Dynamic Mechanical and Dielectric Behavior of Banana–Glass Hybrid Fiber Reinforced Polyester Composites

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ABSTRACT: Hybrid composites of glass and banana fiber (obtained from the pseudo stem of *Musa sapientum*) in polyester matrix, are subjected to dynamic mechanical analysis over a range of temperature and three different frequencies. The effect of temperature on the storage modulus (E'), loss modulus (E''), and loss factor or damping efficiency ($\tan\delta$) is determined. All the properties are compared with those of the neat polyester samples and the un-hybridized composites. The effects of the layering pattern of the two fibers on the ultimate viscoelastic behavior of the composites are also investigated. Composites are prepared with banana as the surface layer and glass as the surface layer and also as an intimate mixture of glass and banana. At temperatures above T_g,, the storage modulus values are found to decrease even with the addition of glass fiber for the geometry where glass is the core material. The value of the storage modulus of the composites with the above mentioned geometry is found to be different, above and below T_g, the value above T_g being lower than that below T_g unlike in unhybridized composite. The loss modulus curves and the damping peaks are found to be flattened by the addition of glass. Layering pattern or the geometry of the composites is found to have a profound effect on the dynamic properties of the composite. An intimately mixed composite is found to have the highest storage modulus values in all compositions. The values are consistent with the results of tensile strength. The $\tan\delta$ curve is found to be affected by the layering pattern followed and gives insight into the interaction in the material. The dielectric behavior of the composites are also found to be dependent on the glass fiber volume fraction as well as the layering pattern employed.

KEY WORDS: hybrid composite, banana fiber, DMA, glass fiber, thermal behavior.

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INTRODUCTION

BIO-FIBERS ARE FINDING improved importance in several technological fields. The current environmental awareness combined with societal needs has resulted in a paradigm shift in the usage of several bio-fibers in composite preparation. The ultimate properties of the prepared composites, however, depend on the interfacial adhesion between the fiber and the matrix. Several tests have been used to characterize the interfacial behavior as well as other properties of these composites. Dynamic mechanical spectroscopy is an effective tool to understand the structure–property relationship and interface in multiphase polymer systems [1–3]. Dynamic mechanical analysis (DMA) of chemically modified banana fiber composites were reported in an earlier publication by the authors [4]. It was concluded that chemical modification improves the interfacial bond based on the results of the viscoelastic behavior of the composites. Jacob et al. [5] have reported on the viscoelastic behavior of sisal fabric reinforced rubber composites. Angles et al. [6] studied the dynamic mechanical behavior of steam exploded soft wood reinforced polypropylene. Lee et al. [7] have reported on the DMA studies of novel silk/poly(butylene succinate) bio composites. It has been concluded that natural fibers based on animal origin are also effective in the preparation of composites. Maffezzolia et al. [8] have studied cardanol-based matrix bio composites reinforced with natural fibers. Dynamic mechanical analysis of the composites was investigated to have an insight into the fiber–matrix interaction. Yuan et al. [9] studied the effect of plasma treatment on enhancing the performance of wood fiber–polypropylene composites. Dynamic mechanical analysis of the composites showed improvement in the storage modulus after chemical treatment. Bledzki et al. [10] studied the water absorption behavior of flax and wood fiber reinforced polypropylene composites. Considering the experimental results, it was concluded that these microcellular composites combine good engineering properties. Wong et al. [11] have reported on the DMA of flax fiber-reinforced polylactic acid. The fiber–matrix adhesion was evaluated based on the results of the dynamic mechanical properties of the composite in addition to other methods. Ali et al. [12] have reported on the viscoelastic behavior of biodegradable composites prepared from Mater B and sisal fibers. Martins and Mattoso [13] have reported on the dynamic mechanical behavior of sisal fiber reinforced tire rubber. The fibers were chemically modified in certain cases. It was observed that DMA can serve as an indicator of the fiber–matrix adhesion in the composites.

In the present study, the effect of hybridization on the dynamic mechanical behavior as well as electrical properties of banana–glass composites is reported. Hybridization of banana fiber with glass fiber has been proved to improve the mechanical performance and the water absorption behavior of the composites [14,15]. Relatively small volume fractions of glass ranging from 0.03 to 0.17 were incorporated along with banana fibers in polyester matrix, for the preparation of composites, keeping the total volume fraction of the two fibers a constant equal to 0.4. The fibers were arranged in different layering patterns, to understand the effect of fiber geometry on the mechanical properties and water uptake of the composites. The effect of the relative glass volume fraction as well as the layering patterns on the properties of the composites like storage modulus, loss modulus, and damping peaks are reported in the present communication. The nature of the storage modulus and damping peaks give an idea about the load transfer efficiency between the polymer and the reinforcement. The layering pattern giving best properties is proposed to be optimized based on the dynamic mechanical response of the composites.

