BEHAVIOUR OF CONCRETE BEAMS REINFORCED JUTE FIBER MAT

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ABSTRAK

Dalam tahun-tahun kebelakangan ini, potensi kegunaan jut sebagai penggantian tetulang dalam konkrit bertetulang telah menarikan perhatian penyelidik, jurutera dan saintis. Penggunaan polimer bertetulang gentian (FRP) sebagai bahan tetulang semakin popular kerana kekuatan mekanikal dan kemurahan kos. Laporan kajian ini adalah mengenai sifat-sifat mekanik jut fiber mat (JFM) serta kelakuan JFM sebagai tetulang keluli dalam rasuk konkrit bertetulang. Gentian jut telah dirawat dengan 5% (w/v) natrium hidroksida, NaOH dalam suhu bilik dengan tempoh 4 jam. Ujian gentian tunggal telah dijalankan untuk mengkaji perbezaan antara dirawat dan tidak dirawat gentian jut dari segi kekuatan tegangan ekapaksi dan pemanjangan. Serat jut yang dirawat telah digunakan dalam fabrikasi JFM dengan kandungan serat yang berbeza 15%, 20%, 25% dan 30%. Semua sampel JFM telah menjalani ujian tegangan dan ujian lenturan denagan menggunakan mesin ujian universal (UTM) untuk menentukan nisbah isipadu gentian optimum. Sebanyak enam (6) sampel rasuk konkrit dengan kekuatan mampatan 25 MPa telah diuji dengan tiga mata loading. Keenam-enam sampel tersebut terdiri daripada dua rasuk kawakan (CB), dua rasuk konkrit bertetulang JFM (JFMB) dan dua rasuk yang diperkuatkan dengan dua keluli dengan diameter 10 mm JFM bertetulang (SB). Rasuk dalam kajian ini mempunyai keratan rentas 100 mm di kedua-dua lebar dan kedalaman serta jumlah panjang 500 mm. Kekuatan tegangan maksimum jut yang dirawat dengan larutan natrium hidroksida didapati meningkat sebanyak 71.3%, manakala pemanjangan pada beban berbuka menurun sebanyak 44.3%. Dari segi sifat-sifat mekanik, JFM dengan 25% kandungan serat menunjukkan bahawa kekuatan tegangan maksimum tertinggi 73.2 MPa, manakala 15% kandungan serat mempunyai kekuatan lenturan yang paling tinggi 75.2 MPa. JFM dengan 25% kandungan serat dianggap sebagai jumlah serat yang optimum dan digunakan sebagai mat tetulang dalam kajian ini. Dari ujian tiga mata loading, JFMB berjaya mengekalkan beban muktamad 10.60 kN dengan pesongan 0.6 mm. Walaupun, kapasiti beban rasuk JFMB adalah 26.34% lebih tinggi daripada rasuk CB tetapi hanya mencapai 28.7% kekuatan rasuk SB. Rasuk JFM telah gagal dengan cara yang rapuh di bawah lentur dengan retak menegak dalam zon ketegangan.

ABSTRACT

Jute fiber has recently become attractive to researchers, engineers and scientists as a potential to be a substitute reinforcement in reinforced concrete. The use of the jute fiber fabric and fiber reinforced polymer (FRP) as the reinforcement materials has gained popularity due to their mechanical strength and inexpensive cost. This research presents a study of the mechanical properties of Jute fibre mat (JFM) as well as the behaviour of the JFM-reinforced concrete beam. Jute fibres were chemically treated with the 5% (w/v) sodium hydroxide, NaOH over 4 hours duration at room temperature, thus the single fiber test was conducted to study the differences between treated and untreated fiber filament in term of uniaxial tensile strength and the elongation. Subsequently, the treated jute fiber was used in the fabrication of the JFM with a different fibre volume ratio of 15%, 20%, 25% and 30%. All the JFM samples were undergone the tensile and flexural test by using the Universal Testing Machine (UTM) to determine the optimum fibre volume ratio. In terms of structural properties, a total of six (6) concrete beams with compressive strength of 25 MPa were tested to failure under three-point loading, which includes two control beams (CB), two JFM reinforced beams (JFMB) and two beams that reinforced by two steel bars with a diameter of 10 mm (SB). The beam had a cross section of 100 mm in both width and depth as well as a total length of 500 mm. By comparing with the untreated fiber, the maximum tensile strength of treated jute fiber with sodium hydroxide solution was found to increase by 71.3%, whereas the elongation at break decreased by 44.3%. In terms of mechanical properties, the JFM with 25% fibre content showed the highest maximum tensile strength of 73.2 MPa, while the 15% of fibre content has the highest flexural strength of 75.2 MPa. JFM with 25% fibre content was considered as the optimum fibre volume and used as the reinforcement mat in this research. From the three-point loading test result, the JFM reinforced concrete beams (JFMB) manage to sustain the ultimate load of 10.60 kN with the deflection of 0.6 mm. Although, the load capacity of beams JFMB is 26.34% higher than the beams CB, only achieves 28.7% strength of beams SB. The JFM beams was failed in a brittle manner under bending with a vertical crack in the tension zone.

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LIST OF SYMBOLS

%	Percentage
% (W/V)	Percent of weight of solution in the total volume of solution
^oC	Degree celsius
c-c	Centre to centre
kg	Kilogram
kg/m^3	Kilogram per cubic metre
kN/sec.	Kilonewton per second
L	Liter
L1	Length
L2	Width
m^3	Cubic meters
mm	Millimeter
mm/min	Millimeter per minute
MPa	Mega Pascal
N/mm^2	Newton per millimeter square

LIST OF ABBREVIATIONS

ASTM	Amerian Society for Testing and Materials
BS	British Standard
CB	Control beams
CFRP	Carbon fiber reinforced polymer
DoE	Department of The Environmental
FFRP	Flax fiber reinforced polymer
FRP	Fiber reinforced polymer
GFRP	Glass fiber reinforced polyemer
JFM	Jute fiber mat
JFMB	JFM reinforced beams
JFRP	Jute fiber reinforced polymer
KF	Kenaf fiber
LVDT	Linear variable displacement transducer
NaOH	Sodium hydroxide
NSM	Near surface mounted
OPC	Ordinary Portland Cement
RC	Reinforced Concrete
S	Satisfactory failure
SB	Steel bar reinforced beams
TPU	Thermoplastic polyurethane
U	Unsatisfactory failures
UMP	Universiti Malaysia Pahang
UTM	Universal testing machine

CHAPTER 1

INTRODUCTION

1.1 Research Background

Concrete is an artificial stone-like material which is composed of a mixture of cement and various aggregates such as sand, gravels and stone chips with water. Concrete is an economical material and has been widely used in the construction field for its low maintenance requirement and capability of being moulded. Despite the fact that concrete has good performance in compressive strength, its tensile strength is relatively low with brittle characteristic when comparing with other building materials. Therefore, concrete need to be reinforced by other materials so that the concrete structure is able to withstand tensile forces.

Meanwhile, the application of fiber has been extensively used to improve the characteristic of construction materials. The fiber is made from either natural material or a manufactured product such as glass, steel, carbon and polymer and can be applied to concrete in the form of bars, plates, and sheets. Fiber reinforced polymeric (FRP) is one of the highly recommendable and potential reinforcement materials in construction. FRP greatly enhances ductility, toughness, tensile, and flexural strength of concrete, as well as the capability of energy absorption for structural components (Sen & Paul 2015). It can be considered as an ideal material for strengthening applications due to its high specific tensile strength and higher strength-to-weight ratio compared to the steel. In the present research, the result was shown that FRP is good in fatigue and corrosion resistance, and also high strength in the required direction (Sen & Jagannatha Reddy 2013a). Nowadays, researchers are more concerned about the application of natural fibers in the construction field due to the sustainability issues. For instance, jute, kenaf, sisal, coil and bamboo are the main natural fibers which used as the reinforced composite.

Among the natural fibers, jute fiber is one of the longest natural fiber that has high specific properties, low density, and good in mechanical strength and dimensional stability. Jute fiber in textile form is the most commonly used in plant mulching and rural road pavement construction (Aggarwal & Sharma 2011). The biodegradable property of jute fiber allows the jute products to be widely used to provide the nutrition to the soil after merging with the soil. The maximum tensile, impact and flexural strength for jute-epoxy and jute-polyester composites are 104.0 MN/m^2 and 22.0 kJ/m^2 respectively. Hence, jute fiber composite can be used as a substitute of timber, metal or masonry by moulding it into a sheet, boards, pallets and other from of shape (Mukherjee 2013). However, structural applications utilizing of jute fiber are rare due to the inapplicability of the existing production techniques. Additionally, a good theoretical knowledge and design guidelines are important to ensure jute fiber reinforced polymer composite (JFRP) are safe and cost effective.

In this study, jute fibre was considered and fabricated in the form of the mat, replacing the reinforcement bar (in the tension zone) to increase the strength and ductility of the concrete beam. Physical properties test on the fiber were conducted to evaluate the strength of the fiber in the form of mat. Structural behavior of the concrete beams was then evaluated in terms of load-deflection behavior and crack pattern of the beams.

1.2 Problem Statement

Concrete, unlike steel, is a heterogeneous material which is weak in both tension and compression. Hence, cracking and failure are easy to occur when the tensile stress is applied to the concrete structure. To address this issue, steel bars are the common material used to increase the tensile strength of a concrete structure. However, the steel bar is prone to corrosion and cutting waste of the steel bar will bring negative impact to the environment. In order to solve this problem, many types of researches have been conducted on the application of fiber reinforced polymer (FRP) composites to reinforce the concrete structure.

Natural fiber using jute fiber was suitable to replace the steel bar in reinforcing the concrete structure due to its mechanical properties and the concept of sustainable building material. To date, most of the FRP researches are focusing on the FRP in the form of sheet or plate while the study of FRP in the form of the mat is very limit. By using jute fiber mat (JFM) as the reinforcement, it can reduce the environmental impact and promote the conservation of non-renewable resources.

1.3 Research Objective

The objectives of this study are as follows:

(i) To determine the mechanical properties of jute fiber mat through tensile test and flexural test

(ii) To obtain the optimum fiber volume ratio

(iii) To determine the behaviour of the concrete beam that reinforced by the jute fiber mat (JFM) in term of the load-deflection curve and cracks pattern under three-point loading test.

1.4 Research Scope

This research was focused on the behaviour of the concrete beams reinforced by jute fiber mat. A total of six concrete beams with the dimension of 100 mm x 100 mm and length of 500 mm was deployed to investigate the influence of jute fiber mat to the flexural strength of the concrete beam. A three-point load test was conducted to analyse the performance of the beam and to determine the strengthen effect of the jute fiber mat. The ultimate load and failure patterns of the concrete beam specimens were reported.

Jute fiber was treated with 5% (w/v) sodium hydroxide, NaOH to increase the interfacial bonding effect between the fiber and epoxy. After the alkaline treatment, the single fiber tensile test was then be conducted with the standard, ASTM C1557 to evaluate the tensile strength and Young's modulus of the jute fiber. Jute fiber was coated with the epoxy and hardener, and then woven into mat form of 20 mm spacing. The mixing was carried out in a ratio of 2 parts of Epoxy DER 331 and 1 part of jointmine hardener. Lastly, the optimum volume ratio of fiber to epoxy was determined from the test result of the fiber mat tensile test and flexural test.

1.5 Significance of Research

Jute fiber mat has great potential and wider applications in the construction industry due to its tensile strength. The jute fiber mat would be able to improve the flexural strength of the concrete beam and become more sustainable. Thus, the understanding of jute fiber mat is important to predict the behaviour of the jute fiber reinforced concrete to be fully utilised in the construction industry.

In the previous researches, jute fiber was added in concrete with a different percentage to increase the compressive, flexural and tensile strength of the concrete. The past researches were also intended to examine the efficacy of jute textile reinforced polymer composite (JFRP) for the flexural strengthening of reinforced concrete beam. However, this research is intended to study beam behaviour in terms of load-deflection behaviour, cracking pattern and failure mode of jute fibre mat reinforced concrete beam.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

In these recent years, FRP composites have been a major concern from the academic world and construction industry. The use of FRP composites in the strengthening of reinforced concrete (RC) has become increasingly popular due to its excellent mechanical properties. In the previous research, the FRP bars have been investigated to replace the corrosion issue of conventional steel reinforcement. Besides of losing its tensile strength due to corrosion, it also leads to the cracking and spalling of the concrete due to the expansion of steel. The advantages of FRP composite over the reinforcing steel bar include the excellent corrosion resistance, high strength-to-weight ratio, good fatigue properties, easy on-site handling, and low energy consumption during fabrication. In addition, the FRP is considered to provide an overall more economical choice for construction facilities. (Anon 2015)

With the increasing environmental concern, the natural FRP composites with good mechanical properties and low energy consumption have been attractive to the researchers. Natural fibers are cost-effective with the high strength-to-weight ratio, biodegradable, lightweight, renewable, non-abrasive and, readily available in the worldwide nation. With the development of epoxy resin adhesive, the technology of FRP has great potential in the field of structural upgrading. The most common technique of FRP strengthening is externally bonded FRP to the tension side of the flexural member in the forms of plate, sheet and strip. The application of FRP strengthening was remarkably increase the ultimate load capacity and deflection of the RC structure. Generally, FRP is applied to the existing structure that requires an increase in load capacity, change in the objective of the structure, and lack of carrying load due to deterioration and poor design or construction consequence. For the structure that experience the aggressive and unexpected events such as earthquake and the wind, the application of FRP strengthening was ensure the structure is safe to be used. (Ravikumar et al. 2014)

2.2 Fiber

2.2.1 Synthetic Fiber

The synthetic fiber or artificial fiber is manufactured from plant-derived cellulose, carbon and polymers that obtained from petrochemicals. The synthetic fiber is suitable to use in the construction of steel or reinforced concrete, steel and wood structures due to its excellence in mechanical and chemical properties and good adhesive properties. In general, the synthetic fibers used for fabrication of FRP are glass, carbon, aramid and Kevlar fiber. The fiber is embedded into the polymer matrix as the load-carrying elements, provides strength and stiffness, while the polymer matrix maintains fiber orientation, and protects fiber from the environment or possible damage. In recent years, the FRP materials are widely used to strengthen the RC members in the form of bar, plate and strip. (Ravikumar et al. 2014)

2.2.2 Cellulosic Fiber

As the increasing trend of awareness in environmental concern, the development of sustainable and energy-efficient material has become a talking point. Cellulose fiber is the example which has been widely used as an alternative reinforcement material within cementitious composites. Examples of cellulosic fibers are jute, kenaf, sisal, coir, flax, pineapple leaf and bamboo. This type of fiber not only have good specific mechanical properties but also biodegradable, renewable, non-hazardous and non-abrasive. In the construction industry, the monofilament cellulosic fibers were adding into the brittle building materials such as cement mortar or concrete to enhance the mechanical properties of the materials, especially the improving ductility, tensile and flexural properties (Yan et al. 2016). The addition of monofilament cellulosic fibers give advantages to the stress transfer by bridging the crack of cement matrix. The embedded monofilament cellulosic fibers can reduce the free plastic shrinkage and thermal conductivity. It also improves cementitious material sound absorption and vibration damping properties.

2.2.3 Chemical Treatment

Alkaline treatment, also known as mercerization, is a method to increase the interfacial bonding strength between lingo-cellulosic fiber and thermoset resin. Alkaline treatment increase fiber’s surface roughness and the amount of cellulose exposed on the fiber surface which results in better fiber-matrix interface adhesion and mechanical interlocking (Fiore et al. 2015). This is one of the simplest and effective surface modification techniques to remove an unwanted element from the fiber and improving the tensile and flexural properties of the fiber. (E.Naveen, N.Venkatachalam 2015) states that, when the jute fiber is treated with 28% of NaOH, it increase 120% of its tensile strength and 81–85% increment in the crystallinity ratio. However, treated jute fiber with high concentrations of alkaline solutions is not industrially viable. On the other hand, the research of Hojo et al. (2014) showed that surface modification could eliminate the surface impurities, increased the surface roughness, reduce the diameter of the jute fiber, thus improve the tensile strength and modulus of the composites, but the decreased elongation at the breaking load.

According to the study of Ramadan et al. (2016), the jute fibers were treated with 1%, 2%, 3%, and 5% of NaOH for soaking times 2, 4, 7 and 24 hours. Then, the fibers were washed several times with distilled water to remove the residual NaOH from fiber surface, proceeding with neutralisation with dilute acetic acid, and then rinsed again with distilled water until achieving a pH value of 7. Thereafter, fibers were dried at room temperature for 48 hours followed by oven drying with 80^{o}C for another 48 hours. The fibers were fabricated according to the DIN EN ISO 527-2 standard and test by using the LRXPLUS universal testing machine. From the research finding, the experimental result showed that the tensile strength of jute fiber increases after 4 hours of treatment. However, the tensile strength of the jute fiber textile decreases when the soaking time more than 4 hours.

