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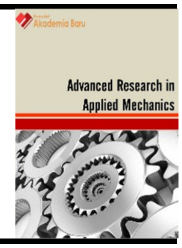

Mechanical Properties and Impact Resistance of Hybrid Kenaf and Coir Fibre Reinforced Concrete

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ABSTRACT

Concrete is brittle and weak in tensile but strong in compressive strength. To improve concrete weakness, fibres are added as reinforcement. In this research, kenaf fibre was hybridized with coir fibre in order to achieve optimum mechanical properties and impact resistance of fibre reinforced concrete (FRC). Since, kenaf fibre has high tensile strength and water absorption but low in ductility while coir fibre possess the opposite, the hybridization of these two fibres could complement each other. Five mixes with different kenaf:coir fibre ratios (S1;100:0, S2;50:50, S3;60:40, S4;40:60,S5; 0:100) at 4% fibre content by concrete volume and fibre length of 3-5 cm were tested for their mechanical properties (compressive, split tensile and flexural strengths) and ultimate energy absorption (via drop-weight impact test). It has been observed that FRC containing 100% kenaf fibre (S1) and 100% coir fibre (S5) shows the increment in all mechanical properties and impact resistance compared to control. For hybrid fibres, samples with higher content of kenaf fibre, S3 shows the highest increase for all mixes in mechanical properties, the increments are 10.8%, 37%, and 9.8% for compressive, split tensile and flexural strengths, respectively, but for impact resistance, the increment is 66.7%. For samples with higher content of coir, S4, the increment in mechanical properties are lower than S3 (8.1%, 17.6% and 3.5% but the impact resistance is the highest at 8 number of blows and 339.03 Nm of ultimate energy absorption with an increment of 166.7% compared to all mixes. The results reveal that hybrid kenaf and coir FRC exhibit enhanced mechanical properties and impact resistance compared to single kenaf/coir FRC and if application where mechanical properties is in need, hybrid fibre mix S3 is suggested and for impact resistance application, hybrid S4 is proposed.

Keywords:
Fibre reinforced concrete, hybrid, kenaf, coir, mechanical properties, impact resistance

1. Introduction

Plain concrete has high compressive strengths but is brittle and very weak in tensile and its flexural strength it only about 1/10 of its compressive. Plain concrete will develop cracks due to

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plastic shrinkage, drying shrinkage and changes in volume of concrete. Development of these micro cracks causes elastic deformation of concrete. To overcome this weakness, micro reinforcement such as fibres could be added in concrete to meet the required values of mechanical strength. The addition of fibres in plain concrete will control the cracking due to shrinkage and also reduce the bleeding of water. Concrete structures have a high possibility to be exposed to dynamic load with high strain rate such as earthquake, impact and explosion. Thus, research on the dynamic behaviour of fibre reinforced concrete (FRC) must be done to because concrete response differently when exposed to static load dynamic load.

Sustainability awareness had encouraged the recycling of agricultural waste in order to reduce greenhouse gas emission and indirectly producing a sustainable product. Based on Dungani *et al.*, [15], agricultural waste fibres (natural fibres) have good potential as component in composites due to its high strength, environmentally friendly, low cost, availability and sustainability. The agricultural waste is one of the most important problems that must be solved for the conservation of global environment [24].

2. Literature Review

Previous researches have shown that natural fibres enhance the mechanical properties, impact resistance and dynamic properties of concrete. Micro structural properties of natural fibres as composites' component in terms of flexibility, ductility and energy absorption improve the seismic resistance. Fibres in concrete serve as crack arrestor which can slow down the crack propagation and gradual failure [22]. Coir fibre is vastly abundant and easily obtained. There are two types of coconut fibres, brown fibres extracted from matured coconuts and white fibres extracted from immature coconuts [2]. Brown fibre is the good one as it is thick, strong and have high abrasion resistance, while white fibre is smoother, finer and weaker. Coir fibres exhibit high toughness compared to other fibres. On the other hand, kenaf fibre is categorized as renewable and environmental friendly as kenaf plant life cycle is only about three to six months. Kenaf fibre is able to absorb approximately 1.5 times its weight of carbon dioxide, which represents the highest level of absorption of all plants [16].

The influence of different percentages of kenaf fibre on the FRC compressive and flexural strengths were determined [23,18] with the length of fibre at 30 mm [18]. Results shows that the compressive and flexural strengths improved [23,18] as the percentages of fibres increased up to 4% and started to decrease at 5% [18]. This show that the optimum percentage of kenaf fibre to be added in concrete mix is 4%. As for coir FRC, the compressive strength increased as the percentage of coir fibre increased [21], however Baruah and Talukdar [10] have shown that the compressive strength of FRC started to decrease at 2% fibre content while the flexural strength still recorded as to be increased.

