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A Review Paper on Load-Deflection Behaviour of Kenaf Fibre Reinforced Concrete Beam and Slab

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Abstract

Concrete is primarily made up of cement, sand, coarse aggregate and water. Kenaf fibre is a natural fibre used in strengthening reinforced concrete beam and slab to enhance structural strength and ductility. This paper presents the experimental study results of load-deflection behaviour of kenaf fibre reinforced concrete beam and slab. This article addresses the experimental parameters includes load-deflection of beam and slab reinforced with kenaf fibre. Load-deflection data results are compared with each other. It is observed that kenaf fibre improves the load-deflection of reinforced concrete beam and slab. This study indicates that kenaf fibre will benefit by using it as additional material in reinforced concrete beam and slab productions.

Keywords: *Load-Deflection, Kenaf Fibre, Reinforced Concrete Beam, Reinforced Concrete Slab*

1. Introduction

Reinforced concrete is a common building material due to its toughness, durability and economy. Despite this, studies are continued to improve the characteristic of concrete known to be weak in tension. Fibre is applied in fresh concrete to enhance shear strength, flexural strength, ductility, energy absorption, slow cracking propagation, and concrete failure mode [1-5]. Kenaf fibre is used in many types of buildings and infrastructures, including seismic structure, precast good, tunnel lining, concrete and pavement slab [6-7]. Kenaf fibre is seen as a potential green material because it is a natural resource used in building. Due to its beneficial properties, there is increased flexural strength, shear strength, and reinforced concrete ductility with fibre inclusion [8-12]. However, to ensure the best efficiency, kenaf fibre must undergo a treatment to reduce the fibre high water absorption characteristic. One of the remedies suggested is to use a chemical such as sodium hydroxide (NaOH) to soften the fibres, thereby improving their adhesion between the fibres surface and the matrix. It is achieved by removing the hydroxyl group in cellulose, which increases the surface roughness resulted in the tensile property improvement of kenaf fibre compared to untreated kenaf fibre [13-15]. Many previous types of research have concentrated on how kenaf fibre influenced the behaviour of reinforced concrete RCB and slab. The natural fibre is also being used since 3000 years ago in Egypt. It is useful in constructing composite structures like brick or plaster wall. Natural fibres have been widely used for industrial applications such as sports equipment, vehicle part and building material for structural and non-structural elements [16-19]. It is also used in a textile application by early humans.

A local natural fibre is known as kenaf fibre is widely used to produce bio-composite material. Kenaf fibre contains specific characteristics such as stiffness, impact resistance, flexibility and module. It is cheap, readily available, and renewable [20-24]. Many research findings before this showed that natural fibre reinforcement gave higher toughness for concrete and mortar products and also improved impact and deformation capacities [25-33]. Next, kenaf fibre is a low cost, low density, less skin and respiratory irritation, less equipment abrasion, improves energy absorption, and vibration damping [34-39] which has led to its use as an effective substitute for conventional materials like rope, mat and straw. Besides that, kenaf fibre is also considered as a hydrophilic material [40-42]. Hydrophilic material is able to absorb water or moisture. The fibre matrix interacts well with water due to such property, resulting in enhancing cellulosic based adhesion. In fact, the age and species of a particular plant will affect the quantity of cellulose. Cellulose is a semi-crystalline polysaccharide with alcoholic hydroxyl groups, which encompasses a linear chain of anhydroglucose units. Summarily, kenaf fibre is a fibre extracted from a plant. As a result of excessive usage, environmental pollution adversely impacts global climate change and cannot be disregarded. The number of people interested in fibre reinforced concrete RCB and slab has been increasing in recent years. The natural fibre is able to replace synthetic fibre in a composite [43]. The general view is that many steps should be taken to conserve and preserve the earth sustainability. Since concrete is considered a brittle material, its enrichment with dispersed short fibres is believed to increase matrice durability and transfer the load between the concrete components from kenaf fibre. This goal is accomplished by avoiding cracking in concrete. In addition, the inclusion of kenaf fibre in reinforced concrete RCB and slab improves their tensile property and resistance to dynamic and earthquake loading. The composite material has recently been adopted locally due to its ability to maintain structural loading close to synthetic and steel fibres. The analysis of possibility reinforcing property of kenaf fibre needs to be studied more. Adding kenaf fibre gives a beneficial result for reinforced concrete RCB and slab. Therefore, the load-deflection behaviour of kenaf fibre reinforced concrete RCB and slab is reviewed in this paper based on numerous research papers before this.

