Structural Behavior of Kenaf Fibre Reinforced Concrete Beams

Comportamiento estructural de vigas de hormigón armado con fibra Kenaf

EÍDOS Nº23
Revista Científica de Arquitectura y Urbanismo
ISSN: 1390-5007
revistas.ute.edu.ec/index.php/eidos

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Abstract:

This paper presents the effect of kenaf fibres in reinforced concrete beams. In investigating the structural behaviour of the beams, four point bending test was conducted on five beams by considering two distinct parameters (i) shear reinforcement arrangement (ii) the amount of kenaf fibres in the aforementioned beams. The beams consists of Two beams with full shear reinforcement by two amount of kenaf fibres, 10kg/m³ and 20kg/m³, respectively and two other beams with 50% increased shear spacing with two different amount of kenaf fibre 10 kg/m³ and 20 kg/m³ were examined. A control beam is made of 0 kg/m³ kenaf fibre with full shear reinforcement. The experimental results suggests that beams with the inclusion of kenaf fibres demonstrates significant increase on the load carrying capacity, ductility and shear strength. Moreover, it was observed that the mode of failure is altered from shear mode to bending mode. Furthermore, this study opines that kenaf fibres are compatible with RC which yields promising results.

Keywords: kenaf fiber, ductility, load carrying capacity, mode of failure.

Resumen:

Este artículo presenta el efecto de las fibras de kenaf en vigas de hormigón armado. Al investigar el comportamiento estructural de las vigas, se realizó una prueba de flexión de cuatro puntos en cinco vigas considerando dos parámetros distintos (i) la disposición del refuerzo de corte (ii) la cantidad de fibras de kenaf en las vigas antes mencionadas. Las vigas constan de dos vigas con refuerzo de corte total mediante dos cantidades de fibras de kenaf, 10 kg/m³ y 20 kg/m³, respectivamente, y otras dos vigas con un 50 % de mayor espaciado de corte con dos cantidades diferentes de fibras de kenaf de 10 kg/m³ y 20 kg. /m³ fueron examinados. Una viga de control está hecha de fibra de kenaf de 0 kg/m³ con refuerzo de corte total. Los resultados experimentales sugieren que las vigas con la inclusión de fibras de kenaf demuestran un aumento significativo en la capacidad de carga, ductilidad y resistencia al corte. Además, se observó que el modo de falla cambia del modo de corte al modo de flexión. Además, este estudio opina que las fibras de kenaf son compatibles con RC, lo que arroja resultados prometedores.

Palabras clave: fibra de kenaf, ductilidad, capacidad de carga, modo de falla.

Recepción: 19, 11, 2023 - Aceptación: 12, 12, 2023 - Publicado: 01, 01, 2024

1. INTRODUCTION

Kenaf is scientifically known as Hibiscus cannabin's L. and it falls under the Malvaceae family. It is cultivated in India, Bangladesh, United States of America, Indonesia, Malaysia, South Africa, Thailand, parts of Africa, and in specific parts of southeast Europe for its fibre [1]. The cracking phenomenon on concrete structures, are often caused by low tensile strength, drying shrinkage and plastic shrinkage. The inclusion of fibre increases the strength load carrying capacity, ductility, stiffness of structure as well as reduces the drying shrinkage and plastic shrinkage. The inclusion of fibres also acts as a crack arrestor and improves the dynamic and static behaviour of concrete structure [5]. Although steel fibre mitigates the problem of low tensile strength of concrete and micro cracks, nonetheless it does not completely solve the problem as over a long period of time, steels are susceptible to corrosion and this will cause sudden catastrophic failure in concrete structures.

This alone motivates the need of the use of different type of fibres such as, natural fibres which is more copious, economical and environmental friendly as compared to synthetic fibres [2, 4]. The inclusion of natural fibres in reinforced concrete structures in enhancing the structural properties are well recognised due to their low density and high specific strength which are desirable in concrete structures [1-4]. The tensile strength of kenaf fibre is between 400-550 MP which is higher than some natural fibre namely sisal and jute [4]. Owing to the desirable characteristics of kenaf fibres, it befits as a potential candidate to be used as fibres in concrete structures [6]. A similar study was conducted for lightweight concrete using oil palm shell (OPS) [7]. The present study intends to investigate the influence of kenaf fibres when added to reinforced concrete beams as well as its effectiveness of as a part of shear reinforcement through the increase of shear links.

