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Free vibration and mechanical behavior of treated woven jute polymer composite

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ABSTRACT

Introduction: Recently, the use of natural fibers have been increased to replace the use of synthetic fibers to save our environment from waste disposal problems, natural fibers have a lower level of mechanical properties. **The purpose of work:** This study examines the effect of treating the surface and deeper layers of jute fiber on the mechanical behavior and characteristics of free vibrations of a composite material based on it. **The methods of investigation:** due to the uniform distribution of stresses in the *WARP* and *WEFT* directions, four-layer basket weave jute fibers were used in this study. **Result and discussion:** the mechanical and free vibration properties of composite materials are significantly improved when *NaOH* is applied to jute fibers because it eliminates the weak matrix material lignin and makes the fibers stiffer and stronger. However, increasing the percentage of *NaOH* and soaking time for the fibers in *NaOH* solution have little effect on these properties. The highest value of tensile strength and tensile modulus are found 50 ± 1.17 MPa and 1.94 ± 0.23 GPa respectively seen in case of basket weave jute fiber composite with 1 hour treatment. Tensile strength and tensile modulus increase about 12 % and 40 % over the stokes value, respectively. Similarly the value of flexural strength and flexural modulus are found 95 ± 1.17 MPa and 3.99 ± 0.23 GPa respectively in case of basket weave jute fiber composite with 1 hour treatment. It also shows the highest value of fundamental frequency 77.837 Hz.The presence of an *O-H* bond in the composite, as revealed by *FTIR* study, gives it a hydrophilic character and limits its use in humid environments. The fiber to matrix ratio is shown in *SEM* images.

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Introduction

Natural fiber composites are good alternatives to synthetic ones for various low and medium load applications due to its low weight, low cost, high strength to weight ratio, biodegradability, high availability, and other characteristics. This is due to the growing demand for materials with special requirements for properties that do not pollute the environment. Natural fibers exhibit better mechanical and free vibration characteristics in a woven state. Properties improve as the number of layers increases [1, 2]. The dynamic mechanical characteristics of composite materials increase as a result of reinforcing. The presence of cellulose and hemicellulose in fiber cells improves the woven natural fiber composite's thermal characteristics [3]. The buckling characteristics of woven natural fiber composite are affected by the type of weave and deteriorate as the number of reinforcing layers increases. Fiberglass reinforcement improves the characteristics of composite materials [4]. The mechanical characteristics of woven natural fiber composites are also affected

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by the orientation of the fibers [5]. *M. Mejri* has studied the use of composite materials made from natural fibers in the production of gears [6, 7].

The properties of the composite material improve as the thickness increases, which requires new processing methods [8–10]. *Tidarut Jirawattanasomkul* and colleagues examined how natural fiber was used in concrete. Natural fibers may be used to absorb sound since it has good acoustics [11]. Nano fillers like carbon nanotubes, nano-SiO_2, nano-clay, etc. were added to the composite to improve its qualities without increasing its density [12]. *S Sri Karthikeyan* and colleagues examined the use of natural fiber composite as a replacement for asbestos fibers, the dust from which is hazard to human health [13]. The ability of natural fibers to absorb water destroys it. Synthetic fibers can be added to natural fiber composites to further improve its qualities [14, 15]. The functional group included in the composition of the composite is revealed using *FTIR* analysis [16, 17]. Surface morphology research was conducted by *Yadvinder Singh et al.*, who came to the conclusion that alkaline-treated fibers exhibit superior properties over untreated ones.

A review of the literature reveals that adding natural fiber to a polymer matrix improves the mechanical characteristics of the composite in both particulate, short and random, long fabric, and woven form, with woven form showing the greatest improvement in attributes [18]. Natural fibers reduce the combustibility of composite materials, and, compared with a polyester matrix, a polylactic acid matrix demonstrates higher mechanical properties when reinforced with banana and sisal fibers [19]. The results of testing composites based on sisal and aloe vera fibers for delamination showed that the composite with sisal fibers delaminates to a lesser extent and the resulting surfaces are characterized by less roughness [20]. In addition to improving the characteristics of composite to a certain extent, the addition of fibers also increases the percentage of voids and water absorption in the composite [21]. The mechanical properties of a natural fiber composite are affected by the type of weaving and the degree of water absorption [22, 23]. Since the addition of nanofillers promotes adhesion between the fiber and the matrix and increases interfacial contact, filling voids in the composite with nanomaterials improves mechanical properties and reduces water absorption [24]. The hybridization improves the characteristics of composite materials, as well as the order of laying and surface treatment [25, 26]. The characteristics of composite material are affected by the number of added layers, as well as the combination effect created between layers by synthetic fibers such as glass [27,28].

