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Viscoelastic Properties of Kenaf/Basalt Reinforced Epoxy Hybrid Composites through Vacuum Infusion Methods

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Abstract:

In recent years, many research interests are focusing on the hybridization of composites consisting of synthetic-synthetic, synthetic-natural, and natural-natural fiber. The advantages of the combination of various fibers can enhance the properties of composites in wide range applications such as automotive, packaging, construction and so on. Kenaf/basalt reinforced epoxy hybrid composites were fabricated through a vacuum infusion method. The purpose of this study to investigate the viscoelastic properties of hybridization of kenaf/basalt reinforced epoxy composites. There are four formulations of pure epoxy (PE), kenaf/epoxy (KE), basalt/epoxy (BE) and kenaf/basalt/epoxy (KBE) were fabricated through vacuum infusion method. The dynamic mechanical properties of kenaf/basalt hybrid composites were characterized to determine damping properties. The results show that the damping properties of basalt composites improved than other composites.

Keywords: *Hybrid Composites; Dynamic Mechanical Properties, Natural Fibre Composites; Kenaf/Basalt Fibre*

I. INTRODUCTION

Recently, the composite industries have seen the emergences of some significant trends that can have enormous potential, which can lead to new market growth throughout the value chain and unprecedented industry shifts. Composite and plastics are lightweight materials with vital growth roles in various industries such as automotive, construction, electrical, and packaging [1]. In recent years, the influence of composite materials has grown rapidly. This is due to the components of composite materials promotes better properties than single materials. In other word, the combination of different materials **improves the properties** of the product[2]. Classification of composites materials is usually based on the reinforcement they use. Reinforcement is utilized to give strength to the composite. It is embedded in a matrix that holds the composites together. The types of composite that can be found are short fiber reinforcement, continuous fiber, particulate reinforcement, flake reinforcement, and filler reinforcement.

Kenaf fibers are available resources plant that can be found in Malaysia, and it has own unique properties such as biodegradability, lighter weight, cost-effectiveness with excellent mechanical properties have been discovered by other researchers[3]. This plant that grows exogenously due to its short-lived plant, easy to grow with built up by core and bark[4]. Moreover, it is easy to isolate them by enzymatic retting and chemicals. The advantage of kenaf plant is that it can adapt to different kinds of soil and requires minimal chemical treatment. Also, studies have shown that the mechanical properties of neat polymers with the addition of kenaf fiber have improved tremendously [5]–[8].

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Basalt can also be a great alternative to produce a low cost and eco-friendly natural fiber where it is a grey to dark, fine-grained volcanic rock. This basalt fibre formed by magmatic movement and cooling of magma in atmospheric conditions. It covers almost 2.5 million square kilometers of the earth, makes this fibres preferable [9]. Moreover, these fibres are environmentally friendly and not harmful. Basalt fibres are known to have high strength and shock resistance modulus [10].

Natural composites are generally preferable in terms of production cost and environmentally friendly. However, to function as a capable composite, the composite has to be highly hydrophobic besides having strong mechanical properties such as high tensile and flexural strength. On the contrary, kenaf is known for its water-absorbing quality which also known as it is hydrophilic. The hybridization of natural-natural fibre such as kenaf/basalt enhanced the mechanical properties [11]. However, there was less study on the viscoelastic properties of the hybrid composites. This paper aims to investigate the viscoelastic properties of kenaf/basalt reinforced epoxy hybrid composites prepared by vacuum infusion technique to improve hybrid composites and damping properties. The four formulations of the epoxy-based composites were fabricated using the vacuum infusion process. The fabricated materials were characterized using DMA analysis to determine its damping properties.

Table 1. Reported works on viscoelastic properties of natural hybrid composites

Hybrid	Matrix	Storage Modulus (MPa)	Loss Modulus (MPa)	Tan Delta (δ)	Refs
Banana/Sisal	Natural Rubber	-	-	0.31-0.79	[12]
Banana/Jute	Polyester	2-4x10^9 Pa	1-3 x10^8 Pa	0.28-0.26	[13]
Jute/hemp/flax	Epoxy	0.5 GPa	0.079 GPa		[14]
Basalt/sisal	Epoxy	9.3x10^9 Pa	1.2x10^9 Pa	0.032	[15]
Jute/Ramie	Epoxy	5717.08	707.4	0.209	[16]
Flax/Jute	PLA	1500-1700	200-250	0.7-0.8	[17]
Aloevera/hemp	Epoxy	16.9 GPa	1.6 GPa	0.47	[18]
Bamboo/woven kenaf	Epoxy	3944	68.67	0.21	[19]
Jute/Sisal	Epoxy	3.5038	0.525	0.2784	[20]
Kenaf/Pineapple leaf	Phenolics	3000-3500	160--170	0.06-0.08	[21]

II. EXPERIMENTAL

A. Materials

In this study, kenaf non-woven and basalt woven mat are used as reinforcement. The Epoxy matrix and the hardener with a weight ratio of 2:1 used as matrix material. The fibres and Epoxy matrix used in the present study were purchased from Innovative Pultrusion Sdn. Bhd., Seremban, Malaysia.

