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Dynamic Mechanical Analysis of Aegle Marmelos / Epoxy matrix Reinforced with Snake Grass Fibre Composite

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Abstract: *Nowadays, Manufacturing and automotive industries have begun to employ renewable resources as a result of public awareness and rigorous legal requirements relating to the usage of polymers. This study has focused on employing Snake Grass (SG) fiber as reinforcement in Aegle Marmelos with Epoxy blended hybrid matrix (AME), since natural fiber reinforced composites provide a significant role in the development of lightweight structural components. The primary study investigated the effects of fibre length and fibre volume percentage on the mechanical properties of snake grass fibre. Based on the test results, the composite with a 15 mm fibre length and a volume percentage of 20% SG fiber has better mechanical qualities. Finally, mechanical and dynamic mechanical properties are used to assess the impact of Aegle marmelos with Epoxy blended hybrid matrix addition into the snake grass fibre composite. The inclusion of natural fiber with epoxy matrix and natural (Aegle marmelos) filler increased composite characteristics due to their synergistic effect. This enhances the adhesion and stress transmission uniformity between the reinforcements. The morphology of the fiber surface is assessed using micrographs acquired with a scanning electron microscope.*

Keywords: *aegle marmelos, snake grass, chemicaly treatment, bio polymer composite*

1. Introduction

The influence of fibre length and amount on the mechanical attributes of the composite was tested, and the results revealed that fibres with a length of 10-20mm and a weight content% had better mechanical properties. Furthermore, due to the affinity of natural fibres for moisture, ageing reduces the mechanical qualities of the composite [1]. To promote fibre-matrix adhesion, natural fibres were treated with varied amounts of alkali. It was discovered that treated NaOH improved the composite's mechanical properties more than the other therapies [2]. The impact of fiber loading, temperature, and amplitude on the mechanical properties of the composite was examined using a dynamic mechanical analyzer [3]. The storage capacity of the composite increases as 40% of the fibres are loaded at temperatures ranging from 30 to 600°C. Fibres in the matrix cause the matrix's temperature at which glass transitions to rise to higher frequencies, improving fibre-matrix adhesion. The Cole-Cole plot was used to calculate theoretical verification of the storing and degradation modulus. As a result, DMA appears to be a viable tool for investigating fibre matrix interactions [4]. Coir fibre decreases the pace of stress relaxation as well as the type of the relaxation curve, which is dependent on the surface characterization of the fibre utilized. The mechanical characteristics and water-absorbing capabilities of a resin transfer molded coir fiber polyester composite show that the greatest tensile, flexural, and impact durability is achieved at 20mm length of fiber and 20% weight percentage. It also shown that at 20% weight percent, the maximum diffusion, sorption, and permeability coefficients are attained [5]. The static and dynamic

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mechanical characteristics of a hybrid woven banana/glass fibre composite were examined, with a focus on the impacts of fiber volume fraction, stacking pattern, and weaving pattern.

The warp portion of the weaving was made in the twisted pattern of banana yarn, while the warp portion was woven in alternating bundles of banana and glass thread. It demonstrates that the two-layered composite has the greatest tensile strength, the tri-layer offers the highest flexural strength, and the impact durability improves as the total amount of layers rises. The modulus of storage for the four-layer woven composites is the highest, whereas the degradation elasticity of the mixed woven composite rises as more layers were added [6]. The effect of chemical therapy on the flexibility, effect, and water absorption characteristics of woven banana-polyester composites was examined.

The results show that the treated composite's flexural and impact strength had increased by up to 10% and 15%, respectively. Furthermore, the presence of fibres had caused the characteristics to deteriorate due to inadequate adherence [7]. The composite samples' critical breaking length and interfacial shear capacity (IFSS) were studied, and the IFSS was found to be up to 50% higher than in materials with extra coupling agents [8].

The effect of hybridization with sisal fiber on banana fiber-polyester composites was studied. The mechanical properties of the composite, such as tensile, flexural, and impact strength, were systematically examined with short randomly oriented fibers at 20-40 volume percent. The effect of layer structure on the modulus of storage, dissipation modulus, and damping characteristics of a banana/sisal hybrid composite as a consequence of ambient temperature and frequency. It shows that the trilayer composite with banana fiber as the skin and sisal as the main layer has the greatest stiffness. Short arbitrarily oriented fibers (20-40 volume percent) were employed to evaluate the mechanical characteristics of the composite, including tensile, flexural, and impact strength. The mechanical characteristics of banana and sisal are optimal, according to the testing results, when the volume ratio is 3:1 [9].

The trilayer laminate using banana fibre as its outer covering and sisal as its central layer has the greatest rigidity. It was also discovered that the banana fibre-PF composite had better specific characteristics than the glass fibre-PF composite [10]. A telephone stand produced from a woven banana fiber-epoxy composite was thoroughly designed and manufactured, demonstrating the composite's potential and suitability for product creation [11]. The strength and elasticity of the woven banana-epoxy laminate in the X and Y directions are 14.14 MPa, 3.4 MPa, 0.976 GPa, and 0.863 GPa, respectively [12]. The mechanical properties of snake grass fiber increased with increasing fiber length and fixation, reaching peak values at 20mm length and 20% v/v fixation. Dynamic mechanical analysis (DMA) showed that the combined material absorbed higher energy up to 140°C, irrespective of frequency [13].

Compression molding was used to generate SGF-reinforced polypropylene (PP)-based longitudinal bio-composites (40 wt% fiber), which were then tested for mechanical in nature, hardness, and the heat properties. Irradiated-SGF/PP bio-composites exhibited much better mechanical properties than un-treated sections. Photocuring with UV light was utilized to graft 2-hydroxyethyl methacrylate (HEMA) monomers onto irradiated SGFs. The quantity of UV passes, and thus the HEMA concentration, have been optimized in terms of HEMA grafting, tensile strength, and impact resistance. Bio-composites strengthened with 10% HEMA and the 50th UV pass of SGF have the highest mechanical properties. The thermal stability of modified alkali-treated SGF with HEMA attached composite specimens outperformed that of the remaining specimens [14].