Although several researchers have conducted extensive study on various natural fiber composites and hybrid polymer composites, none of these studies have been found to be relevant to treated woven natural fiber composite due to weaving challenges. According to a variety of academic sources, treated natural fibers have better qualities than untreated ones. The **objective** of present study is to prepare laminates made of woven natural fiber and polymer and examine how surface treatment affects mechanical and free vibration behavior along with the study of the woven polymer composites' mechanical and free vibration behavior after a period of soaking in a *NaOH* solution. *FTIR* spectrum has been extracted to analyze the functional group in woven jute fiber.

Investigation technique

Material

Woven jute fibers were used as a reinforcing material in the study. Jute cloth that was once loose was turned into yarn. There are around 80 to 120 loose filaments in each strand. Then, as seen in fig. 1, these strands were weaved into a design resembling a basket. Weaved mats for this investigation were bought from Kiran Jute Industry in Kolkata, West Bengal, India. Epoxy resin with HV953 hardener in a 1:1 ratio is used as the matrix material. The components were purchased from Chennai, India's Vasavibala Resins Ltd.

Fabrication method

Composite laminates are made using a compression moulding machine. Then, in a stainless-steel mould with the dimensions 260 × 260 × 4 mm, a sufficient amount of resin was first poured. Then, a basket-weave mat was placed inside the resin, and with the aid of a roller, the resin was distributed over the mat. This process was then repeated for a four-layered mat before the cavity was filled with the calculated amount of resin. A compression moulding machine is then used to compress the mould, curing it for an hour at a temperature of 80 °C and a pressure of 150 kgf/cm^2. The obtained composite laminates were sliced to prepare specimens in accordance with *ASTM* specifications. Fig. 2 and 3 respectively depict the compression moulding machine setup and composite preparation.

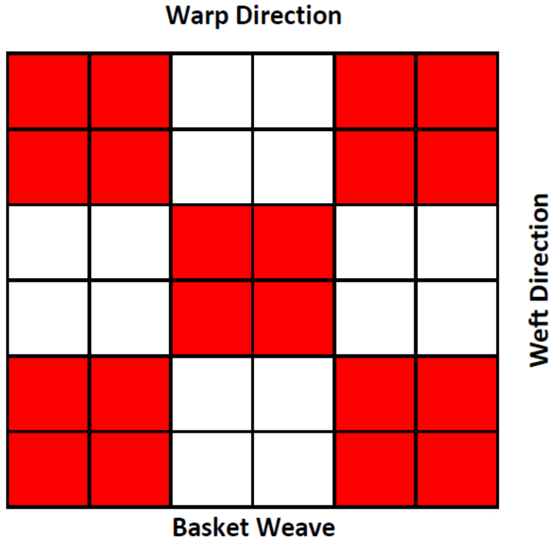

Fig. 1. Basket weave jute fibers

According to *ASTM D-638* standard, a tensile test was performed at a testing speed of 2 mm per minute. The dog bone shaped sample had the following dimensions: length 165 mm, gauge length 57 mm and width 13 mm. Flexural tests using three-point bending were conducted in accordance with *ASTM D-790* standards at a testing speed of 1.7 mm per minutewith position accuracy 0.001 mm and speed accuracy 0.005 % uses for testing. Specimen was made with standard dimensions: 127 mm in length, 12.7 mm in width and 4 mm in thickness. The impact test on the 63.7 × 12.7 ×3 mm composite specimen followed the recommendations of *ASTM D-256* with an angle accuracy of 0.1°.