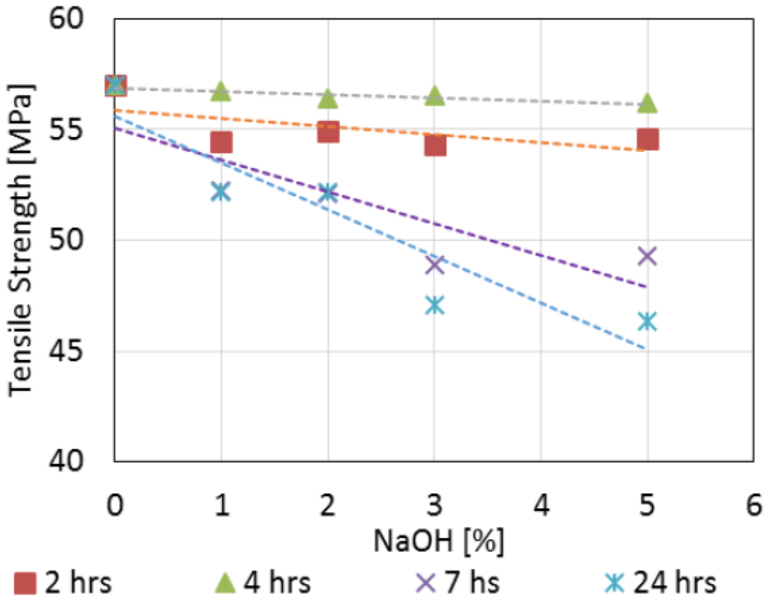


Figure 2.1 Effect of alkali treatment on tensile strength of jute fabric reinforced composites

Source: Ramadan et al. 2016

2.3 Fiber Test

2.3.1 Tensile Test

According to Sanjay and Yogesha (2016), studied on “Studies on Mechanical Properties of Jute / E-Glass Fiber Reinforced Epoxy Hybrid Composites”. The specimens were prepared as per the ASTM D638 standard size of 3 mm thick, 19 mm wide and 216 mm long. A Universal Testing Machine (UTM), model: KIC-2-100-C is utilised for testing with a maximum load rating of 100 kN. The load was applied until the specimen fractures. The fracture load, ultimate tensile strength, tensile stress and strain were recorded. The graph of the load against specimens’ length was plotted for the analyses purpose.

2.3.2 Flexural Test

From the research of Sanjay and Yogesha (2016), the three-point flexural test was conducted by using the UTM machine according to ASTM: D790 standard. The specimen size is 8 mm wide, 3 mm thick and 80 mm long and the load is applied at the middle of the specimen. The flexural strength, stress and strain for the entire test specimens at the breaking load were recorded and the graphs of load against length was generated.

2.4 Fiber Reinforced Polymer (FRP)

2.4.1 Introduction of FRP

Fiber reinforced polymer (FRP) is a composite material which encapsulates the fibers such as glass, carbon, aramid or basalt in a polymer matrix in the form of wires, bars, mat and sheet. In general, the polymers used for fabrication of the FRP are epoxy, vinyl ester and polyester thermosetting plastic. FRP was originally developed for aircraft, ships and high-speed trains, due to the favourable advantages of low weight and resistance to environmental factors. FRP products, especially carbon and glass fiber reinforced polymer are extraordinarily strong, versatile and flexible before curing. This allows the FRP to be easily applied to different shape and size of the surface. Nowadays, FRP has been widely used as an alternative solution to strengthen, repair and retrofitting the existing concrete structures. FRP is a non-metallic material and can consider being an efficient option to meet the increasing of cyclic load or repair the structures that are subjected to durability problems such as corrosion and fatigue cracking.

Pham & Hao (2016), studies had depicted that FRP materials can be used to improve the impact resistance of reinforced concrete structures, including beams, plates, columns and masonry walls. The application of FRP also increases the load capacities, ductility and energy absorption of the RC beam. There are three popular methods of applying the FRP in strengthening the RC beams, bond the FRP sheets to concrete, near surface mounted (NSM) FRP reinforcement and spray FRP to concrete. The experimental verifications and analytical studies about those methods usually in the static discipline, whereas the studies of the dynamic behaviour of RC that strengthening with the FRP are very less. Among the studies of the dynamic behaviour of RC beam, the result showed that the externally bonded FRP sheets were greatly enhanced the impact resistance and reduce the maximum deflection of the RC beams. However, the understanding of the failure mode, the actual fracture strain of the FRP sheet, and the bonding mechanism between concrete and FRP are still unclear. The tensile strength of FRP increases with the increase of strain rate, but the failure strain and stress-strain relationship cannot be concluded.

2.4.2 Advantage of FRP

FRP has great potential and advantages over the conventional material and is often applied in strengthening, rehabilitating and retrofitting the RC structures. FRP composites are available in the desired length and can be designed with different types and proportions of fibers in order to meet a particular purpose. Thus, the ultimate strength of the FRP is varied and likely to at least three times of ultimate strength of the steel for the same cross-section area. Normally, FRP was applied to the concrete structures in the forms of plate, laminate, bar, cable and wraps. Compared to steel, the FRP also has lower density and the higher strength-to-weight ratio. Hence, FRP is easier on-site handling especially the transport and installation of FRP. Because of the corrosion proof properties, FRP does not suffer from the deterioration and only fewer maintenance are needed. Meanwhile, in term of environment impact and sustainability, the energy used to fabricate the FRP is much lower than the manufacturing of the steel.

2.4.3 Jute Fiber Reinforced Polymer (JFRP)

Sen & Reddy (2013), worked on carried out an evaluation of the mechanical characteristics of natural woven JFRP composite subjected to three different pre-treatments, alkali, benzyl chloride and heat treatment. Among the treatments, heat treatment was shown the highest tensile strength of 189.479 N/mm2 and highest flexural strength of 208.705 N/mm2 and can conclude that heat treatment is most suitable treatment methods for enhancing mechanical properties of JFRP. The heat treated woven JFRP composites were subsequently used for flexural strengthening of RC beams in full and strip wrapping configurations. A total of six RC beams with the dimension of 140 mm x 200 mm x 1400 mm were utilised for the study of the effect of flexural strengthening. For the RC beams which fully U wrapping by the JFRP, the ultimate flexural strength of the RC beams was increased by 62.5% compared to the control beam, whereas the ultimate flexural strength of beams with woven JFRP in the strip was increased by 25%. The study concludes that woven JFRP have great potential in increasing the carrying capacity and flexural strength of the RC beam and enhance the material efficiency.

Sen & Reddy (2014), studied on "Efficacy of bio-derived jute FRP composite based technique for shear strength retrofitting of reinforced concrete beams and its comparative analysis with carbon and glass FRP shear retrofitting schemes". The heat treated JFRP, Carbon fiber reinforced polymer (CFRP) and glass fiber reinforced polymer (GFRP) composites were used to investigate the shear strengthening effect and understand the load-deflection behaviour and the failure modes of the strengthened beam. The jute fiber mats were dry in the oven at 80oC for 48 hours subsequently kept in airtight chambers to avoid the jute fiber mats absorb the moisture from the atmosphere. For the strengthened beams with full wrapping technique, the ultimate shear strength increases 67%, 89% and 83% for JFRP, CFRP and GFRP composite respectively. The strip wrapping technique also depicts the improving of shear capacity of RC beam by 22% for JFRP, 44% for CFRP and 33% for GFRP. The use of bio-based woven JFRP for shear strengthening is very effective in enhancing the ultimate shear strength and delay the formation of an initial crack. Additional, the JFRP strengthen beams were shown the ductile failure mode with a huge deflection before failure. Unlike the JFRP, the beams that strengthened by the CFRP and GFRP retrofitting schemes were undergoing the brittle failure mode where the beams underwent sudden FRP rupture followed by FRP debonding.

2.5 Influence of Fiber Content

Base on El-Shekeil et al. (2012), the kenaf fiber was pulverised by using a Fritsch Pulverisette mill and sieved into a size range between 125 and 300µm. Pulverised kenaf fiber (KF) and thermoplastic polyurethane (TPU) were blended, followed by a compression moulding process with 20%, 30%, 40% and 50% of fiber contents. Subsequently, the tensile and three-point flexural tests were carried out according to ASTM D 638 and ASTM790 respectively. For the tensile test, the TPU/KF composites were cut into dumbbell shape by using a hydraulic cutter, while the flexural specimens were prepared by cutting the composites into the dimension of 13 mm x 3 mm x 150 mm. The experimental results depict that the tensile modulus and flexural strength increase with the increasing of the fiber content. Figure 2.2 shows that 30% of fiber content are the optimum fiber content due to the highest tensile strength and a negligible decrease in impact strength.

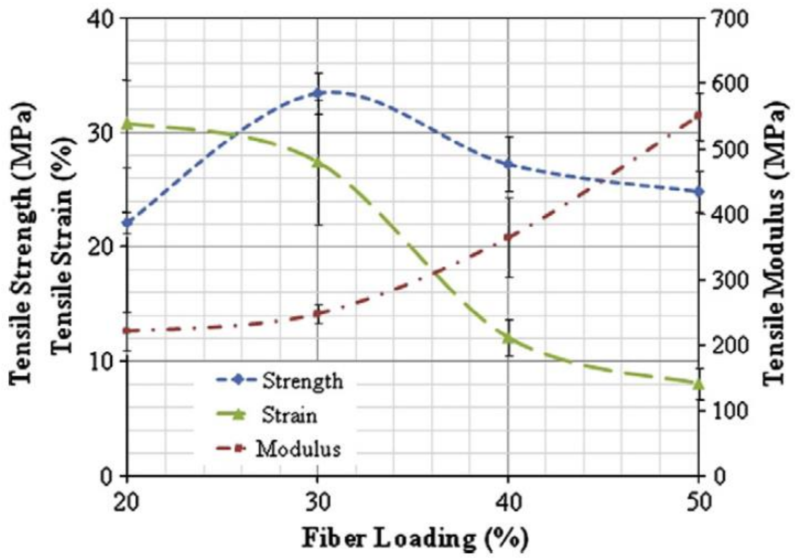


Figure 2.2 Effect of fiber loading on tensile properties of TPU/KF composites.

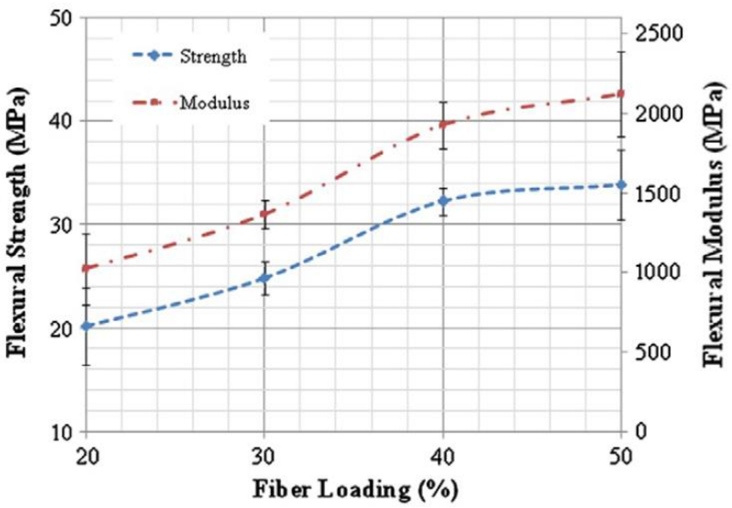


Figure 2.3 Effect of fiber loading on flexural properties of TPU/KF composites.
Source: El-Shekeil et al. (2012)

According to Punyamurthy et al. (2015), the treated and untreated abaca fibers were used in the fabrication of the epoxy composites with a different fiber content of 20%, 30%, 40%, 50% and 60% by using compression moulding technique. The abaca fibers were cut into a varying length of 5 mm, 10 mm and 15mm and mixed with the epoxy resin. The tensile tests and flexural test were conducted according to the ASTM D 638 and ASTM D790 standards respectively. The experimental results show that the chemical treatment is effective in improving the interfacial adhesion between the fiber and the matrix thereby enhancing the mechanical properties of the composites. Figure 2.4 exhibit the effect of fiber treatment on the tensile strength of composites. For the untreated abaca fiber composites with 40% content and 10mm, fiber length shows the highest tensile strength of 36.48 MPa. Among the treated fiber, benzene diazonium chloride treated fiber composites with 40% show the highest tensile strength and flexural strength of 58.62 MPa and 67.86 MPa respectively.

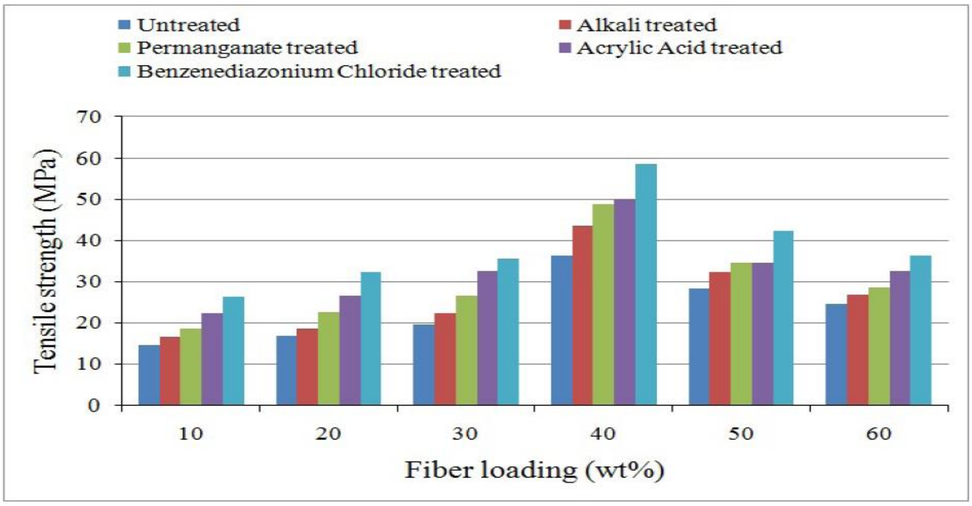


Figure 2.4 Effect of fiber treatment on the tensile strength of composites.
Source: Punyamurthy et al. (2015)

2.6 Method of Strengthening

Nowadays, a large number of reinforced concrete structures were damaged and need to be strengthened due to increasing of carrying loads and soil settlement. In order to repair and strengthening the RC structures, many techniques and materials have been invented and applied to the damaged structure in an appropriate manner. For instance, shotcrete, metal plates and FRP laminate. Among the strengthening method, the use of the FRP plate is the most popular due to the excellent physical and mechanical properties especially the carbon FRP and glass FRP. The application of the FRP can be in the form either external strengthening or internal strengthening.

2.6.1 External Strengthening Method

According to the study of Huang et al. (2016), a total of eight RC beam with the dimension of 150 x 300 x 2000 mm has been fabricated and tested to investigate the strengthening effect of the flax FRP (FFRP) plate. Two RC beams without the FFRP plate act as the control parameter and another six RC beam were strengthened with two different FFRP thickness arrangements: 4 and 6 layers FFRP. In order to evaluate the effect of the steel reinforcement ratio, there were two types of steel reinforcement ratio (0.223% and 0.503%) were used in this research and two RC beams were pre-cracked by applying 80% of the yield of the control beam. The experimental mental results show that FFRP strengthening increases the ultimate load capacity and the beams with more FFRP layers have a higher ultimate load. The FFRP strengthened also show more and wider crack at failure compared with the control beams. For the RC beam with the low steel reinforcement ratio, the increase in load carrying capacity and ductility is larger than the beams with a high reinforcement ratio. For the pre-cracking concrete beams, the effect of FFRP plate on the deflection of failure, ultimate load capacity and energy absorption are no obvious compared to other beams as listed in Table 2.1.

Table 2.1 Flexural test results of the specimens.

Specimen	Steel	Fabric layers	P_c (kN)	P_y (kN)	P_u (kN)	D at P_y (mm)	D at P_u (mm)	D at failure (mm)	Failure mode	$\mu_{\Delta y}$	Energy absorption (kN·mm)
CB-1	2 C8	–	23.0	35.0	46.3	2.5	6.5	10.00	I	2.5	369.7
CB-2	2 C12	–	29.7	79.7	142.3	4.2	10.9	19.00	I	2.6	2055.0
FB-1	2 C8	4	29.0	43.0	77.7	2.7	17.2	19.23	II	6.5	1196.9
FB-2	2 C8	6	33.7	55.7	95.0	4.0	23.4	24.74	II	5.9	1853.9
FB-3	2 C12	4	36.3	93.0	164.3	5.2	19.3	22.13	II	3.7	2720.7
FB-4	2 C12	6	39.7	95.0	172.3	5.4	21.9	22.34	II	4.0	2844.2
FB-5	2 C8	4	11.0	43.7	79.0	2.4	16.9	17.90	II	7.1	1094.8
FB-6	2 C8	6	15.0	53.0	98.3	3.3	22.8	23.89	II	7.0	1821.8

P_c: crack load; P_y: yield load; P_u: ultimate load; D: deflection; Mode I: steel yielding followed by concrete crushing; Mode II: steel yielding followed by FFRP rupture.

Source: Huang (2016)

According to the study of Sen and Reddy (2013), a series of experimental tests were carried out to study the flexural strengthening effect of jute FRP (JFRP) textile on ultimate load and load-deflection behaviour of the RC beams. In this study, the concrete beams with a dimension of 140 x 200 x 1400 mm were bonded externally with a single layer of JFRP, CERP and GFRP. The fiber textile was wrapping either in full wrapping or strip wrapping technique. Figure 2.5 depicts the comparison of ultimate load carrying capacity of all beams. The results indicated that the ultimate flexural strength of the RC beams that full wrapping by JFRP, CFRP and GFRP improved by 62.5%, 150% and 125%, respectively, and increase by 25%, 50% and 37.5%, respectively with strip wrapping technique. The presence of natural and artificial FRP, the initial cracks were at higher loads than the control beams. In another word, the FRP was inhibit and delay the development of the cracks. This showed that the use of both natural and artificial FRP was very effective in strengthening the concrete structures. In this research, JFRP strengthening shows the highest deformability index. Thus, jute textile FRP material has great potential to function as a structural reinforcement material.

