Structural Behaviour of Kenaf Fibre Lightweight Concrete Beams Modelling Via FEM-Abaqus

Comportamiento estructural de vigas de hormigón ligero de fibra Kenaf Modulación mediante FEM-Abaqus

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Abstract:

This study presents the structural properties of oil palm shell kenaf fibre Lightweight concrete (OPS-KFLC) beams. The main objective of this research was to investigate the potential advantage of kenaf fiber for improving the structure properties of OPS-RC beams. This investigation carried out by two methods experimental and consequently numerical modelling. The experimental work focused on two beams. First beam constructed with full shear reinforcement and without fibre (SI = 0% and with Vf = 0%) denoted as a control beam. Meanwhile one more beams with full shear reinforcement (SI = 0%) and with fibre volume fraction of Vf = 1% constructed respectively. The experimental work has been considered four point flexural tests on simply supported beam. Consequently, numerical modelling with finite element method FEM software Abaqus for calibration and validation of experiment results considered. First, sensitivity analysis (mesh and time) conducted up to acquire the best correlation with experimental result. Then, the experiments result of beams was used, for calibration in FEM modelling investigation. The results comparison showed that there is a good agreement between the experimental test and nonlinear finite element analysis NLFEA results. Generally, this investigation demonstrated up to 37% improvement on structure properties of OPS-RC beam by addition of Vf = 2%kenaf fiber.

Keywords: Kenaf fiber, Shear strength, ductility, load carrying capacity, mode of failure, Lightweight concrete.

Resumen:

Este estudio presenta las propiedades estructurales de vigas de concreto ligero de cáscara de palma de aceite con fibras de kenaf (OPS-KFLC). El objetivo principal de esta investigación fue investigar la ventaja potencial de las fibras de kenaf para mejorar las propiedades estructurales de las vigas de OPS-RC. Esta investigación se llevó a cabo mediante dos métodos: experimental y, consecuentemente, modelado numérico. El trabajo experimental se centró en dos vigas. La primera viga se construyó con refuerzo completo de cortante y sin fibras (SI = 0% y con Vf = 0%), denominada como viga de control. Mientras tanto, se construyó una viga más con refuerzo completo de cortante (SI = 0%) y con una fracción de volumen de fibras de Vf = 1%. El trabajo experimental incluyó pruebas de flexión de cuatro puntos en vigas simplemente apoyadas. Posteriormente, se realizó un modelado numérico con el software de método de elementos finitos Abaqus para la calibración y validación de los resultados experimentales. Primero, se realizó un análisis de sensibilidad (malla y tiempo) para obtener la mejor correlación con los resultados experimentales. Luego, se utilizaron los resultados de las pruebas de las vigas para la calibración en la investigación del modelado de elementos finitos (FEM). La comparación de los resultados mostró que hay una buena concordancia entre las pruebas experimentales y los resultados del análisis de elementos finitos no lineales (NLFEA). En general, esta investigación demostró una mejora de hasta un 37% en las propiedades estructurales de las vigas de OPS-RC mediante la adición de un 2% de fibras de kenaf.

Palabras clave: Fibra de kenaf, resistencia al corte, ductilidad, capacidad de carga, modo de fallo, concreto ligero.

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1. INTRODUCTION

Lightweight aggregate concrete (LWAC) is an important economic and versatile material; nonetheless, it has lower tensile strengths and a subsequently reduced shear resistance. As the LWAC has a lower modulus elasticity, the structure deflects more and has a lower rate of loading in cracking than typical concrete structure (Almousawi, 2011). In addition, the usage of LWAC in the concrete industry is still limited due of its lack of ductility and brittleness (Arisoy, 2002). Oil palm shell (OPS) is considered as a waste material, and Malaysia alone produces over 4 million ton OPS annually. OPS as coarse aggregate have been found useful by a number of researchers in producing LWAC. Teo et al. (2006) concluded that 20% dead weight of construction would decrease by replacing sand aggregate with OPS. Numerous articles on the physical, and material properties of OPS as lightweight aggregate for making LWAC have been published. It was also reported that the brittleness effect of OPS-LWAC has yet to be fully mitigated in the concrete industry (Alengaram et al., 2013). Several investigations on the incorporation of different types of fibres in the mix in order to mitigate this issue has been reported (Hassanpour et al., 2012; Carmona et al., 2013; Chaallal et al., 1993).

However, it is worth noting that the literature regarding structural properties of OPS-RC added with fibre is rather limited. Shafigh et al. (2013) enhanced the structural properties of OPS-RC with steel fiber. However, steel fiber is deemed uneconomical and scarce as it comes from non-renewable resources. Therefore, researchers have been investigating on a suitable substitute for steel fibers. The incorporation of natural fibres in concrete as a viable replacement of conventional steel fibers is of immense interest as it is more economical and environmentally friendly in promoting "green" structures (Deka et al. (2013). Akil et al. (2011) revealed that the tensile strength of kenaf fibre is between 400-550 MPa, which is higher than other natural fibres, such as sisal and jute. Therefore, kenaf fiber is capable of improving the structural properties of OPS-RC. However; study on kenaf fibres added to OPS-RC structures has yet been published. Therefore, it is essential to investigate the potential advantages of kenaf fiber in order to enhance the structural properties of OPS-RC beams. From a structural standpoint, the primary reason for adding fiber is to improve structural properties of concrete through the fiber ability. Fiber bridging over the cracks leads to increase shear, moment, ductility, punching resistance, stiffness and reduce cracks widths. Fibre acts as a multi-dimensional matrix and enhances the bond between the matrix that in turn increases the structural integrity of the concrete (Hassanpour et al., 2012).