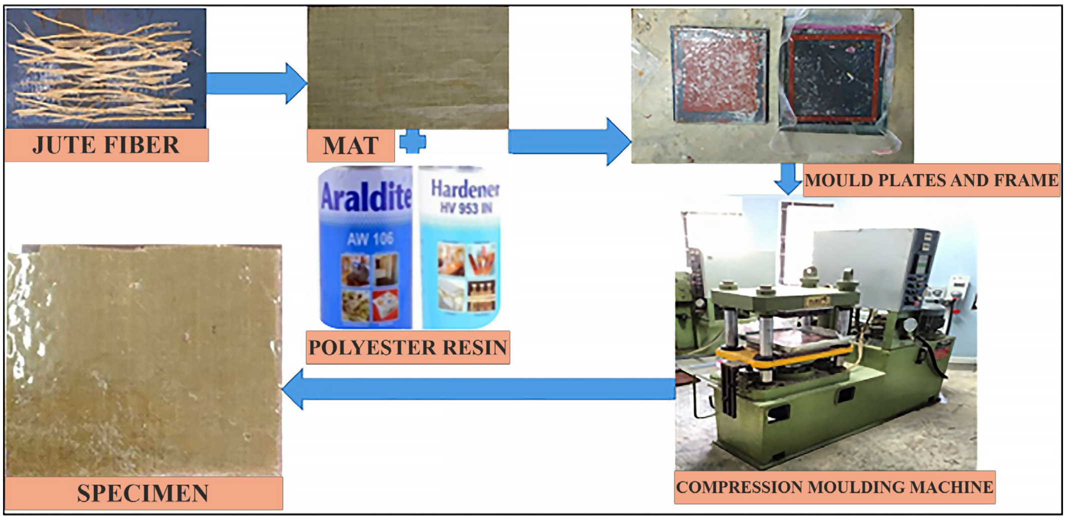

Fig. 2. Composite preparation flow diagram

Analysis of free vibrations has allowed researchers to better understand the dynamic behavior of composite materials. Using experimental modal analysis, the natural frequency and associated damping factor of the composite was found. Experimental modal analysis is performed using the impulse hammer test. Fig. 4 shows a diagram of the impulse hammer test. For this analysis, the first three bending modes of the composite made of basket-woven jute fiber have been taken into account. The investigation of free vibrations was done in a free-free environment. A sample with dimensions of 170 × 17 × 3 mm was mounted on a rigid end support such as a cantilever beam and a 4 gram light accelerometer was positioned over the sample to obtain the first three natural frequencies of the woven jute fiber composite. Utilizing a lightweight accelerometer helps to avoid additional impact on the mass of the woven composite. After the impulse, the impact signal is sent to an 8-channel *DEWE* data acquisition system to use the fast *Fourier* transformation algorithm (*FFT* Algorithm) to convert the time domain signal to frequency form. Direct measurements of the relevant damping factor values may be made with the *DEWE* data gathering system.Depends upon the frequency response resonance peak initially three peaks have been clearly visible and corresponding to