EXPERIMENTAL

Materials Used

Banana fiber obtained from Sheeba Fiber and Handicrafts, Poovancode, Tamil Nadu, India was used in this study. Unsaturated polyester HSR 8131 (sp. gravity 1.12, viscosity 65 cps, gel time 25 min) obtained from M/s Bakelite Hylam, Hyderabad, India was used as matrix. Ceat Ltd, Hyderabad, India, supplied multidirectional glass strand mat used for the study. Methyl ethyl ketone peroxide and cobalt naphthenate were of commercial grade supplied by Sharon Enterprises, Cochin. Glass fiber roving with tex value 1200 was obtained from Bangalore. Properties of the banana fiber and polyester are shown in Table 1.

Optical Microscopy Studies

Fractography of the failure surfaces of the composites was examined by optical microscopy using 'Citoval' stereo microscope Carl Zeiss, Jena. Failed surfaces of the composite were impregnated in polyester and the samples polished with different grades of water paper and finally polished to fineness for the optical photographs.

Electrical Properties

Rectangular specimens of 1.9 mm thickness were used. Samples were prepared by cutting from the composite specimens using a die. The test samples were coated with silver paste on either side and copper wires were fixed on both sides of the samples as electrodes. The capacitance, resistance, and dielectric loss factor were measured directly at room temperature using an Impedance Analyzer by varying the frequencies (500 Hz–6 MHz).

Preparation of Composites

Randomly oriented glass mats and neatly separated banana fiber cut at a uniform length of 30 mm were evenly arranged in a mold measuring $150 \times 150 \times 2.5\,\text{mm}^3$ in the required layering pattern for preparing the samples. Composite sheets were prepared by impregnating the fiber with the polyester resin to which 0.9 volume percent cobalt naphthenate and 1% methyl ethyl ketone peroxide were added. The resin was degassed before pouring and the air bubbles were removed carefully with a roller. The closed mold was kept under pressure for 12 h; samples were post-cured for 48 h at room temperature

Table 1. Mechanical properties of banana fiber.

Sample No.	Diameter of fiber (μm)	Initial Young's modulus (GPa)	SD* initial Young's modulus (GPa)	Breaking strength (MPa)	Strain (%)
1	50	32.1	8	779	3.2
2	100	30.4	4	711	2.4
3	150	29.6	8	773	4.1
4	200	27.2	7	789	3.3
5	250	29.1	4	766	3.2

and test specimens of the required size were cut out from sheets. Different volume fractions of glass were used for the preparation of samples as detailed in Table 2.

Composites were prepared by using various layering patterns of the glass and banana fibers. Samples marked A to F represent composites with increasing glass volume fraction from 0.03 to 0.17. The composites were prepared with banana as the skin and glass as the core material. In combinations marked A, C, and F, in addition to the banana core/glass skin, geometry, other layering patterns represented as L1 to L5 were used. The glass volume fraction is provided in Table 2 and the layering pattern is depicted in Figure 1.

THEORETICAL BACKGROUND

The dielectric constant or static permittivity E' of a material is defined as the ratio of the capacitance of a condenser containing the material to that of the same condenser under vacuum. The capacitance of a condenser measures the extent to which it is able to store charges.

Dielectric constant (ε') can be calculated from the capacitance using the equation:

$$\varepsilon' = \frac{Ct}{E_o A} \tag{1}$$

where C is the capacitance of the material, t is the thickness of the sample, E_o is the permittivity or capacitivity of free space ($8.85 \times 10^{-12}\,\mathrm{F\,m^{-1}}$), and A is the area of sample under electrode.

The insulation resistance of a material depends on its volume resistance, thus the volume resistivity (ρ) can be calculated by using the equation:

$$\rho = \frac{RA}{t} \tag{2}$$

where R is the volume resistance (Ω), A is the area of cross section, and t is the thickness of the samples.

Table 2. ***Description of composite samples with different glass volume fraction.***

Sample marking	Volume fraction of glass
A	0. 03
B	0. 07
C	0. 11
D	0. 15
E	0. 16
F	0. 17

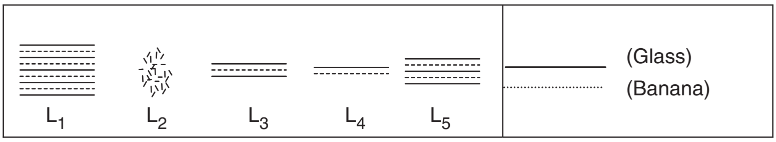

Figure 1. *The layering pattern of composite specimen marked A, C and F.*

The electrical conductivity (σ) is calculated according to the equation:

$$\sigma = \frac{1}{\rho}. \tag{3}$$

The ratio of the imaginary to the real dielectric loss angle constants $\varepsilon''/\varepsilon'$ or tangent of the dielectric loss angle is commonly employed as a direct measure of the dielectric loss. It is also known as the dissipation factor and is a measure of the power dissipated.

Dissipation factor $\tan\delta$ can be calculated from the equation:

$$\tan\delta = \frac{\varepsilon''}{\varepsilon'} \tag{4}$$

where ε'' is the loss factor and ε' is the dielectric constant.

