



Tensile and Flexural Properties of Sisal, Banana and Bamboo Fibre Epoxy Composites

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Abstract	Article History
<p>Opportunities abound for more innovative development work involving naturally-occurring fibrous materials with good strength and stiffness properties in their use as reinforcements/fillers in polymeric composites fabrication. Utilisation of these waste materials in new composite materials fabrication is important in engineering economics especially in resource savings and ecological considerations. It is in realization of this that tensile and flexural behaviour of chemically retted sisal (<i>Agave sisalana</i>), bamboo and banana (<i>Musa sapientum</i>) fibre reinforced epoxy composites were investigated. The carefully characterised fibres were cut into short lengths and ASTM sample pieces were fabricated in appropriate moulds. The three fibres composites show similar trend of strength deterioration with increasing fibre concentration. From the analysis, only sisal showed consistent and steady strength reduction through all the fibre concentration range. The tensile strength, modulus, stress and strain at break for single fibre epoxy composite obtained varied in the range of 34 MPa to 12 MPa, 1.5 GPa to 0.6 GPa, 34 MPa to 12 MPa and 5% to 1% respectively while flexural strength, modulus, stress and strain at break of single composites ranged from 58 MPa to 18 MPa, 1.4 GPa to 0.9 GPa, 8 MPa to 3 MPa and 5% to 1% respectively. The sisal fibre has the highest tensile properties which contributed to increase strengthening of the composites when compared to that of banana and bamboo composites. The data obtained in certain fibre concentration range were found to show promises in various non-load-bearing engineering applications especially in the power sector (wind-power blades), building (panels, flooring etc.), transportation (automobile, railways, aircraft, ship, interiors etc.) and others.</p> <p>Keywords: Natural fibres, Thermosetting Polymer composites and Mechanical Behaviour.</p>	<p>Received: 07 Mar 2026 Accepted: 25 Apr 2026 Published: 02 May 2026</p>  <p>Scan the QR code to view¹</p>
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Introduction

In the recent years, the use of natural fibre reinforced thermosetting resin composites as replacement for traditional materials, notably metals and alloys in various non-load-bearing engineering applications especially in the power sector (wind-power blades), building (panels, flooring etc.), transportation (automobile, railways, aircraft, ship, interiors etc.) has emerged (Zadorecki and Karnerfors, 1986). These composites, which have been considered as replacements for metallic materials (Sakthive and Ramesh, 2013), have continuous primary matrix phase that acts as a binder and holds the fibres in the desired position thereby transferring the external load to the reinforcement (Subhash, 2014).

Naturally-occurring fibres as reinforcement have recently attracted the attention of researchers because of their advantages over other established filler materials. They are

environmentally friendly, fully biodegradable, abundantly available, renewable, cheap and have low density (Girisha *et al.*, 2012; Bongarde and Shinde, 2014). Natural fibres can also be considered as potential replacement for man-made fibres in composite materials especially for specific applications (Xue *et al.*, 2007).

Retting is a common method of extracting naturally-occurring fibres. It is combined action of bacteria and weathering which allows the degradation of the stem material (mainly pectines) binding the fibre bundles together (Luigi, 2013).

Experimental Procedure

Materials

Fibres were extracted from tender bamboo, sisal (*Agave sisalana*) leaves and banana (*Musa sapientum*) trunk. The varieties of the fibres used were those commonly grown in the

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Southwest part of Nigeria. Epoxy 2000 resin and Epoxy hardener HY-2020 from Fiber Glast Corporation, USA, and polyvinyl acetate (PVA) were used as the mould release agent.

The resin has a density of 1.32 g/cm³, tensile strength of 45,326 psi, tensile modulus of 2.53 x 10⁶ psi, percentage elongation of 1.93 and flexural strength of 65,308 psi and flexural modulus of 2.83 x 10⁶ psi.

Equipment and Apparatus

The equipment used includes Instron Universal Tensile Tester 3369, Stereographic microscope, a specially fabricated aluminium mould for the test pieces fabrication and miscellaneous measuring instruments and standard glassware.