According to the results, adding biological filler and fibre length to the material improves its mechanical properties. According to the literature, surface modification enhances fiber-matrix interface adhesion, whereas the inclusion of particles of filler and fiber length increase improves composite tensile performance and glass transition temperature. Furthermore, the mechanical and viscoelastic properties of Aegle Marmelos filler with Epoxy Blended Epoxy Matrix inclusion into the Snake Grass fiber composite were studied. The novelty of this work is the creation of new composites (a mixture of epoxy resin, natural fibers, and natural filler) and the subsequent analysis of their mechanical properties using the Dynamic Mechanical Analysis approach.

2. Materials and methods

2.1. Tensile testing

The fabricated composite specimens are put through the tensile test in order to analyze their behaviour. The Tinus Olesan UTM machine, is used to conduct the tensile tests. Test specimens are held in place in the equipment by several kinds of self-aligning grips. The experiment's testing speed used is 5 mm/min. Extensometer and load cell are built into the equipment properly to measure test loads and extensions accurately. Samples are prepared in accordance with ASTM testing criteria. The tensile test is carried out at a speed of 2 mm/min in line with ASTM D 638. Tensile mode is used to conduct dynamic mechanical research.

2.2 Flexural testing

Using the Tinus Olesan (UTM) Machine and the ASTM D 790 standard, specimens of composites are tested for flexural properties in the three-point bending mode. The test equipment for flexural strength has a load capacity greater than the test specimen's maximum capacity and is capable of applying the loads at the prescribed loading rate. Its configuration allows the force to be applied by pressing at 90° with the bending device at the specified curvature on the test specimen. The cross head speed is maintained at 10 to 200 mm/min while using a span of 125 mm. Adjusting the loading rate, will result in a strain rate in the test part of about 1.0-2.0 % per minute. The test loading is carried out to the point where the test section fractures and measurements are taken and recorded at regular intervals until the maximum load is attained.

The following formula is used to determine the flexural strength of composite materials [1].

$$\tau = 3FL / 2bd^2 \text{ MPa} \tag{1}$$

where:

τ - is the flexural strength of Specimen
F - is the applied load
B - Specimen’s width of the Specimen = 12.7 mm
L - Specimen’s length of the Specimen = 125 mm
D - Specimen’s thickness of the Specimen = 3.2 mm

2.3. Impact test

Izod Testing (Manufacturer: EIE Instruments Private Limited) Machine is used to test the impact strength of unnotched specimens in accordance with ASTM standard D 4812. The hammer is attached to the pendulum so that the first point of contact with the specimen will be 22 mm above the top surface of the clamping vice. The sample is attached to the vice as a vertical cantilever beam so that it aligns with the vice's surface and faces the hammer's striking edge. With 2.45 m/s striking velocity, the pendulum hammer is released from its locked position, which is 90° away from the specimen's axis. After the sample has been stripped, the energy is displayed on the appropriate scale by the pointer in joules.

2.4. Fractography study

Gold coating is applied to composite specimens, which are subsequently placed within a sputter coating apparatus for between 18 and 22 min. Scanning electron microscope (Manufacturer: Thermo fisher scientific and Model: Apreo-S (Quattro S)) with magnification range of 20x-650x and pressure range of 20-25 Pa is used to analyze the microstructure of composites in order to evaluate the mechanical characteristics and structural morphology. The surface of the coated polymer composites are examined using scanning electron microscopy.

2.5. Dynamic Mechanical Analysis (DMA) TEST

DMA (SEIKODMAI- 6100DMSC) test is carried out to assess the storage modulus and damping factor for composites under nitrogen conditions at temperatures ranging between 30 to 240°C (3-5°C/min) at ten Hz in the tensile mode. Temperature dispersion measurements are used to investigate the glass transition (T_g) temperature and the modulus' temperature dependence. Glass transition, side-chain relaxation and local mode relaxation are examples of relaxation phenomena that can be detected by measuring temperature dispersion and frequency dispersion simultaneously. These methods enable us to learn more about the molecular makeup and mobility of polymers.

2.6. Preparation of composites

Snake grass fiber provided the most significant reinforcement in the hybrid matrix. The impact of fiber length, volume percentage, and biological filler on composite mechanical and viscoelastic properties was investigated. Snake grass fibers are cut into lengths of 5, 10, 15, 20, and 25mm, with varied volume fractions (10, 15, 20, and 25% vol) used in composite manufacture. Following the chemical treatment, volume fraction of 20% *Aegle marmelos* with epoxy are introduced to the composites to see how the filler affected the composites. Composite samples are created using the hand lay-up approach, which was subsequently compressed.

3. Results and discussions

3.1. Tensile test

Mechanical properties and analyses of untreated snake grass fiber hybrid composites are conducted in line with ASTM standards. The graphs has indicates the effect of fibre length and fibre volume % on tensile attributes. It demonstrates that increasing the fiber's concentration and length improves the mechanical properties of snake grass fibre by up to 15mm and 20% vol, as illustrated in Figure 1-4. For the aforementioned composition, the maximum tensile strength and modulus are 64 MPa and 3120 MPa, respectively. Researchers discovered several competitive advantages in natural filler ingredients that contributed to boost the endurance of hybrid composites, such as fracture closing and crack preventing [15].

