Tensile, thermal and dynamic mechanical analysis of sisal, jute and banana fiber bio composites for various engineering applications

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Abstract

In this study, tensile, thermal characteristics and dynamic mechanical analysis (DMA) of fabricated hybrid sisal, jute, and banana fibers reinforced with polyester composites are described for the first time. The hybrid composite plates are fabricated for different fiber weights by hand lay-up method. Six different weight compositions and one alkali treated specimen was utilized to investigate the above properties. The tensile properties of the bio composites are examined through tensile test. The inclusion of three different natural fibers reinforced polyester enhanced the ductile properties of the composites. Substantially, the alkali treated fibers achieved maximum tensile strength and tensile modulus are 203.52 MPa and 7.63 GPa. Scanning Electron Micrographs of tensile fractured surfaces of the composites revealed stronger adhesion of the natural fibers to the polyester matrix. Thermal stability and thermal degradation of bio composites are analyzed by Thermogravimetric analysis (TGA) and Derivative thermo gravimetry (DTG). In addition of natural fibers reinforced polyester composites confers highest value of TGA and DTA as compared to other specimens. The dynamic mechanical analysis of composites in the term of storage modulus($E'$), loss modulus ($E''$) and damping parameter (Tan $\delta$) in a temperature range of 30°C to 300°C was investigated. The hybrid composite with 50% of sisal, 25% of jute and 25% of banana reveals the maximum value of storage modulus and loss modulus. These results attained confirmed the viability of the combination between natural fibers and matrix, thus opening new perspectives for the use of these natural by products.

Keywords: banana, DMA, jute, polyester, sisal, TGA

1. Introduction

Natural fibers have already established a track record as simple filler material in automobile parts. Natural fibers like sisal, jute, coir, oil palm fiber have all been proved to be good reinforcement in thermoset and thermoplastic matrices [1–4]. Our earlier studies have proved banana fibers to be an effective reinforcement in polyester matrix [5]. Due to increasing environmental awareness, natural fibers have become very popular among researchers and scientists as reinforcement for polymer matrix in place of synthetic fibers. Natural fibers have many advantages such as low cost, low density,
availability in abundance, environment friendly, non-toxicity, high flexibility, renewability, biodegradability, high specific strength and modulus, and easy processing [6–11]. However, natural fibers have high moisture absorption, low impact strength and low thermal stability as their drawbacks [12–14] Hybridization technique can be used to overcome these drawbacks of natural fibers. Many researchers used hybridization technique and found its positive effect as increase in mechanical, thermal and dynamic mechanical properties. The incorporation of two or more natural fibers into a single matrix has led to development of hybrid composites. Various researchers have tried blending of two fibers in order to achieve the best utilization of the positive attributes of one fiber and to reduce its negative attributes as far as practicable [15]. The behavior of hybrid composites is a weighed sum of the individual components in which there is more favorable balance between the inherent advantages and disadvantages. In an interesting study dynamic mechanical analysis of natural fiber based hybrid composites was performed and observed that the hybridization of nature fiber improved thermal and dynamic mechanical properties [16]. Natural fiber composites such as sisal and jute polymer composites became more attractive due to their high specific strength, lightweight and biodegradability [17]. Krishna Kumar et al. studied the mechanical properties on glass-sisal-banana fibers reinforced on epoxy composites. They observed that the glass-sisal-banana fibers reinforced hybrid composites shows superior properties and used as an alternate material for synthetic fiber reinforced composite materials [18]. Boopalan et al. investigated and compared the mechanical, thermal and water absorption properties of raw jute and banana fiber reinforced epoxy hybrid composites. The results show that the addition of banana fiber in jute/epoxy composites of up to 50% by weight results in increasing the mechanical and thermal properties and decreasing the moisture absorption property [19]. Sathish kumar et al. presented the extraction and preparation methodology of the isophtallic polyester composites using the naturally available fibers like snake grass, banana and coir fibers. The result showed that the snake grass/banana and snake grass/coir fiber composites have the maximum tensile and flexural properties when compared with the snake grass fiber composites [20]. Gupta studied the dynamic mechanical properties of hybrid jute/sisal fiber reinforced epoxy composite at different frequencies. The hybrid composites were prepared by hand lay- up technique keeping constant 30 wt. % of total fibers content with varying weight percentages of jute and sisal fibers. The results revealed that storage modulus, loss modulus and glass transition temperature (Tg) were found to increase with increase in frequencies [21]. The purpose of this work is to investigate the probable utilization of sisal, banana, and jute fiber areas reinforcement in polyester matrix composites. Natural fibers reinforced polyester bilayer hybrid composites fabricated by hand lay-up technique. The aim of this work is to evaluate the effects of incorporating natural fibers into the polyester at different weight % of fibers loadings to enhance tensile, thermal stability and viscoelastic properties to analyze the best and effective filler loading.