It is apparent that the inclusion of fibres brings about significant desirable characteristics as compared to ordinary concrete. It could also be concluded that natural fibre, such as kenaf has the potential to serve as a fibre reinforced concrete owing to its favourable properties as discussed above. Fibre contents in excess of 2% by volume fraction results in poor workability which was pointed out by several investigations. Hence, this research tested three volume fraction (Vf = 0%, Vf = 1% and Vf = 2%) of fibre into the OPS-RC beams experimentally. Several study reported, addition of different types of fibres increased the shear strength of concrete structures and changed the failure mode from shear to bending. Thus, this research aimed to substitute kenaf fibre as a part of shear reinforcement in beams. Substantial amount of work has been carried out on material properties of OPS-LWAC concrete, but limited work has been done to study the influence of fibres on structural performance of the OPS-RC, especially kenaf fibre. It is, therefore, expected that the incorporation of kenaf fiber may improve the structural properties of OPS-RC (strength, ductility, crack propagation and mode of failure). It is also anticipated that kenaf fibre may serve as part of shear reinforcement to reduce the amount of shear reinforcement from OPS-RC beams. In order to investigate the efficacy of kenaf fibres as reinforced concrete, experimental and simulation work is carried out. Abaqus will be used to model the OPS-KFRC as it was proven as an effective tool to study the issues above (Shafigh, et al., 2013; Teo et al., 2006, Mannan and Ganapathy, 2002).

Numerical modelling of fiber reinforced concrete beam with different proposed model for FRC was investigated through FEM software Abaqus by Abbas et al. (2010). The fiber behaviour within matrix is characterised by its tensile strength. “Brittle cracking model” that is available in the Abaqus material model was adopted to describe the concrete behaviour as in tensile cracking. From the study Lok and Xiao (1999) proposed model demonstrated the tensile post cracking behaviour of FRC structure better than other models due to the following reasons. Firstly, different fiber specification can be defined such as fiber volume fraction, aspect ratio and bond stress. Secondly, the orientation factor or randomness distribution of fiber can be considered. Thirdly, this model is capable of modelling of tension softening and hardening behaviour by considering the variables. Finally, a good correlation between numerical modelling and experimental result can be obtained. Furthermore, Abbas et al. (2012) carried out a study on the structural behaviour of a simply-supported FRC beam with Abaqus. The FRC constitutive model proposed by Lok and Xiao (1999) was adopted in the research to describe the tensile behaviour of fiber with “Brittle cracking models”. Firstly, calibration study was carried with existing experimental data. Subsequently, parametric study on fibre content varied from 0 – 2.5% were conducted after the accurate calibration was obtained. The finding based on load deflection and cracking pattern indicated that the inclusion of fiber improves the structural behaviour of the concrete structure. Hence, the present research aimed to study the behaviour of OPS-RC beams upon the inclusion of kenaf fibres and to determine the potential of kenaf fibres as part of the shear reinforcement in the beams.

Fig. 1. Kenaf fiber (cut 30 mm length)

2. PREPARATION OF REINFORCED CONCRETE BEAMS FOR TESTING

The present research centres on both experimental work and numerical modelling. The experimental work focusses on the addition of kenaf fiber in OPS-RC reinforced concrete beams under laboratory conditions. The results obtained from the experimental work were used to calibrate the numerical model before further parametric studies are carried out.

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.

Table 1. Mixture of concrete

Ingredients	Kg/m³	Kg/m³
Concrete	Mix 1	Mix 2
Kenaf fiber (Vf = 1%)	0	1
Coarse aggregate (OPS)	308	308
Super plasticizer (Liter/m³)	5	5
Fine aggregate(sand)	848	848
W/C ratio	0.4	0.4
Cement	510	510

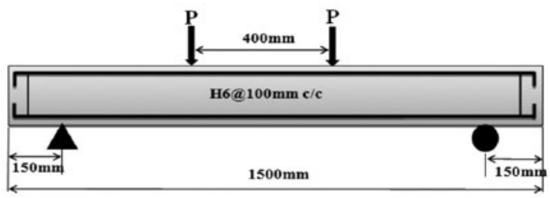

Fig. 2. Loading arrangement and dimensions of the beam

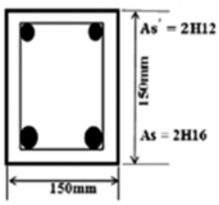

Fig. 3. Main reinforcement arrangement & dimensions of The beam

2.1 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. The cracking of the beams was marked by numbering all the cracks and their location. The loading arrangement and reinforcement properties of the beam are shown in Fig. 2 and Fig. 3. The beams were initially designed by Euro code 2 with shear reinforcement less than that is required to cause shear failure. The test was carried out on the 56th day in order to ensure that the OPS-RC beams added with kenaf were fully hardened. Concrete beams under laboratory conditions. The results obtained from the experimental work were used to calibrate the numerical model before further parametric studies are carried out. 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. The load arrangement and dimension of the beams are given in Figure 3.11. The flexural test was carried out using the MTS hydraulic machine with a capacity of 300 kN. The hydraulic pressure was connected to a computer that records the data and displays the force applied on a graph. A thin coat of 'best temp' paint (white wash) was applied on the surface of the beams to improve the concrete cracking visualization during the testing. The strain gauge was attached at the middle of shear span with a position of 45 degree in order to record the shear strain. The flexural strain of concrete is measured through the strain gauge attached at the bottom of the mid span of beam based on recommendation of Fernando et al (2003). The deflection of the beams during testing were obtained from three linear variable differential transducers (LVDT) placed on the mid span of the beams.