2. METHODOLOGY

2.1. Preparation of reinforced concrete beams for testing

Table 1 lists three sets of concrete mixture proportions for five beams. Kenaf fibres included in the mixtures are 30 mm of length with a diameter between 0.1 mm to 2 mm as shown in Fig. 1. Super-plasticizer was added to achieve the required slump. The concrete mixture used in the fabrication of all specimens has a slump in the range of 95 mm to 105 mm as shown in Fig. 2.

The loading arrangement and reinforcement properties of the beam are shown in Fig. 3 and Fig. 4. The beams were initially designed by Euro code 2 with shear reinforcement less than that is required to cause shear failure. Two arrangements were considered (i) full shear reinforcement and (ii) reduced in shear reinforcement (this was carried out by increasing the spacing between the shear links by 50 %). Subsequently, two amounts of fibres contents were added into the reinforced concrete mixture to examine the effect of kenaf fibres in reinforced concrete beams. Therefore, five beams (three for full shear reinforcement and two for reduced in shear reinforcement) were tested under four point bending test. The beam

Figure 1. Kenaf fiber (cut 30 mm length)

Figure 2. Slump test

ISSN:1390-5007

with full shear reinforcement without 0 kg/m³ fibers was considered as the control beam. The test was carried out on the 56th day in order to ensure that the reinforced concrete beams added with kenaf were fully hardened.

Table1. Mixture of concrete

Ingredients	Kg/m³	Kg/m³	Kg/m³
Concrete	Mix 1	Mix 2	Mix 3
Kenaf fiber	0	10	20
Coarse aggregate	308	308	308
Super plasticizer (Liter/m³)	5	5	5
Water (Liter/m³)	204	204	204
Fine aggregate (sand)	848	848	848
W/C ratio	0.4	0.4	0.4
Cement	510	510	510

2.2. Testing.

Static loading test was conducted using a hydraulic machine under two point loading. The three linear variable differential transducers (LVDT) in the actuator was used to determine the mid-span displacement whilst the load cell indicated the applied and the load test set-up for beams as shown in Fig. 3. The cracking of the beams was marked by numbering all the cracks and their location.

3. RESULTS AND DISCUSSION

Fig. 6 and Fig. 7 illustrate the load deflection curves of the five beams. Fig. 6 depicts the load deflection curve for full shear reinforcement with 0 kg/m³, 10 kg/m³ and 20 kg/m³ amount of kenaf fiber. It could be observed from the load- deflec-