2. Materials and experimental Procedure

Materials In this present investigation Sisal, Jute fibers and banana are used for fabricating the hybrid composite specimen. The sisal, banana, and jute fibers are obtained from Ebenezer fiber products, Coimbatore, Tamilnadu, India. Cobalt Naphthenate as accelerator and Methyl ethyl ketone peroxide (MEKP) as a catalyst is acquired from M/s. Supreme scientific Ltd., Madurai, India. The polymer used in this work development was unsaturated terephthalic polyester resin in the pre-accelerated
form, produced by Royal Polímeros under the commercial name of Denverpoly 754. The Cobalt Naphthenate added as 2% with the resin and the catalyst approximately 2 to 3ml. Purchased natural fibers are shown in Figure 1.

![](image1)

(a) Sisal fiber, (b) Jute fiber, and (c) Banana fiber

**Figure 1. Natural fibers**

### 2.1 Fabrication of biocomposites

Sisal, Jute, and banana fibers are aligned unidirectionally with bi-layer arrangement in polyester matrix to prepare the hybrid composites. The physical, mechanical and chemical properties of natural fibers as shown in Table 1 and Table 2 respectively. The polyester resin and hardener mixed in a ratio of 10:1 by weight to prepare the matrix. The mixture is stirred manually to disperse the resin and the hardener in the matrix. The composite laminates are made by hand-layup technique followed by light compression moulding technique. A stainless steel mould having dimensions of 300 mm x 300mm is used for casting of 3mm thick composite laminates for dynamic mechanical analysis. Stacking of hybrid fibers was carefully arranged random manner after pouring some amount of resin against the mould to keep the poor impregnation. The resin gets mixed with the fibers and may tend to be dried up in the open atmosphere under hot sun for 48 hours. Before the resin gets dried up the second layer must be mounted on it. The process is repeated for another layer also. The epoxy resin applied is distributed to the entire surface by means of a roller and the air gaps formed between layers during fabrication are removed by gently squeezing. The specimen is then pressed at a temperature of 32°C, under the pressure of 6MPa, and the average relative humidity of 65%. To ensure complete curing the composite samples were post cured at 70°C for 1 hour and the test specimens of the required size were cut out from the sheet. As per the dimensions of mechanical tests, excess resin and fiber edges of specimen are properly removed.

Preparation process of natural fibers reinforced polyester composite specimen as shown in Figure 2.

### Table 1. Physical properties of natural fibers

<table>
<thead>
<tr>
<th>Fibers</th>
<th>Physical Properties</th>
<th>References</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Origin (µm)</td>
<td>Diameter (µm)</td>
</tr>
<tr>
<td>Sisal</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Jute</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Banana</td>
<td></td>
<td></td>
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</table>

**References**

Tierärztliche Praxis  
Vol 40, 2020  
ISSN: 0303-6286
Table 2. Mechanical and Chemical properties of natural fibers

