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Enhancing Direct Tensile Strength: A Study of Hybrid Steel and Coconut Rope Fibres in Reinforced Concrete

Shahrizan Baharom[1,*], SM Priok Rashid[1], Muhammad Khairuddin Zulkifli[1], Chong Khai Liang[1]

[1] Department of Civil Engineering and Built Environment, Faculty of Engineering and Built Environment, Universiti Kebangsaan Malaysia, 43600, UKM Bangi, Selangor, Malaysia

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ABSTRACT

Enhanced matrix packing density and tailored fiber-to-matrix interface bond properties have led to the recent development of fiber reinforced concrete with improved material tensile performance in terms of strength, ductility and energy absorption capacity. Concrete is strong in compression but weak in tension. Adding two or more type of fibers into concrete and become hybrid fiber concrete which can solve this problem. The aim of this study was to investigate the use of coconut rope to be hybrid as fiber with steel fibers. In addition, this study also analyzed the differences between hybrid fiber concrete and concrete without hybrid fiber in the direct tensile test. For direct tensile tests, the size of specimens in the form of "dog-bone" was 60 × 100 × 60 mm. Seven samples were prepared for this study. The hybrid concrete sample consists of steel fiber and coconut rope. Total volume fraction of steel fiber and coconut rope were kept to 2% but the volume fraction of steel fiber and coconut ropes were each different, such as 2.0-0%, 0-2.0%, 0.4-1.6% and 1.0-1.0%. In addition, the concrete containing 1% steel fiber and 1% coconut fiber rope had a direct tensile strength 1.36 N/mm^2 and this value was near to the value of the direct tensile strength of concrete containing 2% steel fibers, 1.64 N/mm^2. Their difference was 17.1%. The CS3 and CS4 specimens which included 1% steel and coconut ropes, exhibited the maximum energy absorption. It was observed that CS3 and CS4 specimens were more ductile. These results showed that this hybrid fiber concrete could contribute both tensile strength and energy absorption similar to steel fiber concrete. Moreover, hybrid fiber reinforced concrete can produce greater tensile strength and energy absorption capacities.

1. Introduction

Fiber reinforced composites are widely used in lightweight structural applications by the reason of their superior mechanical properties and lightness. Synthetic and hybrid fibres are extensively used to reinforce polymeric resins in the creation of composite materials due to their advantageous mechanical properties [1-4].

* *Corresponding author.*
E-mail address: shahrizan@ukm.edu.my

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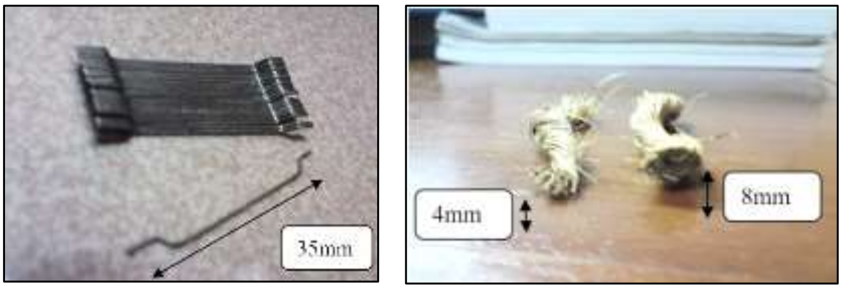
Fibers in concrete can be effective in supporting and controlling the cracks on both micro and macro levels. In addition, hybridization of concrete with a combination of two different types of fibers such as one type of steel fiber is smaller, so that it bridges micro-cracks and therefore controls their growth and delays consistancy. This leads to a higher tensile strength of the composite. The second fiber is larger and is intended to arrest the propagation of macro-cracks and therefore results in a substantial improvement in the fracture toughness of the composite [5-10]. The experimental findings of Güneyisi *et al.,* [8] on the mechanical characteristics of metakaolin (MK) and plain concretes with and without steel fiber are reported in their research. In order to create steel fiber reinforced concrete mixes using metakaolin, 10% of the total binder content was developed by substituting MK for Portland cement. The findings showed that, apart of the w/b ratio, the addition of MK and the use of various steel fiber varieties had a substantial impact on the mechanical characteristics of the concretes.

