MATERIALE PLASTICE
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https://doi.org/10.37358/Mat.Plast.1964

Mechanical, Vibration and Visco-elastic Behavior of *Abelmoschus Esculentus* Fiber Reinforced Epoxy Composite

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Abstract: *Nowadays, research is focused on using bio-degradable natural fibre-based composites for secondary structural members**.** The present study aims to investigate the effect of fiber loading and surface treatment on the mechanical, vibrational, and viscoelastic properties of short, randomly oriented Abelmoschus Esculentus fiber-reinforced epoxy composites. The composite was fabricated by reinforcing various weight percentages of Abelmoschus Esculentus in epoxy resin by hand lay-up method and tested for tensile, flexural, and impact tests as per ASTM standards. Further, the fibres are treated with alkali to evaluate their effect on the mechanical properties of composites. The analysis indicated that fiber loading had a significant impact on the mechanical properties of the composite, withthe maximum tensile strength of 27.8 MPa being obtained at a fiber loading of 20 volume %. The surface treatment of the fiber with 2% NaOH solution increased the tensile strength by 34%. All composite specimens were subjected to vibration analysis. The results showed that composite reinforced with 20% fibre loading provided superior mechanical and damping qualities. Dynamic Mechanical Analysis revealed that the Storage Modulus (E') improved with the addition of Abelmoschus Esculentus fiber.*

Keywords*: Abelmoschus Esculentus fiber, free vibration, SEM analysis, viscoelastic properties,composite*

1. Introduction

Considering the history of researches in the previous few decades, various researchers had been looking at the advantages of using natural fibres as an effective reinforcement in Fiber Reinforced Plastic (FRP) composites. The environmental concerns and the search for eco-friendly, low-cost, biodegradable, and high-performance composite materials have made natural fibers an obvious choice of reinforcement in FRP composites [1- 7]. As a result of benefits such as better strength-to-weight ratio, cheaper cost, biodegradability, ease ofavailability, and reduced carbon footprint, natural fibers are increasingly being used to replace syntheticfibers, especially glass fiber in several applications. Despite the above advantages, natural fibers lack the physical strength of synthetic fibers and they are hydrophilic i.e. they tend to absorb water. As a result, efforts were undertaken to enhance the characteristics of composites by enhancing the fiber- matrix interaction. Many researchers [8-11] have demonstrated that chemical treatment of the surface of the fiber would be used as one of the efficient approaches to enhance the fiber-matrix adhesion, resulting in higher-performance composites. Maheswari et al. [12] studied the influence of mechanical properties on an unsaturated polyester composite reinforced with tamarind fiber and studied the influence of chemical treatment and fiber loading. For a fiber loading of 25 weight %, a maximum tensile strength of 25.2 MPa was achieved. The mechanical characteristics of composites treated with alkali and silane improved significantly.

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Gheith et al. [13] investigated the effect of date palm fiber (DPF) on the mechanical and viscoelasticity of epoxy composites.

It was reported that the composite containing 50% DPF had improved mechanical and dynamic mechanical characteristics. Senthil Muthu Kumar et. al. [14] examined the effect of Musa acuminate peel powder on the characteristics of poly (propylene) carbonate composite. One of the greatest recorded tensile strengths was obtained with a filler loading of *Abelmoschus Esculentus* fiber had been used as potential reinforcement by several researchers [18-22]. The influence of Okra fiber in volume fraction on the mechanical properties using epoxy composites was experimentally investigated by Reddy and Reddy [23]. At 20 volume % fiber loading, the maximum tensile strength was achieved. Abdullah and Hashim [24] investigated the impact and flexural propertiesof Okra fiber-reinforced epoxy composites. The maximum modulus value was obtained at a fiber loadingof 12 weight %. According to Surendra et al. [25], efforts were undertaken to manufacture and study the mechanical characteristics of hybrid composites based on Okra fiber, with mixed results. The experimental results revealed that the hybrid composites reinforced with sisal/jute/okra fiber had better mechanical properties than those reinforced with epoxy composite sisal fiber [26]. The above literature showed that fiber surface treatment can be used as an effective method to enhance the mechanical properties of natural fiber-reinforced composites.