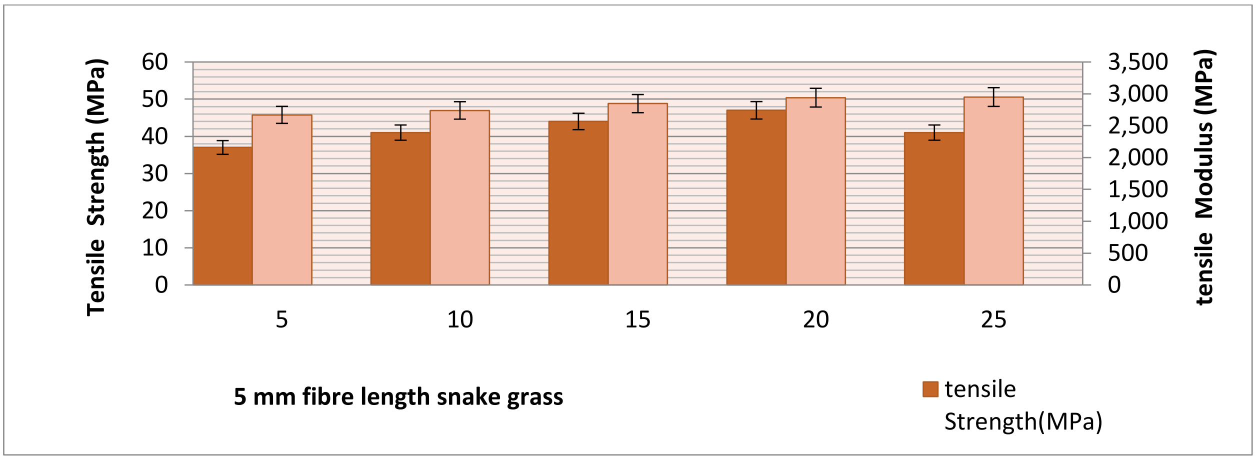

Figure 1. Tensile properties of Snake grass (5mm length) hybrid bio polymer composite

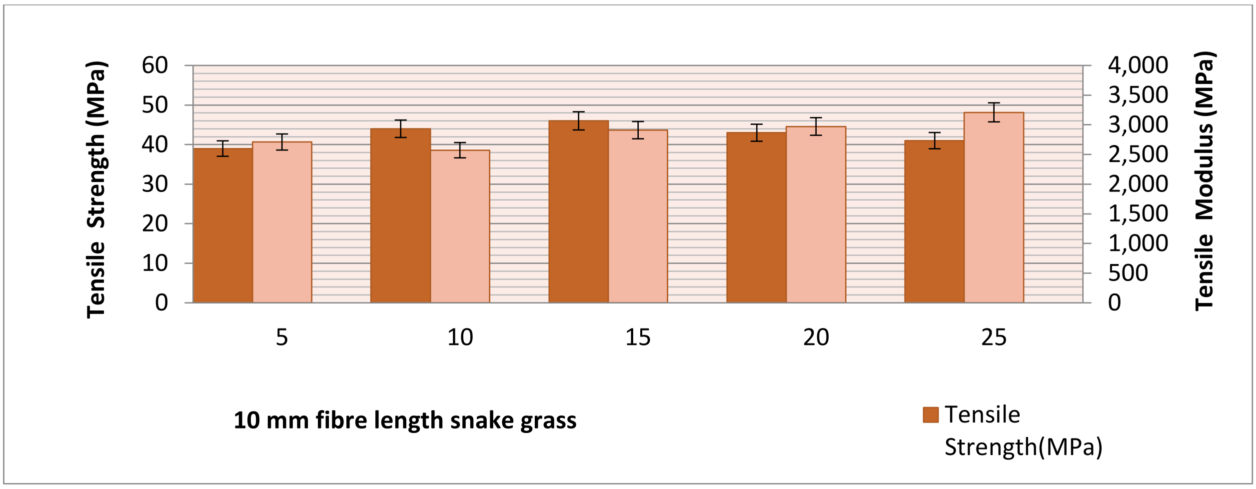

Figure 2. Tensile properties of Snake grass (10mm length) hybrid bio polymer composite

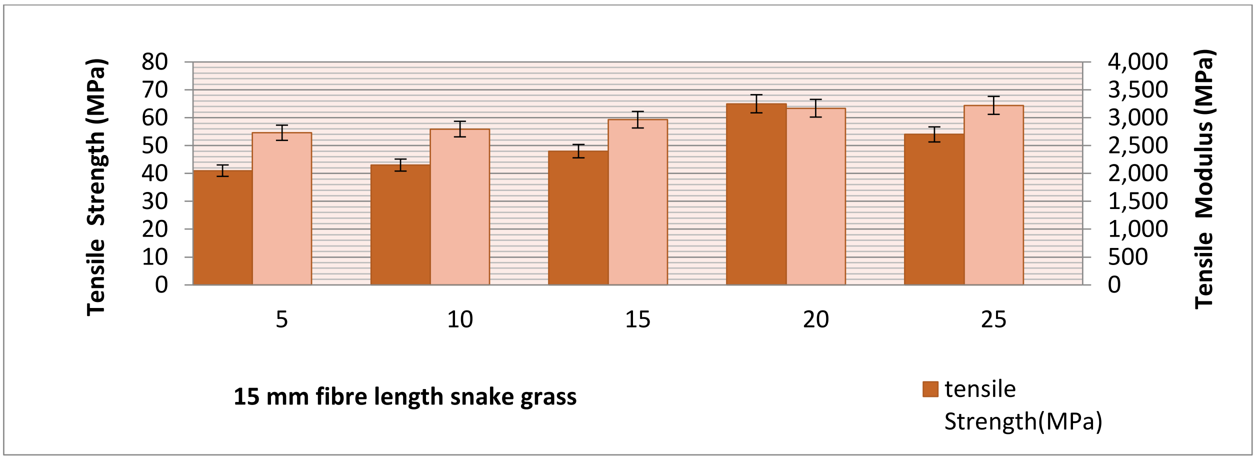

Figure 3. Tensile properties of Snake grass (15mm length) hybrid bio polymer composite