Figure 3 Test set-up

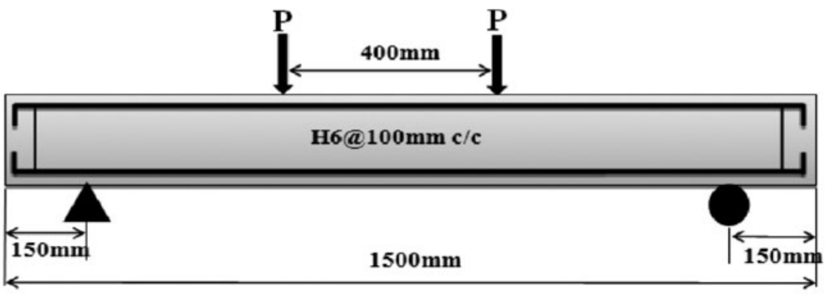

Figure 4. Loading arrangement and dimensions of the beam

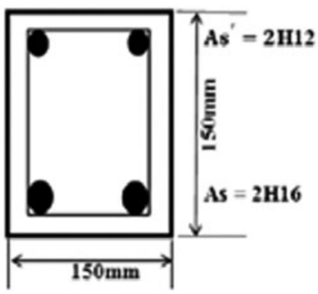

Figure 5. Main reinforcement arrangement & dimensions of the beam

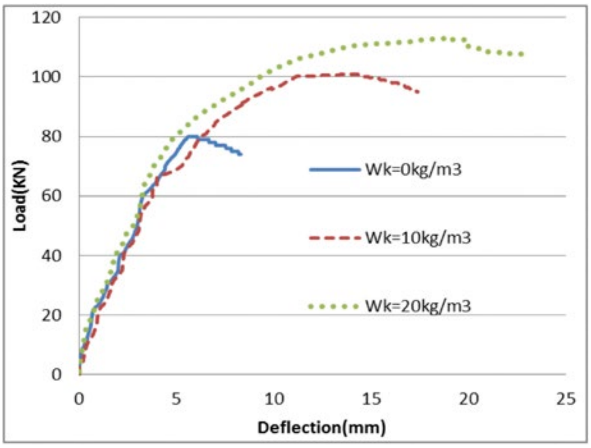

Figure 6. Load-deflection curves for RC beams with full shear reinforcement.

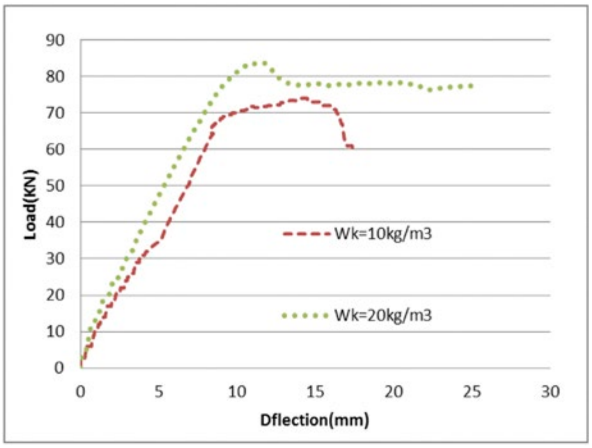

Figure 7. Load-deflection curves for RC beams with reduced in shear reinforcement.

tion curves, that the beam without fibers failed at a deflection of 8mm and at a load carrying capacity of 80 kN. On the other hand, beam with 10 kg/m³ and 20 kg/m³ failed at a deflection of 18 mm with a load carrying capacity of 100 kN, whilst for the deflection of 20 mm, the load carrying capacity is 107 kN. The load deflection curve demonstrates significant increase at load carrying capacity of beam. Moreover, the beams with reduced shear arrangement and with 20 kg/m³ failed at a deflection of 18 mm and load carrying capacity of 88 kN which suggests a good improvement in the load carrying capacity by adequate amount of kenaf fiber.

The results from the load deflection curves of Fig. 6 and Fig. 7 are summarized in Table 2 and Table 3, respectively. Where P_{max} characterizes the maximum strength, $P_{max,0}$ characterizes the maximum strength of the control beam, P_u the ultimate strength, δ_y the yield deflection, δ_u the ultimate deflection, μ the ductility and W_K, the amount of kenaf fiber. Table 2 suggests that the peak strength of the beam is increased to up to 25% for Wk = 10 kg/m³ and 34% for Wk = 20 kg/m³ respectively. The Table 3 shows that the peak strength of the beam is reduced in shear reinforcement with 10 kg/m³ shows a 1% increase in P_{max} as compared to the control beam whist for the 20 kg/m³ kenaf fiber, 9%. However, with reduced shear links demonstrates the potential for kenaf fibers to enhance peak strength to up to 9%.