3. NUMERICAL SIMULATION PROCEDURE

The numerical modelling is accomplished by means of NLFEA built in Abaqus. Fig. 4 briefly explains the numerical work procedure conducted through Abaqus.

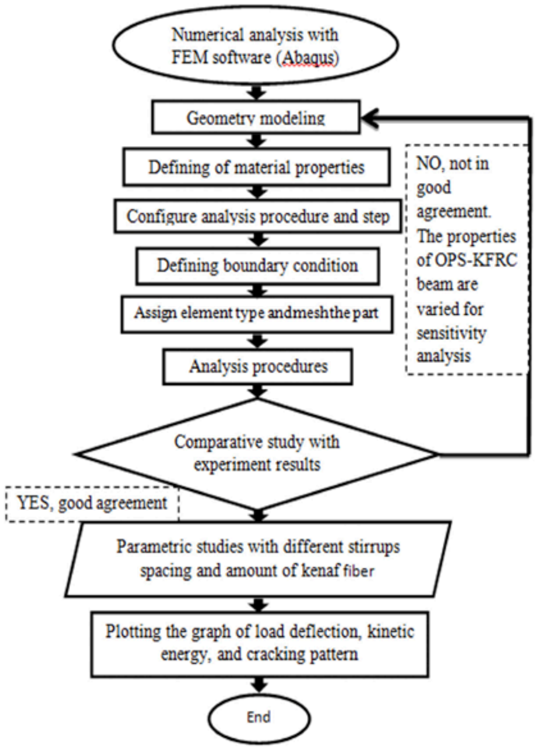

Figure 4. Numerical analysis procedure with FEM software (Abaqus)

The geometry of the beam is modelled similarly to the beam considered in the experimental work created in the part module by entering the dimensions (length, width and height), thickness of the cover, as well as reinforcements. In order to simulate the experimental conditions, steel plates of 10 mm thickness and 20 mm width extending across the breadth of the beam were added at the support and loading points. The steel plate for loading points and support point assigned linear elastic property where the cracking is not allowed. This was done to prevent convergence, where the model could become numerically unstable. In order to reduce the duration for the analysing, a half beam (1500 mm long, 150 mm high and 75 mm wide) was modelled symmetrically along the z-axis as illustrated in Figure 5.

After the geometry model has been constructed, the material properties of OPS-KFRC and reinforcement are assigned into brittle cracking concrete model. The effect of the fibres as reinforcement was adopted in the tension part of the concrete models, as post peak

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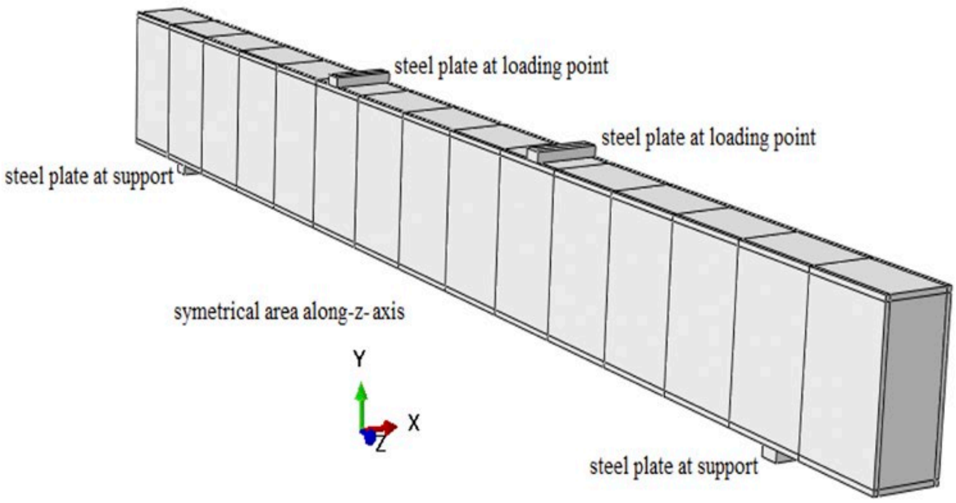

Figure 5. Half of the beam model in Abaqus with defined boundary condition along-z- symmetrical

tensile strain softening or hardening depends on the amount of fibres. Also, the fibres effect on shear response concrete structure considered by using the "shear retention" part of Abaqus concrete model. Shear retention is used to allow for the impact of aggregate interlock and dowel action. After all the aforementioned settings are arranged, the model is then submitted to the analysis procedure. At the calibration stage of this study, numerical modelling is carried out by using beams with Vf = 0%, Vf = 1% fiber content and full shear reinforcement SI = 0%. Once an acceptable correlation was obtained, the parametric studies based on two distinct parameters volume fraction of fiber (Vf) and stirrups spacing incensement (SI) were performed. The NLFEM is used to calibrate and validate the results obtained from the experimental work, and then followed by further parametric studies. The numerical modelling was carried out by using quasi-static analysis in Abaqus/Explicit with brittle cracking concrete model.

