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Original Article

Effect of Chemical Treatment of Kenaf Fibers on the Structural Performance of Reinforced Concrete Beam

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Abstract - *This paper seeks to evaluate the impact of various chemical pretreatments applied to kenaf fibers on both the mechanical characteristics of concrete and the structural behavior of a reinforced concrete beam. The presence of microcracks limits reinforced concrete constructions. Hence, kenaf fibers are used as a substitute. Multiple investigations have demonstrated that inadequate treatment of kenaf fibers fails to resolve the problem of interfacial adhesion between the kenaf fibers and concrete. The study examines the use of chemical treatments to improve the bonding between kenaf fibers and the concrete matrix. Several chemical agents, including Sodium hydroxide (NaOH), Potassium permanganate (KMnO4), Potassium dichromate (K2Cr2O7), and Hydrogen peroxide (H2O2), are employed to alter the surface properties of kenaf fibers. The goal is to enhance the overall mechanical properties of the composite material by improving the compatibility between the hydrophilic nature of kenaf fibers and the hydrophobic nature of concrete. Scanning Electron Microscopy (SEM) and Fourier-Transform Infrared Spectroscopy (FTIR) are used to examine the microstructural and mechanical alterations caused by the chemical treatments. Following the application of analytical procedures to fibers treated with various chemical agents, multiple samples of cubes, cylinders, and small beams are subjected to testing for compressive strength, splitting tensile strength, and flexural strength at intervals of 0%, 0.25%, 0.5%, 0.75%, 1%, 1.25%, 1.5%, 1.75%, and 2%. Ultimately, a set of reinforced concrete beams are constructed, utilizing both untreated fibers and treated fibers, with the precise proportion of fibers determined from previous investigations on the mechanical characteristics of fiber-reinforced concretes. An analysis is conducted on the bending and microfractures of the beams following the bending tests. The findings demonstrated that kenaf fibers, when subjected to an alkaline solution followed by potassium dichromate treatment, had excellent structural properties when used to reinforce concrete beams.*

Keywords - *Kenaf fibers, Chemical pretreatments, Reinforced concrete, Interfacial adhesion, Mechanical properties.*

1. Introduction

In the quest for durable construction materials, natural fibers have emerged as promising alternatives to conventional reinforcements such as steel in reinforced concrete structures. Among these fibers, kenaf, a rapidly growing plant, has garnered attention as a potential candidate due to its favorable mechanical properties and environmental benefits. However, the utilization of kenaf fibers in reinforced concrete remains relatively unexplored, particularly concerning the effects of chemical treatment on their structural performance.

Kenaf, also known by its scientific name Hibiscus cannabinus, is a plant belonging to the Malvaceae family, native to tropical and subtropical regions where it thrives. This plant typically reaches a height ranging from 1.5 to 3.5 meters and has a woody base [1]. The Kenaf fibers used in this study come from the village of Kie, located in the Grand Samba department of the Passoré province in the Northern region of Burkina Faso. Various physicochemical and mechanical characteristics of kenaf fibers from countries such as Malaysia, Thailand, India, China, the southern United States, Mexico, and Korea have been discussed in the literature, which is not the case for kenaf fibers from Burkina Faso [1]. In the field of construction, different plant fibers, such as jute fiber [2], coconut fiber [3], kenaf fiber [4], and sisal fiber [5], have been used as reinforcement in concrete. Despite the numerous advantages of kenaf fibers when mixed with concrete, they have some limitations. When they come in contact with the alkaline pore solution of Portland cement concrete, their mechanical characteristics can degrade due to alkaline hydrolysis, which may jeopardize the longevity of natural fiber-reinforced cement composites [6]. Another aspect to consider regarding kenaf fibers, which have buoyant characteristics, is their content of hemicellulose, lignin, and fats, which can have an inhibitory effect on cement hydration or delay concrete setting [7]. Additionally, unwanted substances like pectin and wax deposit on the surface of plant fibers, thus limiting their integration with concrete.

Given that concrete is a material whose components are inorganic substances, it is preferable to use certain inorganic chemicals to treat fibers in order to eliminate interference from chemicals used on cement hydration. There are several alkaline products, as in [8, 9], potassium dichromate [10] and potassium permanganate [11]. The common method of fiber treatment is alkaline, aimed at reducing hydrogen bonds through the reaction of hydroxyl groups of fibers with alkaline substances.

It has been reported that the use of an alkaline solution in the treatment process can remove pectin, wax, lignin, and hemicellulose from fibers [12, 13]. It has also been proven that alkaline treatment can contribute to reducing water absorption [14] and increasing tensile strength [15]. In addition to alkaline treatment, it has been reported that treatment with potassium permanganate can roughen and enlarge the surface of fibers [16].

In this study, an oxidizing agent (sodium hydroxide) is used initially, followed by oxidizing agents (hydrogen peroxide, potassium dichromate, and potassium permanganate) to modify kenaf fibers. The results obtained through various fiber characteristics have allowed the use of these fibers in the properties of fiber-reinforced concrete and to achieve optimum performance in a reinforced concrete beam.

The use of kenaf fibers as reinforcements in concrete is nowadays a more relevant research field. Several areas, particularly research, attest that kenaf fibers are among the best materials capable of replacing synthetic fibers. Their characteristics of flexural and tensile strength make them a good candidate for application as reinforcement material in concrete [17].

From [4], it is found that Kenaf Fiber-Reinforced Concrete (KFRC) generally exhibits more uniformly distributed cracking and increased strength compared to ordinary concrete. They also noted that this cracking improves the durability of concrete at a relatively low cost compared to other types of fibers. They determined that the optimal mixing proportions of KFRC are 1.2% and 2.4% fiber content. [18] studied the mechanical properties of kenaf fiber-reinforced concrete with different fiber contents and fiber lengths. Their results showed that the workability of KFRC is lower than that of ordinary concrete. Regarding the mechanical characteristics of KFRC, it was observed that its compressive strength decreases with increasing fiber content. However, the study also revealed that by adding an adequate amount of fibers and adjusting their length in the concrete, flexural strength and indirect tensile strength could increase while allowing KFRC to achieve a compressive strength comparable to that of ordinary concrete. [19] conducted their study on mechanical properties with different volumetric fractions of fibers. The results reveal that kenaf fiber, due to its hydrophilic nature, leads to higher water absorption in the mixing proportions. The integration of this fiber improves tensile strength and ductility but leads to a decrease in the compressive strength of concrete.

The study [20] worked on the structural behavior of concrete beams reinforced with kenaf fibers. The experimental results indicate that the addition of kenaf fibers leads to a notable increase in load carrying capacity, ductility, and shear strength of the beams. Additionally, a change in the failure mode was observed, shifting from shear to flexural failure. In conclusion, this study supports that kenaf fibers are suitable for use in reinforced concrete, offering promising prospects. [21] studied the behavior of concrete beams reinforced with oil palm shells supplemented with kenaf fibers.

Their results indicate that the inclusion of kenaf fibers enhances load capacity and ductility while modifying the failure mode of beams from a brittle shear mode to a ductile flexural mode. Furthermore, the study demonstrates that kenaf fibers are suitable for fiber-reinforced concrete with oil palm fibers, yielding satisfactory results.

The objective of this study is to characterize the mechanical properties of concrete reinforced with kenaf fibers treated with different chemicals, as well as to investigate the structural performance of a reinforced concrete beam reinforced with kenaf fibers. The performance of the beam is evaluated using kenaf fibers obtained from the optimal treatment.

2. Materials and Methods

The basic materials used in this study are kenaf fibers, Ordinary Portland Cement (OPC), fine aggregates, coarse aggregates, and water. The kenaf fibers underwent an extensive treatment process with various chemicals followed by several tests.