B. Fabrication of kenaf/basalt reinforced epoxy hybrid composites

The kenaf, basalt, and epoxy composites were then prepared according to Table 2 and fabricated by using vacuum infusion processing. First of all, the vacuum infusion apparatus was set up. The apparatus consists of a vacuum pump, vacuum tubing, fibreglass tray, plastic sheet, roller, and a rubber mould. The plastic sheet was used to create a smooth peeling effect of the composite so that there would not be any distortion of materials. The materials were cut into the dimension of the tray. Each weight of the fibre was then measured using the electronic balance. In this experiment, the resin and hardener were mixed with ratio of 200g to 100g. The mixing time was set for 2 minutes in order to obtain a good mixture with perfect curing time. Then the first layer of epoxy was poured into the tray, followed by a sheet of basalt fibre. A roller was used to make sure the basalt fibre thoroughly absorbed the epoxy. Next, another layer of epoxy was poured onto the basalt fibre and spreader evenly by using the roller. The cut kenaf fibre sheet was placed onto the epoxy layer. It can be seen that the kenaf fibre absorbed the epoxy resin faster than the basalt fibre. This is due to kenaf fibre has a high moisture absorption rate. Lastly, epoxy resin was poured, and basalt was placed onto the epoxy layer, and another layer of epoxy resin was then poured on top of the basalt fibre. It could be seen that the composition of the material was sandwich-like. A rubber mould was placed on top of the orientation and the vacuum was switched on. The vacuum has been kept switched on for 2 hours. This was done to eliminate the presence of air bubbles and voids within the composition. The composites were left to dry for 24 hours to obtain a linearly thick sample. The dried samples were carefully removed from the fibreglass mould and then samples were cut into the desired shape for testing.

Table 2. The formulation of kenaf/basalt reinforced epoxy hybrid composites

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Sample ID	Epoxy (wt. %)	Kenaf Fibre (wt. %)	Basalt Fibre (wt. %)
Pure Epoxy (PE)	100	0	0
Kenaf-Epoxy (KE)	60	40	0
Basalt-Epoxy (BE)	60	0	40
Kenaf/Basalt-Epoxy (KBE)	60	20	20

III. CHARACTERIZATION

A. Dynamic Mechanical Analysis

Dynamic mechanical analysis (DMA) tests of Epoxy based composites were carried out using a TA (DMA Q 800) analyzer, operating in 3-point bending mode at an oscillation frequency of 1Hz under controlled amplitude. The specimen measurement was carried out of 60 x 12x 3 mm^3 from 30° C to 200 °C at a heating rate 5 °C/min were subjected to the test according to ASTM D4065-01. The storage modulus, loss modulus, and tan delta of the Epoxy based composites were discussed in Section 4.0.

IV. RESULTS AND DISCUSSION

A. Storage Modulus (E')

The storage modulus also known as elastic modulus is a measure of the stiffness (Young's modulus) of the materials. Fig. 1 shows the different of fibre reinforcement epoxy composites as function of temperature.

The addition of kenaf and basalt fibre significantly improved the storage modulus at the lower temperature and decreased at higher temperature. This is because the addition of fibre enhances the space of Epoxy matrix to carry mechanical constraints and thermomechanical bending properties. As in Fig. 1, the stiffness of composites is higher with the addition of kenaf and basalt. The trend of pure epoxy and other composites exhibiting quite close of storage modulus value. Among all, BE composites showed the highest value of modulus glassy region with 6392 MPa at 40°C. The storage modulus of BE composites showed improvement by 34 % as compared by previous research done using basalt reinforced epoxy composites through hand lay-up method [22]. Nevertheless, the KBE hybrid composites exhibited a slight enhancement of modulus as compared to KE composites.