4. RESULTS AND DISCUSSION

The load-deflection relationships of beams that were acquired in the experimental works were used to calibrate and validate the FE predictions. The modulus of elasticity of 18.5 GPa was used for all beams. A number of sensitivity studies mesh were also performed as shown in Figures 6 and sensitivity of time as shown in Figure 7. This was conducted to correlate experimental results with our finite element model as it is both mesh and time dependent. The mesh adopted has an element size of 15 mm was selected once the sensitivity analysis mesh and time was

Table 3.3. Material properties of concrete and steel reinforcement

Material properties of concrete		**Material properties of steel reinforcement**	
Compressive strength	20 MPa	Density	7850 kg/m³
Density	2000 kg/m³	Modulus of elasticity	200 GPa
Modulus of elasticity	18.5 GPa	Poisson's Ratio	0.3
Poisson's Ratio	0.2	Yield stress for main reinforcement	610 MPa
Strain value for compression	-0.0035	Ultimate stress for main reinforcement	650 MPa
Strain value for tension of OPS-RC	0.001	Yield strain for main reinforcement	0
Strain value for tension of OPS-KFRC	0.006	Ultimate strain for main reinforcement	0.1
Tensile strength of concrete	2 MPa	Yield stress for shear reinforcement	510 MPa
Shear retention factor	0.5	Density	7850 kg/m³

performed. By reducing the mesh size to 15 mm the duration of the analysis of each model increased up to 10 hours. Therefore, the mesh sizing associated with 15 mm together with T2 were selected it possesses a good correlation with the experimental data. Figure 6 shows kinetic energy plots to determine failure for beams of calibration work. The failure point on the FE investigation in Abaqus is decided via the kinetic energy of the beam. In present calibration work and following parametric modelling, the failure point is determined based on the sudden high jump in the kinetic energy. The sudden high rise of kinetic energy indicates that the sudden movement of structure which specified the presence of wide cracks within the member which representing the structure was under failure stage as demonstrated by Syed Mohsin (2012).

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A comparison between the experimental and numerical MESH and TIME analysis results is presented in Fig. 9 and Fig. 10, for both beams without and with fibres denoted by symbols (Vf = 0%) and (Vf = 1%), respectively. The key values are summarised in Table 2. There is good agreement between the two sets of data.