<table>
<thead>
<tr>
<th>Fibers</th>
<th>Tensile strength (MPa)</th>
<th>Tensile modulus (GPa)</th>
<th>Elongation (%)</th>
<th>Cellulose (%)</th>
<th>Hemi-celluloses (%)</th>
<th>Lignin (%)</th>
<th>References</th>
</tr>
</thead>
<tbody>
<tr>
<td>Jute</td>
<td>393 - 800</td>
<td>13–26.5</td>
<td>1.16–1.5</td>
<td>61–71.5</td>
<td>12.0–20.4</td>
<td>11.8 - 13</td>
<td>[12]</td>
</tr>
<tr>
<td>Banana</td>
<td>161.8</td>
<td>8.5</td>
<td>2.0</td>
<td>63–64</td>
<td>10–19</td>
<td>5</td>
<td>[16]</td>
</tr>
</tbody>
</table>

2.2 Alkali treated composites

The important modification done by alkaline treatment is the disruption of hydrogen bonding in the network structure, thereby increasing surface roughness. This treatment removes a certain amount of lignin, wax and oils covering the external surface of the fiber cell wall, depolymerizes cellulose and exposes the short length crystallites [22]. Addition of aqueous sodium hydroxide (NaOH) to natural fiber promotes the ionization of the hydroxyl group to the alkoxide [23]. It is reported that alkaline treatment has two effects on the fiber: (1) it increases surface roughness resulting in better mechanical interlocking; and (2) it increases the amount of cellulose exposed on the fiber surface, thus increasing the number of possible reaction sites [24]. Consequently, alkaline treatment has a lasting effect on the mechanical behavior of flax fibers, especially on fiber strength and stiffness [25]. The fibers are immersed in 5% NaOH aqueous solution for 30 min. the fibers are then cleaned several times with distilled water followed by immersing the fibers in very dilute HCl in order to remove the NaOH adhering to the surface of the fibers. Finally the fibers are again washed several times with distilled water and then dried in an oven maintained at 80°C. Notation of the Fabricated specimen and weight % of natural fiber composition for hybrid composites as shown in Table.3.
2.3 Tensile strength

The specimen prepared is shaped into required dimension using a hand cutter and the edges are polished using a salt paper. It is prepared according to the ASTM D638 standard. The tensile test is conducted on a Tinius Olsen 10 KN Universal testing machine (UTM) with a gauge length of 75 mm and crosshead speed of the machine is set at 5 mm/min. The specimen size for tensile test is 115 mm x 20 mm x 3 mm according to ASTM D638. The process involves placing the test specimen in the UTM and applying tension to it until the fracture of the material. Then the force is recorded as a function of the increase in gauge length. During the application of tension, the elongation of the gauge section is recorded against the applied force. The tensile force is documented as a perform of the expansion in gauge length. The experiments are conducted for four times in each composition and the average values are taken for the results [26].
Table 3. Designation for bio composite fiber reinforced polyester composites

<table>
<thead>
<tr>
<th>Designation of specimen</th>
<th>weight % of natural fiber composition</th>
<th>sisal</th>
<th>Jute</th>
<th>banana</th>
<th>Chemical treatment</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td></td>
<td>50</td>
<td>45</td>
<td>5</td>
<td>--</td>
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<tr>
<td>B</td>
<td></td>
<td>40</td>
<td>50</td>
<td>10</td>
<td>--</td>
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<td>C</td>
<td></td>
<td>50</td>
<td>35</td>
<td>15</td>
<td>--</td>
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<td>D</td>
<td></td>
<td>40</td>
<td>40</td>
<td>20</td>
<td>--</td>
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<td>50</td>
<td>25</td>
<td>25</td>
<td>--</td>
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<tr>
<td>F</td>
<td></td>
<td>40</td>
<td>30</td>
<td>30</td>
<td>--</td>
</tr>
<tr>
<td>G</td>
<td></td>
<td>40</td>
<td>40</td>
<td>20</td>
<td>Alkali treated</td>
</tr>
</tbody>
</table>

2.4 Scanning Electron Microscopy (SEM)

The morphology of the natural fiber composites is observed using a on a JEOL equipment model JSM-5300LV with 10 kV of voltage acceleration. Tensile fracture specimens are involved to examined the morphological test.