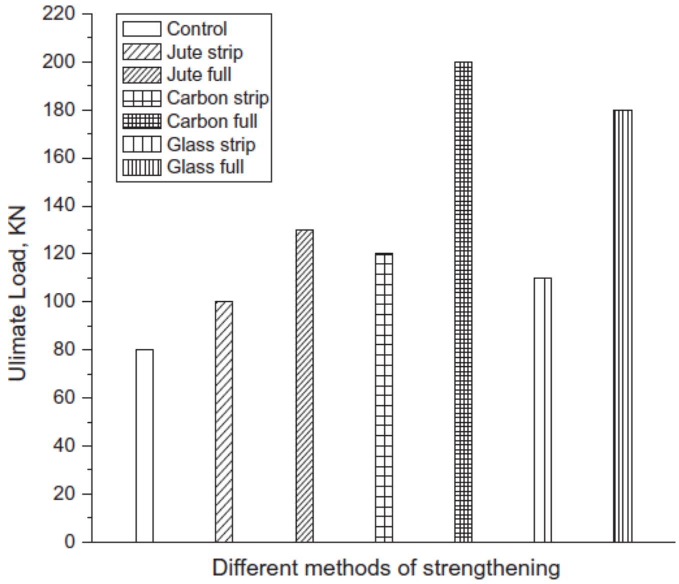


Figure 2.5 Comparison of ultimate loading carrying capacity of all beams
Source: Sen and Jagannatha Reddy (2013)

2.6.2 Internal Strengthening Method

Base on the El-Gamal et al. (2016), a total of ten RC beams with a dimension of 200 x 300 x 2760 mm were strengthened in flexure with near surface mounted (NSM) technique by using CFRP and GFRP as shown in Figure 2.6. For the FRP reinforcement, glass and carbon FRP bars with diameters of 10 mm were made of high strength glass or carbon fiber with a vinyl ester resin and used as the NSM reinforcement. In the results, the ultimate capacity of the strengthened beams showed an increase in the range of 31 and 133% compared with the reference beams. The strengthening effect is more obvious in the beams with lower steel reinforcement ratios and NSM-CFRP strengthened beams gave greater capacities than the NSM-GFRP strengthened. In addition, the NSM-GFRP strengthened beam also showed well ductile behaviour with high deflection values at ultimate load of 125 kN. This gives a full warning before the failure and can be considered an important advantage of using GFRP rods in NSM reinforcement technology.

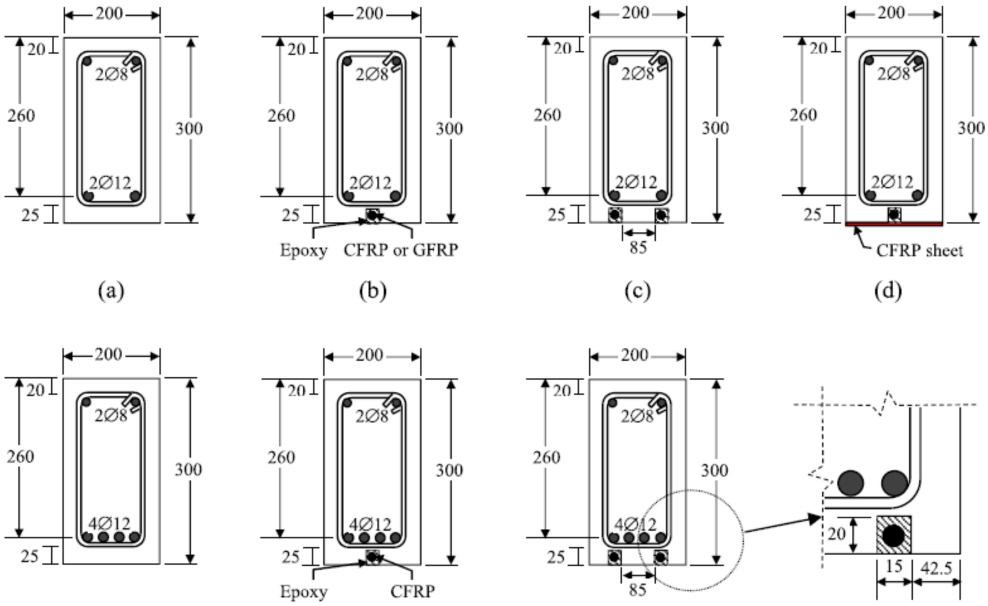


Figure 2.6 Cross section of the tested beams
Source: El-Gamal et al. (2016)

According to the study of El-Mogy et al. (2010), a total of four reinforced concrete beams with a cross section of 200 mm width x 300 mm depth and continuous over two spans of 2,800 mm each was constructed and tested in flexural as shown in Table 2.2. Two beams were reinforced with GFRP bars in a different configuration; one was reinforced with CFRP while the other one steel-reinforced beam as a reference beam. The continuous beams were placed on two roller supports at both end and a hinged support at the middle. Subsequently, two equal concentrated loads were applied to the midpoint of each span. The experimental results showed that the use of the reinforcement configuration that satisfying the elastic moment distribution FRP reinforced continuous beams had the positive effect on deflection reduction while maintaining the load-carrying capacity. The continuous beam with FRP bars exhibits adequate warning in the form of large deflection and wide cracks before failure. With the similar flexural capacity, the FRP reinforced beams show the higher deflections and wider crack compared to the steel reinforcement beam.

Table 2.2 Reinforcement Details and Concrete Properties of the Tested Beams

Beam	Bar type	Top bars at middle support		Bottom bars at midspan		ρ_b (%)	Concrete compressive strength (MPa)
		Reinforcement	Ratio (%)	Reinforcement	Ratio (%)		
SS1	Steel	3 No. 15M	1.19	4 No. 15M	1.59	3.24	28
GS1	GFRP	2 No.16	0.79	3 No.16	1.18	0.50	
GS2		3 No.16	1.18	2 No.16	0.79	0.47	26
CS1	CFRP	2 No.10	0.28	3 No.10	0.42	0.22	

Source: El-Mogy et al. (2010)

2.7 Summary

By referring to the previous studies, research gaps were identified. In this study, beams with a dimension of 100 mm x 100 mm x 500 mm in width, depth and length, respectively were used. In order to increase the interfacial bonding strength between jute fiber and epoxy resin, the jute fiber was treated with 5% (w/v) sodium hydroxide. The tensile test and flexural test were conducted to determine the mechanical properties of the JFM and obtain the optimum fiber to epoxy volume ratio. JFM with an optimum fiber volume ratio would be fabricated in the size of 50 mm x 450 mm and used as the internal reinforcement for the concrete beams. The 25 mm thickness of concrete block spacers was placed at the bottom of the steel mould to act as the concrete cover for JFM. The three-point loading test would be conducted on the beam specimens, in order to determine the strengthening effect of the JFM.

CHAPTER 3

METHODOLOGY

3.1 Introduction

This chapter presents the detail of the experimental setup such as materials properties, experimental works and laboratory testing that have been undertaken to determine the behaviour of the concrete beam that reinforced by the jute fiber mat (JFM). Jute fiber was treated with the sodium hydroxide (NaOH) to remove the impurity and increase its tensile strength. Flexural test and tensile test were then being conducted to determine the mechanical properties of jute fiber mat. Meanwhile, the slump test and compressive test were carried out to determine the properties of the fresh and hardened concrete. The three-point loading test was executed to determine the ultimate load, load-deflection behaviour and the crack pattern of the beams. All experimental procedures are explained in detail with relevant standards.

3.2 Material Properties

In this section, the materials that used in JFM fabrication and casting of the concrete beams were discussed. The properties of concrete and reinforcement bar are important in determining the strengthening effect of the JFM. Besides that, the concentration of the sodium hydroxide, epoxy and hardener are essential to determine the strength of the JFM.

3.2.1 Concrete and Steel Bar

A total of 0.05 m^3 which (including 20% of wastage) of concrete grade 25 was prepared according to BS EN 206:2013 and BS EN 1992-1-1:2004. Ordinary Portland cement (OPC), aggregate with size between 10 mm to 14 mm and sand were used as the raw material of concrete which can achieve the ultimate compressive strength of 25 N/mm^2 without any addition of additives. For the steel reinforced beams, the steel reinforcement bar with a diameter of 10 mm and nominal yield strength of 460 N/mm^2 was used and placed along the flexural zone of the concrete beams (singly reinforced). Table 3.1 summarizes the concrete mix design that used in this research.

Table 3.1 Concrete mix design

Quantities	Cement (kg)	Water (kg or L)	Fine Aggregate (kg)	Coarse Aggregate (kg)
per m^3	400	215	780	950
0.05 m^3	20.16	10.84	39.31	53.25

3.2.2 Jute Fiber and Epoxy Resin

Jute fiber has the superior properties like low density, stiffness, light weight and better mechanical properties. The diameter of jute fiber is varying around 0.025 to 0.05 mm and density of it is 1460 kg/m^3 which is much lower than the steel bar. In this research, the epoxy resin used is known as D.E.R. 331 which is a type of liquid resin that used as the matrix of the jute fiber mat. Table 3.2 listed the properties of jute and epoxy resin.

Table 3.2 Jute and epoxy properties

Material	Arial Weight (g/cm^3)	Density (g/cm^3)	Tensile strength (MPa)	Tensile Modulus (GPa)	Elongation (%)
Jute	290	1.46	400± 120	40± 10	1.8
Epoxy	-	1.17	85± 10	10.5± 4	0.8

Source: M.Shahirul et al. 2016

Figure 3.1 Jute fiber

3.3 JFM Preparations

3.3.1 Frame

In order to fabricate the JFM, a frame was required to fix the position of the jute fiber during the weaving process. In this research, three different sizes of plywood frames was fabricated by using a table saw machine. Next, a void was then created in the middle of the frame allowing a space for weaving by using a jigsaw. In order to fix the position of the JFM, holes with diameter of 6 mm were drilled for tying with screw and nut. Grooves with a width of 4 mm were engraved with the intention to control the dimension of the jute fiber string. Table 3.3 lists the three different dimensions of plywood frame, whereas the Figure 3.2 and Figure 3.3 shown the appearance of the plywood.

Table 3.3 Dimension of plywood frame

Dimension of frame	Function
75 mm x 290 mm	Tensile test sample fabrication
120 mm x 180 mm	Flexural test sample fabricaiton
90 mm x 490 mm	Beam reinforcement mat fabrication

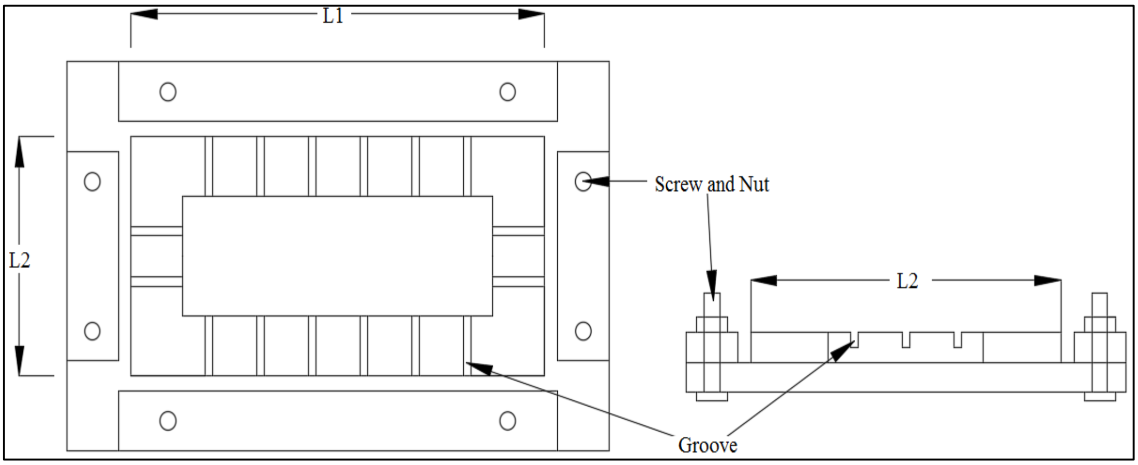


Figure 3.2 Plywood frame layout

Figure 3.3 Plywood frame

3.3.2 Alkaline Treatment

The sodium hydroxide pellets were diluted with distilled water to produce 5% w/v of sodium hydroxide solution. The ground jute fibers were immersed in 5% w/v sodium hydroxide solution, NaOH for 4 hours at room temperature as depicted in Figure 3.4. The purpose of alkaline treatment of jute fibers is to remove the surface impurity and improve the mechanical properties of the jute fiber. Next, the jute fiber was then rinsed thoroughly and neutralised with distilled water several times to remove the chemical residues. A litmus paper was used to test the pH of the distilled water and ensure the fiber was completely neutralised with the pH of six (6). After treatment, the jute fiber was oven-dried at 60^oC until dried and then kept in a desiccator to prevent the jute fiber contact with the moisture.

(a) (b)

Figure 3.4 (a) Sodium hydroxide pellets, NaOH (b) Treat the jute fiber with 5% (w/v) of NaOH

3.3.3 Fiber Mat Fabrication

After drying process, the chemical treated fibers were cut into the desired length. The mass of each fiber string was weighed and recorded to ensure the fiber strings are uniform and homogeneity through the JFM. In this research, three different JFM dimensions were fabricated; eight (8) JFMs with dimension of 2 mm thick, 30 mm width and 250 mm length of tensile testing specimens, twelve (12) JFMs with dimension of 2 mm thick, 50 mm width, 120 mm length of flexural testing specimen and two (2) JFM dimension of 5 mm thick, 50 mm width and 450 mm length of beam reinforcement mat. The JFMs were fabricated with four (4) different fiber volume percentages which are 15%, 20%, 25% and 30%. The Epoxy DER 331 and jointmine hardener were mixing with the ratio of 2 parts of epoxy to 1 part jointmine and applied to coating the jute fiber. After coating with the epoxy and hardener, the jute fibers were woven into mat form with the 20 mm centre to centre (c-c) spacing as shown in Figure 3.6 which to allow the coarse aggregate to pass through. The frame was tightened with the screws to prevent the sliding of the fiber string. For the JFM with a dimension of 50 x 450 mm were fabricated by using the optimum fiber volume ratio.

Figure 3.5 Application of the epoxy resin

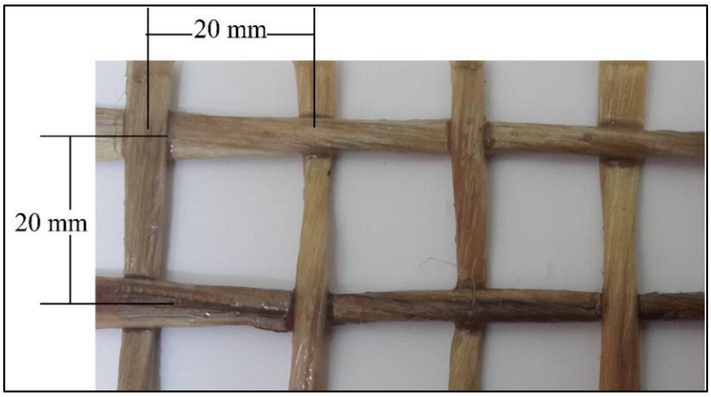


Figure 3.6 Jute Fiber Mat (JFM)

Table 3.4 Dimension of JFM

Dimension of JFM	Purpose	Fiber volume percentages
30 mm x 250 mm	Tensile test	15%, 20%, 25% and 30%
50 mm x 120 mm	Flexural test	15%, 20%, 25% and 30%
50 mm x 450 mm	Beam reinforcement	Optimum fiber volume

3.4 Preparation of Specimens

3.4.1 Reinforcement

In this research, a total of four 10 mm diameter steel reinforcement bars were used to produce steel reinforced beams. The steel bars were cut into 450 mm long and place into a steel mould as a reinforcement of the concrete beam (singly reinforced). Each concrete beam consists of two steel bars.

3.4.2 Concreting and Casting

The ready-mix concrete was designed with the aim the achieving a standard compressive strength of 25 N/mm^2 without any admixture. A total of 0.05 m^3 of ready-mix concrete was used in the casting process. After mixing the concrete, slump test was conducted to test the properties and workability of the fresh concrete. 25 mm thickness of concrete block spacers were placed inside the steel mould to ensure the spacing between the steel mould and steel bar or JFM as shown in Figure 3.8 and Figure 3.9. The vibrating table was used to vibrate the concrete once the fresh concrete was poured into the steel mould to prevent the honeycomb issues as well as reduction of beam capacity. In this research, there are total six (6) beams and twelve (12) cubes were cast. The size of beam mould is 100 x 100 x 500 mm, whereas the size of cube mould is 100 x 100 x 100 mm in width, depth and length respectively. These specimens of cubes and the beam were leaving for curing and the used for compressive strength test and three-point loading test, respectively. Figure 3.7 depicts the schematic loading system for beams.

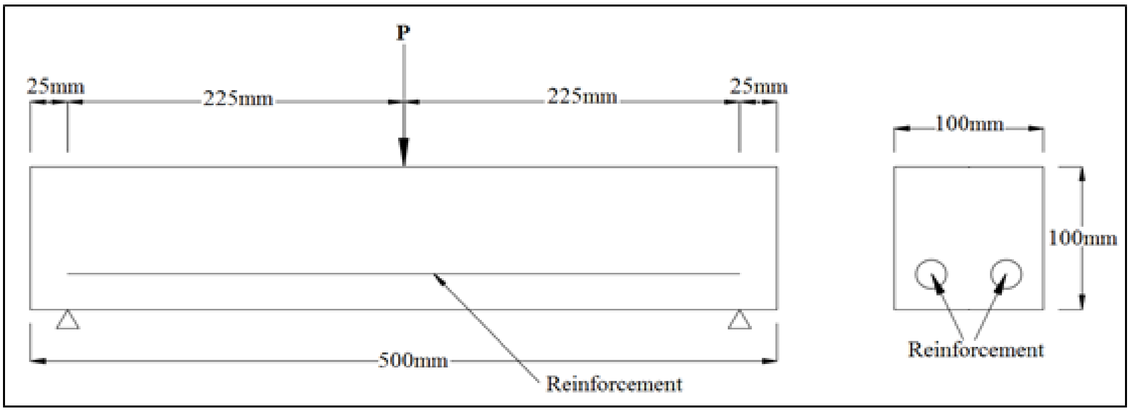


Figure 3.7 Schematic loading system for beams

Figure 3.8 Concrete block spacers

Figure 3.9 Jute fiber mat reinforcement

3.4.3 Process of Mixing

The concrete mixing process complies with BS 1881-125:2013. Coarse aggregate, sand, cement and water were prepared according to the designed concrete mixture ratio. The rotary drum was cleaned and dried before commencing the mixing as shown in Figure 3.10. After all the materials and rotary drum were ready, half amount of coarse aggregate and sand were poured into the mixer and drum was rotated for thirty second. After that, half amount of water was added into the mixer and allowed to rotate for three minutes. Subsequently, the cement and the remaining of water, aggregates, sand were added and mixed for 4 minutes until the mixture become homogeneous. After completion of mixing, the concrete was discharged into the concrete mixing tray and the surface of rotary drum was cleaned by using a brush.