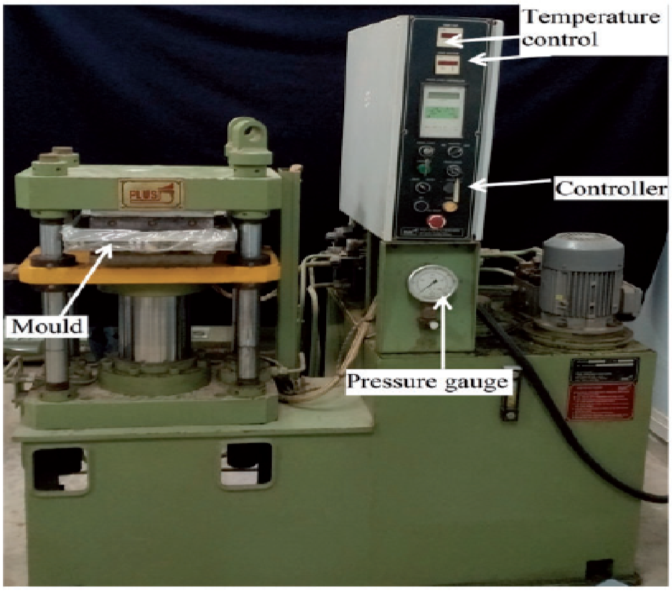

Fig. 3. Experimental Setup

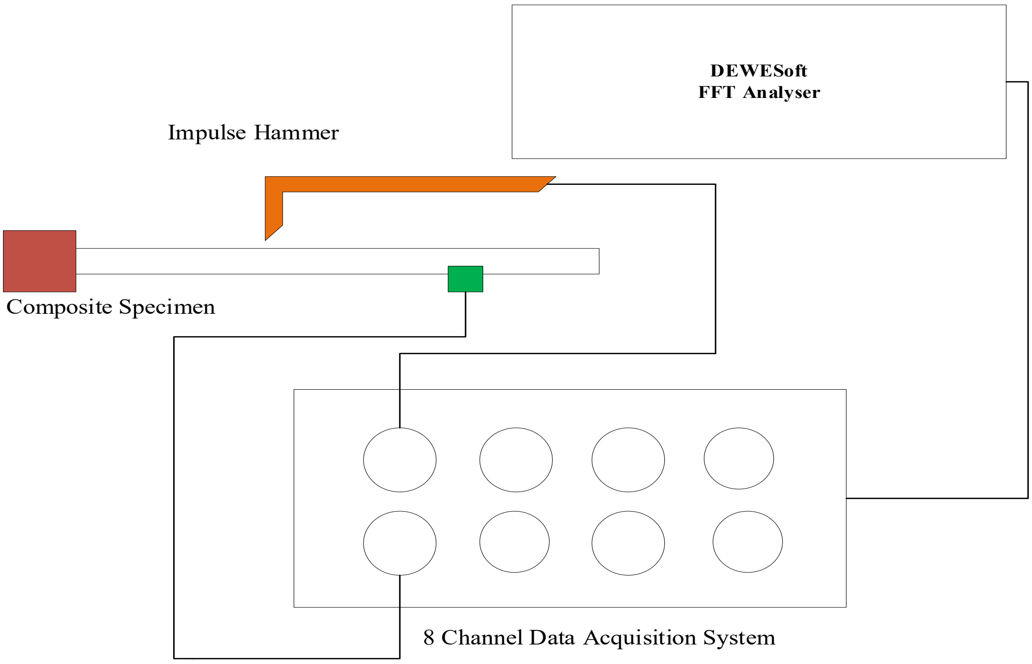

Fig. 4. Freevibration setup

these peeks, the associated natural frequencies have been extracted.The fit circle approach uses the *Nyqust* plot to calculate the damping factor. The fitting circle method took into account only a few places in the vicinity of the response, so the peak amplitude had little effect on the results.The location of the response peak lies on the arc of a circle when using the fitting circle approach. Fig. 5 illustrates a typical *Nyqust* plot using the fitting circle approach. The formula for calculating damping factor is shown in Equation 1.

$$\varsigma = \frac{\omega_2^2 - \omega_1^2}{2\omega_0\left[\omega_2 \tan\frac{\alpha_2}{2} + \omega_1 \tan\frac{\alpha_1}{2}\right]},$$

where ω_0 = angular resonance frequency; ω_1, ω_2 = angular frequencies; α_1, α_2 = angle between angular frequencies.

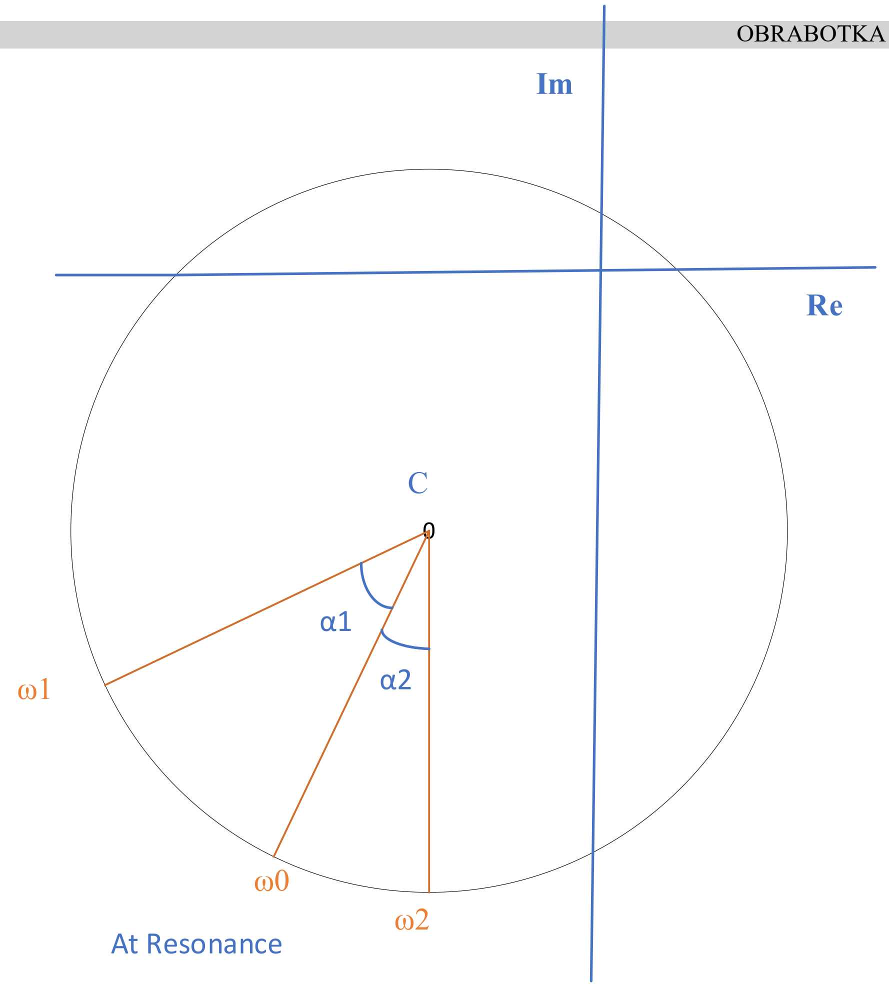

Fig. 5. Nyqust plot for fitting circle method

Results and discussion

In this study, after obtaining a composite material, samples were made from it, the weight and size of which are shown in Table 1

From the foregoing, it can be inferred that that the increase in the weight of the composite material occurs mainly due to the increase in the weight of the resin. Accordingly, in composite studies, the impact of weight is primarily caused by the weight of resin. Jute fibers in a four-layered basket weave were chosen for this study because of its ability to distribute force equally in both the *WARP* and *WEFT* directions. As the number of layers in a composite increase, its qualities improve.