Fibre Extraction Procedure

Sisal leaves were collected at Ile-Ife, from the varieties that are commonly grown in gardens and lawns. Tender banana trunks were collected from post-harvested bananas while tender bamboo was collected from the wild. The collected specimens were soaked in water for about five to six weeks allow rapid fermentation to take place. This process degrades the natural binders through bacterial activities. The fibres were then separated after the fermentation/retting process and washed in clean water and sun dried, we then have bamboo fibre, sisal fibre (*Agave sisalana*) and banana fibre (*Musa sapientum*) as shown in figure 1 to 3.

Tensile test was then carried out on the individual fibre strands after which they were chopped into lengths of not more than 1 mm. The average fibre lengths and diameters were obtained with a stereographic microscope.



Figure 1: Sisal fibre



Figure 2: Banana fibre



Figure 3: Bamboo fibre

Test Sample Fabrication Procedure

In fabricating the composite test pieces, an aluminium mould was fabricated according to ASTM D638 standard. The mould dimension was 200 mm by 150 mm for each piece of the mould. Each set of sample was prepared with 36 ml of Epoxy or, 47.52 g by weight with an appropriate proportion of the hardener.

Mixing Procedures

After a thorough mixing of measured epoxy and the hardener, respective concentration of the mixed fibres was then added and carefully stirred manually. It was allowed to stand for not less than ten minutes before carefully poured into the mould. It was left to stand in the open air until it cured. After it was left for not less than 10 hours, each of the test pieces was carefully removed from the mould.

The composite samples were of weight 0%, 5%, 7%, 10%, 15%, 20% and 25%. All the fabricated test pieces were then put together and annealed at 95°C for 50 minutes before mechanical tests were carried out.

Sample Testing Procedure

Tensile Testing

Tensile testing of each of the fabricated test pieces was conducted after accurate measurement of the actual dimensions. Due to the obvious dimensional variability of each test piece, minor manual finishing had to be done on each sample. This is to prevent possible crack initiation that may lead to premature fracture since the composite test pieces are largely brittle.

Firstly, all the samples width, thickness and gauge length were measured using vernier calliper and micrometre screw gauge, after which the samples were placed in a tension-test machine, where they were gripped at each end and pulled in the axial direction.

Flexural Testing

The flexural test was performed on the Instron universal tensile tester in the 3-point bending test mode in accordance with ASTM D790-03 standards. In this test, the specimen to be tested was subjected to a load at its midway between the supports until it fractured. The test determined the resistance of a material to bending. Equation (1) was used in the calculation of flexural strength.

$$\sigma = \frac{3PL}{2bh^2} \quad (1)$$

where, P is the flexure maximum load, L the support span (mm), b is the width of beam (mm) and h is the thickness (mm).

Flexural modulus was obtained from the ratio of stress to strain in the flexural deformation.

Results and Discussion

Fibre strands testing

Table 1 shows the strengths and modulus average values obtained for the sisal, banana and bamboo fibre strands used in this study. The sisal fibres have greater average strength compared to banana and bamboo fibres. Of the three, the banana fibre has the lowest value of tensile strength.

Table 1: Tensile and modulus values for banana, bamboo and sisal fibre strands.

Natural Fibre	Avg Strength (MPa)	Avg. Modulus (MPa)
Bamboo	0.38	12.75
Banana	0.31	24.85
Sisal	0.41	15.61

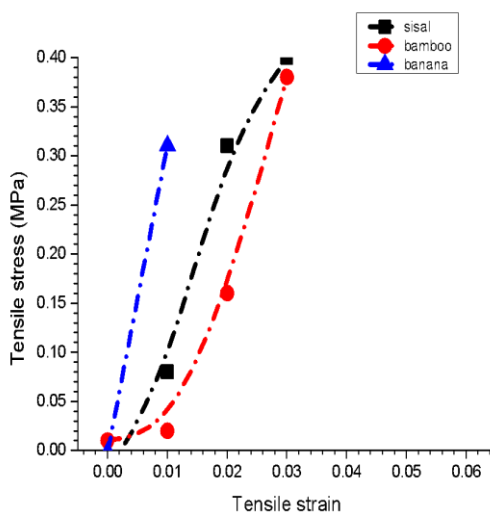


Figure 4: Stress-strain plot for the bamboo, banana and sisal fibre strands.

