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BEHAVIOUR OF REINFORCED CONCRETE BEAMS WITH KENAF AND STEEL HYBRID FIBRE

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ABSTRACT

This paper presents the effect of kenaf fibre and steel fibre mixed and added into reinforced concrete beams. In investigating the structural behaviour of the beams, four-point bending tests were conducted on six beams by considering two distinct parameters; (i) shear reinforcement arrangement (ii) volume of fraction of kenaf fibre and steel fibre. The experimental work consists of six beams, three beams with full shear reinforcement added with fibres by a volume fraction of V_f = 0%, Vf = 1% and V_f = 2%, respectively. Whilst, the other three beams tested with a reduced amount of shear reinforcement added with fibres with a volume fraction of, V_f = 0, V_f = 1% and V_f = 2% were examined. The beam with V_f = 0% kenaf and steel fibre in full shear reinforcement was taken as the control beam. The experimental result suggests promising enhancement of the load carrying capacity (up to 29%) and ductility (up to 22%) as well as controlled crack propagation for the beams with V_f = 1%. Additionally, it was observed that addition of fibres changes the mode of failure of the beam from brittle to a more ductile manner.

Keywords: Kenaf fibres, ductility, load carrying capacity, mode of failure, hybrid fibre, reinforced concrete beam, steel fibre.

INTRODUCTION

Fibre reinforced concrete has been given due attention by researchers over the past few decades (Swamy and Lankard, 1974), (Sharma, 1986), (El-Niema *et al*., 1991), (Syed Mohsin, 2012). This is essentially due to its capability of enhancing the load carrying capacity and ductility of the concrete structures. It also changes the mode of failure, control cracking propagation as well as increasing energy absorption. Furthermore, recent findings suggest that that fibres also have the potential to serve as part of shear reinforcement in reinforced concrete structures (Syed Mohsin, 2012), (Azimi *et al*., 2014), (Abbas *et al*., 2014).

Steel fibres have also demonstrated its capability in improving the structural behaviour of reinforced concrete beams (Mansur and Ong, 1991), (Kwak *et al.*, 2002), (Syed Mohsin *et al*., 2012), (Abbas *et al*., 2014). Recent studies also suggest that the addition of fibres to reinforced concrete beams with reduced shear reinforcement restores the strength and ductility of the beam (Abbas *et al*., 2014), (Syed Mohsin *et al*., 2014). Based on the literature, the study of hybrid fibres (steel and kenaf) to improve the structural behaviour of the reinforced concrete beams and simultaneously serve as part of shear reinforcement in beams has yet been explored. This study attempts at investigating the aforementioned structural properties of a novel hybrid kenaf-steel fibre reinforced concrete.

METHODOLOGY

Preparation of cubes and reinforced concrete beams for testing

Table-1 lists three sets of concrete mixture proportions used in the present research. Kenaf fibres included in the mixtures were 30 mm of length with a diameter that ranges between 0.1 mm to 2 mm as shown in Figure-1. The hooked end type steel fibres with a length of 60 mm and a diameter of 0.75 mm were added into the mixtures as depicted in Figure-2.

Table-1. Concrete mixture.

MATERIALS	Mix 1 (V_f= 0%)	Mix 2 (V_f= 1%)	Mix 3 (V_f = 2%)
Cement (kg/m^3)	510	510	510
Aggregates (kg/m^3)	308	308	308
Sand (kg/m^3)	848	848	848
Water(L/m^3)	204	204	204
W/C ratio	0.4	0.4	0.4
Superplasticizer (L/m^3)	5	5	5
Kenaf fibre(m^3)	0	8.44x10^{-5}	1.688x10^{-4}
Steel fibre (m^3)	0	2.53x10^{-4}	5.06x10^{-4}

Figure-1. Kenaf fibre.

Figure-2. Steel fibre.

In order to measure the compressive stress of the mixtures, a number of 27 cubes with a dimension of 150 mm x 150 mm x 150 mm were prepared. Three cubes were tested for each mixture on the 3rd, 7th and 28th day. The reading represents the effect of fibres in the concrete mixtures. The concrete mixture used in the fabrication of all specimens was ensured to achieve a slump in the range of 95 mm to 105 mm.