2. Load-Deflection

This section presents the load-deflection results of reinforced concrete beam (RCB) and reinforced concrete slab (RCB) containing kenaf fibre.

2.1 Reinforced Concrete Beam (RCB)

[44] (Sayed et al., 2014) investigated the load-deflection curve for full shear reinforcement with 0 kg/m^3, 10 kg/m^3 and 20 kg/m^3 amount of kenaf fibre. The load-deflection curves could be observed, that the RCB without fibre failed at a deflection of 8 mm and at a load carrying capacity of 80 kN [44]. On the other hand, RCB with 10 kg/m^3 and 20 kg/m^3 failed at a deflection of 18 mm with a load carrying capacity of 100 kN, while for the deflection of 20 mm, the load carrying capacity was 107 kN [44]. The load-deflection curve demonstrated a significant increase in the load carrying capacity of the RCB. Moreover, the RCB with reducing shear arrangement and 20 kg/m^3 failed at a deflection of 18 mm and load-carrying capacity of 88 kN, suggesting a better improvement for the load-carrying capacity sufficient amounts of kenaf fibre [44]. Pmax characterizes the maximum strength, $Pmax,_0$ characterizes the maximum strength of the control RCB, Pu is ultimate strength, δy is yield deflection, δu is ultimate deflection, μ is ductility and Wk is the amount of kenaf fibre. The RCB peak strength increased up to 25% for Wk=10 kg/m^3 and 34% for Wk=20 kg/m^3 respectively [44]. The RCB peak strength was reduced in shear reinforcement with 10 kg/m^3 showed a 1% increase in Pmax compared to the control RCB which was Wk=20 kg/m^3 with 9% kenaf fibre [44]. However, reduced shear links demonstrated the potential of kenaf fibre to enhance peak strength up to 9% [44].

[45] (Syed Mohsin et al., 2014) studied the load-deflection curves for oil palm shell kenaf fibre reinforced concrete RCB (OPSKFRCB) with full shear reinforcement. The load-deflection curves could be observed, that the RCB without fibre failed early at a deflection of 12 mm and load carrying capacity of 69.8 kN [45]. However, the RCB with fibre inclusion show an increase in the peak strength and ductility as the fibre content increased. The key results have been summarized, where Pmax=maximum strength, Pmax,o=maximum strength of control RCB, Pu=ultimate strength, δy=yield deflection, δu=ultimate deflection and μ=ductility. The RCB peak strength increased up to 22% with Wk=20 kg/m3 [45]. A notable increase in the stiffness could also be seen for RCB with a higher content of fibres. This suggests that there are clear benefits of adding fibres at the serviceability limit state. Furthermore, a significant increase in ductility, up to 67% could be observed [45]. This increase demonstrates that the inclusion of fibre facilitated a ductile mode of failure [45]. A further investigation was carried out by reducing the shear reinforcement (this was carried out by increasing the spacing between shear links by 50%), adding two amounts of kenaf fibres and tested under a four-point bending test. In this shear links arrangement, only RCB with fibre inclusion was tested as the RCB without fibre is believed to fail in a more brittle manner than the control RCB. The results showed that the peak strength of the RCB with reduced in shear reinforcement increased up to 10% compared to the control RCB with full shear reinforcement [45]. Sufficient ductilities were observed for both RCB with 10% for Wk=10 kg/m^3 and 46% for Wk=20 kg/m^3 [45]. In comparison to the control RCB, the ultimate deflection obtained for RCB with Wk=10 kg/m^3 was similar at 12 mm [45]. This reflected the extremely brittle nature of the RCB with reducing shear link and demonstrated the potential of kenaf fibre to enhance both peak strength and ductility.