RESULTS AND DISCUSSION

Storage Modulus

Dynamic mechanical analysis is one of the best techniques that provide information regarding the structure of the material as well as the quantitative data regarding the modulus of the material. The effect of temperature on the storage modulus of the various hybrid samples with different glass fiber volume fraction, at a frequency 10 Hz is given in Figure 2. The storage modulus values of the hybrid composites were compared with those of the unhybridized samples as well as with neat polyester samples. It may be noted that in all the samples referred to as A to F in Figure 2, there are three layers with glass as the core

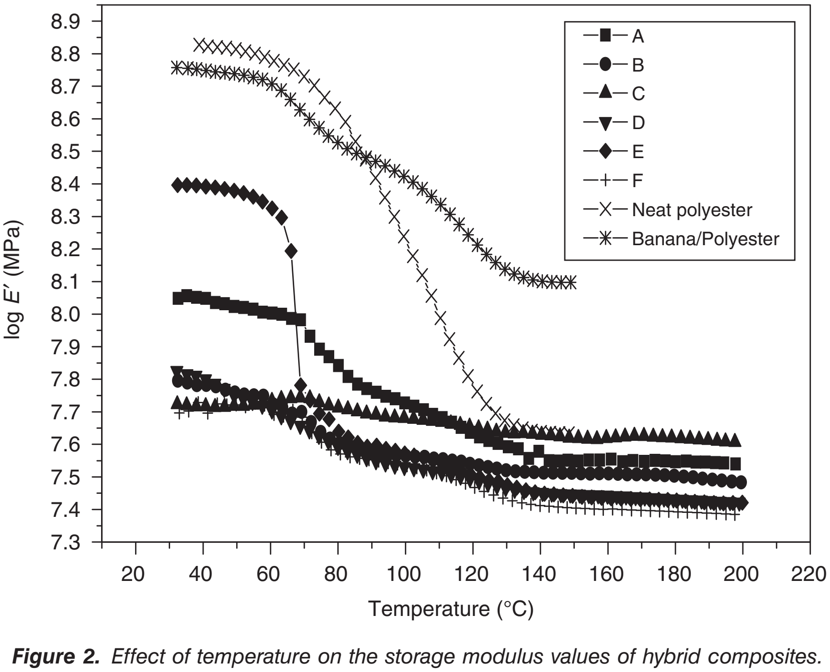

Figure 2. *Effect of temperature on the storage modulus values of hybrid composites.*

and banana as the skin. The details of the layering pattern and the volume of glass fiber used are shown in Table 2. The samples marked A to F represent composites with increasing relative glass volume fraction, from 0.03 to 0.17. Plots of storage modulus allow for the direct comparison of a variety of materials that may be considered as candidates for an application. Any drop in the storage modulus points to the molecular motions happening in a material. Addition of reinforcement to a polymer increases the modulus of the system because the reinforcement prevents the free molecular motions to an extent. The effect is noticeable at temperatures above the glass transition than below it, because molecular motions become prominent above the glass transition. The plot of E' over the whole range of temperature reflects the effectiveness of the stress transfer occurring between the fiber and the matrix. The value of the storage modulus has been reported to be proportional to the interface bonding, by other authors [16].

In all the samples considered in Figure 2, glass was used as the core material and banana fiber as the skin. The storage modulus values for samples with glass as the core material is found to be lower than that of the neat polyester samples at temperatures above and below T_g. However, at the glassy region, of all the hybrid composites considered, the storage modulus values were found to be the highest for samples with the glass fiber volume fraction, 0.16, i.e., samples marked E. The modulus values however, drop steadily at a temperature around 55°C. The drop in the storage modulus value at temperature below the glass transition temperature (T_g) of polyester, i.e., in the glassy region can be explained as due to the following reasons. The glass fiber being the core material and the banana fiber being the skin, the stress will be taken up by the low modulus banana fiber initially. After the initial drop in modulus value at the temperature around 55°C, the composite samples show a second drop in modulus at the temperature range of 120–150°C. Thereafter, the modulus values just level off.

The reason for the higher storage modulus at lower temperature in all composite samples, compared to the values at higher temperature can be attributed to the difference in the ability for stress transfer in the case of the two fibers. At higher temperature and also at dynamic loading conditions, the bonding between the different fiber layers gets affected more. When the temperature is increased, the difference in strength due to the difference in thermal expansion between the two fibers becomes more. The difference in the interfacial properties of the two fibers with the polyester matrix is also an additional factor which leads to the lowering of the storage modulus values.

It has been reported that glass fibers have the highest strength when absorption of moisture is eliminated at high temperatures, because on heating, there is high elastic and plastic deformation, which promotes healing of the micro defects and micro cracks developed on the fibers [17]. This strength difference gives rise to higher shear stresses in the composite and also to a decrease in storage modulus value. In all the samples considered, a layer of glass was kept in between the banana layers. Optical photograph of the composite with glass as the core material is given in Figure 3.

Dynamic loading and high temperature augments the incompatibility of the fiber layers, possibly due to the difference in the thermal expansion coefficient of the two fibers. This also reduces the storage modulus values. Another reason for the lowering of the storage modulus value can be attributed to the difference in the extensibility of the two fibers. The difference in the extensibility of the matrix and fiber as well as that between the two fibers leads to unevenness of deformation. Changes in the filler agglomerates and or breakage of filler polymer bonds, all lead to changes in dynamic properties. All these occur more at higher temperatures and at higher glass fiber content except for the glass volume fraction, 0.16.