In the present work, six numbers of reinforced concrete beams were prepared with two shear reinforcement arrangements. The difference in the shear reinforcement arrangements is to cater for the investigation of the potential of the fibres to act as part of shear reinforcement in the beam. The beams were designed as square (150 mm x 150 mm) with 1500 mm length as shown in Figure-3(a). Two tensile steel bar with diameters of 12 mm (2H12) and 16 mm (2H16) were used for the compression and tension bar, respectively. As for the shear reinforcement, the first three beams were installed with round steel bar of 6 mm in diameter at 100 mm centre-to-centre, whereas, the other three beams were installed with round steel bar of 6 mm in diameter at 200 mm centre-to-centre.

The loading arrangement and dimensions are illustrated in Figure-3(a), whereas, Figure-3(b) shows the steel reinforcement properties of the beam. The beams were initially designed in accordance with Eurocode 2 with shear reinforcement less than that is required to cause shear failure. Two arrangements were considered (i) full shear reinforcement (S=100mm) and (ii) reduced in shear reinforcement (S=200mm). Subsequently, two amounts of fibre contents (1% and 2%) were added to the reinforced concrete mixture to examine the effect of kenaf fibre and steel fibre (hybrid) in reinforced concrete beams. The beams were then tested under four-point bending test. The beam with full shear reinforcement and without fibre (V_f = 0%) was considered as the control beam. The test was carried out on the 28th day as it is conventionally practised.

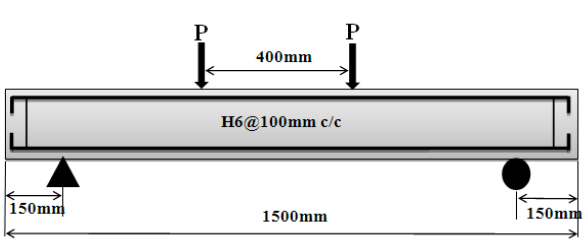

Figure-3(a). Loading arrangement and dimensions of the beam.

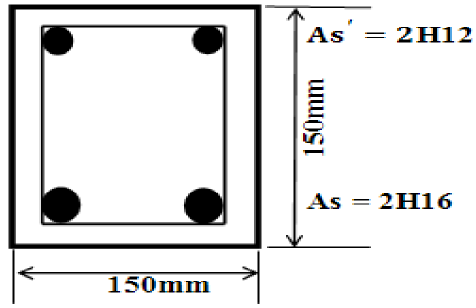

Figure-3(b). Steel reinforcement arrangement.

Testing

Compression (cube) test and four-point bending test were considered in this research. All the cubes samples were tested under compression test on 3rd, 7th and 28th day. Conversely, all specimens were tested under static monotonic loading conducted using a hydraulic machine under four-point loading test on the 28th day. The three linear variable differential transducers (LVDT) was used to determine the mid-span displacement whilst the load cell indicated the applied load test set up for the beams as shown in Figure-4.

Three strain gauges are placed at mid-span and at each location that are prone to crack in shear. During the testing, the crack propagation of the beams was marked by numbering all the cracks and their location.

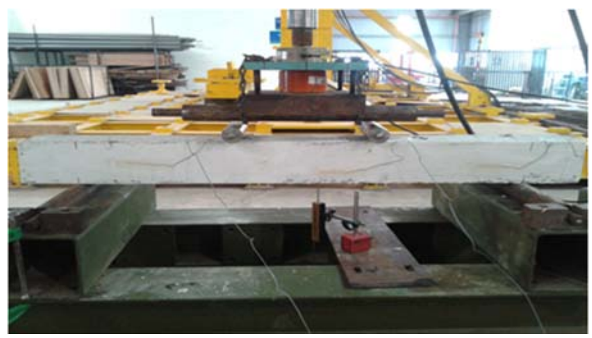

Figure-4. Beam test set up.

RESULTS AND DISCUSSIONS

The compressive strength of the kenaf fibre and steel fibre (hybrid) reinforced concrete beams are shown in Table-2. It can be seen that, initially on the 3rd day of the testing, the compressive strength of the concrete with fibres are higher than the concrete without fibre. However, on the 28th day, the compressive strength of the control concrete mixture is higher as compared to the fibre reinforced concrete mixture. This result agrees well with existing literature (Bencardino *et al*., 2008), (Syed Mohsin, 2012). This behaviour is expected as fibres have a very minimum effect on the compressive strength of the concrete. In most of the cases, the compressive strength of the concrete with fibres is lower compared to the concrete without fibres. However, promising results is observed in term of load carrying capacity and flexural strength.