The epoxy-based composites utilized *Abelmoschus Esculentus* fiber as a reinforcement and were produced at varying fiber volume percentages. Besides looking at how chemical treatment affected mechanical qualities, researchers looked into the material's mechanical properties, its viscoelastic behavior, and the influence of fiber loading on the material's mechanical characteristics. In addition, the vibrational properties were studied. It is obvious from the aforementioned literature that several works had been done in the preparation of composites with *Abelmoschus Esculentus* fiber as reinforcement material, but few had attempted to characterize the effect of the chemical treatment or vibration analysisof the reinforced *Abelmoschus Esculentus* fiber composite.

2. Materials and methods

2.1. Materials

Abelmoschus Esculentus fiber was employed as a bolsting material in the present experimentation task and was procured from M/s PV fibers, Kancheepuram, Tamilnadu. The fibre was sun-dried for three days to eliminate any remaining moisture before being cut to a length of 10mm (approx.). The density of *Abelmoschus Esculentus* was estimated, and its value was found to be 0.6 g/cm^3. Then the fiber material was incorporated into an epoxy matrix with different volume percent. Both the fiber and matrix were stirred by a mechanical mixer for 1h continuously to achieve uniform distribution as indicated in Figure 1. Abelmoschus Esculentus fibres have a mean diameter of 10-50 micrometres. Epoxy resin (LY556) and hardener (HY951) were employed as matrix material and they were procured fromM/s Sakthi fiberglass, Chennai, India.

Figure 1. Chopped *Abelmoschus Esculentus* fibe

2.2. Preparation of composite

The hand layup approach was used to fabricate composite specimens. The mould was first washed with a gentle cloth, then wax was put to it to facilitate the withdrawal of the composite specimens. The composite specimens were produced by integrating varied fibre loadings of *Abelmoschus Esculentus*. (0, 5, 10, 15, 20, and 25 volume %). The compositions of composites are presented in Table 1.

Table 1. *Abelmoschus Esculentus* fiber reinforced Epoxy Composite - specimen ID

Specimen ID	*Abelmoschus Esculentus* Fiber Volume percent (%)	Epoxy resin Volume percent (%)
Epoxy	0	100
A	5	95
B	10	90
C	15	85
D	20	80
E	25	75

2.3. Mechanical characterization

Initially, the void content in the specimens was evaluated. The difference in the experimental and theoretical densities of the composite material indicates the void content of the composite material. The theoretical density of the composite was evaluated using equation 1.

$$T_d = (V_E * \rho_E + V_f * \rho_f) / 100 \qquad (1)$$

where, V_E is the volume percentage of the epoxy matrix in the composite, ρ_E is the density of the matrix,V_F is the volume percentage of the fiber and ρ_f is the density of fiber material.

As required by ASTM standards, the mechanical characteristics of the composite specimens were measured and recorded. To evaluate the effect of fiber loading, tensile tests, flexural tests, and impact tests were carried out. The testing was performed using testing equipment termed Instron Universal Testing Machine at a speed of 0.05 in/s. The results were all drawn from the average of the five samples.Mechanical properties were also evaluated after treating the fiber surface by using a 2% NaOH solution. The characteristics of the composite also changed in the tension mode when it was tested at various frequencies.

2.4. Modal analysis

Modal analysis is a technique used to investigate the vibrational characteristics of materials.Vibrational analysis was carried out with the help of an impact hammer test setup as shown in Figure 2.The experiments were carried out at Rajalakshmi Engineering College, Chennai, India. The composite sample of dimension 200 mm × 19 mm × 3 mm was attached to the free vibration test set-up as shown, representing a cantilever beam. The beam was excited using a sharp tip hammer and the response was logged using a frequency response curve. The displacement gesture from the accelerometer (Type 8778 A500) was registered on a computer with the help of a data acquisition system. The composite specimen was impacted upon by using an Impact Hammer (Model -1H-01).

Figure 2. Computerized Free Vibration set-up used in this experiment

3. Results and discussions

3.1. Density and void content

Initially, the density of the *Abelmoschus Esculentus* fiber was found using the liquid displacement method and was evaluated as 0.6 g/cm^3. The void content of *Abelmoschus Esculentus* fiber-reinforced composites samples was calculated and the outcomes are represented in Table 2. The void content of the composites was found to grow as the fibre loading increased. The rise in void content suggests that the entrapment of air in the composite sample results in poor fibre dispersion in the matrix.