2.1. Chemical Treatment

2.1.1. Alkaline Treatment

The manually extracted fibers collected in Burkina Faso were treated with a 6% Sodium hydroxide solution (LOBA CHEMIE PVT.LTD) for one hour at room temperature. The kenaf fibers were mixed with a NaOH solution in a ratio of 1:25 (by weight). After the alkaline treatment, the kenaf fibers were washed with water until they reached a neutral pH. Subsequently, they were dried in the air for 24 hours and then subjected to 4 hours of heating at 100°C in an oven.

2.1.2. Alkaline-Potassium Permanganate Treatment

The kenaf fibers, which had been pre-treated in an alkaline solution, were subsequently treated with a 0.02% solution of potassium permanganate ($KMnO_4$, SPAN CHEMIE LAB) for 2 minutes at room temperature. The pH of the solution was 8.83. Following the application of potassium permanganate, the kenaf fibers were washed with water until they reached a neutral pH. Subsequently, they were dried in the open air for 24 hours and then subjected to an additional 4 hours of drying at a temperature of 100°C in an oven.

2.1.3. Alkaline-Potassium Dichromate Treatment

The kenaf fibers, which had been pre-treated in an alkaline solution, were subsequently treated with 0.02% potassium dichromate ($K_2Cr_2O_7$, SPAN CHEMIE LAB) for 2 minutes at room temperature. The pH of the solution during this treatment was measured to be 6.47. Following the potassium dichromate treatment, the kenaf fibers were washed with water until they reached a neutral pH. Subsequently, they were dried in the open air for 24 hours and then subjected to an additional 4 hours of drying at a temperature of 100°C in an oven.

2.1.4. Alkaline-Hydrogen Peroxide Treatment

The kenaf fibers that had been pre-treated in an alkaline solution were then treated with 11.2 ml of hydrogen peroxide (H_2O_2, SPAN CHEMIE LAB) per 100 ml of solution for 2 hours at a temperature of 80°C, with a pH value of 6.73. Following the hydrogen peroxide treatment, the kenaf fibers were washed with water until they reached a neutral pH. Subsequently, they were dried in the air for 24 hours and then subjected to an additional 4 hours of drying at a temperature of 100°C in an oven.

2.2. Properties of Kenaf Fibers

2.2.1. FTIR Spectroscopy

The kenaf fibers in this study were evaluated using a Fourier Transform Infrared (FTIR) spectrometer after they were grounded.

The FTIR study was performed utilizing a Spectrum 100 series spectrometer. An analysis was conducted on kenaf fibers that had undergone different chemical treatments within the wavenumber range of 550 to 4400 cm^{-1}. The FTIR test enables the identification and analysis of chemical alterations taking place in kenaf fibers, such as the elimination of hemicellulose, lignin, and other contaminants.

2.2.2. Scanning Electron Microscopy Test

The surface morphology of kenaf fibers was analyzed using Scanning Electron Microscopy (SEM). An electron detector, specifically designed to detect secondary electrons, was utilized at a voltage of 20 kV to examine any alterations in the surface structure of the fibers after the treatment.
The Scanning Electron Microscopy (SEM) analysis was conducted in the mechanical laboratory of the Faculty of Mechanical Engineering at the University of Johannesburg. The investigation utilized the VEGA3 scanning electron microscope, which TESCAN provided.

2.3. Mechanical Properties Test

To achieve the objectives regarding mechanical properties, various laboratory tests were conducted. Different sets of tests, including the compressive strength test, flexural strength test, and indirect tensile strength test, were performed to study the mechanical properties of hardened concrete.

2.3.1. Mix Design

The objective of the study was to attain a concrete strength of Grade 30 by employing the Design of Experiments (DOE) methodology. The cubes had dimensions of 100 mm x 100 mm x 100 mm; the cylindrical mold had a height of 200 mm and a width of 100 mm, and the rectangular beam mold had dimensions of 100 mm x 100 mm x 350 mm. The concrete samples' mix proportions are specified in Table 1. A total of 486 specimens underwent testing, with distribution based on each fiber treatment procedure.

Table 1. Mix design

Fiber Content (%)	Cement (Kg/m3)	Fine Aggregate (Kg/m3)	Coarse Aggregate (Kg/m3)	Water	w/c Ratio	Superplasticizer (%)
0	390	750	881	230	0. 59	0
0.25	390	750	881	230	0. 59	0
0.50	390	750	881	230	0. 59	0
0.75	390	750	881	230	0. 59	0.9
1.00	390	750	881	230	0. 59	0.9
1.25	390	750	881	230	0. 59	0.9
1.50	390	750	881	230	0. 59	0.9
1.75	390	750	881	230	0. 59	0.9
2.00	390	750	881	230	0. 59	0.9

The concrete mixing process entails the precise measurement of aggregates and cement, followed by thorough mixing until a uniform consistency is achieved. Afterwards, a measured quantity of water was added and thoroughly mixed until a suitable texture was obtained. Then, the required fibers were added and blended. The superplasticizer was introduced into the water and subsequently blended with the fiber-reinforced concrete, commencing with a fiber concentration of 0.75%. Compaction was achieved by employing a concrete vibrator.

A slump test was performed on every concrete sample collected. After 24 hours, the solidified concrete was extracted from the mold and subsequently submerged in water to ensure proper curing. The curing technique adhered to the BS 1881, part 111 (1983) standard, with a curing duration of 7 days and 28 days for this research

2.3.2. Compressive Strength Test

The compressive strength test was conducted at 7 and 28 days for the KFRC cubes. For each percentage of fibers, 3 cubes with dimensions of 100 mm x 100 mm x 100 mm were prepared, cured, and crushed until the maximum compressive load was obtained.

2.3.3. Flexural strength test

The flexural strength test was conducted at 7 and 28 days for the KFRC beams. For each percentage of fibers, 3 beams with dimensions of 100 mm x 100 mm x 350 mm were tested to evaluate the flexural strength. Equal loads were applied on each side of the beam from the support points and at the center of the beam.

2.3.4. The Split Tensile Strength

Split tensile strength tests were conducted on cylinders with dimensions of 100mm in diameter and 200mm in depth. Samples of plain concrete and Kenaf fiber reinforced concrete (treated with different chemical solutions) were cast at varying percentages of fibers (0.25%, 0.5%, 0.75%, 1%, 1.25%, 1.5%, 1.75%, and 2%). The strength values at 7 and 28 days were obtained using a compression machine. An average strength of 3 samples was considered for each.

2.3.5. Structural Performances

After studying the mechanical properties of kenaf fibers under different chemical treatments, kenaf fibers treated with an alkaline solution and potassium dichromate with a proportion of 1.5% were selected to assess their performance in a reinforced concrete beam. A series of reinforced concrete beams were used for control, while others were reinforced with the fibers and tested at 28 days. The beams had dimensions of 1500mm x 200mm x 150mm. Two beams were cast for each composition in both series and then subjected to a four-point bending test. The loading arrangement on the beam is provided in Figure 1.

3. Results and Discussion

3.1. FTIR Spectroscopy

The FTIR spectra of untreated kenaf fibers and kenaf fibers treated with chemicals are depicted in Figure 1. Details of the FTIR spectra and qualifications of functional groups of the samples are provided in Table 2.The peak between 3500 and 3000 cm^(-1) represents the O-H stretching vibration, N-H stretching, and H-bonding of hydroxyl groups attributed to intramolecular and intermolecular hydrogen bonding and free OH hydroxyl groups. The peak at 3300 cm^(-1) could be attributed to strongly bound water, i.e., water directly bound by hydrogen bonds to the OH groups of cellulose and hemicelluloses [22]. The peak between 3000 and 2500 cm^(-1) signifies the C-H stretching vibration of methyl and methylene groups present in cellulose and hemicellulose [23]. The peak between 2000 and 1500 cm^(-1) denotes the stretching vibration of the carbonyl group (C=O), indicating the presence of ketones and aldehydes. The peak between 1500 and 1000 cm^(-1) denotes the stretching vibration of the C-C, C-H, symmetric N-O, C-N, =C-H groups present in cellulose, hemicellulose, and lignin [24, 25]. The peak was between 526 and 516 is attributed to the alkyl halides bond.

