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An experimental study for different types of natural fiber reinforced composite material

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ABSTRACT

The mechanical properties of plain-woven natural fiber-reinforced composites (NFRC) were investigated in the present study. Three types of natural fibers, Cotton, Kenaf, and Wool, were used as reinforcements for Epoxy-based overlaid composites. The properties E-type fiberglass/Epoxy composite were brought to comparison with the features of NFRC's. The mechanical properties of samples exposed to tensile, shear, and flexural loadings were obtained. The results showed that the ratio of the specific tensile strength of the cotton/epoxy laminates to laminates, which reinforced with kenaf or wool fibers were 1.71 and 4.47, respectively. Under shear loadings, the specific strength of the cotton fiber samples was also 1.24 and 2.45 times greater than kenaf and wool fiber samples, respectively. The particular flexural strength of the cotton/epoxy samples were 1.42 and 2.34 times greater than kenaf/epoxy and wool/epoxy composites. As a comparison for specific energy absorption between cotton/epoxy samples and glass fiber reinforced specimens under tensile loading, the cotton samples were 2.7 times greater than that of the glass samples. The work also included measurements of the amount of water absorption by different examples, moisture absorption tests were carried out in intervals of 3 and 10 days. The results showed that the most significant percent of the water absorption, which is (7.47%) was related to the cotton reinforced specimens at an interval of 10 days.

Keywords: Natural fibers, mechanical properties, absorbed water, composite materials

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1. Introduction

In recent years, due to the ever-increasing requirements for individuals to utilize wood and increase environmental awareness, industry; has been forced to find a replacement for wooden products. An alternative of wood is the use of natural fiber-reinforced composites. Natural fiber-reinforced composites, also known as green composites, are environmentally friendly materials [1]. Therefore, the use of NFRCs have been expanded widely in various sectors, such as marine, automotive, packaging materials, and so on. That is chiefly due to the advantages of natural fibers compared to industrial tissues, including cheap cost, low density, less damage to processing equipment, suitable mechanical characteristics, renewal resources, and degradability. The most commonly used natural plants used as reinforcements in composites are fibers like jute, flax, and bamboo [2].

M. Ramesh et al. [3], investigated the tensile and flexural properties of hybrid glass fiber-sisal/jute reinforced epoxy composites, there tensile experiments showed that, sisal-glass fiber composites were stronger and, for flexural tests; the jute-GFRP composites performed better. Maiandra Reddy et al. [4] investigated mechanical properties of (Pineapple leaf fibers, Jute fibers, and fiberglass) by 1:1:1 ratio with epoxy and polyester resins. The results showed that the Pineapple leaf, Jute, and glass fibers reinforced epoxy composites gave mechanical properties better than

Pineapple leaf, Jute, and glass fibers reinforced polyester resin. J. I. Singh et al. [5] studied the mechanical properties (tensile, compressive and impact) of various kinds of natural fibers like jute, banana, and sisal reinforced polymer composites, and they found that composite materials reinforced with jute fibers had the best tensile properties compared to other natural fibers. Wamba et al. [6] prepared composite materials from polypropylene reinforced by different natural fibers (sisal, kenaf, hemp, jute, and coir). They found from the experimental tests that tensile strength and elastic modulus increase with increasing fiber volume fraction. Fadhel A. A. et al. [7] established experiments of mechanical and fatigue properties of natural reinforced polymers (palm leaf, eggshell, and date seeds) with polyester. They also discussed the effect of ultraviolet rays. They found that increasing the volume fraction causes an increase in endurance stress for the natural composite materials. Palm leave samples showed better mechanical properties than eggshell samples and date seed samples. While Increasing UV exposure time caused a decrease in endurance and tensile stress. D. Chandramohan et al. [8] investigated the mechanical characteristics (tensile, flexural, shear, and impact strengths) for natural hybrid composites with and without moisture conditions. Samples were made from (coconut shell powder, walnut shells, and rice husk) reinforced bio epoxy resin. A result of the test showed that the hybrid composites have far better properties than single fiberglass reinforced composites under mechanical loads.

The main goal from the present study is to discover some of the mechanical properties of composites reinforced by two kinds of natural fibers from the vegetarian origin (cotton and kenaf) and a natural fiber type of animal origin (wool) under various loading conditions. The results have been compared with glass-reinforced composite properties.

2. Materials used in this study

2.1. Resin

LY5052 Epoxy resin was used with HY5052 hardener, from Hermiston chemical company. Table 1 shows the specifications of the resin.

