STRENGTHENING OF R[illegible] USING DIFFERENT CONFIGURATION OF CARBON FIBRE REINFORCED POLYMER STRIPS

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ABSTRACT

This paper present the experimental research on strengthening of reinforced concrete (RC) beams using different configuration of carbon fibre reinforced polymer (CFRP) strips. In general, FRP material is fairly expensive compared to other materials. In order to increase the capacity of structural members damaged by deterioration and overloads or even aggressive environment condition, more economic and effective for building structures have been needed. According to Dong, Wang, & Guan, (2011), it can be seen that the beams retrofitted with CFRP have a much smaller crack width and exhibit a less number of cracks than the control beam. Therefore, difference configurations of CFRP strips have been investigate to provide potentially economical solution. The work carried out is to investigate the effect of different configurations of CFRP strips towards ultimate shear capacity, beam deflection and on crack propagation of the retrofitted beams. The test consists of three reinforced concrete beams which two beam is retrofitted with CFRP strips at preloaded stage and one is not preloaded or retrofitted with CFRP strips and act as a control beam which subjected to four points loading system. Under loaded condition, beams are retrofitted with different configurations of CFRP strips then the load increases until the beams reach failure. Research output has shown that the strengthening effects of CFRP towards shear capacity, beam deflection and on crack propagation of RC beams depend on the arrangements of CFRP. Based on experimental it shows that by using CFRP retrofitted beam in L shape and U shape configuration was proved to be effective because it can reduce the number of crack as well as increased the shear capacity. The experimental result shows that by using CFRP strips in L shape configuration is the most effective configuration in order to improving the ultimate shear capacity and stiffness of a strengthened RC beam. Other than that, from the result it also proved that retrofitted beam in CFRP L shape configuration show the lowest midspan deflection at peak load and least number of cracking after failure compared to others.

ABSTRAK

Kertas ini membentangkan kajian eksperimen pengukuhan konkrit bertetulang (RC) rasuk menggunakan konfigurasi yang berlainan daripada serat karbon polimer bertetulang (CFRP) jalur. Secara umum, bahan FRP agak mahal berbanding dengan bahan-bahan lain. Dalam usaha untuk meningkatkan keupayaan anggota struktur rosak akibat kegagalan konkrit, beban dan keadaan persekitaran yang agresif, maka alternatif yang lebih ekonomi dan berkesan untuk struktur bangunan amat diperlukan. Menurut Dong, Wang, & Guan, (2011), ia boleh dilihat bahawa rasuk dipasang dengan CFRP mempunyai saiz keretakan yang lebih kecil dan dapat mengurangkan keretakan berbanding rasuk kawalan tanpa dipasang dengan CFRP. Oleh itu, perbezaan konfigurasi jalur CFRP telah dikaji supaya dapat menghasilkan penyelesaian yang berpotensi dan menjimatkan untuk kerja-kerja pengukuhan konkrit bertetulang (RC) rasuk. Kajian yang telah dijalankan adalah untuk mengkaji kesan konfigurasi yang berlainan daripada CFRP jalur ke arah keupayaan ricih, pesongan rasuk dan keretakan pada konkrit tetulang rasuk. Ujian ini terdiri daripada tiga rasuk konkrit bertetulang, dimana dua rasuk telah dipasang dengan jalur CFRP pada peringkat penambahan beban manakala satu rasuk konkrit tetulang tidak dipasang jalur CFRP dan bertindak sebagai rasuk kawalan yang tertakluk kepada empat mata sistem muatan. Di bawah keadaan penambahan beban, rasuk dipasang dengan konfigurasi yang berlainan jalur CFRP dan beban ditambah sehingga rasuk mencapai kegagalan. Hasil penyelidikan telah menunjukkan bahawa kesan-kesan pengukuhan CFRP terhadap keupayaan ricih, pesongan rasuk dan keretakan rasuk RC bergantung kepada konfigurasi CFRP. Berdasarkan eksperimen ini, ia menunjukkan bahawa dengan menggunakan CFRP dipasang rasuk dalam bentuk L dan konfigurasi bentuk U telah terbukti berkesan kerana ia boleh mengurangkan bilangan retak serta peningkatan kapasiti ricih. Keputusan eksperimen menunjukkan bahawa dengan menggunakan jalur CFRP dalam L konfigurasi bentuk adalah konfigurasi yang paling berkesan untuk meningkatkan keupayaan ricih terhadap konkrit tetulang rasuk. Selain daripada itu, dari hasil ini, ia juga membuktikan bahawa rasuk dipasang menggunakan CFRP L konfigurasi menunjukkan bahagian tengah rasuk pesongan paling rendah pada beban puncak dan menghasilkan keretakan paling sedikit selepas kegagalan berbanding konkrit tetulang yang lain.