2.5 Thermogravimetric analysis (TGA)

Thermogravimetric analysis is performed by EXSTAR TG/DTA 6300, Hitachi, Japan. TG instrument with the temperature accuracy ± 5°C to examine the thermal degradation behavior of maximum tensile strength achieved specimen (D). Approximately, 10mg of powdered samples are placed in an alumina crucible with a diameter of 7mm and are heated under the dynamic linear rate of 10°C/min., with a 50cm³/min nitrogen flow from 50 °C to 600°C.

2.6 Dynamic mechanical analysis (DMA)

DMA was executed according to ASTM D4065-01 to determine the viscoelastic behavior (E’, E”, Tan δ) of polyester composites as a function of temperature. DMA test was performed using TA (DMA Q 800) instrument, operating in a three-point bending mode at an oscillation frequency of 1 Hz under controlled amplitude. The temperature was ramped from 25°C to 200 C, under controlled sinusoidal strain with a heating rate of 5°C/min. The samples were in dimension of 60 × 12.5 × 3 mm. The viscoelastic properties such as storage modulus, loss modulus and damping of specimens are measured.
3 Results and Discussion

3.1 Tensile properties of bio composites

It can be observed from Figure.3 and Figure.4. that tensile properties of bio composite increases with natural fiber loading in all cases. The natural fiber composites A,B,C,D,E,F and G shows good enhancement of tensile strength. The tensile strength and tensile modulus are gradually increasing upto the maximum load carrying capacity of the material. From Figure.3, it has been clearly indicated that the 40% sisal, 30% jute and 30% banana (specimen F) polymer composites are performing better than the other composite combinations tested. Normally, fibers such as these can improve the strength, as lignocellulose fibers can support stresses transferred from the polymer [27]. From the results, maximum weight % of the sisal, jute and banana fiber contents holds the tensile property of polymer composites. From the results, Other composites A,B,C, D and E are revealed better tensile strength and tensile modulus. Due to proper dispersion and good interfacial link between fiber and polyester matrix may be enhanced the tensile properties. In fiber based natural composites, dispersion of the filler and matrix interface adhesion makes the advancement in mechanical properties [28]. Alkaline treatment also significantly improved the mechanical behaviors of fiber-reinforced composites [29, 30, 31]. The alkali treated fibers obtained the high tensile strength value of 203.52. From the results , Alkali treated fibers content increased the maximum tensile strength and tensile modulus of the composites in Specimen G. All tensile values of the specimens compared to specimen G, the values are 17.8%,15.8% , 13.9%, 10.3%, 7.1% and 4.2% of A,B,C,D,E and F respectively. This may be due to the bonding of the fiber with the polyester matrix thereby improving the fiber-matrix interaction. The significance of alkali treatment is the disruption of hydrogen bonding in the fiber surface, thus increasing surface roughness [32]. The elongation and tensile modulus are shown in Table.4. In Figure.4, the tensile modulus of the composites gradually increased from A,B, C, D, E, F and G specimens of 5.26 Gmpa, 5.73 GPa, 6.17 GPa, 6.48 GPa ,6.86 GPa, 7.24 GPa and 7.63 GPa respectively. From this results, the alkali treated specimen was achieved the maximum tensile modulus of 7.63 GPa. G specimen compared with other specimens 31% , 24.9% , 19.1%, 15%, 10% and 5.11% of A,B,C,D,E and F composite specimens respectively. Furthermore, the tensile modulus of the composites also increased due to enhance of the elongation at break.

