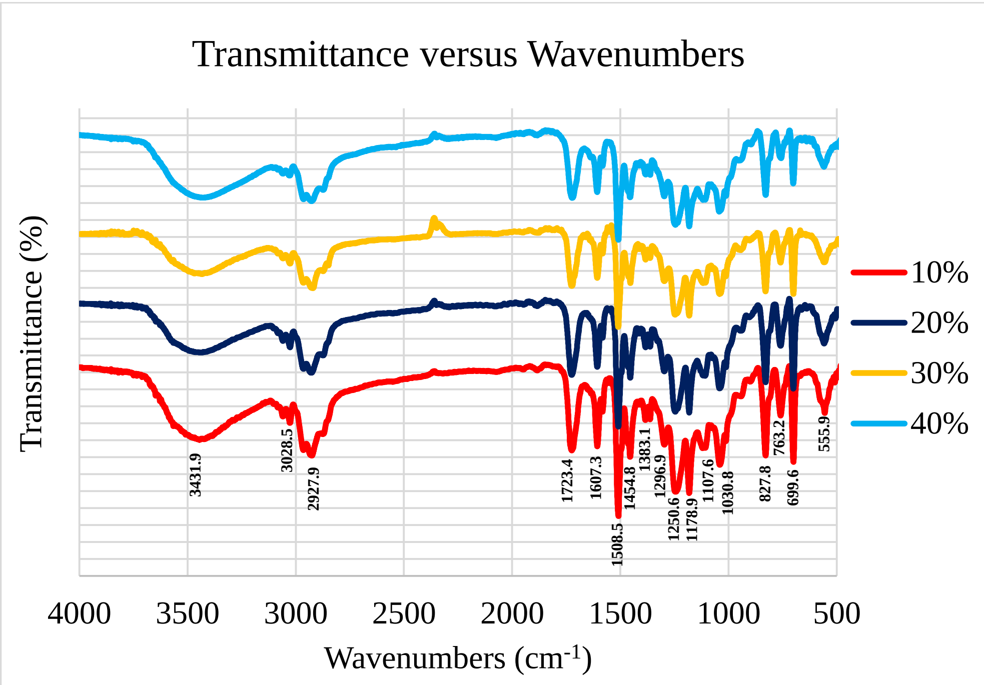

Figure 4.4: Transmittance versus Wavenumbers of FTIR

4.3.2 MECHANICAL PROPERTIES TEST

Mechanical test was performed to evaluate the flexural and tensile strength of bamboo fiber reinforced composite plate (BFRCP). All the fabricated composites were prepared as per ASTM standard. In this present study, the mechanical test that carried out including flexural test (ASTM D790-03) and tensile test (ASTM D3039). The following section discussed all the related mechanical test in details.

4.3.2.1 FLEXURAL TEST (ASTM D790-03)

Table 4.2 summarizes the result of ultimate flexural strength and peak load for different volume fractions of bamboo fiber reinforced composite plate (BFRCP) under three-point loading test. From the result, neat vinyl ester plate with samples 0F1 to 0F5 posed the lowest ultimate flexural strength compared to other volume fraction of BFRCP. Sample 10F1 to 10F5 reinforced with 10% of fiber volume ratio contributed ultimate flexural strength of 77.6 MPa and 246.6 N of average peak load. An improvement in the ultimate flexural strength of about 104.7 % observed as compared to the neat vinyl ester plates. For the 0.2, 0.3 and 0.4 volume fraction of fibers samples, showed higher flexural strength than the neat vinyl ester plates with 91.1 MPa, 129.1 MPa and 140.9 MPa respectively. The total improvement of 140.2 %, 240.4 % and 271.6 % for the flexural strength of 0.2, 0.3 and 0.4 volume fraction compared to the neat vinyl ester plate, indicating that the use of vinyl ester reinforced using bamboo fiber are effectively than neat vinyl ester plate.

The stress versus strain result for each fiber volume ratio are shown in Figure 4.5 to Figure 4.9. However, the graphs show inconsistent result for some tested sample. The reason may due to the existence of bubbles void in the samples. Bubbles formed during the process of mixing vinyl ester and hardener in the fabrication stage may affect the interfacial adhesion between bamboo fiber and resin, hence reduced the flexural strength of fiber composite plate.

Table 4.2: Flexural strength of three-point bending test.

Sample	Volume Ratio of Fiber (%)	Peak load (N)	Average Peak load (N)	Ultimate flexural Strength (MPa)	Average Ultimate (MPa)
0F1	0	93.98	120.58	29.6	37.9
0F2		162.80		51.1	
0F3		124.66		39.2	
0F4		110.60		34.8	
0F5		110.84		34.9	
10F1	10	100.33	246.57	31.6	77.6
10F2		279.75		88.1	
10F3		311.03		97.9	
10F4		286.67		90.3	
10F5		255.06		80.3	
20F1	20	300.96	289.67	94.3	91.1
20F2		177.53		55.9	
20F3		297.98		93.9	
20F4		286.97		90.4	
20F5		384.93		121.1	
30F1	30	446.65	411.31	140.7	129.1
30F2		451.07		142.1	
30F3		426.44		134.3	
30F4		397.87		123.2	
30F5		334.51		105.3	
40F1	40	466.47	475.65	146.9	141.0
40F2		525.38		165.5	
40F3		448.52		141.2	
40F4		417.28		131.4	
40F5		520.60		119.8	

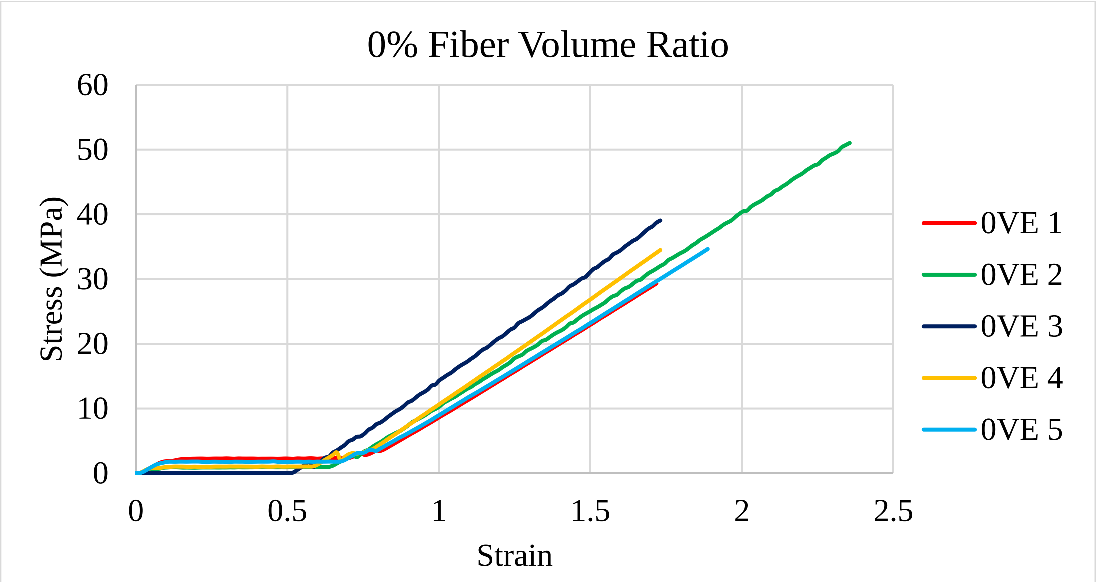

Figure 4.5: Stress versus strain curve in flexural test with 0% fiber volume ratio.

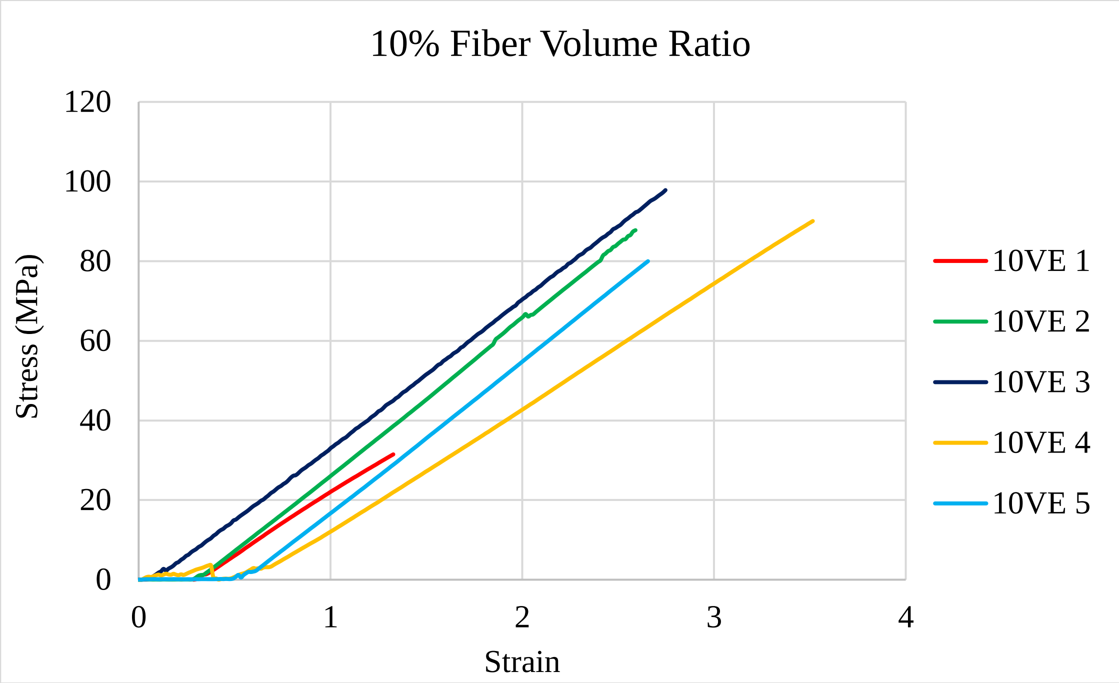

Figure 4.6: Stress versus Strain curve in flexural test 10% fiber volume ratio.

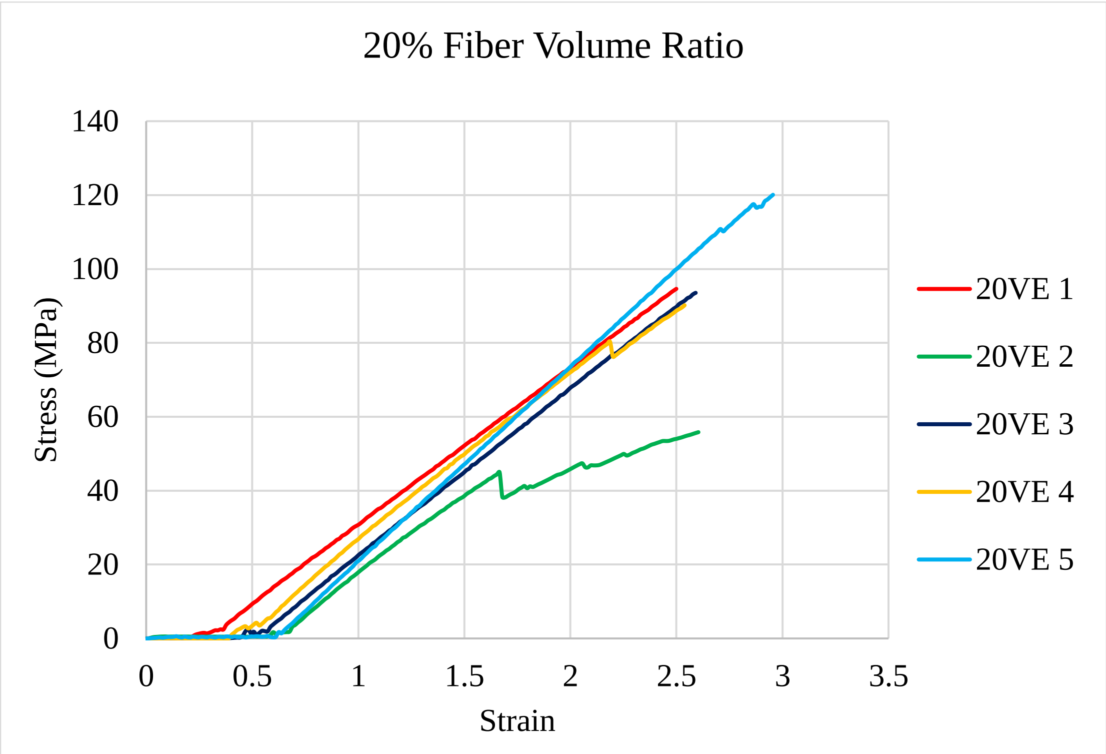

Figure 4.7: Stress versus Strain curve in flexural test with 20% fiber volume ratio.