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LIST OF ABBREVIATIONS

RC	Reinforced Concrete
FRP	Fibre Reinforced Polymer
CFRP	Carbon Fibre Reinforced Polymer
GFRP	Glass Fibre Reinforced Polymer
NDT	Non-Destructive Testing
NSMR	Near Surface Mounted Reinforcement
ASTM	American Standard of Testing and Materials
LVDT	Linear Variable Displacement Transducer
ANOVA	Analysis of Variance

CHAPTER 1

INTRODUCTION

1.1 INTRODUCTION

Strengthening techniques for damaged structures have been developed over the years in order to lengthen its serviceability time. Therefore, in order to increase the capacity of structural members damaged by deterioration and overloads or even aggressive environment condition such as earthquake in Japan or China, strengthening techniques which is more economic and effective for building structures have been needed. The material that is widely used for repairing or retrofitting damaged existing structures such as reinforced concrete (RC) beam is epoxy bonded fiber reinforced polymer (FRP) sheet.

According to Kachlakev & Damian, (2002) the bridges in both the United States and Canada are 40 percent structurally deficient. Structural element made of concrete and reinforcing steel is often determined not sufficient to sustain current or new load imposed on the bridges. Recently, (Kachlakev & Mccurry, 2000) performed four bending experiments on RC beams by using carbon FRP and glass FRP. The experimental study is to compare the structural behaviour design of the beams retrofitted by carbon FRP and glass FRP for flexural and shear strengthening. The results show that FRP retrofitted for structural strengthening can increase the load capacity up to 150 percent of the original beam capacity depends on the material properties, geometry and the mode of failure.

1.2 PROBLEM STATEMENT

In the last decade, the use of FRP materials for strengthening buildings and bridges has been used widely. In general, FRP materials have a lot of advantages such as light weight, high strength, and simple installation method. However, it also has disadvantages that need to be taken into consideration such as FRP material is fairly expensive compared to other materials. According to Witt, (2012) the most common practice of using FRP materials is externally bonded layup system which they fully wrapped on the member to be strengthened. Therefore, in order to provide potentially economical solution, different sequences of FRP strips have been investigate to overcome the problems.

Another important factor why we need to strengthened the damaged existing structures is because aggressive environment condition. There are many structures due to their original design limit or aggressive environment condition such as earthquake in China and Japan that need to be retrofitted to meet the demand usage in more economic and effective ways. In fact, according to the case (Magnitude 5.3 eartquake hit eastern Japan, 2013) it mentioned that a 5.3 magnitude earthquake struck eastern Japan causing building in Tokyo to shake. Government of Japan has taken an initial step by repairing the existing damaged existing structure using FRP composite. The use of FRP composite was increase after the incident on 1995 Hyogoken Nanbu Eartquake in Japan.

Lastly, is the structure defect which contributes to the structure failure. Severe structure defects in building are generally due to the poor design, poor construction materials and poor maintenance. According to Andra & Maier, (2009) severe cracks in the cross heads of the T-shaped piers of the Kepong Flyover in Kuala Lumpur are a typical results of such error. One of the techniques in rehabilitation procedures to every pier is apply moderate permanent post-tensioning force for crack control by 18 externally bonded Carbon FRP tendons. Another similar case to this factor was noted which is the sudden and brittle collapse of the bridge seat of the Reichsbruecke in Vienna on 1976.

