Study on Dynamic Mechanical Properties of Pultruded Kenaf Fiber Reinforced Composites

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ABSTRACT

This paper reports the dynamic mechanical properties of pultruded kenaf fiber reinforced composites. A series of dynamic mechanical tests were performed by varying the fiber loading and test frequencies over a range of testing temperatures. It was found that the storage modulus (E') recorded above the glass transition temperature (T_g) decrease with increasing temperature. For a given fibre loading, pultruded kenaf fibre reinforced composite containing highest percentage of Kenaf fibre (70%) retains minimum loss of storage modulus values. The loss modulus (E") and damping peaks (Tan δ) values were found to be reduced with increasing fibre loading and temperature. In terms of test frequency, for a given fibre loading (70%), highest test frequency (100 Hz) resulted in minimum loss of dynamic mechanical properties such as Tan δ' and E".

Keywords: Kenaf fibers, Polymer–matrix composites (PMCs), Thermal properties,Dynamic mechanical analysis (DMA), Pultrusion

1. INTRODUCTION

Manufacturing high performance engineering materials from renewable resources is one ambitious goal currently being pursued by researchers across the world. The ecological benefits of renewable raw materials are clearly saved valuable resources are environmentally sound and do not cause health problems. Natural fibers have already established a track record as simple filler material in automobile parts. Natural fibers like sisal,kenaf, jute, coir, oil palm fiber have been proved to be good reinforcement in thermoset and thermoplastic matrices [1–4]. Previous studies have proved kenaf fibers to be an effective reinforcement in polyester matrix [5]. Dynamic mechanical test methods have been widely employed for investigate the structures and viscoelastic behaviour of polymeric materials to determine their relevant stiffness and damping characteristics for various applications. The dynamic properties of polymeric materials are of considerable practical significance when determined over a range of temperature and frequencies. Composite damping property results from the inherent damping of the constituents.

Works done on the dynamic mechanical properties of fibrous composite materials are mainly aimed at two objectives.

1. To study the dynamic mechanical properties of pultruded kenaf reinforced composites (PKRC) in different fiber loading system
2. To study the viscoelastic behaviour of pultruded kenaf reinforced composites PKRC in different frequency application

The previous workers [6-11] were carried out an improvement on dynamic mechanical properties of different polymeric composites system. The comparative studies in their investigation on the enhancement of damping in polymer composites have been suggested analyzing different fiber combinations. Extensive research work is being carried out by Thomas and co-workers in this laboratory regarding the viscoelastic behaviour of various polymer composites and blends [12-13].

In the present communication, we report on the influence of kenaf fiber on the viscoelastic properties of polyester. The effect of fiber content, frequency and temperature on the viscoelastic properties is reported. The elevation of T_g is taken as a measure of the interfacial interaction and the effect of fiber content on the T_g values is reported. The T_g is usually interpreted as the peak of the tan δ or the loss modulus curve that is obtained during a dynamic mechanical test conducted at a low frequency. The T_g values of the different samples and the shift in T_g were determined from the loss modulus and the tan δ curves to have more insight into the fiber/matrix adhesion. The effect of interlayer on the micro mechanical transitions is also reported.

2. EXPERIMENTAL

2.1 Materials

Kenaf fiber was locally supplied by Lembaga Tembakau Negara (LTN) Malaysia. Kenaf fiber was further processed into yarn form by Institute of Natural Fibres, Poznan, Poland. Unsaturated polyester resin (Reversol P-9941) for pultrusion grade was obtained from Revertex (Malaysia) Sdn.

2.2 Preparation of pultruded composites

Pultruded composites were prepared an average diameter of all composite rods is 12.7 mm of kenaf fiber composites with fiber and matrix respectively with the (50, 60, 65, 70 and 75) % of fiber loading. Dynamic Mechanical Analysis (DMA) was done using Mettler Toledo Model 861 under three-point bending configuration following ASTM D5023-7. The Pultruded

Kenaf Reinforced Composites (PKRC) samples were tested in temperature range from 0 °C -250 °C, with a heating rate of 5 °C per min, in several operating frequencies applied (0.1 Hz, 1 Hz, 10 Hz, and 100 Hz), force amplitude of 4.5 KN and the displacement amplitude of 10 μm.

