Characteristics of Bonding of Kenaf Fibrous Concrete and Normal Concrete Interface

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Abstract. Regarding the design of structures, the interfacial bonding between different elements plays an important role in the efficiency of a structural system. This study observed the bonding characteristics of two different type of concrete which is Kenaf fibrous concrete and normal concrete with different ages. The bonding interface between concrete layers must assure enough in terms of compressive, shear and tensile strengths as the main requirement to resist the applied loads on the structure. In this study, three laboratory tests were carried out to investigate the interfacial bonding behaviour of Kenaf fibrous concrete with normal concrete in terms of shear, tensile and compressive loadings. A total of 12 samples for shear test, 12 samples for tensile test and 12 samples for compression test have been prepared for testing. The samples are the attachment of two units of concrete, which are kenaf fibrous concrete unit and normal concrete unit. The normal concrete units were prepared until 28 days age before being attached with kenaf fibrous concrete units. All samples were ready for testing after the kenaf fibrous concrete units reached age of 28 days. Result showed that cracks occurred at the interface between the kenaf fibrous concrete and normal concrete at ultimate failure. The latter diagnostic was shown that kenaf fibrous concrete did affect the strength properties when combined with other old normal concrete. It was also found that different grade of kenaf fibrous concrete influenced the strength of the interfacial bonding.

Introduction

Biocomposites or green materials are the next solution for sustainability approach in building material and structures nowadays. The usage of biocomposites in engineering application has recently used to achieve the target of creating a green building. Biocomposites contain natural fibers which offer lots of advantages such as renewability, recyclability, biodegradability, low specific gravity and provide high specific strength [6]. Using biocomposites in construction industry will also help to reduce the manufacturing of petroleum-based material which helps in reducing cost effectively. Combination of two different concretes is common in the building structures. Bonding of two concretes plays an important role in the effectiveness of structural system. Different strength of concrete, different ages of concretes and type of the concretes affect the effectiveness bonding strength mechanism at the interface.

There are some parameters also included that influence the interfacial bonding behaviour such as moisture condition, amount of reinforcement crossing the interface, the compression resistance of weaker concrete, the roughness of the interface mode, the presence of cracking or the stress caused by the normal forces that acting across the interface [1]. Application of biocomposites in enhancing the bonding of concretes will gradually help to increase the efficiency of the building system. Since 1960s, the research has been done to study the behaviour of bonding of two concrete. The mechanism behaviour of combination of concretes plays an important role in structural system. Many applications involve in the bonding of concretes such as repairing, casting joints, or precast element connection. However, as we know the use of concrete has been used worldwide and need a lot of the manufacturing of Portland Cement which emitting a lot of carbon dioxide into the air. Using kenaf fibers in the concrete has been proved to overcome the problem since Kenaf can absorb three times carbon dioxide compare to other plants [4]. The use of kenaf fibrous reinforced concrete as replacement of existing concrete to be used as repairing and rehabilitation purpose may give a great impact in engineering application towards sustainability.

The objective of this study is to investigate the bonding of kenaf fibrous concrete and normal concrete interface. The scope of this study covers the factors that will affect the interfacial bonding between kenaf fibrous concrete and normal concrete. The ages between two concrete is different. The normal concrete units will be prepared first and after 28 days, the Kenaf fibrous concrete units will be attached with the old normal concrete until 28 days. The strength of two concrete is different. Normal concrete will use grade 35 MPa and Kenaf fibrous concrete will use 25 MPa, 35 MPa, and 45 MPa. The degree of roughness is the same with the same pattern at the bonding surface. The moisture condition at the interface will be the same which is surface air dry (AD). This study involved laboratory tests such as compression test, tensile test, and shear test. The data obtained are the compressive strength, tensile strength and shear stress along the interface. The cracking behaviour of the samples will be observed.

Previous Studies

Due to the concerned about the environment friendliness and high carbon dioxide released during the manufacture of Portland cement, natural fibers have become the solution to overcome the issues. Fibrous composite materials are one of the interests in the wide range of both low and high technology engineering application. They provide outstanding mechanical properties, unique flexibility in design capabilities and ease of fabrication. Natural fibers has low specific weight which results in a high specific strength and have low cost production with less equipments required when compare to the synthetic fibers. Synthetic fibers has higher specific strength compare to natural fibers however due to its chemical components, any waste produced from synthetic fibers will pollute the environment which are not sustainably concerned. These natural fibers have several advantages include low density, low cost, renewable, recyclable, low energy consumption, no abrasion to machines, burning of natural fibers will not risk the health when inhaled and they are biodegradable which easy to dispose [7].

Kenaf or its scientific name, Hibiscus Cannabinus, L. is a fiber plant that has been grown as resources for food and its fiber. Kenaf plant natively growth at east-central Africa where it is a common wild plant of tropical and subtropical Africa and Asia. Kenaf fibers have been used regularly as textile fiber for such products as rope, twine, bagging and rugs. Kenaf is a promising source of raw material fibers for pulp, paper and other fiber products, and has been introduced since WWII in China, USSR, Thailand, South Africa, Egypt, Mexico and Cuba [5]. Kenaf has become one of the interests among selected types of fibers by the researchers worldwide to understand its properties towards the important in application of engineering as shown in Table 1.