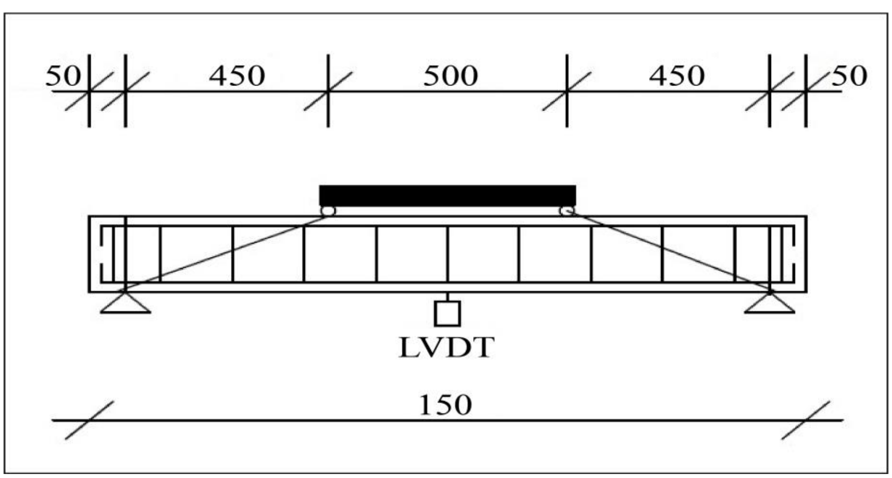

Fig. 1 Loading arrangement for the beam

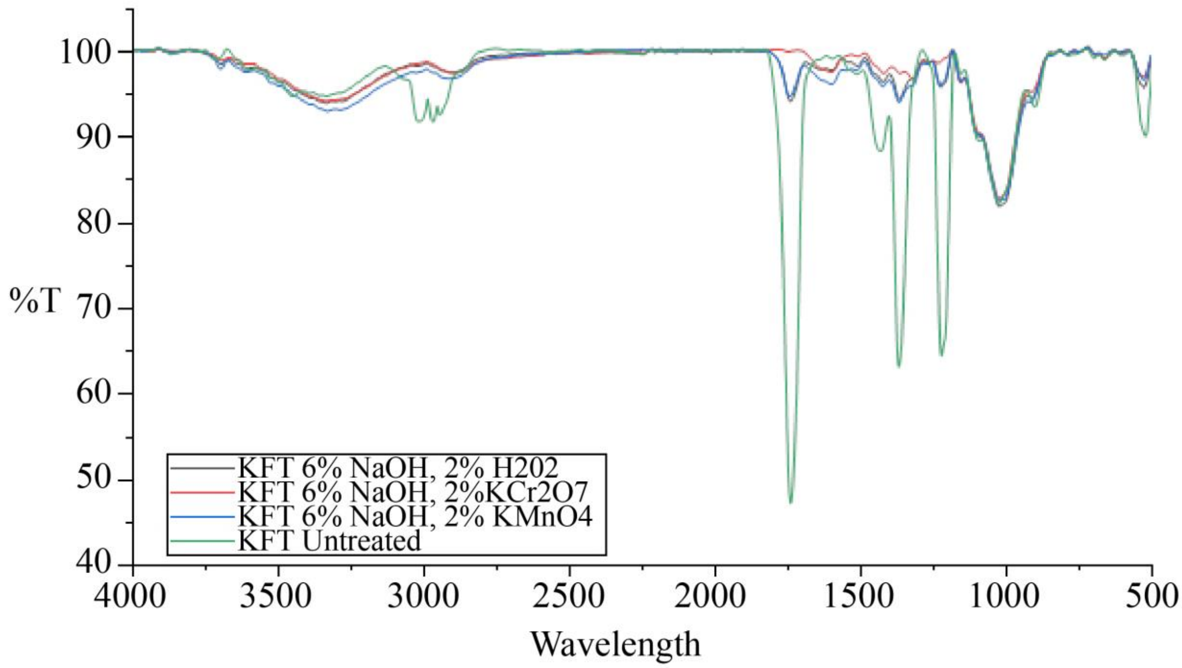

Fig. 2 FTIR spectra

Table 2. FTIR spectral data

Peak Label	Wavelength	Peak Position				Chemical Bounds
		Untreated	6% NaOH, 2% KMnO4	6% NaOH, 2% H2O2	6% NaOH, 2% K2Cr2O7	
	3500-3000	3350	3319	3315	3327	O-H stretch, H-bonded, N-H stretch
		3024	-	-	-	O-H stretch, C-H stretch
	3000-2500	2968	2916	2899	2899	C-H stretch
	2500-2000	-	-	-	-	
	2000-1500	1735	1730	1741	1604	C=O stretch
		-	1591	-	-	C-C stretch, N-H bend
	1500-1000	1431	-	-	-	C-C stretch
		1363	1363	1361	1325	C-H rock, N-O symmetric stretch
		1217	1226	1224	-	C-N stretch
		1022	1016	1012	1024	=C-H bend
	1000-500	516	526	526	526	C-Cl stretch

3.2. SEM Analysis

The morphology of the fiber surface was observed using the Scanning Electron Microscope (SEM) apparatus. By analyzing each image (Figures 3, 4, 5, and 6), a significant difference is noticeable between the untreated fibers and the fibers treated with different proportions of chemical components. The treatments involving alkaline potassium dichromate, alkaline potassium permanganate, and alkaline hydrogen peroxide render the fibers a cleaner surface compared to untreated fibers. Untreated fibers are covered with lignin, hemicellulose, and wax, which the chemical treatments can remove from the fiber surfaces. Kenaf fibers that underwent alkaline treatment with potassium dichromate exhibit a smoother surface compared to fibers treated with alkaline potassium permanganate and alkaline hydrogen peroxide solutions.