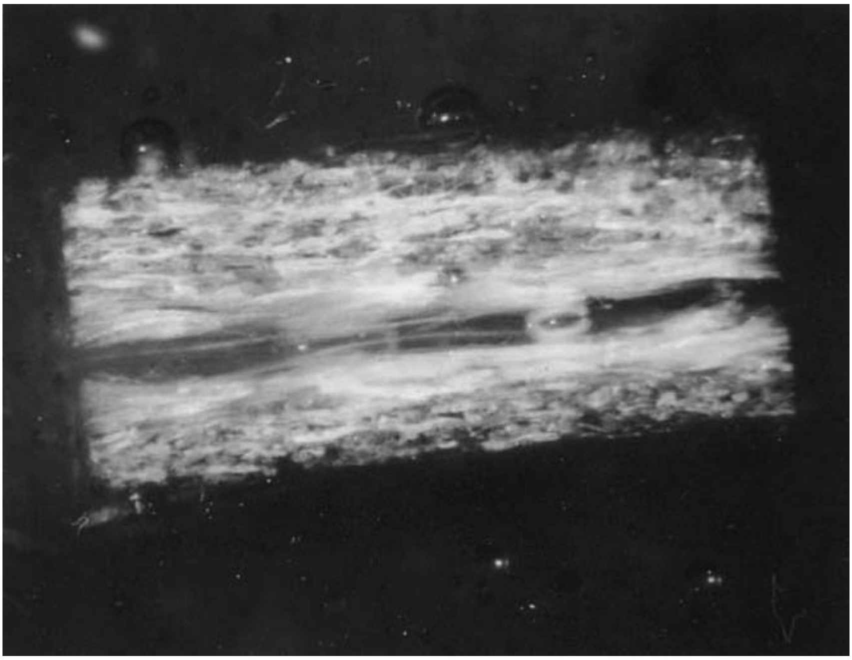

Figure 3. *Optical photograph of the failed composite with glass as the core material (sample A).*

The reason can very well be attributed to the uneven extensibility of the two fibers, which becomes more prominent at higher glass fiber content. However, the tensile strength values showed an increasing trend with the incorporation of glass volume fraction.

Loss Modulus

The loss modulus curve is the contribution of the viscous component in the polymer and is indicative of the energy dissipated by the system. The rapid rise in loss modulus in a system indicates an increase in the structural mobility of the polymer, a relaxation process that permits motions along larger portions of the individual polymer chains than would be possible below the T_g. During the glass transition, which is the largest and most important of these relaxations, those regions within the polymer structure that are not either crystallized or cross-linked, become capable of an increased degree of freedom. The variation of E'' with temperature for the various hybrid composites and the neat polyester sample is shown in Figure 4. The maximum heat dissipation occurs at the temperature where E'' is maximum, indicating the T_g of the system [18]. The peak of the loss modulus curve is conventionally identified as the glass transition temperature (T_g), even though the DMA plot clearly shows that the transition is a process that spans a temperature range. The magnitude of the loss modulus peak varies with the severity of the decline in the storage modulus. During a transition, the loss modulus increases due to the molecular motions occurring in the polymer. However, the sharp drop in storage modulus in the present case is expected to be more due to the difference in load transfer ability of the different layers than the molecular motions. It is also observed that by the incorporation of fibers in the matrix, the T_g is shifted to the higher temperature region. Increase in the