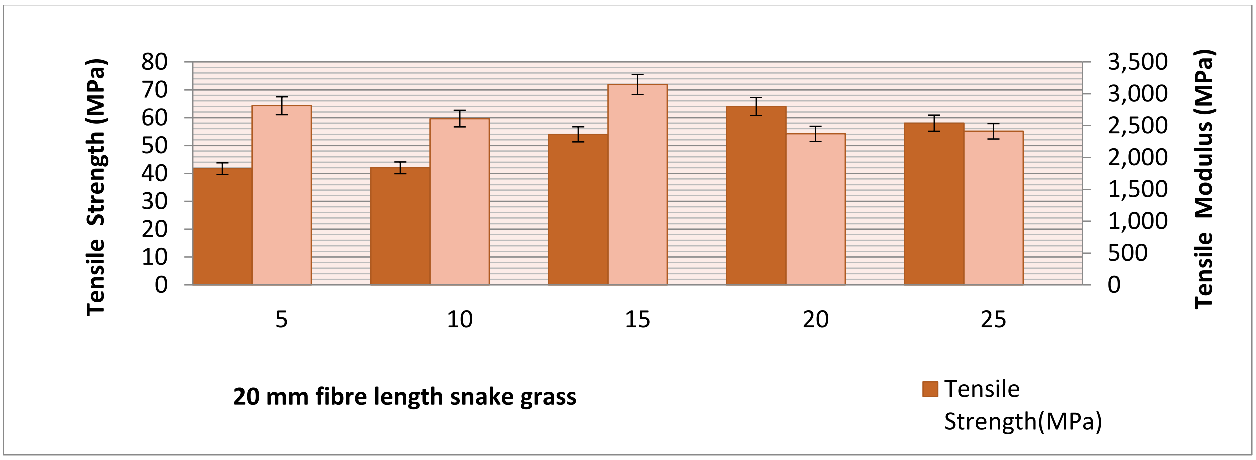

Figure 4. Tensile properties of Snake grass (20mm length) hybrid bio polymer composite

3.2. Fractography observation

Figure 5 and 6 depicts a SEM image of a laminate with a 15mm fiber length and a composite content of 20% & 25%. It demonstrates that the fibre and matrix are well-adhered. Even if many fibres are damaged, the load can be carried by the fibres' integral section across a strong interface, allowing the composite to withstand the applied strain. Furthermore, Figure 5 depicts the even dispersion of fibres, which is important for stress distribution and, as a result, mechanical strength. As the fiber volume percentage grows, the tensile strength begins to diminish due to fiber aggregation. Furthermore, fibre clustering causes the matrix to moisten the fibre inefficiently, resulting in inadequate fibre bonding. Mechanical qualities are reduced as a result of this. In addition, as fibre length increases, the fibre curls and bends, affecting the stress transfer between the matrix and the fibre. As demonstrated in Figure 6, this phenomenon is identical to the SEM images. Because the material is subjected to a large volume of strain for a short period of time during the impact test [16], no significant variations in the value were detected. SEM images show that fibre interaction with the matrix has a substantial effect on the characteristics of fiber-reinforced composite materials. Natural filler addition to modify the surface of natural fibres was extensively utilized to promote fibre-matrix compatibility. This adjustment boosts the overall composite strength by improving surface adhesion between fibre and matrix.

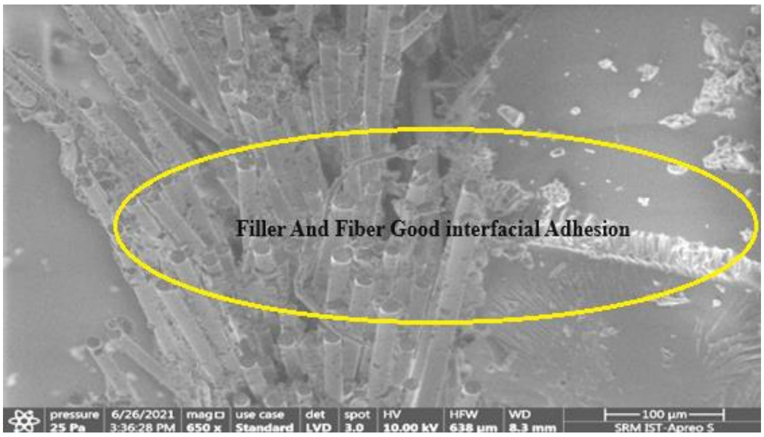

Figure 5. SEM image of a laminate with a 15 mm fiber length and a composite content of volume 20%

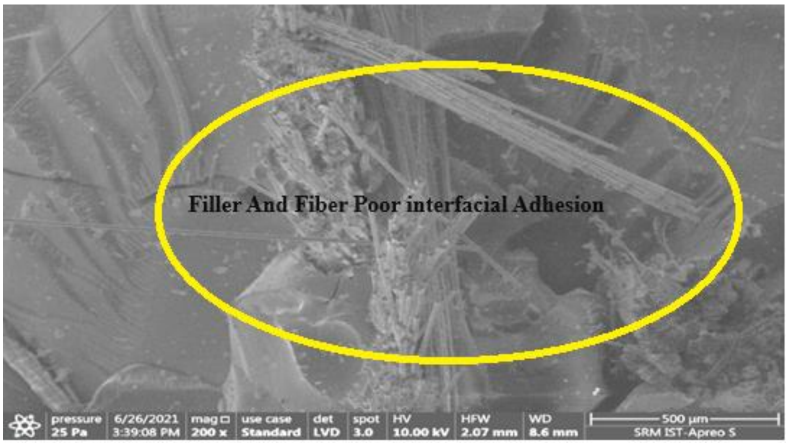

Figure 6. SEM image of a laminate with a 15 mm fiber and a composite content of volume 25%

3.3. Flexural test

The flexural tests are carried out in accordance with ASTM D 790, as seen in Figures 7-10. In a three-point bending test, the highest flexural strength and modulus is determined to be 96 MPa for a fibre length of 15mm and a moisture content of 20%. In terms of flexural modulus, it has been noticed that as the fibre values for parameters increase, so does the composite's impact energy, but the rise in percentage is not valuable when contrasted to a composite with 15mm and 25% (4020 MPa) volume and 20mm and 20% (4160 MPa) volume. The decrease in flexural characteristics caused by an increase in the volume-to-volume ratio is attributable to two factors: agglomeration and porous contact between the filler and matrix [17].