Table 1: Summary of Tensile Strength and Young's Modulus for Kenaf fiber from previous researchers [5]

Type of Fibers	Diameter (mm)	Average Ultimate Tensile Strength (MPa)	Young's Modulus (MPa)	Reference	Year
Kenaf	0.04-0.16	18-180	-	G. Ramakrishna and T. Sundararajan	2005
Kenaf	0.081	250	43000	Byoung-Ho Lee et al.	2009

Kenaf fibrous reinforced concrete (KFRC) is one of biocomposites that developed as a sustainable approach and green construction materials. The mechanical properties of KFRC have been outstanding which help to improve the engineering application towards environmental friendly. According to [4], the compressive strength of KFRC decreased with the higher fiber contents and the use of short fiber. However, KFRC can achieve the required design compressive strength with the appropriate fiber contents and fiber length. Based on his research, the optimum amount of Kenaf fiber is 0.75% of total concrete volume with the used of short types of fibers of 25

– 50 mm. The flexural strength and indirect tensile strength of KFRC are directly proportional to the fiber content and fiber length. The increase in fiber content and fiber length will result in higher flexural strength and tensile strength. The result of the strengths show that the KFRC exhibits failure mode compare to conventional concrete [4]. Based on his research, the observed improvement of cracking behaviour as shown in Figure 1 indicates the increased in durability of concrete at a low cost production compared to other types of fibers. Hence, KFRC could be applied as members that resist impact loading.

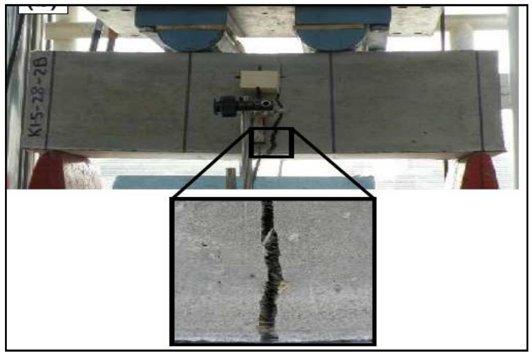


Figure 1: Cracking Failure mode of Kenaf fibrous reinforced concrete

Regarding the design of structures, the combination between different elements plays an important role in the effectiveness of a structural system. The combinations such as in casting joints, precast elements connection or concrete repairing are always applied in any building where structural concrete is used. The interface between concrete can be categorised based on different ages between layers and different types of elements between layers. The shear stress transfer between two concrete layers mostly is a complex phenomenon that involves the combination of different interactions and depends in several parameters that the affect the transmission process such as the amount of reinforcement crossing the interface, the compression resistance of weaker concrete, the roughness of the interface mode, the presence of cracking or the stress caused by the normal forces that acting across the interface [1].

Bond and roughness of interface between concrete layers are the keys to the efficient of the connection. In 1960, Hanson studied on the connection both with precast or casting in-situ element was analyzed. In those experiments, the adhesive bonding, roughness, keys and the shear reinforcement is considered. The tests were carried out to establish a common basis of difference between various contact surfaces condition as illustrated in the Figure 2. The shear strength may be defined as the transference of stress between two layers. Both bond and roughness are the important aspects to provide higher shearing stress to the connection of the two concrete layers. Different mode of interface will give different strength of friction between interfaces. By applying a constant surface roughness to a concrete, a study on the behaviour of the bonding at the interface with different type of concrete can be done to determine the effect of different concretes with the strength of the bonding.

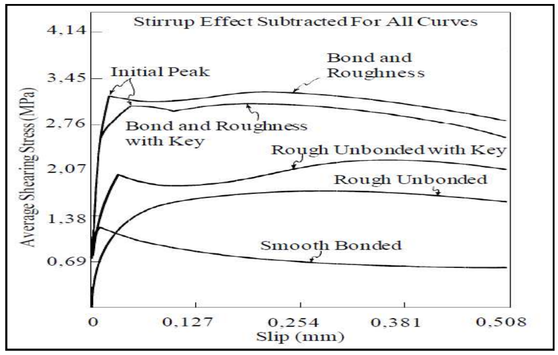


Figure 2: Typical Shear-Slip Curves [1]

The interface of old and new concrete layers will have different in strength based on surface and moisture condition of the existing concrete. Moisture condition of the existing concrete greatly affects the bonding behaviour between two layers. Based on research by [2], using old concrete with different moisture condition results in difference shear bonding strength at the interface with the new concrete as shown in Table 2. Two types of moisture condition are considered which saturated surface dry condition (SSD) showed higher bonding strength compare to air dry surface condition. However, the increase in the compressive strength of the new concrete reduces the shear bond strength at the interface. Adding silica fume in the new concrete significantly increase the compressive strength and shear bond strength [2]. This show by adding another element in the new concrete mix affects the strength of the bonding interface. By applying another type of concrete such as Kenaf fibrous concrete as the new concrete to the old normal concrete, the strength of bonding at the interface can be determined for further study.

