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DEFLECTION AND STRAINS PERFORMANCE OF KENAF FIBRE-REINFORCED CONCRETE BEAMS

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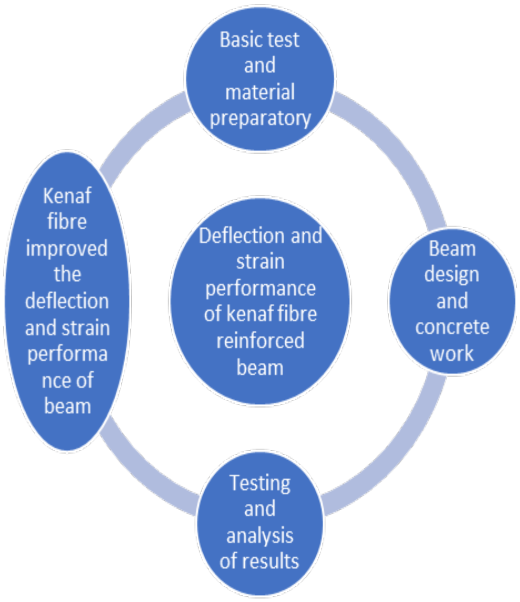
Graphical abstract



Abstract

There has been a need to find a lasting means to improve beams' deflection and strain performance without necessarily increasing the beam stirrups. The limitations of steel and other synthetic fibres have reduced their application. Given its tensile strength, renewability, sustainability, and affordability compared to steel and synthetic fibres, kenaf fibre development is of great interest in Malaysia. Therefore, this research work experimentally investigated the deflection and strain performance of Kenaf Fibre Reinforced concrete beams. The volume and length of kenaf fibre used were 0.75% and 25mm, respectively. Kenaf fibre was treated with 5% NaOH to improve its performance. The alkaline-treated and untreated kenaf fibres morphology was observed under a variable-pressure scanning electron microscope. It was discovered inclusion of kenaf fibre reduced the workability of concrete. Also, plain and KFR concrete morphology was observed under a variable-pressure scanning electron microscope. Four beams were designed to study the deflection and strain performance of the KFR concrete beam; one was well reinforced but without kenaf fibre. The stirrups spacings were increased by 25%, 50%, and 75% for the other three beams. The beams were tested under centre loading. Deflection and concrete strain at the centre and along the beam span were measured using LVDTs and concrete strain gauges for the four beams. Furthermore, the strains on the shear and bottom flexural reinforcements at the centre of the beam were measured using steel strain gauges. It was discovered that kenaf fibre enhanced the deflection and strain performance of beams between 25% and 50% stirrups deficiency.

Keywords: Cellulose, Deflection, Fiber, Kenaf, Strain.

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1.0 INTRODUCTION

Exploring environmentally friendly and sustainable options in various engineering applications has gained popularity recently [1]. One such promising route has been the development of fibre-reinforced composites, which provide superior mechanical qualities and environmental benefits over conventional materials [2]. In Malaysia, kenaf fibre, used to create biocomposite [3], is a well-known natural fibre [4]. It is an environmentally friendly material with unique mechanical properties, including stiffness, impact resistance, flexibility, and modulus. Kenaf fibre is free, easy to produce, accessible, available, renewable, biodegradable and CO_2 neutrality [5]. It has drawn much interest from private and governmental organisations because of its exceptional properties [6].

Concrete contains fibres to perform specialised functions under demanding circumstances, such as deflection and strain resistance [1, 7]. The use of plant-based fibres in concrete results from the high cost of producing traditional fibres and the demand for more environmentally friendly biomaterials [5]. Due to its comparatively high stiffness, low processing energy requirements, and CO_2 neutrality, significant research efforts are currently being made. Since they have been used, biofibre from plants like cotton, hemp, jute, bamboo, flax, ramie, coconut, sisal, bagasse, and kenaf have significantly improved concrete properties and provided more research options [8].

Even while biofibre have intrinsic advantages, they frequently have challenges with water absorption and poor fibre-matrix affinity that degrade the qualities of composites. As the most common way to enhance interfacial attributes, they are controlled by fibre alkaline treatment [9; 10]. The kind and selection of biofibre, harvesting period, mode of processing and modification, volume, orientation, and dispersion within the matrix are other factors that affect their performance [6].

Moreover, Kenaf fibre is a very appropriate resource. Numerous studies indicate that its utilisation could enhance structural response in concrete or reinforced concrete mixtures [11]. The kenaf fibre has been used as an alternative to other conventional materials, including rope, matting, and straw, because of its affordability, low density, skin irritation, and reduced potential for machine abrasion [12]. Due to its ability to absorb water, kenaf fibre is also regarded as a hydrophilic material [3]. As a result, the fibre-matrix interface adhesion is improved by the interaction between water-soluble cellulosic and the interface [13]. The amount of cellulose in the kenaf fibre depends on the age and species of the plant. The Bast, part of kenaf, contains the largest cellulose that aids its structural performance [14]. Unlike the manufacture of cement, which contributes 8% to the world's CO_2 emissions [15], the production of kenaf fibre absorbs about 1.5% of its weight in CO_2 [16].

Since reinforced beams are the fundamental element of so many building projects, the structural performance of these beams is of utmost importance in engineering design. Understanding how these beams behave under various loading scenarios requires deflection and strain analysis, which also serves as a critical indicator of structural integrity. The response of traditional fibres (steel, synthetic, and hybrid) to deflection and strain in concrete beams has been extensively studied. It was reported that steel fibre-reinforced concrete is the most effective method for enhancing the strength of beams without stirrups. Compared to non-fibre reinforced concrete beams, steel fibre-reinforced concrete beams have reduced crack widths and improved aggregate interlock. In members with no or little shear reinforcement but with fibre, the failure mechanism changed from diagonal shear failure to flexural failure [17]. Concrete with fibre reinforcement made of steel and polypropylene can be used structurally in some cases with little to no traditional reinforcing. The concrete beam subjected to shear could benefit from using the fibres to increase its capacity to support loads [18]. Using banana fibre, lightweight self-compacting concrete beams' deflection resistance was improved [19]. Adding coir fibre significantly boosted the beams' load, strength, and energy. Moreover, natural fibre can be applied to renovating or repairing existing concrete structures[20]. Pan et al. [21] studied the shear performance steel fibre-reinforced concrete beam after exposure to high temperatures. It was concluded that steel fibre reinforced concrete beams exhibited higher load-carrying capacity than reinforced concrete beams without steel fibre at the same temperature. Also, Deng *et al.*[22] investigated the shear characteristics of steel-reinforced NC/HDC continuous deep beams. Their results expressed that steel fibre well dispersed in concrete beam tends to reduce stain in concrete deflection while the load capacity of the beam is improved. El-Karim Shoeib *et al.*[23] worked on the assessment of hybridised material bars' shear strengths in reinforced concrete beams without stirrups. Concrete compressive strength, shear span to depth ratio (a/d), beam depth (d), reinforcement ratio, and fibres (steel and glass) are the factors employed in this study. The experiments show a notable increase in ductility and a perceived reduction in deflection and deformation of the hybrid GFRP/steel reinforced concrete beams. Better performance is found in hybrid GFRP/steel reinforced concrete beams during crack initiation and propagation. In addition, Kumar *et al.*[18] studied the Shear behaviour analysis of the steel and polypropylene fibre-reinforced concrete beams. It was discovered that steel fibre performed better than polypropylene fibre in capacity, deflection reduction and shear capacity. This was similar to the o research work of [24]. Except that basalt and steel fibres were used. Steel fibre-reinforced beams gave more load-carrying ability than basalt fibre-reinforced beams.