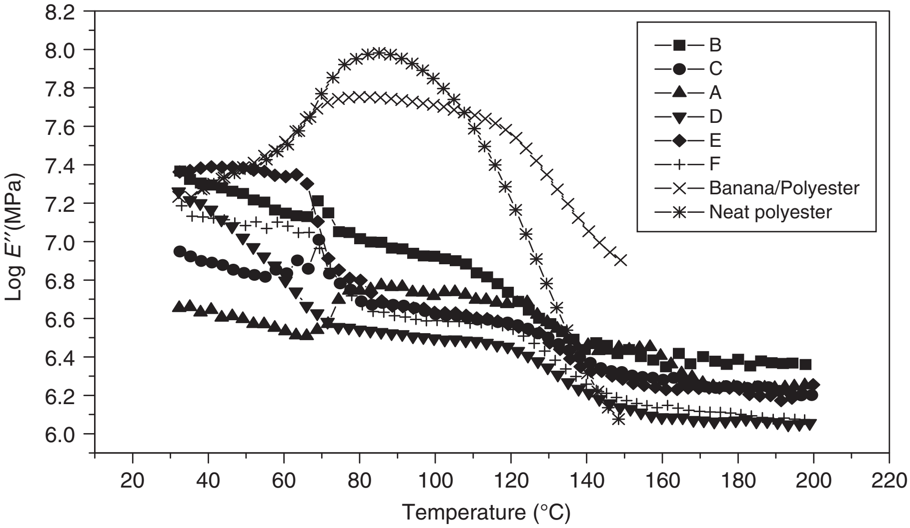

Figure 4. *Effect of temperature on the loss modulus curve.*

relative glass volume fraction, shifts the peak region positively. In addition, the loss modulus curves show an additional peak when the glass volume fraction is higher. The initial relaxation peak around 55°C has also been found to be affected depending on the glass volume fraction. Compared to the samples with no glass fiber, the relaxations are found to be shifted to the higher temperature side. However, the loss modulus peaks are found to be lowered by the incorporation of glass fiber. In addition to the lowering, the loss modulus curves are also found to be flattened. Flattening of the loss modulus curves point to an increased range of order. The second relaxation peak around the temperature range 120°C has also been found to be affected by the incorporation of glass fiber. It has been reported by other authors that in the case of hybrid composites, a change in the volume fraction ratio of the two types of fibers leads to a change in their fiber lengths. The change in fiber length arises due to the damage caused by the friction of the different fibers. This can occur during the processing of the composites. Even though this has been suggested in processes like injection molding, the likelihood of fiber breakage cannot be ruled out in the present case also.

Damping Coefficient

Damping is a sensitive indicator of all kinds of molecular motions that are going on in a material. The high damping peaks in a composite indicate that once the deformation is induced in a material; the material will not recover its original shape. In a composite, the molecular motions at the interface contribute to the damping of the material. Fiber–matrix interphase effects can also be understood to a very good extent based on the damping curves. The lower tan δ values and in particular the lower peak height associated with the glass transition, reflects the improved load bearing properties of the system (Table 3). Strong interactions of fibers and matrix tend to reduce the mobility of the molecular chains at the interface and therefore to reduce the damping. Figure 5 shows the effect of temperature on the damping peaks of the composites with different relative glass volume fractions.

Table 3. Values of the tan δ maximum and T_g of neat polyester and banana fiber composites with relative glass volume fractions.

	tan δ_{max}			**T_g from tan δ (°C)**		
	Frequency (Hz.)			**Frequency (Hz.)**		
Samples	**0.1**	**1**	**10**	**0.1**	**1**	**10**
A	0.25	0.22	0.20	107	116	131
B	0.24	0.17	0.20	117	128	135
C	0.15	0.12	0.11	122	125	127
D	0.33	0.28	0.27	119	127	135
E	0.39	0.25	0.21	122	126	129
F	0.43	0.32	0.30	126	127	132
Banana/poly	0.21	0.24	0.22	106	115	133
Neat poly	0.41	0.42	0.45	104	114	124
	E'' Max × 10^{-7}(Pa)			T_g from E''(°C)		
A	6.8	6.9	6.5	113	120	124
B	6.6	6.7	6.5	128	130	122
C	6.7	6.8	6.6	122	124	124
D	6.4	6.5	6.5	125	125	119
E	6.6	6.9	6.5	125	130	127
F	6.5	6.6	6.5	124	129	120
Banana/Poly	7.72	7.68	7.75	79	103	124
Neat poly	7.53	7.97	7.98	85	95	105

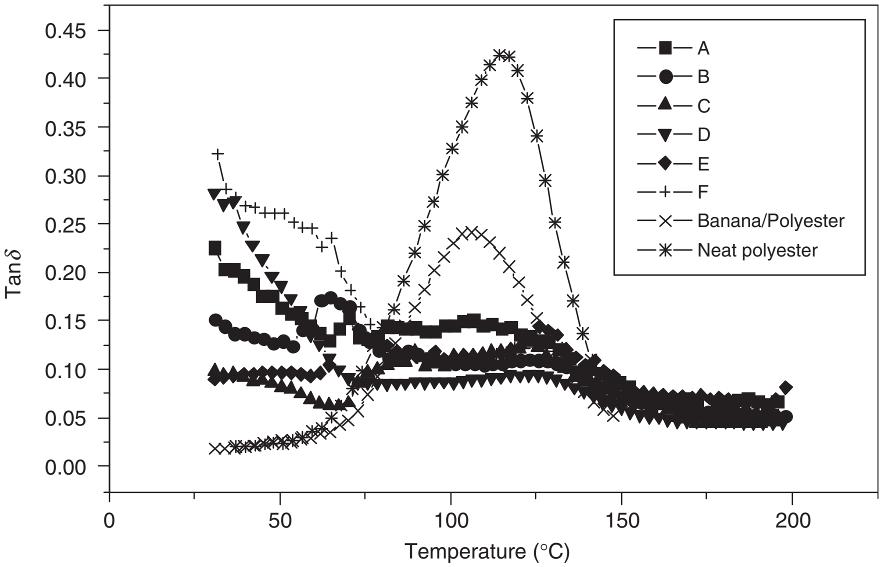

***Figure 5.** Effect of temperature on the tan δ curve of different hybrid samples (frequency 10 Hz).*

Analysis of the damping curves (Figure 5) reveals that the damping peaks have been lowered and that the relaxation peaks have been shifted to the right. Both the lowering of the damping peaks and the shifting of the peak heights point to the effective stress transfers between the fiber and the matrix. The lowering of the damping peaks also occur due to the decrease in the amount of the polymer due to fiber incorporation. The increased stress transfer can be attributed to the increase in the high modulus glass fiber in the composite. Unlike the storage modulus and the loss modulus curves where there is a lowering of the ultimate values, the damping peaks point to the increased fiber–matrix interaction.