Table 2: Average Shear Bond Strength at the Interface [2]

Mixture (w/c ratio)	Silica Fume	Compressive Strength of New Concrete (lb)	Moisture Condition	Average Shear Bond Strength at Interface (psi)
A (0.45)	No	5239	SSD	269.8
			Air dry	150.8
B (0.6)	No	3698	SSD	485.1
			Air dry	263.9
C (0.45)	Yes	7492	SSD	767.9
			Air dry	518.8

The transfer of shear stress developed along the connection concrete layers with different strength is very complex. The mechanism when under loading may be affected by the various parameters such as the amount of reinforced steel in the interface, the compressive resistance of the lower concrete, the degree of roughness of the interface, and the stress applied by the vertical loading. Study on this kind of mechanism started in 1960s like the works of Hanson who conducted various experiments on the shear frictional behaviour. Recently, [3] established a research on the transfer mechanism of the shear stress occurring at the interface between two concrete layers with different strengths. Investigation on the capability of the formula for shear resistance in concrete-to-concrete interface suggested in Eurocode with the case of two different compressive strengths of 80MPa and 30MPa has been performed using finite element analysis. The result has been verified where the value using finite element method is 1.3 times the value of the formula as illustrate in Figure 3. This shows that different strength of concrete will result in different strength at the bonding interface.

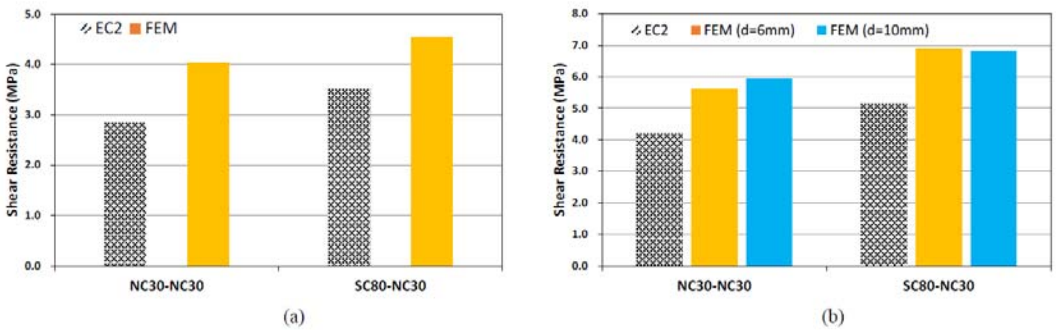


Figure 3: Differences of shear resistance of finite element method and Eurocode formula [3]

Methodology

Three laboratory tests were conducted which were compression test, shear test and direct tensile test. A total of 12 samples for shear test, 12 samples for tensile test and 12 samples for compression test have been prepared for testing. The samples are the attachment of two units of concrete, which are kenaf fibrous concrete unit and normal concrete unit. The normal concrete units were prepared until 28 days age before being attached with kenaf fibrous concrete units. All samples were ready for testing after the Kenaf fibrous concrete units reached age of 28 days. The samples were tested until failure. Cube tests are done to determine the mix design of normal concrete of grade 25 MPa, 35 MPa and 45 MPa.

Preparation of Kenaf Fiber

Kenaf fibers are used as the important material in this research which obtained from the laboratory that originally ordered from Bachok, Kelantan. All the fibers were kept in the dried bag to avoid from moisture absorption. Preparation and treatment of kenaf fiber is the important part to ensure the optimum properties of the fiber. The optimum length of kenaf fibers is 25 – 50 mm and in this study 50 mm was used. Sodium hydroxide (NaOH) was used as kenaf surface treatment with the concentration of 5% with water. The steps of preparation are illustrated in Figure 4.

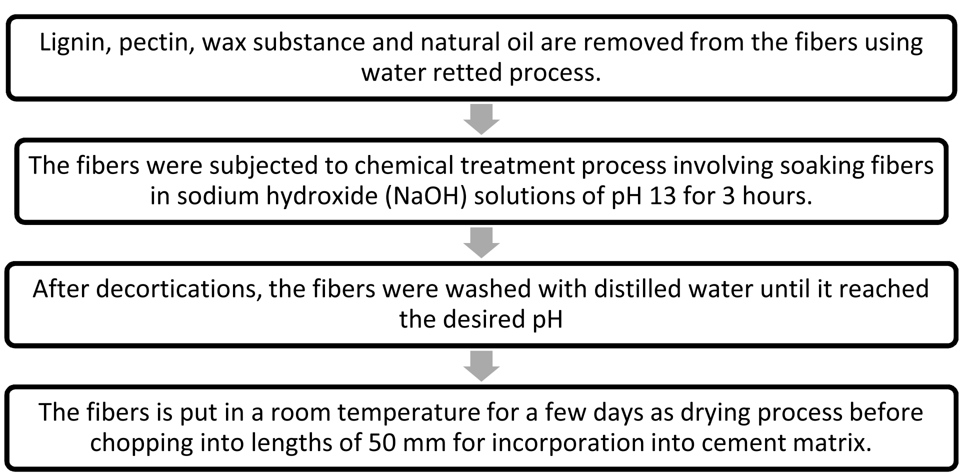


Figure 4: Steps preparation of kenaf fibers

Figure 5: Treatment of kenaf fibers with sodium hydroxide

Cement
In this experiment, Holcim Top Standard brand of ordinary Portland cement - Type I cement is used. The cement has a specific gravity of 3.15, and initial and final setting time of 170 and 245 minutes, sulphate content of 2 % and chloride content of 0.01 %, respectively.