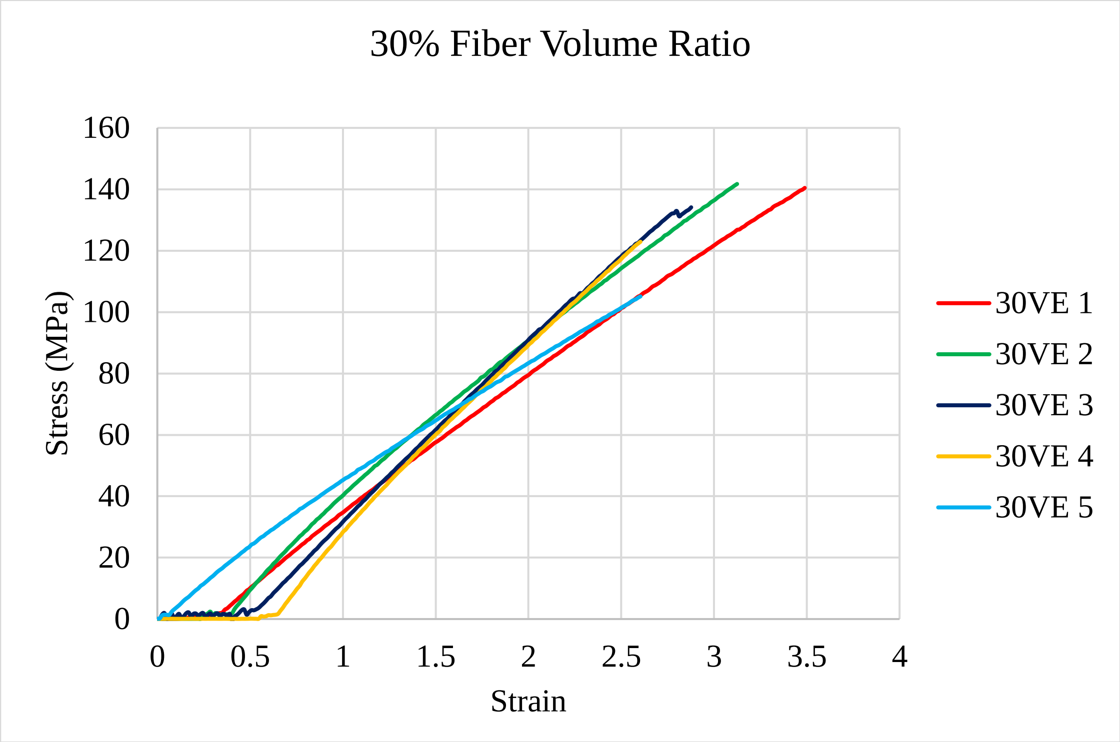

Figure 4.8: Stress versus Strain curve in flexural test with 30% fiber volume ratio.

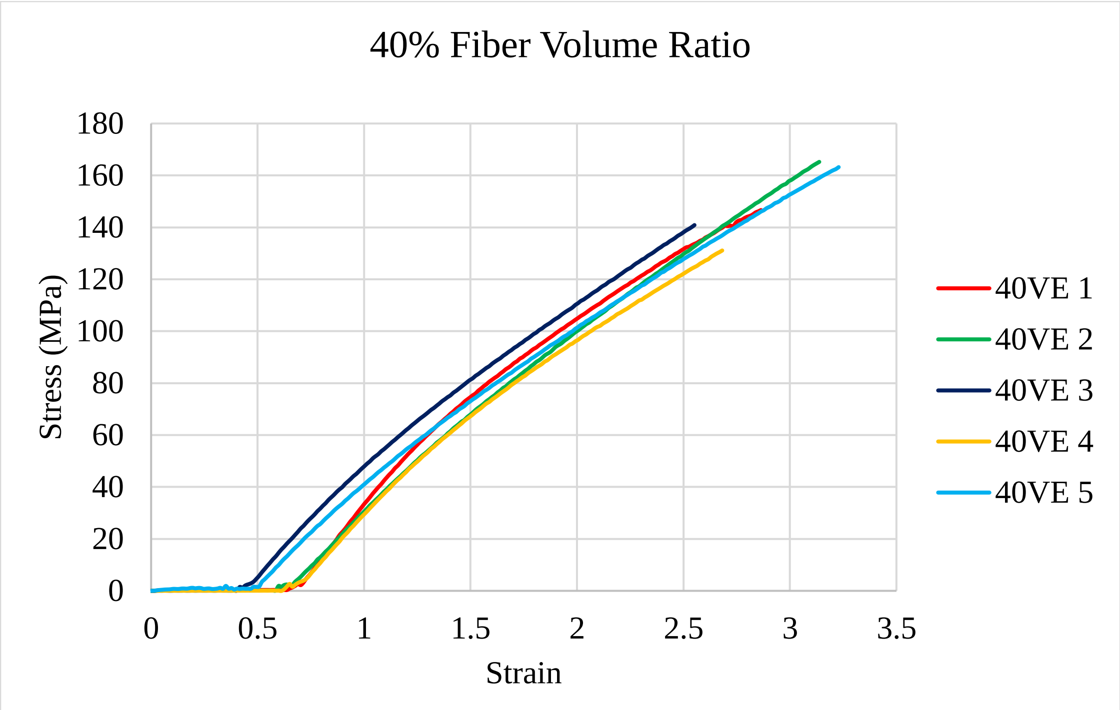

Figure 4.9: Stress versus Strain curve in flexural test with 40% fiber volume ratio.

Table 4.3 lists the effect of fiber volume ratio on the flexural modulus of elasticity. From the result, the modulus elasticity varies from range of 3003.1 MPa to 5525.3 MPa and the maximum of modulus elasticity was obtained in the composite plate with 40% of fiber to volume ratio.

Table 4.3: Flexural modulus of properties

Samples	Modulus of Elasticity (MPa)
0%	3003.1
10%	3851.5
20%	5265.6
30%	5359.2
40%	5525.3

The comparison of stress versus strain behaviour of bamboo fibre-vinyl ester composite plates are plotted in Figure 4.10. The trend shows that the ultimate flexural strength increased with the increases of fiber volume ratio from 0% to 40%. The possible reason may due to 40% fiber loading poses the ideal mix of the amount of bamboo fiber bonding with vinyl ester, whereas all the bamboo fiber are bonded with vinyl ester completely to form a strong composite plate. Hence, the study shows that 40% of fiber-to-volume ratio in composite plate is the optimum ratio to be used in strengthening.

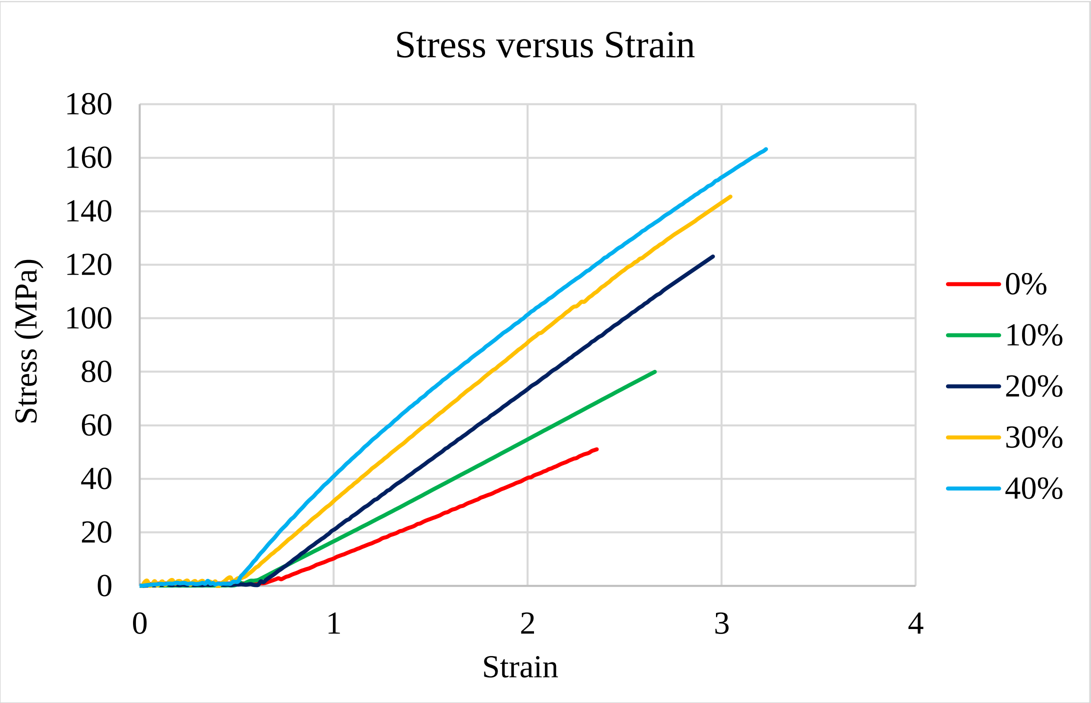

Figure 4.10: Comparison of stress versus strain in flexural test.

4.3.2.2 TENSILE TEST (ASTM D3039)

Table 4.4 summarizes the effect of fiber loading on tensile strength of composite plate. Referring to the Table 4.4, the ultimate tensile strength of the composite plate increases with the increase of fiber volume ratio up to 40%. The control samples, 0T1 to 0T5 of neat vinyl ester has the weaker ultimate strength among all. The BFRCP with 10% fiber volume ratio presented an ultimate tensile strength of 215.6 MPa with a total improvement of 111.7 % compared to the control samples. Composite plate with 20%, 30% and 40% of fiber volume ratio achieved an ultimate strength of 465.4 MPa, 698.9 MPa, 817.3 MPa which are higher than the strength of control samples, neat vinyl ester for about 357.1 %, 586.4 % and 702.7 % , respectively. For instance, the tensile strength of bamboo fiber- vinyl ester composite increased from 101.8 MPa to 817.3 MPa.

Figure 4.11 to Figure 4.15 shows the graph of stress versus strain of each fiber volume ratio. All the plates exhibited similar trend with linear elastic nature until it failure. The results of all five samples in each fiber ratio were found to be compatible. However, the ultimate strengths of plates in some fiber ratio group were found lacking in consistency which may be due to the existing of air bubbles trapped inside the composite plate that affecting the properties of composite plate.