As a conclusion, FRP has been used in different configurations and techniques for effective use of materials and to ensure long service life of the selected system. Although a lot of research has undertaken on the flexural strengthening by using FRP materials bonded onto the tension face of the beam, the main focus here in this research was in the different configuration of Carbon Fibre Reinforced Polymer (CFRP) strips which can reduce the overall cost of repairing the existing structures. In comparison by using FRP strips is much lower cost compared by using FRP sheets or FRP laminates.

1.3 OBJECTIVES

The objectives of this study are:

1. To investigate the effect of different configurations of CFRP strips on ultimate shear capacity.
2. To investigate the effect of different configurations of CFRP strips towards beam deflection.
3. To investigate the effect of different configurations of CFRP strips on crack propagation of the retrofitted beams.

1.4 SCOPE OF STUDY

This study mainly focuses on the strengthening of reinforced concrete beams using different configuration of CFRP strips using experimental. Scopes of this study included the following procedure:

i. Beam specimens of 150 mm x 250mm x 2000 mm are used.

ii. Longitudinal reinforcement are consisted of two steel rebars of 12 mm placed on the bottom of the beam and two steel rebars of 12 mm was used on top of the beam.
iii. For shear reinforcement, stirrups of 8 mm in diameter are used.
iv. Grade 30 Mpa of concrete is used for the specimens.
v. Test that will be conducted is flexural test.
vi. The specimens will be cured for 28 days after concrete mix design.
vii. Different configuration of CFRP strips will be applied on the surfaces of reinforced concrete beams.

1.5 EXPECTED OUTCOME

Different configuration of CFRP strips is expected to be effective materials in retrofitted the damaged existing structure for improving the shear capacity, beam deflection and cracks propagation of the retrofitted beams. Besides that, CFRP strips are also expected to provide an economical solution for extending the service life of reinforced concrete structures. Based on experimental done by Kachlakev & Mccurry, (2000) the results show that FRP materials retrofitted for structural strengthening can increase the load capacity up to 50 percent of the original beam capacity.

CHAPTER 2

LITERATURE REVIEW

2.1 REINFORCED CONCRETE STRUCTURES

Reinforced concrete is one of the principle materials uses in many civil engineering applications such as the construction of buildings, retaining walls, foundations, highways and bridges. According to Nilson, Darwin, & Dolan, (2003) reinforce concrete structures is the concrete in which steel is embedded in such manner that the two materials is act together in resisting forces. The reinforcing steel absorbs the tensile, shear and the compressive stresses in a concrete structure. Furthermore, (Yassin & Abdullah, 2012) said that by providing steel bars within a concrete member which will be subjected to tensile stresses, an economical structural material can be produced which is both is strong in compression and in tension.

Reinforcement is design to carry the tensile forces which are transferred by bond between the interfaces of the two materials. If this bond is not adequate, the reinforcing bars will just slip within the concrete and there will not be a composite action. This will cause a major failure in structure. It can be concluded that reinforced concrete can fail due to inadequate strength, leading to mechanical failure and due to reduction in its durability.

2.1.1 Issue of Reinforced Concrete Structures

Nowadays, existing reinforced concrete structures may experience various load throughout their service life. This may cause a major signs of concrete deterioration such as cracking, spalling, deflection and corrosion. For cracking, every reinforced concrete structures will crack but it is different in depth, width, direction and pattern. Cracks can be active which widen and deepen that can cause facilitate moisture in concrete cause damage if they are not repaired. Structural cracks can result from temporary or continued overloads, uneven foundation settling or original design inadequate.

Besides that, spalling is the loss of surface material in varying size because of the corrosion of reinforcement steel and freeze thaw action. Corrosion is the rusting of the reinforcing steel in concrete due to carbonation of concrete and the increase of chloride ions. The rust will expand in volume and creates cracking and spalling of concrete. In addition, it also reduces the load carrying capacity of the structural member. After that, it can cause deflection which is the bending of reinforced concrete structural elements such as beams, column and slabs which can be due to overloading, corrosion of steel, inadequate construction technique or by concrete creep.