Aggregate
The coarse aggregate used in this study was granite. The maximum size required in this experiment is 10 mm. The aggregate used was in dry condition to gain a better quality of results. The fine aggregate used in this study was sand. It was a filler material in a sample of concrete mix to fill up all possible voids which appear in the mix. Coarse and fine aggregate need to be sieved before added into concrete mix to ensure the uniformity of the particle size and to remove impurities.

Sample Preparation
Cube Concrete. The normal concrete in this study was designed to achieve Grade 25 MPa, 35 MPa, 45 MPa strengths using DOE Method. Size of each cube is 100 mm x 100 mm x 100 mm. Table 3 shows the mix proportion of concrete based on different grade strength. Before casting, kenaf fibers were soaked in the water to get a constant weight with water absorbed. The aggregates and cement were mix thoroughly until homogeneous mix was achieved. Then, add measured quantity of water and mix the whole materials until a workable mix was obtained. For cube test with kenaf, the fibers will only be added after the water was mixed with the cement and aggregate. The Kenaf was distributed evenly to get better uniformity. All mixing was done by using the concrete mixer and the compaction was carried out by using the concrete vibrator. Wooden mould was used and covered with cello tape before putting the fresh concrete into the mould.

Table 3: Mix proportion of concrete based on different grade

Type of concrete	Concrete Grade	Cement (kg/m^3)	Fine Aggregate (kg/m^3)	Course aggregate (kg/m^3)	Water (kg/m^3)	w/c ratio	Kenaf fibers (kg/m^3)
Normal	35	460	230	761	969	0.5	-
KFRC	25	383	230	903	903	0.6	1200
KFRC	35	460	230	761	969	0.5	1200
KFRC	45	575	230	727	888	0.4	1200

Units of Normal Concrete. The units of normal concrete in this study were designed to achieve grade 35 MPa. Size of each unit was different based on type of experimental tests. For the compressive test and direct tensile test the unit size was 100 mm x 100 mm x 250 mm each. For shear test, the unit size was 100 mm x 100 mm x 100 mm. The surface roughness of the normal concrete units was constant by resurface one side of the unit's surface with the pattern as shown in Figure 6.

Figure 6: The roughness surface pattern of old normal concrete units

Sample Preparation

In order to achieve the objective of the study, laboratory tests are required. The tests were conducted such as slump test of fresh concrete, compression test, shear test, and indirect tensile test to investigate the characteristic of bonding of kenaf fibrous concrete and normal concrete interface.

Slump Test. The test was according to standard as stated in BS 1881-102:1983. A mould with cone shape of 200 mm diameter at bottom and 100 mm diameter at the top and 300 mm of height was used. The cone is filled with fresh concrete in three layers where each layer took about one third of the volume of the cone mould. Every layer was tamped throughout its depth 25 times with a 16 mm diameter and 610 mm long tamping rod. When the cone was full with concrete, the mould was immediately removed by raising it vertically with a steady upward lift. The number of mm the original centre of the cone sink or settle uniformly will be measured. Type of slump is determined either it is collapse, shear or true slump as shown in Figure 7.

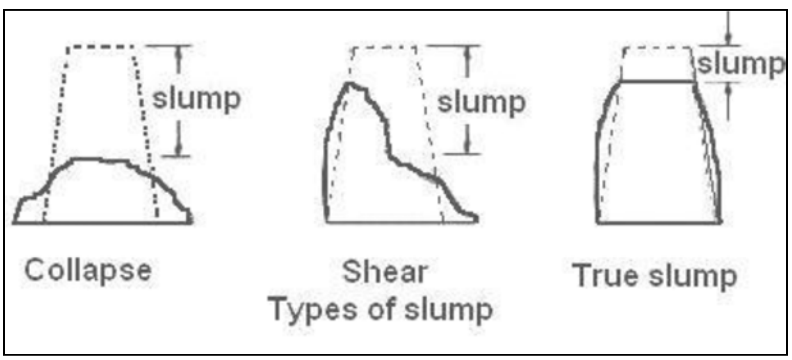


Figure 7: Type of Slump

Compressive Strength Test. The test was the modified standard practice for capping concrete method for compression testing base on ASTM C1522-14a. The test included plane surface on two bearing surface of samples which purpose to provide consistent and standardized procedure for compression testing. Capping plate was used having a thickness of not less than 25 mm. The test was carried out using the compression machine with the capacity of 3000kN. The grade of normal concrete used units was 35 MPa and kenaf fibrous concrete units used were 25 MPa, 35 MPa and 45 MPa.