Table 1

Weight and Size of specimen

No.	**Type (Thickness)**	**Weight, gram**
1	Single Layer (Approx. 4 mm)	16–18
2	Double Layer (Approx. 4 mm)	18–19
3	Triple Layer (Approx. 4 mm)	21–22
4	Tetra Layer (Approx. 4 mm)	24–25
	Test	**Specimen size**
1	Tensile (ASTM D-638)	30 cm × 3 cm
2	Flexural (ASTM D-790)	125 mm × 12.7 mm
3	Impact (ASTM D-256)	63.5 mm × 12.7 mm
4	Free Vibration Test	170 mm × 17 mm

Tensile Test

Tensile test has been performed using universal tensile machine for different percentage of *NaOH* and for different time has been taken for surface treatment. The results are shown in Table 2.

Table 2

Tensile test behavior of woven jute composite

Number of layers	**Pattern & time with NaOH Concentration**	**Tensile strength, MPa**	**Tensile modulus, GPa**
4	Basket (30 minutes, 1%)	48 ± 0.61	1.90 ± 0.11
	Basket (1 hour, 1%)	49 ± 0.60	1.90 ± 0.10
	Basket (30 minutes, 4%)	48.8 ± 2.61	1.91 ± 0.18
	Basket (1 hour, 4%)	50 ± 1.17	1.94 ± 0.23
Number of layers	**Pattern & time without *NaOH* Concentration**	**Tensile strength, MPa**	**Tensile modulus, GPa**
4	Basket	43.60±2.3	1.15±0.27

As can be seen from the table above, tensile strength and tensile modulus increase about 12 % and 40 % over the stokes value, respectively. It can be concluded that the influence of the soaking time during the treatment of the surface of the fibers with a *NaOH* solution does not lead to a significant improvement of the tension characteristics of the composite material; the increase in the tensile strength is so minimal that it can be overlooked. Similar results were obtained with an increase in the *NaOH* strength. It indicates that when *NaOH* is applied, lignin and hemicellulose are swiftly removed from fibers.

It can be clearly seen that

– the highest value of tensile strength for basket-weaved *CM* is 50 ± 1.17 MPa when treated with 4 % alkali solution for 1 hour, and its tensile modulus is 1.94 ± 0.23 GPa;

– the second largest value of tensile strength for basket-weaved *CM* is 49 ± 0.60 MPa with treatment with 1 % alkali solution for 1 hour, and its tensile modulus is 1.90 ± 0.10 GPa;

– the lowest value of tensile strength for basket-weaved *CM* is 48 ± 0.61 upon treatment with 1 % alkali solution for 30 minutes, and its tensile modulus is 1.90 ± 0.11 GPa;

– the second and last lowest tensile strength for basket-weaved *CM* is 48 ± 0.61 MPa when treated with 4 % alkali solution for 30 minutes, and its tensile modulus is 1.91 ± 0.18 GPa.

Flexural Test

Flexural test has been performed for the study of flexural strength and flexural modulus as shown in Table 3.

According to the results of the aforementioned tests, it is clear that surface treatment of composite materials enhances its ability to bend. The greatest value of flexural strength and flexural modulus was

Table 3

Flexural test behavior of woven jute composite

Number of layers	**Pattern & time with *NaOH* Concentration**	**Flexural strength, MPa**	**Flexural modulus, GPa**
4	Basket (30 minutes, 1 %)	70.6 ± 0.20	2.6 ± 0.11
	Basket (1 hour, 1 %)	71.7 ± 0.60	3.2 ± 0.10
	Basket (30 minutes, 4 %)	70 ± 0.60	2.8 ± 0.18
	Basket (1 hour, 4 %)	95 ± 1.17	3.99 ± 0.23
Number of layers	**Pattern & time with *NaOH* Concentration**	**Flexural strength, MPa**	**Flexural modulus, GPa**
4	Basket	69.44 ± 0.60	2.38 ± 0.11

discovered with 4 % *NaOH* during 1 hour. Compared to other results, the results with an hourly soaking in 4 % alkali are noticeably better. It may be caused by an increase in cellulose content and the maximum possible adhesion between the fiber and matrix. Flexural strength and modulus variation are not very different for the other three situations. The increase in flexural strength and elastic modulus of layered samples without preliminary surface treatment is about 10.40 % and 32.24 %, respectively. Therefore, it may be said that surface treatment greatly enhances flexural qualities.