Table 2. Void content of composite material

Specimen ID	Experimental density (g/cm^3)	Theoretical density (g/cm^3)	Void content (%)
A	1.19	1.21	2
B	1.16	1.18	2
C	1.12	1.15	3
D	1.13	1.16	3
E	1.12	1.15	3

3.2. Mechanical properties of *Abelmoschus Esculentus* dispersed polymer composites

The outcomes from the mechanical experimentations are presented in Figure 3 to 5. Figure 3 depicts the tensile characteristics (tensile modulus and strength) of the composite samples. The highest magnitude of the tensile strength was achieved at the fiber volume percentage of 20%. The tensile strength of the composite at 20% fiber loading was achieved as 27.8 MPa, shown in Figures 3-5. The result shows that the addition of fibre increases the mechanical properties of fibre-reinforced polymer composite.

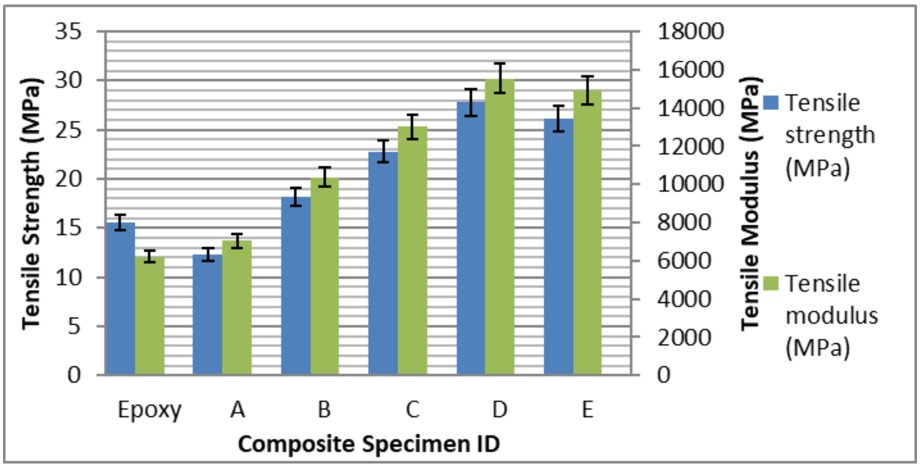

Figure 3. Impact of *Abelmoschus Esculentus* - Epoxy compositeson tensile Properties

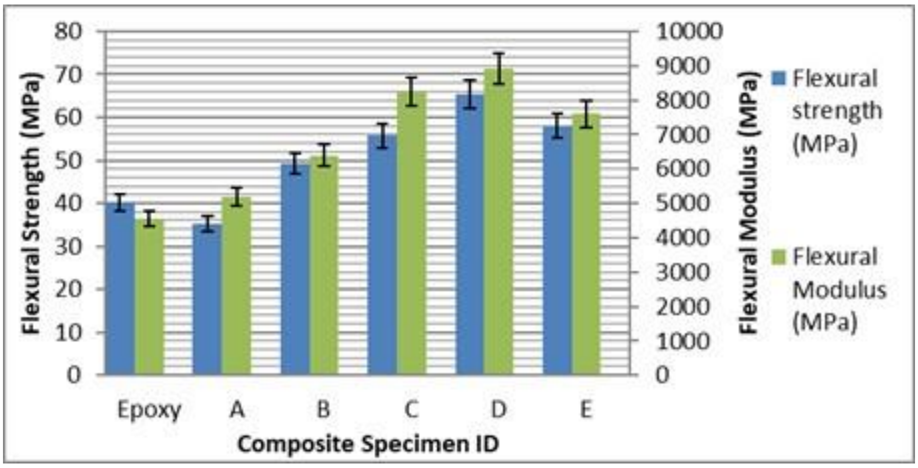

Figure 4. Impact of *Abelmoschus Esculentus* - Epoxy compositeson flexural properties

The highest flexural and impact strength were obtained as 65.3 MPa and 35.8 J/mm^2, respectively using the prepared specimen with 20% fiber loading. As fiber content increased by more than 20 volume %, a declining trend in tensile strength could be seen. As a consequence of the inclusion of *Abelmoschus Esculentus* fiber into the composite, the mechanical characteristics of the composite were shown to be improved. Over 20 percent of fibre addition causes the fibre to entangle and aggregate, which impairs the resin's ability to wet the individual fibres. Agglomeration and inadequate fibre wetting led to weak bonding and ineffective load transfer between the fibre and matrix. Additionally, it was found that the neat resin had marginally superior mechanical properties than the composite with 5% fibre content. This finding may be explained by the fact that adding fibre in modest amounts leads in larger void content than the neat resin [27].