The size of each unit is 100 mm x 100 mm x 300 mm for both kenaf fibrous concrete and normal concrete. The normal concrete units were prepared until 28 days age before being attached with Kenaf fibrous concrete units to form a triple as shown in Figure 8. Increasing compressive loading was applied at the sample until ultimate failure and thus, the maximum compressive load was obtained. The cracks occurred at the samples were observed. The result from this test was plotted in the graph of compressive strength versus type of concrete with different grade.

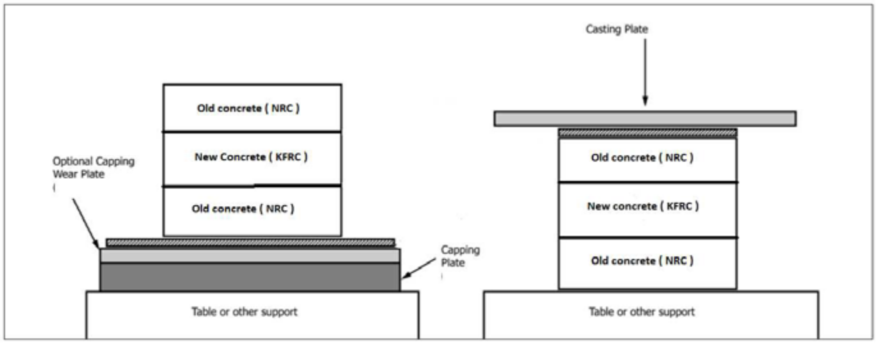


Figure 8: Compression test set up apparatus

Shear Strength Test. This test method covers the determination of the shear strength at the interfacial bonding of two concretes by using a modified simple beam with center-point loading based on ASTM C293 and C293M-10. The size of each unit was 100 mm x 100 mm x 300 mm for normal concrete and kenaf fibrous concrete. The normal concrete units were prepared until 28 days age before being attached with kenaf fibrous concrete units to form a prism sample of size 100 mm x 100 mm x 300 mm as shown in Figure 9. The grade of normal concrete used units was 35 MPa and kenaf fibrous concrete units used were 25 MPa, 35 MPa and 45 MPa.

Additional plate was added to ensure even loading at the bearing surface. Increasing load at the center of loading will be applied at the sample until the sample no longer withstand the load and thus, the ultimate shear loading was obtained at the interfacial bonding. The cracks occurred at the interface were observed. The result from this was plotted in the graph of shear strength versus type of concrete with different grade.

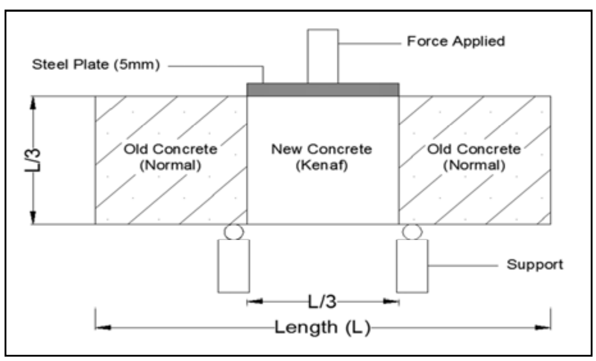


Figure 9: Shear test set up apparatus

Tensile Strength Test. This direct tensile test covers the modified standard test method for tensile strength of concrete surface and the bond strength based on ASTM C1583/C1583M. The test method was carried out to determine the near surface tensile strength and the bond strength of a repair or overlay material. The method of this test involved two attached units of kenaf fibrous concrete and normal concrete to form a cross couplet sample as illustrated in Figure 10. The test was carried out using the compression machine with the capacity of 3000kN.The grade of normal concrete used units was 35 MPa and kenaf fibrous concrete units used were 25 MPa, 35 MPa and 45 MPa. The size of each unit is 100 mm x 100 mm x 250 mm for both kenaf fibrous concrete and normal concrete. Increasing load at both points loading will be applied at the sample until ultimate failure and thus, the maximum tensile strength of interfacial bonding was obtained. The cracks occurred at the interface was observed. The result from this was plotted in the graph of shear strength versus type of concrete with different grade.