Table 1. Resin and hardener properties

material	Type	Density g/cm^3	Viscosity MPa.s
Epoxy	LY5052	1.17	1000-1500
Hardener	HY5052	0.94	40-60

2.2.Reinforcement Fibers

Four types of fibers were used, cotton, kenaf, wool, and glass type (E). As shown in figure 1. and table 2 gives the density for the mentioned materials.

Figure 1. The fibers used in this work

Table 2. The Density of fibers used in this study

Fiber type	Density g/cm^3
cotton	1.5
Kenaf	1.4
wool	1.3
Glass (E)	2.4

2.3. Chemical treatment of natural fibers

This operation is very important for natural fibers to improve their quality. First, the fibers were washed repeatedly with clean running water and then dried. After 3 hours, the grains have been treated for the other 3 hours with a solution prepared from 1% sodium hydroxide and 99% distilled water, as suggested by Senthiil & Sirsshti [9]. The fibers then were rinsed with running water and treated for another 2 hours.

3. Composite Specimens Fabrication

The composite plates were made with a hand lay-up technique. The epoxy resin and hardener were mixed with a ratio of 100 epoxies to 38 hardeners. Six layers of cotton fiber samples, three plies of loops of kenaf has woven fiber samples, one thickness of wool woven fiber samples, and four plies of glass fiber samples. The specimens were prepared and coated for seven days at ambient temperature. The specimens were cut by water jet to the standard dimension 150*15 mm^2 according to ASTM 3039 [10] for flexural test and 250*20 mm^2 for the tensile test according to ASTM790 [11]. Figure (2-A) shows specimens of wool fiber. The specimens were placed in the curing box for 4 hours; figure (2-B) shows the samples in the cured box. Table (3) gives the test samples' codes and their densities.

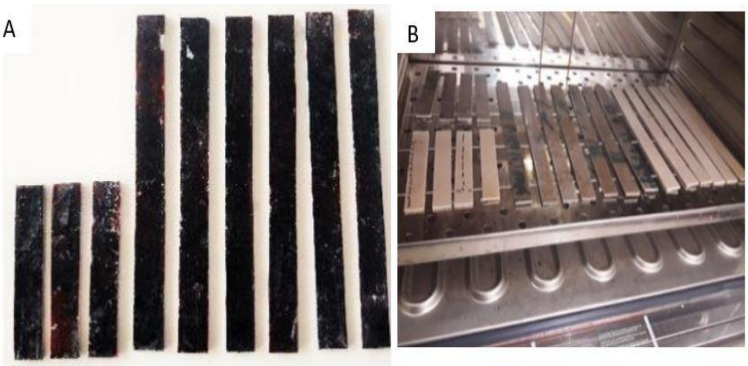

Figure 2. A) The wool fiber-reinforced laminated composites, B) Post-cure process of the specimens

Table 3. The specification of composite test samples

Fiber type	Density (Kg/m^3)	Type of test	Samples' code
Cotton	1236	Tensile, Flexural, shear	CT,CB,CS
Kenaf	1210	Tensile, Flexural, shear	KT,KB,KS
wool	1193	Tensile, Flexural, shear	WT,WB,WS
Glass (E)	1598	Tensile, Flexural, shear	GT,GB,GS

4. Experimental tests

4.1. Tensile test

The tensile test procedure has been carried out according to ASTMD3039 [10]. The test machine speed was 10mm / min. to increase the accuracy, the results of an extensometer with a length of 50 mm were used. Given that the used fibers were in perfect exact specifications, the same properties were for both transverse and longitudinal directions, so the tensile test applied in only one direction. Specimens of the test of various types of composites and the experimental setup for the tensile test are presented in figure 3 (a and b). The standard deviation (σ or S.D) of the test results for all types, and all specimens were found using equation 1.

$$\mathrm{S.D} = \sqrt{\frac{\sum_{1}^{N}(Xi-\mu x)^2}{N-1}} \qquad (1)$$

Where Xi is the data element, μx is the mean value, and N is the number of data.
The coefficient of variation (C_V) was calculated using equation 2.

$$C_v\% = \frac{\sigma}{\mu x} * 100 \qquad (2)$$

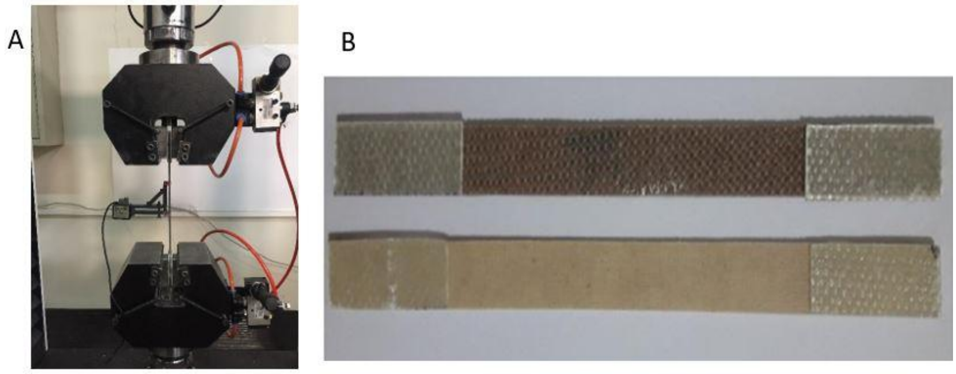

Figure 3. A) The sample in the universal test machine, B) The specimens contain tabs to perform the tensile.