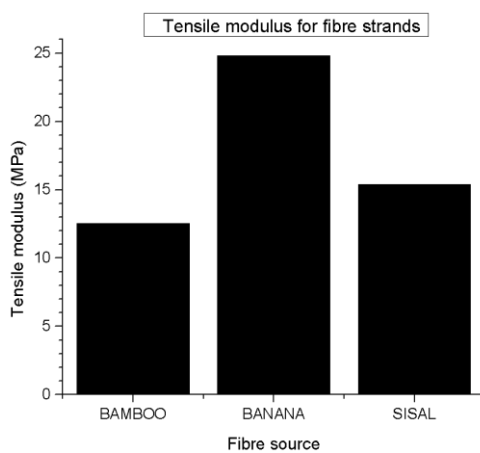


Figure 5: Tensile modulus for bamboo, banana and sisal fibre strands.

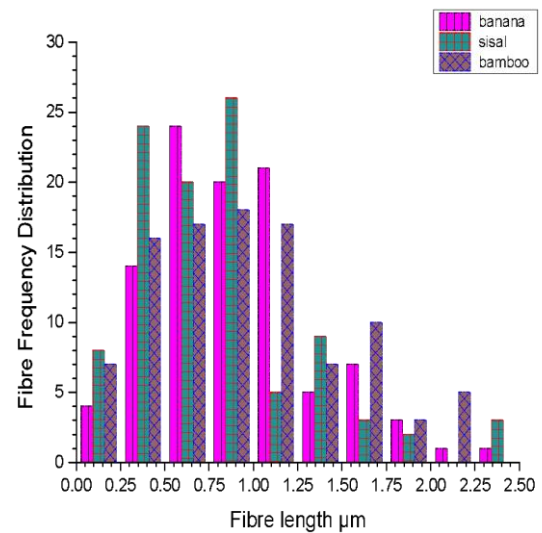


Figure 6: Fibre length frequency distribution for chopped banana, bamboo and sisal fibres.

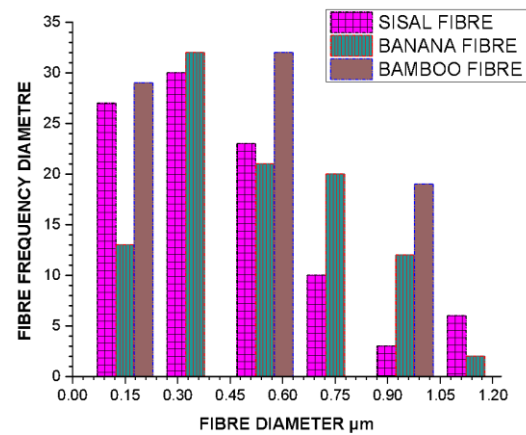


Figure 7: Fibre diameter frequency distribution for chopped banana, Bamboo and sisal fibres.



Figure 8: Mould



Figure 9: Fabricated Composite Samples before testing.



Figure 10: Fabricated Composite Samples after testing.
2. Tensile Properties of Composites Fabricated with Single Fibres

Figure 8 show the mould diagram while figure 9 and 10 presented the picture of well-prepared composites before and after testing

Figure 11 presents a plot of the tensile strength of epoxy fibre composites prepared with single fibre. The three fibres composites show similar trend of strength deterioration with increasing fibre concentration. From these curves, only sisal showed consistent and steady strength reduction through all the fibre concentration range. The single fibre composite follow the trend of range 34 MPa in the unfilled composite to 12 MPa for 25% concentration.

Figure 12 shows the plot of tensile modulus against single banana, bamboo and sisal fibre concentrations epoxy composite. There was not much of difference in the reduction trend in the three composites. However, the tensile modulus of the sisal fibre composite showed a steady increase for all other concentrations above 10%. In the case of banana and bamboo fibre reinforced composites, it is obvious from the plots that bamboo had a marginal (very small) increase while banana in epoxy showed no further increase in modulus above 10% concentration.

Figures 13 and 14 respectively show the tensile stress (Figure 13) and tensile strain (Figure 14) at break against banana, bamboo and sisal fibre concentration, Tensile stress and strain at break are very important in composite tensile behaviour. It can be seen from Figure 13 that in the three fibres under investigation, the tensile stress at break ranged from a maximum of about 33 MPa in the unfilled composite to about 12 MPa for the 25% concentration. The downward trend in the tensile stress at break in the three composite was more consistent in the sisal reinforced composites compared to banana and bamboo. A single curve can be plotted through the bamboo and banana curves because they overlap.