[46] (Syed Mohsin et al., 2016) observed the load-deflection curves for kenaf fibre and steel fibre reinforced concrete beam (KFASFRCB) with full shear reinforcement (S=100mm). It was evident that the addition of fibres had a moderate effect on the structural performance of the KFASFRCB. The strength of KFASFRCB with fibre addition, Vf = 1% is slightly higher in comparison to the control RCB, whereas the KFASFRCB with Vf = 2% exhibited the lowest load carrying capacity for this shear reinforcement arrangement [46]. The low strength performance was due to a high amount of kenaf fibre in the RCB, which absorbs water and delayed the internal hardening of the concrete. Consequently, the RCB strength with the highest amount of fibre was lower than 1% of fibre content. A similar pattern was observed in the RCB with reducing shear

reinforcement (S=200mm). It is apparent that RCB with reducing shear reinforcement produces better strength than RCB without fibre [46]. As mentioned above, the results suggested that kenaf and steel fibres demonstrated their prospective characteristic as part of shear reinforcement in the KFASFRCB. It could be seen that the maximum load carrying capacity (Pmax) and yield load (Py) of the KFASFRCB with reducing shear reinforcement (S=200 mm) were higher than without fibre content [46]. Evidently, the fibres were acting to hold the matrix together. Accordingly, a higher load was required to initiate the crack propagation. Besides that, fibres also serve as part of shear reinforcement to improve the shear capacity of the RCB. In term of ductility, it was observed that the ductility ratio (μ) of KFASFRCB continued to increase with increasing fibre content. The highest ductility was observed from the KFASFRCB with Vf=2% [46]. In conclusion, the addition of fibre managed to introduce a ductile characteristic for the concrete material.

[47] All strengthened RCB improved maximum flexural strength and reduced maximum deflection of approximately 40% and 24%, respectively compared to control RCB as studied by (Hafizah et al., 2014). Concurrently, this had proven that with up to 50% of fibre content, the performance of all composite materials resembled each other to a certain extent. Their ultimate flexural strength and deflection improve to 40% and 24%, respectively. The RCB strengthened by kenaf fibre reinforced polymer composites with 50% fibre volume fraction exhibit similar stiffness under flexural action [47]. This performance corresponded to resin type behaviour used in composite materials. The control RCB exhibited ductile behaviour after achieving maximum load, whereas other RCB demonstrated brittle behaviour and failed abruptly at the maximum load. It could also be inferred that all strengthened RCB, in general, had been over reinforced. Nonetheless, all the strengthened RCB increased the structural stiffness as compared to the control RCB. Thus, kenaf fibre reinforced polymer composite laminate had the potential to be used as a strengthening material where it could increase the bearing capacity and stiffness of RCB [47].

[48] (Hafizah and Jamaludin et al., 2011) compared the load-deflection behaviour between control RCB and RCB with kenaf fibre reinforced polymer composite (KFRPC) plate. The load-deflection curve clearly showed that RCB with KFRPC plate has a steeper slope than control RCB [48]. This meant that RCB with KFRPC plate was stiffer compared to control RCB. In term of deflection at the ultimate load, RCB with a KFRPC plate gave the lowest deflection compared to control RCB [48]. RCB with KFRPC plate has lower deflection at mid-span, which was 15.16 mm while for the control RCB, the deflection was 18.75 mm [48]. The deflection ratio of RCB with KFRPC plate based on control RCB is 0.81 and this lowest value was due to the high stiffness of the RCB with KRPC plate to resist high load when deflects slightly [48]. Flexural failure was observed when the test was done onto the control RCB. Vertical cracks first began to occur when 8 kN of the load was acted onto the RCB. The length of the cracks increases as the load increased. Moreover, the width of the cracks had also become more widespread as the load increased. For the RCB with KFRPC plate, the same pattern of crack happened such as the control RCB. The first vertical crack appeared at 24.1 kN load. Besides that, the width of cracks also became more widespread as the load increased. When the ultimate load was achieved at the end of the plate, the rupture happened because the adhesive layer was too thin. This rupture occurred because when G-clamp was used to make a better bonding and rotated energetically. This will result in the adhesive becomes thinner. This rupture failure proved that the composite material was brittle, which could not accommodate a large strain when a huge vertical crack appeared on the RCB surface.