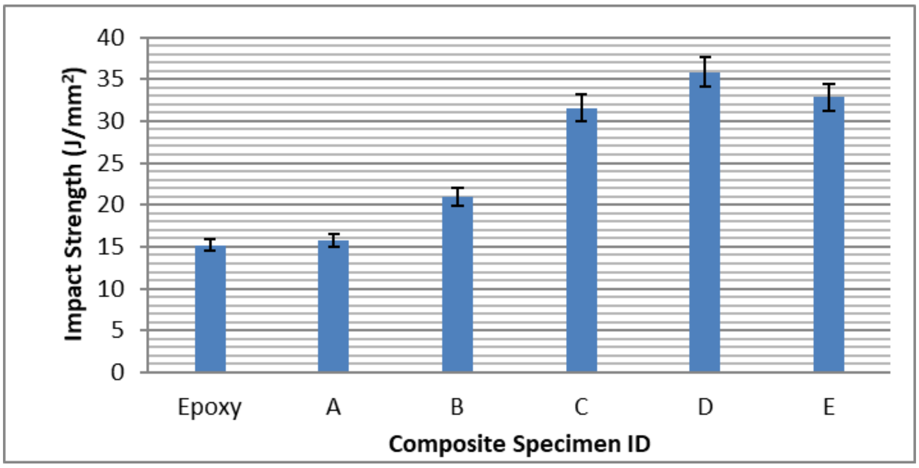

Figure 5. Influence of *Abelmoschus Esculentus* - Epoxy composites on impact strength

3.3. Effect of surface treatment of *Abelmoschus Esculentus* fiber on the mechanical properties

The performance of composite materials in a range of applications is highly dependent on the interaction between the reinforcing matrix and fiber, which is discussed in detail below. Adhesion between component materials in composites has been improved by treating the fiber surface with a chemical to enhance adhesion between the constituent materials. In this work, Sodium Hydroxide (NaOH) was used as a surface modifier. The fibers were thoroughly washed in 2% NaOH solution and distilled water and they were dried completely. Natural fibers include cellulose in the form of long, slenderpolymer chains. During the chemical treatment, the hydroxyl group in the cellulose chain interacts, forming strong intermolecular and intramolecular connections that strengthen the fibers. The cellulose in the fiber swells and the monoclinic crystalline structure of the cellulose is transformed into several polymorphous forms during alkali treatment. Composite specimens were made utilizing treated fibers ata volume percentage of 20 volume %. The produced composite was subjected to a series of tests to evaluate its mechanical characteristics. It was found via testing that the surface modification of the fiber resulted in a significant improvement in the composite material's mechanical properties. Figure 6 depicts the test findings. The value of tensile strength increased by 27.5 % for the composite reinforced with chemically treated fibers. The increased performance shows that the interaction between the fiber and the matrix has been improved as a result of the chemical treatment. Due to alkali treatment, hemicellulose and impuritiesare removed from the surface of the fiber, resulting in improved surface adherence and increased load- bearing capability of the fibers. The flexural and impact strength were increased by 17 and 21% respectively due to the surface modification of the fibers.

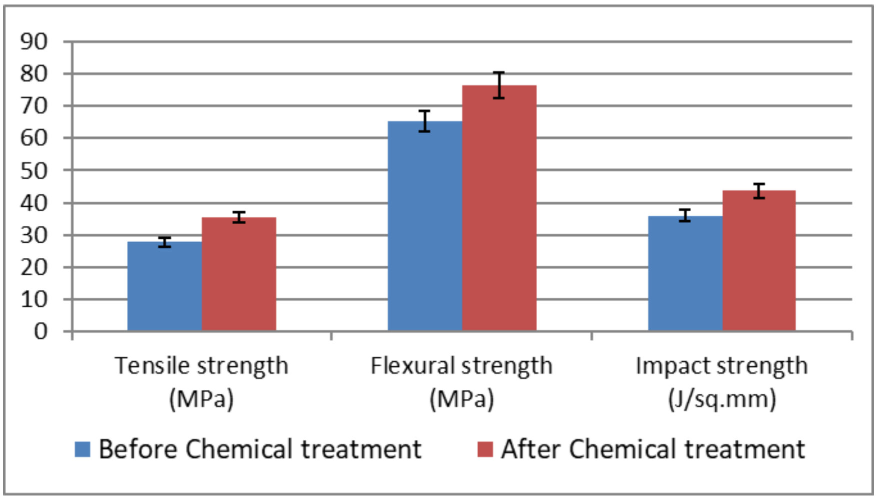

Figure 6. Mechanical properties of treated *Abelmoschus Esculentus* – epoxy composite