In addition, much research has been carried out on kenaf fibre. Syed Mohsin *et al.*[25] worked on kenaf fibre's impact on a reinforced concrete slab. For this investigation, three different types of mixes with varying fibre volume fractions (0%, 1% & 2%) were produced. It was concluded that kenaf fibre has the potential to improve the reinforced concrete slab's ductility, limit crack propagation, and increase flexural strength. Consequently, the addition of kenaf fibre did not make up for the reduction in the thickness of the slab, which reduced the concrete's shear capacity. Fook & Yatim [26] investigated the Mechanical characteristics of concrete reinforced with kenaf fibres with varying fibre lengths and volumes. According to the findings, KFRC is less workable than regular concrete; regarding the mechanical characteristics of KFRC, the compressive strength dropped as the fibre content rose. However, the study discovered that the flexural strength and indirect tensile strength of concrete increased. At the same time, the KFRC can have comparable compressive strength to plain concrete by adding the right amount of fibre content and fibre length to concrete. Additionally, KFRC often has greater toughness and crack resistance than plain concrete. To enhance the mechanical qualities of concrete, it was recommended that kenaf fibre be added in quantities of 0.75% and 25 mm in length. Finally, there has been substantial research on kenaf fibre-reinforced concrete's flexural and compressive performance [16, 26, 27, 28]. Also, diameter (d=50µm), aspect ratio ((l/d) = 500µm), tensile strength (337MPa), young modulus (24GPa), and optimum volume (Vf=0.75%) were determined in previous research [29]. Still, little or no data exists on the deflection and strain performance of the kenaf fibre-reinforced beam. Furthermore, Mohsin et al.[30] investigated the use of hybrid fibre (steel and kenaf fibres) in concrete beams. It was concluded that the beam's ductility and load-carrying capability rose by 29% and 22%, respectively. Additionally, it was shown that the addition of fibres causes the beam to collapse in a more ductile manner instead of a brittle one. Nevertheless, the impact of kenaf fibre in concrete beams was investigated. However, the study's limitation was only one shear spacing employed with the control sample. One sample is insufficient to verify Kenaf's performance in the beam [31]. The demand for more environmentally friendly solutions in the construction sector served as the driving force for this study. Traditional building materials, such as steel and concrete, significantly impact the environment during manufacture and disposal. It hopes to contribute to a more environmentally friendly method of structural engineering by investigating Kenaf fibre. Therefore, this study intends to investigate the deflection and strain performance of kenaf fibre-reinforced concrete beam experimentally using four different shear reinforcement spacings. This will provide essential insights into the mechanical behaviour of Kenaf fibre-reinforced beams, evaluating their performance in deflection and strain also sheds light on Kenaf fibre's potential as a viable and sustainable replacement for traditional materials. The results of this study could help to better understand the mechanical behaviour and prospective uses of Kenaf fibre-reinforced beams by providing insightful information about how well they work. Additionally, it is anticipated that the results of this study will open the door for further research, promote the use of sustainable materials in engineering design, and support ongoing efforts to transform the construction sector into one that is more environmentally conscious.

2.0 METHODOLOGY

2.1 Materials

The experimental investigation used ASTM Type I (ASTM C150-07) [32] cement from a single supplier. With a maximum particle size of 10mm, crushed granite served as the coarse aggregate. The fine aggregate utilized was natural river sand. Aggregates were batched in a saturated, dry surface state. Throughout the experiment, tap water was used for mixing and other operations. The Advanced composite research lab acquired kenaf fiber from Malaysia and processed them with 5% NaOH. The kenaf bast was selected because it has the largest concentration of cellulose (56.4%), which improves its engineering performance [6]. According to earlier studies, the ideal kenaf fiber length and volume were 25 mm and 0.75% [26]. For the main bar and shear reinforcement, high-yield steels with 16 mm and 10 mm diameters, respectively, were chosen. To measure the concrete and steel under loading, strain gauges were used. Rheobuild 1100 was then utilized as a superplasticizer at 149.6ml and 148.45ml for plain concrete and kenaf fibre concrete, respectively, for each concrete beam prepared. The concrete used was of grade 40. This is because the normal concrete strength is used. The compressive strength of normal concrete ranges between 20MPa and 50MPa [33]. Table 1 shows the mix proportion of concrete constituents using the DOE method.

Table 1: Mix Design of Kenaf Fiber Reinforced Concrete (Grade 40)

Mix (MPa)	Slump (mm)	Cementitious (kg/m³)	10mm graded (kg/m³)	Sand (kg/m³)	Water (kg/m³)	W/C ratio	Fiber (kg/m³)
Plain concrete	60 - 180	531.9	832.8	730.3	250	0.47	-
Kenaf fiber concrete	60 - 180	527..91	826.55	724.82	248.13	0.47	17.58

2.1.1 Beam

Four beams were prepared, cast, and tested in this research work. The beam used had a 2000 mm by 150 mm by 150 mm sectional size. Based on BS 8110 [34], Porta Structure Software 2016 was used for the design. It was reinforced with 2Y16T and 2Y16B. Figure 1 shows the cross-section of the beams. The differences between the four beams are the shear reinforcement or stirrups spacing and addition of kenaf fiber. A beam sample was used for each shear reinforcement spacing. The beam with 100mm shear spacing represents the control, while samples with 125mm, 150mm, and 175mm were samples with a deficiency in shear reinforcement. Still, their lack was compensated with the addition of kenaf fibre.

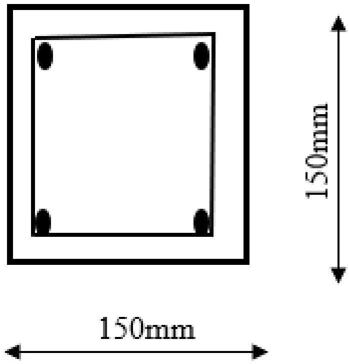


Figure 1: Cross-section of Beam

2.2 Methods

2.2.1 Basic Tests

Before the main work, the specified materials were subjected to basic tests. These were necessary to verify that the materials were appropriate for the intended use. The fine and coarse aggregates were subjected to sieve analysis using ASTM C33-18 [35], while the water absorption and SEM of kenaf fiber were studied using ASTM D570-98 [36] and ASTM F1877-18 [37], respectively. The tensile strength of 16mm and 10mm steel used was determined based on BE EN ISO 6892-19 [38]. Meanwhile, the workability, SEM and water absorption of concrete were studied based on ASTM C143-20 [39], ASTM C1723-16 [40], and ASTM D570-98 [36], respectively.