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Table-2. Compressive strength result.

Days / V_f (%)	3	7	28
0	16.8	20.74	31.1
1	18.38	26.6	26.67
2	19.24	20.74	27.73

Figure-5 and Figure-6 illustrate the load-deflection curves of six beams tested in this study. Figure-5 depicts the load-deflection curves for kenaf fibre and steel fibre reinforced concrete (KFSF-RC) beams with full shear reinforcement (S=100mm). From the figure, it is evident that the addition of fibres has a moderate effect on the structural performance of the KFSF-RC beams. The strength of the KFSF-RC beam with V_f = 1% is slightly higher in comparison to the control beam, whereas the KFSF-RC beam with V_f = 2% exhibits the lowest load carrying capacity for this shear reinforcement arrangement. The low strength performance is due to the high amount of kenaf fibre in the beam, which absorbs the water and delay the internal hardening of the concrete. Consequently, the strength of the beam with the highest amount of fibres is lower than the one with 1% of fibre content. A similar pattern was observed in the case of the beam with reduced in shear reinforcement (S=200mm) as illustrated in Figure-6. It is apparent that the beam with reduced in shear reinforcement produced better strength as compared to the beam without fibre (refer to Figure-6). The aforementioned results suggest that kenaf and steel fibres demonstrate its prospective characteristics as part of shear reinforcement in the KFSF-RC beams.

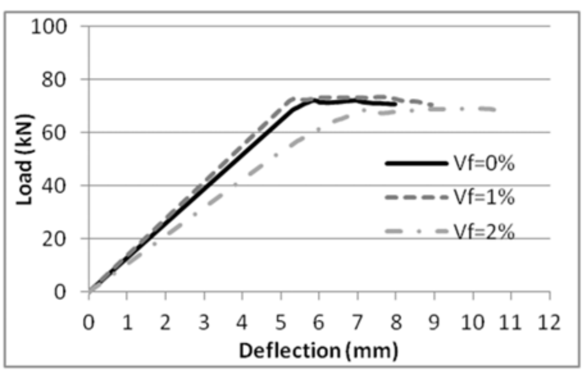

Figure-5. Load deflection curves for kenaf fibre and steel fibre reinforced concrete beams with full shear reinforcement (S=100mm).

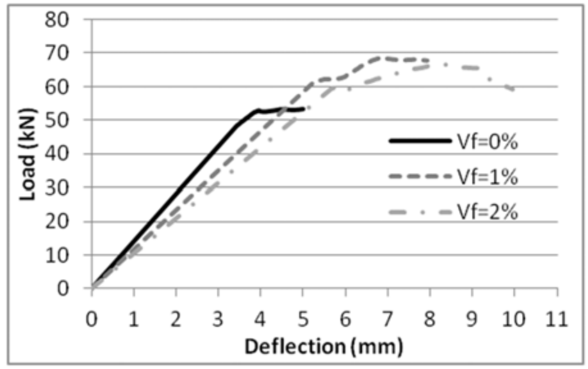

Figure-6. Load deflection curves for kenaf fibre and steel fibre reinforced concrete beams with reduced in shear reinforcement (S=200mm).

Previous research on kenaf fibre reinforced concrete beams (Mansur and Ong, 1991), (El-Niema *et al*., 1991),(Syed Mohsin *et al*, 2014), (Azimi *et al*., 2014) as well as steel fibre reinforced concrete beams (Syed Mohsin, 2012), (Syed Mohsin *et al*., 2012) (Azimi *et al*., 2014) show that the strength of the beams increased consistently with the increase of the fibre content. However, in the present study, the increase of the strength was not consistent as to testing was conducted on the 28th day. Azimi *et al*. (2014) suggests that beams added with kenaf fibre should be tested on the 56th day to allow the beam to be fully dried and hardened. Only upon such treatment, reasonably good results can be obtained. Moreover, during the investigation, most of the fibres were pulled out from the matrix (as it was not fully dried and hardened) instead of fibres rupture. This phenomenon also has some effect towards the strength of the structure as higher strength was needed to rupture the fibre during the pull-out phase.