4.2. Flexural test

The flexural test was performed according to ASTM D 790 [11] under a three-point bend arrangement. Samples with dimensions of 150 mm length and 15 mm wide were cut from the laminate with water jet saw. The specimens were loaded in three-point bending with a recommended span to depth ratio of 16:1. The test have been conducted using a load cell of 10 KN at a 2 mm/min loading rate. The flexural stress in a three-point bending test is given by equation (3).

$$\sigma_{max} = \frac{3P_{max}L}{2bh^2} \qquad (3)$$

where P_{max} is the maximum load at failure (N),
L is the span (mm),
b and h are the width and thickness of the specimen (mm).
The flexural modulus was calculated from the slope of the initial portion of the load-deflection curve. Flexural modulus is given by equation (4).

$$E = \frac{mL^3}{4bh^3} \qquad (4)$$

Where m is the initial slope of the load-deflection curve.
Three specimens of each fiber type are tested, and the average results are obtained.

4.3. In-plane shear test

The in-plane shear experiment was done according to ASTM D5379 [12]. Typically, shear stress is smaller compared to the bending weight in the loading condition. Although sometimes, the shear stress becomes very significant in specific design calculations. The shear test specimens and the experimental setup are shown in figure (4- a & b).

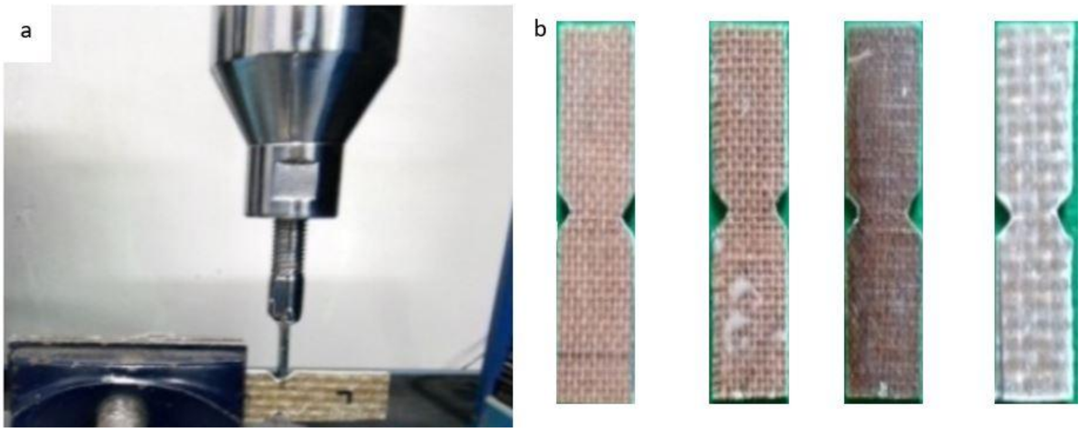

Figure 4. a-the specimen under shear test b- samples prepared for a test

4.4. The test of water absorption

Samples containing cotton, kenaf, wool, and glass fibers were used in experiments to evaluate the water absorption percentage. The samples were dried in an oven with a regulated temperature for 4 hours to ensure that they were completely dried up. The samples were weighed with a digital scale. Then, the samples were placed in distilled water in two containers. The examples kept in one of the boxes for three days and ten days for the other within an environment temperature kept at (23 ± 2 ° C). After that time, the specimens were removed from the water, and their outer surface is completely dried with a soft clad. The samples were weighed again. In accordance to ASTM D5229 [13] the amount of water absorption for each example is shown in table (4).

5. Results and Discussion

In this section, the result of the experimental tests for tensile, flexural, and in-plane shear are presented and discussed.