This change in tensile properties is attributed to interacting factors such as the rupture of alkali-sensitive bonds existing between the cellulose and hemicellulose (due to removal of hemicellulose making the fiber more homogeneous), and the stress transfer between interfibrillar regions [33]. Further, in the case of untreated fibers, hemicellulose remains dispersed in the interfibrillar region separating cellulose chains from one another and because of this barrier, these chains are in a state of strain. The fibers tend to get closely packed owing to the large scale removal of hemicellulose by alkali treatment and formation of new hydrogen bonds in between the chain of cellulose fibrils. Thereby the fibrils rearrange themselves in a more compact manner resulting in closer fiber packing [34]. The fiber tensile properties tend to decrease after 8 h alkali treatment, possibly due to the degradation of cellulose in longer duration alkali treatment.
### Table 4: Elongation and tensile modulus of bio composites

<table>
<thead>
<tr>
<th>Designation of composite Specimen</th>
<th>Elongation (mm)</th>
<th>Tensile modulus (GPa)</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>6.4</td>
<td>5.26</td>
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<td>B</td>
<td>6.8</td>
<td>5.73</td>
</tr>
<tr>
<td>C</td>
<td>7.3</td>
<td>6.17</td>
</tr>
<tr>
<td>D</td>
<td>7.7</td>
<td>6.48</td>
</tr>
<tr>
<td>E</td>
<td>8.1</td>
<td>6.86</td>
</tr>
<tr>
<td>F</td>
<td>8.3</td>
<td>7.24</td>
</tr>
<tr>
<td>G</td>
<td>8.6</td>
<td>7.63</td>
</tr>
</tbody>
</table>

**Figure 3. Tensile strength of bio composites**
Figure 4. Elongation and Tensile modulus of bio composites

3.2 Morphological study of bio composites

After tensile test result, the tensile properties increased gradually from A, B, C, D, E, F and G. Specimen F (sisal 40%, jute 30% and banana 30%) achieved the high tensile properties compared to other specimens A, B, C, D and E. Furthermore, compared with specimen F alkali treated specimen G is attained maximum tensile properties. Due to this maximum results of two specimens, the F and G specimens were involved the morphological observation. Figure 5 (a) and Figure 5 (b) is clearly revealed the interaction of natural fibers with resin matrix. In Figure 5 (a), the fiber interactions occurred one specific area and some of the broken particles are identified at right side top of the corner. At the same time, fibers were formed at specific area is called cluster formation. In this cluster formation, bonding between the fibers and polyester matrix are better but dispersion of fibers are not covered the all area of specimen and the even and proper distribution of fibers are partially observed. This improper dispersion of fibers may be reduced the ductile properties of specimen F compared with G. The alkali treatment improved fiber matrix interaction by the removal of lignin and hemicellulose, which led to the better incorporation of fiber with the matrix [35].

In alkali treated specimen G Figure 5 (b), the three fibers are highly interlinking between the polyester matrix. Furthermore, the image displaying the uniform distribution of three fibers. From this image the broken particles of the fibers also not identified. No interfacial gaps were observed from the natural fibers and polyester matrix. It is interesting to note that there is better fiber/matrix bonding in composites with alkali fiber loading. Whereas fiber/matrix de-bonding is evident in composites with 40% sisal, 30% jute and 30% banana fiber loading, composites with alkali fiber loading show no gap between the fiber and the matrix because of the stronger bonding. When the fiber concentration is lower, the packing of the fibers will not be efficient in the composite. This leads to matrix rich regions and thereby easier failure of the bonding at the interfacial region. When there is closer packing of the fibers crack propagation will be prevented by the neighboring fibers.
3.3 Thermogravimetric Analysis (TGA) of composite specimens

The thermal degradation was determined by the TGA as shown in Figure 6. Three degradation stages are observed in each case of samples. First stage involves the thermal degradation of all polyester composites with an initial weight loss about 150 – 200°C due to moisture loss through dehydration of secondary alcholic groups and evaporation of physically weak and loosely bound moisture on the surfaces of the composites [36]. As expected, the two stages of degradation are evident in all the profiles which correspond to temperature regions of different constituents like moisture evaporation (upto 200°C) and degradation of the hybrid composite material (100 - 350°C). The depolymerization of composites usually occurs between 320 and 400°C. The initial peak of fibers reinforced polyester composites was found at 85°C which represents the loss of moisture and other volatiles at the first degradation. It is observed between room temperature and 100°C.