On the other hand, the ductility of the KFSF-RC beams increases with the increase of fibre content. This is due to the fact that fibres improve the ductility of the concrete's brittle characteristics. Even without being fully hardened, it was observed that the KFSF-RC beams behave more ductile as compared to the control beam. It can be seen that the deflection of the KFSF-RC beams was higher compared with the KFSF-RC beam with 0% fibre. Moreover, the higher load was needed to produce the deflection, suggesting that the beam is ductile and can sustain higher load carrying capacity. Furthermore, it is worth to mention that kenaf fibres have the capability to increase the bendability of the concrete structures if it was not fully dried and hardened.

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Table-3. Result for kenaf fibre and steel fibre reinforced concrete beams with full shear reinforcement (S=100mm).

V_f (%)	0	1	2
P_y(kN)	**68.49**	**71.98**	**58.96**
δ_y (mm)	5.35	5.22	5.66
P_{max} (kN)	72.28	73.59	69.35
δ_{max} (mm)	6.99	7.64	10.06
P_u (kN)	70.83	70.66	67.48
δ_u(mm)	7.99	8.92	10.98
$\mu = \delta_u / \delta_y$	1.49	1.71	1.94

Table-4. Result for kenaf fibre and steel fibre reinforced concrete beams with reduced in shear reinforcement (S=200mm).

V_f (%)	0	1	2
P_y(kN)	**50.99**	**58.70**	**56.43**
δ_y (mm)	3.70	4.82	5.41
P_{max} (kN)	53.35	68.76	66.54
δ_{max} (mm)	5.00	6.88	8.52
P_u (kN)	53.35	67.91	60.48
δ_u(mm)	5.00	7.94	9.74
$\mu = \delta_u / \delta_y$	1.35	1.65	1.80

Tables 3 and 4 lists the key parameters of strength and ductility summarised from the load deflection curves. The key parameters include P_y which is the loading at yield and its respective deflection (δ_y), P_{max} representing maximum load carrying capacity and its respective deflection (δ_{max}), and ultimate load at failure and its respective deflection (δ_u). Ductility ratio (μ) is calculated by dividing the ultimate deflection to the deflection and yield. From the tables, it could be seen that the maximum load carrying capacity (P_{max}) and yield load (P_y) of the KFSF-RC beams with reduced in shear reinforcement (S=200mm) are higher than that without fibre. Evidently, the fibres are acting to hold the matrix together. Accordingly, higher loading is required to initiate the crack propagation. Furthermore, fibres also serve as part of shear reinforcement to improve the shear capacity of the beam. In term of ductility, it was observed that the ductility ratio (μ) of KFSF-RC beams continue to increase with the increase in the fibre content. The highest ductility is observed from KFSF-RC beams with V_f= 2%. Therefore, it could be concluded that the addition of fibres managed to introduce a ductile characteristic into the concrete material.

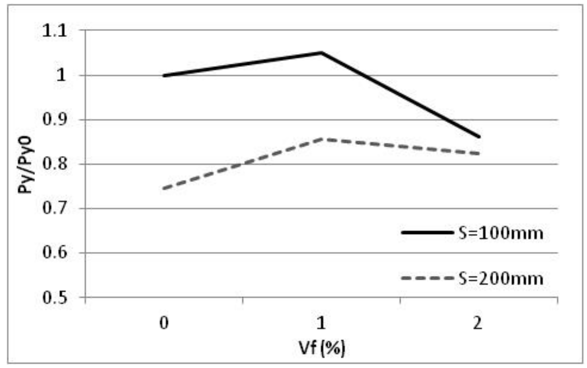

Figure-7. Graph P_y/P_{yo} versus V_f.

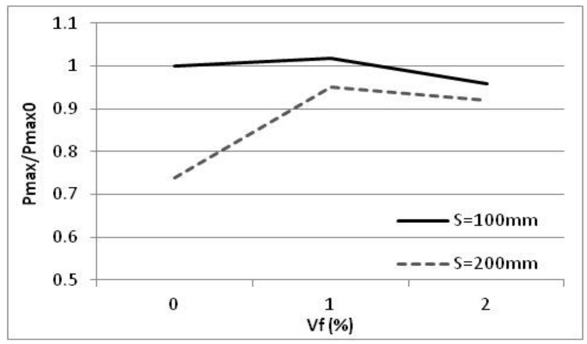

Figure-8. Graph P_{max}/P_{maxo} versus V_f.