TABLE 2. Results for beams with full shear reinforcement

(* this ratio represents the change in maximum strength, † this ratio represents the change in residual strength, ‡ this ratio represents the change in ductility)

W_K(kg/m³)	0	10	20
P_{Max}(KN)	80	100	107
$P_{Max}/P_{Max,0}$*	1	1.25	1.34
P_u(KN)	74	102	116
P_u/PMax†	0.9	1.275	1.45
δ_y(mm)	6	12	12
δ_u(mm)	8	18	20
$\mu=\delta_u/\delta_y$ ‡	1.3	1.5	1.67

TABLE 3. Results for reduced shear reinforcement beams

(* this ratio represents the change in maximum strength, † this ratio represents the change in residual strength, ‡ this ratio represents the change in ductility)

W_K(kg/m³)	10	20
P_{Max}(KN)	70	88
$P_{Max}/P_{Max,0}$*	1.01	1.09
P_u(KN)	76	78.8
P_u/PMax†	1.085	0.98
δ_y(mm)	10	12
δ_u(mm)	18	24
$\mu=\delta_u/\delta_y$ ‡	1.8	2

ISSN:1390-5007

The result obtained opines that the fiber acts appropriately in controlling the crack propagation of the beams. Presence of the fibres bridge the crack opening, thus higher load is required to produce similar deflection with the control beam. As the load increases, more cracks formed in the KFRC beam. Eventually, the fiber starts to pull out from the matrix which consequently drops the load carrying capacity. Failure of the control beam (beam with 0 kg/m^3 and full shear reinforcement) occurred due to the formation of a single crack led to shear failure of the beam as shown in Fig. 8. Therefore, fibres serve potential as part of shear reinforcement, which in turn changes the mode of failure from brittle (beam without fibres) to a more ductile manner (beam with fibres). All KFRC beam have flexural cracks distributed over the entire section of maximum and constant bending moment as shown in Fig. 9, Fig. 10, Fig. 11 and Fig. 12. The two beams with normal spacing and with 10 kg/m^3 and 20 kg/m^3 kenaf fiber show high multiple cracking behaviours than other two beams with increased spacing. Cracks widths were measured at every load interval and the crack formations were marked on the beams. It was observed that the first crack constantly appears close to the midspan of the beam. The cracks forming on the surface of the beams were mostly vertical, suggesting failure in flexure with KFRC beams. By enhancing the fiber amount the number of crack increased, and show multiple cracking failure. It was also observed that for KFRC beams, the crack widths at service load were below the maxi- mum allowable value as conformed by Erocode2 for durability requirements.

In this study, the ductility (μ) was investigated and presented in Table 2 and Table 3. The ductility ratio is taken in terms of $\mu=\delta_u/\delta_y$, which is the ratio of ultimate to first yield deflection, where δ_u is the deflection at ultimate load and δ_y is the deflection when steel yields. In general, high ductility ratios indicate that a structural member is capable of undergoing large deflections prior to failure. In this investigation adequate ductility is observed for both beams shear arrangement. The Fig. 6 and Table 2 show ductility increased up to 50% for Wk = 10 kg/m^3 and 67% for Wk= 20 kg/m^3 with full shear reinforcement. Furthermore, significant increase in the ductility with reduced shear reinforcement 80% for Wk = 10 kg/m^3 and 100% for Wk = 20 kg/m^3 as shown in Fig. 7, and Table 3. This demonstrates that with the addition of the fibers facilitates ductile mode of failure.