Table 4.4: Summary of tensile strength result.

Sample	Volume Ratio of Fiber (%)	Peak load (N)	Average Peak load (N)	Ultimate flexural Strength (MPa)	Average Ultimate (MPa)
0T1	0	1047.1	1021.9	105.1	101.8
0T2		725.2		72.4	
0T3		1247.8		124.6	
0T4		1362.1		134.6	
0T5		727.3		72.4	
10T1	10	2293.4	1918.1	247.4	215.6
10T2		2149.0		214.4	
10T3		932.3		160.1	
10T4		2026.3		205.6	
10T5		2189.2		250.3	
20T1	20	3631.9	4263.5	362.5	465.4
20T2		3751.5		525.8	
20T3		5013.6		499.8	
20T4		4309.1		478.9	
20T5		4611.5		459.8	
30T1	30	7933.2	6991.5	793.0	698.9
30T2		4632.9		462.9	
30T3		4034.1		410.8	
30T4		7448.4		739.4	
30T5		10900.2		1088.2	
40T1	40	9773.6	8310.2	900.9	817.3
40T2		3141.9		313.6	
40T3		9998.4		993.6	
40T4		9125.4		912.5	
40T5		9512.3		965.5	

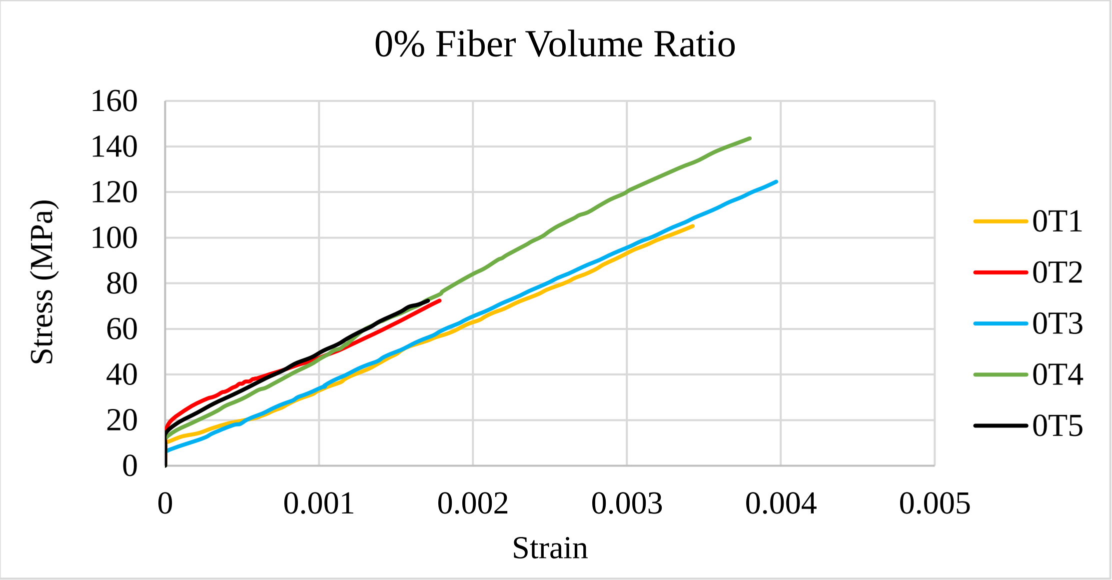

Figure 4.11: Stress versus Strain curve in tensile test with 0% fiber volume ratio.

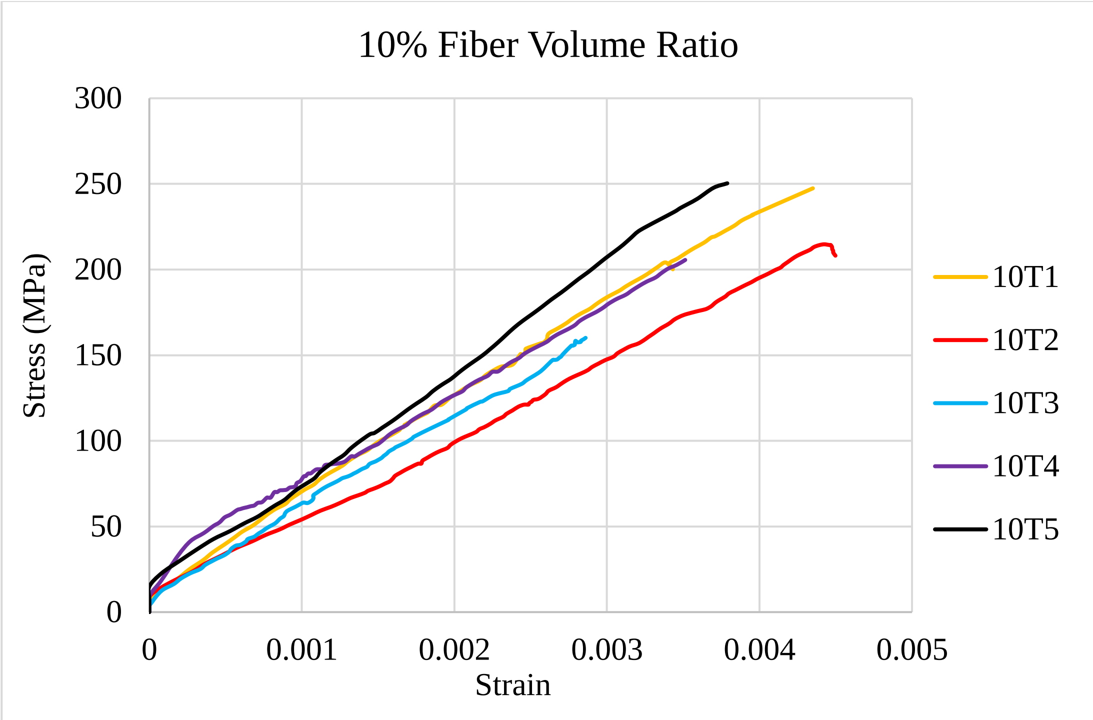

Figure 4.12: Stress versus Strain curve in tensile test with 10% fiber volume ratio.

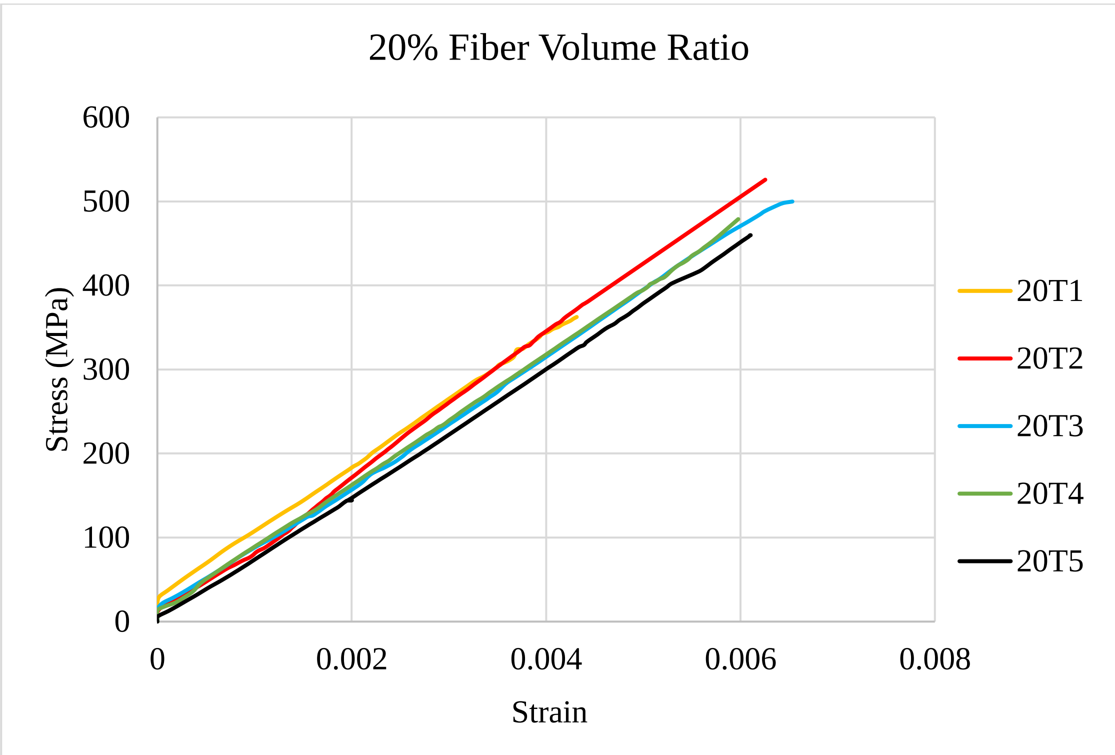

Figure 4.13: Stress versus Strain curve in tensile test with 20% fiber volume ratio.

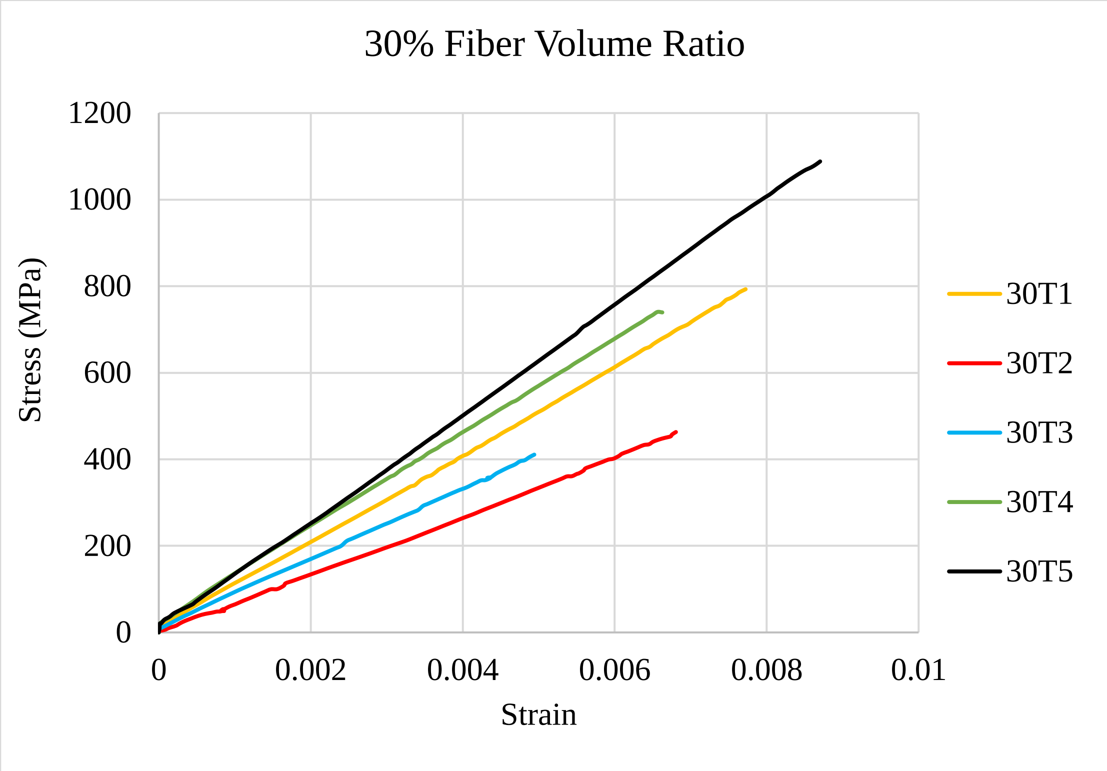

Figure 4.14: Stress versus Strain curve in tensile test with 30% fiber volume ratio.