Effect of Layering Pattern

Figure 6 shows the effect of layering patterns on the storage modulus values of the different composites. Table 4 gives details of the layering patterns followed.

Storage Modulus

The storage modulus values of the composites with a glass fiber volume fraction of 0.11 are given in Figure 6. The different layering patterns that are followed are given by L_1, L_2, etc. and they are designated as Cl_1, Cl_2, etc. in samples with a glass volume fraction, 0.11. In all the cases, samples where an intimate mixture of glass and banana was used as the reinforcement has been found to have the highest tensile properties, i.e., the samples marked Cl_2. The consistently high storage modulus value in the case of intimately mixed

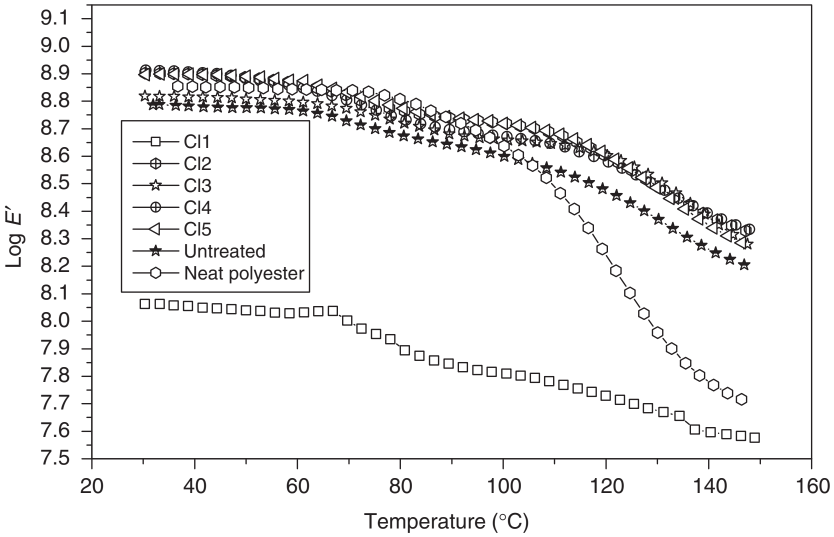

Figure 6. Effect of layering patterns on the storage modulus values of the composites with glass volume fraction 0.11.

Table 4. Details of layering pattern.

Sample marking	Layering pattern
L_1	G-B-G-B-G-B-G-B-G
L_2	Intimate mixture of G and B
L_3	G-B-G
L_4	G-B
L_5	G-B-G-B-G

G – glass; B – banana.

composites can be attributed to the high elongation fibers acting as crack arrestors in the case of a matrix failure. Unlike in the other geometries followed, the fibers being intermingled, failure of the matrix or the low elongation fiber will give way to crack arrest by the high elongation fibers. The high shear strain stored in the interphase due to the mismatch between the fiber and the matrix properties will also be minimized when the two fibers are intimately mixed. In the case of composites with different layering arrangements, the stress concentration at the crack tip induces delamination. The material in the periphery takes the stress and in composites where glass is kept in the periphery, the high modulus glass fibers will take the stress. This leads to relatively higher strength values compared to composites where banana is the skin.

In addition, the polymer chains immobilized on the fiber surface make a link between the fibers, creating a flexible network whose properties are dependent on the modulus of these chains. These additional networks serve as supplementary cross-link points. The nature of the network is different in the case of banana fiber and glass fiber. In dynamic experiments, the two networks respond in a different way. But depending on the way in which the different fiber layers are arranged, the responses of the materials differ, which is revealed in the modulus values. The difference in response gets nullified based on the fiber arrangement. Chazean et al. [19] have suggested formation of networks on the surface of cellulosic fibers.

Damping Coefficient

Figure 7 shows the effect of layering pattern on the damping curve of the composites with glass volume fraction 0.11. The damping curves of all the samples, except that where glass forms the core and banana the skin are found to be following almost the same trend. All the damping curves show two peaks irrespective of the layering pattern followed. The two distinct damping peaks in all cases can clearly be attributed to that due to the two

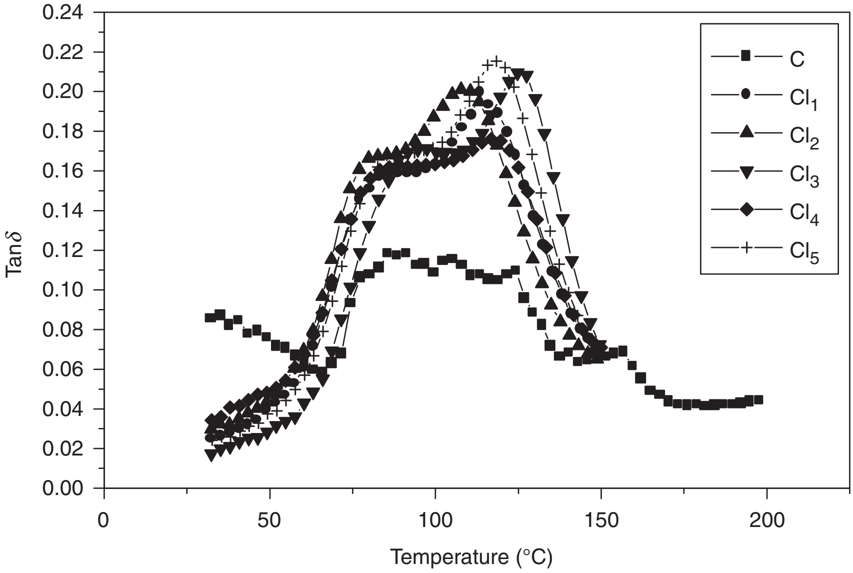

Figure 7. *Effect of layering on the damping curves of the composite with glass volume fraction 0.11.*