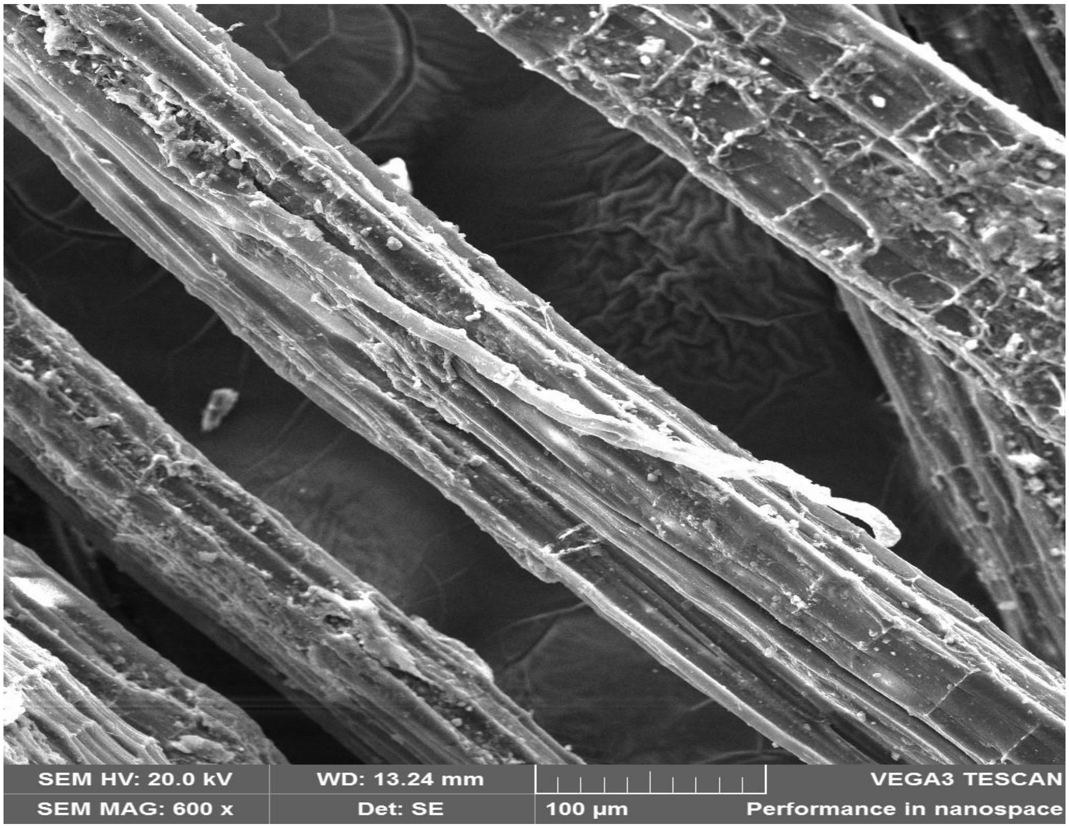

Fig. 3 Kenaf fibers untreated

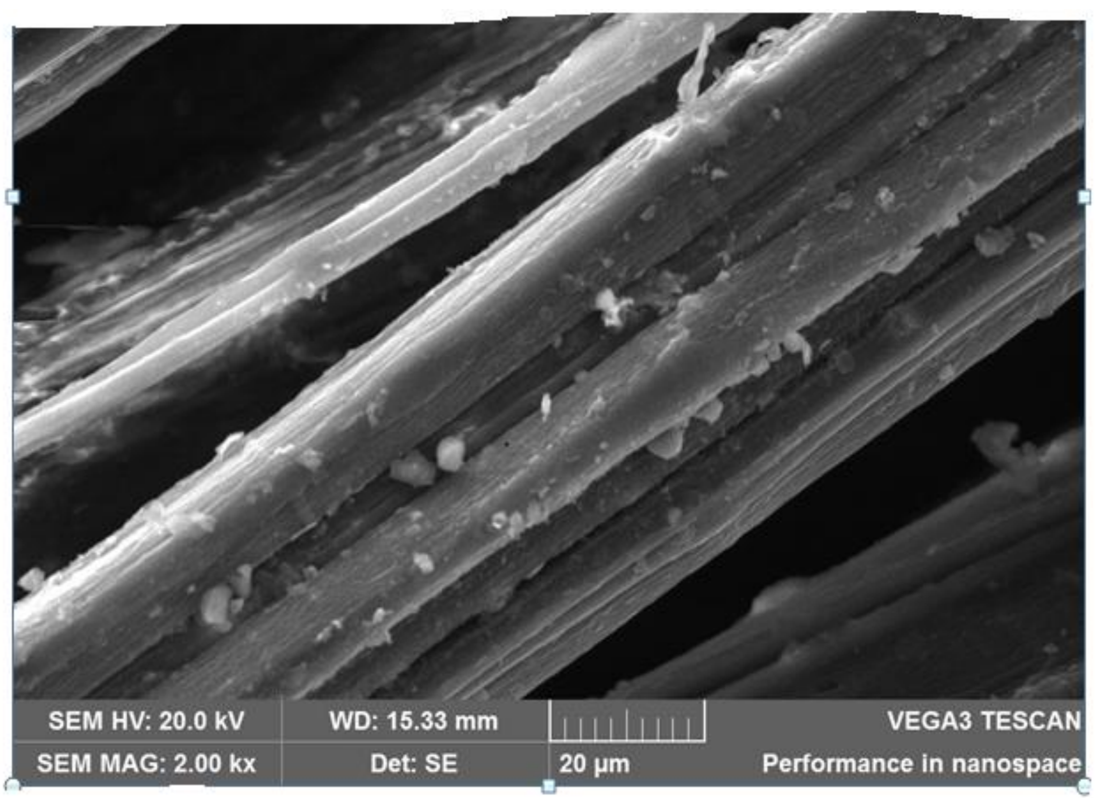

Fig. 4 Kenaf fibers treated with 6% NaOH, 2% $K_2Cr_2O_7$

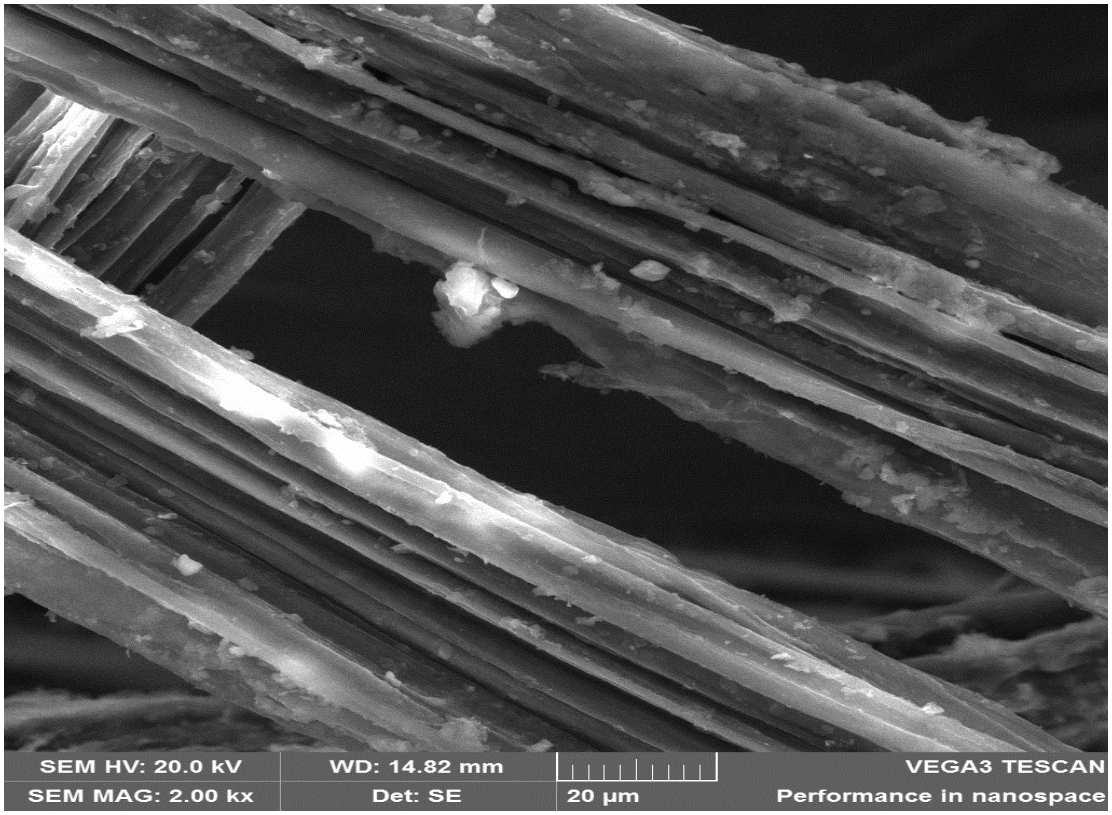

Fig. 5 Kenaf fibers treated with 6% NaOH, 2%$KMnO_4$

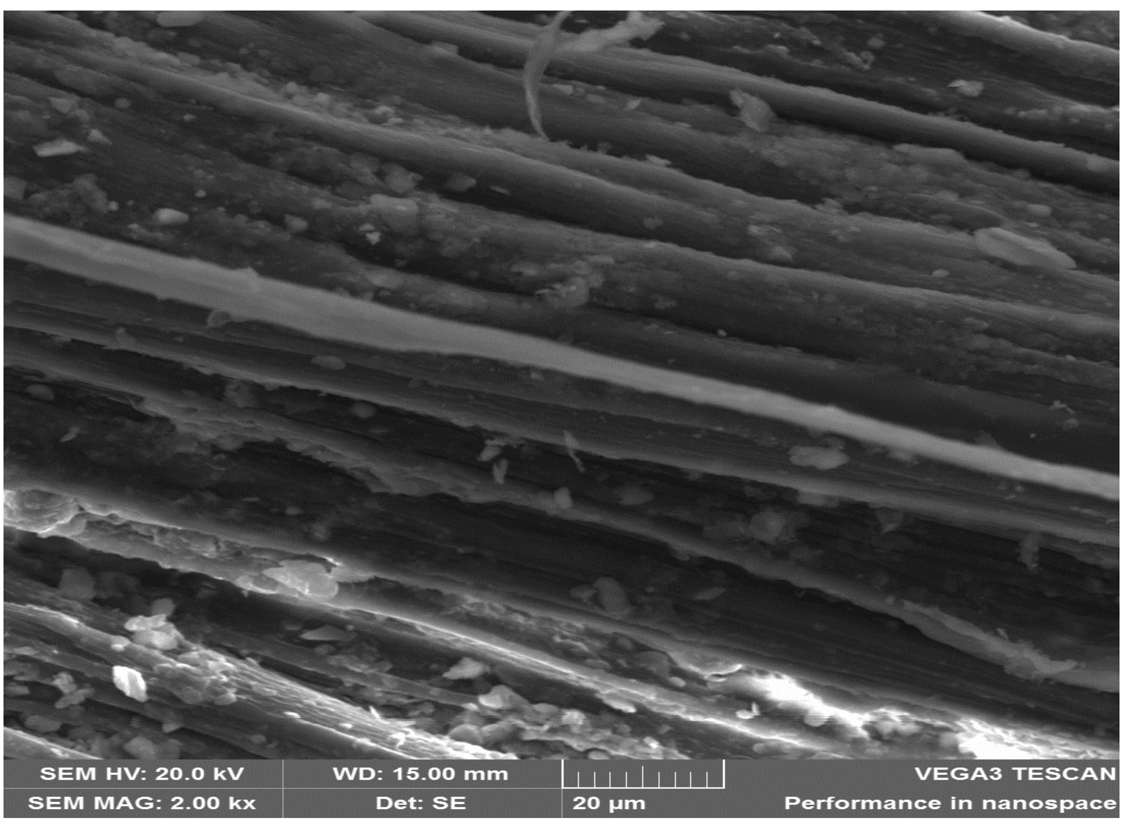

Fig. 6 Kenaf fibers treated with 6% NaOH, 2% H_2O_2

3.3. Compressive Strength Test

To evaluate the compression strength of KFRC under different types of chemical treatment, several cube samples were tested at 7 and 28 days. The compression strength conducted on the cubes was compared to that of normal concrete, which served as the control. The control concrete cubes exhibited sudden cracking upon failure. In contrast, the kenaf fiber-reinforced cubes with different treatments applied to the fibers showed multiple cracks distributed across their surface. It was observed that the cracks appeared progressively before failure.Figures 7, 8 and 9 show the results of compression strength tests