3. RESULTS AND DISCUSSION

3.1. Effect of temperature

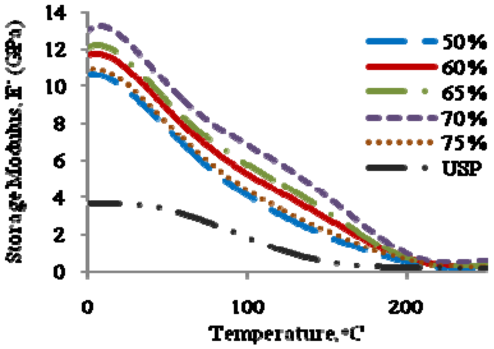

Fig. 1 The effect of temperature on the dynamic modulus of the neat polyester and various composites with different fiber content

Fig. 1 shows the effect of temperature on the dynamic modulus of composites with different fiber loading. Variation in modulus occurs due to the effect of the incorporated fibers. The increase of E' in the rubbery plateau is at maximum for the composites with 70% of fiber loading with respect to matrix. The drop in the modulus on passing through the glass transition temperature is comparatively less for reinforced composites than for un-reinforced resin. This can be attributed to the combination of the hydrodynamic effects of the fibers embedded in a viscoelastic medium and to the mechanical restraint introduced by the filler at the high concentrations, which reduce the mobility and deformability of the matrix.

Other authors have also reported similar observations. [14]. At higher temperatures any water molecules adhering on to the fiber will get evaporated making the fiber stiffer. Air-dried cellulose is rather resistant to mechanical impact and a large amount of mechanical energy has to be spent in order to destroy the macroscopic and microscopic structure. This ultimately contributes to the improved modulus of the composite at high temperatures.

Fig. 2 delineates the effect of temperature on tan δ. Improvement in interfacial bonding in composites occurs as observed by the lowering in tan δ values. The higher of damping at the interfaces, have been influenced on interface adhesion. 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 neighbouring fibers. The effective stress transfer occurs in the case of composites with 70% loading. It has been reported before that composite with poor interface bonding tends to dissipate more energy than that with good interface bonding [18].

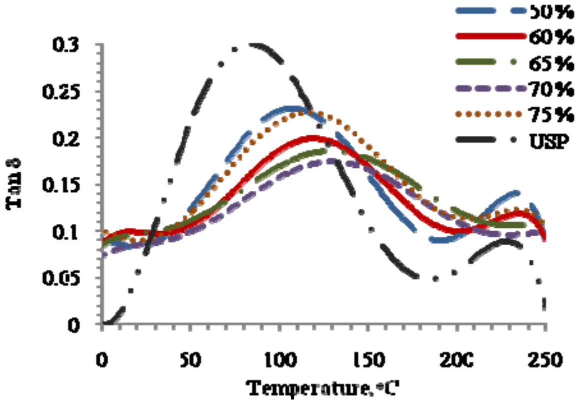

Fig. 2 Effect of temperature on the tan d value of the composite at different fiber

Fig. 3 shows the variation of loss modulus with temperature of composites with different fiber loading. It can be seen from the figure that the loss modulus peak values increase with increase of fiber content at temperatures below and after the glass transition. Another interesting result that is observed is the broadening of the loss modulus curve when the fiber content is increased to 70%. The increase in width of the loss modulus curve is taken to represent the presence of an increased range of order. The greater constraints on the amorphous phase could give rise to higher or broader glass transition behaviour Figure shows the maximum peak width is found to be for the composites with 70 % fiber loading.

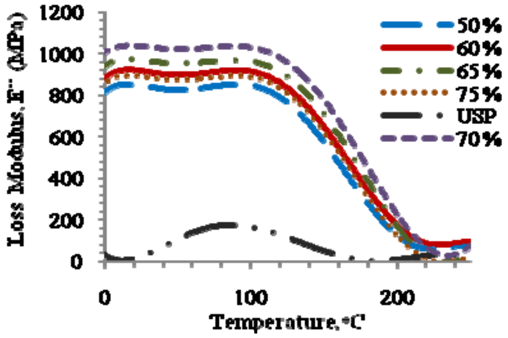

Fig. 3 The variation of loss modulus with temperature of composites with different fiber loading