5.1. Tensile test

Figure (5) shows the stress-strain curve for the tested samples. The epoxy reinforced by glass fibers specimens showed the highest ultimate tensile stress. For the natural fiber composites, the cotton fiber/epoxy gave the most significant value of tensile strength compared with other natural fiber samples. From the figure, one can conclude that under tensile load, the glass/epoxy behave very fragile, and this is one point. Still, the drawbacks of this type of composites are: dynasty connector failure for cotton fiber composites were five times greater than glass fiber samples. That topic is because of the nature of fiberglass lint compared to cotton fibers. On the other side, the strain of composites reinforced with woven kenaf fibers was also on the average of 70% more than reinforced fiberglass. However, the samples of wool/epoxy were much lighter than all other samples

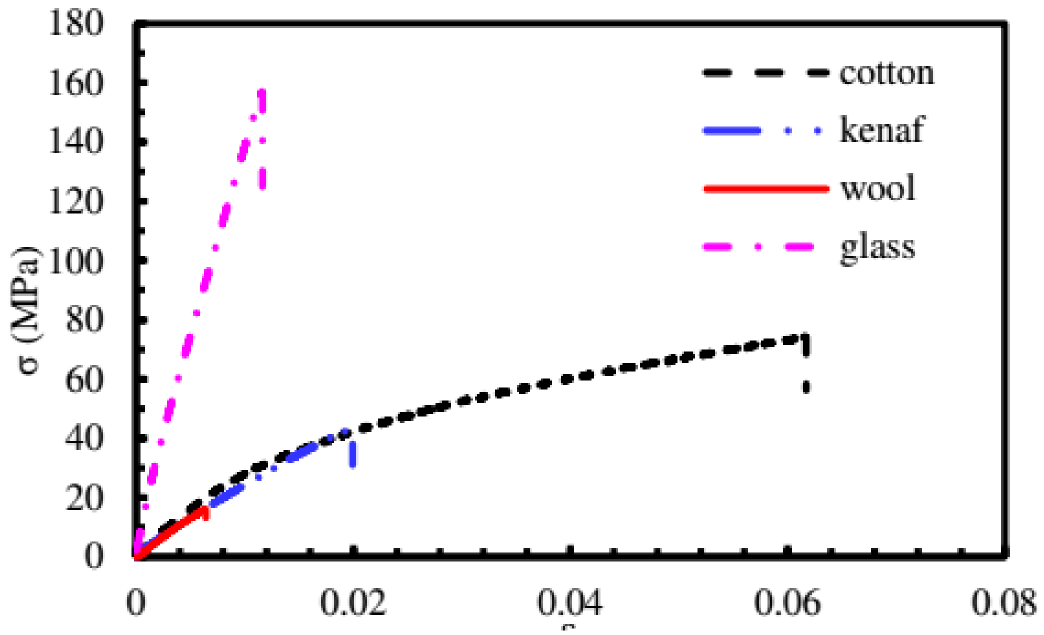

Figure 5. Stress-strain curve of the specimen with cotton, kenaf, wool, and glass fibers under tensile loading

Based on the results obtained and applying the relationship ($E = \frac{\Delta\sigma}{\Delta\varepsilon}$) for the linear region of the Stress-strain curves, the result of tensile strength for each sample was calculated. When dividing the stiffness by the density of each sample, the specific stiffness was determined. As can be seen, the stiffness of specimens with cotton fibers was more than other natural fiber samples and less than the glass fiber samples. Portella et al [14], studied mechanical properties of glass/ polyester and cotton/ polyester composites and found that the tensile strengths were 3.90 and 8.50 GPa. The reason for the lowest stiffness of composite material reinforced by natural fibers because of the power of natural fibers. Specific tensile stiffens values for different specimens are shown in figure (6) using the average density of each type of sample. Results obtained using the bar graph for specific strength are shown in figure (7). As seen, specific tensile stiffness of the reinforced glass fibers was higher than the other Samples.