Figure 14 shows the plot of tensile strain at break against the concentration of banana, bamboo and sisal single fibre composite. The trend followed by the tensile strain at break for the three fibre reinforced composites is not different from those of tensile stress at break, tensile modulus and tensile strength presented in Figures 11-13. This appears to conclude that the tensile properties of the banana, bamboo and sisal reinforced fibre composites generally deteriorate as the fibre content increased. Sisal was however found to be the best of the three, followed by bamboo and then banana fibre reinforced composite.

Investigations on the tensile properties of natural fibre-reinforced thermosetting polymer composites have previously been reported for banana fibre in epoxy (Santhosh et al., 2014), vinyl ester (Shash et al., 2013; Sumail et al., 2013; Sapuan et al., 2006), and polyester matrices (Srinivasababu et al., 2009). Studies have also examined bamboo fibre in epoxy (Subhash, 2014; Suyash, 2012) and sisal fibre in epoxy and polyester matrices (Somashekar & Shanthakumar, 2014; Girisha et al., 2012; Srinivasababu et al., 2009). All these investigations indicate a strong and growing interest in understanding the tensile behaviour of naturally occurring fibres, with the aim of developing new materials of engineering importance for practical applications.

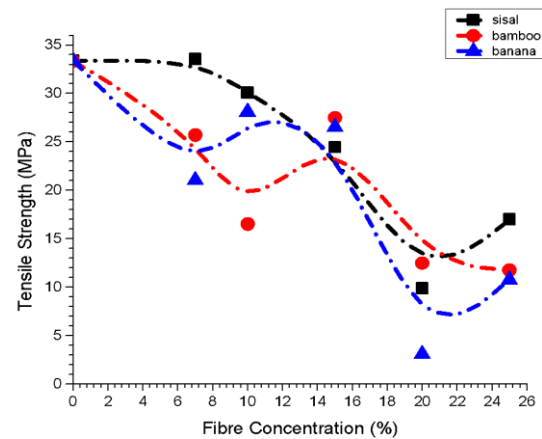


Figure 11: A plot of tensile strength for banana, bamboo and sisal single fibre reinforced epoxy composites against fibre concentration.

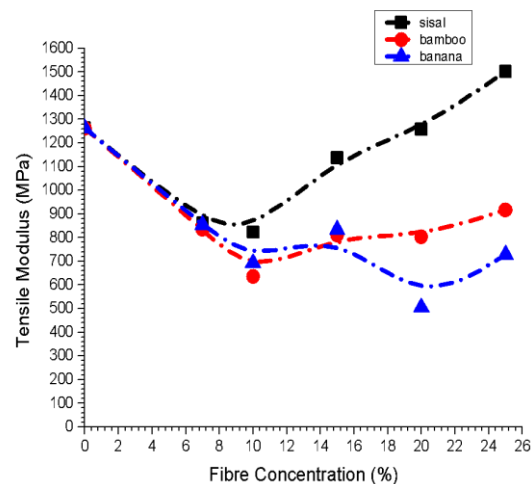


Figure 12: A plot of tensile modulus for banana, bamboo and sisal single fibre reinforced epoxy composites against fibre concentration.

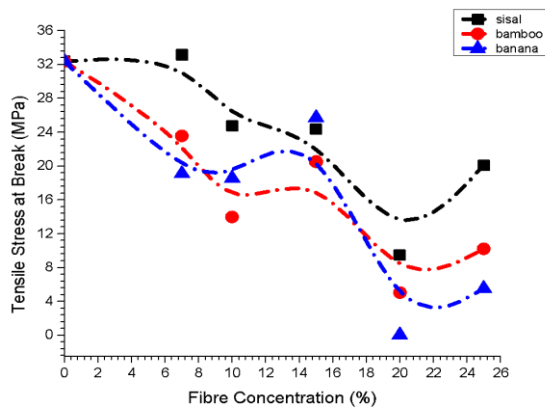


Figure 13: A plot of tensile stress at break for banana, bamboo and sisal single fibre reinforced epoxy composites against fibre concentration.