The next peak which is obtained around 405°C which denotes DTA degradation of natural fibers and the prominent peak appears at the temperature corresponding to the maximum degradation rate. Moreover, natural fiber reinforced with polyester composites increases the degradation temperature (340°C to 400°C) due to retaining and improving the structural order to minimizing the amorphous content. A greater crystalline structure essentially requires a higher degradation temperature which is evident in optimal natural fibers with polyester composites.

3.4 Derivative thermogravimetric (DTG) analysis of composite specimens

The thermal degradation was determined by the Differential Thermal Analysis (DTA) thermogram as shown in Figure 7. It is also obvious from the thermograph that polyester inflection temperature or (decomposition temperature) shifts from 360°C to relatively higher temperature (455°C) by the incorporation of natural fibers in polyester composites, as the peaks of the DTG curves correspond to the decomposition temperature of each constituent of the composites.
The DTG curve shows the decomposition temperature of polyester composite material value which is above 400°C. As high thermal stability is attributed on account of higher heat resistibility and thermal stability of highly cross linked natural fibers with the polyester matrix in polyester composites.
3.5 Storage modulus (E’)

Storage modulus is a measure of the stiffness of the material. Influence of natural fibers reinforcement on dynamic mechanical characteristics are shown in Figure 8, 9 and 10. From Figure 8, it can be seen that E specimen has a higher storage modulus compared to other wt.% of natural fibers added composite up to 95°C. Further, on increasing the temperature the storage modulus decreases suddenly. From the results, lowest value observed form the specimen B. Specimen B compared to all specimens (A, C, D, E and F) it has very lowest storage modulus value. The Specimen E showed highest storage modulus values above the $T_g$ region in the rubbery plateau, and the fiber matrix interface is not much deteriorated at higher temperatures.

**Figure 8. Effect of fiber loadings on storage modulus of bio composites**

In this case the lowest value has been obtained for sisal 40% jute 50% and banana fiber 10% (specimen - B) loading and the highest value for sisal 40% jute 30% and 30% banana fiber loading (specimen - F). The effectiveness of the filler is the highest at sisal 40% jute 50% and banana fiber 10% fiber loading. It is important to mention that modulus in the glassy state is determined primarily by the strength of the intermolecular forces and the way the polymer chains is packed. In alkali treated G specimen lost stiffness because of the higher molecule movement at higher temperature. In order to improve the stiffness of the material, the researchers added fibers in the composite which increases the storage modulus of the material at higher temperature [37]. It also indicates an increase in the $T_g$ of the material, the addition of fiber in the composite increases the stiffness of the material even at higher temperature, because it reduces the molecular...
mobility of the material in thermal environment. Even though the storage modulus of A,B,C, D and F composites are less compared to that of specimen E and G at 30 – 90°C, an increase in the storage modulus is observed beyond 85°C in the rubbery region. This is because of low molecular mobility of polymer chain and good interfacial bonding between the matrix and fiber [38]. It should be noted that it is difficult to pinpoint a single glass transition temperature for all formulations because the transition actually occurs over a range of temperature. Above the Tg, the decrease in the E’ is less marked in the composites than in pure resin, which means that above the Tg the reinforcing effect of the fibers is emphasized. This is typical in semicrystalline polymers and as it is seen, the general trend is quite the same in composites and pure plastic and no significant change in the location of the transition is observed. Figure 8 shows that the storage modulus of specimen C has a lower storage modulus in glassy, transition and rubbery region compared to that of other composite specimens. Due to the non-uniform arrangement of natural fiber in matrix, the fiber could not transfer the stress uniformly and looses the stiffness at lower temperature. From the study it is concluded that storage modulus of the material is significantly influenced by bonding between the natural fibers and polyester matrix. Specimen F shows low storage modulus compared with specimen E. When the amount of fibers augmented in hybrid composite, a slight reduction in the E’ value was observed, probably due to fibers agglomeration. It represents at higher fiber loading; dispersion becomes poor leading to a decrease in fiber matrix interaction.