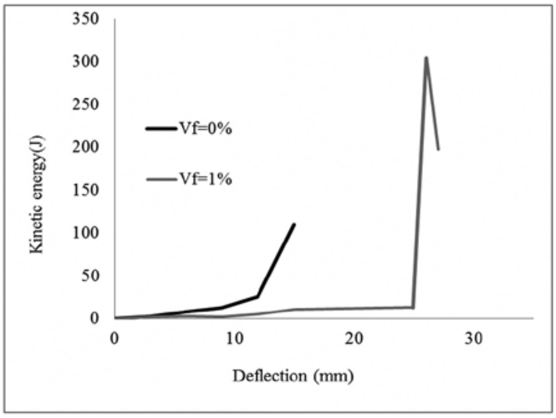

Figure 6. Kinetic energy plots to determine failure for calibration work

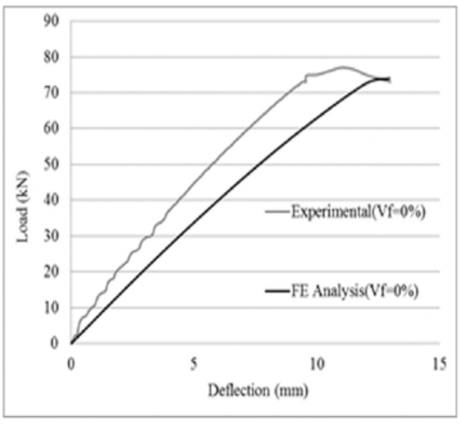

Figure 7. Load-deflection curves for mesh analysis with SI = 0%

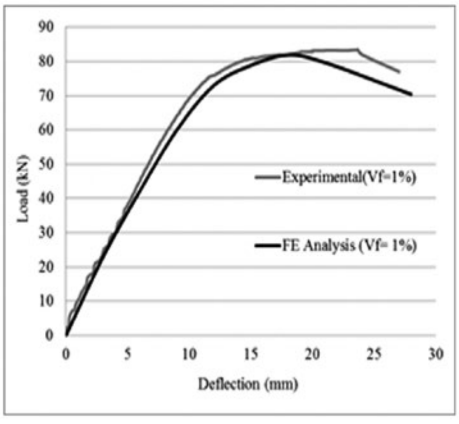

Figure 8. Load-deflection curves for time analysis with SI = 0%

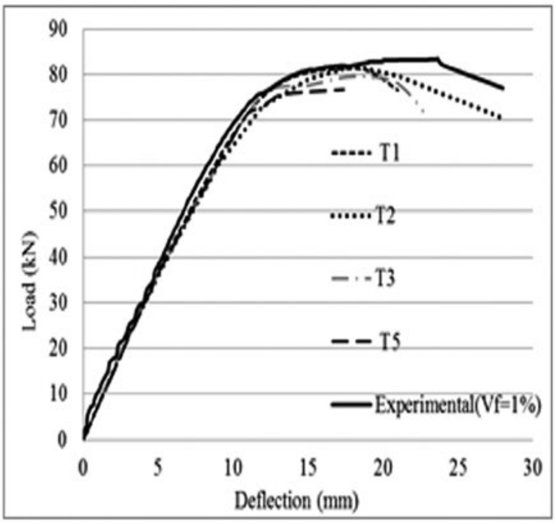

Figure 10. Load-deflection curve of OPS-KFRC beam with SI = 0%

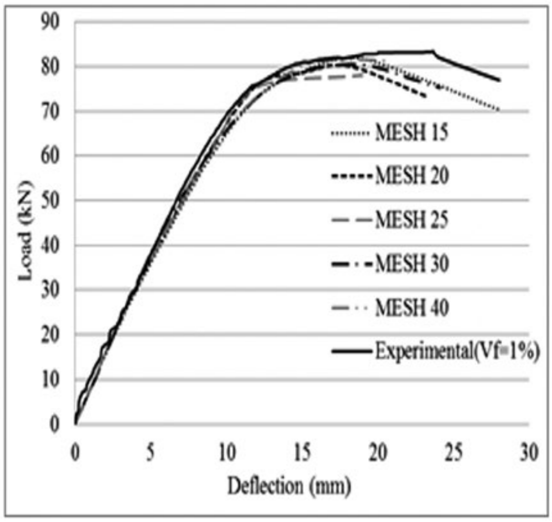

Figure 9. Load-deflection curve of OPS-RC beam with SI = 0%

Table 2. Calibration results summary for beams with full shear reinforcement

Beam	Py kN	δy mm	Pu kN	δu mm	Pma kN	μ=δu/δy
EX (Vf = 0%)	58.0	6.9	73.0	13.0	77.0	1.8
FE(Vf = 0%)	61.0	9.0	73.9	12.9	73.9	1.4
EX(Vf = 1%)	69.0	9.9	70.1	28.1	84.5	2.8
FE (Vf = 1%)	64.5	9.0	70.4	27.9	81.9	3.1

4.1 Parametric Studies

Following the calibration work, parametric studies are conducted with two broad parameters, kenaf fibres volume fraction (Vf) and the increase in stirrups spacing (SI). The effects of fibres amount on structural enhancements are studied by six-volume fraction of kenaf fibres which are Vf = 0%, Vf = 0.5%, Vf = 1%, Vf = 1.5%, Vf = 2% and Vf = 2.5% on three stirrups spacing arrangement of SI=0%, SI=50% and SI= 100%. Furthermore, the beams were modelled with reduced shear reinforcement in order to induce a shear mode of failure. The additions of fibres for improving shear strength of the beam in case of changing the mode of failure from shear to bending are examined. The stress-strain relationship in tension that was adopted in the parametric studies are shown in Fig. 11 and with the main values summarised in Table 3.

The load- deflection curves in Fig. 12 and Fig. 13 display that the beam without fibres failed prematurely suggesting a sudden brittle mode of failure which associated with shear strength insufficiency.

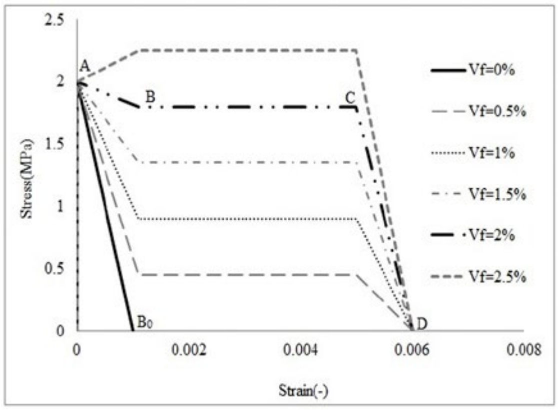

Figure 11. Stress-strain relations in tension for parametric studies

Table 3. Tensile stress-strain parameters or OPS-RC

Point	Strain (‰)	Stress, Vf = 0% (MPa)
Origin	0.00	0.00
Peak tensile stress (A)	0.10	2.00
Ultimate tensile strain(B0)	1.00	0.00