[49] (Ashraful et al., 2015) conducted research on load-deflection behaviour of kenaf fibre reinforced polymer (KFRP) laminate RCB, carbon fibre reinforced polymer (CFRP) laminate RCB and control RCB. The load-deflection behaviour of these three types of RCB was compared with each other. Once the shear reinforcement had shown large strain, the maximum deflection concentration could be shifted at the shear span rather than the mid-span of the RCB. Both KFRP and CFRP laminate strengthened RCB had almost the same trend of deflections in the elastic region. The KFRP and CFRP laminate strengthened the RCB fail after yielding flexural reinforcements whereas the control RCB failed prior to yielding flexural reinforcement. Since KFRP and CFRP laminate strengthened RCB fail after yielding flexural reinforcement, it showed higher mid-span deflection during the failure than the control RCB [49]. However, before yielding flexural reinforcement, the deflection of both strengthened RCB was almost similar to the control RCB. In general, the shear strip did not have significant effects on mid-span elastic deflection. The yield loads of flexural reinforcements of KFRP and CFRP laminates strengthened RCB were found to be 163 kN and 157 kN, respectively, 10 % and 15 % lower than their failure loads [49]. Strengthened RCB with KFRP laminate has shown 33 % higher and 2 % lower failure loads as compared to the control RCB and CFRP laminate strengthened RCB respectively. It was concluded that the KFRP laminate could enhance the maximum shear capacity of RCB through the strengthening process.

[50] (Felix and Adetifa, 2012) researched the characteristics of kenaf fibre reinforced mortar composites of size 650 mm x 450 mm x 8 mm with three different fibre contents such as 0.5%, 1% and 1.5% and four different fibre contents like 20 mm, 30 mm, 40 mm and 50 mm. The average peak pull-out load of ten fibre strands embedded in the mortar matrix to a depth of 15 mm is 15.33 N and the breaking load at 20 mm embedment was 16 N [50]. The bond strength was computed to be 0.25 N/mm^2 [50]. From this result, it was evident that kenaf fibre had a better bonding with cement-based matrices than akwara, also known as a vegetable fibre. [51] According to (Uzomaka, 1976), the critical bond length of akwara was reported to be 100 mm while that of kenaf obtained in this work was 20 mm. Comparing the 0.25 N/mm^2 value obtained in this work with a 0.11 N/mm^2 value reported by (Dave, 1979) [52] as the bond strength for polypropylene fibre-reinforced mortar was strong and kenaf fibre also had a better bonding with mortar matrix than polypropylene fibre. Lastly, the inclusion of up to 1.5 % volume of kenaf fibre into the mortar matrix resulted in improvement of flexural toughness and impact resistance between 1.28 and 3.30 and 1.47 and 1.67 times than the unreinforced sheet, respectively [50].