According to Hansson, (2000) corrosion cause damage in a North American elevated highway which the structure is exposed to de-icing salts and this can be notice through the spalling of the concrete cover and leaving the rebar to be exposed. Therefore, there is various effective ways for rehabilitating corrosion damaged reinforced concrete structures to extend the service life and the safety of the structures. Before rehabilitations starts, the causes of the damaged should be identified by in situ test or Non-destructive testing (NDT) to avoid unnecessary or expensive rehabilitation costs and to select the appropriate repair method.

2.2 MATERIAL USED FOR RETROFITTING DAMAGED EXISTING STRUCTURES

There have been number of studies in the past on strengthening of reinforced concrete beams using different technique such as external prestressing and plate bonding using steel plates or FRP materials. Even though the use of FRP materials is gaining popularity in recent years, the use of steel plates for strengthening operation has its own merits. Due to its established status as reliable construction material and it excellent compatibility with concrete, use of steel plates for strengthening application still remains strong.

External prestressing reinforcement refers to a post-tensioning method in which tendons are placed on the outside of a structural member (Collins & Mitchell, 1991). It is an alternative method in strengthening structure because it adds little weight to the original structure and it allows the monitoring, re-stressing and replacement of tendons. Now external prestressing techniques with steel tendons have been widely used to improve existing structures in the United States, Japan and Switzerland. However there can be a problem with corrosion in the steel that forces the use of steel protection on the external tendons such as by using plastic sheeting. This problem can be resolved by the use of FRP materials.

Other than that, the prestressing steel is more sensitive to corrosion than reinforcement steel bars. This is because the diameter of tendons is small and high grade steel is more susceptible to corrosion compared to ordinary reinforcement steel. Even a small corrosive layer or a corroded spot can reduce the cross-sectional area of steel. The exposure of unprotected steels to the environment can produce a large reduction of mechanical properties but also in the fatigue life. If unbounded tendons are used, they must be protected by anti-corrosive material such as asphalt, oil or grease.

The use of Near Surface Mounted Reinforcement (NSMR) for concrete structures is not a new technique. Steel bars are placed in slots in the concrete structure and then slots are grouted. However, these applications are often difficult to get a good bond to the original structure and in some cases it is not always easy to cast the concrete around the whole steel reinforcing bars. The use of steel NSMR is not a great success due to the corrosion of steel bars but by using CFRP NSMR some of the advantages of steel NSMR can be overcome.

The FRP materials consist of laminates, sheet, and NSMR rod. The CFRP strengthening technique may be used for different applications. For example CFRP fabric is often used for curved surface while CFRP laminates are used for flat surfaces. Besides that, a NSMR rod may be used for both flat and curved surfaces as long as the radius is not too small. Although there is a lot of FRP materials, but the main focus in this research is the different configuration of CFRP strips which can provide an economical solution in extending the service life of existing structure.

2.2.1 Fibre Reinforced Polymer (FRP) Strips

The application of FRP material for structural strengthening has continuously growing in civil engineering field. FRP material can be a cost effective and a practical technique for repair and strengthening of structures and bridges using externally bonded sheets or prefabricated laminates. According to Tann, D.B., & Delpark, (2000) it is estimated that the repair of structures due to corrosion of rebars in reinforced concrete structures cost over $600 million. A possible solution to overcome this problems is to use FRP material because it has high tensile strength, lightweight, adequate ductility and corrosion resistance characteristics. Furthermore, the results demonstrate by Mark, Whittemore, & Durfee, (2003) show the overall cost of strengthening using FRP strips is only $35,000 compared to the other material. It can be concluded that costs will be less if the existing structure can be effectively rehabilitated using FRP strips.

