Mechanical properties of steel/kenaf (hybrid) fibers added into concrete mixtures

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Abstract. This paper investigates the potential advantages of adding hybrid steel-kenaf fibers to concrete mixtures. Compression and flexural test were conducted on six concrete mixtures at 28 days to investigate the mechanical properties of the concrete. The experimental work consists of six concrete mixtures, in which the first mixture was a control mixture without adding any fiber. The following five concrete mixtures contain a total of 1% of volume fraction for steel, kenaf and a mixture of steel-kenaf (hybrid) fibers. Three ratios were considered for hybrid fibers with the ratios of 0.25/0.75, 0.5/0.5 and 0.75/0.25 for steel and kenaf fibers, respectively. From the investigation, it was observed that fibers have minimal effect on compressive strength of the concrete. However, the findings suggest promising improvement on the flexural strength of the concrete added with hybrid fiber (up to 86%) as well as manages to change the mode of failure of the beam from brittle to a more ductile manner.

1. Introduction
Concrete has become one of the most important construction materials commonly used in many types of engineering structures. Concrete is a material which is very strong in compression and weak in tension, thus causes cracking in the tension zone. In the past decades, fiber reinforced concrete (FRC) has been gaining more attention in the concrete research development and were used in numerous types of civil engineering application such as pavement slabs, precast products, shotcrete, tunnel linings, seismic structures, marine and refractory applications [1-4]. There are many advantages of inclusion of fiber into reinforced concrete structures, such as improving the load carrying capacity and ductility of the structural members, controlling crack propagation, increasing energy absorption and altering the mode of failure [5-11].

Steel fiber has been demonstrated its efficiency in enhancing the structural behaviour of reinforced concrete structural members [11-16]. The addition of kenaf fibers into concrete mixtures as this type of fiber reinforced concrete was investigated as a potentially promising “green” construction material to be used in many types of structural engineering [17,18]. However, since kenaf fiber is a natural fiber, some treatment is needed to reduce the hydrophobic characteristic of the fiber in order to maintain water/cement ratio and ensure sufficient workability of the concrete mixtures [17,19]. One of the treatments recommended is to use a chemical such as sodium hydroxide (NaOH) to reduce the hydrophobic characteristic, thus enhancing the adhesion between the fiber surface and the matrix, by removing the hydroxyl group in cellulose and increased the surface roughness which resulted in the improvement of the tensile properties of kenaf fibers as compared to untreated kenaf fibers [17,20-22].
Previous works reported in literature have shown that promising results were observed in the potential of steel fibers and kenaf fiber to improve the structural behaviour of reinforced concrete members. Present work aims to study the behaviour of single and hybrid (steel-kenaf) fibers and its ratio in the mechanical properties of concrete through compressive strength, flexural strength, cracking pattern and mode of failure of concrete.

2. Materials and Methods
The control concrete mixture is designed in accordance to British Standards (BS EN 206-1, 2000) for 20 MPa of concrete compressive strength. In order to investigate the mechanical behaviour of single fibers and hybrid fibers added into the concrete mixture, three types of fibers, namely steel fiber, kenaf fiber, and hybrid steel-kenaf fiber were added in the concrete. The fiber volume fraction ($V_f$) considered was 1% for single and hybrid fiber, where the hybrid fiber divided between steel-kenaf into ratios of 0.25–0.75%, 0.5–0.5% and 0.75–0.25%, respectively.

Six concrete mixtures were produced for single and hybrid fibers using different fiber volume fraction as listed in Table 1. The first mixture (Mix 1) is a control mixture without adding any fiber, $V_f = 0\%$. The following five concrete mixtures contain $V_f = 1\%$, 1%, 0.25/0.75%, 0.5/0.5% and 0.75/0.25% and represent in Mix 2, Mix 3, Mix 4, Mix 5 and Mix 6, respectively. Hooked-end steel fiber and kenaf fiber were considered for this study. The properties of the steel fiber and kenaf fiber are presented in Table 2 while the shape of steel and kenaf fibers are shown in Figure 1 and 2, respectively. In addition, the kenaf fiber was treated by 1% of NaOH in order to clean and remove impurities from the fiber surface as well as enhancing the tensile properties of kenaf fiber. Moreover, super-plasticizer (SP) is added into the mixtures to improve workability and achieve the required slump.

| Table 1. Concrete mix design. |
|--------------------------------|
| Properties | Mix 1 C0 | Mix 2 S1 | Mix 3 K1 | Mix 4 H25/75 | Mix 5 H50/50 | Mix 6 H75/25 |
|-------------|----------|----------|----------|--------------|--------------|--------------|
| Type of fiber | Control | Steel | Kenaf | Hybrid | Hybrid | Hybrid |
| $V_f$ (%) | 0 | 1 | 1 | 0.25-0.75 | 0.5-0.5 | 0.75-0.25 |
| Cement (kg/m$^3$) | 280 | 280 | 280 | 280 | 280 | 280 |
| Fine Aggregate (kg/m$^3$) | 556 | 556 | 556 | 556 | 556 | 556 |
| Coarse Aggregate (kg/m$^3$) | 1292 | 1292 | 1292 | 1292 | 1292 | 1292 |
| Water (Liter/m$^3$) | 162 | 162 | 162 | 162 | 162 | 162 |
| W/C ratio | 0.58 | 0.58 | 0.58 | 0.58 | 0.58 | 0.58 |
| SP (Liter/m$^3$) | 5.6 | 5.6 | 5.6 | 5.6 | 5.6 | 5.6 |
| Steel fiber (kg/m$^3$) | 0 | 75 | 0 | 18.8 | 37.5 | 56.3 |
| Kenaf fiber (kg/m$^3$) | 0 | 0 | 6.5 | 4.9 | 3.3 | 1.7 |