3.6 Loss modulus (E”)

Loss modulus defines the viscous responses (or) the damping properties of the material and it measures the amount of energy dissipation under cyclic loading. Figure 9 shows the loss modulus variation with temperature for different natural fiber composites. From E” plot it is apparent that loss modulus also displays very similar trend with the E’ having variation of Natural fiber loadings in polyester composite system. Figure 9 shows the lowered E” peak height for polyester composites (specimen B,C,D and F) but the addition of Akali treated fiber (specimen G ) and specimens A and E into the polyester matrix increases the loss modulus peak values. Interestingly as like E’ plot, higher E” peak height was observed for specimen E with respect to rest polyester composites, emphasizing better dispersion, distribution and no visibility of agglomeration in the polyester matrix.

The agglomeration conferred the non-homogenous dispersion and two phase system in the polymer leading to reduction in peak height of E”. The glass transition temperature of specimens E and C have shifted towards higher temperature. At higher concentrations of jute in specimen B, agglomeration takes place resulting in incompatibility between the fiber and the matrix. The Tg from tan δ shows a positive shift with increase of frequency and the mechanical damping of the composites is decreased. The shifting of Tg towards higher temperature can be associated with the decrease in mobility of matrix due to incorporation of jute fibers. The distinct viscoelastic changes observed with the incorporation of hybrid fibers in the matrix were attributed to the formation of an interphase because of strong interactions between the reinforcing fibers and the matrix. The value of glass transition temperature for polyester reinforced natural fiber composites obtained from loss modulus curve is given in Table 5. The increase in width of the loss modulus curve is taken to represent the presence of an increased range of order.
Figure 9. Effect of fiber loadings on loss modulus of bio composites

The greater constraints on the amorphous phase could give rise to a higher or broader glass transition behaviour [39]. The data suggest that alkali treated fibers have not provided significant improvements in the resin properties. It can be seen from the Figureure that the loss modulus peak values decrease with increase of fiber content at temperatures below the glass transition. The effect of the filler is prominent above the glass transition temperature in this case also. The modulus values increase with fiber content above the glass transition temperature. Another interesting result that is observed is the broadening of the loss modulus curve when the fiber content is increased to sisal 40% jute 30% and 30% banana. Figure 9 shows the plot of peak height vs. fiber volume fraction. The peak height shows a regular increase with increase of fiber content. At a fiber loading of sisal 40% jute 30% and 30% banana, the most pronounced effect of the filler has been the broadening of the transition region as the fiber concentration increases.

3.7 Material loss factor (Tan δ)

Tan is a damping term that can be related to the impact resistance of a material. Since the damping peak occurs in the region of the glass transition where the material changes from a rigid to a more elastic state, it is associated with the movement of small groups and chains of molecules within the polymer structure, all of which are initially frozen in. In a composite system, damping is affected through the incorporation of fibers. This is due mainly to shear stress concentrations at the fiber ends in association with the additional viscoelastic energy dissipation in the matrix material. Another reason could be the elastic nature of the fiber.
Table 5 Peak height and Tg from loss modulus and tan delta value of Bio composites