3.4. Free vibration analysis

In the free vibration analysis, the dynamic behavior of the composite material was studied by using the experimental set-up for the transverse vibration of the cantilever beam. The experimental results are listed in Table 3. According to the test findings, the mode I and mode II frequencies, logarithmic decrement, and damping ratio of the composite samples reinforced with 20 volume % were all higher than for the control samples. When compared to other samples, *Abelmoschus Esculentus* fiber showed superior characteristics. The magnitude of mode I frequency was attained as 50.82 Hz and the damping ratio was 0.60 for the specimen with 20% fiber loading. Figure 7 shows the accelerometer output graph for the composite specimen - D. The damping ratio is the amount of energy expended in bringing the material to a complete stop as rapidly as feasible. It was also inferred that as the fibre content increased, the vibration characteristics gradually improved; this is because the fibre helps to dampen intramolecular movement and dissipates energy more quickly when it is present. As fibre loading increases in composites, the connection between the matrix and fibre tightens, resulting in a decrease in maximum displacement and an increase in natural frequency. The increased natural frequency value and improved damping ratio indicate that the composite can be utilised safely in applications involving induced vibrations at higher frequencies.

Table 3. Results of modal analysis

Specimen ID	Mode I frequency (Hz)	Mode II frequency (Hz)	Logarithmic Decrement	Damping Ratio
A	47	222.21	0.30	0.047
B	48.12	251.12	0.33	0.052
C	49.50	290.20	0.35	0.055
D	50.82	339.40	0.38	0.060
E	50.17	338.95	0.37	0.059

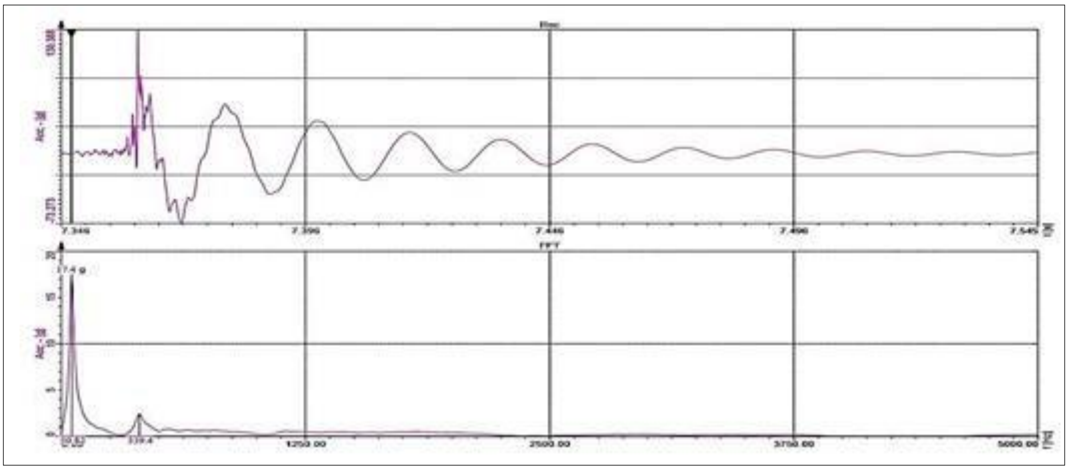

Figure 7. Sample plot for modal analysis of *AbelmoschusEsculentus* – epoxy composite

3.5. Surface morphology

SEM pictures obtained from the tensile test fractured surface of the composite specimens were used to investigate the interaction between the fibre and the matrix. Figure 8 shows the surface morphology of tensile fractured specimens. It was observed that a strong adhesion between fiber and matrix is visualized shown in Figure 8d compared to all other micrographic images. Figure 8e further showed that the addition of too much fibre caused fibre aggregation and inadequate bonding between the fibre and matrix. As a result of the fibre moving away from the matrix due to poor fiber-matrix interaction, the load could not be carried by the fibre effectively, reducing the composite's overall strength.