2.2.2 Deflection and Strain Performance of Kenaf Fibre Reinforced Beam

Shear reinforcement spacing was adjusted for concrete samples of grade 40 by 0% (control), 25%, 50%, and 75% to examine the effect of kenaf fibre on the deflection and strain performance of the beam under centre-point loading ASTM C293-02 [41]. According to this standard, the following steps were involved: sample preparation, testing preparation, and testing.

Sample preparation: A total of four beams were prepared, one for each shear spacing. To cater for the deficiency in shear reinforcement, 0.75% of Kenaf fiber of length 25mm was added.

Testing preparation: To measure steel strain, steel strain gauges were attached to stirrup and bottom flexural reinforcements at the centre of the beams, as shown in Figure 2a. Meanwhile, concrete stains were attached at the centre and 300mm from the left support to measure concrete strain, as shown in Figure 2b. The concrete strain gauge covered 60mm of the concrete depth. Also, the LVDTs that measure deflections were fixed at the centre and 300mm from left support, as shown in Figure 2c.

Testing: After 28 days of curing the samples, they were tested by setting them on a Magnus apparatus. All the LVDTs and strains were fixed to a load logger, and loads were applied at centre through the pump. The load logger recorded the corresponding deflections and strains. This was conducted at the Structures and Materials Laboratory (DO4), Faculty of Civil Engineering, UTM, Malaysia. Meanwhile, in Figure 3, deflection and concrete strain were measured at points A and B. While Shear strain was measured on the stirrup at point B, and the flexural strain was measured on flexural reinforcement at point B at bottom reinforcement.

(a)

(b)

(c)

Figure 2: (a) Reinforcement with steel strain gauges, (b) Concrete beam with a concrete strain gauge, (c) Concrete beam with LVDT

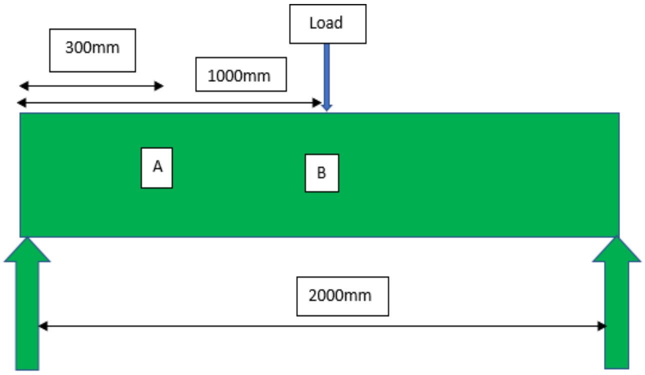


Figure 3: Schematic Representation of the locations (A & B) where Beam Deflection, concrete strain, Shear strain and flexural strain were measured

3.0 RESULTS AND DISCUSSION

3.1 Sieve Analysis for Fine and Coarse Aggregates

The fineness modulus for fine and coarse aggregates was 2.39 and 2.63, respectively. 96.5% of the coarse aggregates would pass through the 10mm sieve sizes, as shown in Figures 4a and b. This indicates that a bigger, more signification of the coarse aggregates is within the required scope for the research task. The Figures also display well-graded fine and coarse aggregate. Also, the percentage of all the aggregates, as depicted by the curves, lies between the lower and upper limits. As a result, it was classified into the medium category.

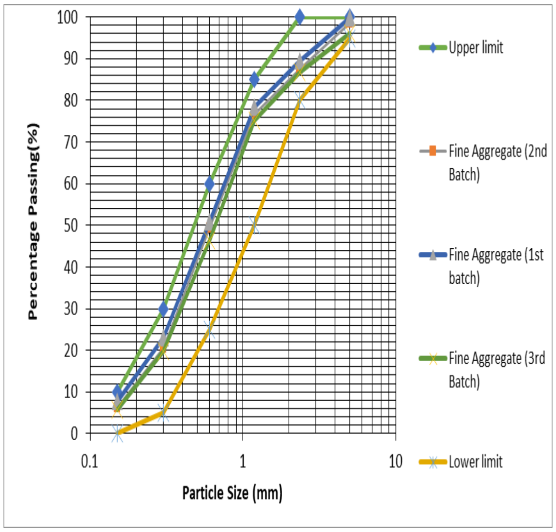


Figure 4a: Grading chart for fine aggregates

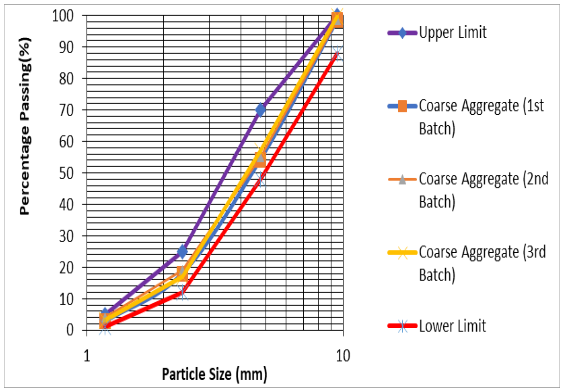


Figure 4b: Grading chart for coarse aggregates

3.2 Water Absorption of Treated and Untreated Kenaf Fibre

Applying the ASTM D570 [36] standard revealed that treated and untreated kenaf fiber absorbed water at rates of 8% and 16.67%, respectively. This result shows that the rate at which kenaf fibre absorbs water can be decreased by treating it to remove its dirt [6; 10]. The rate at which the untreated sample absorbed water was almost twice that of the treated sample, as indicated by the result. Therefore, another major problem of using untreated kenaf in concrete is its high-water absorption rate which will affect the workability of concrete and cause an incomplete hydration process within the concrete matrix.

3.3 Scanning Electron Microscopy for Kenaf Fiber

At T03, Universiti Teknologi Malaysia, Johor Bahru, a variable-pressure scanning electron microscope (SEM), JEOL JSM-IT300LV with a working voltage of 20kV, was used to observe the morphology of the alkaline-treated and untreated kenaf fibers. Figure 5 (a&b) shows the micro and macrographs of treated and untreated kenaf fiber. The micrographs of the treated fibre showed that the alkaline solution eliminated the wax and oil covering the exterior of the fiber cell wall. Additionally, it stopped the hydrogen bonds in the cellulose, hemicellulose, and lignin fibres linked to the structure, enhancing the fibre's surface roughness and interfacial characteristics (Figure 5b). The smooth surface of the untreated fibre shows the network of cellulose, wax, and oil covering the surface(Figure 5a), as reported by [5]. Figure 5d shows the chopped kenaf fibre to be used in concrete.

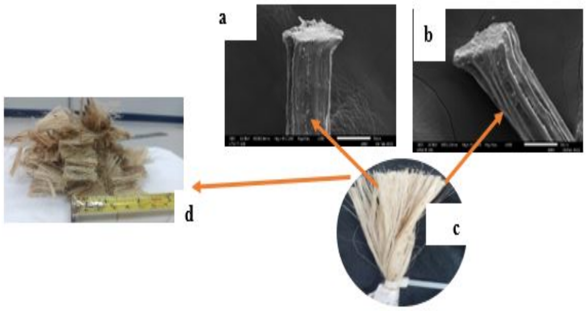


Figure 5: (a) SEM of untreated kenaf fiber, (b) SEM of treated kenaf fiber, (c) Kenaf fiber macro image, (d), Short discrete kenaf fiber

3.4 Elastic Modulus and Yield Stress of Steel

These steel characteristics were established using the BS EN ISO 6892-19 standard. The elastic modulus, yield stress, elongation, and ultimate stress for 16mm and 10mm yield high steel samples obtained were 224500MPa, and 238500MPa, 567.5MPa and 653MPa, 13% and 6.95%, 660.3MPa and 772.5MPa, respectively, all met the BS EN ISO 6892-19 [38] requirements for steel used in reinforced concrete.