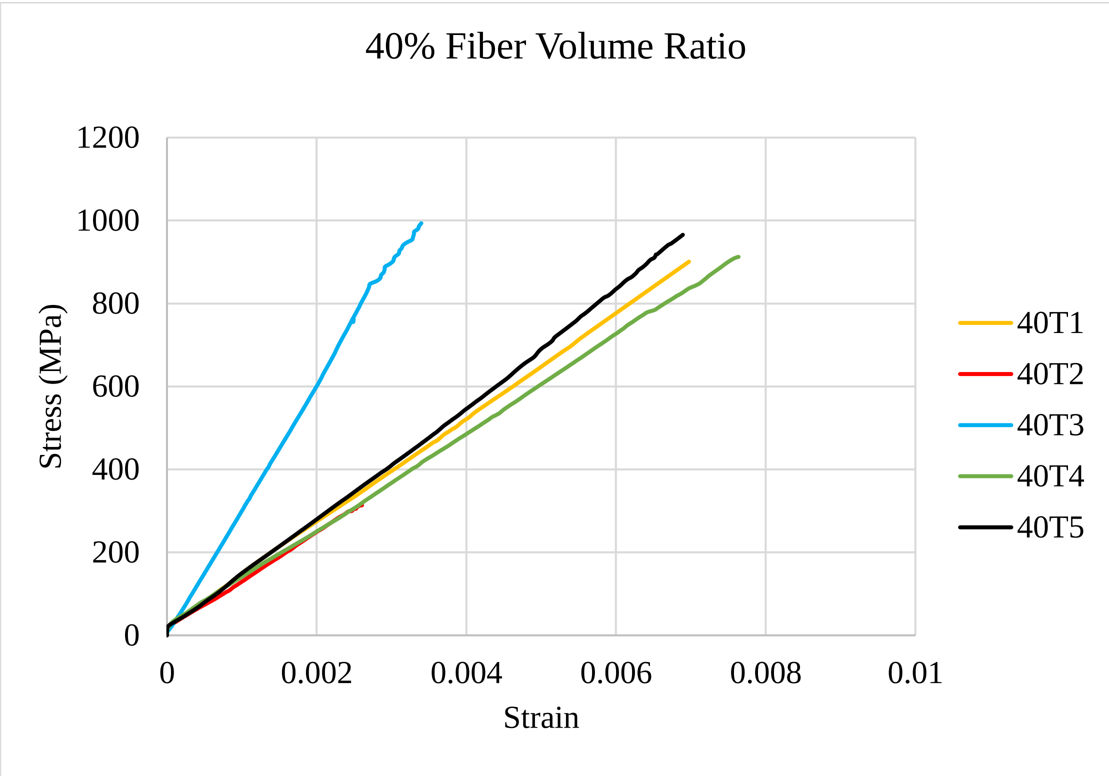

Figure 4.15: Stress versus Strain curve in tensile test with 40% fiber volume ratio.

The effect of fiber volume ratio on the tensile modulus of elasticity are listed in Table 4.5. The modulus elasticity varies from range 32643.2 MPa to 142501.7 MPa and the maximum of modulus elasticity was obtained in the composite plate with 40% of fiber to volume ratio.

Table 4.5: Tensile modulus of properties

Samples	Modulus of Elasticity (MPa)
0%	32643.2
10%	52069.3
20%	77874.2
30%	108474.5
40%	142501.7

When comparing to the trend lines of each BFRCP with respect to their fiber volume ratio, it is clearly shown that 40% of fiber loading contributed the highest ultimate strength due to the ideal mix amount that created strong adhesion between the fiber and resin. Therefore, the performance of 40% fiber ratio composite plate greatly improved the mechanical properties.

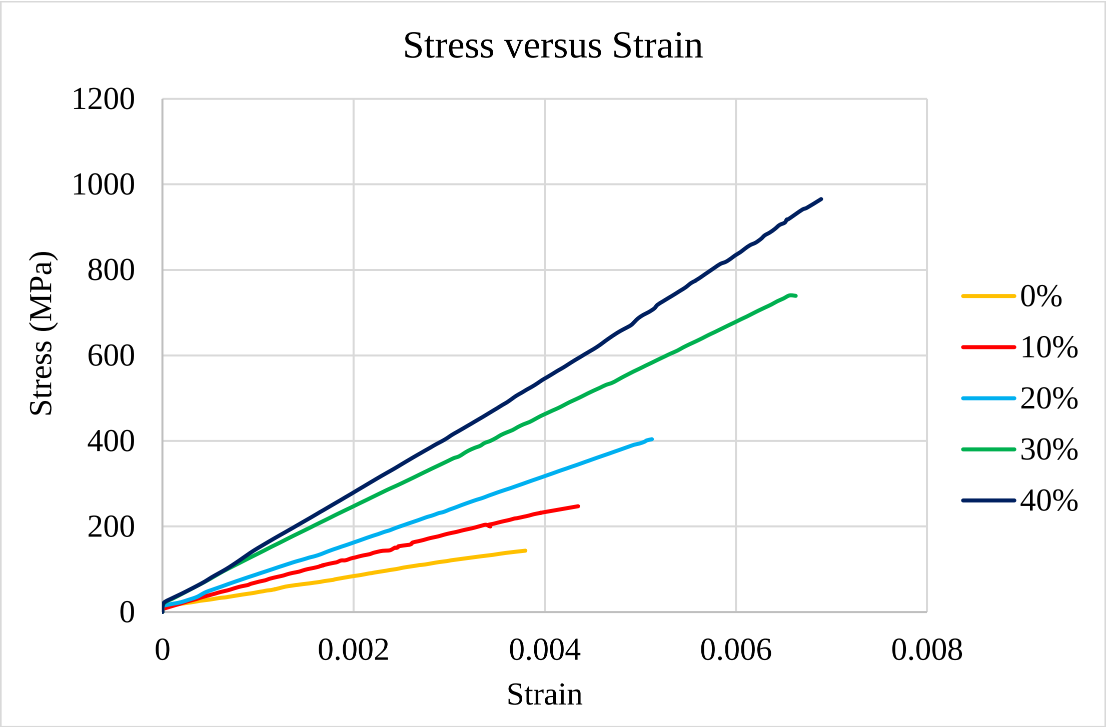

Figure 4.16: Comparison of stress versus strain in tensile test.

4.3.3 THERMAL PROPERTIES TEST

Thermogravimetric Analysis (TGA**)** was performed to examine the degradation mechanisms and reaction kinetic of fiber composite plate.

4.3.3.1 THERMOGRAVIMETRIC ANALYSIS (TGA)

The TGA curves of the composite plate with 0% to 40% of fiber volume ratio is shown in Figure 4.17. During the process of fabrication, the bamboo fiber were exposed to high temperatures of around 200 °C for most of the thermoset polymers (Matheus, et al., 2014). Thermal degradation of fiber due to the high temperatures may affect the mechanical properties of the composite plate. Thus, TGA analysis was conducted to determine the degradation profile of the fiber prior to their use in composite applications.

Referring to the Figure 4.17, there was a peak of weight loss at approximately 100°C indicating the removal of moisture from the fiber and further thermal degradation takes place as a three-step process. In the first step, the degradation of hemicellulose takes place at around 300 °C. After that, a second weight loss occurs at around 400 °C, due to the main degradation of cellulose. Finally, the slow lignin degradation takes place between 250 °C and 600 °C. Thermal decomposition in the temperature range of 240–350°C. However, the exact thermal decomposition temperature for bamboo fiber - vinyl ester composites was 320°C.

Hemicellulose is one of the fiber components which is responsible for the initial thermal degradation behavior and is also associated with the moisture content. The higher activity of hemicellulose in thermal decomposition might be attributed to its chemical structure. Hemicellulose has a random amorphous structure, and it is easily hydrolyzed. Therefore, fibers containing high hemicellulose content should absorb more moisture and degrade at a lower temperature. In contrast, the cellulose molecule is a very long polymer of glucose units, and its crystalline regions improve the thermal stability of lignocellulosic fibers. Lignin is different from hemicellulose and cellulose, because it is composed of three kinds of benzene-propane units, being heavily cross-linked and having very high molecular weight. The thermal stability of lignin is thus very high, and it is difficult to decompose (Matheus, et al., 2014).

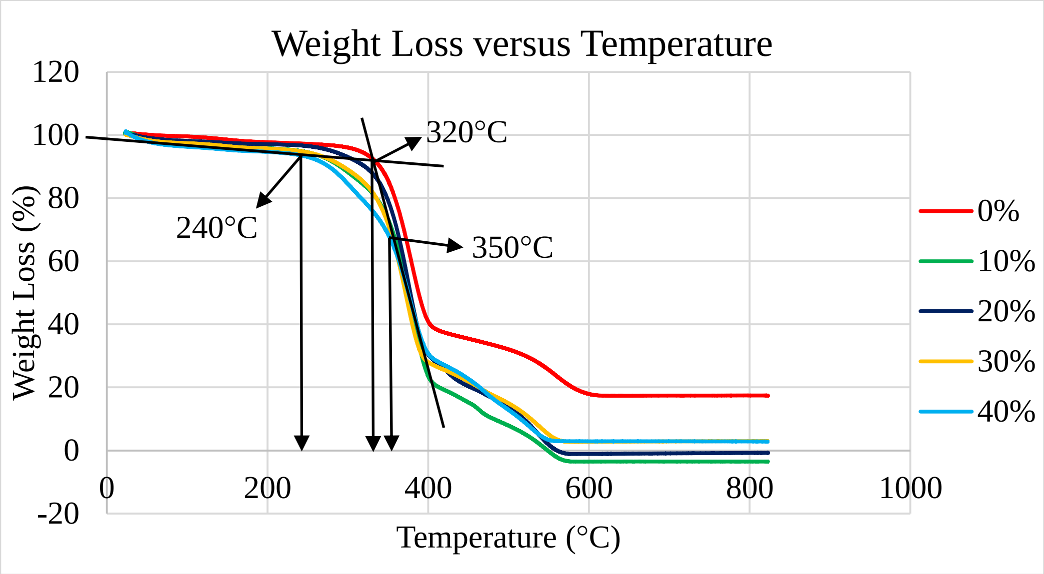

Figure 4.17: Weight versus Temperature graph of TGA.

4.4 STRENGTHENING BEHAVIOUR OF RC BEAMS IN FLEXURE

Four-point loading system was adopted for the test. For strengthening of RC beams in the flexural zone, 40% fiber to volume ratio of bamboo fiber-vinyl ester composite plate (BFRCP) in a dimension of 120 mm in width, 10 mm in thick with a total length of 450 mm was fabricated and bonded to the mid-span of the RC beam soffit by using Sikadur-30 epoxy adhesive. The ultimate load, deflection, ultimate load, cracks pattern and type of failure were observed and recorded.