Figure 3.10 Concrete mixer drum

3.4.4 Curing

The samples were removed from the mould after 24 hours and placed in a curing tank for the curing process as shown in the Figure 3.11. Curing is a process to maintain the satisfactory moisture content inside the concrete, which is essential for the process of hydration and hence for hardening. Curing the concrete by putting it in the curing pond is important in preventing the exposure of concrete under a hot atmosphere and to drying winds. The exposure of concrete lead to quick drying out of moisture in the concrete and cause the cracking due to thermal stresses, thus resulting in the concrete insufficient to resist stress.

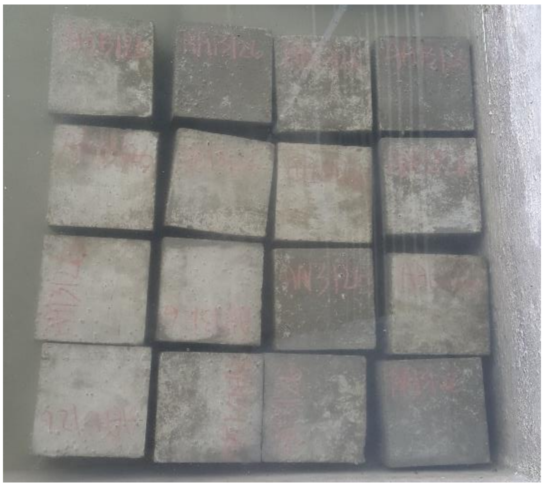


Figure 3.11 Curing the specimens

3.5 Laboratory Testing

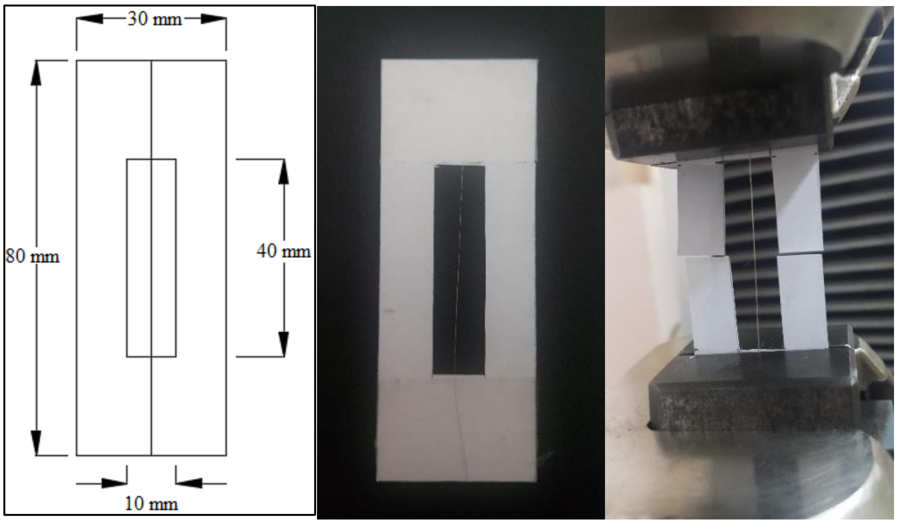
In this study, a total of six (6) laboratory tests were conducted to determine the physical properties of jute fiber, mechanical properties of JFM and the behaviour of concrete beams. Table 3.5 summarized the laboratory tests in this research.

Table 3.5 Summary of testing

Sample	Laboratory Test	Refer Standard
Jute fiber filament	Single fiber test	ASTM C1557-10
JFM	Tensile test	ASTM D3039/ D3039M-14
JFM	Flexural test	ASTM D790 | ISO 178
Fresh concrete	Slump test	BS1881 Part 102:1983
Hardened concrete	Compressive test	BS1887-116:1983
Concrete beam	Three-point loading test	ASTM C 293-02

3.5.1 Single-Fiber Test

In order to determine the axial tensile modulus, ultimate strength and failure strain of the jute fiber, the single-fiber test was conducted according to ASTM C1557-10. The slot of length equal to the 40 mm of gage length was cut out in the middle of a paper for mounting the jute fiber as illustrated in Figure 3.12 (a). A single filament was chosen from the jute fiber bundle and pasted at the both ends of the slot in the paper. Then, the specimen was gripped on the UTM machine and the load was applied to the specimen with the rate of 1 mm/min until the specimen failed. The load and elongation of the specimen were recorded and analyse the tensile strength of treated and untreated jute fiber.



(a) (b) (c)

Figure 3.12 (a) Paper for fixing the fiber, (b) Tensile sample of single fiber test and (c) Single fiber test

3.5.2 Jute Fiber Mat

3.5.2.1 Tensile test

A total of eight (8) JFM specimens with a dimension of 30 mm width, 2 mm thick and 250 mm long as depicted in Figure 3.14 were undergone the tensile testing accordance with the standard of ASTM D3039 / D3039M – 14. The testing specimens were placed in the UTM with the gage length of 150 mm as illustrated in Figure 3.13 and the load was applied to the specimen at the rate of 1mm/min until the specimen break. The breaking load, ultimate tensile strength and elongation of the specimen during the test were recorded. The experiments were repeated for the rest of the specimen and the loads against length are generated.

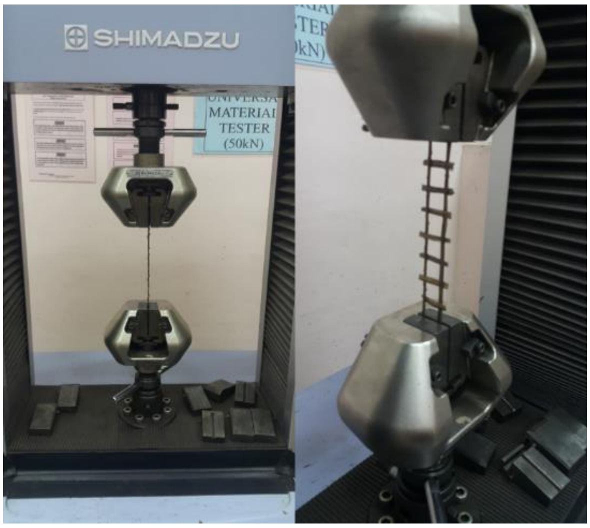


Figure 3.13 JFM tensile test

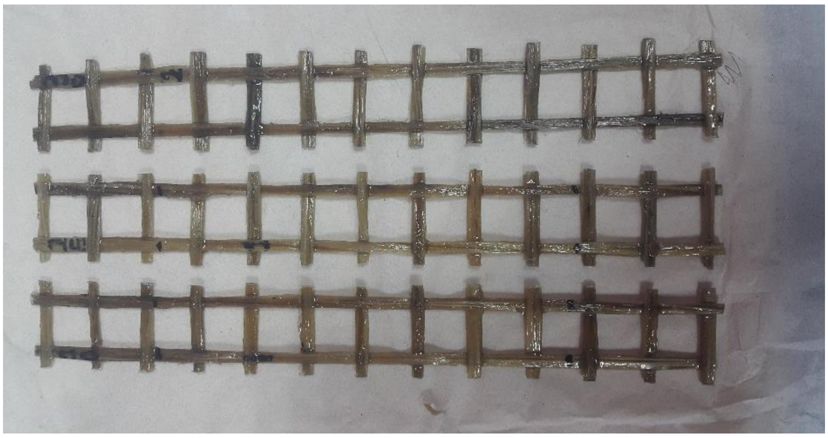


Figure 3.14 Tensile testing sample

3.5.2.2 Flexural Test

The flexural test was conducted in a three-point flexural setup as per ASTM D790 standard, but the size of the specimens had been modified. In this research, the specimen size used for testing is 50 mm wide, 2 mm thick and 120 mm long as illustrated in Figure 3.16. The JFM specimen was placed on the UTM machine and the distance between the support is 80 mm as shown in Figure 3.15. The load was applied to the specimen at the constant rate of 2 mm/min. The breaking load was recorded for all the test samples and the stress against strain graph was plotted.

Figure 3.15 JFM flexural test

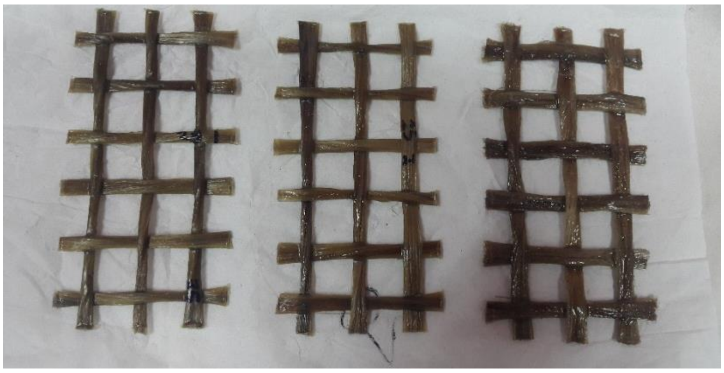


Figure 3.16 Flexural testing sample

3.5.3 Slump Test

Slump test is a method of assessing the consistency and degree of workability of fresh concrete. This test was conducted in accordance with the BS 1881 part 102:1983. Before commencing the slump test, the internal surface of the steel cone is cleaned and damped, but free from superfluous moisture. The steel slump cone placed on a solid level base and filled with three equal layers of fresh concrete. Each layer was tamped with 25 strokes of the tamping rod, the strokes being distributed uniformly over the cross-section of the layer. Subsequently, the cone was carefully lifted up and placed beside the concrete to act as a reference. The difference between the top of the steel cone and the highest point of the specimen was measured and recorded. The profile of the slumped concrete was observed and recorded.

Figure 3.17 Slump test

3.5.4 Compression Test

In order to obtain the compressive strength of the hardened concrete, a total of twelve (12) concrete cubes with a dimension of 100 X 100 X 100 mm were tested according to the standards of compression test (BS 1881: Part ll6: 1983). The concrete cubes were tested at the age of 3,7,14 and 28 days by using the concrete compression machine as shown in Figure 3.18. The concrete cube specimens were subjected to the compression load at the rate of 2 kN/sec. The concrete cube specimens were tested to its failure and the mode failure, ultimate load, and ultimate compressive strength of each specimen was observed and recorded.

Figure 3.18 Concrete compression machine

3.5.5 Three-point Loading Test

All the concrete beams were tested under three-point loading test by using the Magnus frame as exhibited in Figure 3.20. The standards used for this experiment are ASTM C 293-02. The specimens were removed from the curing tank and the weight of each concrete beam was measured and recorded. The contract point of support and third-point loading was marked on the surface of the beam. Next, the beam specimens were placed on two supporting pins a set distance of 450 mm apart and a third loading pin was lowered continuously from above at a constant rate until the breaking point as shown in Figure 3.19 and Figure 3.21. To ensure the accuracy of deflection, the linear variable displacement transducer (LVDT) was mounted at the bottom soffit of the mid-span of the beam. The crack pattern and maximum load at failure were recorded and then the measure of the flexural strength and ultimate load capacity.

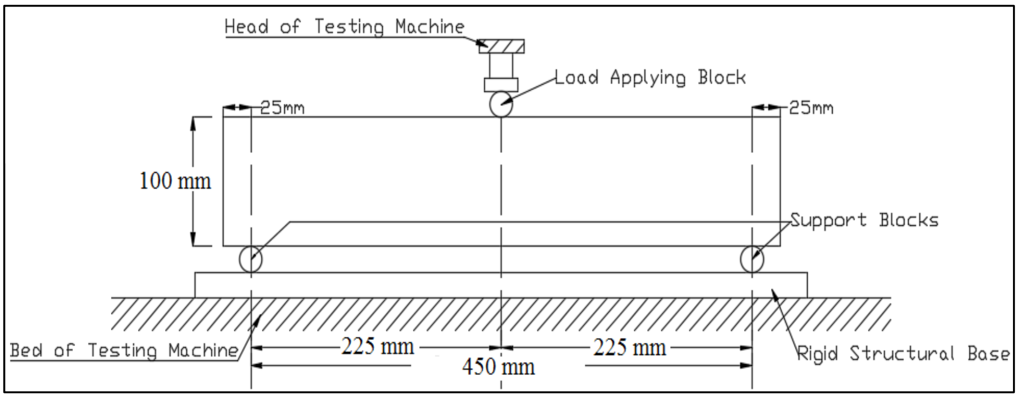


Figure 3.19 Loading Arrangement on Beam Specimen

Figure 3.20 Magnus's frame

Figure 3.21 Setup of concrete beam on the Magnus's frame

3.6 Research Experimental Work Flow

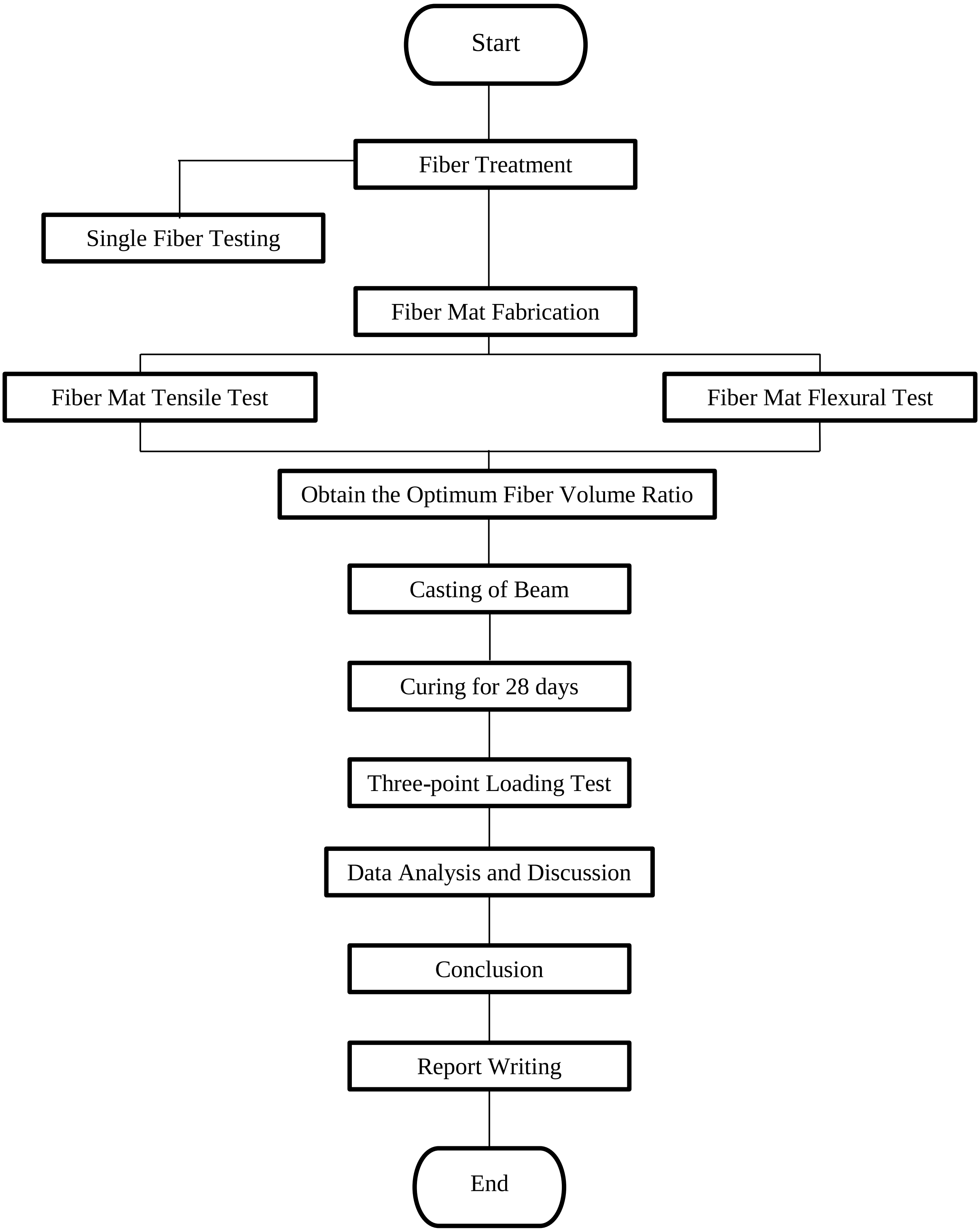


Figure 3.22 The work flow of this study

CHAPTER 4

RESULTS AND DISCUSSION

4.1 Introduction

All the experimental testing results were analysed and discussed in this chapter. The mechanical properties of the Jute Fiber Mat (JFM) were determined by undergone the tensile and flexural tests. The tensile and flexural strength of the JFM were determined by analysing the results obtained from the tensile and flexural tests. The results gained from both tensile and flexural test for each jute fiber content were analysed and compared in order to identify the optimum jute fiber content. The behaviour of the concrete beam throughout the test is mainly described in both fresh and hardened properties tests. The properties of the fresh concrete were determined by executing slump test, whereas the hardened properties of the concrete beams were measured by conducting the compressive strength test and three-point loading test. Throughout the three-point loading test, the strengthening effect of the JFM was determined by comparing and analysing the maximum loading applied to the beam specimens. This chapter also compares the data gained for each of the beam specimens which are Control Beam (CB), steel bar reinforced Beams (SB) and Jute Fiber Mat Reinforced Beams (JFMB). The results of the load deflection profile were determined by analysing the displacement of the line variable displacement transducer (LVDT) throughout when the beam specimens were deformed due to the loading applied during the testing process. The crack pattern of each concrete beams was observed and marked when the first visual crack appeared.