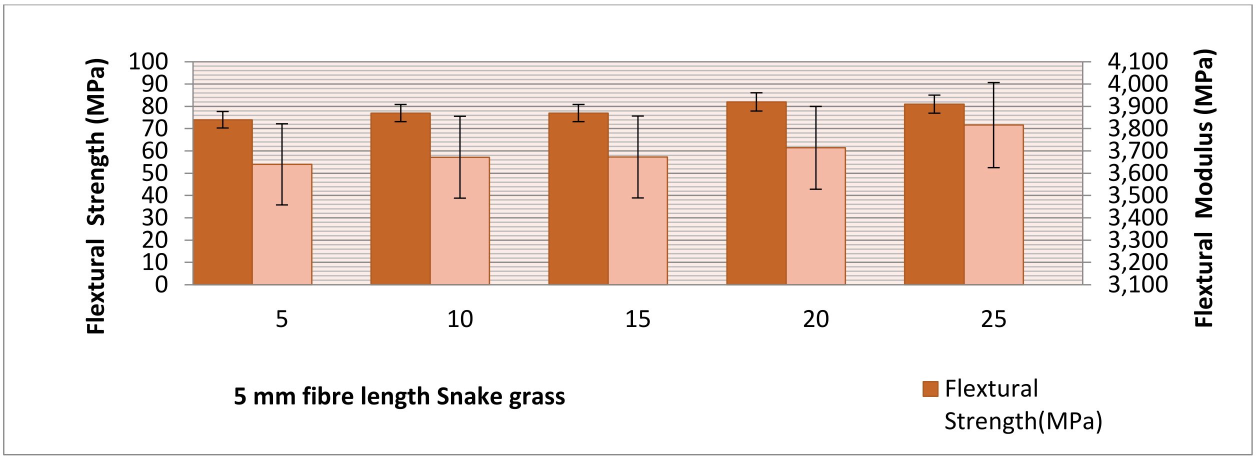

Figure 7. Flexural properties of Snake grass (5 mm length) hybrid bio polymer composite

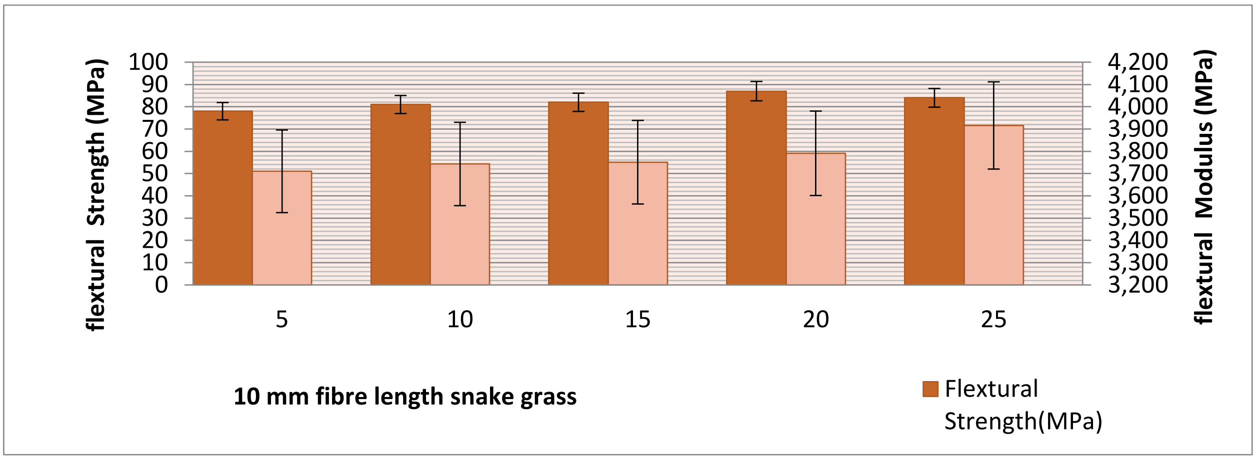

Figure 8. Flexural properties of Snake grass (10 mm length) hybrid bio polymer composite

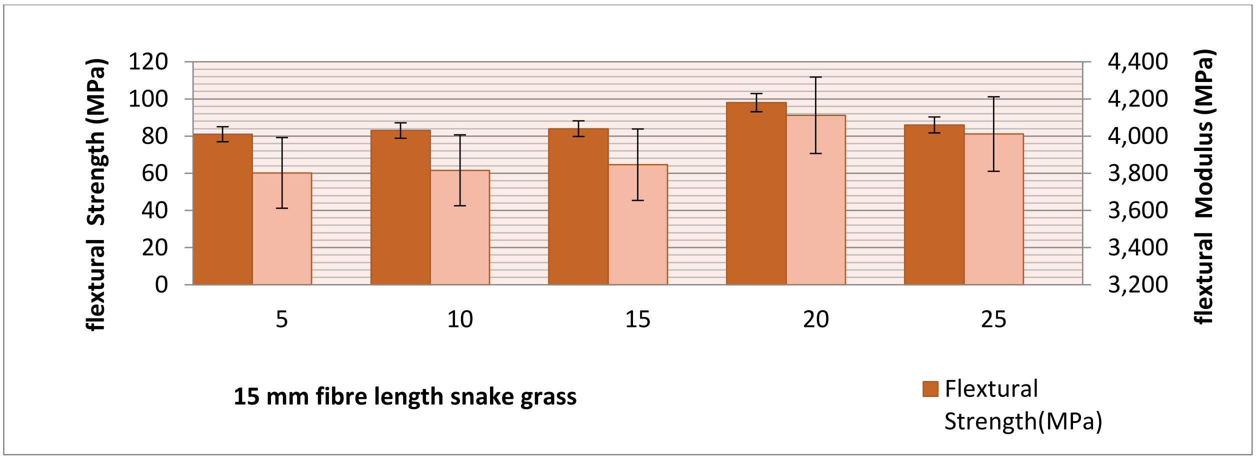

Figure 9. Flexural properties of Snake grass (15 mm length) hybrid bio polymer composite