FRP composite have lower density compared to other materials. Since 1990s, several bridges have been built in the United States using lightweight FRP composite decks and slabs. The reduced deck dead load allows the bridge to carry increased live loads. Despite of that, the lower weight of FRP materials makes handling and installation is much easier for retrofitted the existing structure than steel plates. FRP composite applied to the soffit bridge girders do not require heave lifting equipment. When pressures are applied on surface of FRP strips to remove adhesive in excess and entrapped air, they can be practically be left unsupported. In general there is no need to use bolts for FRP strips and this can avoids the risk of damaging the existing steel reinforcing bars.

Currently, strengthening of concrete structure and bridges often requires welding or bolting steel plates to other member of the structure. Welding is not desirable in many cases due to the poor fatigue performance and bolted connections are often used to improve the fatigue performance. However, the cross section loss resulting from drilling holes requires additional strengthening material to be used in addition to the cost of labour for drilling. In order to overcome the problem FRP material is highly suggested because installation of FRP material is much simpler because the laps and joint are not required. This is because the material can accommodate some irregularities and the thin FRP sheet can allow a slightly curved shape without prebending. Other than that, FRP material has an effective resistance to the effects of environmental exposure.

2.3 THE EFFECT OF FRP TOWARD ULTIMATE SHEAR CAPACITY, BEAM DEFLECTION AND ON CRACK PROPAGATION OF THE RETROFITTED BEAMS.

Based on experimental by Adhikary & Musuyoshi, (2004), they carried out the test on eight simply supported reinforced concrete beams strengthened for shear with CFRP sheet using different wrapping technique. The technique consist wrapping on two sides of the beam and U-wrap. The results show that the maximum shear strength was obtained for the beam with full U-wrapped sheets while horizontal aligned fibres showed increasing in shear strength when compared to the control beams. The beam with full U-wrapped of a single layer of CFRP was observed at a maximum of 80 percent increase in shear strength.

In another study similar finding were noted (Jayaprakash, Samad, Abbasovich, & Ali, 2008), they conducted test to study shear capacity of pre-cracked and non-precracked reinforced concrete beam with externally bonded bi-directional CFRP strips.

The experiment consisted of six beams which have two categories and each category had eight beams, four control beams, six pre-cracked and six initially strengthened beams. From the results, they observed that the external CFRP strips act as shear reinforcement similar to the steel stirrups. It also shows that by increasing the amount of longitudinal tensile reinforcement ratios and spacing of CFRP strips can affect the shear capacity. This study found that the orientation of CFRP strips not only affect the cracking pattern but also affect the shear capacity.

Furthermore, according to Kim & Shin, (2011) they conduct experimental studies of reinforced concrete beams retrofitted with new hybrid FRP system which consisting Carbon FRP (CFRP) and glass FRP (GFRP). There are 14 reinforced concrete beams are retrofitted with hybrid FRPs having different combination of CFRP and GFRP sheets. Under loaded condition, beams are retrofitted with two or three layers of hybrid FRPs, then the load are increase until the beams reach failure. From the results, it is found that the deflection ductility of the FRP retrofitted reinforced concrete beams is decreased by 1-22 percent of the control specimens. The beams retrofitted with two hybrid layers of FRPs such as carbon-glass and glass-carbon specimens are more ductile than the carbon-carbon and glass-glass specimens. In addition, the glass-carbon-carbon specimen is the most ductile among the beams retrofitted with three layers of FRPs. In conclusion, the beams with the glass fibre applied prior to carbon fiber have more ductility than beams with carbon fibre applied first.

Moreover, (Dong, Wang, & Guan, 2011) they present experimental research on reinforced concrete beams with external flexural and flexural-shear strengthening by FRP sheets consisting CFRP and GFRP. The work carried out has examined both the flexural and flexural-shear strengthening capacity of retrofitted reinforced concrete beams and has indicated how different strengthening arrangements of CFRP and GFRP sheets affect behaviour of the reinforced concrete beams strengthened. Research output shows that by comparing the beam reinforced by one layer and two layers of CFRP sheets, the cracks load and ultimate load are increased by 23 percent and 22 percent while the deflection is decreased by 39 percent. Therefore, one more layer of CFRP seems quite effective in enhancing the stiffness.