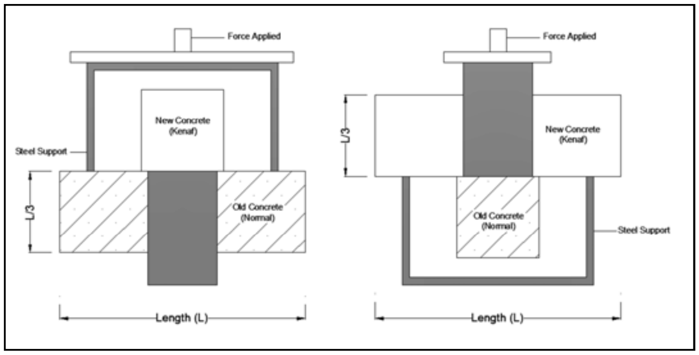


Figure 10: Schematic procedure of direct tensile test

Results and Discussion

Concrete Cube Compression Test

Concrete cube compression test was done to ensure the mix of concrete satisfy their target compressive strength. For this research, the target compressive strength was 25, 35 and 45 MPa. The result shows that the mix design for the normal concrete satisfied the required compressive strength of 25 MPa, 35 MPa and 45 MPa at the age of 28 days. However, when adding the kenaf fibers into the concrete, at the age of 28 days the compressive strength reduced due the characteristic of kenaf fiber which is good in tension resistance but weak in compression.

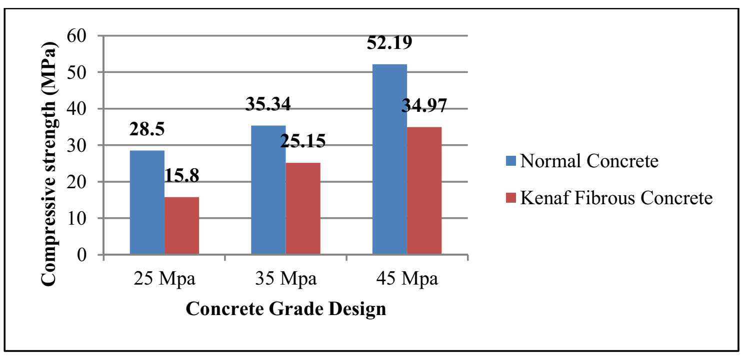
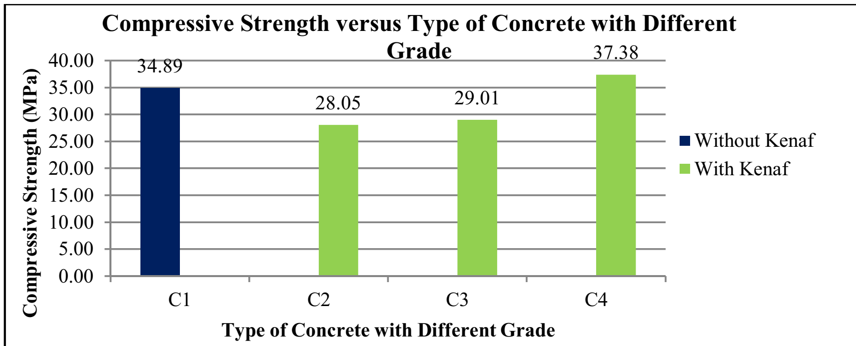


Figure 11: Result of compression test cube

Compression Test

The compression test was done using the compression testing machine with a capacity of 3000kN. All samples were tested until ultimate failure and the cracks were observed. The maximum load carried by each sample was recorded. Figure 12 shows the result of maximum load obtained from each sample. The result showed that the control sample with new normal concrete unit of 35 MPa had higher compressive strength of 20% more compared to the sample with new kenaf fibrous concrete unit of the same concrete grade. Present of kenaf fiber in the concrete reduced the compressive strength of the concrete which was proven in previous research of [4].

However, the compressive strength of sample with new Kenaf fibrous concrete unit was improved by increasing of concrete grade to 45 MPa. Crack was occurred at the side surface of the sample where the pattern of the crack was found to be inclined from top to bottom as shown in Figure 13. Both control sample and sample attached with Kenaf fibrous concrete were having the same crack pattern. However, the Kenaf fibrous concrete helped to bridge the crack and the crack was smaller compared to control sample which led to a more ductile failure mode with greater toughness.



Sample	C1 (control)	C2	C3	C4
Old Concrete	Normal (35 MPa)	Normal (35 MPa)	Normal (35 MPa)	Normal (35 MPa)
New Conrete	Normal (35 MPa)	Kenaf (25 MPa)	Kenaf (35 MPa)	Kenaf (45 MPa)

Figure 12: Result of compressive strength versus type of concrete with different grade