Much previous research on kenaf fibre RCB before this [53-58] (Mansur and Ong, 1991; El-Niema et al., 1991; Syed Mohsin et al., 2014; Azimi et al., 2014; Syed Mohsin, 2012; Syed Mohsin et al., 2012) showed that the strength and structural behaviour of RCB increased consistently with increasing fibre content. However, in the present study, the rose in strength was not consistent as the test was conducted on 28th day. [56] (Azimi et al., 2014) suggested that RCB added with kenaf fibre should be tested on the 56th day to allow the RCB to be fully dried and hardened. A reasonable good result could be obtained only upon such treatment. Next, during the investigation, most of the fibres were pulled out from the matrix (as they were not fully dry and harden) instead of fibres rupture. This phenomenon also affected the structural strength as higher strength was needed to rupture the fibre during the pull-out phase. Table 1 shows the summary table of authors, years and load-deflection findings for kenaf fibre RCB.

Table 1: Load-Deflection findings for kenaf fibre RCB

Authors & Years	Load-Deflection findings
Sayed et al., 2014 [44]	• The load-deflection curves could be observed, that the RCB without fibre failed at a deflection of 8 mm and at a load carrying capacity of 80 kN . • On the other hand, RCB with 10 kg/m^3 and 20 kg/m^3 failed at a deflection of 18 mm with a load carrying capacity of 100 kN, while for the deflection of 20 mm, the load carrying capacity was 107 kN. • Moreover, the RCB with reducing shear arrangement and 20 kg/m^3 failed at a deflection of 18 mm and load-carrying capacity of 88 kN, suggesting a better improvement for the load-carrying capacity sufficient amounts of kenaf fibre. • The RCB peak strength increased up to 25% for Wk=10 kg/m^3 and 34% for Wk=20 kg/m^3 respectively. • The RCB peak strength was reduced in shear reinforcement with 10 kg/m^3 showed a 1% increase in Pmax compared to the control RCB which was Wk=20 kg/m^3 with 9% kenaf fibre. • However, reduced shear links demonstrated the potential of kenaf fibre to enhance peak strength up to 9%.
Syed Mohsin et al., 2014 [45]	• The load-deflection curves could be observed, that the RCB without fibre failed early at a deflection of 12 mm and load carrying capacity of 69.8 kN. • The RCB peak strength increased up to 22% with Wk=20 kg/m^3. • Furthermore, a significant increase in ductility, up to 67% could be observed. • This increase demonstrates that the inclusion of fibre

	facilitated a ductile mode of failure. • The results showed that the peak strength of the RCB with reduced in shear reinforcement increased up to 10% compared to the control RCB with full shear reinforcement. • Sufficient ductilities were observed for both RCB with 10% for Wk=10 kg/m^3 and 46% for Wk=20 kg/m^3. • In comparison to the control RCB, the ultimate deflection obtained for RCB with Wk=10 kg/m^3 was similar at 12 mm.
Syed Mohsin et al., 2016 [46]	• The strength of kenaf fibre and steel fibre reinforced concrete beam (KFASFRCB) with fibre addition, Vf = 1% is slightly higher in comparison to the control RCB, whereas the KFASFRCB with Vf = 2% exhibited the lowest load carrying capacity for this shear reinforcement arrangement. • It is apparent that RCB with reducing shear reinforcement produces better strength than RCB without fibre. • It could be seen that the maximum load carrying capacity (Pmax) and yield load (Py) of the KFASFRCB with reducing shear reinforcement (S=200 mm) were higher than without fibre content. • The highest ductility was observed from the KFASFRCB with Vf=2%.
Hafizah et al., 2014 [47]	• All strengthened RCB improved maximum flexural strength and reduced maximum deflection of approximately 40% and 24%, respectively compared to control RCB. • Their ultimate flexural strength and deflection improve to 40% and 24%, respectively. • The RCB strengthened by kenaf fibre reinforced polymer composites with 50% fibre volume fraction exhibit similar stiffness under flexural action. • Thus, kenaf fibre reinforced polymer composite laminate had the potential to be used as a strengthening material where it could increase the bearing capacity and stiffness of RCB.
Hafizah and Jamaludin et al., 2011 [48]	• The load-deflection curve clearly showed that RCB with kenaf fibre reinforced polymer composite (KFRPC) plate has a steeper slope than control RCB. • In term of deflection at the ultimate load, RCB with a KFRPC plate gave the lowest deflection compared to control RCB. • RCB with KFRPC plate has lower deflection at mid-span, which was 15.16 mm while for the control RCB, the deflection was 18.75 mm. • The deflection ratio of RCB with KFRPC plate based on control RCB is 0.81 and this lowest value was due to the high stiffness of the RCB with KRPC plate to resist high load when deflects slightly.
Ashraful et al., 2015 [49]	• Since KFRP and carbon fibre reinforced polymer (CFRP) laminate strengthened RCB fail after yielding flexural