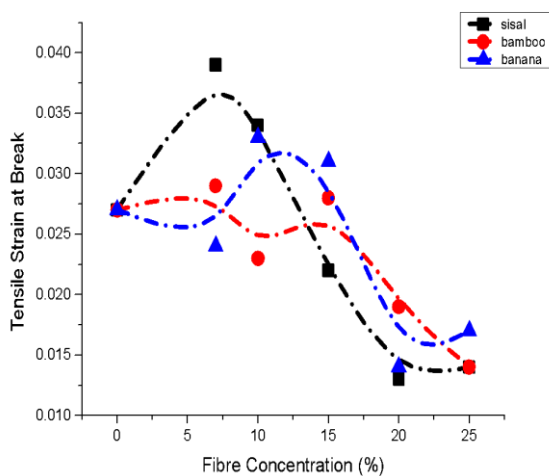


Figure 14: A plot of tensile strain at break for banana, bamboo and sisal single fibre reinforced epoxy composites against fibre concentration.

Flexural Properties of Composites Fabricated with Single Fibre

This is the 3-bend testing on the composite and it illustrates the flexure modulus of the tested composites, the flexure strength, the flexure stress and the strain at break.

Figure 15 shows the plot of flexural strength against the fibre concentration; the strength trend for bamboo and sisal fibre composite among the three-fibre composite shows regular trend manner of decreasing with increase fibre concentration while banana fibre composite showed an unsteady downward trend. Bamboo reinforced composite has the highest fractured strength followed by banana and sisal has the least bending strength at fibre concentration of ~7%.

Figure 16 shows the plot of flexural modulus (stiffness) against the fibre content for bamboo, banana and sisal fibre composite. In sisal and banana fibre composite, the flexural modulus follows the same trend; it increases as the fibre content increases up to 18%, banana fibre composite drops rapidly, while sisal fibre composite drops steadily. For bamboo fibre composite, the flexural stiffness reduces as the fibre concentration increases and rises again at 11%, the peak is found in 15%. Bamboo fibre composite also has the highest bending/flexural stiffness.

Figure 17 shows the plot of flexural stress at break against the single content; for sisal and banana fibre composite, the stress at

break followed the same trend of downward flexure stress at break while bamboo fibre composite has an increase flexure stress at break with increase in fibre concentration.

Figure 18 shows the plot of flexural strain at break against the single content; the strain trend for the three-fibre composite follows similar trend. The strain at break decreases as fibre content increases. Flexural strain at break for the composites shows a general decrease as the concentration of the content increased. The strain at break for the entire single composite varied from about 1.0% to 5.0%. It can be suggested here that the straining at break is stable for single composite.

Santhosh *et al.*, 2014, found out that the flexural strength for banana/epoxy (also vinylster) is high for vinylster than epoxy; Dheeraj, 2014 reinforced bamboo/epoxy composite and found out that the peak is in 25%; Subhash, 2014 and Suyash, 2012 reinforced bamboo/epoxy composite; Somashekar and Shanthakumar 2014 reinforced sisal/epoxy and the peak is found in 20%. Sapuan *et al.*, 2006 and Sumail *et al.*, 2013 found out that non-woven banana/epoxy composite has high flexural stiffness.

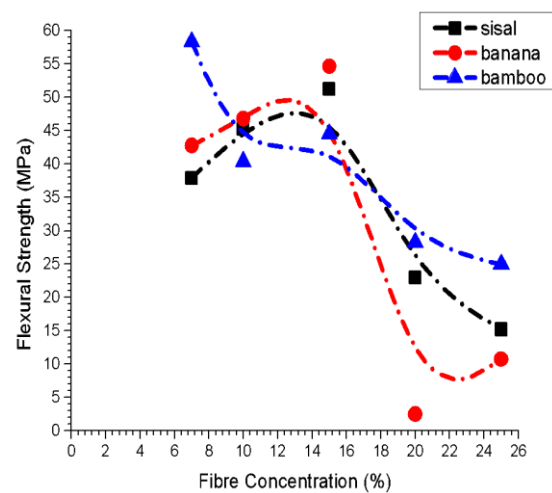


Figure 15: A plot of flexural strength for banana, bamboo and sisal single fibre reinforced epoxy composites against fibre concentration.