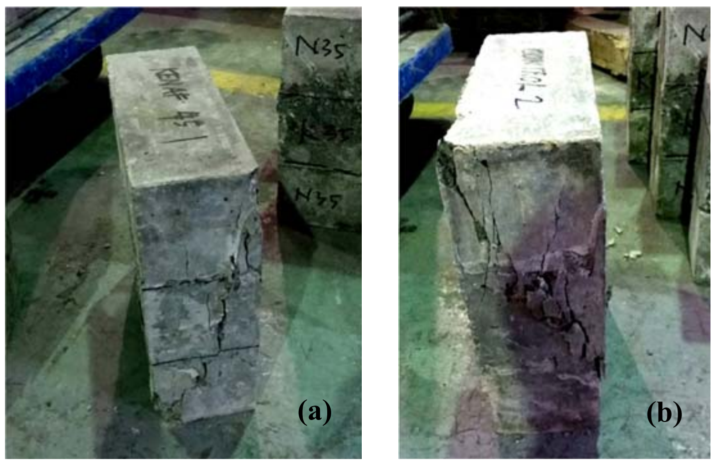


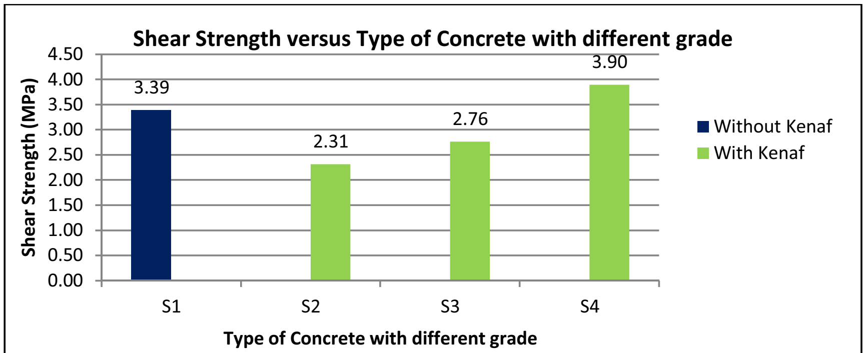
Figure 13: (a) Cracking of sample with kenaf fibrous concrete of grade 45 MPa (b) Cracking of sample with normal concrete of grade 35 MPa

Shear Test

The shear test was done using the one point loading machine with a capacity of 100kN. All samples were tested until ultimate failure and the cracks were observed. The maximum load carried by each sample was recorded. Figure 14 shows that the control sample of with new normal concrete unit of grade 35 MPa had higher shear strength of 23% more compared to sample with new kenaf fibrous concrete unit with the same grade.

Present of kenaf in the concrete reduced the shear strength of the concrete. It was found that the surface roughness pattern did not clearly see as the kenaf fiber filled some of the empty area of the interlocking surface roughness. Present of kenaf fibers reduced the friction resistance of both surface hence reduce shear strength at the interfacial bonding. However, the shear strength of sample with new Kenaf fibrous concrete unit was improved by increasing concrete grade to 45 MPa.

Based on Figure 15, all samples were experiencing crack failure only at one sided of bonding attachment. This was happened because the ultimate failure occurred at either one of the interfacial bonding surface where it was the weakest. The crack was found to be occurred at the interfacial bonding between the old concrete and the new concrete. When the sample reached ultimate loading, an explosion sound was produced when failed.



Sample	S1 (control)	S2	S3	S4
Old Concrete	Normal (35 MPa)	Normal (35 MPa)	Normal (35 MPa)	Normal (35 MPa)
New Conrete	Normal (35 MPa)	Kenaf (25 MPa)	Kenaf (35 MPa)	Kenaf (45 MPa)

Figure 14: Result of shear strength versus type of concrete with different grade

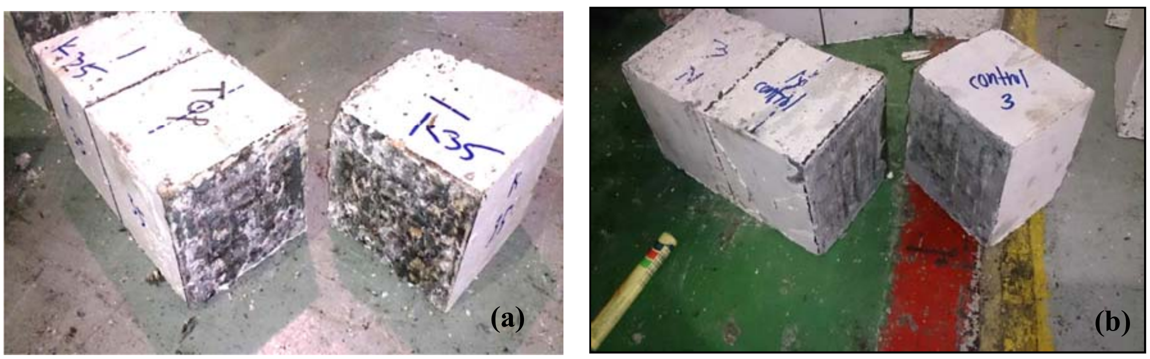
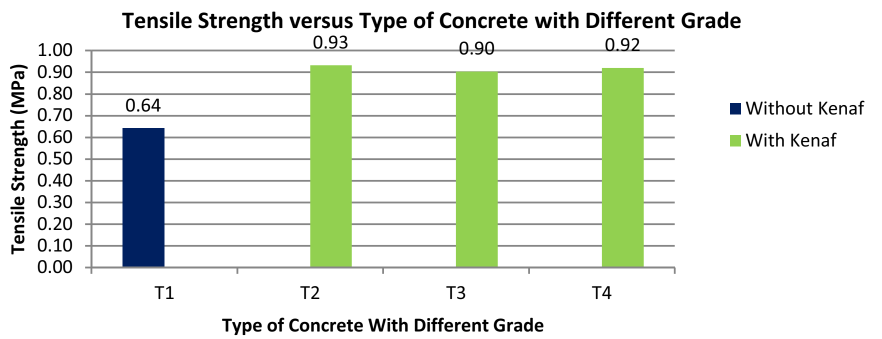


Figure 15: (a) Sample with kenaf fibrous concrete (b) Sample with normal concrete both cracked at one side of the interface bonding

Direct Tensile Test

The shear test was done using the compression machine with the aid of supporting steel. All samples were tested until ultimate failure and the cracks were observed. The maximum load carried by each sample was recorded. Figure 16 shows the result of maximum load obtained from each sample. Result showed that the control sample of with new normal concrete of 35 MPa had lower tensile strength compare to sample with new kenaf fibrous concrete of 35 MPa which has higher tensile strength.