different fibers. The damping peaks also get shifted depending on the layering patterns followed. The maximum shifting of the damping peaks occur in the case of samples marked Cl_3 and Cl_5. In samples marked Cl_3, banana forms the core material and glass the skin. In samples marked Cl_5, there are altogether five layers, with glass as both the skin and the core and banana layers in between. Glass forms the outer layer in both the samples. Moreover, the glass and banana layers are interdispersed.

In the different layering patterns followed, the composite with five layers, where glass forms both the core and the skin has given the maximum impact properties as well [20]. The shifting of the damping peak to the high temperature region points to the effective stress transfer between the fiber and the matrix in the particular geometry followed. Table 5 shows the values of the damping peaks obtained for composites with a relative glass volume fraction of 0.11 and with different layering patterns.

For intimately mixed composites also, the damping peak values are more or less the same as that of the composites with glass as the periphery material. In intimately mixed composites, the high elongation cellulose fibers serve as crack arrestors in a micro mechanical way, better than in layered composites, and help in effective stress transfer. An optical photograph of the intimately mixed composite is given in Figure 8. The broken glass fibers and the cellulose fibers, which act as bridges can very well be seen in the optical photographs.

The three-layer composite samples, where glass forms the core material is found to have a damping curve different from that of the other samples. The two fibers take the stress applied on the composite differently. The high modulus glass fiber being the core material, the banana fibers will have to take the stress initially.

In all glass–banana combinations, there are two peaks visible. The additional peak can be attributed to the micro mechanical transitions. The micro mechanical transitions arise due to the presence of the immobilized polymer layer in between the fiber and the matrix. The evidence for immobilized polymer layer has already been reported in our earlier publications [21,22].

Other authors have also reported on the additional peak due to the presence of the immobilized polymer layer [23]. The intensity of the additional $\tan\delta$ peak is found to be greater due to the difference in the nature of the immobilized polymer layer on the two different fibers. The $\tan\delta$ peak also gets shifted depending on the layering pattern.

Dielectric Properties

The volume resistivity values of the neat polyester and the various composites are shown in Figure 9. As the value of the frequency is increased, it is found that the volume resistivity

Table 5. Values of $\tan\delta$ max obtained for composites with relative glass volume fraction 0.11 and different layering patterns.

Sample	$\tan\delta_{max}$	T_g from $\tan\delta_{max}$°C
C	0.127	123
Cl_1	0.182	122
Cl_2	0.193	117
Cl_3	0.211	131
Cl_4	0.170	126
Cl_5	0.210	128

values are almost the same for all the composites irrespective of the ratios of the various fibers used. The volume resistivity value is found to be affected by the incorporation of glass fiber at relatively lower frequencies. In the various samples marked A1 to F1, there is an increase in glass fiber content and the same layering pattern of glass and banana.

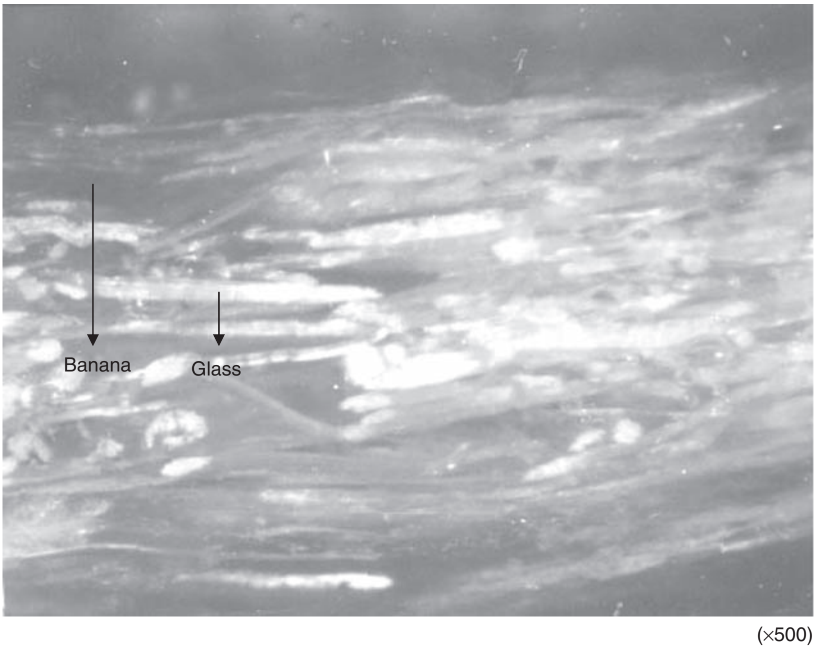

Figure 8. *Optical photographs of the failed composite with an intimate arrangement of glass and banana (relative glass volume fraction 0.1).*