4.2 Fresh and Hardened Properties of Concrete

4.2.1 Slump Test

The concrete slump test is an empirical test that conducted with the intention to measure the consistency and workability of plastic concrete in a specific batch. More specifically, the slump test result is a measurement of the stiffness or fluidity of concrete. Due to the simplicity of the apparatus used and simple procedure, the test is extensively used at a construction site for detecting changes in workability of the plastic concrete in the same or difference mixing batch. The ready-mix concrete used for the fabrication of beams specimens was prepared by referring to the standard of the design of normal concrete, Department of The Environmental (DoE), HMSO, 1988. The concrete used was categorised as an M25 normal mix, which mean the materials used were ordinary Portland cement (OPC), fine aggregate, coarse aggregate, sand and water, no addictive or plasticisers were added. The water-cement ratio was controlled at 0.53 in order to achieve the concrete compressive strength of 25 N/mm^2 after 28 days.

The concrete slump test was conducted immediately after the concrete was poured out from the mixer drum according to the procedure stated in the BS 1881 part 102:1983. As a result, concrete having a slump of 50 mm and the profile of the slumped concrete was slumped evenly all around without disintegration and considered as a true slump as display in Figure 4.1. The 50 mm of the slump is categorised as medium workability which is normally used for normal reinforced concrete manually compacted and a heavily reinforced section with vibrations on site.

Figure 4.1 The concrete having a slump of 50 mm.

4.2.2 Compressive Strength Test

The compressive strength test was conducted to determine the compressive strength of the hardened concrete samples by using the compression testing machine. A total of twelve (12) concrete cubes samples with the dimension of 100 x 100 x 100 mm were undergone the compressive test at the age of 3, 7, 14 and 28. The compressive strength result was summarized in Table 4.1. The gaining of the compressive strength of M25 concrete at the different ages of 3, 7, 14 and 28 was illustrated in Figure 4.2. The failures are categorised into two components which are Satisfactory failure (S) and Unsatisfactory failures (U). Figure 4.3 shows the failure profile of the tested cubes.

Table 4.1 Compressive strength test results of twelve hardened concrete cubes with different sample ages.

Sample Mark	Weight (kg)	Date of Test	Sample Age (days)	Load (kN)	Compressive Strength (N/mm2)	Type of Failure (S/U)
C1	2.36	3/4/2017	3	293.2	29.3	S
C2	2.33	3/4/2017	3	272.4	27.2	S
C3	2.29	3/4/2017	3	273.1	27.3	S
			Total	838.7	83.9	
			Average	279.6	28.0	
C5	3.33	7/4/2017	7	373.7	37.4	S
C6	2.31	7/4/2017	7	390.7	39.1	S
C8	2.34	7/4/2017	7	397.7	39.8	S
			Total	1162.1	116.2	
			Average	387.4	38.7	
C9	2.37	14/4/2017	14	431.3	43.1	S
C11	2.30	14/4/2017	14	446.0	44.6	S
C12	2.29	14/4/2017	14	420.6	42.1	S
			Total	1297.9	129.8	
			Average	432.6	43.3	

C13	2.10	28/4/2017	28	500.1	50.0	S
C14	2.37	28/4/2017	28	510.6	51.1	S
C15	2.29	28/4/2017	28	493.6	49.4	S
			Total	1504.3	150.5	
			Average	501.4	50.2	

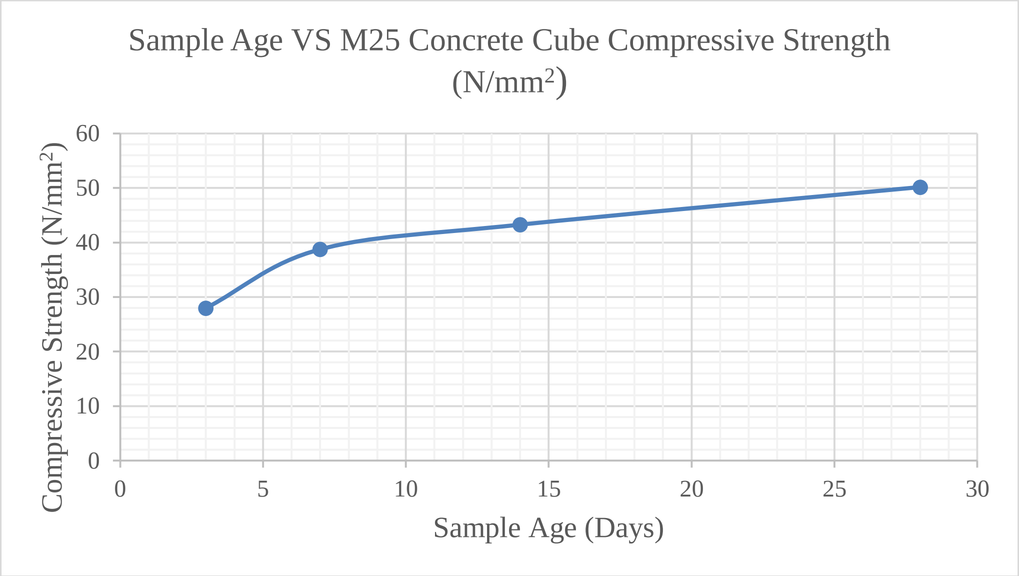


Figure 4.2 Results of concrete compressive strength at different ages.

Figure 4.3 Tested cubes

4.3 Physical Properties of Jute Fiber

4.3.1 Single-fiber Test

Both chemically treated and untreated jute fibers were subjected the single fiber test to determine the uniaxial tensile strength and the elongation at the breaking load. Table 4.2 illustrates the mechanical properties of jute fiber in term of maximum tensile strength and elongation of fiber at the breaking load. From Table 4.2, the treated fiber filaments are having a higher tensile strength in comparison with the untreated fiber filaments. The treated fiber filaments shown the average maximum tensile strength of 774.4 MPa and the elongation of 1.34%, whereas the untreated fiber filaments have the average maximum tensile strength of 452.0 MPa and the elongation of 2.40%. On treatment with 5% NaOH over 4 hours duration at room temperature, the maximum tensile strength was found to increase by 71.3% compared to untreated fibers and the elongation at break was found to decrease by 44.3%. The increment of tensile strength after the 5% (w/v) of NaOH treatment is due to the removal of non-cellulosic materials and impurities, which remain dispersed in the interfibrillar region of jute fiber. As the hemicellulose leaches out, the cellulose chain in the fibres becomes dense due to the release of the internal strain and resulting in the higher tensile strength. (Roy et al. 2012). Figure 4.4 illustrated the specimen after the single fiber test.

Table 4.2 Mechanical properties of jute fiber

Type of jute fiber	Samples	Tensile strength (MPa)	Elongation at break (%)	average	
				Tensile strength (MPa)	Elongation at break (%)
Treated	S1	659.8	1.1	774.4	1.3
	S2	785.2	1.3		
	S3	878.3	1.6		
Untreated	S1	469.5	3.5	452.0	2.4
	S2	570.7	2.2		
	S3	315.7	1.5		

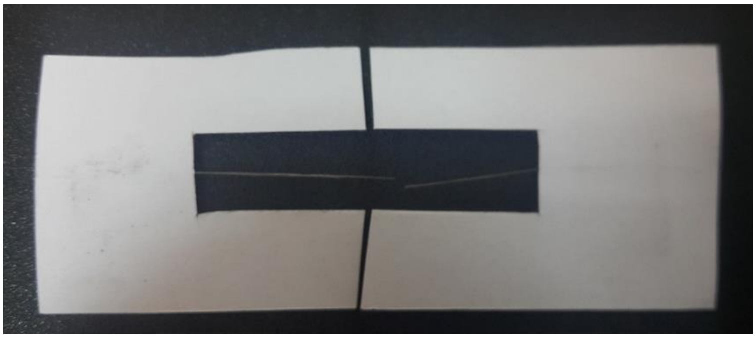


Figure 4.4 Specimen after single fiber test

4.4 Mechanical Properties of JFM

4.4.1 Tensile Properties

In this work, a total of eight (8) jute fiber mats (JFM) were fabricated with a dimension of 30 mm width, 2 mm thick and 250 mm long and different fiber content of 15%, 20%, 25% and 30%. All the specimens were undergone the tensile test by using the Universal Testing Machine to evaluate the tensile properties and obtain the optimum fiber volume ratio. The variation of different fiber content was studied.

Figure 4.5 - 4.8 illustrate the ultimate tensile stress and strain of the JFM with the fiber content of 15%, 20%, 25% and 30%. From Figure 4.5, the ultimate tensile strength of 45.3 MPa and 45.6 MPa were shown by the sample 1 and 2, respectively. The strain at the breaking load of sample 1 was 2.4%, while sample 2 was 1.4%. From Figure 4.6, sample 1, and 2 with the 20% jute fiber content shows the ultimate flexural strength of 60.3 MPa and 52.0 MPa corresponding to the strain of 1.27%, 1.9%, respectively. From Figure 4.7, sample 1 with the 25% fiber content had the ultimate tensile of 67.4 MPa and with the strain of 2.5% whereas the sample 2 depicted the ultimate tensile strength of 78.9 MPa with the strain of 3.3%. From Figure 4.8, the ultimate tensile strength of 49.84 MPa and 56.54 MPa shown by the sample 1 and sample 2 respectively. The strain at the breaking load of sample 1 is 4.3% while sample 2 is 2.5%.

Figure 4.9 exhibiting the average ultimate tensile strength result of each different fiber content tested JFM samples, whereas the Table 4.3 summerized the tensile strength of each different fiber content. From test result, the average ultimate tensile strength of 15%, 20%, 25% and 30% fiber content are 45.5MPa, 56.1MPa, 73.2MPa and 53.2 MPa respectively. Figure 4.6 indicated that the tensile strength of JFM increase as the fiber content surged to 25% and then decreased. For 25% fiber content ultimate tensile strength increased by 60.97% compared 15% fiber content and for 30% fiber content it decreased by 27.29% compared to 25% fiber content. This decrease is due to lack of proper bonding between the interface of fiber resulting in voids generating a fragile structure. The highest ultimate tensile strength of 78.93 MPa is exhibited by JFM with 25% fiber content. The JFM with 25% fiber content has the better fiber distribution with the coating of epoxy and more efficient stress transfer between fiber and epoxy. As the fiber content increased beyond 25%, the tensile strength decreased due to the lack of proper adhesion and ineffective stress transfer between jute fiber and epoxy. (El-Shekeil et al. 2012)

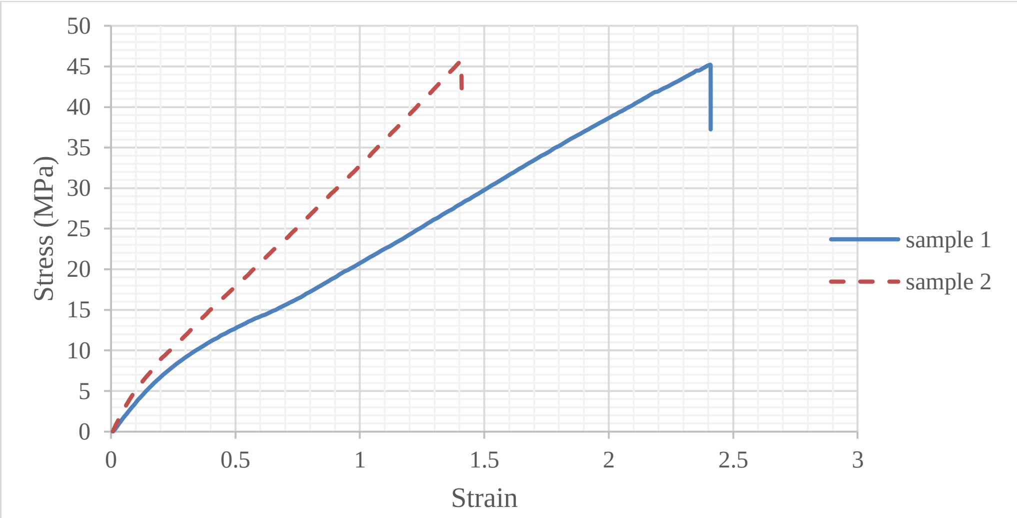


Figure 4.5 Stress-strain curve of JRM with fiber content of 15%

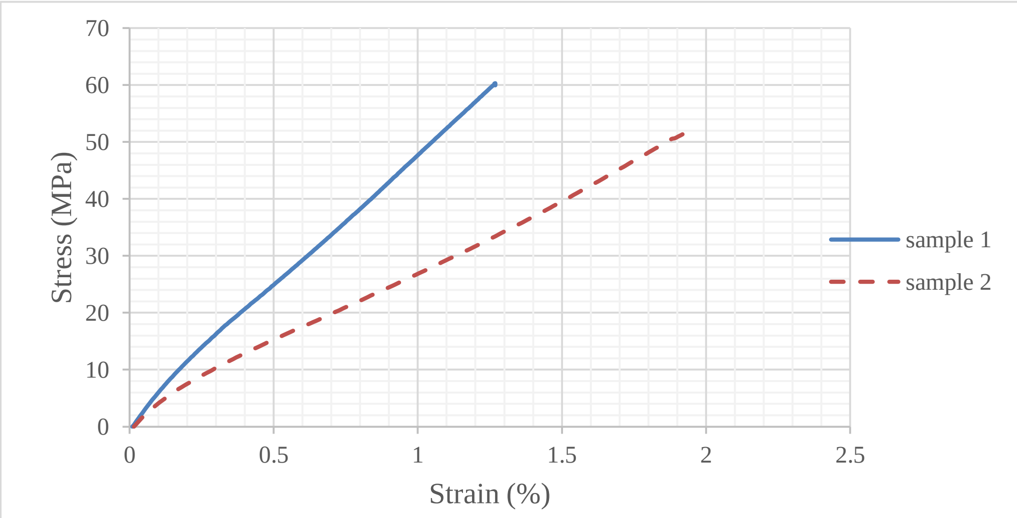


Figure 4.6 Stress-strain curve of JRM with fiber content of 20%

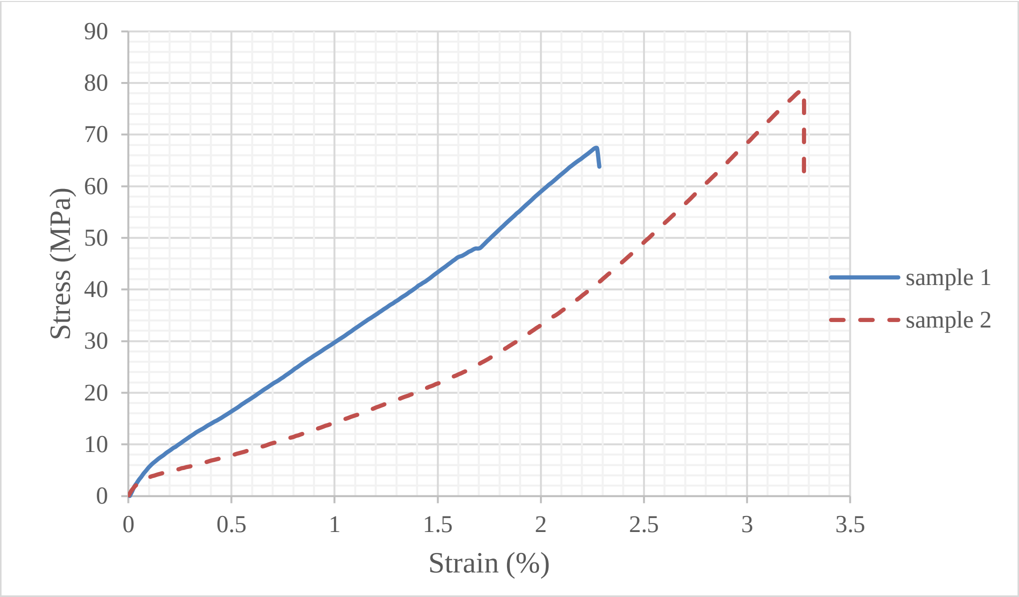


Figure 4.7 Stress-strain curve of JRM with fiber content of 25%

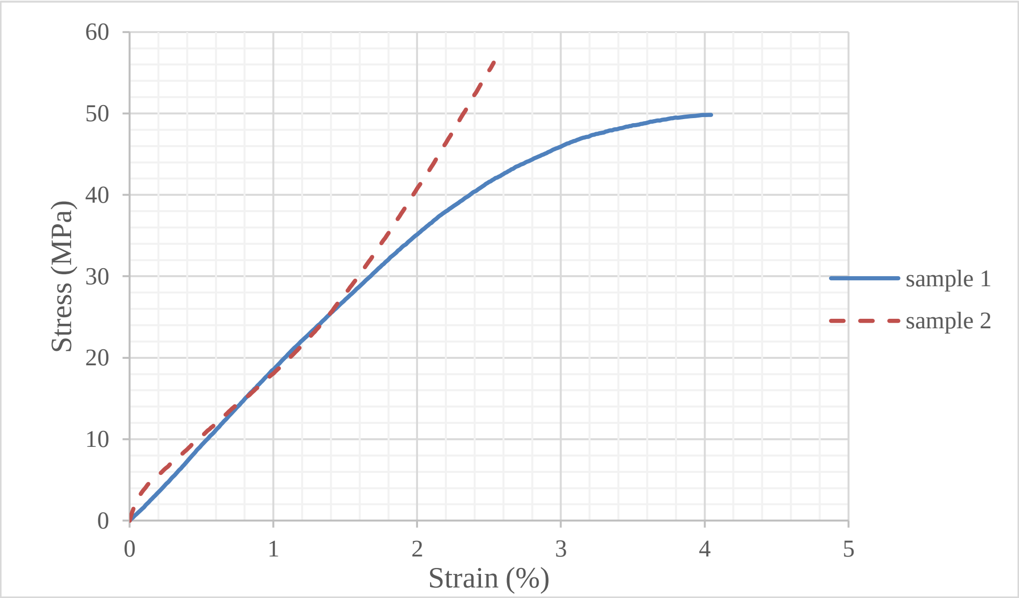


Figure 4.8 Stress-strain curve of JRM with fiber content of 30%

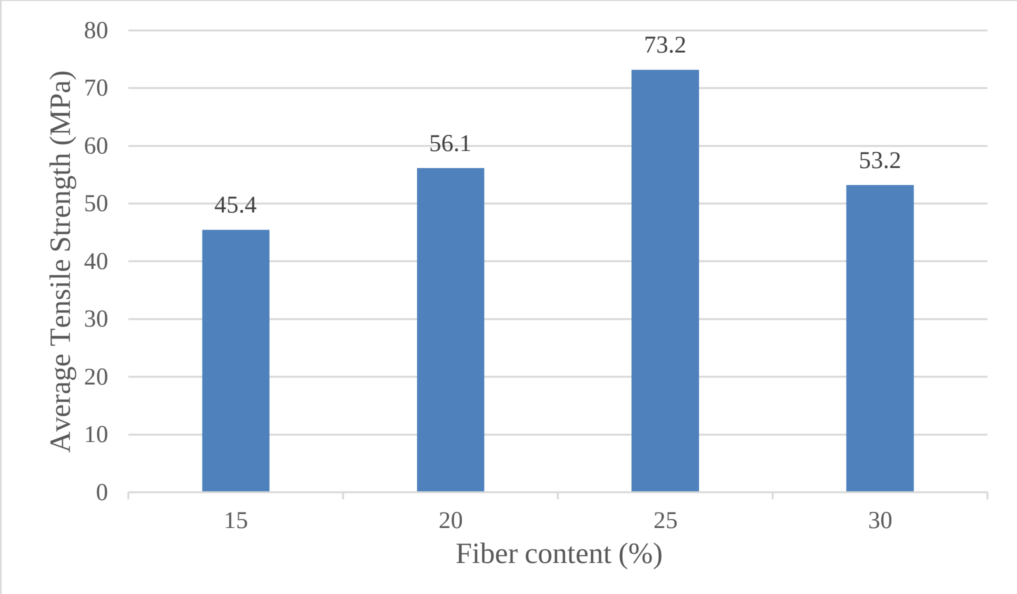


Figure 4.9 Average tensile strength of each different fiber content

Table 4.3 Summary of tensile strength result

Fiber Content (%)	Ultimate Stress (Mpa)		
	1	2	Average
15	45.3	45.6	45.5
20	60.3	52.0	56.1
25	67.4	78.9	73.2
30	49.8	56.5	53.2

Figure 4.10 Tensile test

4.4.2 Flexural Properties

Flexural strength is an important property which indicated the capability of a material to resist the deformation under load and withstand bending before the specimen fails. It represents the maximum stress that the material can bear at the failure point. The flexural strength test was conducted to determine the flexural strength and optimum fiber content among the specimens.