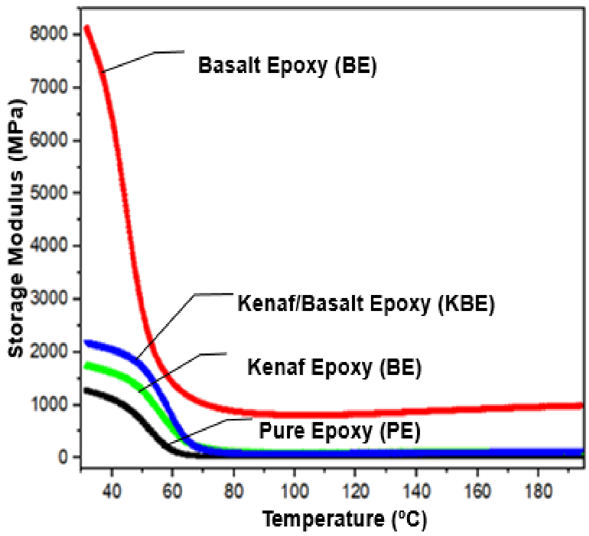

Fig. 1 Storage modulus of kenaf/basalt reinforced epoxy hybrid composites

B. Loss Modulus (E'')

The measurement of material's viscosity, also known as loss modulus, *E''* can be defined as the energy loss as heat under stress or in a deformation cycle. Fig. 2 illustrates the variation in loss modulus of Epoxy based single fibre and hybrid composites as a function of temperature (°C). The glass transition (T_g) can be observed when the elastic modulus decreased rapidly and the loss modulus achieved the highest value. It had been observed that all loss modulus graphs are reduced at higher temperature is due to free movement of the polymer chain. The similar trend of *E'* curve to that *E''* curves of this Epoxy based kenaf and basalts composites. The T_g represented by the peak values of the graph which represents the transition region form glass state to the rubbery region for the Epoxy based composites. The maximum value of *E''* is found 1329.37 MPa for the BE composites but this value decreased for KBE hybrid composites at value 292 MPa. The T_g of the KBE hybrid composites is shifted to higher temperature because of the addition of kenaf fibres into basalt composites leads to a decrease in mobility of epoxy chain.

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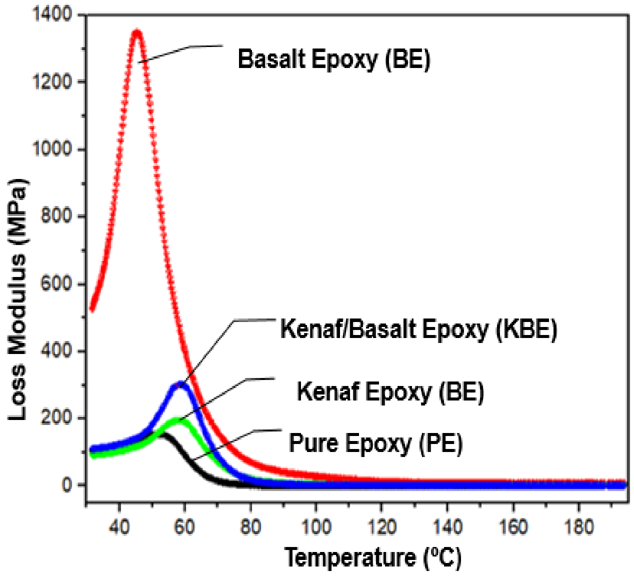

Fig. 2 Loss modulus of kenaf/basalt reinforced epoxy hybrid composites

A. Tan Delta (Tan δ)

The ratio of elasticity (storage modulus) to viscosity (loss modulus) is corresponding to the damping factor (tan δ) of a material. The increased value of tan δ is indicating a high degree of non-elastic deformation and energy dissipation. Fig. 3 shows the effect of kenaf and basalt reinforcement in Epoxy composites.

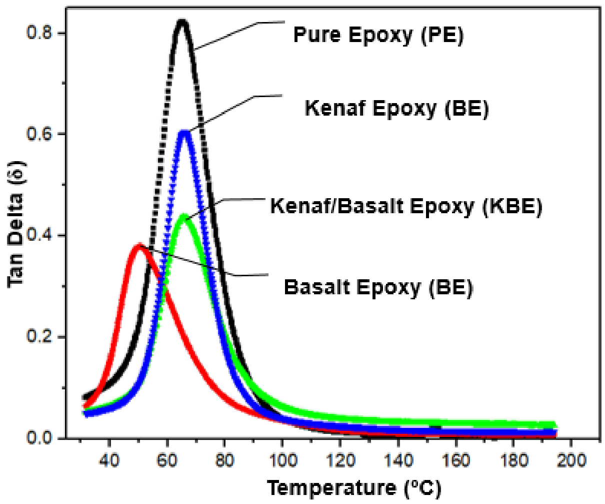

Fig. 3 Tan delta (δ) of kenaf/basalt reinforced epoxy hybrid composites

From the curve, the highest peaks are Pure Epoxy showing a higher degree of mobility. At the range of 40 to 80°C, it can be observed the lower peak of BE composites. The BE composites showing lower mobility as compared to neat epoxy and other composites. Conversely the hybridization of both natural fibres should show the lower tan δ peak height. This is due to that the incorporation of the fibres into the polymer led to reduce polymer chain mobility and reduces the flexibility of the composites[15], [21]. However, the value of tan δ was close to other hybrids of natural fibres reinforced epoxy composites[18]. The value of Tan δ peak and T_g obtained from Tan δ curve for epoxy based composites are given in Table 3.

Table 3. Glass transition temperature and peak height of kenaf/basalt reinforced epoxy hybrid composites.

Sample ID	Peak height of Tan δ	Temperature (°C)	
		T_g from Tan δ	T_g from Loss Modulus
PE	0.819	65.47	51.98
KE	0.598	65.90	58.43
BE	0.377	51.15	45.94
KBE	0.495	65.83	58.82

CONCLUSION

The damping properties of kenaf/basalt reinforced epoxy hybrid composites has been investigated. The variation type of natural fibre on kenaf, basalt and hybrid kenaf/basalt give variation of viscoelastic properties. Storage modulus as well as loss modulus is found to be high for BE composites. It is found that BE composites has better damping properties as compared to hybrid composites due to higher stiffness and good interfacial bonding of the composites.

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