According to Dong, Wang, & Guan, (2011), it can be seen that the beams retrofitted with CFRP have a much smaller crack width and exhibit a less number of cracks than the control beam. The smallest number of cracks appears in the beam with two layers of CFRP sheets and the higher concrete strength. The ultimate crack width on the beam with stirrup 6 mm at 100 spacing show the smallest one, which means the internal stirrups reinforcement ratio is more effective than the concrete strength to control crack growth. It can be concluded that the internal stirrup reinforcement does affect the crack propagation on the retrofitted beams.

As a conclusion, FRP material can be used as strengthening technique for damaged existing structure to improve the shear capacity, the ductility of the beams and lower the number of crack appear on the retrofitted beams. However, the contribution of FRP materials to durability and shear capacity of retrofitted beams appear to be strongly dependent on the layer of FRP materials, the technique of wrapping FRP material on retrofitted beams and the internal stirrup reinforcement ratio.

CHAPTER 3

METHODOLOGY

3.1 RESEARCH DESIGN

In this chapter, reinforced concrete beams were employed. The series of formulation of reinforced concrete beams comprises ordinary Portland cement, sand, water, aggregates and steel rebars were used. The specimens were undergoing curing for 28 days. There were three reinforced concrete beams in order to prepare for flexural test. This experiment were to determined process flow for evaluation of shear strength, beam deflection and cracks pattern on reinforced concrete beams by using flexural test. Figure 3.1 shows the process flow for the experimental programs.

3.2 SELECTION OF MATERIALS

Materials that are using to produce the specimen in the present study were discussed in this section. Reinforced concrete beams were prepared comprises of ordinary Portland cement, sand, water, aggregates and steel rebars. However, different configurations of carbon fibre reinforced polymer (CFRP) strips were used on the reinforced concrete beams.