4.4.1 LOAD AND DEFLECTION RESPONSE

Control Beam (CB)

At the initial stage of loading, a steady upward trend was observed proportional to the load and deflection as shown in Figure 4.18. When the yield stress point reached at load of 133.6 kN with a deflection of 6.7 mm, the behaviour of the beam changed into plastic behaviour and increased gradually resulting in a curve that rises continuously on the strain hardening stage until it achieved the ultimate load at 151.9 kN with a deflection of 15.8 mm. Upon reaching the ultimate load, a sharp drop can be seen at the necking stage until it failure.

Un-strengthened Solid Beam (VUSB)

Referring to Figure 4.18, at the initial proportional limit stage, the value of load and deflection remains proportional with a steep slope upward curve. The entire concrete section is considered in resisting the loads effectively when the deflection is directly proportional to the applied load. The yield stress point occurred at 112.4 kN of load and 6.3 mm of deflection. After the yielding point, the graph shows a progressive increase in load and deflection until it reaches the ultimate load point indicating high ductility. The beam failed at the peak load of 132.1 kN along with a deflection of 20.5 mm. Beyond the ultimate load, the deflection of the beam was increasing appreciably with the load declined dramatically.

Strengthened Solid Beam (VSSB)

Figure 4.18 depicts a linear straight line at the initial phase of testing. The load and deflection of the strengthened solid beam was linearly increased up to the yielding point at 112.1 kN with a deflection of 6.1 mm. Prior to the breaking point, it achieved an ultimate load of 134.9 kN and deflection of 20.2 mm. The load dropped gradually with the increase in deflection. The loads were mainly carried by the flexural reinforcement individually was now strengthened by using BFRCP.

Comparison

The response of the RC solid beam was included for the purpose of comparison. The control beam (CB) and solid beam strengthened using BFRCP (VSSB) are used to compare with solid beam un-strengthened using BFRCP (VUSB). In addition, the solid beam strengthened using BFRCP (VSSB) was also compared to the control beam (CB). Table 4.6 lists the comparison in ultimate load and Table 4.7 summarizes the maximum deflection value at the mid span beam. Figure 4.18 shows the comparison graph of load versus deflection curves for beams CB, VUSB and VSSB.

Comparison between CB and VUSB

Referring to Figure 4.18, the beams CB and VUSB showed similar elastic deformation pattern, however, un-strengthened beam showed slightly lower in load capacity than the control beam. As the deflection was about 6.3 mm, yield points for VUSB was reached at 112.4 kN and started the phase of plastic deformation. However, the yield point of CB achieved later than VUSB which is at deflection of 7.0 mm. Control beam started to deform when the load achieved an ultimate point at 151.9 kN. The beam VSUB showed a reduction in ultimate load of about 13.0% compared to CB due to the elimination of shear link at the tension zone which reduced the ultimate load carrying capacity of the RC solid beam significantly. According to Table 4.7, the deflection of un-strengthened solid beam (VUSB) at the maximum ultimate load is higher than the control beam (CB) with approximately of 29.7%.

Comparison between VUSB and VSSB

The curve pattern for beams VUSB and VSSB are almost similar. As the deflection was about 6.3 mm, yield points for all the beams were reached and started the phase of plastic deformation. However, beam VSSB showed a slightly higher load capacity compared to VUSB. Beam VSSB increased the ultimate load for about 2.0% compared to VUSB. From the result of Table 4.7, the deflection rate for strengthened beam is lower than un-strengthened beam with 1.5%. The result indicates that BFRCP was potential to enhance the strength of the beam in carry higher loading than the un-strengthened beam. No significant difference in load increment was traced due to the span ratio of BFRCP used in strengthened the beams is not sufficient. In order to have significant enhancement in the ultimate load, span ratio of BFRCP must be at least equal to or more than $\frac{2}{3}$ of the overall beam's ratio.

Comparison between CB and VSSB

In comparison, it was found that strengthened beam was not capable to restore the load carrying capacity of the control beam. The beam VSSB still requires about 11.2% increment in load in order to restore the original beam capacity and the deflection had increased for about 27.8% of control beam. Increase the span ratio of BFRCP will be the possible reason to obtain higher ultimate load over the control beam.

Table 4.6: Comparison in terms of ultimate load.

Specimen	Ultimate Load (kN)	Strengthening Percentage (%)
Control Beam (CB)	151.9	-
Un-strengthen Solid Beam (VUSB)	132.1	13.0 (compared to CB) [-]
Strengthen Solid Beam (VSSB)	134.9	2.0 (compared to VUSB) [+] 11.2 (compared to VSSB) [-]

Table 4.7: Comparison in terms of deflection at mid span.

Specimen	Deflection at ultimate load (mm)	Deflection Percentage (%)
Control Beam	15.8	-
Un-strengthen Solid Beam (VUSB)	20.5	29.7(compared to CB) [+]
Strengthen Solid Beam (VSSB)	20.2	1.5(compared to VUSB) [-] 27.8(compared to CB) [+]

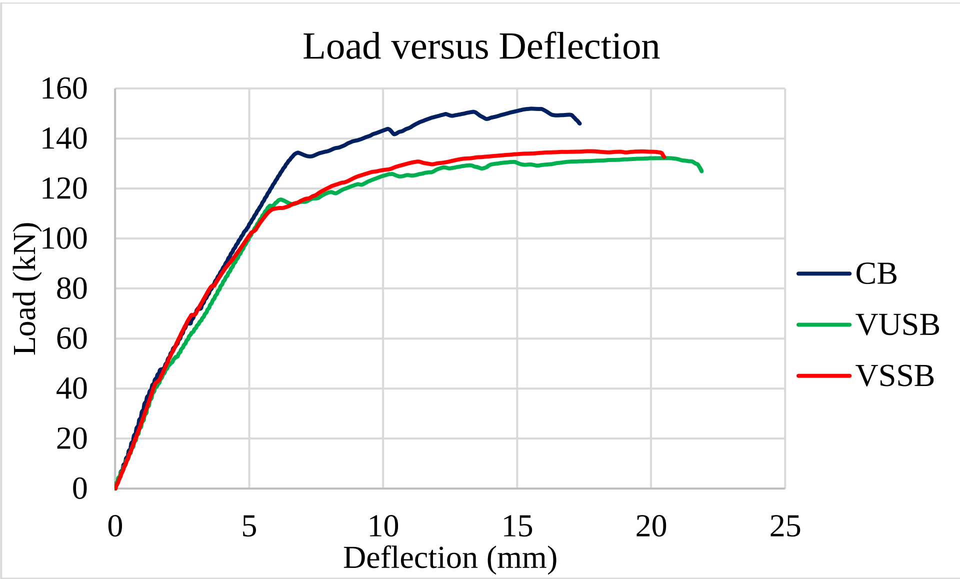

Figure 4.18: Load deflection curve of the different beam specimens

4.4.2 CRACK PATTERN

Control Beam (CB)

Figure 4.19 shows the cracks pattern of control beam. At the initial stage of loading, vertical cracks can be seen along the tension zone. Eventually, all the vertical cracks are concentrated in the mid span of the beam. The first crack appeared at about 70.0 kN and the vertical cracks propagated to the neutral axis of the beam. The cracks width enlarged along the mid-span before beam failure.

Un-strengthen Solid Beam (VUSB)

Figure 4.20 shows the cracks pattern of un-strengthened solid beam. From the figure, it is observed that more vertical cracks are formed along the tension zone compared to control beam due to removal of shear link at the flexural zone. The first crack happened at load beyond 50 kN and crack pattern was drawn and marked. The crack width at the beam mid-span is greater than the control beam as there are no shear links provided which is designed to reduce the strength in bending.

Strengthen Solid Beam (VSSB)

Figure 4.21 illustrates the cracks pattern for strengthened solid beam. It was found that little vertical cracks were formed along the flexural zone. At load 52 kN, vertical cracks were formed at the both edge sides of the plate away from the strengthened zone due to the effective strengthening of BFRCP. These vertical cracks then propagated with the increased of load until the neutral axis of the beam. The cracks width enlarged upon beam failure.

Table 4.8: Comparison in terms of first crack load and maximum crack width.

Specimen	First Crack Load (kN)	Max. Crack Width (mm)
Control Beam (CB)	70	7
Un-strengthen Solid Beam (VUSB)	50	12
Strengthen Solid Beam (VSSB)	52	15

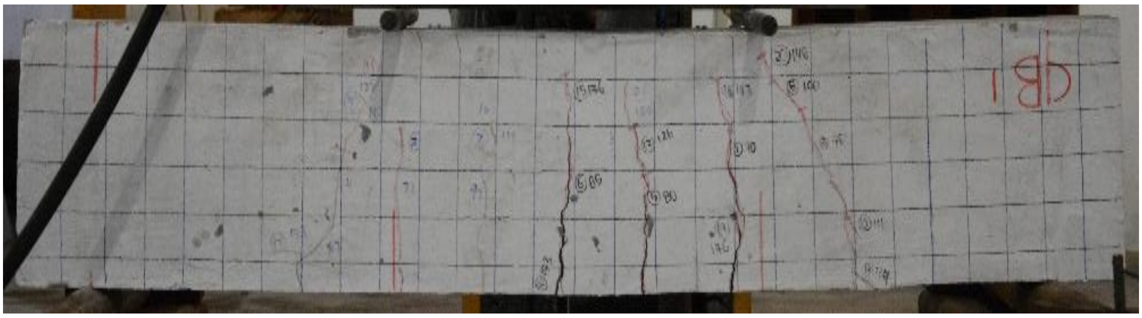

Figure 4.19: Crack pattern after failure for control beam (CB)

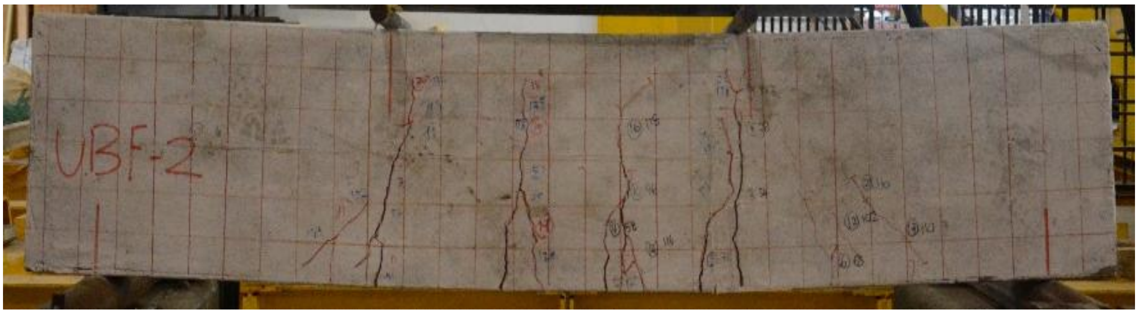

Figure 4.20: Crack pattern after failure for un-strengthened solid beam (VUSB)

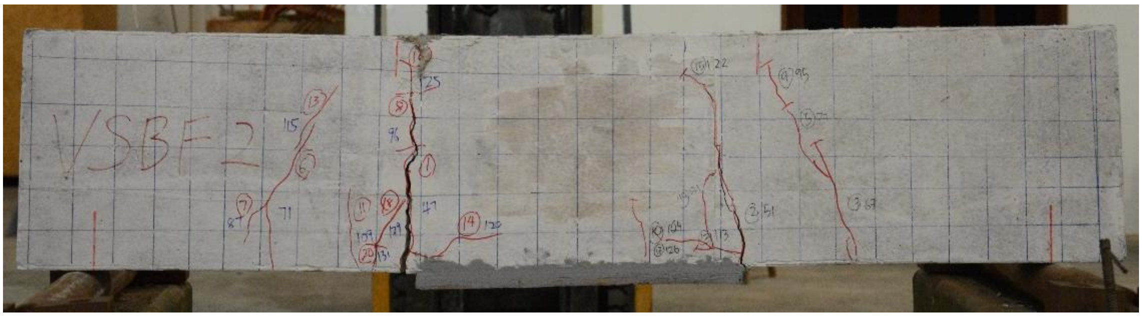

Figure 4.21: Crack pattern after failure for strengthened solid beam (VSSB)

4.4.3 FAILURE MODE

When the load is applied to the reinforced concrete beams, the vertical cracks appear in all solid specimens and the test was halted due to flexural failure of the specimens. Table 4.9 summarizes the failure modes of the solid beam specimens during the test.