Table 1 shows that kenaf fibre has higher tensile strength but low in ductility while coir fibre exhibits low tensile strength but high ductility. Coir fibre is good as concrete fibre reinforcement due to its physical properties and high toughness. Since natural fibre inherit its physical and mechanical properties when applied as concrete reinforcement, increasing and decreasing in concrete strength were pretty much comes from the fibre itself. The effectiveness of hybridization kenaf and coir fibre as concrete reinforcement was investigated in this paper. The aim of this hybridization is to produce a product that attain all the best properties mechanical properties and impact resistance to the optimum level.

Table 1
Physical and Mechanical Properties of Kenaf and Coir Fiber

Properties	Kenaf fibre	Coir fibre
Density $(\mathbf{kg/m^3})$	1193	1150
Elastic Modulus (GPa)	53	16 – 26
Tensile Strength (MPa)	930	500
Ductility (%)	1.6	17
Water Absorption (%)	307 (Millogo *et al.*, [19]	11.36
Reference	Wambua *et al.*, [25]	Ali [2]

Hybrid Fibre Reinforced Concrete (HFRC) is formed from a combination of different types of fibres, which differ in material properties, remain bonded together when added in concrete and retain their identities and properties. In a hybrid, two or more different types of fibres are rationally combined to produce a composite that derives benefits from each of the individual fibres and exhibits a synergistic response. The use of optimized combinations of two or more fibre types in the same concrete mixture can produce a composite with better engineering properties than that of individual fibres [17]. The static properties of HKFRC inherit better properties and enhanced of concrete strength up to its maximum [20]. The addition of hybrid fibres improves the ductility performance of concrete [17].

This paper main aims are to investigate the static properties and impact resistance and energy absorption (using weight drop impact test) of FRC with different kenaf and coir fiber ratio (100:0, 50:50, 60:40, 40:60, 0:100).

3. Methodology

3.1 Materials

The cement used was Portland cement ASTM C Type 1 with specific gravity of 3.15. The dry and clean crushed gravel (coarse aggregate) is 20 mm maximum nominal size. The fine aggregate passes through sieve size 4.75 mm (No. 4) minimum size retained on sieve 75 µm (No. 200). Cleaned kenaf and coir fibre with length of 3 to 5 cm was used in this research. The fibres must be cleaned from its impurities and core parts as it can affect the effectiveness of the fibre.

3.2 Mix Proportions and Preparation

The concrete composition of each cubic meter of concrete (used as basis) is given in Table 2. The mix design is proportioned in accordance with the British Department of Environment method (DOE Method of Concrete Mix Design). The targeted compressive strength of concrete is 30 MPa, and hence the water cement ratio is set constant at 0.50. The binder content of 360 (kg/m^3) was determined by setting the water content at 180 (kg/m^3) for the desired slump between 30 to 60 mm. As the kenaf and coir fibre is added into the mixtures the water content reduced due fibre properties which is high in water absorption and was included in the water correction calculation.

The procedures for mixing the FRC are as follows. First, the coarse and fine aggregate were placed in a concrete mixer and were allowed to dry mixed for 2 minutes. Second, the cement and fibre were spread and mixed with little amount of water of about ¼ of water content for approximately 2 minutes. Third, remaining ¾ portion was added and mixed for another 2 minutes. Finally, the freshly mixed FRC was cast into the mould, and the moulds were vibrated to remove any trapped air. Each of the specimens was allowed to stand for 24 hours in the laboratory before demolding. The specimen were cured in water for 7 and 28 days before testing according to ASTM C192.

Table 2
Mix Proportion

Cement (kg/m^3)	Water (kg/m^3)	Coarse aggregate (kg/m^3)	Fine aggregate (kg/m^3)	Kenaf (kg)	Coir (kg)	Slump (mm)
360	180	1097	763	1.536	1.481	30-60

3.3 Sieve Analysis

Sieve analysis was conducted in order to determine the distribution of particle sizes of coarse and fine aggregate following ASTM C33.

3.4 Specific Gravity and Water Absorption Test

Specific gravity and water absorption for coarse aggregate is determine according to ASTM C127. Specific gravity and water absorption for fine aggregate is determine according to ASTM C128.