Coconut rope made from coconut fibers have many uses. Coconut fiber is a natural fiber that can be obtain by soaking the fiber in the water or using a mechanical process. Coconut fibers with high lignin and low cellulose content is strong, durable and harder [11-15]. Flexural characteristics of coir fiber reinforced cementitious composites (CFRCC) that have been naturally formed and chemically modified was investigated by Li *et al.,* [14]. Two typical lengths of coir fibers were utilized, and for comparison, the longer coir fibers were also treated with a 1% NaOH solution. The findings demonstrated that the CFRCC samples weighed between 5-12 % less than the typical mortar and that the CFRCC materials' flexural strength had increased with the addition of coir fibers. Steel fibers has a high tensile strength and elasticity. Therefore, effectively improve the behavior of concrete like ductility and strength of concrete. Steel fibers bridge microcracks and restrain their widening, thus delaying the cracks further propagation [16,17].

To the best of the author’s knowledge, there is a lack of published tests of hybrid fibre reinforced concrete with steel fibre and coconut rope fibres in direct tension, which primarily motivated the work in this paper. In this study, coconut ropes that made from coconut fibers have a higer tensile strength than coconut fibers were used to mix with hooked steel fibers to produce a higher tensile strength of hybrid fiber concrete. "Dog bone" shape concretes were produced for direct tensile test. The objective of this study was to examine the direct tensile strength of hybrid fiber concrete that contains steel fibers and coconut ropes with different volume fraction and different diameter of the coconut ropes.

2. Methodology

In this study, hooked steel fibers with 35 mm length and 0.54 diameter were mixed with coconut ropes with 50 mm length and different diameter 4 mm and 8 mm to produce hybrid fibre concrete. Hooked steel fibers and coconut ropes are shown in Figure 1.The water to cement ratio was 0.57. The percentage of sand in this research was 57% of the total aggregate. Firstly, the materials were prepared such as water, aggregate 10 mm size, cement, hooked steel fibers and coconut ropes for mixing process. After the mixing, it was poured to "dog bone" shape moulds for furthur direct tensile test as shown in Figure 2. The concrete samples were kept in room tempeture for 1 day. After the 1 day, the samples were removed from the mould and putted in the water for curing for 28 days. After the curing process, the samples were taken for direct tensile test. To fix the specimen on the jaws of the tensile machine, a special device was designed and manufactured to assist the value analysis method (see Figure 3). The "dog bone" shape sample was set up with special device and the device was attacted to Universal testing machine so that the direct tensile test can be run which is displayed in Figure 4.



(a) (b)

Fig. 1. Material for hybrid concrete (a) Steel fibre (b) Coconut rope

Fig. 2. "Dog bone" shape sample

Fig. 3. Special device

Fig. 4. Universal testing machine

3. Results and Discussion

3.1 Direct Tensile Strength

Table 1 illustrates the results of direct tensile test of hybrid concrete containing steel fibers and coconut ropes with different volume fraction and different diameter of the coconut ropes. Direct tensile strength for sample S1 containing 2% steel fibers was greater than other concrete samples containing lower amount of steel fibers. It was noticed that the higher amount of the steel fiber in hybrid concrete showed higher direct tensile strength. This is because the steel fiber has higher Young modulus than coconut rope. However, sample CS4 containing 1% steel fibers and 1% coconut ropes with a diameter 4 mm had 1.36 N/mm^2 direct tensile strength and it was near to direct tensile strength of sample S1 that containing 2% steel fibers which was 1.64 N/mm^2. These results demonstrated that coconut ropes as a fiber in concrete can give direct tensile strength similar to steel fibers in concrete with a low price while compared to steel fibers.