at 7 and 28 days. The compression strengths of the control concrete, concrete reinforced with fibers treated with potassium dichromate alkaline solution, potassium permanganate alkaline solution, and hydrogen peroxide alkaline solution, are presented. The results indicate that the addition of kenaf fibers at each proportion results in a reduction in compression strength. It is evident that with each increase in the proportion of fibers, there is a decrease in compression strength. It can be observed that the concrete reinforced with fibers treated with potassium dichromate alkaline solution does not exhibit a more significant decrease in compression strength compared to the others. This negative reduction in compression strength may be due to the overall reduction in concrete density.

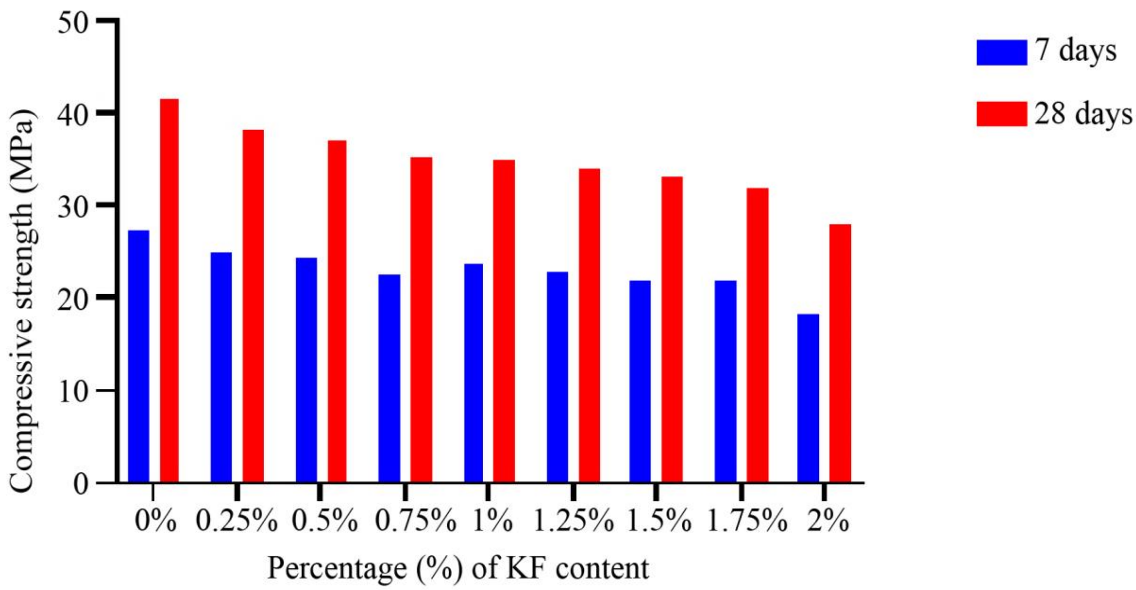

Fig. 7 Compressive strength of (KF treated with NaOH and $K_2Cr_2O_7$)

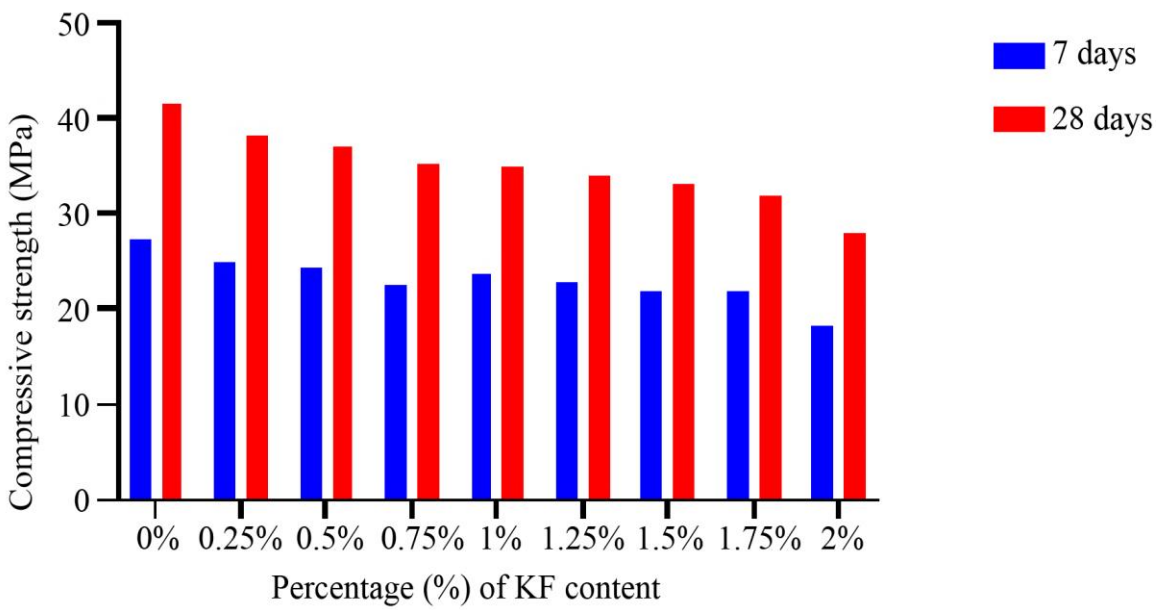

Fig. 8 Compressive strength of (KF with NaOH and $KMnO_4$)