Table 4.9: Failure modes of the solid beam specimens

Specimen	Failure Mode	Sequence of Failure Mode
CB	Flexural	i. Vectical crack ii. Concentrated cracks at mid-span iii. Beam failed gradually iv. Ductile failure
VUSB	Flexural	i. Vectical crack ii. Concentrated cracks at mid-span iii. Beam failed with vertical crack iv. Ductile failure
VSSB	Flexural	i. Vectical crack at the edge of the BFRCP ii. Mild cracks at mid-span iii. Beam failed with vertical crack iv. Ductile failure

4.5 STRENGTHENING BEHAVIOUR OF RC BEAMS IN SHEAR

For RC beam with circular openings, fabricated bamboo fiber-vinyl ester composite plate (BFRCP) with a dimension of 120 mm in width, 10 mm in thick and a total length of 450 mm was attached to the shear zone surface of the beam around the circular openings which is perpendicular to the diagonal cracks happened from the support to the loading point.

4.5.1 LOAD AND DEFLECTION RESPONSE

Control Beam (CB)

At the early elastic stage, the load and deflection of control beam remains proportional up to the yield point limit of 114.4 kN with a deflection of 6.1mm. Once the yield point is reached, the behaviour of the beam becomes plastic phase and continues to increase until it reaches the ultimate stress. The ultimate stress of control beam achieved at 147.6 kN with a deflection of 17.2 mm. Beyond the ultimate load, a sudden drop observed indicates the beam failure.

Un-strengthened Circular Opening Beam (VUOB)

The load versus deflection graph of the un-strengthened circular opening beam is plotted in Figure 4.22. At the initial linear part of the graph, the curve shows a very steep slope in which the deflection is directly proportional to the applied load and the entire concrete section is considered to be effective in resisting the loads. The end point of this linear part of the curve indicated the changing behaviour from elastic phase to plastic phase with a yield point limit of 46.7 kN in along with deflection of 1.7 mm. After the yielding point, the graph shows a steady increase in both load and deflection which indicating that the deflection rate per unit load is much faster that the beam cracks. This is also an indication of the stiffness reduction of the beam. The beam failed at the peak load of 68.7 kN along with a deflection of 4.7 mm. Beyond the ultimate load, the deflection of the beam was increasing appreciably with a dramatic decline in load.

Strengthened Circular Opening Beam (VSOB)

Figure 4.22 depicts a linear straight line in the initial phase of testing. The load and deflection of the strengthened circular openings beam (VSOB) were linearly increased up to the yielding point at 115.7 kN with a deflection of 6.3 mm prior to the ultimate load of 122.1 kN. The load dropped gradually after the peak point in along with detached of BFRCP showed that the ultimate load was achieved and both the beam and composite plate no longer can withstand any applied load.

Comparison

Table 4.10 shows the comparison in ultimate load and Table 4.11 present the maximum deflection value at the peak load. Figure 4.22 shows the comparison graph of load versus deflection curves for beam CB, VUOB and VSOB. The control beam (CB) and openings beam strengthened using BFRCP (VSOB) were used to compare with openings beam un-strengthened using BFRCP (VUOB). In addition, the openings beam strengthened using BFRCP (VSOB) was also compared to the control beam (CB) to determine the ability of BFRCP to restore loss strength.

Comparison between CB and VUOB

The results shows that the existence of the circular openings in the shear zone significantly reduced the ultimate load capacity of the RC beam. The ultimate load in beam VUOB was about 52.8 % lower than the beam CB. The beam CB failed gradually with vertical cracks in the mid-span zone while beam VUOB failed abruptly once it reached the ultimate load due to the de-bonding between the concrete and longitudinal steel reinforcement after the rapid progression of shear cracks developed from the support across the openings to the loading point. The web reinforcement in control beam (CB) effectively restricts the development of diagonal cracks. From Figure 4.22, it can be seen that the beam CB exhibited a higher deflection value at yield point and ultimate load as compared to the beam VSOB because the control beam deformed more elastically rather than plastically whereas beams with opening deformed more plastically instead of elastically.

Comparison between VUOB and VSOB

By comparing the results from Table 4.10, it is clearly shown that the ultimate load of surface strengthened openings beam (VUOB) was improved when compared to un-strengthened openings beam (VSOB). The shear zone was reinforced by BFRCP becomes stiffer, therefore VSOB was able to withstand higher load compared to VUOB. The ultimate load-carrying capacity of the beam VSOB at 122.1 kN showed that BFRCP are able to restore the loss strength in beam VUOB and added a strength of 77.8 % for openings beam with BFRCP strengthening. Due to the low elastic modulus of BFRCP, the stiffness of the strengthened openings beam was higher and shows a significant improvement in ductility. Highest failure loads of the beam VSOB resulted increases in deflection by 4.2 mm or 89.4% as compared to the beam VUOB. Thus, the BFRCP is effectively in strengthening the RC beam with circular openings.

Comparison between VSOB and CB

The beam VSOB shown a similar steady upward trend with the beam CB in the early stage of load versus deflection curve remarked that the BFRCP has a significant influence in strengthening the RC beam with circular openings as compared to the beam CB. However, Figure 4.22 indicates that the beam VSOB still unable to regain the load-carrying capacity of the beam CB. The beam VSOB still requires approximately 17.3 % of the load increment to fully restore the original beam capacity.

Table 4.10: Comparison in terms of ultimate load for circular openings beams

Specimen	Ultimate Load (kN)	Strengthening Percentage (%)
Control Beam (CB)	147.6	-
Un-strengthen Opening Beam (VUOB)	68.7	52.8 (compared to CB) [-]
Strengthen Opening Beam (VSOB)	122.1	77.8 (compared to VUSB)[+] 17.3 (compared to CB) [-]

Table 4.11: Comparison in terms of deflection for circular openings beams

Specimen	Deflection at ultimate load (mm)	Deflection Percentage (%)
Control Beam	17.2	-
Un-strengthen Solid Beam (VUSB)	4.7	72.7 (compared to CB) [-]
Strengthen Solid Beam (VSSB)	8.9	89.4 (compared to VUSB)[+] 48.3 (compared to CB) [-]

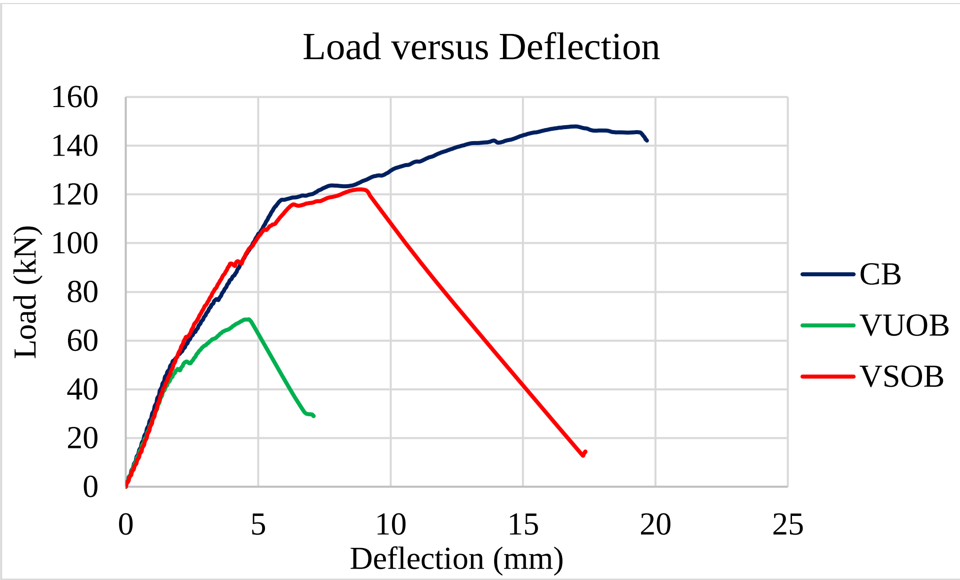

Figure 4.22: Load -deflection curve of circular opening beams.

4.5.2 CRACK PATTERN

Control Beam (CB)

Figure 4.23 shows the cracks pattern of control beam. All the vertical cracks are concentrated in the mid-span zone of the beam. The first crack appeared at about 65.0 kN and the vertical cracks propagated to the neutral axis of the beam. The cracks width enlarged along the mid-span before beam failure.

Un-strengthened Circular Openings Beam (VUOB)

It was observed that the diagonal cracks in beam VUOB started to appear at the support and slowly propagated towards the loading point. These diagonal shear cracks began at approximately 47 kN of the ultimate load which is appeared ealier than the bneam CB for about 27.7%. The shear cracks were the major failure planes of the beam. Few of the flexural cracks were seen developed at the tension mid-span of the beam. Eventually, when the applied load was increased, new diagonal cracks which approximately parallel to the initial diagonal cracks were appeared at the top and bottom chord of the openings. The failure occurred abruptly by a formation of two independent diagonal cracks at the top and bottom chords below and above the openings as shown in Figure 4.24. The maximum crack width value of failure mode was recorded as 12 mm. The beam VUOB was failed by shear across the circular openings due to the existence of openings interrupted the natural load path of the beam.

Strengthened Circular Openings Beam (VSOB)

Figure 4.25 shows the cracks pattern of strengthened beam with circular opening using BFRCP after failure. The strengthening procedure is designed based on the cracks pattern observed in beam VUOB. It was found that, the first cracks started to appear at 60 kN is almost similar to the control beam. Based on the test observations, the BFRCP detached at the ultimate load at the left bottom chord of opening upon beam failure. A wide crack width of 20 mm was detected on the left side of the beam. A sudden failure was observed with the detachment of BFRCP. The result shows that beam strengthened with BFRCP managed to resist stresses around the openings restricting diagonal cracks to form around the openings.

Table 4.12: Comparison in terms of first crack load and maximum crack width.

Specimen	First Crack Load (kN)	Max. Crack Width (mm)
Control Beam (CB)	65	7
Un-strengthen Opening Beam (VUOB)	47	12
Strengthen Opening Beam (VSOB)	60	20

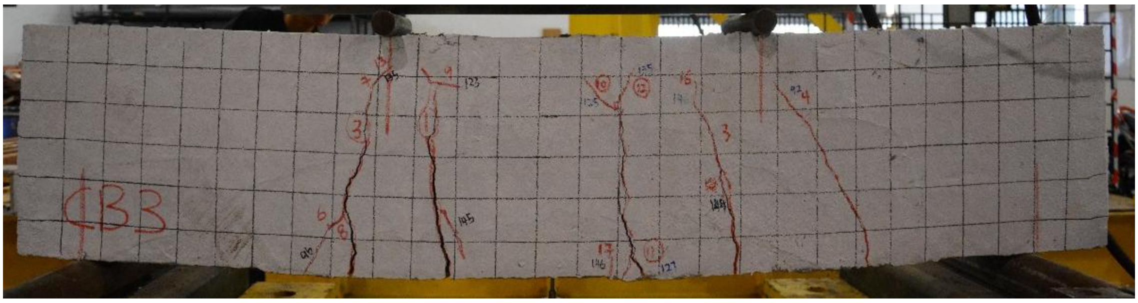

Figure 4.23: Crack pattern after failure for control beam (CB)

Figure 4.24: Crack pattern after failure for un-strengthened circular openings beam (VUOB)

Figure 4.25: Crack pattern after failure for strengthened circular openings beam (VSOB)

4.5.3 FAILURE MODE

Table 4.13 summarizes the failure modes of the control beam and beams specimens with circular openings during the test.