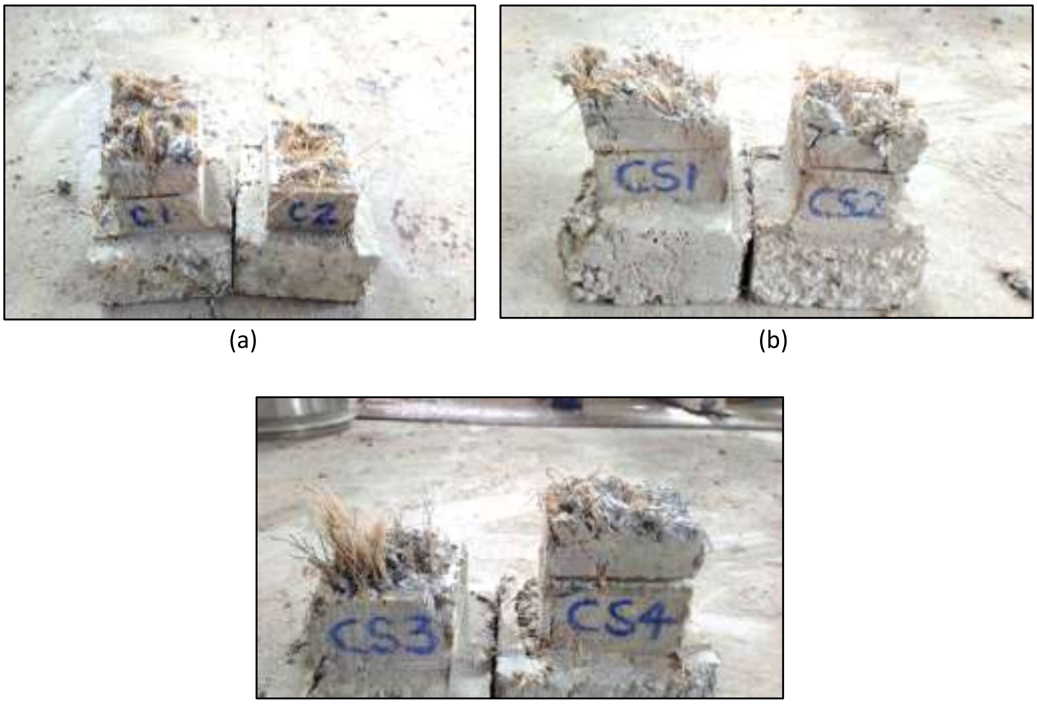
Table 1
The results of direct tensile test

Sample	Volume fraction of steel fibre (%)	Volume fraction of coconut rope (diameter 8 mm)	Volume fraction of coconut rope (diameter 4 mm)	Direct tensile strength, N/mm^2	Percentage difference between S1 and other sample (%)
S1	2	-	-	1.64	-
C1	-	2	-	0.238	85.5
C2	-	-	2	0.297	81.9
CS1	0.4	1.6	-	0.805	50.9
CS2	0.4	-	1.6	0.944	42.4
CS3	1	1	-	1.25	23.8
CS4	1	-	1	1.36	17.1

A comparison is presented in Table 2 which shows the direct tensile strength of samples C2, CS2 and CS4 were higher than C1, CS1 and CS3. The diameter of coconut ropes in sample C2, CS2 and CS4 were smaller than the coconut ropes in C1, CS1 and CS3. The coconut ropes that had same length but different cross-sectional area, the coconut ropes with smaller diameter would impact around the matrix of the concrete and give direct tensile strength more effectively [18-20]. In other word, the smaller the diameter of coconut ropes in concrete, the higher the direct tensile strength of concrete. Figure 5 shows that the bigger diameter coconut ropes 8 mm in samples C1, CS1 and CS3 were concentrated in one place while the smaller diameter coconut ropes 4 mm in samples C2, CS2 and CS4 were spread around the matrix of the concrete [21,22].

Table 2
Comparison of direct tensile strength between samples (a) C1 and C2 (b) CS1 and CS2 (c) CS3 and CS4

(a) Volume fraction of steel fibre-coconut rope 0-2.0 %		
Sample	Direct tensile strength (N/mm^2)	Percentage difference between C1 and C2 (%)
C1	0.238	-
C2	0.297	24.79
(b) Volume fraction of steel fibre-coconut rope 0.4-1.6 %		
Sample	Direct tensile strength (N/mm^2)	Percentage difference between CS1 and CS2 (%)
CS1	0.805	-
CS2	0.944	17.27
(c) Volume fraction of steel fibre-coconut rope 1.0-1.0 %		
Sample	Direct tensile strength (N/mm^2)	Percentage difference between CS3 and CS4 (%)
CS3	1.25	-
CS4	1.36	8.8