3.5 Workability of Fresh Concrete

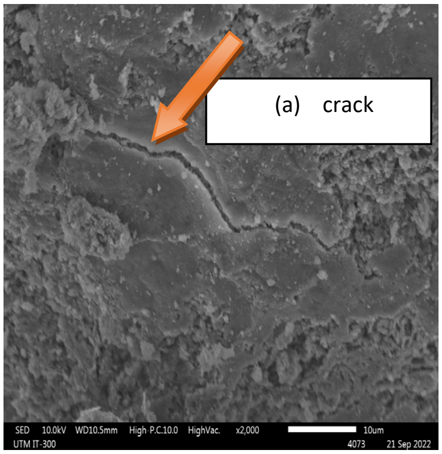
This study used the slump test to examine the workability of plain and fibre-reinforced concrete. A total of four mixes were prepared and tested. There are two samples for plain concrete (PCG40-1 and PCG40-2) and two for kenaf fiber concrete (KFCG40-1 and KFCG40-2). Table 2 lists the slump values of all the concrete mixtures for grade 40 concrete. Despite the fibre being hydrated before being added to the concrete, the amount of kenaf fibre had an impact on slump value. Compared to slump values for plain concrete, about 7.63% reduction was observed in the slump value of kenaf fibre-reinforced concrete as indicated in Table 2. It is important to note that the threads' interlocking hinders the flow of concrete, which impacts the substance's workability. Additionally, using KFR concrete reduces the dead load of the structures because its unit weight is less than plain concrete on the same Table. Existing studies show that fibre reduces the workability of concrete [42, 43, 44].

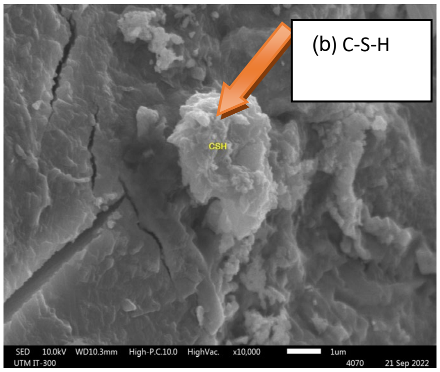
Table 2: Slump and Unit Weight of Concrete Mixtures.

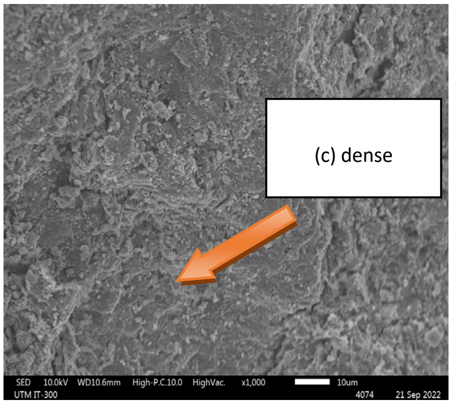
Mixture code	Slump (mm)	Average Slump (mm)	Unit weight (kg/m³)	Average Unit weight (kg/m³)
PCG40-1	66	65.5	2460	2422.5
PCG40-2	65		2385	
KFCG40-1	60	60.5	2350.32	2351.69
KFCG40-2	61		2353.06	

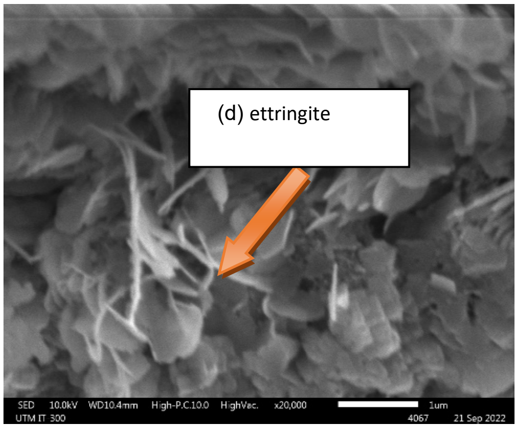
3.6 Scanning Electron Microscopy for Concrete Samples

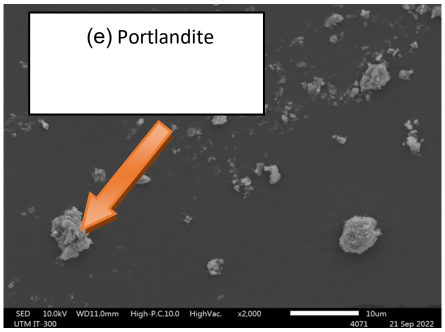
The results of plain concrete (grade 40) and kenaf fiber reinforced concrete (grade 40) are presented in Figures 5 and 6 below. Figures 6(a-g) and 7(a-g) show the micrograph of plain and KFR concrete that depicts an undamaged matrix at ambient temperatures, with ettringite, portlandite, quartz and C-S-H formations. It showed that C-S-H gel formations spread across both matrices. Also, Figure 9h shows the fiber, while Figure 9 shows a micrograph with a hole where the fiber has been pulled out. Meanwhile, Figures 9c and 10c show how dense the concrete samples were after observation. The concrete constituents were well compacted (with few or no voids,), especially with the addition of fiber. There was no unreacted cement during observation. The kenaf fibers could bridge the cracks, thereby reducing the number of cracks in concrete. Both matrices were without microcracks or pores, showing how the fibers are firmly enfolded by C-S-H gel, indicating the existence of a strong bond between the kenaf and cement paste. The SEM image shows that fiber has good interfacial bonding with the cement paste, leading to no cracks along the fiber surface.

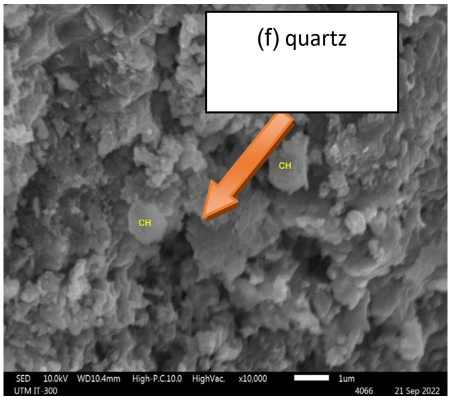












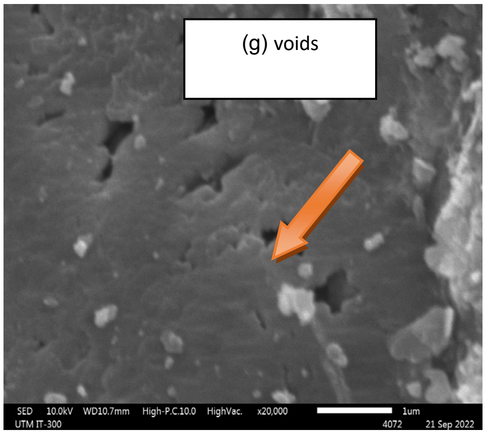


Figure 6: SEM for Plain Concrete (a-g)