It can be clearly seen that

– the highest value of flexural strength for basket-weaved *CM* is 95 ± 1.17 MPa when treated with 4 % alkali solution for 1 hour, and its flexural modulus is 3.99 ± 0.23 GPa;

– the second highest value of flexural strength for basket-weaved *CM* is 71.7 ± 0.60 MPa with treatment with 1 % alkali solution for 1 hour, and its flexural modulus is 3.2 ± 0.10 GPa;

– the lowest value of flexural strength for basket-weaved *CM* is 70.6 ± 0.20 MPa upon treatment with 1 % alkali solution for 30 minutes, and its flexural modulus is 2.6 ± 0.11 GPa;

– the second and last lowest flexural strength for basket-weaved *CM* is 70 ± 0.60 MPa when treated with 4 % alkali solution for 30 minutes, and its flexural modulus is 2.8 ± 0.18 GPa.

Impact Test

Impact test was carried out on a woven jute composite to investigate impact energy* and result is shown in Table 4.

Table 4

Impact test of woven jute composite

Number of layers	Pattern & time with *NaOH* Concentration	Impact energy, J/m
4	Basket (30 minutes, 1 %)	272 ± 23
	Basket (1 hour, 1 %)	274 ± 24
	Basket (30 minutes, 4 %)	278 ± 25
	Basket (1 hour, 4 %)	280 ± 26
Number of layers	**Pattern & time with *NaOH* Concentration**	**Impact energy, J/m**
4	Basket	250 ± 26

The test results indicate the ability of the material to store energy when loaded. According to Table 4, the impact energy of the composite increased significantly after surface treatment by about 10 %.

It is clearly seen that

– the highest impact energy for basket-weaved *CM* is 280 ± 26 J/m when treated with 4 % alkali solution for 1 hour;

– the second highest impact energy for basket-weaved *CM* is 278 ± 25 J/m with treatment with 1 % alkali solution for 1 hour;

– the lowest impact energy for basket-weaved *CM* is 274 ± 24 J/m upon treatment with 1 % alkali solution for 30 minutes;

– the second and last lowest impact energy for basket-weaved *CM* is 272 ± 23 J/m when treated with 4 % alkali solution for 30 minutes.

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* The *ASTM* impact energy is measured in J/m or ft-lb/in. Impact strength results from dividing the value for impact energy in (J or ft-lb) by the notch thickness (mm or inches) of the specimen, for an average of 5 test cycles. The *ISO* method is slightly different, deriving impact strength with units kJ/m^2 from the impact energy in J by the area under the notch. This test is performed on 10 specimens and the results are averaged.

Free Vibration Test

The results of tests for free vibrations, carried out on a four-layer jute basket-weaved composite material are presented in Table 5.

Table 5

Free vibration test results

No.	**Number of Layers (Time Duration and % *NaOH*)**	**Free – Free Condition (Natural Frequency (Hz) and Corresponding Damping Factor)**		
1	4 (30 minutes, 1 %)	75.493 0.06224	422.72 0.024813	1387.0 0.044182
2	4 (30 minutes, 4 %)	75.81 0.0468	427.06 0.0500	909.0 0.04479
3	4 (1 hour, 1 %)	76.55 0.068	484.78 0.066	1200 0.0706
4	4 (1 hour, 4 %)	77.837 0.055	494.30 0.038071	806 0.0377
No.	**Number of Layers (Time Duration and % *NaOH*)**	**Free – Free Condition (Natural Frequency (Hz) and Corresponding Damping Factor)**		
1	4	68.4 0.0455	410.2 0.0353	1079.1 0.0364

It is evident from the above study that surface treatment improves the vibrational characteristics of the composite. In addition, it is shown that changes in vibrational characteristics are only 3 %, which is not very significant, regardless of the increase in *NaOH* strength and the soaking time.

The free vibration test has been performed on an experimental setup and are presented in table 5. There are three natural frequencies and associated with damping factor with the help of fitting circle was obtained from this experiment.

The first mode of three frequencies for basket-weaved *CM* after treatment with 1 % alkali solution for 30 min was found as 75.493; 422.72; 1387.0 and is related to the damping factor 0.06224, 0.024813, 0.044182.

The second mode of three frequencies for basket-weaved *CM* after treatment with 4 % alkali solution for 30 min was found as 75.81; 427.06; 909.0 and is related to a damping factor of 0.0468; 0.0500; 0.04479.

The third mode of three frequencies for basket-weaved *CM* after treatment with 1 % alkali solution for 1 hour was found as 76.55; 484.78; 1200 and is associated with a damping factor of 0.068; 0.066; 0.0706.

The last mode of three frequencies for basket-weaved *CM* after treatment with 4 % alkali solution for 1 hour was found as 77.837; 494.30; 806 and is associated with a damping factor of 0.055; 0.038071; 0.0377.

FTIR Analysis

FTIR was carried out to study the functional group in the composite. For *FTIR* analysis, a sample in the form of a powder was used, and the obtained data are shown in fig. 6.