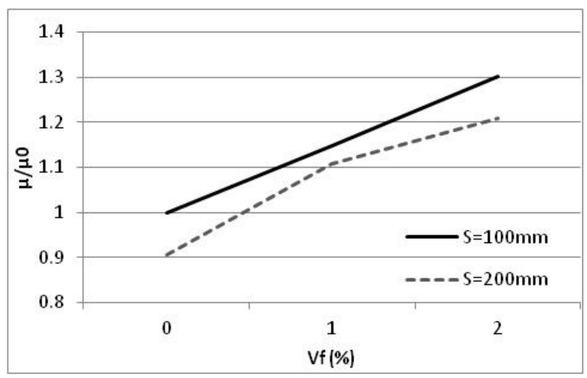

Figure-9. Graph P_{max}/P_{maxo} versus V_f.

Figure-7 to Figure-9 illustrates the strength and ductility of the KFSF-RC beams normalised to control beam (S=100mm and Vf= 0%) against fibre content. In Figure-7 and Figure-8, the yield load (P_y) and maximum load carrying capacity were normalised to its respective loads (P_{max}) and the pattern show that KFSF-RC beam with Vf= 1% upward trend before drop at KFSF-RC beam with Vf= 2%. Based on the figures, if the testing of the beams were carried out at a later date, a positive upward trend may be obtained. This behaviour is substantiated with numerical modelling results carried out by Huzazi (2015). It was reported that the strength of the KFSF-RC beams increases consistently with the increase of the fibre content. Therefore, it can be hypothesised that a consistent increase in strength may be attained if the KFSF-RC beam was experimentally tested once the beam is fully hardened and achieved its full strength capacity. On the other hand, the ductility performance of the KFSF-RC beams is promising as an upward trend is observed (refer Figure-9). It should also be noted that 1% of fibres was able to restore the ductility of the KFSF-RC beams with reduced in shear reinforcement (S=200mm) as compared to the control beam.

Figure-10. Beam 1 (spacing = 100mm with V_f= 0%).

Figure-11. Beam 2 (spacing = 100mm with V_f= 1%).

Figure-12. Beam 3 (spacing = 100mm with V_f= 2%).

Figure-13. Beam 4 (spacing = 200mm with V_f= 0%)

Figure-14. Beam 5 (spacing = 100mm with V_f= 1%).

Figure-15. Beam 6 (spacing = 200mm with V_f= 2%).

Figure-10 to Figure-12 represents the cracking pattern of the KFSF-RC beams with full shear reinforcement (S=100mm) and volume fraction of V_f=0%, V_f=1% and V_f=2%, respectively. Whilst, the cracking pattern of the KFSF-RC beams with reduced shear reinforcement (S=200mm) and volume fraction of V_f=0%, V_f=2% and V_f=2%, are shown in Figure-13 to Figure-15, respectively. From the figures depicted above, it is apparent that most of the beams show cracking propagation along the mid-span and between the loading and support point. During testing, it was observed that Beam 1 and Beam 3 failed in bending-shear, whilst, Beam 2 failed in bending mode. As for the beams with reduced in shear reinforcement, Beam 4, with no fibres added was observed to fail in shear. Moreover, as the fibres were added to the beams, the failure mode of the beams change to bending-shear (Beam 5) and bending (Beam 6).

CONCLUSIONS

Based on the results presented and discussed, it is evident that the combinations of kenaf fibres and steel fibres have the potential to serve as part of shear reinforcement in reinforced concrete beams. The increase in strength of the reinforced concrete beams was not consistent during the testing as the beams with fibres were not fully dried and hardened. Therefore, the full capability and capacity of the fibre reinforced concrete in increasing the strength consistently with the increase in the fibre content was not observable. However, for the case of three beams with reduce in shear reinforcement, it can be clearly seen that the fibres improved the load carrying capacity of the beam up to 29% and 25% for KFSF-RC beams with V_f = 1% and V_f = 2%, respectively. Therefore, it can be concluded that hybrid fibres does demonstrate its potential as part of shear reinforcement in the beams.

Furthermore, satisfactory results were obtained for the ductility of the KFSF-RC beams, especially the ones with reduced in shear reinforcement. It was observed that the addition of 2% of fibres improved the ductility up to 30%. Moreover, the ability of the fibres in controlling the crack propagation of the beams was demonstrated by the change of the failure mode from brittle to a ductile manner.

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