3.5 Testing

Slump test was carried out to determine the workability of fresh concrete based on ASTM C143. The compressive strength of the concrete was determined according to BS 1881:1983-116. Six cubes sized (150×150×150) mm^3 were tested under static compression load using compression machine at ages 7 days and 28 days for each mix. The load is applied continuously, uniformly and without shock. The rate loading is 0.02 kN/s continuously. The load is increased until the specimen fails the maximum loads carried by the each specimen during the test are recorded.

The static split tensile strength test was conducted following BS 1881:1983-117 using six cylinders with diameter 100 mm and length of 200 mm tested at ages 7 days and 28 days. The apparatus used is similar like the one used in compressive strength test.

The static flexural strength test has been carried out using two-point loading method at ages 7 days and 28 days for six beam samples sized (100×100×500) mm^3 according to BS 1811:1983-118. The load is applied continuously, uniformly and without shock. The rate of loading is 200 N/s continuously. The load is increased until the specimen fails and maximum loads carried by the each specimen during the test are recorded.

The testing apparatus for impact resistance was Drop Weight Impact test apparatus, illustrated in Figure 1, which consists of three main components; a base, drop-weight guide system and drop weight. This test has been carried out to determine the ultimate energy absorption of the concrete. Three cylinders with diameter of 100 mm and height of 200 mm were tested at age 28 days according to ASTM D7136. Samples were tested by dropping the impactor. The samples are placed exactly at the centre of the apparatus. Then, the 1.8 kg impactor was dropped from height 2.4 m. The number of impact for cracking to start to propagate was recorded and then when the number of impact when the samples start to fail was also recorded. The energy absorption at service and ultimate energy absorption can be determined using equations

$$E_s = E_{ult} = mghn \tag{1}$$

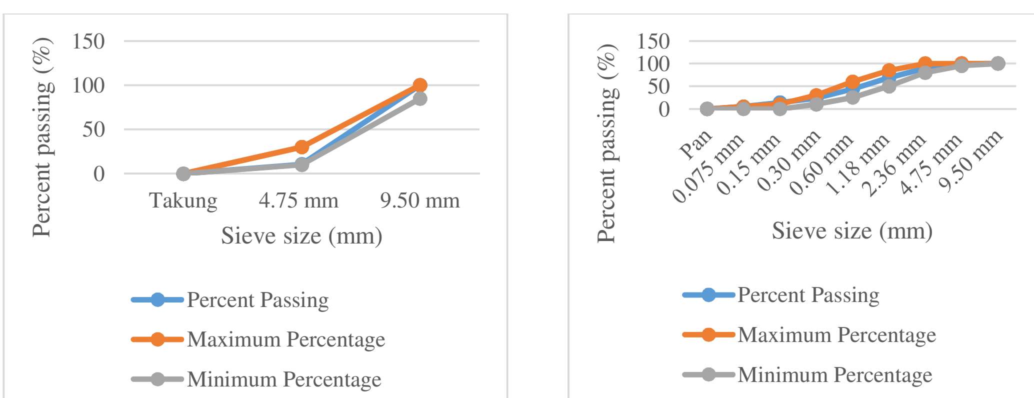
where; m = weight of drop weight
g = 9.81 m/s^2
h = height between sample and apparatus
n = number of impact (N_1) for E_s and (N_2) for E_{ult}

Fig. 1. Drop-weight test apparatus

4.Results and Discussion

4.1 Aggregate Gradation

The gradations of coarse and fine aggregate are as shown in the Figure 2 a) and b). Figure 2a) and b) show that both aggregates gradations are within the limit of ASTM C33.



a) b)

Fig. 2. Aggregate gradation a) coarse and b) fine

4.2 Specific Gravity and Water Absorption

Table 3 shows the specific gravity and water absorption of coarse aggregate and fine aggregate. These properties are used in determining the mix design proportion.

Table 3
Physical Properties of coarse aggregate and fine aggregate

Properties	Coarse Aggregate	Fine Aggregate
Fineness Modulus	1.878	3.559
Bulk specific gravity (dry-oven)	2.726	2.488
Bulk specific gravity (SSD)	2.739	2.505
Apparent specific gravity	2.762	2.530
Water absorption	0.5%	0.67%

4.3 Slump

Based on the mix design, the slump value chosen is between 30 to 60 mm. Table 4 shows that the workability of the concrete decreased as the more fibres are added to the mixture. It can be seen that coir fibre did not absorb as much water compared to kenaf fibre alone and hybrid fibre (refer Table 1, water absorption of kenaf = 307% compared to coir = 13.36%). It also can be seen that hybrid *S4* had produced the highest workability among the HFRC.