The existence of a peak in the region of 650–2,000 cm^{-1} indicates the presence of single and double bonds of carbon with nitrogen, carbon, and oxygen, according to the comparison of the *FTIR* graph above with the standard graph. Peaks in the 3,000 cm^{-1} range indicate the existence of the *O-H* functional group, which gives composites its hydrophilic character. This composite absorbs moisture, which limits its use in situations where people are exposed to water.

Surface Morphology

SEM images study was conducted to analyze t the interaction of the fibrous matrix with the polymer composite. *SEM* images of composite material are shown in in fig. 7.

The nature of the interaction of the fibers and the matrix of the composite material is shown above. Fig. 7c shows the fracture of the matrix in the direction opposite to the applied force, indicating its fragility.

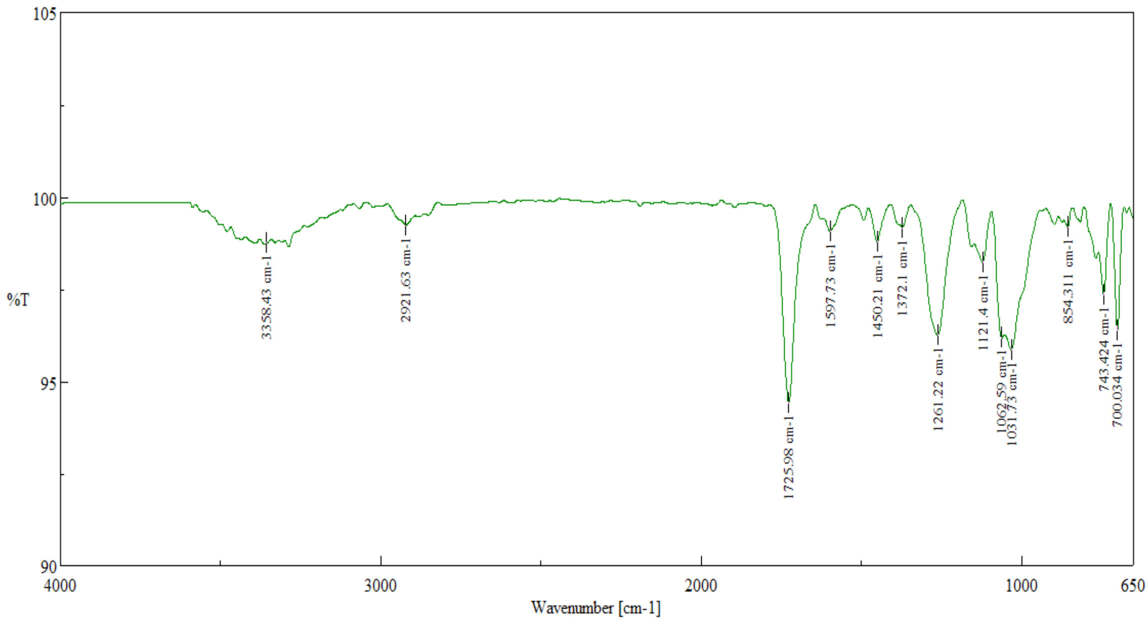
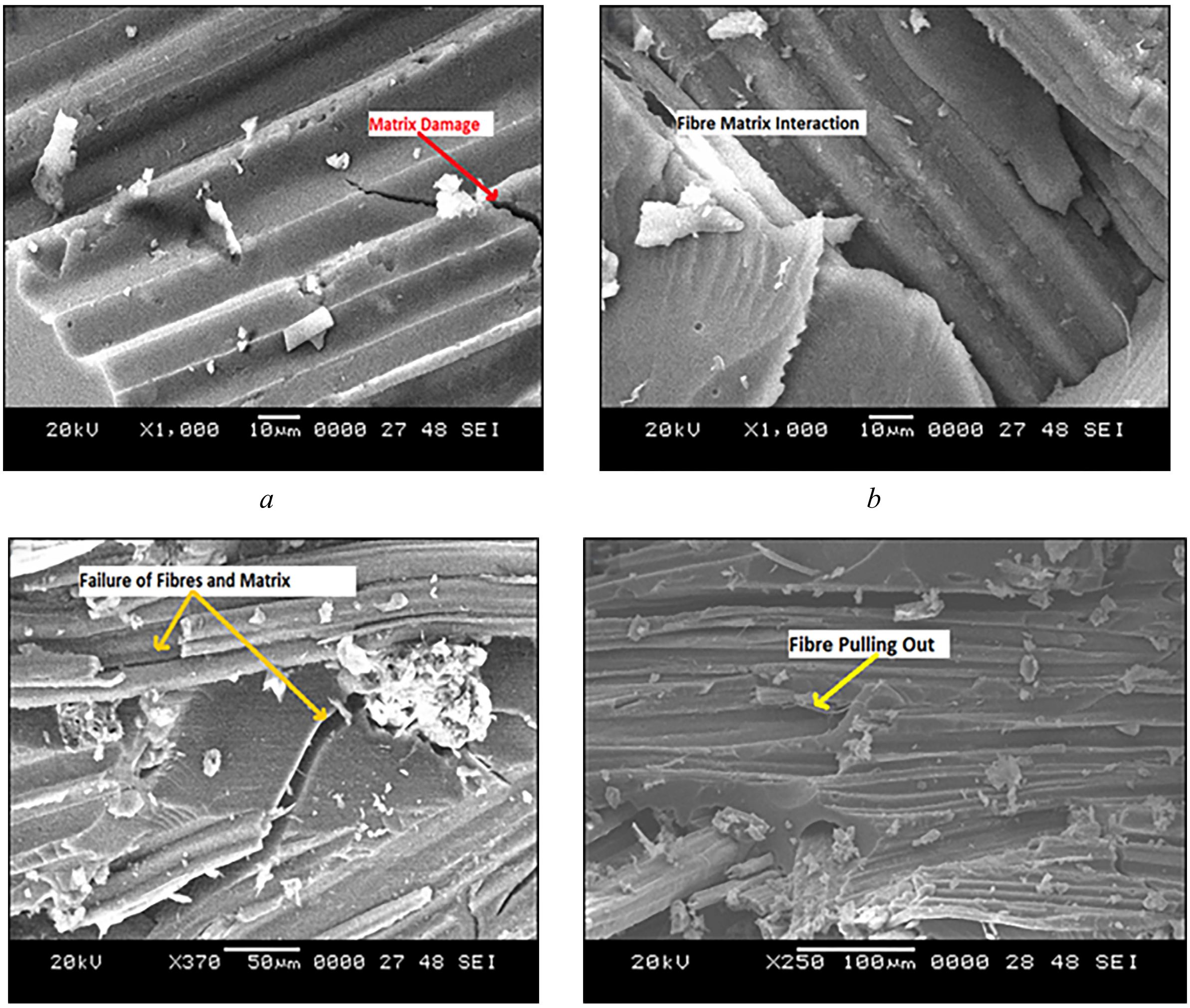