(a) (b)

(c)

Fig. 5. Comparison between (a) C1 and C2 (b) CS1 and CS2 (c) CS3 and CS4

3.2 Stress-Strain Behaviour

Figure 6 displays the stress-strain of S1 containing 2% steel fibers. The linear phase shown in Figure 6 is elastic in behavior and it occured before concrete cracking. This phase ended with the appearance of a large crack. The second phase where there was a fall after the concrete cracks. In this phase, the concrete matrix broke and the edge cracks were connected by steel fibers which prevented sudden cracks.

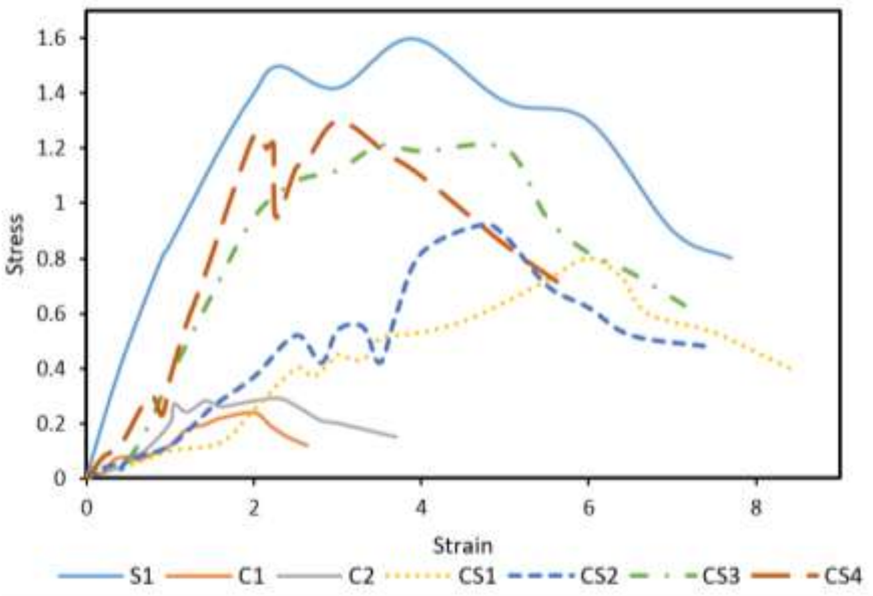


Fig. 6. Stress-strain curve of the specimens

Figure 6 indicates the stress-strain of C1 and C2 which contains 2% coarse and 2% fine coconut coir rope. The linear phase shown in Figure 6 behaves elastically and it was observed before the concrete crack. This phase ended with the appearance of a crack. In this second phase there was slight fall and the edge cracks continued to be connected by coconut coir rope to prevent sudden cracks. This coconut coir rope provided additional direct tensile strength from 0.2 N/mm^2 to 0.238 N/mm^2. The direct tensile strength of C2 was higher than C1 due to the higher aspect ratio of C2 coir rope than C1.

Figure 6 depicts the stress-strain curves of CS1, CS2, CS3 and CS4. Prior to the concrete cracking, there was an elastic linear phase, as seen in Figure 6. A large crack appeared to indicate the end of this phase. In the second stage, there was a fall after the crack occurred in the concrete. In order to prevent sudden cracks, the concrete matrix breaks during this phase, and steel fibers and coconut coir ropes bridge the edge cracks. Although hybrid concrete showed the same function as concrete that contains only one fiber, which is steel fiber concrete and coconut fiber reinforced concrete, but one of the hybrid concrete, CS4, provided a direct tensile strength that was almost the same as steel fiber concrete, S1, which had the higher strengthamong all samples. The difference between S1 which had a direct tensile strength of 1.64 N/mm^2 and CS4 which had a direct tensile strength of 1.36 N/mm^2 is 17.07%.

Hybrid CS4 concrete is more economical than S1 concrete because the production cost of coir rope is cheaper than steel fiber. In addition, coir rope produced by coir fiber is biodegradable and a renewable resource. This shows the advantage of adding coconut coir rope in the concrete hybrid compared to concrete containing only steel fibers.