Table 4.13: Failure modes of RC beams with circular openings

Specimen	Failure Mode	Sequence of Failure Mode
CB	Flexural	i. Diagonal cracks ii. Crushing of concrete at shear zone iii. Beam failed gradually iv. Ductile failure
VUOB	Flexural	i. Diagonal cracks ii. Crushing of concrete at shear zone iii. Beam failed abruptly iv. Brittle failure
VSOB	Flexural	i. Diagonal cracks ii. Crushing of concrete at shear zone iii. Beam failed abruptly iv. Brittle failure

CHAPTER 5

CONCLUSION AND RECOMMENDATION

5.1 INTRODUCTION

This chapter summarized all the discussions and discoveries of the research. The physical properties, mechanical properties and thermal properties of the bamboo fiber-vinyl ester composite plate were investigated as well as the potential use of bamboo fiber-vinyl ester composite plate in RC strengthening. At the end of this chapter, the recommendations for future work reference are given.

5.2 CONCLUSION

In view of the results obtained from the discussion, the entire experimental project has achieved the goal. Several conclusions can be drawn based on the results discussed:

i. The FTIR result certify the existence of cellulose, hemicellulose and lignin in bamboo fiber-vinyl ester composite plate where its function were to enhance the adhesion between the fiber and the matrix. The bands in wavelength are the same for all the fiber volume ratio from 10% up to 40%. In terms of mechanical properties test, it was found that both flexural strength and tensile strength of BFRCP increased with the increases of fiber volume ratio from 0% to 40%. The optimum ratio of plate fabrication was 40% of the fiber volume ratio due to the highest strength achieved by a total improvement of 271.6% and 702.7% in flexural test and tensile test respectively when compared to neat vinyl ester plate. On the other hand, the TGA test revealed that the precise degradation temperature of BFRCP was 320°c.

ii. Strengthened solid RC beams with BFRCP increased the strength of the beam approximately by 2.0% when compared to un-strengthened solid beam that reduced the load-carrying capacity for about 13.0% of control beam. However, the strengthened solid RC beams with BFRCP still require for 11.2% increment in load in order to restore the original beam capacity completely. In terms of crack pattern and failure mode, vertical crack were found along the mid-span in the tension zone of the control and un-strengthened solid beams. However, concentrated vertical cracks in the un-strengthened solid beam were traced compared to the control beam as shear link at the mid-span have been eliminated. Control beam failed gradually while the un-strengthened solid beam failed with vertical crack in ductile mode. Strengthened solid beam with BFRCP had diverted the vertical cracks that initially formed in the mid-span of the beams to the edge of the plate and had failed when the ultimate load was achieved.

iii. The application of BFRCP contributed significant enhancement in ultimate load-carrying capacity and the crack speed of strengthened circular openings beam. An improvement of 77.8% was observed when compared to un-strengthened beam with circular openings that had decreased the beam strength in about 52.8%. However, the strengthened beam with circular openings still requires approximately 17.3 % of the load increment to fully restore the original beam capacity. In terms of crack pattern, all vertical cracks are concentrated in the mid span zone of the control beam and the beam failed slowly with increasing of load to the ultimate. The strengthened and un-strengthened circular openings beam were failed by shear across the circular openings due to the existence of openings interrupted the natural load path of the beam. The diagonal cracks started to appear at the support and slowly propagated towards the loading point. The BFRCP of strengthened circular openings beam was detached from the surface upon beam failure.

5.3 RECOMMENDATIONS

Recommendations to enhance the performance of BFRCP in strengthening the RC beams as well as the ultimate load-carrying capacity of beams are elaborated as below:

i. In order to obtain a significant improvement in the tension of reinforced concrete (RC) soild beam, the span ratio of BFRCP must be equal to or greater than $\frac{2}{3}$ of the total length of the beam.
ii. For RC beams with circular openings, it is recommended to use a double surface strengthening method to achieve a higher ultimate load, which can fully restore the original beam strength or even superior than the control beam.

5.4 LIMITATION OF CURRENT RESEARCH

In the present study, it was difficult to obtain long bamboo fiber in excess of 450 mm due to the presence of internodes in bamboo that resulting in a weak strength which could affect the properties of bamboo fiber and fabrication of composite plate. Therefore, the span of BFRCP used in flexural strengthening was limited and only showed a little increment in the ultimate load compared to the control beam.

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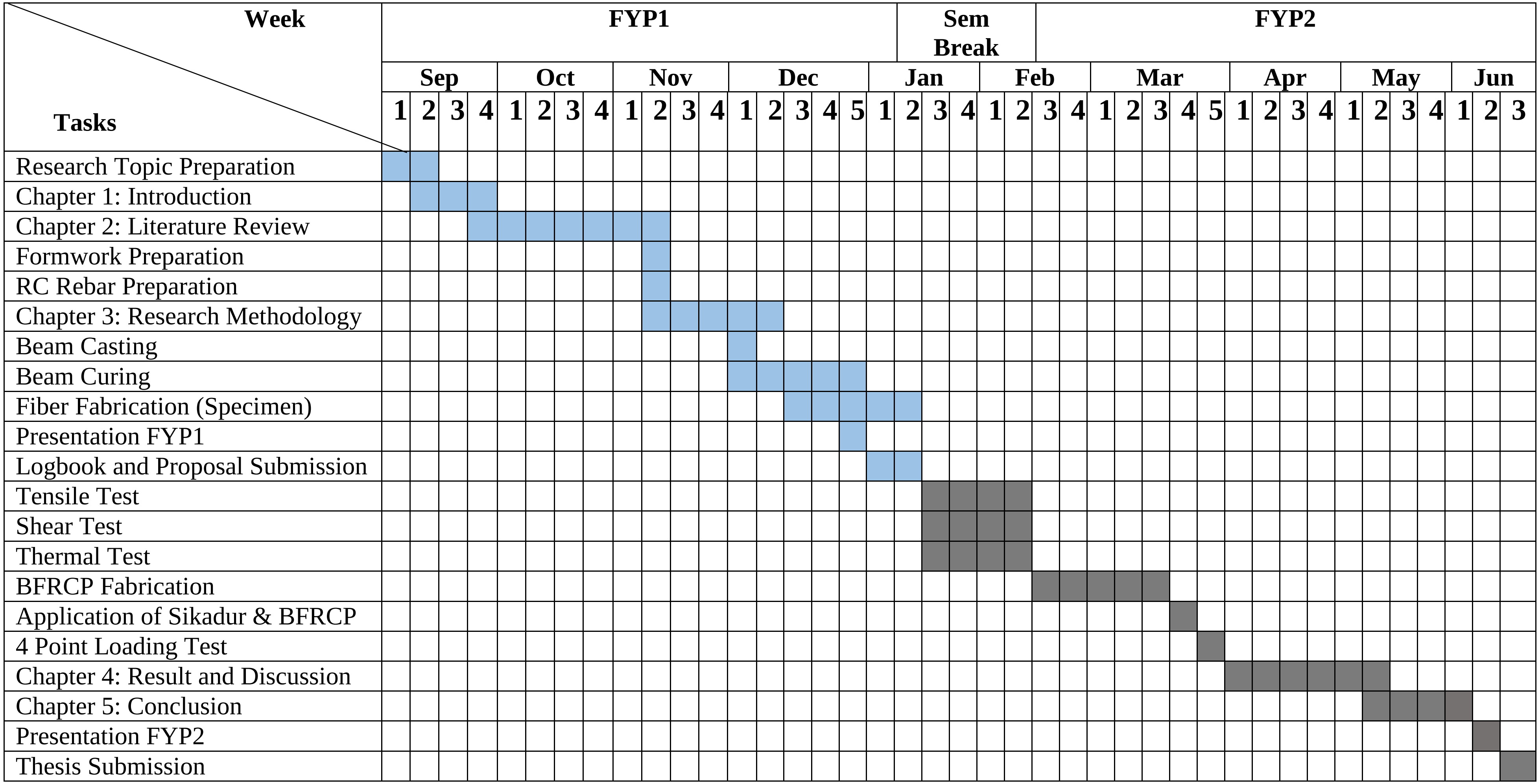
APPENDIX A

GANTT CHART



APPENDIX B

CALCULATION BY VOLUME FOR DIFFERENT FIBER LOADING OF BFRCP

Flexural Specimen										
	Density of Bamboo Fiber			=	890 kg/m3	0.89 g/cm3				
	Density of Vinyl Ester			=	1050 kg/m3	1.05 g/cm3				
	Dimension of Composite Plate			=	127 x 12.7x 4 mm					
	Volume of Plate			=	6451.6 mm3	6.4516 x 10^-6 m3				
Vinyl Ester										
Fiber (%)	Weight (g)	Resin (%)	Resin (g)	MEKP (g)	Cobalt (g)	No	Total Fiber (g)	Total Resin (g)	Total MEKP (g)	Total Cobalt (g)
0	0	100	6.774	0.13548	0.006774	5	0	33.87	0.6774	0.03387
10	0.5742	90	6.097	0.12194	0.006097	5	2.871	30.485	0.6097	0.030485
20	1.1484	80	5.419	0.10838	0.005419	5	5.742	27.095	0.5419	0.027095
30	1.7226	70	4.472	0.08944	0.004472	5	8.613	22.36	0.4472	0.02236
40	2.2968	60	4.065	0.0813	0.004065	5	11.484	20.325	0.4065	0.020325
50	2.781	50	3.387	0.06774	0.003387	5	13.905	16.935	0.3387	0.016935

Tensile Specimen										
	Density of Bamboo Fiber			=	890 kg/m3	0.89 g/cm3				
	Density of Vinyl Ester			=	1050 kg/m3	1.05 g/cm3				
	Dimension of Composite Plate			=	250 x 25 x 3 mm					
	Volume of Plate			=	18750 mm3	1.875 x 10^-5 m3				
Vinyl Ester										
Fiber (%)	Weight (g)	Resin (%)	Resin (g)	MEKP (g)	Cobalt (g)	No	Total Fiber (g)	Total Resin (g)	Total MEKP (g)	Total Cobalt (g)
0	0	100	19.688	0.39376	0.019688	5	0	98.44	1.9688	0.09844
10	1.6688	90	17.719	0.35438	0.017719	5	8.344	88.595	1.7719	0.088595
20	3.3375	80	15.75	0.315	0.01575	5	16.6875	78.75	1.575	0.07875
30	5.0063	70	13.781	0.27562	0.013781	5	25.0315	68.905	1.3781	0.068905
40	6.675	60	11.813	0.23626	0.011813	5	33.375	59.065	1.1813	0.059065
50	8.3438	50	9.844	0.19688	0.009844	5	41.719	49.22	0.9844	0.04922