3.2. Effect of frequency

The storage modulus, loss modulus and damping peaks have been found to be affected by frequency. The variation of E' with frequency of neat polyester as a function of temperature is shown in Fig. 4. Increase of frequency has been found to increase the modulus values. Fig. 5 shows the effect of frequency on the dynamic modulus of samples with 70% fiber loading. Frequency has a direct impact on the dynamic modulus especially at high temperatures. The modulus values are found to drop at a temperature around 45°C. The drop in modulus value continues steadily till a temperature of 140 °C is reached. The molecular motion can be believed to be set in at 45 ^{o}C. The change in dynamic properties is also associated with crazing and formation of microscopic cracks and voids. At high temperature breaking up of the fiber agglomerates and breaking up of the bond between the fiber and polymer phases may also occur [15]. The lowering of the modulus peak is at maximum for the neat USP due to the development of microscopic cracks in the unfilled resins. Frequency is seen to have a direct impact on the tan δ values as well.

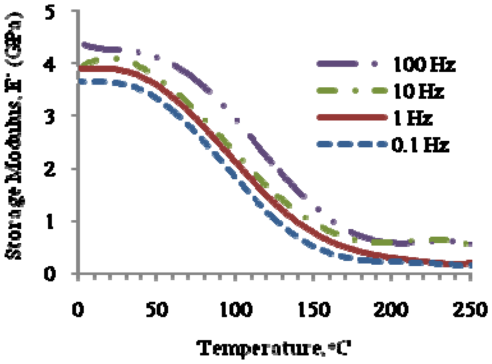

Fig. 4 The variation of E' with frequency of neat polyester as a function of temperature

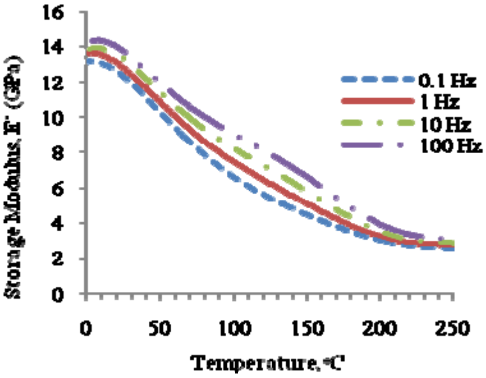

Fig. 5 The effect of frequency on the dynamic modulus of samples with 70% fiber loading

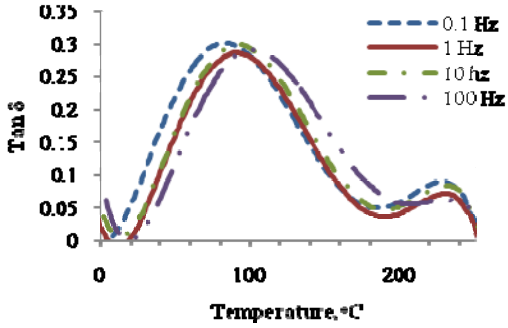

Fig. 6 Effect of frequency on the tan d curve of neat polyester.

The viscoelastic properties of a material are dependent on temperature, time and frequency. If a material is subjected to a constant stress, its elastic modulus will decrease over a period of time. This is due to the fact that the material undergoes molecular rearrangement in an attempt to minimize the localized stresses. Modulus measurements performed over a short time (high frequency) result thus in higher values whereas measurements taken over long times (low frequency) result in lower values [16]. In this system also, the modulus measurements over a range of frequencies have been studied. Higher values were observed for measurements made over a short time. The tan δ values measured over a range of frequencies for the neat polyester samples are shown in Fig. 6. The tan δ peak is found to shift to higher temperature with increase of frequency. The damping peak is associated with the partial loosening of the polymer structure so that groups and small chain segments can move. The tan δ curve peak, which is indicative of the glass transition temperature, is also indicative of the degree of cross-linking of the system. Fig. 7 shows the effect of frequency on the tan δ curve of samples with 70% loading. The nature of the tan δ curve is affected by the incorporation of fiber.