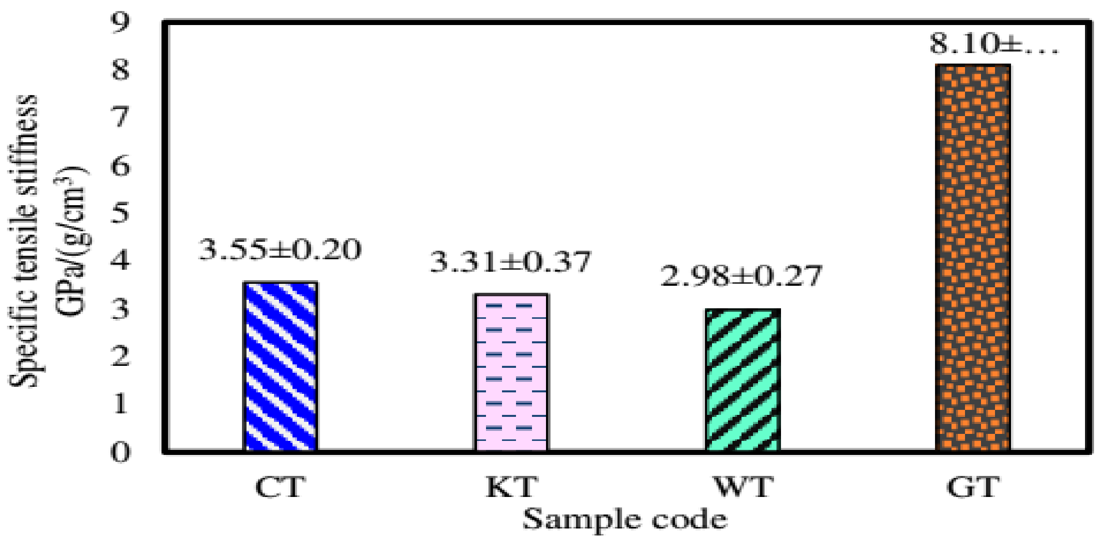

Figure 6. Comparison of specific tensile stiffness of laminated composites reinforced by cotton, kenaf, wool or glass fiber

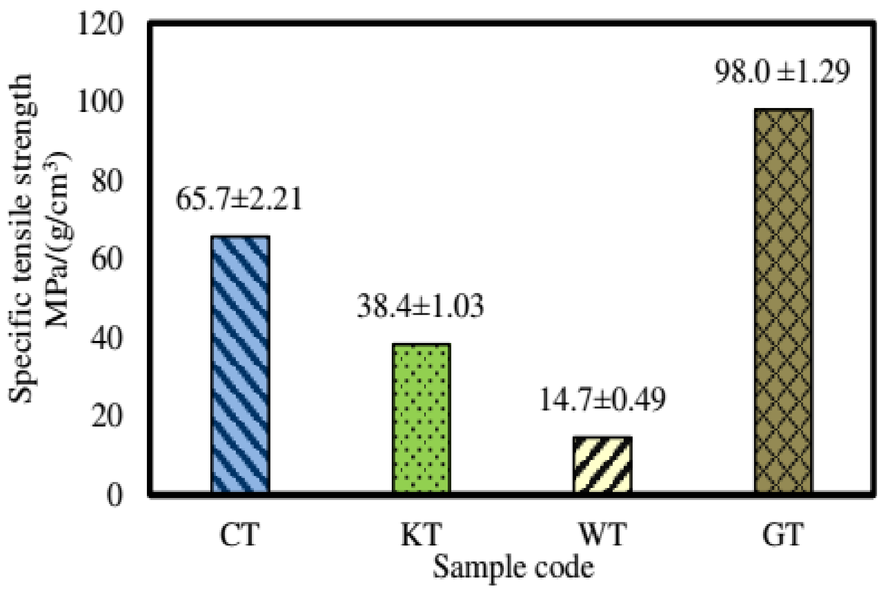

Figure 7. Comparison of the specific tensile strength of laminated composites reinforced by cotton, kenaf, wool, or glass fiber.

Among the investigated natural fibers, the cotton samples have superior tensile strength. The tensile strength of any composite ultimately depends on the tensile strength of its reinforcing fibers [15-16]. For instance, the tensile strength of the glass fiber is between 2000 and 3000 MPa and tensile strength of the cotton fiber is approximately 400 MPa [17], this is the conflict between the tensile strength of the reinforced specimens describes the glass fiber and cotton fibers.

5.2. In-Plane Shear Strength test result

Shear characteristics of the natural fibers and glass fiber composites were investigated from the experimental data, the stress-strain curves, as shown in figure (8) were generated to determine the shear strength and shear modulus.