Figure 4.11 - 4.14 illustrate the ultimate flexural stress and deflection of the JFM with the fiber content of 15%, 20%, 25% and 30%. From Figure 4.11, sample 1, 2 and 3 with the 15% jute fiber content shows the ultimate flexural strength of 72.7 MPa, 65.0 MPa and 88.0 MPa corresponding to the deflection of 5.1 mm, 5.4 mm and 5.1 mm, respectively. Figure 4.12 illustrates the flexural strength of JFM with 20% fiber content. Sample 1 has the ultimate flexural strength of 28.1 MPa with the deflection of 6.6mm, whereas sample 2 and sample 3 depicts the ultimate flexural strength of 43.6 MPa and 34.1 MPa with the corresponding deflection of 8.5 mm and 5.9 mm, respectively. From Figure 4.13, the ultimate tensile strength of 61.3 MPa, 54.3 MPa and 53.6 MPa obtained by the samples 1 to 3, respectively. The deflection at the breaking load of sample 1 is 7.06 mm while sample 2 and sample 3 are 6.7 mm and 6.6 mm, respectively. Figure 4.14 indicates the ultimate flexural stress of the JFM with 30% fiber content. Sample 1, 2 and 3 have the ultimate flexural strength of 47.6 MPa, 47.6 MPa and 49.1 MPa corresponding to the deflection of 6.5 mm, 7.6 mm and 6.1 mm, respectively.

Table 4.4 lists the average ultimate flexural strength of different fiber content, while Figure 4.15 shows the comparison of ultimate flexural strength for each different fiber content. Different from tensile strength, the result indicated that 15% of jute fiber content have the highest ultimate flexural strength compared to other fiber content specimens. The average flexural strength obtained for 15%, 20%, 25% and 30% fiber content were 75.2 MPa, 35.3 MPa, 56.4 MPa and 48.1 MPa respectively. The highest flexural strength of 15% fiber content may owe to the strength of the epoxy. Flexural strength of JFM ascended as fiber content increased from 20% to 25% then decreased. For 25% fiber content flexural strength increased by 59.9% compared to 20% fiber content, while for 30% fiber content it decreased by 14.7% compared to 25% fiber content. The flexural strength decrease beyond 25% may be due to lack of proper bonding at the interface of fibre and epoxy resulting in voids generating a brittle structure. The lack of proper adhesion between the interface of fiber cause the ineffective stress transfer across epoxy and fiber. (Punyamurthy et al. 2015)

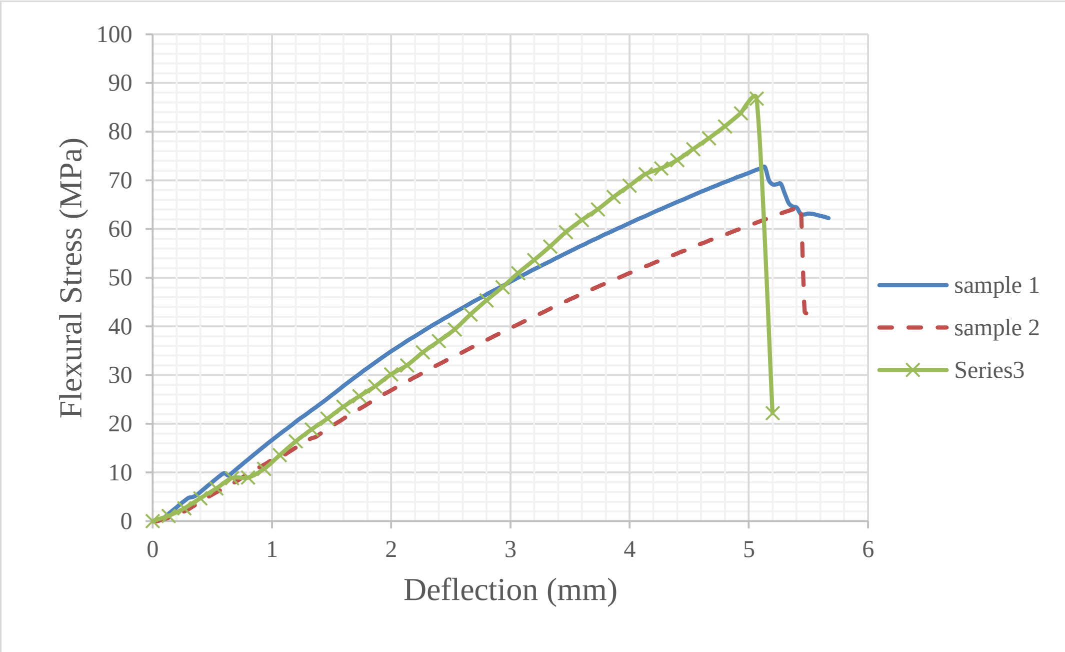


Figure 4.11 Flexural stress vs deflection curve of JRM with fiber content of 15%

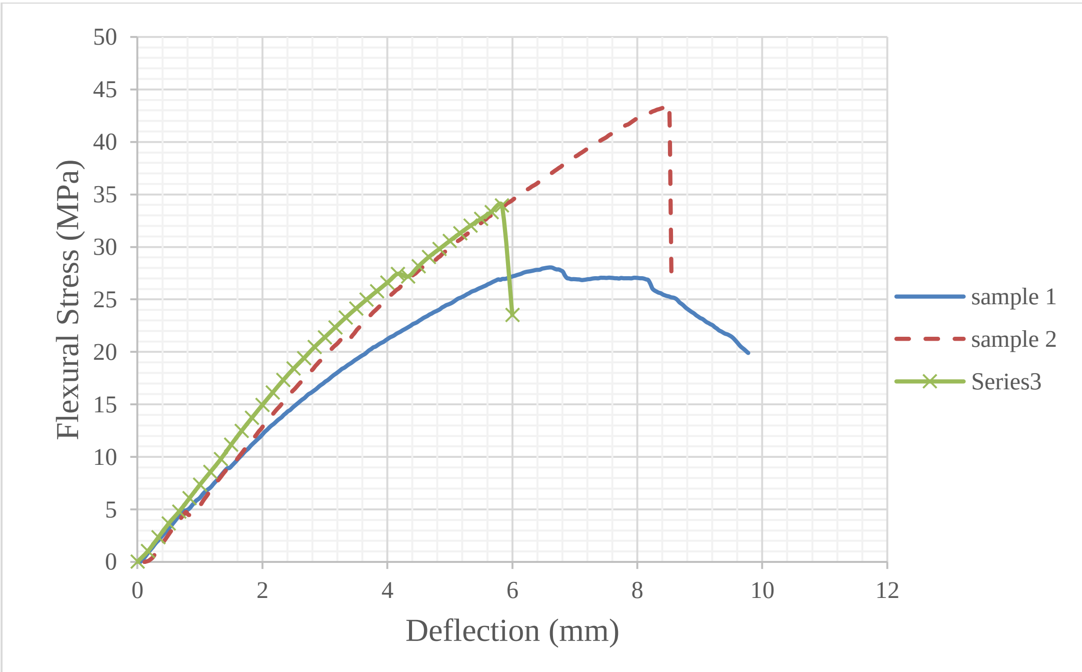


Figure 4.12 Flexural stress vs deflection curve of JRM with fiber content of 20%

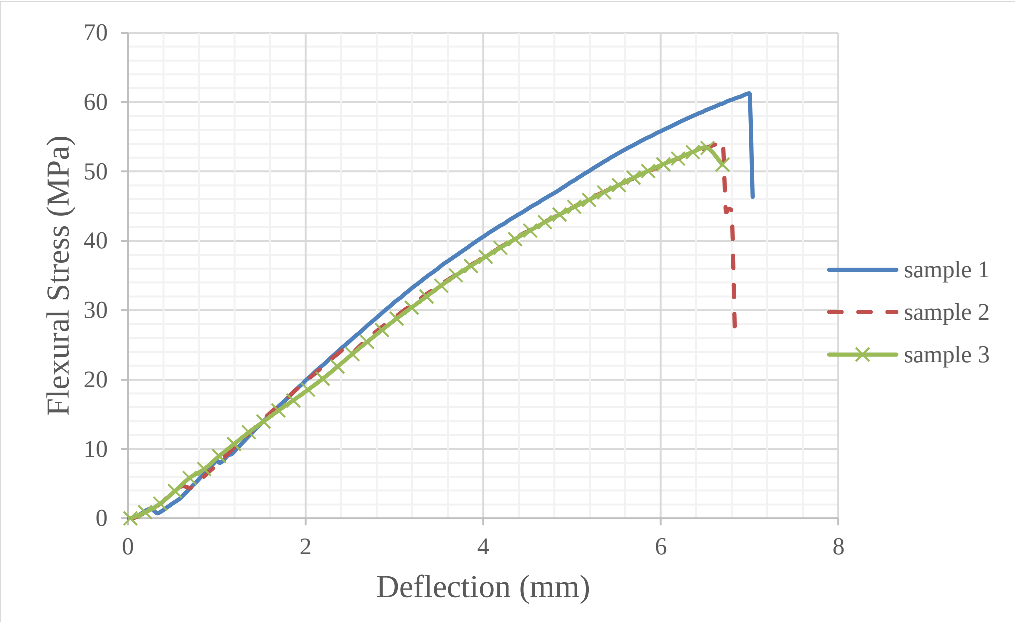


Figure 4.13 Flexural stress vs deflection curve of JRM with fiber content of 25%

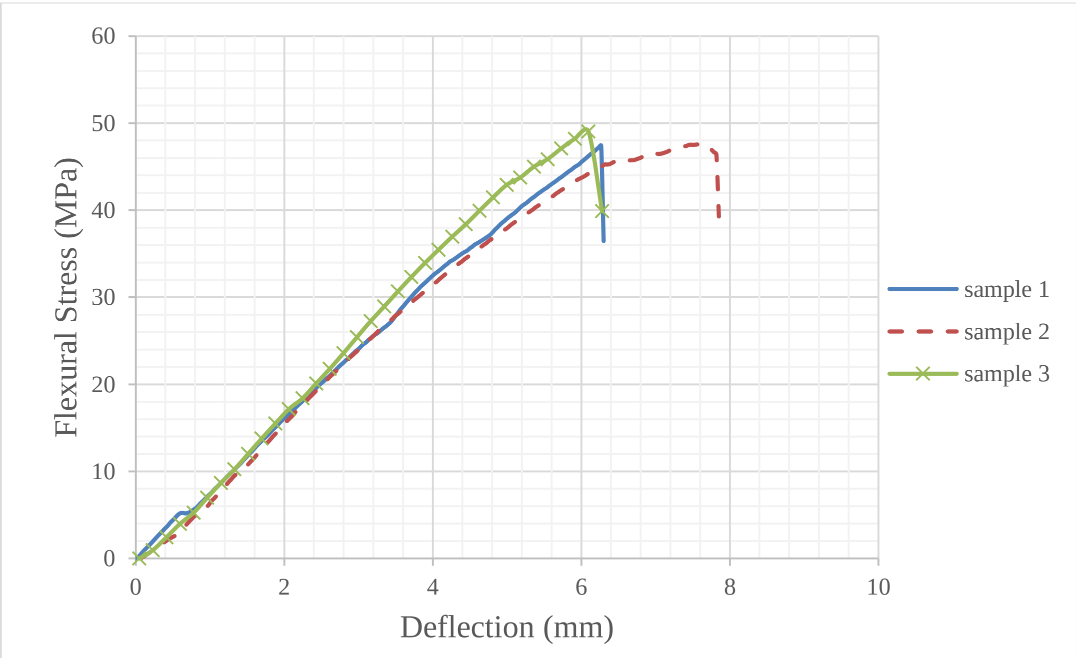


Figure 4.14 Flexural stress vs deflection curve of JRM with fiber content of 30%

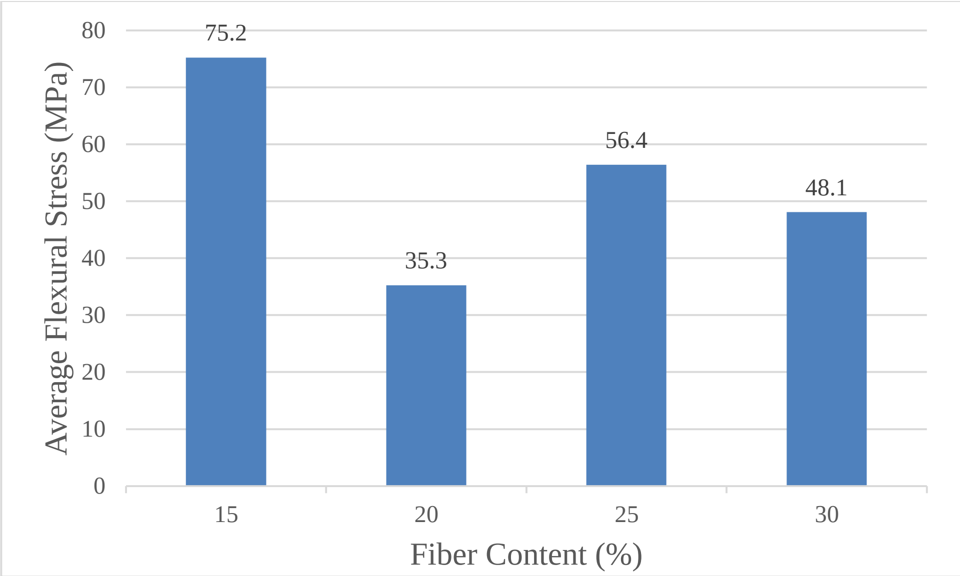


Figure 4.15 Average flexural strength of each different fiber content

Table 4.4 Summary of flexural strength result

Fiber content (%)	Ultimate Stress (Mpa)			
	1	2	3	Average
15	72.7	65.0	88.0	75.2
20	28.1	43.6	34.1	35.3
25	61.3	54.3	53.6	56.4
30	47.6	47.6	49.1	48.1

4.4.3 Optimum Fiber Volume Ratio

It is clear that both tensile and flexural strengths of JFM was significantly affected by the jute fiber content. Based on the overall results obtained from the tensile and flexural test of the JFM, it can be concluded that the 25% fiber content is the optimum fibre volume ratio between jute fiber and epoxy resin. JFM with 25% fiber content had the highest tensile strength of 73.2 MPa among the test sample and second highest flexural strength of 56.4 MPa. Although JFM with 15% fibre content shown the highest flexural strength of 75.2 MPa, it depicted the lowest tensile strength of 45.4 MPa among the tested sample. On the other hand, when the concrete beam is tested in flexure, the tensile stresses are produced in the layers below the neutral axis and the beam was failed in the tensile portion. Since the concrete beam fails in tensile portion, the JFM with 25% fiber content was considered as the optimum fiber volume as it had highest tensile strength.

4.5 Structural Properties of Beams

4.5.1 Load and Deflection Behaviour

The three-point loading test was conducted to determine the load-deflection curve and the crack pattern of the concrete beams. The data of the loading and deflection were recorded throughout the experimental testing.

4.5.1.1 Control Beam (CB)

Figure 4.16 and Table 4.5 show the load-deflection curve and the result of load and deflection of control beams (CB). The curve indicates that the beams CB only undergone the nonlinear elastic deformation. Referring to Figure 4.16 and Table 4.5, beam CB 1 and beam CB 2 were failed at the maximum load of 8.4 kN with the deflection of 0.5 mm and 7.7 kN with the deflection of 0.4 mm, respectively. On the other hand, a sharp reduction in load was observed once the maximum load was achieved, which exhibit that both beams experienced brittle failure. The experimental testing was terminated immediately once the specimens failed at the maximum load.