Table 4
Slump of mixes

Mixture	Slump (mm)	Percentage different (%)
Plain concrete -SC	36	-
100:0 (2% kenaf) -S1	25	-30.56
50:50 (1% kenaf and 1% coir) -S2	27	-25.00
60:40 (1.2% kenaf and 0.8% coir) -S3	26	-27.78
40:60 (0.8% kenaf and 1.2% coir) -S4	29	-19.44
0:100 (2% coir) -S5	32	-11.11

Comparing with Al-Bashiri [1], the slump of HFRC (hybrid kenaf and coir fibre with ratio of 50:50) decreased as the percentage of fibre content increased, i.e., at 1%, 3% and 5% hybrid fibre content, the percentage of difference in slump are 18.20%, 33.33% and 54.66% compared to control sample. This shows that the slump depends on the ratio of hybrid fibre and the percentage of fibre used.

4.4 Compressive Strength

Compression test of cube specimens are done as soon as practicable after removal from curing pond. Table 5 shows the average compressive strength of 3 cube samples foe each mix. It can be seen that the compressive strength of single fibre and hybrid FRC are higher compared to control.

Table 5
Average compressive strength of mixes

Age (days)	Average compressive strength (MP) of mixes					
	SK (control)	**S1**	**S2**	**S3**	**S4**	**S5**
7	24.22	25.17	27.06	27.54	28.07	26.80
28	31.65	32.89	34.22	33.98	35.07	33.40

Figure 3 shows the percentage of increment of each mix compared to control. The mix that produced the highest percentage increment in compressive strength is S3 (60:40) up to 10.8% at age 28 days which directly shows that this fibre ratio combination (where kenaf fibre content is maximum) is the optimum for attaining the best compressive strength. As the kenaf fibre is generally has high elastic modulus, and tensile strength than coir (refer to Table 1), it's higher content in the hybrid had improved the compressive strength of HFRC.

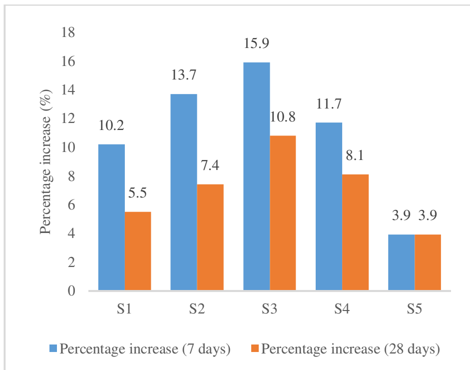


Fig. 3. Percentage Increment in Compressive Strength

Comparing with Al-Bashiri [1], the compressive strength of HFRC (hybrid kenaf and coir fibre with ratio of 50:50) increased as the percentage of hybrid fibre increased until 3% and start to decrease at percentages higher than that. At fibre contents 1%, 3% and 5%, the increment in compressive strength compared to control sample are 1.5%, 4.5% and 3.3%. The optimum percentage obtained is at 3% hybrid fibres and it is also found that HFRC possesses higher compressive strength than individual FRC. The compressive strength of HFRC are influenced by amount of fibre content and the ratio of hybrid fibre.

4.5 Split Tensile Strength

Table 5
Average split tensile strength of mixes

Age / Percent Increment	Average split tensile strength (MP) of mixes					
	SK (control)	**S1**	**S2**	**S3**	**S4**	**S5**
7 days	2.34	2.51	2.76	3.13	2.73	2.42
Increment (%)	-	**7.3**	**17.9**	**33.8**	**16.7**	**3.4**
28 days	3.30	3.54	3.89	4.52	3.88	3.50
Increment (%)	-	**7.3**	**17.9**	**37.0**	**17.6**	**6.1**

Table 5 it shows that the addition of kenaf, coir and hybrid fibres increased the tensile strength of plain concrete. But HFRC shows higher split tensile strength compared to single FRC. HFRC S3 gives the highest increment up to 37.0% in tensile strength compared to plain concrete. This shows that the hybridization kenaf and coir fiber at ratio 60:40 produced the best combination of fibres' tensile properties. As kenaf fibre has high tensile strength (Table 1), it improved the tensile strength of HFRC and with combination of coir fibre, produced a synergy composite that complement each other.