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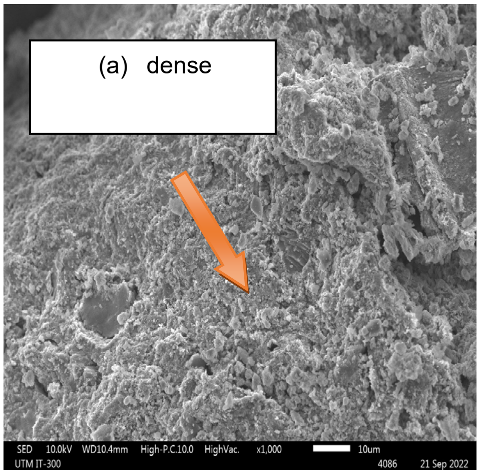

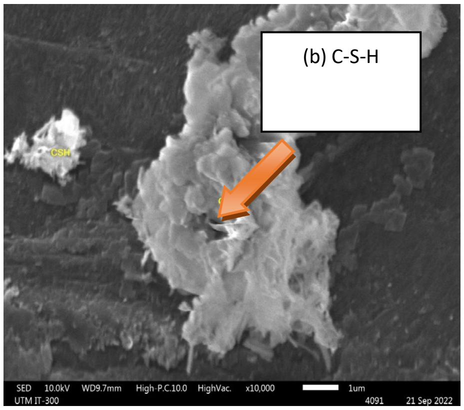

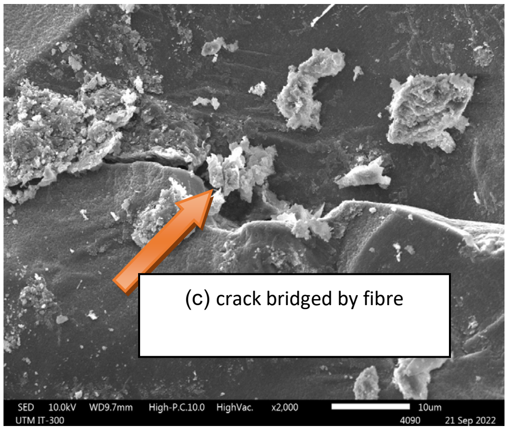

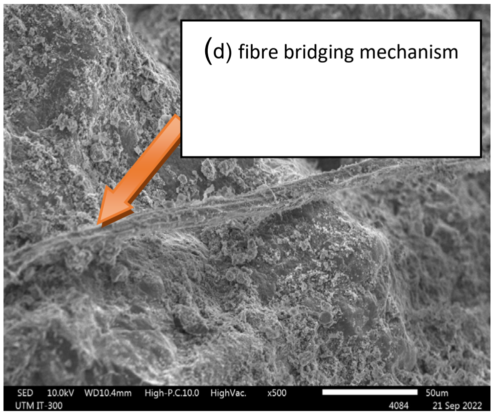

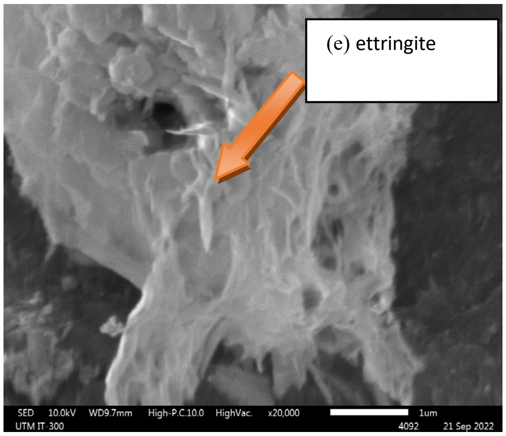

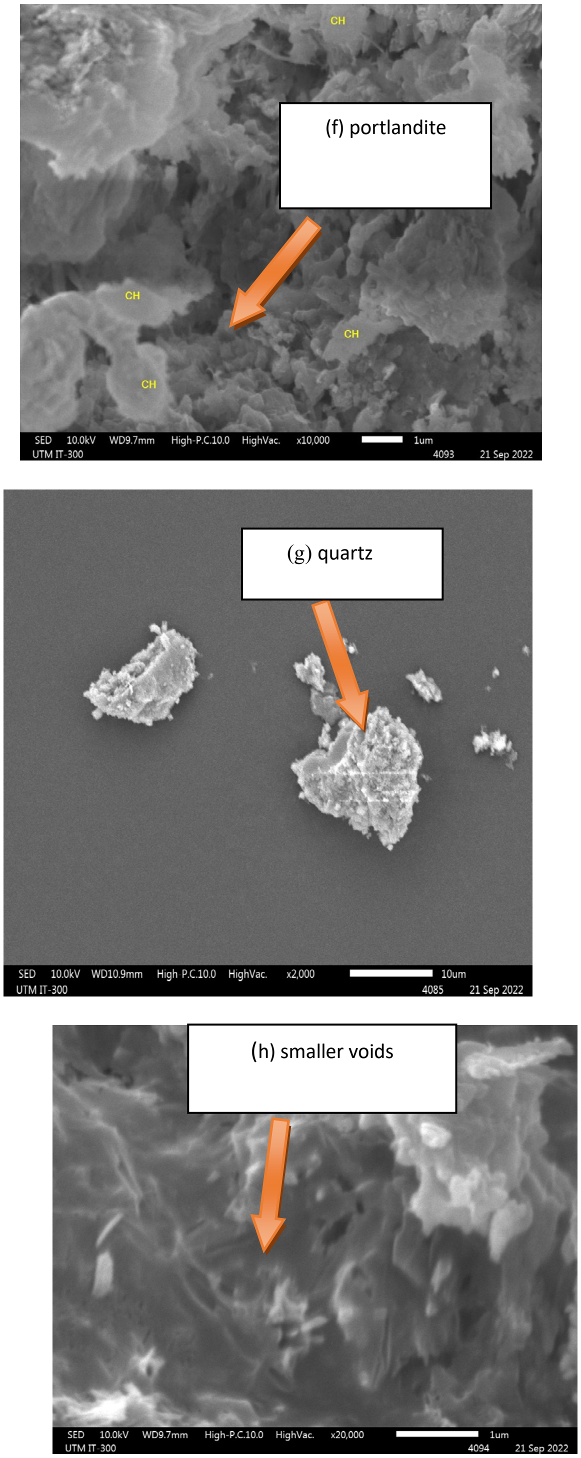

Figure 7: SEM for Kenaf Fiber Concrete (a-h)

3.7 Deflection and Strain Performance of Plain and Kenaf Fiber Beam Concrete

This section focused on deflections and strains of KFR concrete beams measured at its centre and along the span. Also, the strain on the shear and bottom flexural reinforcement at the centre of the KFR concrete Beam was measured.