Figure 8. RC beam with full shear reinforcement without fibres

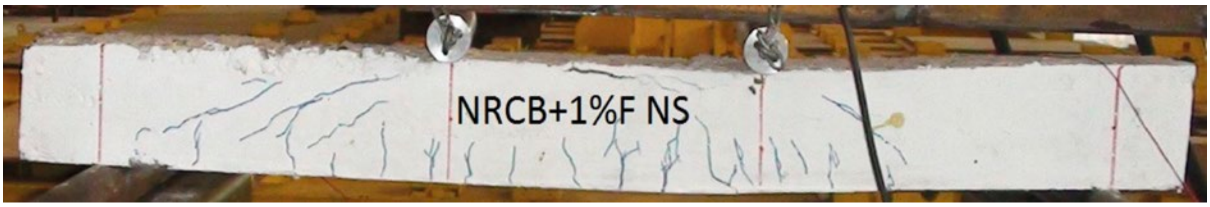

Figure 9. RC beam with full shear reinforcement,10kg/m^3 kenaf fiber

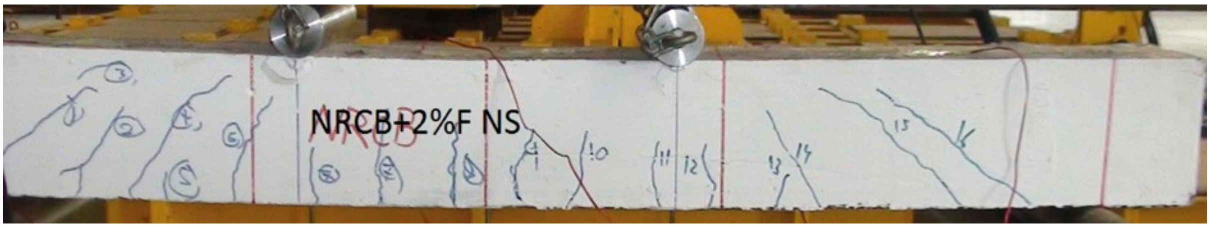

Figure 10. RC beam full shear reinforcement with 20kg/m³

Figure 11. RC beam reduced shear reinforcement with 10kg/m³

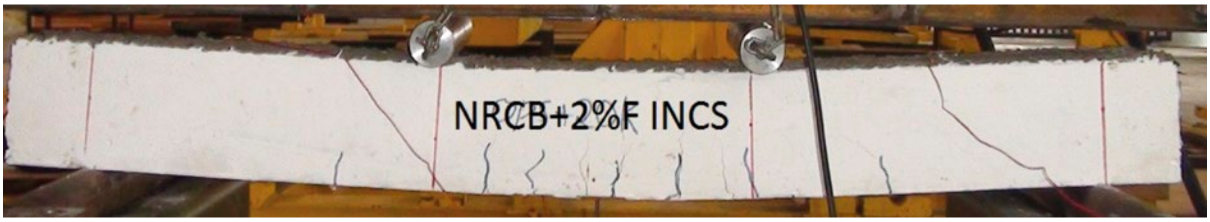

Figure 12. RC beam reduced shear reinforcement with 20kg/m³

4. CONCLUSION

Based on the finding of this study, it can be concluded that the addition of kenaf fiber consistently enhances the load carrying capacity, ductility, and changes the mode of failure of RC beams from brittle to ductile manner. This shows that there are clear benefits of adding kenaf fibres at both serviceability and ultimate limit state which are important for design consideration. The study indicates that in order to maintain the workability of the KFRC requires the use of a cement rich mixture. Furthermore, superplasticizer should be added to account for water absorbed by the fibres and to maintain the workability of the fresh KFRC. Kenaf fiber exhibits the ability to control crack opening and reduce the crack width considerably as compared to RC beam without fibres. As sufficient amount of fiber was added the load carrying capacity, ductility were increased at certain point. The difference in capacity of the beams with 20 kg/m³ amount of kenaf fiber was significantly larger than the difference of the beams with low kenaf fiber 10 kg/m³).

- Kenaf fibre showed favourable contribution in improving the strength (P_y and P_{max}) and ductility as well as changing the mode of failure of NRC beams. The addition of fiber at Vf = 2 % into the beam with SI = 0 % demonstrates the increase in strength of P_y and P_{max} up to 31 % and 37 %, respectively.

- It is also observed that the ductility ratio is increased; nonetheless only a certain limit of fibre inclusion should be observed as the inclusion beyond this limit exhibits poor ductility.

- Mode of failure of beams with an adequate amount of fiber changed from shear to bending as illustrated by the beam with SI = 100 % added fiber at Vf = 2 %.

- Cracking pattern indicated that with a sufficient quantity of fiber the mode of failure of beams changes from shear to bending as illustrated by adding a minimum fibre of Vf = 1 % Vf = 1.5 % and Vf = 2 % into the beams with SI = 0 %, SI = 50 % and SI = 100 % respectively

ACKNOWLEDGMENT

This study is partly funded by the Ministry of Higher Education, Afghanistan and University Malaysia Pahang, Malaysia, under internal research grant number RDU 1203108.

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