Fig. 6. Basket-type composite material after treatment with 1 % alkali solution for 1 hour



a *b*

c *d*

Fig. 7. SEM images of composite:

a – matrix damage; *b* – fibre matrix interaction; *c* – failure of fibres and matrix; *d* – fibre pulling out

When jute fibers are used to strengthen the matrix (fig. 7a), fracture occurs at an angle, which indicates an increase in the plasticity of the composite. Fig. 7b, 7d also show that the matrix failed first, and then the fibers, which indicates that the fibers in the composite had to withstand the highest loads. The matrix also served as a binder for the jute fibers.

M. Rajesh et al [1, 3, 4, 5] and *Savendra Pratap Singh* [2] worked on composite materials from woven jute fiber and noted its improved properties. However, they investigated *CM* based on 1, 2 and 3 layers of woven jute fiber in various combinations. In this research work, the author considered a composite material based on four layers of woven jute fiber. The author performed a preliminary surface treatment of the fibers and revealed its positive effect on the properties, which opens up prospects for further structural use of such a composite material and replacement of *CM* based on synthetic fibers, which will reduce the level of environmental pollution by synthetic waste.

Conclusions

According to the study, the natural fiber composite has excellent mechanical and free vibration properties, making it suitable for use in low to medium loading conditions. The mechanical and free vibration characteristics of jute fibers increase significantly after surface treatment with *NaOH*, but the qualities are not significantly improved by increasing the *NaOH* strength or soaking time. The hydrophilic character of composite is shown by *FTIR* analysis, which prevents its use in a humid environment. SEM analysis shows that as the amount of fiber increases, the composite material changes from brittle to ductile. The conclusion of the study of the free vibration and mechanical behaviour of treated woven jute polymer composite would depend on the specific finding and result obtained from the research. however, here are some possible conclusions that could be drawn from such study.

Improvement of mechanical properties. treating a woven jute polymer composite can result in improved mechanical properties compared to an untreated one. The treatment process may include methods such as chemical modification, surface treatment or the addition of a reinforcing agent. These processing methods can improve the strength and stiffness of the composite material, as well as the resistance to deformation.

Improvement of vibration absorption. Free vibration analysis helps to evaluate the dynamic behavior of materials and structures. Treated woven jute polymer composites can exhibit improved vibration absorption characteristics compared to untreated composites. The treating process can change the interface of the fiber matrix, which will lead to improved energy dissipation during vibrations and an increase in damping capacity.

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Conflicts of Interest

The authors declare no conflict of interest.