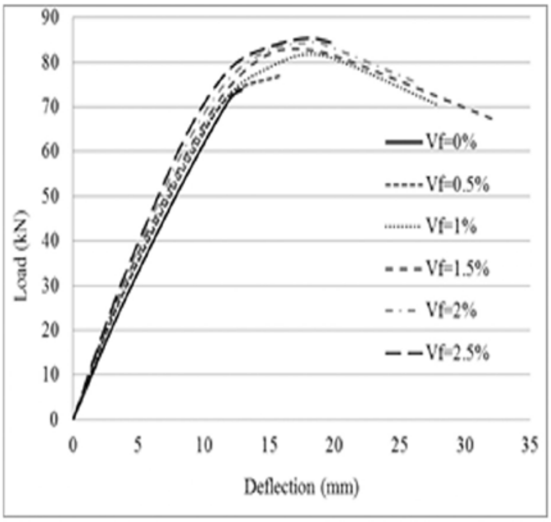

Fig. 12. Load-deflection curves for OPS-KRFC beams with SI = 100%

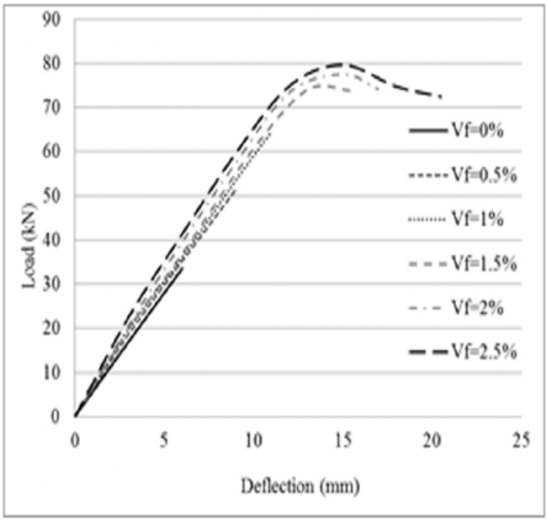

Fig. 13. Load-deflection curves for OPS-KRFC beams with SI = 50%

As compared to control beam, the beam with fiber illustrates significant increase in strength, stiffness and ductility that is more vital pertaining for design considerations. Inspection of the load deflection show that by increasing the amount of fiber the stiffness, load at yield (Py), and maximum load (Pmax) consistently increases. The ductility ratio shows improvement upon the inclusion of fibre up to a certain extent, nonetheless beyond this limit, the ductility behaves otherwise. This is due to the addition of more kenaf fiber, as the amount of kenaf fiber increases, the beam became stiffer and deflects less which is essentially contributed by the fiber acting as pull-out mechanism and cracks arrestor which cause multiple cracking to the beam. Hence, it is apparent that kenaf fiber increased the shear capacity of the beam as the mode of failure changed from shear failure to more bending ductile one. Therefore, the improvement of shear strength due to fibres endorses their possibility to substitute conventional shear reinforcement that in turn suggests that the fibres significantly increase structure properties of OPS-RC beam.

Table 4. Results summary for parametric studies for beams with SI = 100%

Vf (%)	Py (KN)	δy (mm)	Pu (KN)	δu (mm)	Pmax (KN)	μ=δu/δy
0%	50.30	8.00	50.30	8.00	50.40	1.00
0.50%	57.80	9.20	70.90	10.60	67.44	1.15
1%	61.50	9.20	79.98	16.94	78.16	1.84
1.50%	63.00	9.20	75.38	21.90	79.11	2.38
2%	64.50	9.20	74.48	24.93	80.49	2.71
2.50%	66.00	9.20	80.10	20.90	81.63	2.27

Table 5. Results summary for parametric studies for beams with SI =50%

Vf (%)	Py (KN)	δy (mm)	Pu (KN)	δu (mm)	Pmax (KN)	μ=δu/δy
0%	33.61	6.00	33.61	6.00	33.61	1.00
0.50%	51.46	9.00	51.46	9.00	51.46	1.00
1%	58.60	9.40	64.50	10.90	64.50	1.16
1.50%	60.20	9.40	73.87	15.50	74.84	1.65
2%	61.60	9.40	74.24	16.95	77.59	1.80
2.5%	62.80	9.40	72.48	20.50	79.69	2.18

4.2 Principal Strain Contour

The principal strain contours of beams at failure phase with SI = 0%, is presented in Fig. 14. In order to observe the contours at failure, the principal strain range is selected between an ultimate tensile strain of 0.001 cracking strain for beams without fibres and 0.006 pull-out strain for OPS-KFRC beams and an ultimate compressive strain of -0.0035. The grey colour highlighted as tensile failure in principal strain contour of beam representing the area where exceeding the ultimate tensile strain 0.006 for OPS-KFRC and 0.001 for OPS-RC while the region of compressive failure are highlighted in black where the value exceeds the maximum compressive strain. It was found that the failure of beams were considered by tensile cracking at the bottom of middle point of the longest span of beam (at the section where the loads (P) were applied) and top of central support. By associating the contour of beams with different percentage of fiber (Vf), it is observed cracking formation decreases by increases in fibre amount. Throughout the analysis, only one of these small cracks developed earlier will continue to propagate into a large one. This led to a different location for the single main crack at failure in the beams. Moreover, the pull-out failure region is limited to the narrow zone that situated at the areas of tensile cracking as show for OPS-KFRC beams. Furthermore, it is observed from the cracking pattern the beams without fiber showed high expanded compression zone and diagonal cracking since more fiber added the cracking pattern concentrated at mid-span and showed altering of mode of failure. However, the beams with insufficient amount of fiber did not exhibit cracking pattern more limited at mid-span of the beam that indicates the importance of the amount of fiber for altering the mode of failure. For instance the beams with full shear reinforcement when added fiber up to Vf = 0.5% the cracking pattern indicated