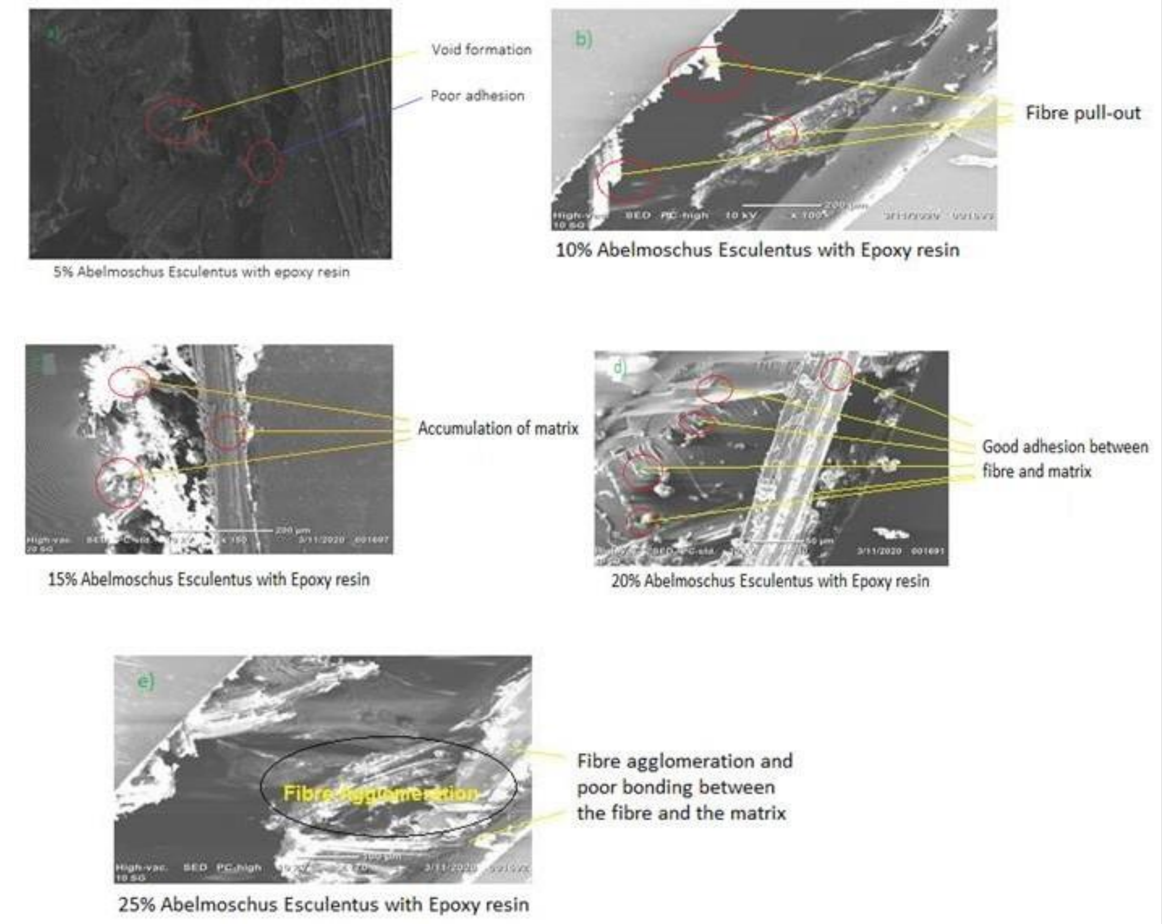

Figure 8. SEM images of fractured specimen a) 5% v/v, b) 10% v/v, c) 15% v/v, d) 20% v/v and 25% v/v