3.7.1 Deflection measured at the Centre of the Beam

Figure 8 portrays deflection measured by LVDTs attached at the centre of the beam (loading point). Despite the deficiency in shear reinforcement, adding kenaf fibre reduced deflection with a 25% and 50% increase in shear reinforcement spacings. Kenaf fiber acted as reinforcement in concrete beams, providing additional resistance to deflection. The deflections obtained at 25% and 50% were less than that of control under the same loads. 25% and 50% increase in shear reinforcement spacing provided a 10.15% and 6.98% reduction in deflection when compared with control, while 75% increment, the addition of kenaf fiber could not offer effective resistance to deflection, deflection at this shear spacing was more than that of control. This is in line with other research suggesting that fibres could be used to complement shear reinforcement in reinforced concrete elements [45]. This was also observed by [31]. According to Solahuddin [1], kenaf fibre could give beams lacking shear reinforcement the ability to resist deflection. Additionally, it illustrates how kenaf fibre can reduce beam deflection by preventing cracks from developing and propagating in a beam with insufficient shear reinforcement when loaded [46].

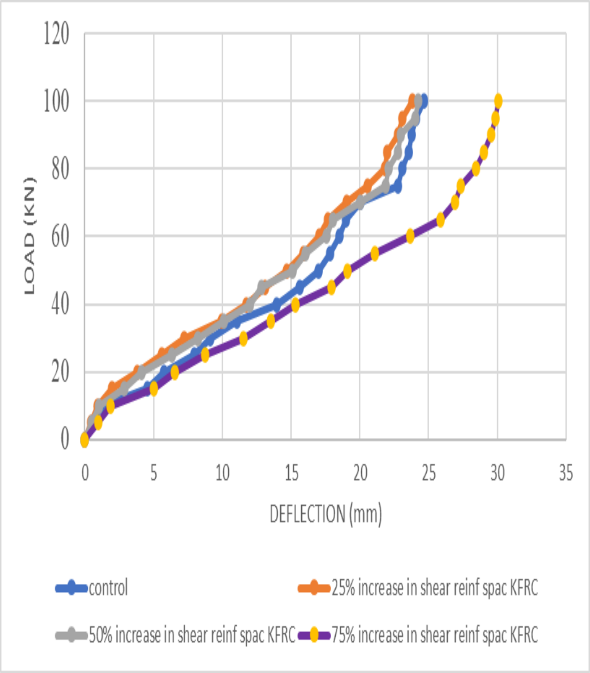

Figure 8. Beam deflection at the centre

3.7.2 Deflection Measured At 300mm From Left Support Of The Beam

Deflections were measured 300 mm from the left support of the beams because measuring deflection at a single point may not be sufficient to determine the deflection behaviour of kenaf fiber-reinforced beams. This is shown in Figure 9. It was generally observed that deflection increased as the load increased; adding kenaf fibre in concrete beams enhanced the beam's tenacity to resist deflection even at shear reinforcement deficiency. The beam with a 25% increment in shear reinforcement spacing gave the highest resistance to deflection along the beam span, followed by 50%. They performed better than the control, although a 75% increment was performed below the control. 25% and 50% increase in shear reinforcement spacing provided an 8.43% and 3.21% reduction in deflection when compared with control This result shows that the KFR concrete beam would perform satisfactorily in resisting deflection even with less shear reinforcement. Deflection along the span and at the loading point was reduced with kenaf fibre [30]. Fibre reinforcing is a valuable technology created to regulate better the tensile performance, the tensile post-cracking, and the tensile post-yield behaviour of concrete because plain concrete is frequently weak and brittle in tension compared to its capacity in compression. These defects can be partially fixed by using fibres with short and small diameters for reinforcement. The fibres' random distribution greatly enhances the material's tensile strength, ductility, and toughness [26].

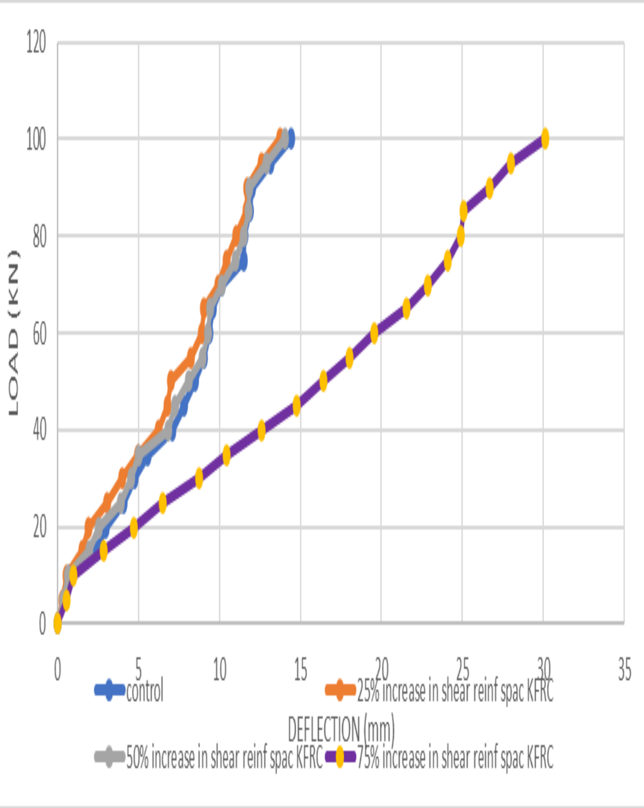

Figure 9. Beam deflection measured at 300mm from left support of beam

3.7.3 Concrete Strain Measured At Centre Of The Beam

Strain is the most delicate physical factor controlling how mechanically sound concrete structures behave. Due to the tendency of beam deterioration and damage (cracks, fire, and prestress loss) or external environmental changes (external force, support conditions, and temperature changes) to be reflected on the strain of concrete structures, strain measurement should be the first choice for structural health monitoring [47]. Figure 10 demonstrates the concrete strain measured by the concrete strain gauge attached to the concrete beam at the centre. There was a significant reduction in the concrete strains when kenaf fibre was introduced into concrete. It revealed that kenaf fibre enhanced concrete resistance to strain (deformation). Concrete deformation, cracks, etc., affect its durability; since kenaf fibre reduces concrete deformation, it indirectly improves concrete durability [48]. The beams with 25% and 50% increments in shear reinforcement spacings gave better resistance to concrete strain than the control; meanwhile, the beam with a 25% and 50% increase in shear reinforcement spacing provided a 37.56% and 19.58% reduction in concrete strain when compared with the control. The ability of kenaf fibre to bridge micro- and macro-cracks in the cementitious matrix may be the cause of its ability to lessen structural strain in concrete [12]. Also, good bonding between concrete and fibre could account for reducing concrete strain. Alogla & Kodur [49] concluded that normal-strength concrete experiences reduced strain when added fibres.