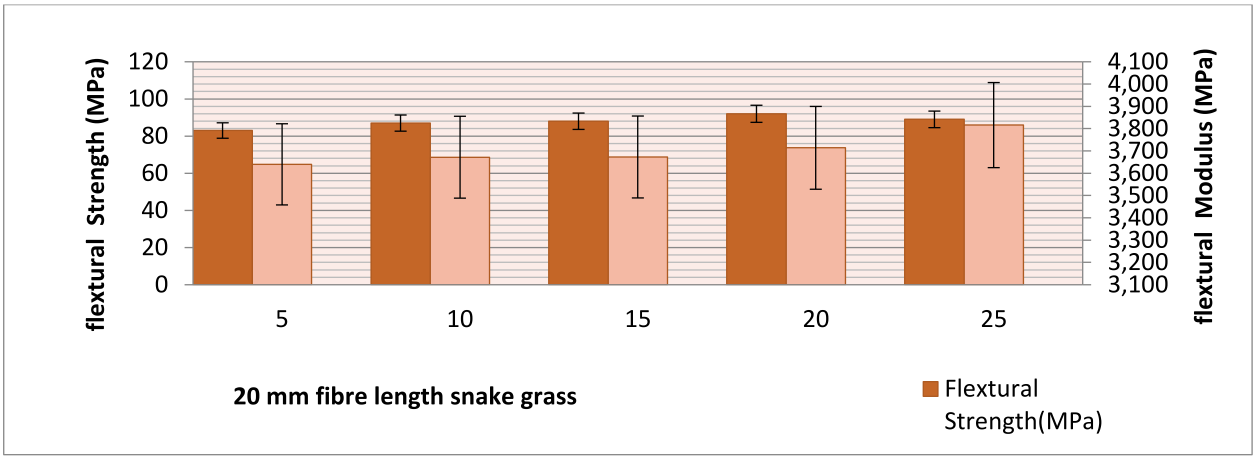

Figure 10. Flexural properties of Snake grass (20 mm length) hybrid bio polymer composite

3.3. Impact test

The impact tests are performed in accordance with ASTM 256, as shown in Figures 11-14. The maximum strength is found to be 4182 J/m^2 and 4490 J/m^2 for a fibre length of 15mm and a moisture content of 20%, and for a fibre length of 20mm and a moisture content of 20%, respectively. In terms of impact strength, it is determined that as the fibre parameter values increased the impact energy measured by the composite. In all cases, the mechanical properties were improved by incorporating bio filler up to a fibre length of 20mm and a moisture content of 20%, but with more filler content, the properties reduced due to filler accumulation and inadequate bonding between the filler and the matrix [18].

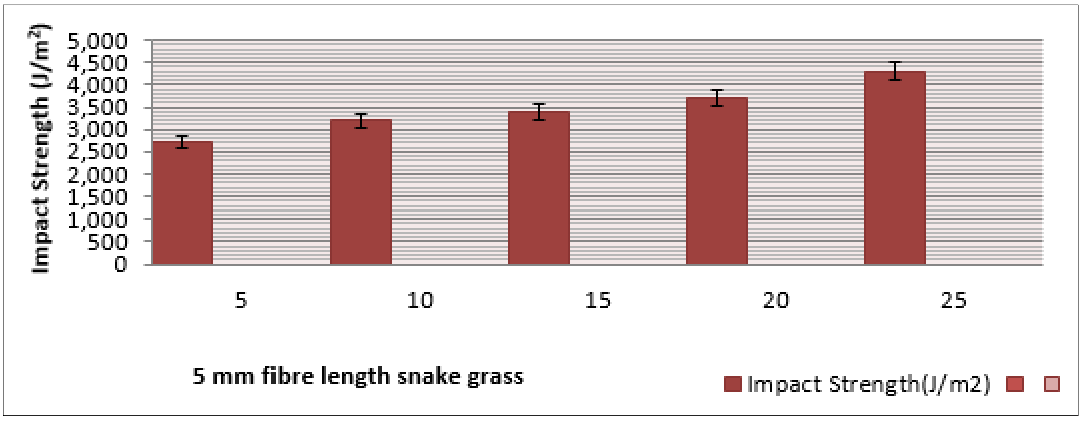

Figure 11. Impact properties of Snake grass (5 mm length) hybrid bio polymer composite

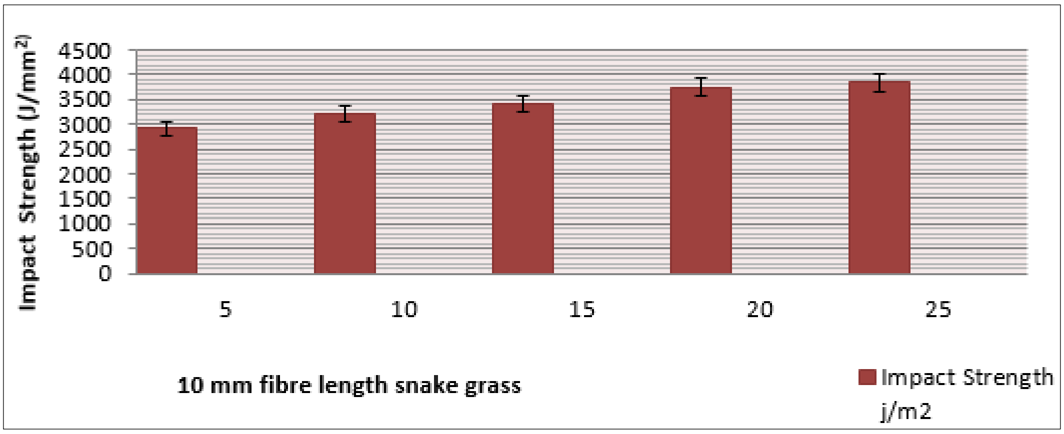

Figure 12. Impact properties of Snake grass (10 mm length) hybrid bio polymer composite