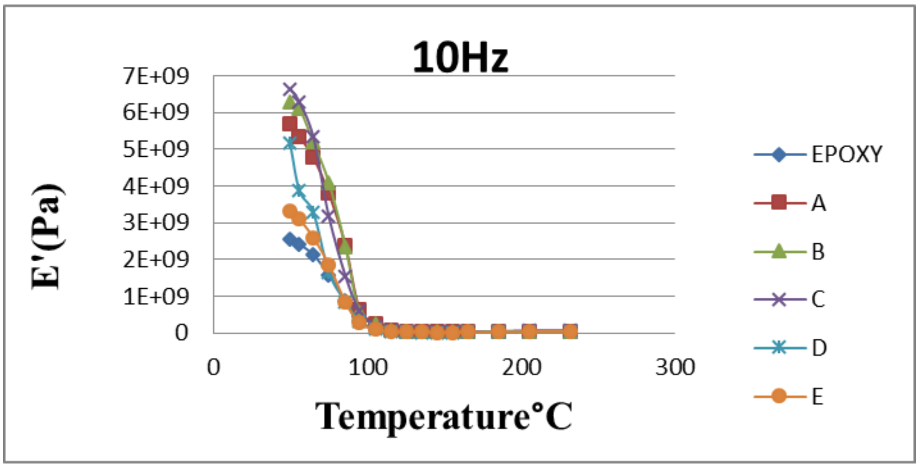

Figure 9. Storage modulus Vs temperature

3.6. Dynamic mechanical analysis

3.6.1. Storage modulus (E') and damping factor (Tan δ)

Viscoelastic properties indicate the response of the polymer composites under different types of service conditions such as dynamic stresses, thermal stability, and dimensional stability. Temperature a *Abelmoschus Esculentus* fiber loading are two variables that significantly influence the storage modulusof the epoxy composite at 10 Hz, as shown in Figure 9. It is observed from the figure that LY 556 epoxy possesses a lower-storage modulus among all the composites, which indicates that it has lower stiffness than composite. It was observed from the figure that the addition of the chapped *Abelmoschus Esculentus* fiber resulted in an improvement in the absorption energy of the composite. The incorporation of *Abelmoschus Esculentus* fiber material into the epoxy matrix material made the composite material more energy-absorbent. All the storage modulus curves show these regions; a relatively higher region at a lower temperature corresponds to the rigid (glassy) state of the polymers and their composites. After the higher region, the curve shows a steep drop causing a rapid decrease in the modulus value due to softening and rubbery flow [28].

Physical cross-links are formed as a result of the inclusion of *Abelmoschus Esculentus* fiber, which toughens the composite and results in a higher storage modulus value both below and above the glass transition temperature. This increase in the composite's glass transition temperature (Tg) was ascribed tothe polymer's free molecular mobility across the chain. The difference in the Tg values was 130°C. According to the researchers, including the *Abelmoschus Esculentus* fiber in the polymer matrix increasesthe stiffness of the composite material due to limitations in free molecular mobility when heated. The presence of the *Abelmoschus Esculentus* fiber has led to an increase in storage modulus, which occurs inboth the rubbery and glassy zones. A study of the testing findings has shown that storage modulus valueswere found to be higher when measured in a shorter period (high frequency), while exposure for a longerlength of time (low frequency) resulted in lower values. A reduction in local tensions was also noted, dueto the molecular rearrangement in the material.