<table>
<thead>
<tr>
<th>Designation of composite Specimen</th>
<th>Peak height of loss modulus curve, MPa</th>
<th>Peak height of tan delta curve</th>
<th>Tg, °C (from loss modulus curve)</th>
<th>Tg, °C (from tan delta curve)</th>
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<tbody>
<tr>
<td>A</td>
<td>785</td>
<td>0.84</td>
<td>110.7</td>
<td>132.6</td>
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<tr>
<td>B</td>
<td>670</td>
<td>0.66</td>
<td>100.4</td>
<td>116.4</td>
</tr>
<tr>
<td>C</td>
<td>690</td>
<td>0.72</td>
<td>117.2</td>
<td>115.1</td>
</tr>
<tr>
<td>D</td>
<td>710</td>
<td>0.76</td>
<td>91.8</td>
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<tr>
<td>E</td>
<td>780</td>
<td>0.88</td>
<td>128.7</td>
<td>141.8</td>
</tr>
<tr>
<td>F</td>
<td>580</td>
<td>0.71</td>
<td>90.3</td>
<td>123.5</td>
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<td>G</td>
<td>845</td>
<td>0.63</td>
<td>88.8</td>
<td>110.3</td>
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</tbody>
</table>

The variation of tan δ with temperature of the composites has been analyzed with respect to fiber loading and frequency. Incorporation of fibers reduces the tan δ peak height by restricting the movement of the polymer molecules. Magnitude of the tan δ peak is indicative of the nature of the polymer system. Addition of fibers above 40% show the peaks making the two phases, fiber and matrix distinct. The appearance of peaks can also be explained as due to a microgel structure cross-linked to a general matrix structure. Damping curve indicates the level of the interaction between fiber and matrix in a composite as a function of temperature as shown in Figure 10. Higher interaction between fiber and matrix means higher energy dissipation of the composite. Damping parameter is the ratio of loss modulus and storage modulus which shows the impact properties of material. The peak of Tan δ curve occurs in glass transition region, where composite changes from rigid to more elastic state due to the movement of molecules in polymer structure as shown in Figure 10. The value of Tg obtained from tan delta curve is higher than Tg from loss modulus curve. Specimen B,C,D and F shows low Tg values compared with specimen A and E. Alkali treated specimen G has very low Tg rate. However, E has very high Tg value compared with all specimens. The higher value of Tan δ shows the better impact properties [40]. These results indicated, when the fiber increasing the Wt. % in the specimens it shows the positive effect of Tan δ. Further increasing the Wt. % of the specimen it has reduced the Tan δ. The low value obtained for natural fiber composite was attributed to the poor stress transfer between the fiber and the matrix. Composite with the bi-layer pattern also revealed the maximum Tan δ max value and the narrowest peak width, confirming the poor fiber/matrix adhesion.

It is known that the incorporation of fibers leads to an increase in the Tg values that can be attributed to the decreased mobility of the polymer chains. The damping values also
revealed that these composites presented the lowest Tan δ peak height and the broadest peak, indicating the best fiber-matrix interaction.

Figure 10. Effect of fiber loadings on the tan delta of bio composites

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4. CONCLUSIONS

The sisal, jute, and banana natural fibers are reinforced polyester composites on different weight percentages by hand layup method. Tensile properties of the bio composites are examined. Maximum tensile values reached the specimen F and alkali treated specimen G. The tensile values of F and G are 194.92 MPa and 203.52 MPa respectively. The G specimen was attained up to 4.2% and 5.1% enhancement of tensile strength and tensile modulus respectively compared to specimen F. Morphological images proved the interlinking between the natural fibers and polyester matrix. Furthermore, thermal characterizations through TGA, DTG, and Tg, as well as dynamic mechanical analysis such as storage modulus, loss modulus and Tan delta were performed in this work. The obtained results explicitly apparent that the incorporation of natural fibers enhanced the thermal stability and extremely improves E’ and E” dynamic properties of all polymer
composites. However, increase the sisal fiber and equal sharing of jute and banana fiber loadings in polyester composites enhances the thermal and DMA characteristics. These effects are attributed to the good reinforcing effects of natural fibers and the formation of interfacial interaction to the polyester matrix. This type of composite material can be useful for packaging, light weight automotive parts, shipping industry for mooring small craft, and construction fields.


References