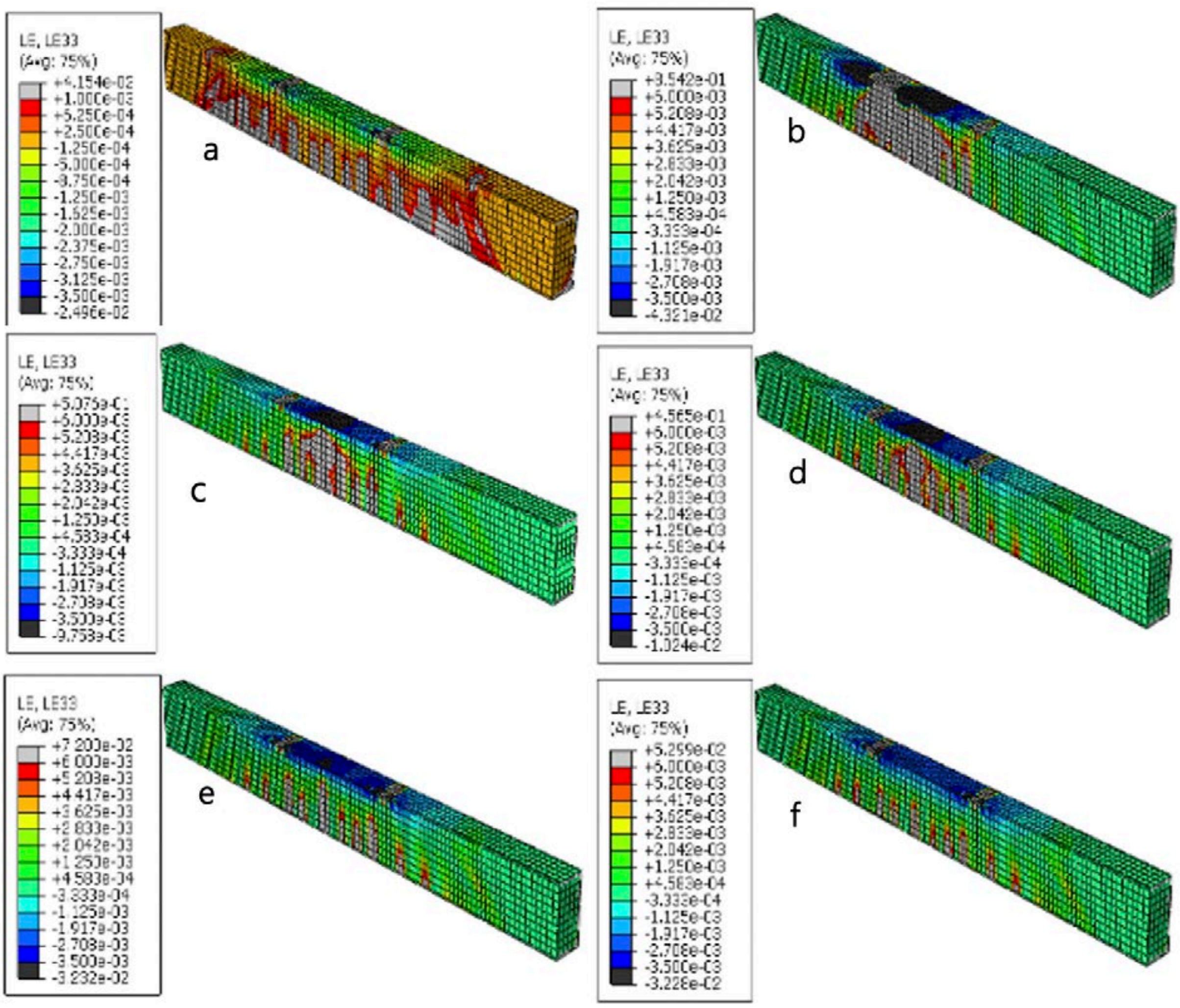

Figure 14. Principal strain vector for beams with SI = 0% and (a)Vf = 0%, (b) Vf = 0.5%, (c) Vf = 1%, (d) Vf = 1.5%, (e) Vf = 2% and (f) Vf = 2.5%

mode of failure not altered since added fiber up to Vf = 1% the cracking pattern concentrated at mid-span and mode of failure properly altered from shear to bending. This suggest that the pull-out mechanism and bridging mechanism of fibres caused to restrained cracks propagation and increased the tensile characteristic of OPS-KFRC structure and prevent from diagonal cracking. Meanwhile the mode of failure of beam with sufficient amount of fiber altered from sudden shear to ductile bending.

4.3 Comparative Study of Control Beam Using Non-Dimensional Ratios

In this section, the overall comparison between the beams with various fibres content and stirrups arrangement are made by taking the control beam (Vf = 0% and SI = 0%). Normalised value with ductility and energy absorption is by dividing them with associated control beam. Considerations on each normalised value are made to conclude the effectiveness of fibres on mentioned structural response.

4.3.1 Strength Ratio

The ratio of load at yield to the control beam (Py/Py0) and load at max to control beam (Pmax/ Pmax,0) shown in Fig. 15 and Fig. 16 respectively. Similar trend was observed for the load at max (Pmax) and load yield (Py) as compared to the control beam. By the the addition of more fibres (Vf) both values increased steadily. Beams without fibres and with reduced shear reinforcement (SI = 50% and SI = 100%) showed a decrease in load at max and load at yield ratios as compared to control beam. The fibre act multi-dimensional into the matrix that improve the bond between the matrix and caused to increase the load at yield (Py). Also, upon crack initiation, the fiber act as crack bridging or pull-out mechanism and the occurrence of multiple cracking causes the load at max (Pmax) to increase.

Adding fibres at Vf = 0.5% and at Vf = 1% with SI = 50% restored the capability of Py and Pmax level of the control beam respectively. Meanwhile, the beam with SI = 100% at Vf = 1% and Vf = 1.5% restored the capability of Py and Pmax level of the control beam respectively. The highest improvement of Py/Py0 and Pmax/ Pmax, 0 ratio was achieved beams with SI = 0% at Vf = 2.5% up to 12.2% and 11.2% respectively. This concludes that the addition of kenaf fiber into the mixture considerably enhanced the strength (Py and Pmax) of OPS-RC structures.