	reinforcement, it showed higher mid-span deflection during the failure than the control RCB. • The yield loads of flexural reinforcements of KFRP and CFRP laminates strengthened RCB were found to be 163 kN and 157 kN, respectively, 10 % and 15 % lower than their failure load. • Strengthened RCB with KFRP laminate has shown 33 % higher and 2 % lower failure loads as compared to the control RCB and CFRP laminate strengthened RCB, respectively.
Felix and Adetifa, 2012 [50]	• The average peak pull-out load of ten fibre strands embedded in the mortar matrix to a depth of 15 mm is 15.33 N and the breaking load at 20 mm embedment was 16 N. • The bond strength was computed to be 0.25 N/mm^2. • The critical bond length of akwara was reported to be 100 mm while that of kenaf obtained in this work was 20 mm. [51]. • Comparing the 0.25 N/mm^2 value obtained in this work with a 0.11 N/mm^2 value reported by (Dave, 1979) [52] as the bond strength for polypropylene fibre-reinforced mortar was strong and kenaf fibre also had a better bonding with mortar matrix than polypropylene fibre. • Lastly, the inclusion of up to 1.5 % volume of kenaf fibre into the mortar matrix resulted in improvement of flexural toughness and impact resistance between 1.28 and 3.30 and 1.47 and 1.67 times than the unreinforced sheet, respectively.
Mansur and Ong, 1991; El-Niema et al., 1991; Syed Mohsin et al., 2014; Azimi et al., 2014; Syed Mohsin, 2012; Syed Mohsin et al., 2012 [53-58]	• Much previous research on kenaf fibre RCB before this showed that the strength and structural behaviour of RCB increased consistently with increasing fibre content.

2.2 Reinforced Concrete Slab (RCS)

[59] (Syed Mohsin et al., 2018) demonstrated three types of RCS such as RC1-0, KF1-1, and KF1-2, where the concrete mixtures had 0%, 1,% and 2% kenaf fibre contents, respectively. A sample was taken from RC1-0 for comparison. Py and δy stand for load at yield and its respective deflection, Pu and δu stand for ultimate load at failure and its respective deflection, while Pmax and δmax stand for maximum load carrying capacity and its respective deflection. Ultimate deflection was divided by deflection at yield to obtain ductility ratio (μ). The greatest μ was discovered in KF1-1 due to its greater numbers of fibres. However, the KF1-1 slab has the lowest μ, rendering it stiffer and weaker. After adding kenaf fibre to the RCB, the amount of load carrying capacity needed to bridge the crack increases. The increase was up to 13% and 21% for KF-1 and KF-2, respectively [59]. In the first series of the slab, the addition of 2% of kenaf fibre caused the slab to become stiffer and failed suddenly after resisting a higher load to produce a larger crack opening width [59]. The pattern of failure exhibited that the slab was over reinforced for KF1-2. For KF1-1, the structure had higher ductility and strength. Therefore, it could be justified that the optimum amount of fibre for this series could be taken at 1% as the highest ductility ratio was observed at 3.1 [59].