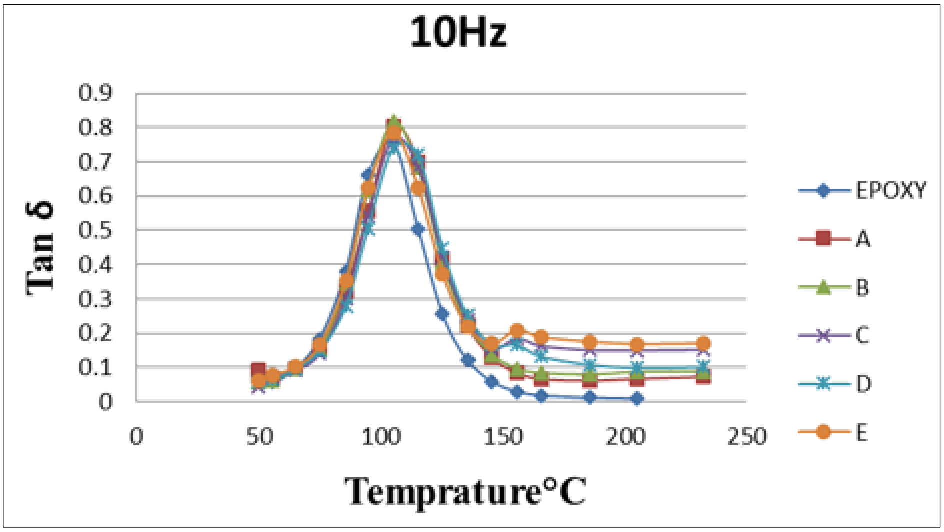

Figure 10. Tan δ Vs temperature

Loss percentage (or) Loss modulus is the ratio of the material's loss modulus to its storage modulus,and it shows how much energy is dissipated in the material when loaded. It is a dimensionless characteristic linked to a material's ability to absorb vibration energy. Figure 10 shows the damping factor of the *Abelmoschus Esculentus* fiber composite at various frequencies. The damping parameter for Epoxyresin is 0.8 and the addition of the *Abelmoschus Esculentus* fiber causes a decrease in the tan delta valueto 0.75 for 20 volume % of the fiber. Further addition of the *Abelmoschus Esculentus* fiber to 25 volume % showsonly a slight increase in the tan delta value. The damping peak occurs in the glass transition region wherethe material starts to become plastic. During this phase, the molecules in the epoxy start to mobilize. Asthe tan delta rises, molecular mobility increases. Due to the addition of the *Abelmoschus Esculentus* fiberinto the Epoxy matrix, the free movement of the polymer molecules is interrupted and results in a lowering of the tan δ value. An increase in the reinforcement volume % beyond a certain value causes agglomeration and results in decreasing the Epoxy matrix volume, thereby lowering the dissipation of energy.

Cole-Cole plot

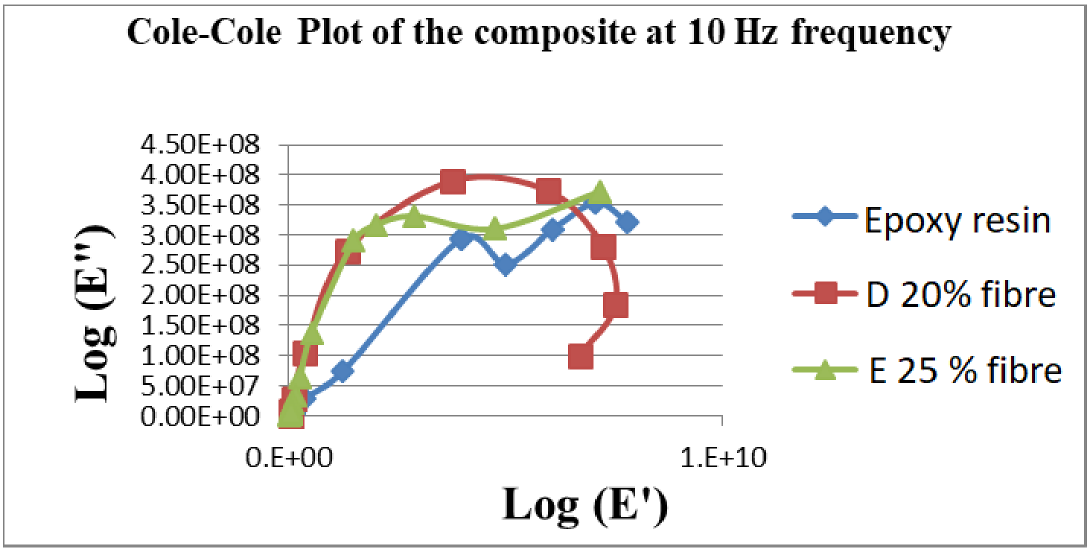

Figure 11. Cole-Cole Plot of the epoxy Vs composite at 10 Hz frequency

The Cole-Cole plot for the epoxy with 20 volume % and 25 volume % *Abelmoschus Esculentus* composite is shown in Figure 11. The semicircular shape of the curve of specimen D indicates that the composite has been produced in a homogeneous environment. While the plot of the composite with 25 volume % fiber revealed that the composite was heterogeneous as the plot shape deviate from its semicircular nature. The Cole-Cole plot shows the relation between the loss modulus (E”) and the storage modulus (E'). From Figure 11 it is seen that E' has a greater relative contribution than E”. This demonstrates that the material can absorb rather than release energy.

4. Conclusions

The study of epoxy composite materials subjected to increasing fiber loading was carried out in this work. Another investigation included examining the effects of surface adaption on mechanical characteristics. The assessment of the mechanical characteristics of the composite found that mechanical qualities improved with the addition of *Abelmoschus* Esculentus fiber. However, the addition of *Abelmoschus Esculentus* fiber over 20 volume % resulted in the downswing of mechanical properties. The composite with 20 volume % fibre content achieved a maximum tensile strength of 27.8 MPa, which is 79% higher than the neat resin. The tensile strength of the fibers also improved by 27% as a result of the improvement in fiber-matrix interaction brought about by surface adaptation. The inclusion of *Abelmoschus Esculentus* fibre increased the damping qualities and the Mode I natural frequency, according to a free vibration investigation of the composite specimens. In the dynamic mechanical properties investigation, a similar pattern was observed. This composite contained 20% fiber by volume,and as a result, it had larger storage modulus and glass transition temperature values, making it strongerand more stable.

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Manuscript received: 30.04.2022