Comparing with Al-Bashiri [1], the split tensile strength of HFRC (hybrid kenaf and coir fibre with ratio of 50:50) increased with the increase in fibre content, which are, at 1%, 3% and 5%, the increments are 1.2%, 14.5% and 26.7% compared to control sample. The same conclusion can be made as in the compressive strength of HFRC, that is, the split tensile strength of HFRC are influenced by amount of fibre content and the ratio of hybrid fibre.

4.6 Flexural Strength

Table 6 shows that the addition of kenaf, coir and hybrid fibres had increased the flexural strength of plain concrete. HFRC S3 (ratio 60:40) gives the highest increment up to 9.8% in flexural strength compared to plain concrete and single fibre concrete. This is due to high tensile strength of kenaf that has improved the flexural strength of HRC. The same conclusion can be made if the results are compared with Al-Bashiri [1], where the flexural strength of HFRC at 1%, 3% and 5% are 6.54 MPa, 6.6 MPa and 6.87 MPa with increment of 3.5%, 4.4% and 8.7% compared to control sample. It also stated that hybrid fiber gives better result in flexural strength compared to individual fiber. From this research and Al-Bashiri [1] (hybrid kenaf and coir fibre with ratio of 50:50), the flexural strength of HKCFRC is influenced by the ratio of fibre and the percentage of fibre used.

Table 6
Average flexural strength of mixes

Age / Percent Increment	**Average flexural strength (MP) of mixes**					
	SK (control)	**S1**	**S2**	**S3**	**S4**	**S5**
7 days	5.68	5.80	5.84	5.91	5.81	5.72
Increment (%)	-	**2.1**	**2.8**	**4.0**	**2.3**	**0.7**
28 days	6.30	6.49	6.59	6.92	6.52	6.49
Increment (%)	-	**3.0**	**4.6**	**9.8**	**3.5**	**3.0**

4.7 Impact Resistance Test

Table 7 shows the service and ultimate energy absorption of the samples before failure. Based on that results, the addition of kenaf, coir and hybrid fibres show the enhanced energy absorption compared to plain concrete. Fibres act as energy absorber when the concrete is exposed to impact load, preventing cracking propagation and lengthen the time for the concrete to fail.

Table 7
Number of impact and ultimate energy absorption

Sample	$\mathbf{N_1}$	$\mathbf{E_s}$	$\mathbf{N_2}$	$\mathbf{E_{ult}}$	**Increment (%)**
SK	1	42.38	3	127.14	-
S1	2	84.76	4	169.52	**33.3**
S2	3	127.14	5	211.90	**66.7**
S3	3	127.14	5	211.90	**66.7**
S4	3	127.14	8	339.03	**166.7**
S5	3	127.14	6	254.28	**100.0**

It is observed that the HFRC and coir FRC give very high increment in energy absorption compared to the others. The results are reversed from the static mechanical properties, where combination of higher ratio of kenaf (HFRC S3) produced enhanced mechanical properties. For impact resistance, single coir FRC produced almost the same resistance as HFRC S4 under the impact load, due to the very high ductility of coir fiber (Table 1), approximately 17 times more than kenaf fibre. HFRC S4 with ratio 40:60 is the optimum composition which gives the highest ultimate energy absorption, 339.03 Nm with increment of 166.7%. Previous researcher, Nurudin [20] (hybrid kenaf and coir fibre with ratio of 50:50) had determined that the highest ultimate energy absorption of HFRC is at 1% hybrid fibre (296.7 Nm) with increment 75% from control sample. The energy absorption start to decrease at 3% and 5% which are 253.3 Nm and 211.9 Nm. Comparing these two researches, it can be concluded that the energy absorption of HFRC depends on the ratio of fibre and the percentage of fibre used.

5. Conclusion

As the natural fibres area added into the mixture, the mix become more cohesive. Workability decreased as the fibre absorb the water especially kenaf fibre which has high percentage of water absorption compared to coir fibre. HFRC S3 with kenaf:coir ratio of 60:40 gives the highest increment in compressive, split tensile and flexural strengths. At this ratio, the improvement in compressive strength is 10.8%, 37.0% for split tensile strength, a very significant increase, and the flexural strength improved by 9.8% compared control sample, due to the higher tensile strength and toughness of kenaf fibres compared to coir. However, HFRC (S4) with kenaf : coir ratio of 40:60 gives the highest increment in ultimate energy absorption up to 166.7% compared to plain concrete with the number of impact of 8 due to the very high ductility of coir fibre compared to kenaf fiber. If application where mechanical properties is in need, FRC with hybrid fibre mix 60:40 kenaf:coir is suggested and for impact resistance application, hybrid fibre mix 40:60 kenaf:coir is proposed.

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