APPENDIX C

DATA SHEET OF VINYL ESTER BISPHENOL A

Technical data sheet

Epovia® Optimum KRF 1001

Resin Epoxy at base of Vinylester Bisphenol A

Version : April 2015
Page 1/2

Appearance
Clear liquid resin

Main resin characteristics
Resin Epoxy Vinylester Bisphenol A
Medium Viscosity / Medium Reactivity
Low Colour - Controlled Exotherm

Approvals
Complies with Group 7A according to
EN 13121-1 : 2003 (Table 2)
LLOYD'S Register Shipping Approved

Moulding information
Hand lay-up

Other possible process
Filament Winding – Pultrusion - Injection moulding

Main applications
Corrosion resistance

Other possible applications
Glass flake coatings – Heat resistance
Pipes, tanks, containers, floor coverings

Shelf life and storage
- Store in the shade out of direct sunlight below 30℃ in sealed containers
- The shelf-life will be reduced if the resin is exposed to higher temperatures
- Use within shelf life specified on the container.
For tanker deliveries the shelf-life is 3 months after delivery date

Precautions for handling
Please find the current SDS on internet
www.ccpcomposites.com

Characteristics, Methods and Conditions	Values (Average values)
Liquid properties	
-Specific weight at 25 ℃ :	1.05 – 1.10 g/cm³
-Viscosity (dPa.s): V23	Brookfield at 23 ℃
Spindle 2 Speed 50 rpm :	2.5 – 4.5
-Solid content (%) : PC53	56 – 60
-Reactivity :	
Method :	R 200 (100g)
Test temperature :	23 ℃
Catalyst system :	0.5 % NL-23 1.5 % MEKP 8.5 % active oxygen (Butanox LPT or K12)
Gel time :	15 – 25 mn
Peak time :	25 – 45 mn
Peak temperature :	145 – 165 ℃
Mechanical properties (cured resin non reinforced)	
-Tensile ISO 527 (1999)	
-Tensile strength (MPa) :	85
-Tensile modulus (Mpa) :	4000
-Elongation at break (%) :	4
-Flexural ISO 178 (2003)	
-Flexural strength (MPa) :	150
-Flexural modulus (MPa) :	3600
Thermomechanical properties (cured resin non reinforced)	
-HDT ISO 75-2 A (1999) (℃):	108
-Tg (by DMA method) (℃) :	131

Post Cure Conditions – 24 hours room temperature / 2 hours at 80℃ / 1 hour at 120℃

Polynt Composites France Route D'Arras CS 50019 – 62320 Drocourt • France •
Tél. +33 3 21 74 84 00 • Fax +33 3 21 49 55 84 • www.polynt.com •

APPENDIX D

DATA SHEET OF COBALT ACCELERATOR

Product Report List

Product Name : Cobalt 10 %
Model : AC931-A
Quantity : 200 kg
Manufacturing Date : 13.08.08

Potential Threats :
Fire & Explosion Risks : Inflammable , avoid high temperature , keep away from sources of fire . May burn or explode if react with strong oxidants .

Health Risks :
Toxic , Inhale a high concentration of fumes may cause headache , nausea , vomiting and other symptoms .

First Aid Measures :
If inhaled or come into contact with mouth or eyes , rinse thoroughly with fresh water immediately .For serious cases , consult a doctor at once .

Fire protection measure :
Method: Use dry CO_2 powder anti-solvent foam extinguishers or sand to put out fire.
Caution : First of all, cut off power supply , wear anti-fire suit and anti-poison mask.

Delivery information :
Packaging : packed in tightly sealed, clean, dry iron barrels or plastic barrels.
Caution : Handle with care. Avoid sources of fire. Do not pack or deliver together with strong oxidants.

Storage :
Store in a cool and ventilated place. Avoid sources of fire and heat. Do not store together with strong oxidants. Use with other fire protection materials.

Constituent :
cobalt octoate
2-ethyl hexanoic acid

Quality inspection :

Areas of inspection	**Index**	**Inspection results**	**Remark**
Appearance	-glue liquid blue purple colour		Pass
Total metal content	≥ 10% - ±0.2%	≥ 10% - ±0.2%	Pass
Specific gravity	0.95- 1.10	0.95- 1.10	Pass
Viscosity	270-350	270-350	Pass

Conclusion : This product is qualified.
Received by : Date :

APPENDIX E

DATA SHEET OF HARDENER METHYL ETHYL KETONE PEROXIDES

BUTANOX M-50
BUTANOX M-60

Methyl ethyl ketone peroxides
Phlegmatised with dimethyl phthalate

BUTANOX M-50 and the about 10% higher concentrated BUTANOX M-60 are general purpose organic peroxides for the curing of unsaturated polyester resins in the presence of a cobalt accelerator. The may be used for the curing at room temperature or at elevated temperatures.

The curing system BUTANOX M-50 / cobalt accelerator are particularly suitable for the gelcoat resins laminating resins, lacquers and castings; moreover the manufacture of light resistant parts may be possible contrary to the curing system benzoyl peroxide / amine accelerator.

<u>PRODUCT INFORMATION</u>

A.1. CHARACTERISTICS

	Butanox M-50	**Butanox M- 60**
Appearance	clear, colourless liquid	clear, colourless liquid
Active oxygen content *	9.0 % min	9.9 % min
Specific gravity at 2°C	50 % min	50 % min
Critical temperature in a highly reactive unsaturated polyester resin	70 °C	70 °C
Flash point ** (M.C.O.C.)	> 100 °C	> 100 °C

A.2 PACKAKING SIZE

Standard packaging size : Butanox M-50, 30 kilos net
Butanox M-60, 30 kilos net

BUTANOX M-50 and BUTANOX M-60 can be supplied in 5 kg packs if required. The containers are provided with a venting device.

A.3 STABILITY

The stability of BUTANOX M-50 and BUTANOX M-60 is seriously impaired by a wide range of impurities. Therefore, contamination and contact with iron, copper, other heavy metals and their compounds, metal soaps, siccatives, amines and reduring agents must be avoided.

APPENDIX F

DATA SHEET OF SIKADUR® 30 EPOXY LAMINATING RESIN

Product Data Sheet
Edition 01/02/2012
Identification no:
01 04 01 04 001 0 000001
Sikadur®-30

Construction

Sikadur®-30

Adhesive for bonding reinforcement

Product Description	Sikadur®-30 is a thixotropic, structural two part adhesive, based on a combination of epoxy resins and special filler, designed for use at normal temperatures between +8°C and +35°C.
Uses	Adhesive for bonding structural reinforcement, particularly in structural strengthening works. Including: ■ Sika® CarboDur® Plates to concrete, brickwork and timber (for details see the Sika® CarboDur® Product Data Sheet, the "Method Statement for Sika® CarboDur® Externally Bonded Reinforcement" Ref: 850 41 05 and the "Method Statement for Sika® CarboDur® Near Surface Mounted Reinforcement" Ref: 850 41 07). ■ Steel plates to concrete (for details see the relevant Sika® Technical information).
Characteristics / Advantages	Sikadur®-30 has the following advantages: ■ Easy to mix and apply. ■ No primer needed. ■ High creep resistance under permanent load. ■ Very good adhesion to concrete, masonry, stonework, steel, cast iron, aluminium, timber and Sika® CarboDur® Plates. ■ Hardening is not affected by high humidity. ■ High strength adhesive. ■ Thixotropic: non-sag in vertical and overhead applications. ■ Hardens without shrinkage. ■ Different coloured components (for mixing control). ■ High initial and ultimate mechanical resistance. ■ High abrasion and shock resistance. ■ Impermeable to liquids and water vapour.

Tests

Approval / Standards	Deutsches Institut für Bautechnik Z-36.12-29, 2006: General construction authorisation for Sika® CarboDur®. IBMB, TU Braunschweig, test report No. 1871/0054, 1994: Approval for Sikadur®-30 Epoxy adhesive. IBMB, TU Braunschweig, test report No. 1734/6434, 1995: Testing for Sikadur®-41 Epoxy mortar in combination with Sikadur®-30 Epoxy adhesive for bonding of steel plates. Testing according to EN 1504-4

APPENDIX G

CONCRETE MIX DESIGN COMPUTATION & SUMMARY

PAMIX SDN BHD	**PAMIX SDN. BHD.** (Company No. 261694-H) A-9, 2ND & 3RD Floor, Pusat Komersial Kuantan Perdana Jalan Tun Ismail, 25000 Kuantan, Pahang Darul Makmur, Tel : 09-5172810 / 2813 / 2819 / 2820 Fax : 09 - 5172821	Document No. Revision No. Effective Date Page No.	: PSB-F-QA-01-02 : 0 : 01/04/2017 : 1 of 1

CONCRETE MIX DESIGN COMPUTATION & SUMMARY

CONTRACTOR :

PROJECT :

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 **30 N/mm2 at 28 days** below which 5 % of test results may be expected to fall	
	1.3	Designed Standard Deviation	4 N/mm2	
	1.4	Designed Margin	1.64 * = 7 N/mm2	
	1.5	Target Mean Strength	**37 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	0.52	
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	170	Kg/m3
3	3.1	Cement Content (OPC)	330	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	2332	Kg/m3 (Average)
	4.3	Total Aggregate Content	1832	Kg/m3
5	5.1	Grading of Fine Aggregate	BS 882 C or M Limit	
	5.2	Proportion of Fine Aggregate	43.3%	
	5.3	Fine Aggregate Content	793	Kg/m3
	5.4	Coarse Aggregate Content	1039	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
30	**75 ± 25**	**330**	**1039**	**793**	**170**	**5.55**	**0.52**

7 **ADMIXTURES**

Mighty 85 RA (RETARDAR) at	500	ml / 100 kg of OPC @	**1.7**	lit / m3
Mighty 150M (PLASTICIZER) at	0	ml / 100 kg of OPC @	**0.0**	lit / m3

8 **REMARKS**

Mix Code : P304
Plant : BATU 12

Prepared by,
Name : Mohd Faisal Bin Ali
Position : Sr. QA/QC Executive

Date : ***20/04/2017***

APPENDIX H

BONDS WAVELENGTH REFERENCE TABLE FOURIER TRANSFORM INFRARED SPECTROSCOPY

Peak wavenumber (without dislocation) (cm^{-1})	Peak wavenumber (with dislocation) (cm^{-1})	$\Delta\nu(cm^{-1})$	Bonds
3327	3332	5	OH stretching
2883	2882	-1	C–H symmetrical stretching
1724	1724	0	C=O stretching vibration
1623	1624	1	OH bending of absorbed water
1506	disappear	-	C=C aromatic symmetrical stretching
1423	1423	0	HCH and OCH in-plane bending vibration
1368, 1363	1367,1363	-1/0	In-the-plane CH bending
1325	1325	0	S ring stretching
1314	1313	-1	CH_2 rocking vibration at C6
1259	1261	1	G ring stretching
1245	1244	-1	C-C plus C-O plus C=O stretch; G condensed > G etherfied
1232	1231	-1	COH bending at C6
1204	1199	-5	C-O-C symmetric stretching, OH plane deformation
1152	1156	4	C-O-C asymmetrical stretching
1046	1043	-3	C-C, C-OH, C-H ring and side group vibrations
1020	1018	-2	C-C, C-OH, C-H ring and side group vibrations
994	996	2	C-C, C-OH, C-H ring and side group vibrations
895	894	-1	COC,CCO and CCH deformation and stretching
662	663	1	C-OH out-of-plane bending