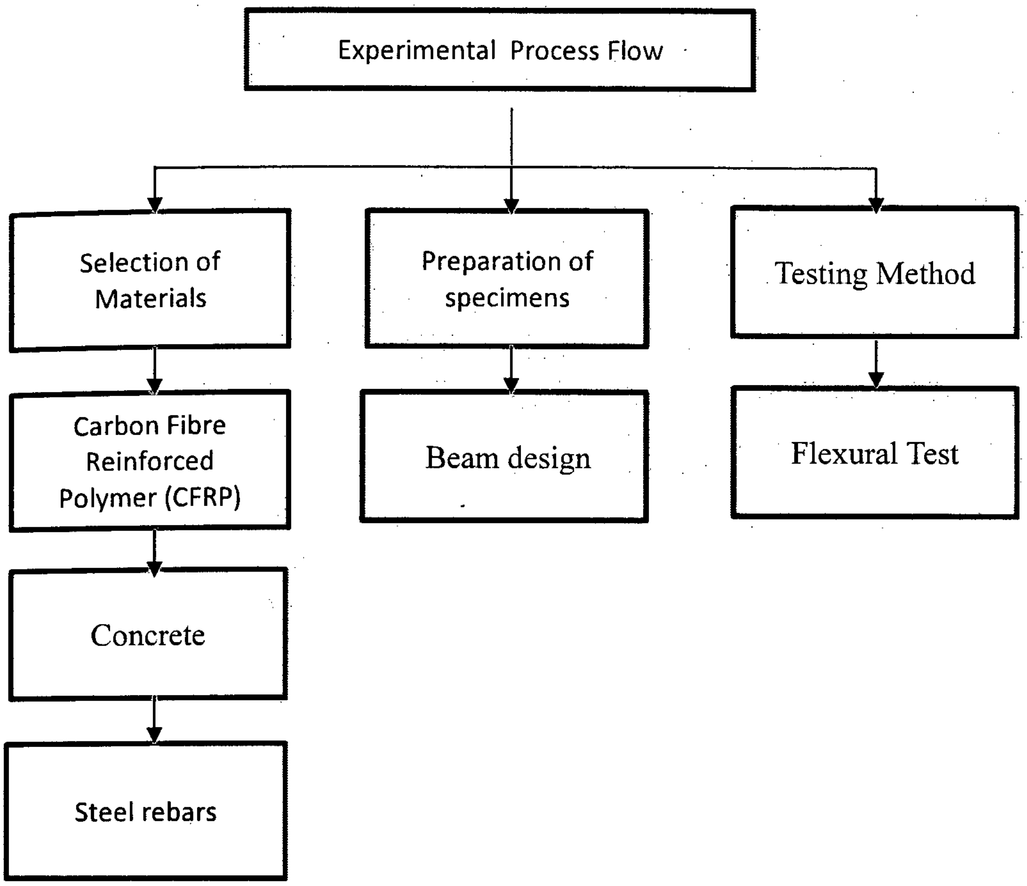

Figure 3.1: The process flow for the experimental programs.

3.2.1 Carbon Fibre Reinforced Polymer Strips

Carbon Fibre reinforced polymer were used in this experiment. FRP composite materials have been used in structural strengthening around the world. When the comparison of CFRP with steel materials was made, it was found that CFRP material provide unique opportunity in term to facilitate their use in construction and to develop their shapes. Although CFRP material is relatively expensive but the installation of CFRP systems are lower in cost because it does not need a skill labour to install it.

3.2.2 Concrete

For concrete, the fine aggregates used in this investigation was clean river sand. According to ASTM C33 Standard Specification for Concrete Aggregates, fine aggregates shall be free of injurious amounts of organic impurities (American Standard of Testing and Materials, 2000). In addition, as stated by Surahyo.A.H, (2002), sand are considered clean if it is free of excess clay, silt mica organic matter chemical salt and coated grains. Furthermore, the maximum size of coarse aggregate used was 20 mm. Based on ASTM C33, course aggregates for concrete shall consist of natural gravel or crushed rock or a mixture of natural gravel and crushed rock. The separation of size was conducted during high capacity sieve machine. The concrete mix proportion was design by mix design methods to achieve the strength of 30 N/mm^2. Three reinforced concrete beams were cast and tested at the age of 28 days to determine the ultimate shear capacity, beam deflection and cracks pattern. The data of compressive strength taken at 28 days are shown in Table 3.1.

Table 3.1: Compressive strength of concrete.

Material	Grade	Specimen	Compressive strength (Mpa)
Concrete	C30	Control	33.86
		CFRP L Shape	33.16
		CFRP U Shape	33.45

3.2.3 Steel rebars

The longitudinal reinforcements are consisted of two steel rebars of 12 mm in diameter placed on the bottom and two rebars of 12 mm in diameter on top of the beam. For shear reinforcement, stirrups of 8 mm in diameter were used.

3.3 Preparation of Specimens

Preparation of specimen is to gather all the materials and apparatus in order to produce reinforced concrete beam specimen. Proper preparations of the specimen are essential parts of the testing process. Reinforced concrete beam specimen that is representative of a distinct batch of concrete must be sample and analysed for the purpose of quality control.

3.3.1 Beam Design

The reinforced concrete beam specimens are design to be in size of 150 mm x 250 mm x 2000 mm respectively. There are three reinforced concrete beams with this size. The reinforced concrete beam specimens were undergo batching, mixing, casting and curing before it going to be tested. Batching is the process of measuring concrete mix ingredients either by volume or by mass and introduces the specimens into mixture. Traditionally batching is done by volume but most specifications require that batching to be done by mass rather than volume.

After that is the mixing process which the mixing operation consists of stirring or rotation. The objective of mixing process is to make sure all the aggregates particles are being coated with cement paste and to blind all the ingredients of the concrete into a uniform mass. This uniformity must not be disturbed by the process of discharging from the mixer. Moreover, casting of the concrete is the process of pouring the fresh concrete into mould and wait it to be hardened.

Lastly is the curing process which one of the most important steps in concrete construction because proper curing greatly increases concrete strength and durability. Concrete hardens as a result of hydration which the chemical reaction between cement and water. However, hydration occurs only if water is available and if the concrete's temperature stays within a suitable range. During the curing period from five to seven days after placement for reinforced concrete beams, the concrete surface needs to be