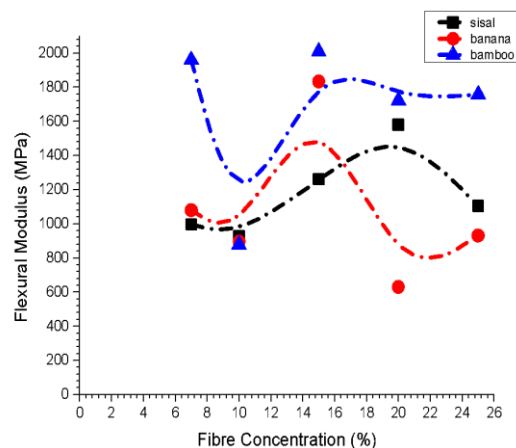


Figure 16: A plot of flexural modulus for banana, bamboo and sisal single fibre reinforced epoxy composites against fibre concentration.

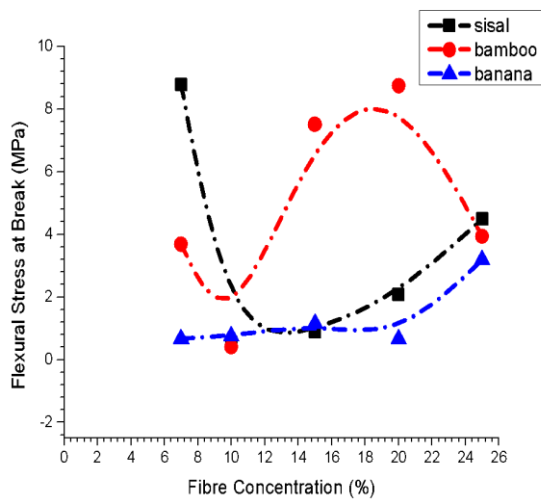


Figure 17: A plot of flexural stress at break for banana, bamboo and sisal single fibre reinforced epoxy composites against fibre concentration.

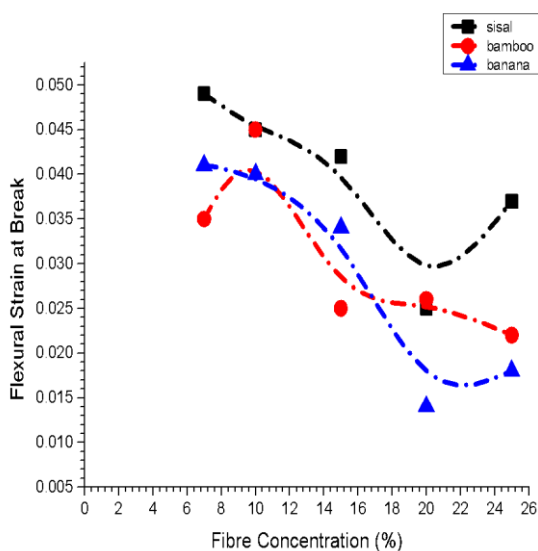


Figure 18: A plot of flexural strain at break for banana, bamboo and sisal single fibres reinforced epoxy composites against fibre concentration.

Conclusion

The fabrication of single fibre epoxy composite have been carried out and the effect on the mechanical properties was analysed.

The single strands for the three fibres were subjected to tensile test, where sisal fibre strands had the highest tensile strength of 0.41 MPa while the tensile modulus was 15 MPa. The banana fibre strands had a strength and modulus of 0.307 MPa and 25 MPa and bamboo fibre strands had a strength and modulus of 0.383 MPa and 13 MPa respectively.

The tensile strength, modulus, stress and strain at break for single fibre epoxy composite obtained varied in the range of 34 MPa to 12 MPa, 1.5 GPa to 0.6 GPa, 34 MPa to 12 MPa and 5% to 1% respectively while flexural strength, modulus, stress and strain at break of single composites ranged from 58

MPa to 18 MPa, 1.4 GPa to 0.9 GPa, 8 MPa to 3 MPa and 5% to 1% respectively.

Single composites have flexural strength, modulus, stress and strain at break in range of about 58 MPa to 18 MPa, 1.4 GPa to 0.9 GPa, 8 MPa to 3 MPa and 5% to 1% respectively

It can be concluded that the sisal fibre had an increased strengthening and stiffening effect compared to the other fibres in the tensile and flexural test modes thereby resulting in improved tensile and flexural properties of the composite.

This shows that composites in which the natural fibre components are of high modulus (i.e. as shown by sisal rather than banana or bamboo) can be used in various non-load-bearing engineering applications such as power sector (wind-power blade), building (panels, flooring) and transportation (automobile, railways, aircraft, ship) interior as indicated by the flexural properties presented in this study.

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