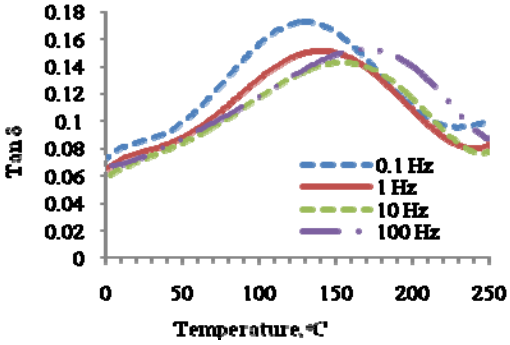

Fig. 7 Effect of frequency on the tan delta curve of composites with 70%

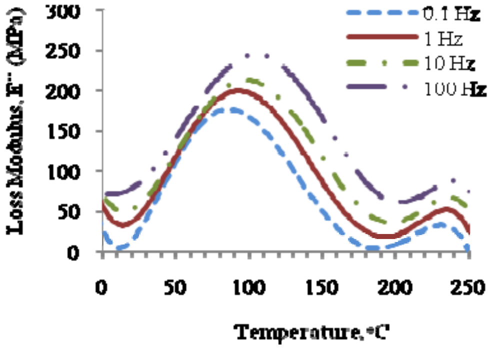

Fig. 8 Effect of frequency on the loss modulus curve of neat polyester.

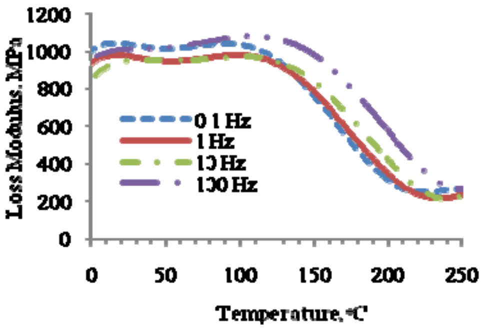

Fig. 9 Effect of frequency on the loss modulus curve of composites with 70% fiber loading.

Fig. 8 shows the effect of frequency on the loss modulus values of neat USP samples. The peak of the loss modulus curve is seen to be shifted to higher temperatures with increase of frequency. Fig. 9 shows the effect of frequency on the loss modulus curve of the samples with 70% fiber loading. The E'' peak of the composite is broader revealing the morphological rearrangement resulting in a highly plasticized amorphous region and also the improved interaction between the fiber and matrix. The loss modulus curves in addition show two peaks. These very well support the micro mechanical transition observed in the tan δ peaks.

Table 1 shows the tan δ max and the corresponding T_g values for the different composites. The values of T_g obtained positively shift due to plasticization results from the addition of fiber within the polyester matrix. With increase in frequency, the tan δ peak, which corresponds to the glass transition temperature, is also found to be shifted to higher temperature.

Table 1 Values of tan δ maximum T_g values of neat polyester and kenaf fiber reinforced polyester composites at different fiber loading\

Fibre Loading	Tan δ_{max}				T_g fromTan δ_{max} (°C)			
	Frequency (Hz)				Frequency (Hz)			
	0.1	1	10	100	0.1	1	10	100
UP	0.3	0.29	0.27	0.28	85.2	90.3	97.1	102.1
50%	0.24	0.23	0.21	0.22	105	113	120	127
60%	0.22	0.21	0.17	0.19	120	130	139	150
65%	0.19	0.16	0.15	0.16	125	137	151	160
70%	0.17	0.15	0.14	0.15	130	140	155	171
75%	0.23	0.225	0.22	0.21	108	115	123	132

4. 0 CONCLUSIONS

Dynamic mechanical properties of pultruded kenaf fiber reinforced polyester composites are greatly dependent on the volume fraction of the fiber. The dynamic modulus shows a decrease with incorporation of fiber below the glass transition temperature and has a positive effect on the modulus at temperatures above T_g. The maximum improvement in properties is observed for composites with 70% fiber loading, which is chosen as the critical fiber loading. Increase of frequency shifts the T_g to higher temperatures supporting the good fiber/matrix interaction. At the maximum possible fiber loading in this study i.e. 70% loading, the loss modulus peak gets broadened emphasizing the improved fiber/matrix adhesion. Moreover, an additional peak occurs at high fiber loading in the tan δ curves, due to the interlayer effect. Addition of fiber lowers the tan δ peak height, which again points to the improved fiber/matrix adhesion. The glass transition temperature is shifted positively on the addition of fiber.

6.0 References

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