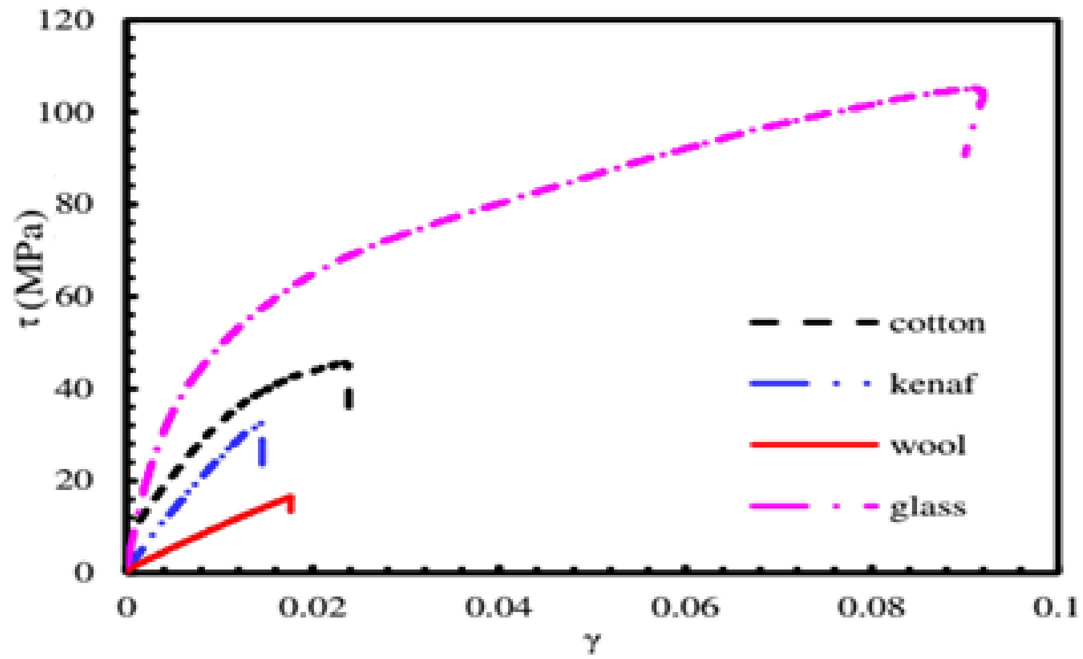

Figure 8. Stress-strain curve of different under shear loading

The shear stiffness values were obtained according to ASTM D5379 [12]. The values obtained of the specific shear stiffness are plotted in figure (9).

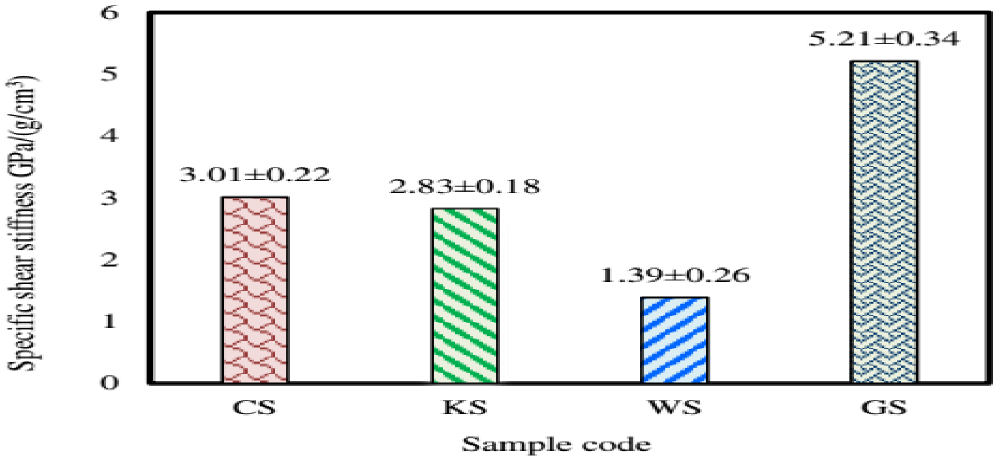

Figure 9. Comparison of specific shear stiffness of various specimens.

Figure (10) shows that the cotton samples had the highest value of specific shear strength compared with other kinds of natural fibers.