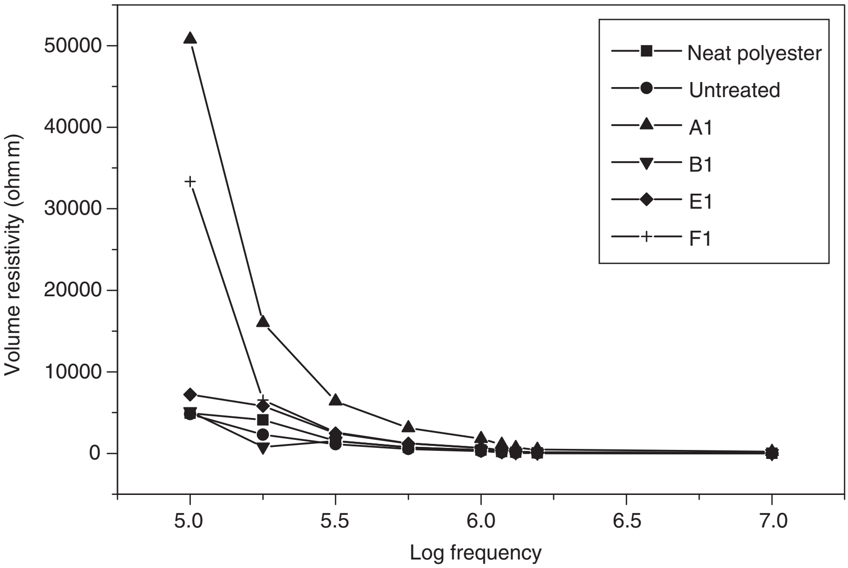

Figure 9. *Effect of glass volume fraction on the volume resisitivity of composites.*

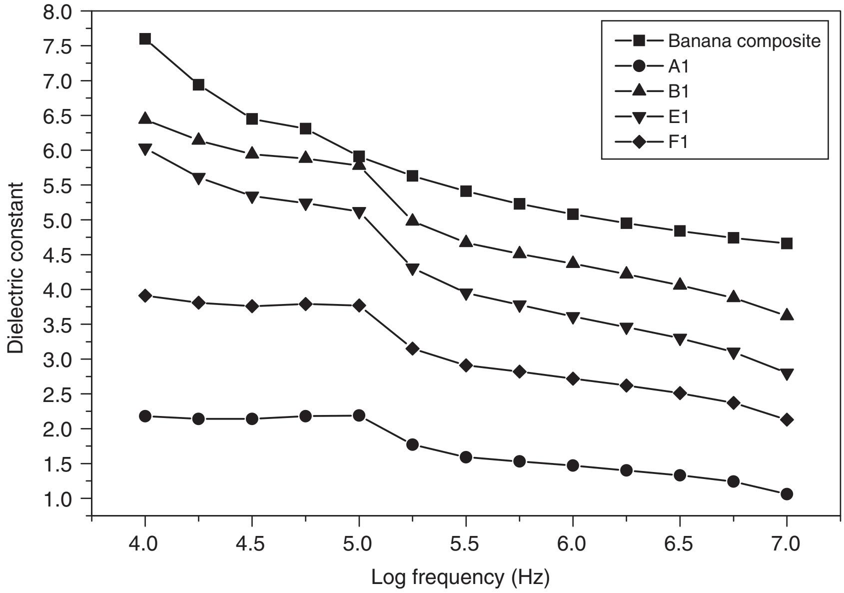

Figure 10. *Effect of glass volume fraction on the dielectric properties of composites.*

The maximum volume resistivity is found to be for the composites with the minimum glass fiber content in the present case. However, the composites with maximum glass fiber content have the second highest value of volume resistivity. The results show an interesting observation that in the case of all the other composites with varying glass fiber volume fractions, the values of the volume resistivity decreases with increasing glass fiber volume fraction. In other words, the conductivity of the composites increases with increasing glass fiber content. However, interestingly, the composites with the lowest glass fiber volume fraction in the present case have the highest value of volume resistivity.

The dielectric constant of the various composites with different glass volume fraction has been compared and is shown in Figure 10. It is interesting to note from the figure that the value of dielectric constant is lowest in the case of composites with relatively lower glass volume fraction. The dielectric constant values however, do not show any regular trend in the case of the other hybrid composites. The composites with higher glass fiber volume fraction have dielectric constant values in between that of banana fiber composites and composites with the lowest glass fiber volume fraction.

CONCLUSIONS

The hybridization of banana fiber with glass has been found to affect the dynamic mechanical response of the composites. More than the volume fraction of glass involved in the hybridization, it is the layering pattern, which has been found to affect the properties. An intimate mixture of banana and glass or a layering pattern with detailed distribution of both the fibers give better properties. A layering pattern where glass fibers are incorporated between two banana layers lower the properties considerably due to property mismatch of the fibers. The effect of the property mismatch has been found to decrease based on the fiber layering pattern. The damping has also been found to shift to higher temperatures based on the layering pattern followed.

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