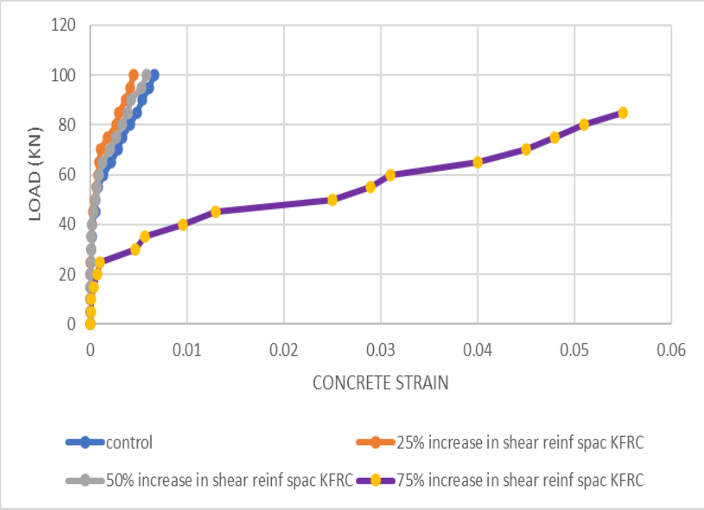

Figure 10. Concrete strain at the centre

3.7.4 Concrete Strain Measured At 30mm From Left Support The Beam

To ascertain the influence of kenaf fibre on concrete strain, concrete strains were measured 300mm from the left support, and the corresponding loads were recorded. The result is plotted in Figure 11. It shows a similar effect to concrete strain measured at the centre of the beam except that concrete strain at centre was higher; this was because loads were applied at that centre where concrete strains were taken. Therefore, it could be generalized that kenaf fiber could reduce concrete strain anywhere on the concrete beam where strain is considered. Furthermore, a 25% and 50% increase in shear reinforcement spacing provided a 28% and 13.2% reduction in concrete strain compared to control. This is because adding fibre reduces the transverse strain in concrete [45]. Deformation caused by strain in concrete influences the material's durability and overall performance. This shows the kenaf fiber's inadequacy at such an irrational rise in shear spacing, even though the concrete strain increased in the kenaf fibre reinforced beam with a 75% increment in shear spacing. It is significant to highlight that the correct volume and length of kenaf fibre additions, with shear spacing remaining below 50%, reduced concrete strain.

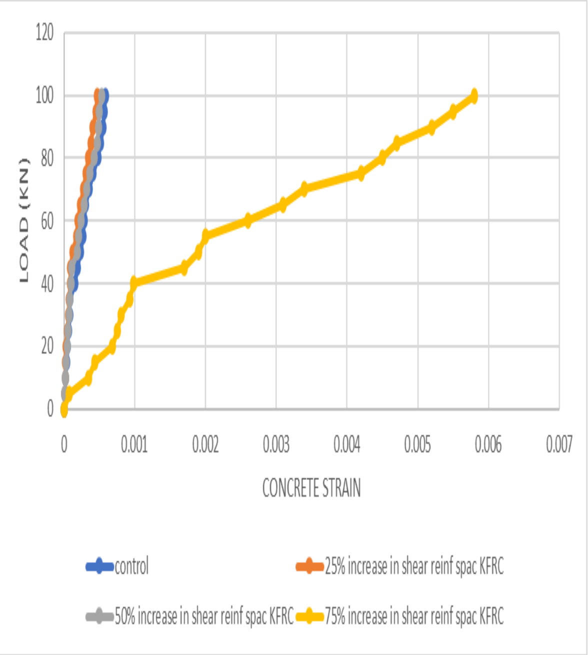

Figure 11. Concrete strain measured at 300mm from left support of the beam

3.7.5 The Strain on Shear Reinforcement at the Centre of the Beam

The strain on stirrups was measured using a steel strain gauge attached to stirrup at the centre of the beams. It was observed that kenaf fibre aided the performance of stirrups to resist steel strain, as shown in Figure 12. Stirrups' deformation affects the beam shear strength, causing the beam to fail in shear. Since kenaf fiber reduces the stirrup deformation, it increases the beam shear strength, thereby preventing the beam from failing in shear. 25% and 50% increase in shear reinforcement spacing provided a 46.43% and 15.48% reduction in shear steel strain when compared with the control. Fibre could act as a shear reinforcement supplement [45]. It helps to resist the strain that could have been borne alone by shear reinforcement. This was evident by the amount of strain experienced by shear reinforcement in the control sample. The effectiveness of kenaf fibre is limited to shear reinforcement not exceeding 50% increment; this was because, at 75% increment, more strain was experienced by the shear reinforcement.

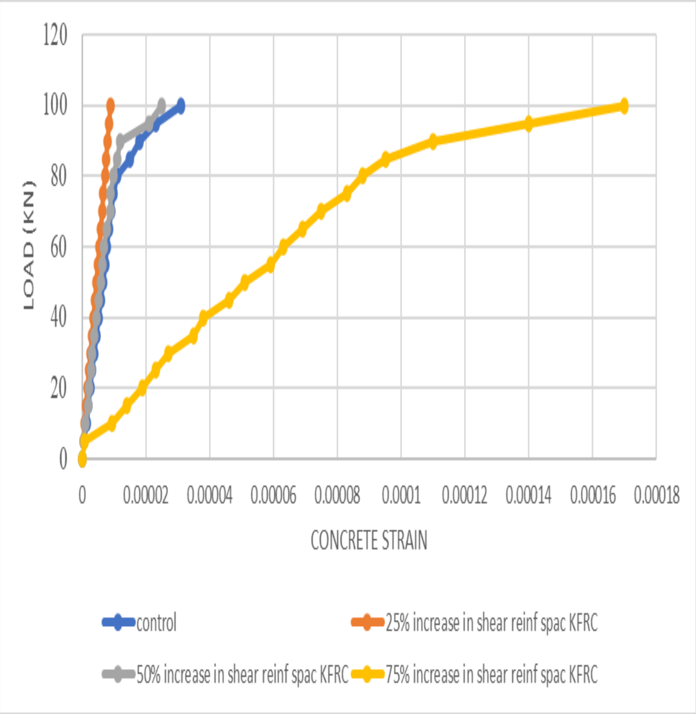

Figure 12. The strain on shear reinforcement at centre

3.7.6 Strain on the Bottom Flexural Reinforcement at the Centre of the Beam

Strain is not only experienced by concrete and shear reinforcement but also by flexural reinforcement. The bottom flexural reinforcement was selected because the bottom is in tension which caused it to experience more strain than the reinforcement. Figure 13 shows the flexural steel strain obtained at corresponding loads. Steel strain was observed to be reduced when kenaf fibre was introduced even at a lesser stirrup. Steel deformation affects structural integrity or safety of structures, but this can be prevented by including kenaf fibres. 25% and 50% increase in shear reinforcement spacing provided 13.79% and 6.25% reduction in flexural steel strain when compared with control. This is possible due to proper bonding between the fibre and steel. It was generally observed that kenaf fibre could reduce the number and cost of shear reinforcement without any adverse effect on the concrete and steel strain [45].