| Table 2. Properties of steel and kenaf fibers. |
|---------------------------------|
| Properties | Steel Fiber | Kenaf Fiber |
|-------------|--------------|--------------|
| Steel fiber | 75 | 18.8 |
| Kenaf fiber | 6.5 | 4.9 |
In order to measure the compressive and flexural strength of the concrete mixtures, compression test and flexural test were conducted in this study using cube compression test machine MATEST and Universal Testing Machine under four-point bending test, respectively. Three cubes, as well as three beams were prepared for each mixture. A total number of eighteen cubes with a standard size of 150 x 150 x 150 mm as well as eighteen beams with a dimension of 100 x 100 x 500 mm were tested on the 28th day as recommended in British Standards BS EN 12390-3, 2009 and BS EN 12390-5, 2009, respectively. Figures 3 and 4 show the machine used for compression test and flexural test, respectively.

3. Results and Discussion
Present work discusses the mechanical properties of concrete mixtures added with fibers, which includes the compression and flexural strength of the concrete and its cracking pattern.

3.1 Compressive Strength Test
Figure 5 shows the average compressive strength of fiber reinforced concrete cube specimens tested at 28th day. It is noteworthy that all concrete mixtures achieved more than its target compressive strength (20 MPa) except the kenaf fiber reinforced concrete mixture which was due to the low density of kenaf fiber concrete mixture compared to the control mixture. In comparison to the control cubes (C0),
only steel fiber reinforced concrete (S1) and hybrid fiber reinforced concrete (H75/25) show higher compressive strength with increasing up to 6% and 11%, respectively. This is due to the increase in the amount of steel fiber in the concrete mixture that makes the specimen denser and stronger. However, the compressive strength of cube specimens K1, H25/75 and H50/50 that contain kenaf fiber decrease up to 27%, 7% and 4%, respectively, in comparison to the C0, as the amount of kenaf fibers increases. This observation is in agreement with the previous study [17]. It was reported that the compressive strength of the concrete mixture decreases with an increase of kenaf fiber volume fraction. Moreover, this can be explained due to the decrease in the density of the mixture as well as the specimens with kenaf fiber were almost not thoroughly dried and hardened as reported by [19].

![Figure 5. Compressive strength of concrete mixtures.](image)

3.2 Flexural Strength Test
The results of the flexural strength of the fiber concrete mixtures beam specimens tested on the 28th day is illustrated in Figure 6. The results show that the inclusion of single and hybrid fibers into concrete mixture fibers has a moderate influence on the flexural strength of the concrete mixtures. The findings showed that the beams specimens that contain steel fiber and hybrid fiber have a higher flexural strength compared to control specimen. However, kenaf fiber specimen and control specimen have almost same flexural strength.

![Figure 6. Flexural strength of concrete mixtures.](image)
The highest flexural strength of the beam specimen was observed in beam S1 with 7.5 MPa, which is 114% higher than beam C0. In addition, the flexural strength of hybrid concrete beam specimens H75/25, H50/50 and H25/75, show improvement up to 23%, 40%, and 86%, respectively, in comparison to the beam C0. The best ratio of hybrid fibers can be seen from beam H75/25. As the amount of steel fibers in the hybrid fibers’ ratio increases, the flexural strength of the concrete also increases. This observation can be explained in terms of the synergy between steel and kenaf fiber which implies that the comprehensive performance in the flexural strength would exceed that produced by steel fibers or kenaf fibers separately at the same amount of fiber.

3.3 Cracking pattern and mode of failure
Looking at the cracking pattern of the beams at failure shown in Figure 7, most of the beams show cracking propagation along the mid-span between the two-point of loading. During testing, it could be observed that the control beam (C0) has failed in a brittle manner which occurred suddenly without any warning. However, the beams S1, K1, H25/75, H50/50 and H75/25 failed in the ductile manner, in which the cracking is propagated and extended without breaking the beam into half as shown in Figure 7. This confirms the fact that adding fibers to concrete has potential to delay the cracking propagation and change the mode of failure from brittle to ductile manner.

| Beam  | Cracking pattern | Failure mode |
|-------|-----------------|--------------|
| C0    | ![Cracking pattern](image) | Brittle      |
| S1    | ![Cracking pattern](image) | Ductile      |
| K1    | ![Cracking pattern](image) | Ductile      |
| H25/75| ![Cracking pattern](image) | Ductile      |
| H50/50| ![Cracking pattern](image) | Ductile      |
| H75/25| ![Cracking pattern](image) | Ductile      |

**Figure 7.** Cracking pattern and failure mode of beam.

4. Conclusion
Based on the findings, it can be seen that the inclusion of steel fiber and a higher ratio of steel fiber in hybrid fiber slightly improve the compressive strength of the concrete. In term of flexural strength, significant enhancement was observed in the concrete beam added with fibers. With a minimum ratio of steel fiber in hybrid fiber (H25/75), a notable improvement on the flexural strength can be observed. Furthermore, the cracking propagation was delayed and the mode of failure of the beam also change to a ductile manner.
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