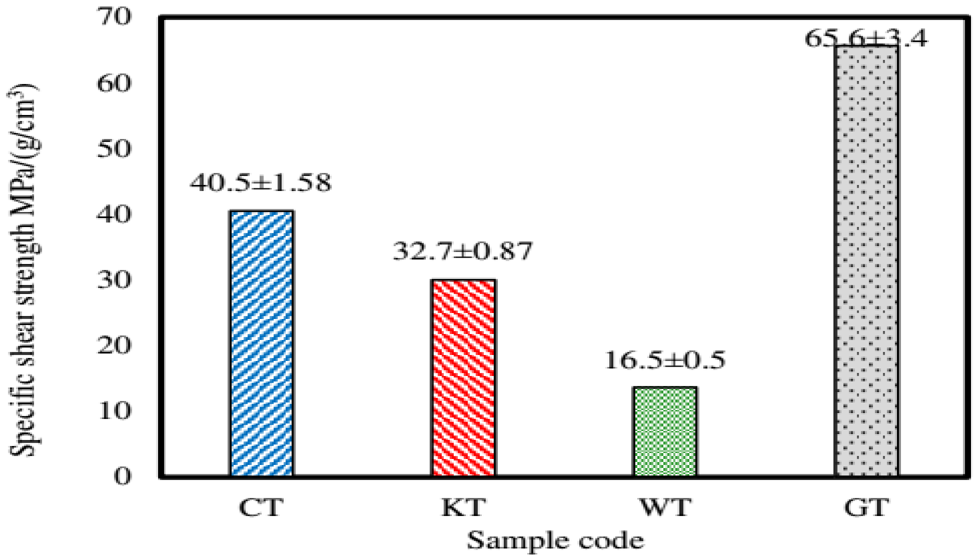

Figure 10. Comparison of specific shear strength of various specimens

5.3. Flexural Strength result

A three-point bending test was performed on the samples; the results are presented in figure (11). It can be noticed that, under a bending load, strain layered composite reinforced with cotton fibers, glass, and wool have no significant behavior. However, Kenaf/epoxy specimens slowly behave other composites under bending load. The flexural strength and modulus strength were calculated according to ASTMD790 [11], and the flexural stiffness for each type of composite material is displayed in figure (12). The result showed that the highest value of flexural rigidity was for glass fiber. Among the natural fibers, kenaf had the highest flexural stiffness. The study by [18-19] showed that the flexural strength of composite reinforced with kenaf fibers is about 4.9 GPa taking into account the density of the composite layers related to this paper, the results were somewhat similar to the results of this study.

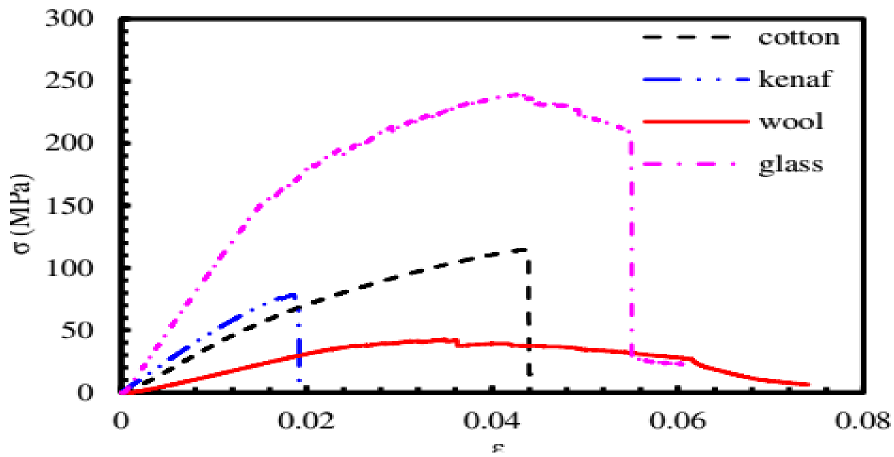

Figure 11. Stress-strain curve of the specimen with cotton, kenaf, wool, and glass fibers under flexural loading

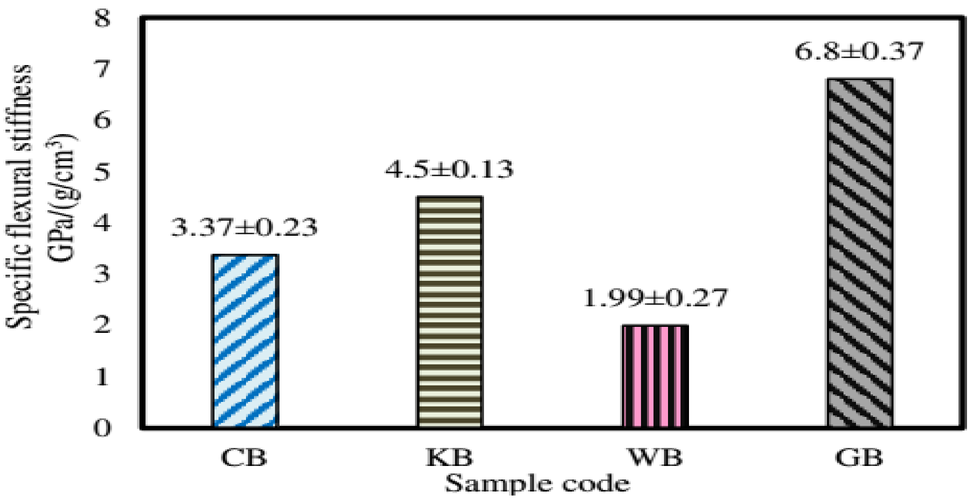

Figure 12. Comparison of specific flexural stiffness of various specimens

Figure (13) makes a comparison for the specific flexural strength in the four composite types. As seen, the highest amount of specific flexural strength was obtained by the composite samples reinforced with glass fibers. According to the graph, the specific bending strength of the composite reinforced with kenaf fibers was approximately half that of the corresponding value of glass fiber reinforced composites. Ramesh et al. [20] also confirmed that specific flexural strength of a sample containing cotton fibers is noticeable compared to other natural fibers, as presented in the figure above. The results reported by Peretola et al. [14] for cotton and glass-reinforced composites were similar to those obtained in this study.