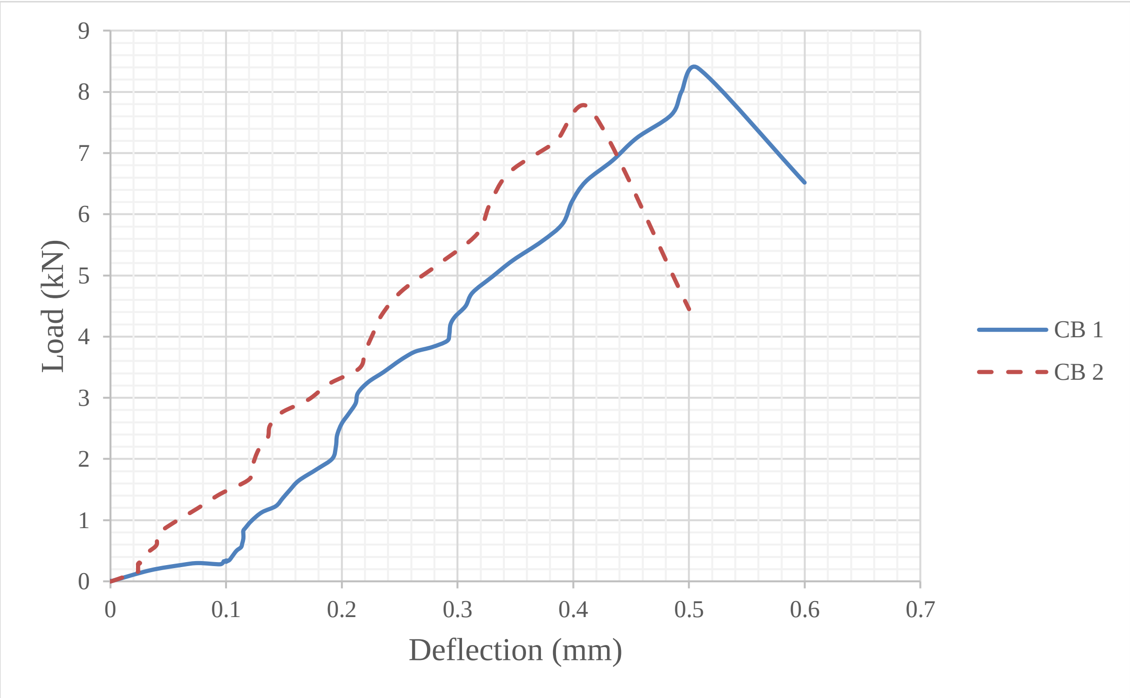


Figure 4.16 Load deflection curve for control beams (CB)

Table 4.5 Result of load and deflection of CB

Specimen	Maximum load	
	Load (kN)	Deflection (mm)
CB 1	8.4	0.5
CB 2	7.7	0.4

4.5.1.2 Beam Singly Reinforced with Steel Bar (SB)

Figure 4.17 shows the load-deflection curve of steel bar reinforced beams (SB) whereas Table 4.6 lists the deflection of beams at yield load, maximum load and failure load, respectively. The beam SB 1 and beam SB 2 had reached the yielding point at 13.7 kN with deflection of 0.9 mm and 12.0 kN with deflection of 0.9 mm, respectively. The yielding of beam indicates that the beam entering into the plastic region from the elastic region and achieved plastic behaviour. The beams were experiencing the strain hardening phase after first cracking at load 9 kN. With the continual application of load, the beams SB 1 and SB 2 achieved the maximum load of 35.7 kN with deflection of 2.6 mm and 37.0 kN with deflection of 3.0 mm, respectively. Once the maximum load was reached, the continuity of the applied load resulting in the diagonal shear crack at the support and the sharp reduction of load. This depicts that both beams were experiencing the brittle failure. The experimental testing was terminated immediately once the load dropped to 15.8 kN and 17.4 kN for beam SB 1 and SB 2, respectively.

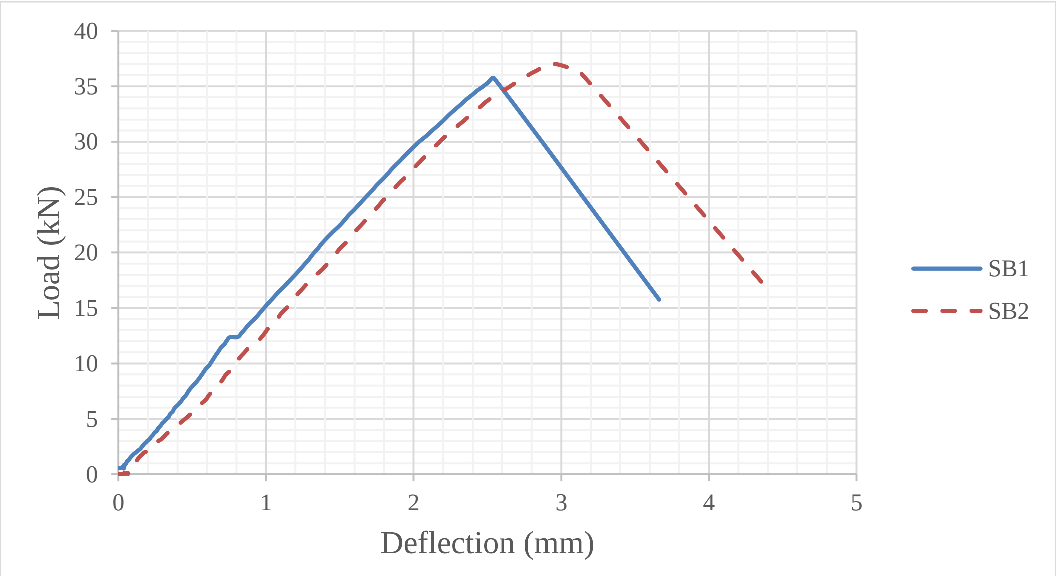


Figure 4.17 Load deflection curve for steel bar reinforced beams (SB)

Table 4.6 Result of load and deflection of SB

Specimen	Yield load		Maximum load		Failure load	
	Load (kN)	Deflection (mm)	Load (kN)	Deflection (mm)	Load (kN)	Deflection (mm)
SB 1	13.2	0.9	35.7	2.6	15.8	3.7
SB 2	12.0	0.9	37.0	3.0	17.4	4.4

4.5.1.3 Beam Singly Reinforced with JFM (JFMB)

Figure 4.18 shows the load-deflection curve of JFM reinforced beams (JFMB) whereas Table 4.7 lists the deflection of the JFMB at the maximum load and failure load. From Figure 4.18, the load-deflection curve indicates that beam JFMB 1 and JFMB 2 experienced elastic deformation till achieving the maximum load of 10.6 kN with the deflection of 0.6 mm and 10.0 kN with the deflection of 0.6 mm, respectively. Subsequently, the load capacity of beams starts to decrease as the crack appears. This exhibit that the beams undergone the plastic deformation and experiencing strain hardening. The load capacity of beam JFMB 1 and JFMB 2 increased again when reached the load of 6.7 kN with 1.1 mm deflection and 6.8 kN with 1.1 mm deflection. The increasing of load capacity of beam JFMBs may be due to the strain hardening of the JFM. The beam JFMB 1 and JFMB 2 experienced a sharp reduction of in load, exhibited a brittle failure at the deflection of 1.8 mm and 1.6 mm corresponding to the load of 8.9 kN and 7.7 kN respectively. Figure 4.19 shown the failure pattern of JFM after three-point loading test of beam JFMB.

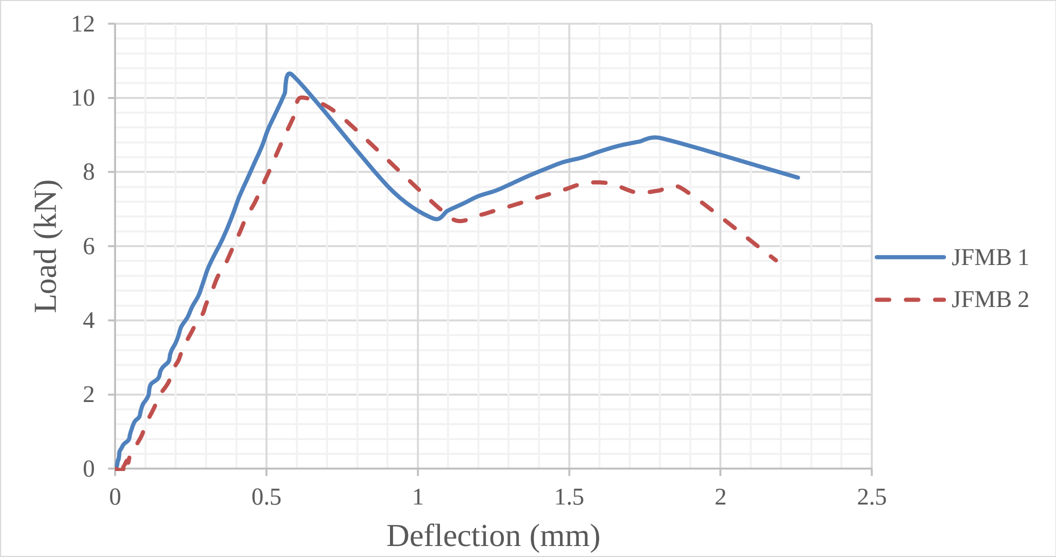


Figure 4.18 Load deflection curve for JFM reinforced beams (JFMB)

Table 4.7 Result of load and deflection of JFMB

Specimen	Maximum load		Failure load	
	Load (kN)	Deflection (mm)	Load (kN)	Deflection (mm)
JFMB 1	10.6	0.6	8.9	1.8
JFMB 2	10.0	0.6	7.7	1.6

Figure 4.19 JFM after three-point loading test of beam JFMB

4.5.1.4 Comparison of Load-deflection Curves

Load-deflection curve comparison of control beam, CB with steel bar reinforced beam SB and JFM reinforced beam JFMB is shown in Figure 4.20. A summary of the three-point loading results is listed in Table 4.8.

From Table 4.8, the experimental result obtained for CB indicates that the ultimate load that the beam was able to sustain was 8.4 kN with a deflection of 0.5 mm. For beam SB, the maximum load that managed to achieve 37.0 kN with the deflection of 3.0 mm. The steel bar increased the beam capacity about 340.9% of the load of the CB. On the other hand, the maximum load of beam JFMB is 10.6 kN, about 26.3% higher than the control beam, but only achieves 28.7% strength of beams SB. The deflection of the beam JFMB beam is 0.6 mm. From the load-deflection curve trend, the control beam, CB experienced abrupt failure once the load of 8.4 kN was achieved. However, the load-deflection curve line of beam SB had experienced strain hardening after the first cracking at load 19 kN. The load increased gradually with deflection until the maximum load was achieved before the failure. This indicates that beam SB experienced plastic deformation exhibiting the ductile behaviour.

On the other hand, the load-deflection curve line of beam JFMB was found dissimilar than SB. After achieving a maximum load of 10.6 kN, a decrease in load was observed before an increase in load owing to strain hardening. At the deflection of 0.6 mm, a sharp decreasing of the load was observed indicating a brittle failure. The beam with JFM failed in a brittle manner which explained that the JFM was weak to resist tensile force and most of the loading was resisted by the concrete strength. There is no significant difference in load was traced when the JFM was used to reinforce the concrete beam.

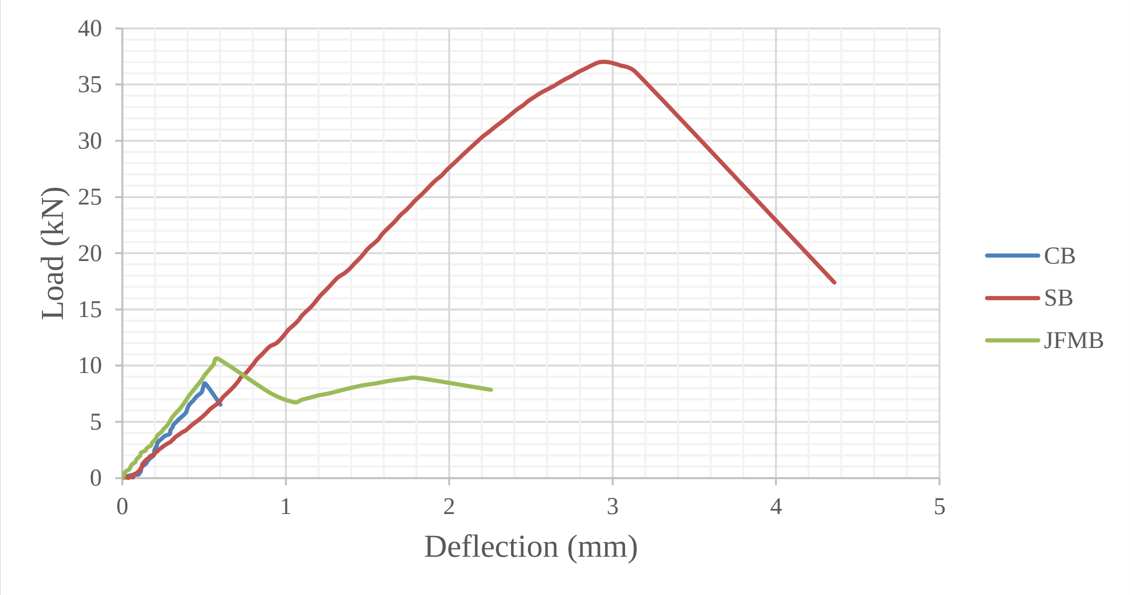


Figure 4.20 Comparison of beam load-deflection curves

Table 4.8 Comparison of load-deflection curve of tested beams

Specimen	Maximum Load		Percentage Incremental of Beam Capacity (%)	Comparison of Beam Capacity (%)
	Load (kN)	Deflection (mm)		
CB	8.4	0.5	-	-
SB	37.0	3.0	340.9	-
JFMB	10.6	0.6	26.3	28.7

4.5.2 Cracking Pattern and Failure Mode

The crack pattern was analysed through observing the cracking pattern produced during and after the three-point loading testing. The cracking was observed and recorded by marking and numbering the cracking throughout the testing. The results discussed included a total of six beams; two control beams, two steel bar reinforced beams two and JFM reinforced beams.

Figure 4.21 shows the crack pattern of the control beam, CB. From the crack pattern obtained, the concrete beam exhibited a sudden failure in a brittle manner without showing any appearance of crack. Dissimilar with the CB, cracks were identified before beam failure in SB. At the early stage of load application, initial vertical cracks were observed in the middle of the tension zone at the load of 19 kN. With the continual application of load, the diagonal shear cracks were found at the support loading point and propagated to the neutral axis of the beam near to the loading point. The crack width was found visible and enlarged before the beam failed in a brittle manner, signifying a shearing failure. The crack patterns and final failure of the beam SB was illustrated in Figure 4.22. The crack pattern for JFM reinforced beams was found similar with the beam CB. Referring to Figure 4.23, the beam JFMB shows the tension crack in the middle of the beam at the load of 10 kN. With the gradual increase of the applied load, the initial crack was enlarged and propagated until reaching the upper part of the beam as failed in a brittle manner which is similar to a typical failure pattern of the unreinforced concrete beam.

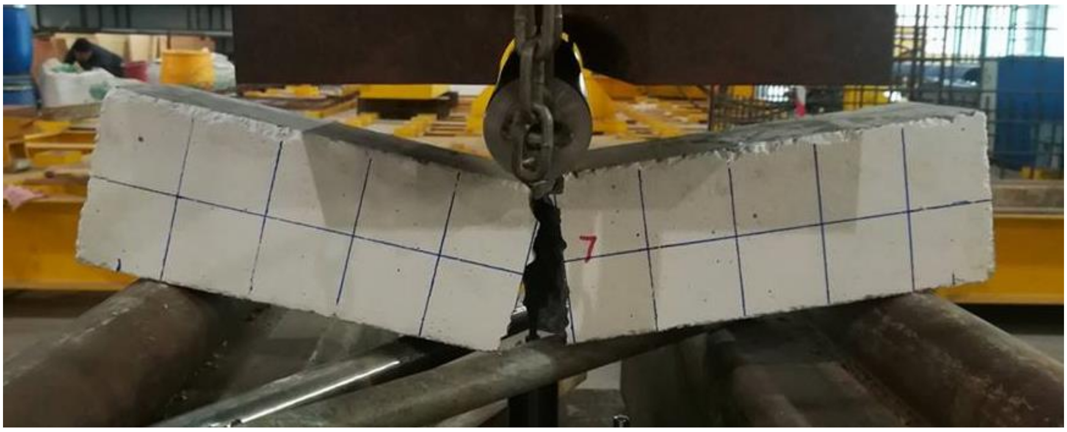


Figure 4.21 Overview of crack pattern of CB

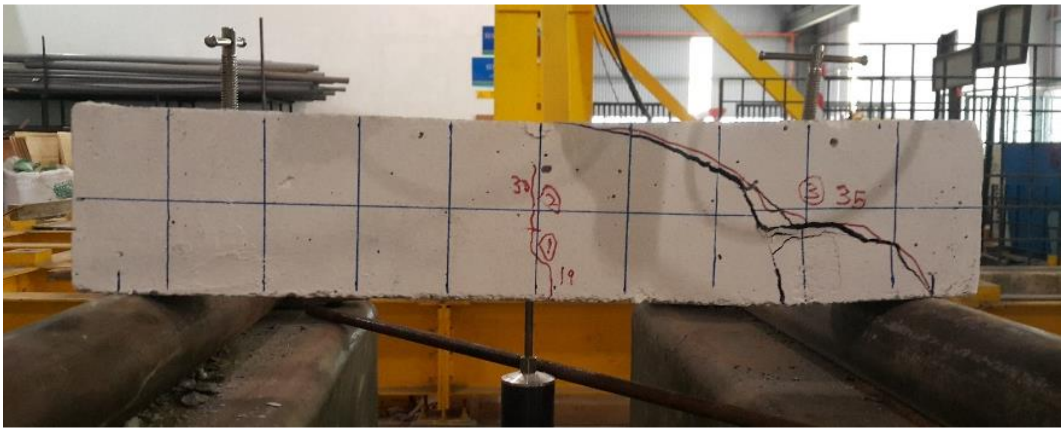


Figure 4.22 Overview of crack pattern of SB

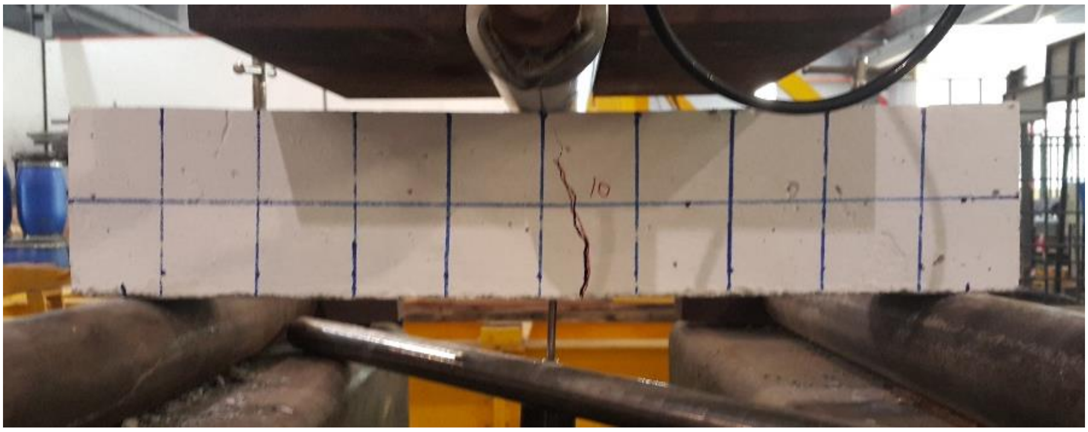


Figure 4.23 Overview of crack pattern of JFMB

CHAPTER 5

CONCLUSION

5.1 Introduction

This chapter discusses the conclusion and recommendation of the research. The finding of the properties of jute fiber, mechanical properties of the jute fiber mat, behaviour of the concrete beam and strengthening effect of JFM are presented in this section.