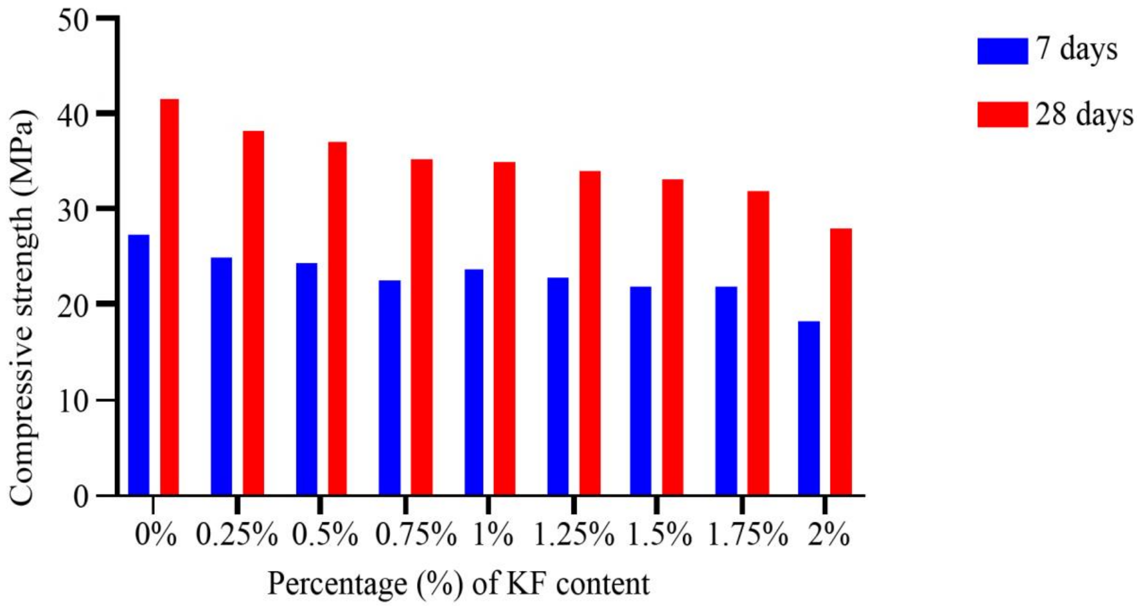

Fig. 9 Compressive strength of (KF treated with NaOH and H_2O_2)

3.4. Flexural Strength Test

The samples underwent flexural strength tests to evaluate their strength at 7 and 28 days. The results of the flexural strength tests are illustrated in Figures 9, 10 and 11. It was observed that the flexural strength of the prisms slightly increased compared to the control concrete. However, the flexural strengths of the KFRC with different proportions do not show a consistent trend. This may be due to an uneven distribution of kenaf fibers within the concrete matrices. This can be observed in the case of the replacement of 1.5% of fibers treated with the alkaline solution of potassium dichromate. From the results of these tests, it can be concluded that the fibers have a slight effect on the flexural strength of the KFRC.In Figures 10, 11 and 12, it can be observed that the control prisms underwent total rupture under the effect of the load, while the KFRC prisms did not experience the same effect as the control concrete.

The KFRC did not undergo total rupture. Regarding the cracks, a reduction in cracks is observed in the KFRC compared to the control concrete. This indicates a more ductile failure accompanied by greater resistance.

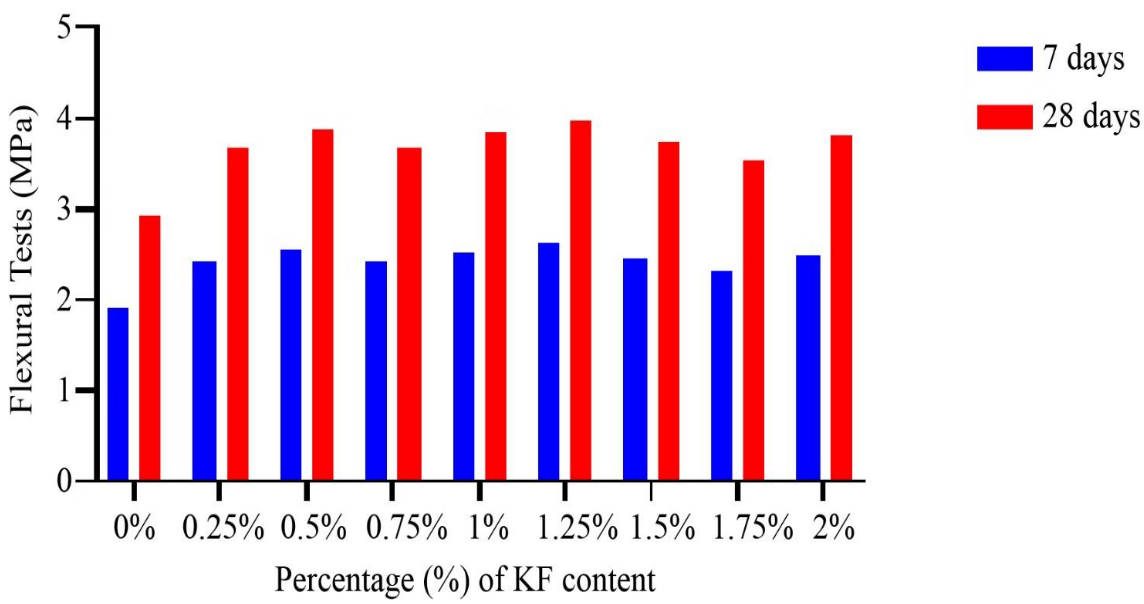

Fig. 10 Flexural strength of (KF treated with NaOH and $K_2Cr_2O_7$)