As kenaf fiber has the characteristic to resist better in tension, the sample that attached with kenaf fibrous concrete unit of 35 MPa has higher tensile strength of 43% more compare to control sample with the sample grade. However, the tensile strength of sample with new kenaf fibrous concrete unit remained constant with less significant different when concrete grade was changed to 25 MPa and 45 MPa. This showed that different grade of kenaf fibrous concrete did not affect the different in tensile strength.



Sample	T1 (control)	T2	T3	T4
Old Concrete	Normal (35 MPa)	Normal (35 MPa)	Normal (35 MPa)	Normal (35 MPa)
New Conrete	Normal (35 MPa)	Kenaf (25 MPa)	Kenaf (35 MPa)	Kenaf (45 MPa)

Figure 16: Result of tensile strength versus type of concrete with different grade

Figure 17 (a) shows that the sample with kenaf fibrous concrete unit having the same crack pattern compared to control sample with normal concrete unit in Figure 17 (b). It was found that the surface roughness pattern did not clearly see as the kenaf fiber filled some of the empty area of the interlocking surface roughness. This showed that the kenaf fibers act as the binding agent between two concrete surfaces to resist tensile force. The crack was found to be occurred at the interface between the old concrete and the new concrete without damaging both units.

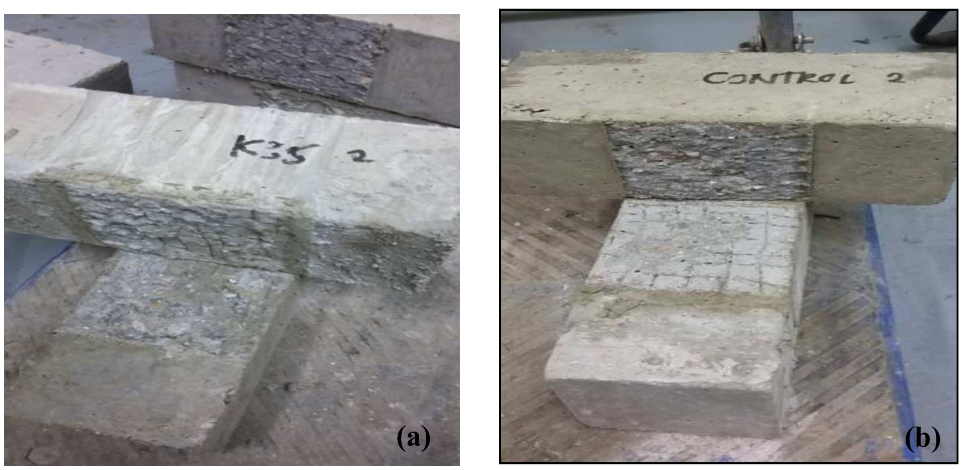


Figure 17: (a) Sample with kenaf fibrous concrete of grade 35 MPa (b) Control sample with normal concrete of grade 35 MPa

Conclusion

Based on the results, observations and analysis of bonding behaviour of kenaf fibrous concrete and normal concrete interface can be drawn as follow:

1. Compressive strength of the bonding of kenaf fibrous concrete and normal concrete is lower than normal concrete with normal concrete with the same grade. However, the compressive strength of bonding of kenaf fibrous concrete and normal concrete can be increased by increasing the concrete grade of kenaf fibrous concrete.
2. Shear strength of the bonding of kenaf fibrous concrete and normal concrete is lower than normal concrete with normal concrete with the same grade. However, the shear strength of bonding of kenaf fibrous concrete and normal concrete can be increased by increasing the concrete grade of kenaf fibrous concrete.

3. Tensile of the bonding kenaf fibrous concrete and normal concrete is higher than normal concrete with normal concrete with the same grade. However, the different grade of kenaf fibrous concrete does not increasing or decreasing the tensile strength of bonding of kenaf fibrous concrete and normal concrete.
4. In terms of cracking behaviour, the samples were cracked at the bonding interface except for compressive test where the samples were cracked at the side surface of the combined units. Kenaf fibrous concrete shows smaller crack compare to normal concrete in term of compressive failure.

As far for the overall conclusion, kenaf fibrous concrete is a good rehabilitation or repairing materials for concrete. Kenaf fibrous concrete can improve the tensile strength bonding with other concrete as well as compressive strength and shear strength by increasing the kenaf fibrous concrete grade.

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