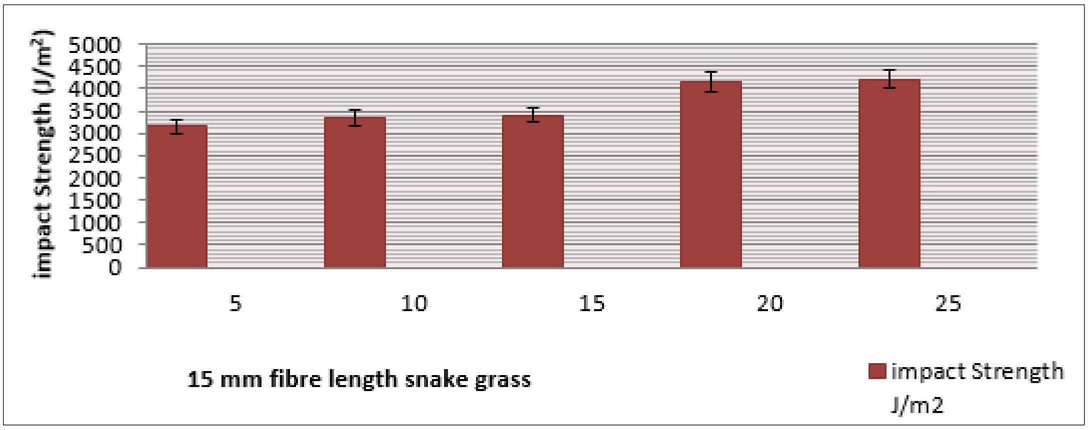

Figure 13. Impact properties of Snake grass (15 mm length) hybrid bio polymer composite

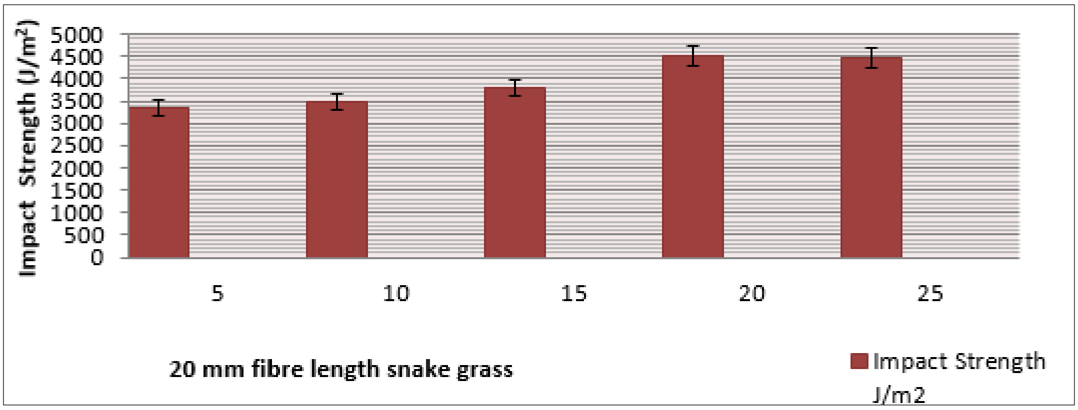

Figure 14. Impact properties of Snake grass (20 mm length) hybrid bio polymer composite

3.4. Effect of *Aegle marmelos* with Epoxy Blended Hybrid Matrix

Following the determination of the optimal fibre length, volume %, and more experiments were conducted using the *Aegle marmelos* natural gum. The filler was added to the sisal fibre reinforced polyester composite in amounts of 5, 10, 15, and 20% by volume. Snake grass fibre was preserved at 20% by volume, with the rest made up of varied filler and matrix proportions. The influence of filler on the mechanical properties of the composite was evaluated by tests. The 20 percent filler volume resulted in better mechanical characteristics. The greatest tensile strength was discovered to be 64 MPa. Similarly, for the composite with a 20% filler volume fraction, the highest values of flexural strength and impact strength were found to be 96 MPa and 4182 J/mm^2, respectively. The inclusion of *Aegle marmelos* natural gum increased the mechanical capabilities to a degree, but it also impaired the interface adhesion, which affected the composite material's strength. Gum material is utilized as extra reinforcement to aid in transferring stress inside the structure of the material. Excessive gum addition resulted in gum accumulation, which led to poor matrix continuity and a decrease in composite strength.

3.5. Dynamic mechanical analysis

3.5.1. Storage modulus (E′)

Figures 15-16 show how temperature and frequency affect the storage modulus of epoxy resin and alkali-treated snake grass fiber with a 15-volume percent filler epoxy composite. The test temperature ranges from 28 to 241°C, and the frequency is ten Hz. The findings show that, regardless of frequency, the composite absorbs more energy at all temperatures up to 140°C. As the testing increases in temperature, the energy generated by both the resin and the composite is roughly comparable. This means that until the temperature reaches 140°C, the fibres and filler are efficiently transferring the load.

After that, they tend to loosen their link with the matrix, resulting in failure of the desired function. According to the studies, adding filler/fiber to the epoxy matrix increases the storage modulus or stiffness of the composites. Figure 15 further demonstrates that adding filler to treated fibre enhances the storage modulus, which is measured in less time and yields higher results. Whereas exposure over a larger time (low frequency) leads in reduced value. This is because molecules that are subjected to lower frequencies undergo more rearrangement than those that are subjected to higher frequencies. The material's molecular rearrangement results in a reduction in localised stress. Because molecular structures are so static at low temperatures, they cannot resonate with the oscillatory forces and so remain solid. The cross-link between every 20 atoms in thermoset polymers remains intact at all temperatures, which makes them strong.