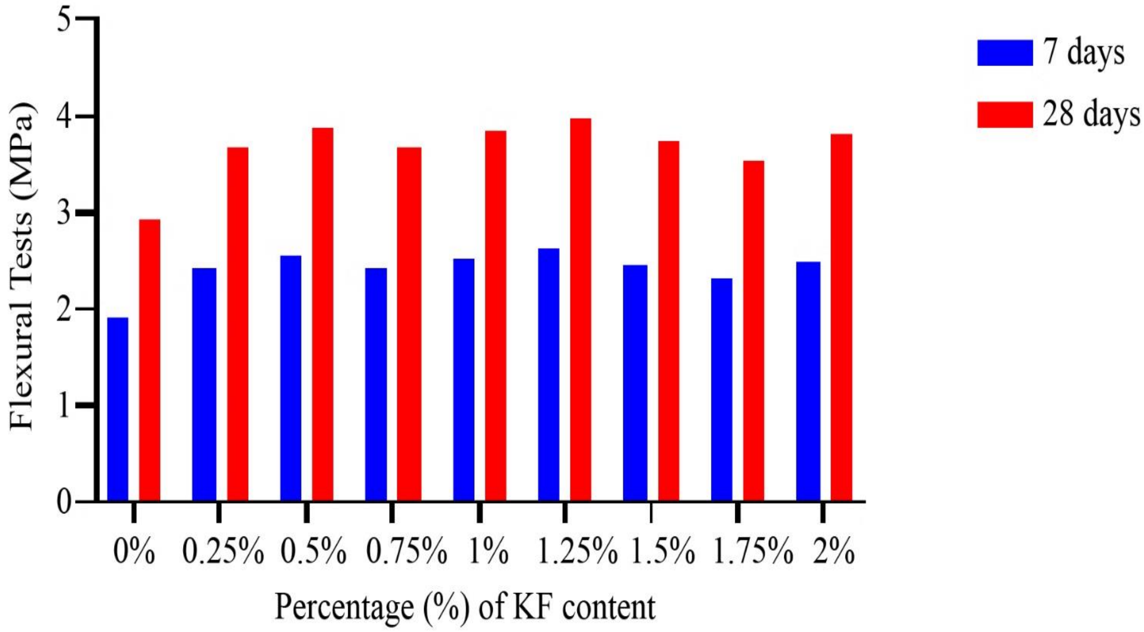

Fig. 11 Flexural strength of (KF treated with NaOH and $KMnO_4$)

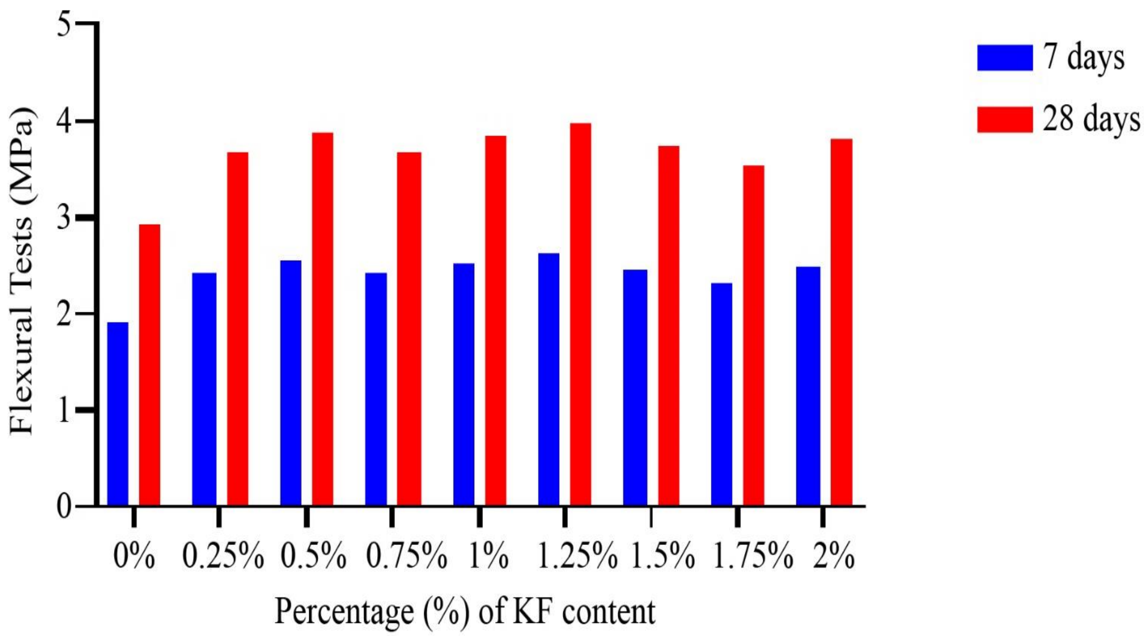

Fig. 12 Flexural strength of (KF treated with NaOH and H_2O_2)

3.5. The Split Tensile Strength

The cylinder samples were subjected to a series of indirect tensile strength tests to evaluate the strength of the samples at 7 days and 28 days. A comparison was made between the KFRC samples and the behavior of ordinary concrete. The results of the indirect tensile strength are depicted in Figures 13, 14 and 15. The results show that the kenaf fiber-reinforced concretes have higher indirect tensile strength than the control concrete. It is noted that the indirect tensile strengths are not consistent and regular across different fiber dosages. This may be due to irregularities in the distribution of fibers within the concrete matrices. It is also observed that a high density of kenaf fibers leads to a reduction in indirect tensile strength. This could be attributed to a high rate of kenaf fibers in the matrix, which decreases the influence of aggregates and cement. The fiber-reinforced samples exhibit multiple cracking compared to ordinary concrete.

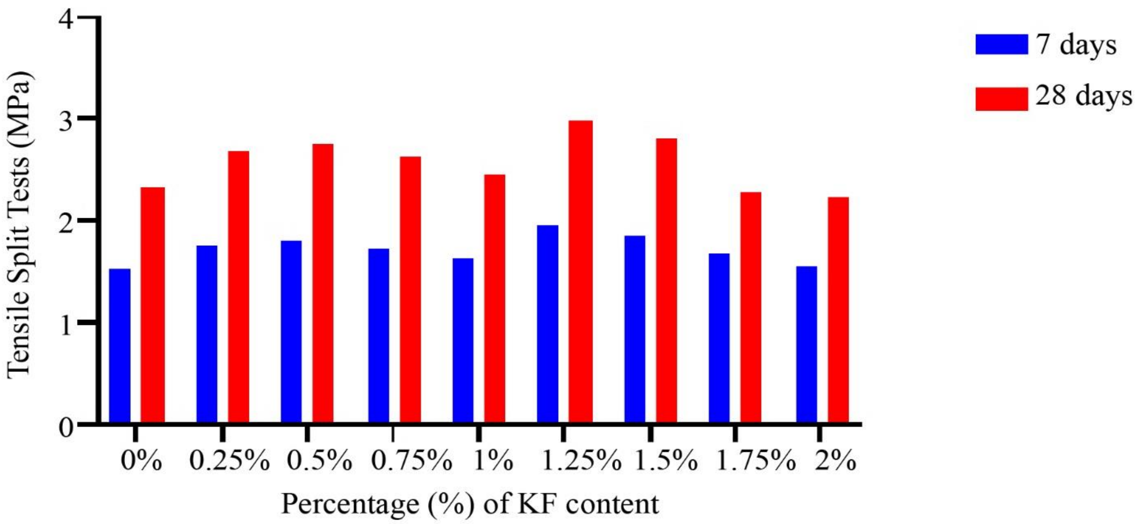

Fig. 13 Split tensile strength of (KF treated with NaOH and $K_2Cr_2O_7$)

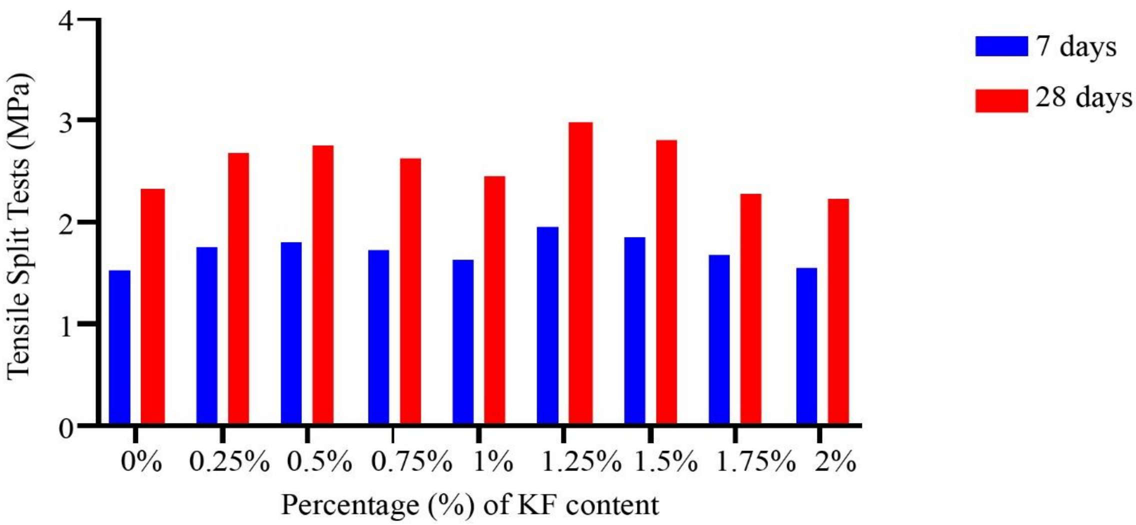

Fig. 14 Split tensile strength of (KF treated with NaOH and $KMnO_4$)