5.2 Conclusions

Based on the overall results obtained, several conclusions can be drawn which referred to the respective objectives.

i. Alkali treatment of jute fibre with 5% (w/v) NaOH over 4 hours duration at room temperature was an effective technique to enhance the mechanical properties of jute fibre. The chemically treated fiber filaments showed the average maximum tensile strength of 774.4 MPa about 71.3% higher than the untreated fiber. This increase resulted from the removal of surface impurities and closer packing of the cellulose chains. On the other hand, treated fiber had the elongation of 1.34% about 44.3% lower than the untreated fiber.

ii. Tensile strength of JFM increased as the fiber content surged to 25% and then decreased. The sample with 25% jute fibre content shows the highest average tensile strength of 73.2 MPa among the testing samples. However, the sample with 15% of fibre content has the highest average flexural strength of 75.2 MPa. The second highest of flexural strength of 56.4 MPa was shown by the 25% fibre content. Thus, it can be concluded that the 25% jute fiber content is the optimum fiber volume ratio between jute fiber and epoxy resin.

iii. The JFM reinforced concrete beam showed an increase in the ultimate load capacity compared to the control beam, CB. The beam JFMB managed to achieve a maximum load of 10.6 kN, about 26.3% higher than CB, but only achieve 28.7% strength of beams SB and had a deflection of 0.6 mm. From the load-deflection curve trend, the control beam, CB was failed once the maximum load was achieved at 8.4 kN, whereas beam SB and JFMB achieved the maximum load of 37.0 kN and 10.6 kN, respectively. This indicates that the beam SB experienced plastic deformation and strain hardening. In terms of crack pattern, beam CB failed without the appearance of crack lines. For beam SB, the cracks were found in the mid-span of the beam and display the diagonal shear failure. Meanwhile, beam JFMB contained a vertical crack in the mid-span of the beam. Propagation of crack was observed with a sudden crack sound upon failure. Beam with JFM strengthening failed in a brittle manner which explains that the JFM was weak to resist tensile force and most of the loading was resisted by the concrete strength. Beam reinforced with JFM did not show a significant effect on the beam strength.

5.3 Recommendation for Future Research

Future work to examine the behaviour of the JFM reinforced beam and the strengthening effect of the JFM is still on-going. The experimental results found in this research should only be considered as a starting point for a better understanding of the strengthening method and the effects of JFM in the structural industry. The gaps as identified for future research include:

i. Experimental research with different amount of layer of the JFM should be conducted in order to comprehend the strengthening effect of the JFM. In this research, only a single layer of JFM was used in reinforcing the concrete beam, thus the effect of strengthening is not obvious compared to the steel bar reinforced beam.

ii. In order to determine the potential of JFM in the replacement of steel bar, the research may be conducted by setting the 16 mm diameter steel bar reinforced beam as the control beam. On the other hand, the beam strengthened by the 10 mm diameter and different amounts of layer JFM may be the variable beam specimens. Both CB and variable beam specimens will undergo the four-point loading test to determine the strengthening effect of the JFM.

iii. The strain gauge should be used to detect the deformation of beam and provide the alternating load-deflection data. Both strain gauge data and LVDT data are analysed and compared in order to improve the accuracy and credibility of the result.

REFERENCES

Aggarwal, P. & Sharma, B., 2011. Application of Jute Fiber in the Improvement of Subgrade Characteristics. *int. J. on Transportation and urban Development,*, 1(1), pp.2–4.

Anon, 2015. ANALYSIS OF RC CONTINUOUS BEAMS STRENGTHENED IN FLEXURE WITH FRP USING. , (May).

E.Naveen, N.Venkatachalam, N.M., 2015. Alkalichemical Treatment on the Surface of Natural Fibre. , 4(4), pp.172–178.

El-Gamal, S.E. et al., 2016. Efficiency of near surface mounted technique using fiber reinforced polymers for the flexural strengthening of RC beams. *Construction and Building Materials*, 118, pp.52–62. Available at: http://dx.doi.org/10.1016/j.conbuildmat.2016.04.152.

El-Mogy, M., El-Ragaby, A. & El-Salakawy, E., 2010. Flexural Behavior of Continuous FRP-Reinforced Concrete Beams. *Journal of Composites for Construction*, 14(6), pp.669–680.

El-Shekeil, Y.A. et al., 2012. Influence of fiber content on the mechanical and thermal properties of Kenaf fiber reinforced thermoplastic polyurethane composites. *Materials and Design*, 40, pp.299–303. Available at: http://dx.doi.org/10.1016/j.matdes.2012.04.003.

Fiore, V., Di Bella, G. & Valenza, A., 2015. The effect of alkaline treatment on mechanical properties of kenaf fibers and their epoxy composites. *Composites Part B: Engineering*, 68, pp.14–21. Available at: http://dx.doi.org/10.1016/j.compositesb.2014.08.025.

Hojo, T. et al., 2014. Tensile properties of bamboo, jute and kenaf mat-reinforced composite. In *Energy Procedia*. pp. 72–79.

Huang, L. et al., 2016. Reinforced concrete beams strengthened with externally bonded natural flax FRP plates. *Composites Part B: Engineering*, 91, pp.569–578.

M.Shahirul, M.J., Yahya, M.Y. & Nur Izan Syahriah, H., 2016. The effect of fibre layering pattern in resisting bending loads of natural fibre-based hybrid composite materials. In *MATEC Web of Conferences*. pp. 1–6.

Mukherjee, K., 2013. Prospects and Challenges of ASEAN. *Strategic Analysis*, 37(6), pp.742–757. Available at: http://www.tandfonline.com/doi/abs/10.1080/09700161.2013.847035.

Pham, T.M. & Hao, H., 2016. Review of Concrete Structures Strengthened with FRP Against Impact Loading. *Structures*, 7, pp.59–70. Available at: http://dx.doi.org/10.1016/j.istruc.2016.05.003.

Punyamurthy, R., Sampathkumar, D. & Bennehalli, B., 2015. Influence of Fiber Content and Effect of Chemical Pre-Treatments on Mechanical Characterization of Natural Abaca Epoxy Composites. *Indian Journal of Science and Technology*, 8(June). Available at: https://www.researchgate.net/publication/279178147_Influence_of_Fiber_Content_and_Effect_of_Chemical_Pre-Treatments_on_Mechanical_Characterization_of_Natural_Abaca_Epoxy_Composites.

Ramadan, N. et al., 2016. Assisted Resin Infusion Alkali Treatment of jute fabric for Vacuum Assisted Resin Infusion. , (April 2015).

Ravikumar, C.S. et al., 2014. APPLICATION OF FRP FOR STRENGTHENING AND RETROFITTING OF CIVIL ENGINEERING STRUCTURES. , 4(1), pp.49–60.

Roy, A. et al., 2012. Improvement in mechanical properties of jute fibres through mild alkali treatment as demonstrated by utilisation of the Weibull distribution model. *Bioresource Technology*, 107, pp.222–228. Available at: http://dx.doi.org/10.1016/j.biortech.2011.11.073.

Sanjay, M.R. & Yogesha, B., 2016. Studies on Mechanical Properties of Jute / E-Glass Fiber Reinforced Epoxy Hybrid Composites. *Journal of minerals and materials characterization and engineering*, 4.0(January), pp.15–25.

Sen, T. & Jagannatha Reddy, H.N., 2014. Efficacy of bio derived jute FRP composite based technique for shear strength retrofitting of reinforced concrete beams and its comparative analysis with carbon and glass FRP shear retrofitting schemes. *Sustainable Cities and Society*, 13, pp.105–124. Available at: http://dx.doi.org/10.1016/j.scs.2014.04.010.

Sen, T. & Jagannatha Reddy, H.N., 2013a. Strengthening of RC beams in flexure using natural jute fibre textile reinforced composite system and its comparative study with CFRP and GFRP strengthening systems. *International Journal of Sustainable Built Environment*, 2(1), pp.41–55. Available at: http://www.sciencedirect.com/science/article/pii/S2212609013000265.

Sen, T. & Jagannatha Reddy, H.N., 2013b. Strengthening of RC beams in flexure using natural jute fibre textile reinforced composite system and its comparative study with CFRP and GFRP strengthening systems. *International Journal of Sustainable Built Environment*, 2(1), pp.41–55. Available at: http://www.sciencedirect.com/science/article/pii/S2212609013000265.

Sen, T. & Paul, A., 2015. Confining concrete with sisal and jute FRP as alternatives for CFRP and GFRP. *International Journal of Sustainable Built Environment*, 4(2), pp.248–264.

Sen, T. & Reddy, H.N.J., 2013. Pretreatment of woven jute FRP composite and its use in strengthening of reinforced concrete beams in flexure. *Advances in Materials Science and Engineering*, 2013.

Yan, L., Kasal, B. & Huang, L., 2016. A review of recent research on the use of cellulosic fibres, their fibre fabric reinforced cementitious, geo-polymer and polymer composites in civil engineering. *Composites Part B: Engineering*, 92, pp.94–132. Available at: http://dx.doi.org/10.1016/j.compositesb.2016.02.002.

APPENDIX A
CONCRETE MIX DESIGN FORM

Stage	Item	Reference or Calculation	Values
1	1.1 Characteristic strength 1.2 Standard Deviation 1.3 Margin 1.4 Target mean Strength 1.5 Cement type 1.6 Aggregate type: coarse Aggregate type: fine 1.7 Free- water/cement ratio 1.8 Maximum free-water/cement ratio	Specified Table 1.1 C1 or Specified C2 Specified Table 1.3, Figure 2 Specified	25N/mm² at $28 days$ Proportion Defective 5% $5N/mm^2$ (k=1.64) $1.64 \times 4 = 6.56N/mm^2$ $25 + 6.56 = 31.56\ N/mm^2$ **OPC**/SRPC/RHPC Crushed/**uncrushed** Crushed/**uncrushed** 0.59 0.53 Use the lower value 0.53
2	2.1 Slump or Vebe Time 2.2 Maximum aggregate size 2.3 Free water content	Specified Specified Table 2.1	Slump 75 mm or Vebe time __s 14 mm $213kg/m^3$
3	3.1 Cement Content 3.2 Maximum cement content 3.3 Minimum cement content 3.4 Modifie free-water/cement ratio	C3 Specified Specified	213 / 0.53 = 401.89 kg/m^3 $- kg/m^3$ $- kg/m^3$ Use 3.1if < 3.2 Use 3.3 if > 3.1 - kg/m^3
4	4.1 Relative density of aggregate(SSD) 4.2 Concrete density 4.3 Totally Aggregate content	 Figure 3 C4	2.6 known/**assumed** $2346kg/m^3$ 2346 – 213 – 401.89 = 1731.11 kg/m³
5	5.1 Grading of fine aggregate 5.2 Proportion of fine aggregate 5.3 Fine aggregate content 5.4 Coarse aggregate content	Percentage passing 600µm sieve Figure 4 C5 C5	40% - 60% 45% 0.45 x 1731.11 = 779 kg/m³ 1731.11 - 779 = 952.11 kg/m³

Quantities	Cement(kg)	Water(kg or L)	Fine Aggregate(kg)	Coarse Aggregate(kg) 10mm 20mm 40mm
Per m^3 (to nearest 5kg)	400	215	780	950
Per trial mix of 0.079 m^3	31.68	17.03	61.78	75.24

1 N/mm² = 1 MN/m² = 1 MPa
OPC = ordinary Portland cement; SRPC = sulphate-resisting Portland cement; RHPC = rapid-hardening Portland cement
Relative density = specific gravity
SSD = based on a standard surface-dry basis.

APPENDIX B
PHOTOS





APPENDIX C
CONTROL BEAM RAW DATA

Load, kN	Deflection, mm
0	0
0	0
0.27	0.062
0.28	0.095
0.33	0.098
0.33	0.099
0.32	0.1
0.34	0.1
0.33	0.101
0.35	0.103
0.5	0.109
0.62	0.114
0.77	0.115
0.88	0.117
1.13	0.131
1.36	0.149
1.65	0.163
2.01	0.192
2.39	0.196
2.74	0.206
3.08	0.214
3.42	0.236
3.67	0.255
3.83	0.278
4.04	0.293
4.33	0.298
4.72	0.313
5.25	0.348
5.85	0.391
6.54	0.411
7.25	0.455
8.02	0.494
6.52	0.6

Load, kN	Deflection, mm
0	0
0.09	0.014
0.18	0.024
0.2	0.024
0.24	0.024
0.29	0.024
0.31	0.025
0.31	0.026
0.37	0.027
0.5	0.034
0.77	0.041
1.19	0.075
1.67	0.12
2.15	0.128
2.55	0.138
2.97	0.171
3.48	0.215
4.05	0.227
4.75	0.252
5.68	0.317
6.69	0.345
7.71	0.415
4.45	0.5

APPENDIX D
STEE BAR REINFORCED BEAM RAW DATA

Load, kN	Deflection, mm
0	0
0.098	-0.087
0.254	-0.134
0.387	-0.098
0.422	-0.043
0.493	-0.012
0.546	0.017
0.644	0.029
0.638	0.035
0.52	0.036
0.741	0.041
0.876	0.041
1.195	0.059
1.861	0.107
2.545	0.163
3.076	0.202
3.566	0.235
4.241	0.275
5.205	0.341
6.403	0.413
7.745	0.488
9.149	0.573
10.761	0.66
12.361	0.755
13.975	0.919
16.024	1.056
18.102	1.205
20.325	1.349
22.498	1.503
24.707	1.655
26.982	1.816
29.243	1.978
31.287	2.149
33.394	2.322
35.388	2.509
5.875	4.378
6.7	4.499

Load, kN	Deflection, mm
0	0
0.114	0.038
0.121	0.063
0.402	0.082
0.767	0.108
1.344	0.129
1.95	0.171
2.661	0.237
3.331	0.302
4.042	0.363
5.247	0.473
6.777	0.594
8.573	0.707
10.564	0.823
12.386	0.97
14.461	1.099
16.605	1.237
18.593	1.389
20.775	1.531
22.947	1.675
25.142	1.825
27.357	1.981
29.58	2.144
31.583	2.311
33.547	2.484
35.173	2.673
36.721	2.873
17.387	4.356
13.057	4.994

APPENDIX E
JFM REINFORCED BEAM RAW DATA

Load, kN	Deflection, mm
0	0
-0.064	0
-0.061	0.001
-0.048	0.001
-0.058	0.002
0.011	0.003
0.15	0.007
0.252	0.011
0.378	0.013
0.535	0.019
0.78	0.044
1.258	0.063
1.561	0.084
1.864	0.102
2.173	0.113
2.407	0.138
2.627	0.149
2.877	0.175
3.077	0.181
3.387	0.199
3.83	0.218
4.369	0.254
5.014	0.29
5.71	0.324
6.501	0.371
7.342	0.41
8.266	0.461
9.153	0.505
10.121	0.56
7.561	0.907
6.955	1.098
7.35	1.2
7.689	1.31
8.091	1.424
8.394	1.544
8.705	1.663
8.916	1.801
7.848	2.256

Load, kN	Deflection, mm
0	0
-0.039	0.019
-0.008	0.024
0.002	0.027
0.049	0.027
0.018	0.028
0.059	0.031
-0.016	0.031
0.015	0.029
0.084	0.029
0.189	0.036
0.167	0.043
0.482	0.062
0.891	0.087
1.338	0.109
1.747	0.134
2.17	0.163
2.496	0.184
2.772	0.198
3.103	0.217
3.475	0.238
3.945	0.269
4.454	0.301
5.185	0.339
5.916	0.386
6.761	0.432
7.607	0.485
8.557	0.537
9.546	0.593
9.559	0.737
6.821	1.194
7.151	1.334
7.502	1.476
7.692	1.633
7.502	1.798
5.619	2.183