4.3.2 Ductility Ratio

Fig. 17 illustrates the results for the ratio of ductility ratio for each beam and that in the control beam plotted against fibre volume fraction on three stirrups spacing arrangement SI = 0%, SI = 50% and SI = 100%. There was a considerable increase in the ductility ratio especially for beams with SI = 0% at Vf = 1.5% up to 212% as compared to control beam. For beams SI = 50% and SI = 100% the maximum ductility enhancements are achieved at Vf = 2% and Vf = 2.5% respectively.

The ductility trend shows improvement for all beams with shear reinforcement arrangement SI = 0%, SI = 50% up to a certain limit, beyond that the ductility dropped. The optimum amount of fiber was found to be Vf = 1.5% and Vf = 2% with

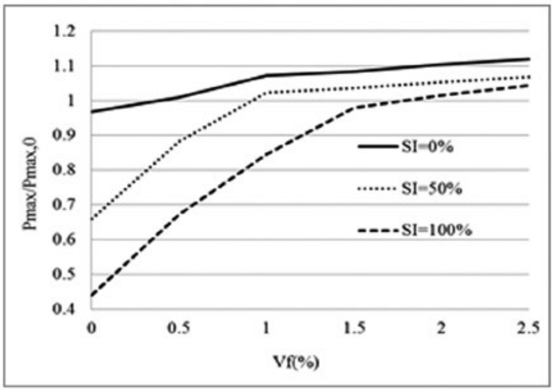

Fig. 15. Ratio of maximum load to that of the control specimen (SI = 0%, Vf = 0%)

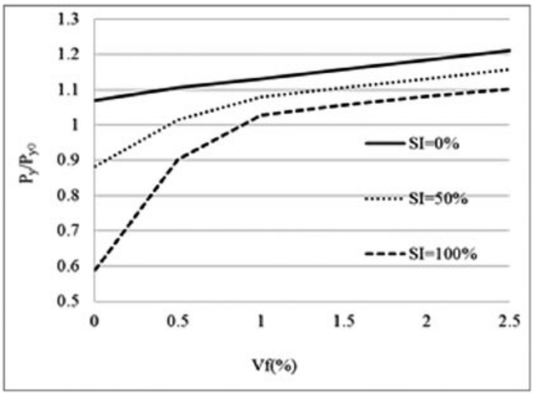

Fig. 16. Ratio of yield load to that of the control beam (SI = 0%, Vf = 0%)

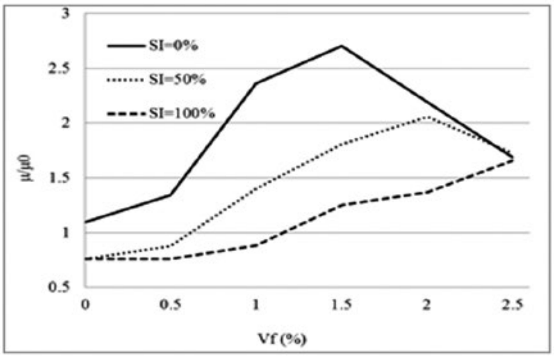

Fig. 17. Ratio of ductility ratio to that of the control beam (SI = 0%, Vf = 0%)

SI = 0% and with SI = 50% respectively. The beams with SI = 100% the ductility consistently increased by increasing the amount of fiber. This is due to the shear reinforcement taken-out from the beam. Itis observed, that the ductility ratio decreases when the shear reinforcement reduced from the beams. As the shear reinforcement reduced, a high amount of fibres was needed for achieving the same capability of ductility. It was found that when shear reinforcement spacing increased from the beam up to 50% and 100%, with addition of Vf = 1% and Vf = 1.5% the same capacity of ductility with control beam was restored. It indicates that the improvements in ductility are reduced when more than optimum amounts of fibres are added. This can be explained as effectiveness of fibres' in bridging cracks and limiting their opening. It was observed, crack propagation was delayed leading to enhanced ductility of the OPS-KFRC structures as more fiber content added to the beam, caused the became stiffer and result in failure at small amount of deformation as explained by Syed Mohsin (2012).

5. CONCLUSION

It can be concluded; Kenaf fiber showed good compatibility in order to improve the structure properties of OPS-RC beams. Thus, fiber with crack-bridging mechanism or pull-out mechanism restrained the crack opening and increased the strength (Py and Pmax) and as well as increased the ductility up to certain limit. In addition, kenaf fibres were efficient for improving the tensile strength of OPS-RC to prevent from diagonal-tension cracking and caused to change the mode of failure of OPS-RC beams from shear to bending. Hence, it is clarified that kenaf fiber with adequate amount could increase the shear capacity of beam as the mode of failure of beam changed from shear to bending. Therefore, this is confirmed that by addition of a proper amount of kenaf fiber possible to reduce the amount of shear reinforcement from OPS-RC beams. It is highly recommended to use kenaf fiber with an adequate amount into OPS-RC structure for producing green concrete structure and improving the structure properties of OPS-RC beams.

- Then nonlinear finite element analysis program (Abaqus) successfully had been used to calibrate and validate against experimental results. Abaqus has shown the capability to model the OPS-KFRC beams, and the calibration results showed a good agreement with experimental results

- Kenaf fibre showed favourable contribution in improving the strength (Py and Pmax) and ductility as well as changing the mode of failure of OPSKFRC beams. The addition of fiber at Vf = 2% into the beam with SI = 0% demonstrates the increase in strength of Py and Pmax 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.

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