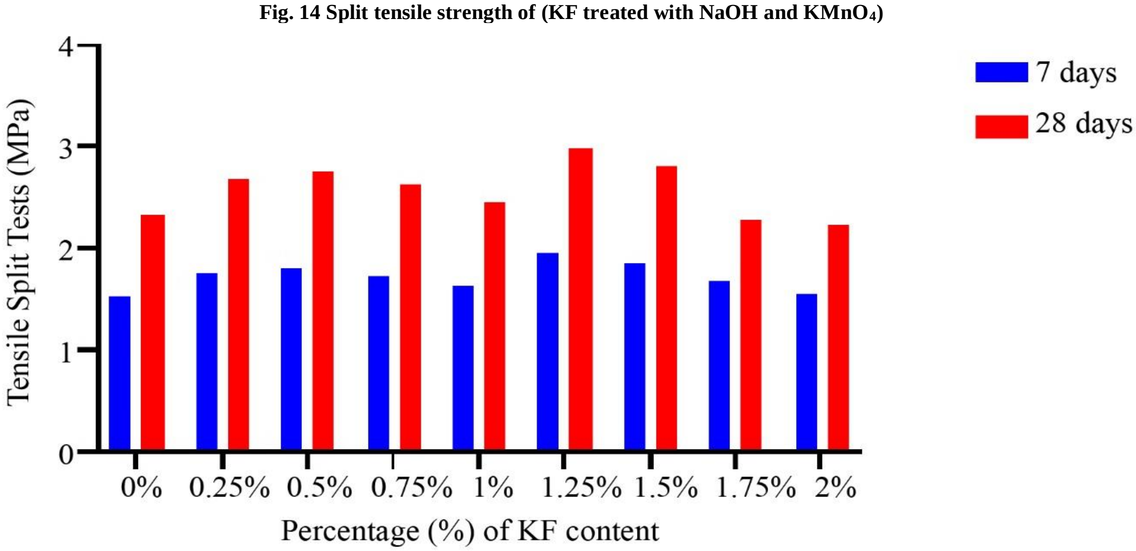

Fig. 15 Split tensile strength of (KF treated with NaOH and H_2O_2)

3.6. Structural Performance Assessment

Figure 16 depicts the load-deformation curve of the beam series subjected to a four-point bending test. CCB and KFRCB represent beams with 0% and 1.5% kenaf fiber content subjected to 6% alkaline treatment and potassium dichromate. CCB was taken as the control beam for comparison with the Kenaf fiber-reinforced beam. The parameters considered are presented in Table 3. Py and δy describe the load at the yield state and its respective deformation, and Pu and δu describe the load at the ultimate failure state and its respective deformation. Ductility is calculated by taking the ratio of the ultimate deformation to the yield deformation. The Kenaf fiber-reinforced concrete beam has higher ductility than the control beam, with a ratio of 3.08. According to the results summarized in Table 3, the addition of kenaf fibers in the concrete matrix increases the load, which is important for bridging the crack in the beam. The increase in load was more than 7% for the KFRCB.

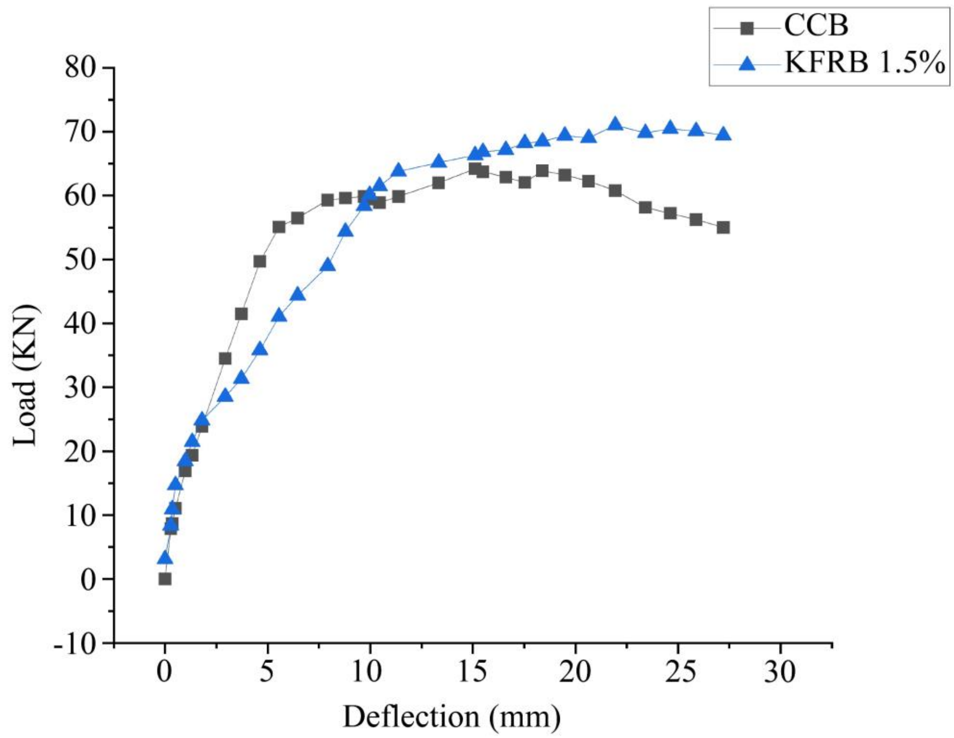

Fig. 16 Load versus deflection of the beams

Table 3. Beams data

Specimen	**Yielding state**			**Ultimate state**		
	Load(KN)	Mid Span deflection δy (mm)	Flexural stiffness (KN/mm)	Load(KN)	Mid Span deflection δu (mm)	Ductility μ
CCB	55.1	5.75	9.58	66.34	15.12	2.63
KFRCB	60.11	7.12	8.44	71.01	21.95	3.08

4. Conclusion

Through various chemical treatments such as sodium hydroxide, hydrogen peroxide, potassium dichromate, and potassium permanganate, the interfacial adhesion between kenaf fibers and the concrete matrix can be enhanced, leading to improved mechanical properties.

Based on the results, it was observed that the mechanical properties of concrete reinforced with kenaf fibers treated with an alkaline solution and potassium dichromate are most optimal at 1.5% fiber content. This optimum percentage was used in the concrete matrix for testing in a reinforced concrete beam. The experimental results from studies indicate that the inclusion of chemically treated kenaf fibers with an alkaline solution and potassium dichromate leads to notable increases in load capacity, ductility, and shear strength of reinforced concrete beams.

Additionally, a change in failure mode from shear to flexural failure is observed, highlighting the effectiveness of chemical treatments in improving the structural performance of kenaf fiber-reinforced concrete.Studies on the structural performance of reinforced concrete beams with fibers treated with an alkaline solution, potassium permanganate, and hydrogen peroxide have not been addressed. Future studies considering these parameters would be important.

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