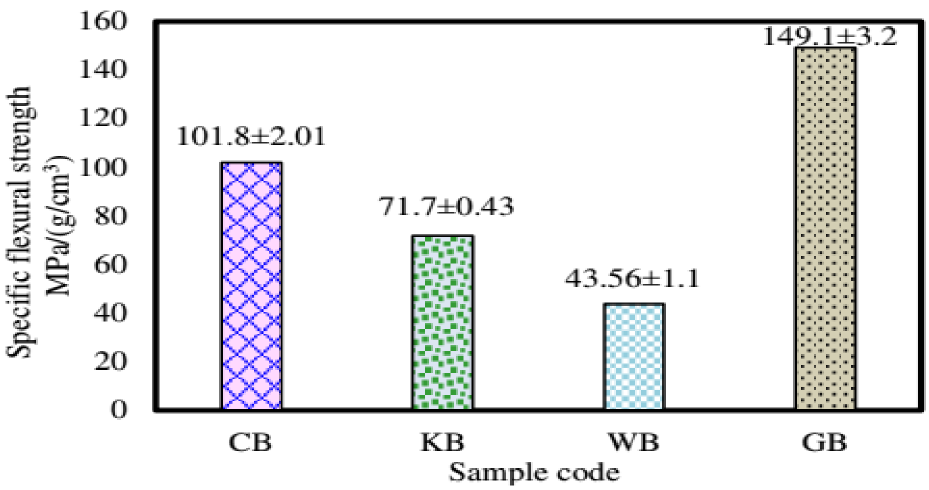

Figure (13) Comparison of specific flexural strength of various specimens

Comparing the results in figures 5 and 11, The bending strength values for cotton and Kenaf fibers have been more than the tensile strength. This point agrees with the results mentioned by Portella al. [14], Ramesh [20] and Sapiai et al. [21].

5.4. The result of the water absorption test.

The results of the water absorption test areas in table (4) for the four types of investigated materials. The specimens were analyzed in terms of moisture weight gain, according to ASTM D 5229 [13]. As shown in the table, the samples of cotton/epoxy had the highest value of water absorbed compared with other samples. This value of water-absorbent increased in the samples immersed for ten days compared to those of three days. This value increases until the material reaches saturation [22]. The water absorption of the Kenaf/epoxy after ten days reached 4.55%; other research references mentioned a value of 5 to 5.6% after a long period of immersion [23], [24]. Also, the recommendations agree with this work for the glass fiber/epoxy water-absorbent percentage, which rarely reaches 2% after a long time.

Table 4 Water absorption test results for various specimens

Sample	Mass before the test (g)	Mass after 3days Immersion (g)	Moisture content after three days (%)	Mass after 10days Immersion (g)	Moisture content after ten days (%)
Cotton/epoxy	7.65	7.965	3.95	8.022	4.63
kenaf/epoxy	11.12	11.42	2.6	11.627	4.55
wool/epoxy	7.82	7.983	2.04	8.04	2.73
Glass/epoxy	4.328	4.41	1.85	4.419	2.07

6. Conclusions

In this research, as reported in the previous sections, samples of composites reinforced with cotton, kenaf, and wool natural fibers were investigated for tensile, shear, and flexural load effects and compared with fiberglass reinforced composite. Natural fibers have unique features such as abundance, biodegrade ability being, and low-price to weight aspect. It spends less energy on production and easy recycling compared with unnatural fibers. According to the results obtained from the tests and comparisons, the following can be deduced:

1. In general, cotton fiber-reinforced composite specimens with a tensile strength of 74.14 MPa, Shear Strength 45.61 MPa, and Flexural Strength 114.77 MPa have the best results among other samples. It has natural fibers and can be used in situations where things are alive in an environment and essential as an alternative to glass fiber.
2. Due to the low density of natural fiber-reinforced cotton composites, compared with glass fiber, by increasing the thickness, natural fibers can be used as substitutes for artificial fibers.
3. Wool fiber-reinforced composite samples with poor mechanical properties, compared with the other discussed materials; it is the weakest. And that is because of the low strength and adhesion between the resin and the fibers.
4. Generally, composite reinforced with natural fibers was observed; green mechanical properties are superior to natural animal fibers.
5. After ten days, the highest percentage of water absorption in the samples was for the Cotton fiber samples, which was (4.63%). The lowest rate of water absorption was for glass fiber (2.07%). Among the natural fibers, the most moderate water absorption in the samples was for the wool fibers (2.73%).

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