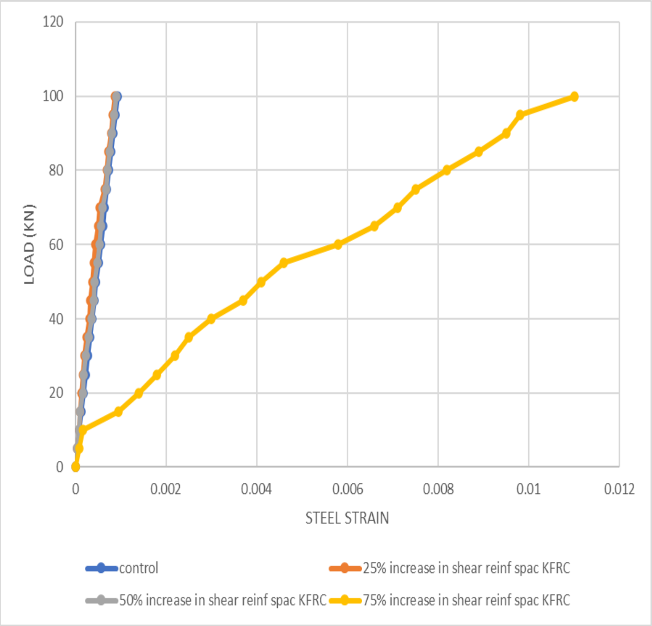

Figure 13. The strain on bottom flexural reinforcement at centre

3.8 Summary of Statistical Parameters

Table 3 contains the summary of the statistical data generated using SSPS software. The following data were generated; mean, standard deviation, R, R^2, Adjusted R, F change, Covariance, Std error of the estimate, and models to predict the beam parameters. It was observed from the same Table that all the mentioned data reduced for KFR beams with a 25% and 50% increase in shear reinforcement spacings. Also, deflection at the centre and along the span of the KFR beam was reduced by 10.15% and 6.98%, 8.43% and 3.21% for KFR beams, with 25% and 50% increase in shear reinforcement spacings, respectively. This reduction in deflection was traced to the impact of kenaf fiber in the beam. In the same vein, there were 37.56% and 19.58%, 28% and 13.2% reductions in concrete strain at the centre and along the span of the KFR beam with 25% and 50increasesse in shear reinforcement spacings, respectively. Finally, strains on shear and flexural reinforcements were reduced by 46.43% and 15.48%, 13.795 and 6.25% for KFR beams, with 25% and 50% increase in shear reinforcement spacings, respectively. Each of these beam parameters can be predicted by using the models in Table 4

Table 3: Summary of Statistical Data

S/N	**Beam parameters**		**STATISTICAL PARAMETERS**								
			Mean	**Std. Deviation**	**R**	**R Square**	**Adj. R Square**	**F Change**	**Covariance**	**The std error of the estimate**	**Model**
1	Deflection @ centre	Control	14.48	8.46	0.98	0.96	0.958	460.346	0.028	6.337	Defl. = 0.27load + 1.112
		KFRB (25%)	13.01	8.34	0.988	0.977	0.975	791.71	0.017	4.87	Defl. = 0.266load – 0.288
		KFRB (50%)	13.47	8.48	0.989	0.978	0.977	857.381	0.015	4.686	Defl. = 0.27load – 0.054
		KFRB (75%)	17.73	10.60	0.983	0.965	0.964	529.545	0.016	5.923	Defl. = 0.336load + 0.939
2	Deflection along the span	Control	7.47	4.43	0.989	0.978	0.977	853.34	0.056	4.69	Defl. = 0.141load + 0.399
		KFRB (25%)	6.84	4.39	0.995	0.989	0.989	1721.139	0.029	3.32	Defl. = 0.141load – 0.2
		KFRB (50%)	7.23	4.41	0.991	0.981	0.98	1005.74	0.048	4.33	Defl. = 0.141load + 0.184
		KFRB (75%)	15.21	9.93	0.994	0.988	0.988	1588.80	0.006	3.46	Defl. = 0.318load -0.704
3	Concrete strain centre	Control	0.00189	0.00227	0.914	0.835	0.826	95.93	1624010	12.94	Strain = 6.69x10^{-5}load-0.001
		KFRB (25%)	0.00118	0.00149	0.886	0.785	0.774	69.394	4861754	14.75	Strain = 4.27x10^{-5}load-0.001
		KFRB (50%)	0.00152	0.00189	0.898	0.806	0.796	78.92	272320.039	14.02	Strain = 5.5x10^{-5}load-0.001
		KFRB (75%)	0.0278	0.0275	0.962	0.926	0.922	236.45	4975.283	8.68	Strain = 0.001load-0.015
4	Concrete strain along the span	Control	0.00025	0.000204	0.983	0.966	0.964	538.758	41379055.84	5.87	Strain = 6.47x10^{-6}load-0.000073
		KFRB (25%)	0.00018	0.000158	0.973	0.947	0.945	342.735	105712670.9	7.29	Strain = 4.98x10^{-6}load-6.6x10^{-6}
		KFRB (50%)	0.000217	0.000185	0.975	0.95	0.948	364.32	7349788.271	7.086	Strain = 5.8269x10^{-6}load-0.000073
		KFRB (75%)	0.00236	0.00194	0.976	0.953	0.95	381.954	632161.231	6.928	Strain = 0.0000613load-0.001
5	The strain on shear reinforcement @ centre	Control	0.0000084	0.0000077	0.89	0.792	0.781	72.527	6.86E-16	14.502	Strain = 2.23x10^{-7}load - 2.8x10^{-6}
		KFRB (25%)	0.0000045	0.00000278	1.00	1.00	1.00	255321.737	3.16E-20	0.2745	Strain = 8.98x10^{-8}load – 8.7x10^{-9}
		KFRB (50%)	0.0000071	0.0000063545	0.893	0.797	0.786	74..426	4.49E-16	14.354	Strain = 1.83x10^{-7}load - 2.1x10^{-6}
		KFRB (75%)	0.0000578	0.00004531	0.96	0.921	0.917	220.65	8.9E-15	8.962	Strain = 1.4x10^{-6}load - 1.2x10^{-5}
6	The strain on flexural reinforcement @ centre	Control	0.000464	0.000289	1.00	1.00	1.00	186574.805	4.65E-16	0.321	Strain = 9.31x10^{-6}load – 1.5x10^{-6}
		KFRB (25%)	0.0004	0.000276	0.994	0.988	0.987	1559.529	5.01E-14	3.492	Strain = 8.84x10^{-6}load – 4.2x10^{-5}
		KFRB (50%)	0.000435	0.000282	0.999	0.998	0.998	9321.69	8.89E-15	1.435	Strain = 9.1x10^{-6}load - 2x10^{-5}
		KFRB (75%)	0.00471	0.0035	0.993	0.986	0.985	1358. 502	9.42E-12	3.73	Strain = 0.0001load -0.01

4.0 CONCLUSION

The following conclusions were drawn based on the outcomes of the investigation carried out:

- The concrete matrix and kenaf fiber have a good interaction, as observed by scanning electron microscopy.
- Kenaf fiber reduced the deflection of the beam not only at the loading point but also along the span of the beam
- Kenaf fiber improves concrete resistance to strain
- The inclusion of kenaf fiber reduces the strains on shear and flexural reinforcements in concrete
- The shear reinforcement spacing could be increased between 25% to 50% without adverse effects on the deflection and strain performance of the beam if kenaf fibre is introduced into concrete to complement shear reinforcement deficiency
- Number of shear reinforcement in concrete beam could be reduced when kenaf fibre is added.

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