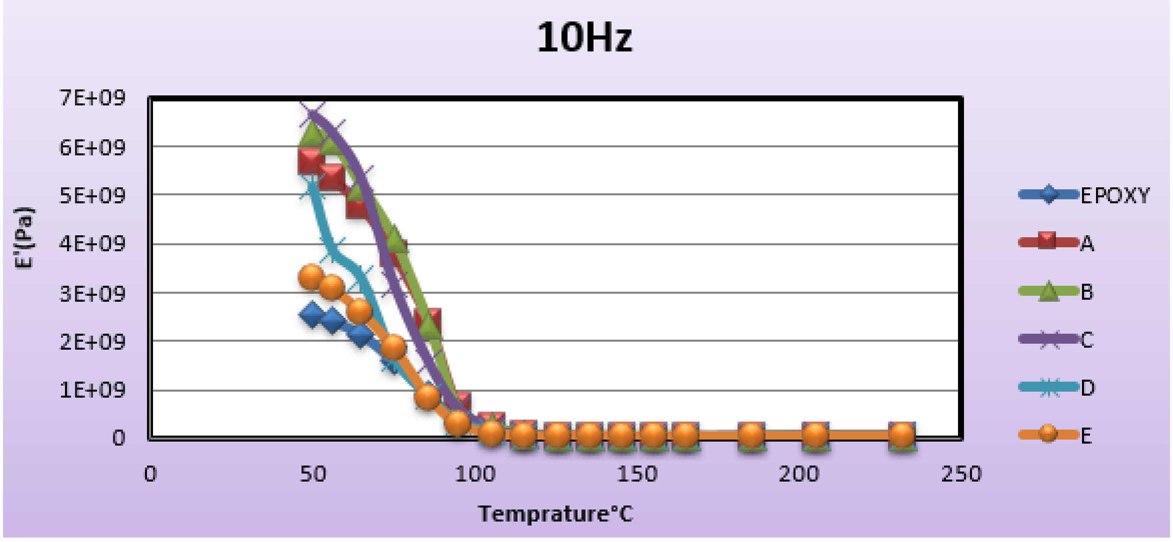

Figure 15. Storage modules VS Temperature of *Aegle marmelos* blended snake grass reinforced bio polymer composite

3.5.2. Loss factor

The loss factor is defined as the ratio between the material's modulus for loss and its capacity for storage modulus. This illustrates the degree of mobility of molecules in the polymer chain, as well as the material's loss of energy under loading. The plot of the loss factor of *Aegle marmelos* gum filler and snake grass fibre integrated composite material is shown in Figures 16. The findings demonstrate that providing reinforcements to a composite material reduces the loss factor. This shows that the composite's loss of energy process is better than the matrix's. At low temperatures, the material is considered to be in the glass state or energy elastic state; however, when the temperature rises, the material phase shifts to the rubber or entropy flexible state. The glass changeover is the change from a glass state to a rubber-elastic state. The temperature of the highest loss modulus [E" max or the maximum loss factor (tan max.) is commonly considered to be the glass transition temperature. The glass transition temperature is calculated in this study utilising the peak of tan value. When compared to epoxy resin, the tan peak lowers regardless of the degree of the applied force, but the glass transition temperature (Tg) shifts noticeably along the way. This depicts how the Tg value shifts due to a synergetic action between the filler and the fibre.

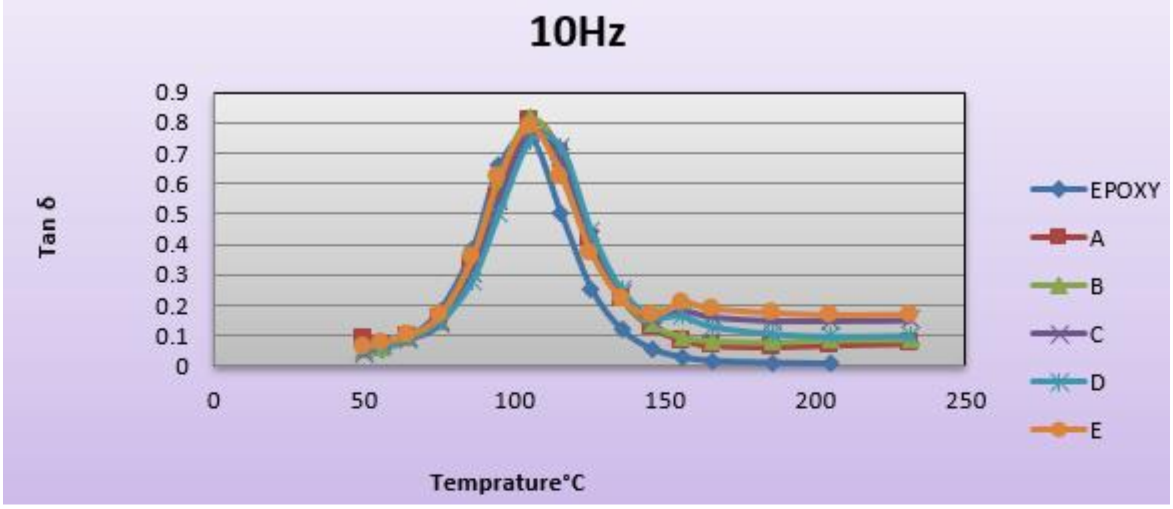

Figure 16. Tan δ vs Temperature of *Aegle marmelos* blended snake grass reinforced bio polymer composite

The glass transition area, where the material transitions from hard to pliable, is connected with the damping peak. The molecules are initially stable, but as the temperature rises, tiny groups and chains of molecules inside the polymer structure begin to migrate. As a result, as molecule mobility increases, so do the tan peaks. The peak width at half height describes the interaction of the material's homogenous and amorphous phases. The drop in peak height and increase in width suggest lower molecular mobility and higher inhomogeneity phases. Property degradation occurs when a material's phase changes owing to polymer chain breaking. Studies showed that adding natural filler to the Epoxy matrix enhanced the stiffness of the hybridized composite material in both brittle and ductile zones [19].

4. Conclusions

The impact of fibre characteristics as well as the use of secondary reinforcement the effects of snake grass and *Aegle marmelos* gum filler on the dynamic mechanical properties of composites were investigated, and the following findings were drawn: The ideal fibre length and fibre volume percent for superior mechanical qualities are 15 mm and 20%, respectively. Additionally, extending the fibre length causes spiralling of the fibre, which reduces contact adhesion. Agglomeration of fibre occurs when the volume % is increased. As a result, after reaching the optimum value, these two features cause the static mechanical properties to decrease. The above conclusion is supported by the SEM image. The effect of surface modification on fibre length and volume fraction has been investigated. The gum filler *Aegle marmelos* improves the characteristics of composites as well. The filler acts as a secondary reinforcement in the polymer composite, allowing it to withstand higher loads and evenly distribute stress. The addition of filler with treated fibre increased the storage modulus measured in a shorter period and resulted in higher values, according to dynamic mechanical analysis. Exposure over a longer period of time (low frequency) yields a lower value. This is because molecules that are subjected to lower frequencies undergo more rearrangement than those that are subjected to higher frequencies. The loss factor result demonstrates that adding reinforcements reduces the composite material's loss factor. This suggests that the composite's energy dissipation process is superior to the matrix's.

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