3.3 Energy Absorption Capacity

The energy absorption capacity was determined by calculating the area under the stress-strain curve. It is known that the specimen absorps more energy, it is more ductile. The energy absorption capacity was calculated from Eq. (1).

$$U = \frac{1}{2} \int \sigma \in \quad (1)$$

The energy absorption capacities can be seen fron the Figure 7. The energy absorption capacity for S1 was 5.6 Mpa whether the energy absorption capacity for C1 and C2 samples were 1.65 and 2.55 Mpa. The highest energy absorption capacity was obtained from CS3 and CS4 samples which were 12.15 and 10.92 Mpa. The use of hybrid fibres with 1% steel and 1% rough coir rope can be considered the most effective. This is because the coir fiber's greater flexibility results in increased energy absorption in the post-crack zone, and hybridization helps to arrest cracks. It was observed that the use of hybrid fiber (CS3 and CS4) 1% steel fiber and 1% coir rope fiber showed the greatest increase in the toughness indices. This suggests that adding hybrid fiber combinations to reinforced concrete will improve its overall performance as well as its energy absorption and ductility.

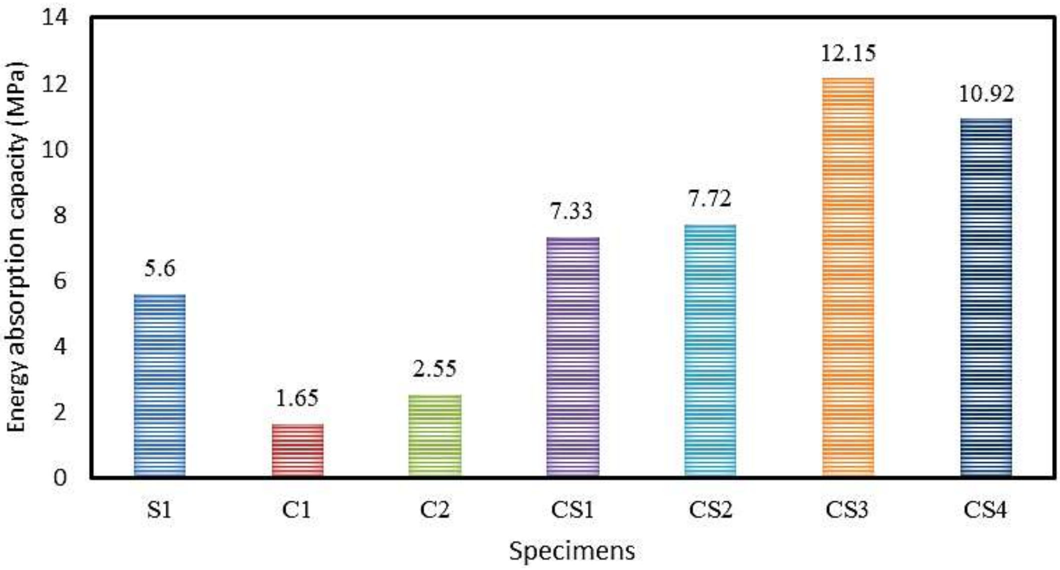


Fig. 7. Energy absorption capacities

4. Conclusions

The experimental results indicated that the CS4 concrete containing 1% steel fibers and 1% coconut ropes with a diameter 4 mm had a 1.36 N/mm^2 tensile strength which was near to direct tensile strength of S1 concrete that containing 2% steel fibres, 1.64 N/mm^2. The highest energy absorption was obtained from CS3 and CS4 specimens that includes 1% steel and coconut ropes. CS3 and CS4 specimens were found to be more ductile. It was observed from the results that coconut ropes as a fibre in concrete can give direct tensile strength similar to steel fibres in concrete but with a low price compared to steel fibres. This experimental result also showed that the bigger the diameter of coconut rope as a fibre in hybrid concrete, the higher the tensile strength of hybrid concrete. In can be concluded that hybrid fibre reinforced concrete can be economical and more effective in civil engineering practices.

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