For this series, RC2-0 was considered the control RCS with 0% fibre content and 20 mm reduction in RCS thickness. KF2-1 and KF2-2 is the kenaf fibre RCS with a 20 mm reduction in slab thickness added 1% and 2% fibre content, respectively. The addition of fibre caused the slab to become stiffer as higher loading is required to induce first cracking and propagated the crack opening [59]. As the amount of fibre increased, the load at yield and maximum load carrying capacity increased to 26% and 9%, respectively [59]. In term of ductility, an upward trend was observed with the incrementation of fibre content. The control RCS failed in shear as designed, and the inclusion of fibre improved the RCS ductility, changing the failure mode to a more ductile manner [59]. Comparing the second series of RCS with the control RCS from the first series depicted that kenaf fibre could not fully compensate the loss in concrete shear capacity due to the thickness reduction. The highest maximum load carrying capacity was 62.53 kN for KF2-2, which about 8% lower than the control RCS, RC1-0 [60]. Interestingly, the ultimate deflection of KF2-2 RCS was 24% higher than the control RCS (RC1-0), showing better ductility in the concrete structure [59].

Table 2: Load-Deflection findings for kenaf fibre RCS

Authors & Years	Load-Deflection findings
Syed Mohsin et al., 2018 [59]	• The increase was up to 13% and 21% for KF-1 and KF-2, respectively. • In the first series of the slab, the addition of 2% of kenaf fibre caused the slab to become stiffer and failed suddenly after resisting a higher load to produce a larger crack opening width. • Therefore, it could be justified that the optimum amount of fibre for this series could be taken at 1% as the highest ductility ratio was observed at 3.1. • The addition of fibre caused the slab to become stiffer as higher loading is required to induce first cracking and propagate the crack opening. • As the amount of fibre increased, the load at yield and maximum load carrying capacity increased to 26% and 9%, respectively. • The highest maximum load carrying capacity was 62.53 kN for KF2-2, which about 8% lower than the control RCS, RC1-0. • Interestingly, the ultimate deflection of KF2-2 RCS was 24% higher than the control RCS (RC1-0), showing better ductility in the concrete structure.

3. Conclusion

Based on this load-deflection behaviour of RCB and RCS study findings, it can be concluded that the addition of kenaf fibre consistently enhances the load carrying capacity, ductility, and changes the mode of failure of RCB from brittle to ductile manner. These results show that there are clear benefits of adding kenaf fibre at both serviceability and ultimate limit state, which are important for design consideration. Kenaf fibre exhibits the ability to control the crack opening and reduce the crack width considerably as compared to RCB without fibre. As a sufficient amount of fibre is added to the load carrying capacity, the ductility increases at a certain point. Next, this result shows that kenaf fibre also has the potential to compensate for the reduction in shear links. Hybrid fibre demonstrates its potential as part of shear reinforcement in the RCB. The structural stiffness of all RCB strengthened by kenaf fibre reinforced polymer composites increase compared to control RCB. As a result, kenaf fibre reinforced polymer composites can be used as strengthening materials for RCB. The RCB that fitted with KFRPC plate increases the flexural strength than the control RCB. In term of cracking behaviour, all the RCB display a flexural mode of failure as expected. From the conclusion above, an overall conclusion can be drawn that KFRPC plate can be employed as strengthening material to strengthen the RCB. The KFRP laminate had excellent bonding behaviour with strengthening adhesive. The KFRP laminate increases 100 % of the shear crack load of the strengthened RCB compared to the un-strengthened control RCB, which found to be similar to the CFRP laminate RCB. In addition, kenaf fibre enhances the flexural toughness and the impact resistance of mortar sheet. The finding also shows that kenaf fibre has the capability to enhance RCS flexural strength, reduce cracking propagation, and improve RCS ductility. However, the concrete shear capacity loss due to the RCS thickness reduction is not compensated by kenaf fibre addition. This loss is probably due to insufficient treatment of the kenaf fibre. Further investigation can be carried out by adding kenaf fibre into the concrete mixture to improve kenaf fibre properties to perform better.

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