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Effect of jute fibre loading on tensile and dynamic mechanical properties of oil palm epoxy composites

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ABSTRACT

Hybrid composites prepared by hand lay-up technique by reinforcing jute and oil palm fibres with epoxy matrix. The tensile properties of hybrid composites were found to increase substantially with increasing jute fibres loading as compared to oil palm–epoxy composite. The nature of fibre/matrix interface was examined through scanning electron microscopy of tensile fracture samples. Addition of jute fibres to oil palm composite increases the storage modulus while damping factor shifts towards higher temperature region. Cole–Cole analysis was made to understand the phase behaviour of the composite samples. The hybrid composite with oil palm:jute (1:4) showed maximum damping behaviour and highest tensile properties. The overall use of hybrid system was found to be effective in increasing tensile and dynamic mechanical properties of the oil palm–epoxy composite probably due to the enhanced fibre/matrix interface bonding. The potential applications of the oil palm based hybrid composites in automobiles and building industry are going to increase in near future.

1. Introduction

Natural fibres from renewable natural resources offer the potential to act as a biodegradable reinforcing materials alternative for the use of synthetic fibres. Natural fibres offer various advantages such as low density, low cost, biodegradability, acceptable specific properties, better thermal and insulating properties, and low energy consumption during processing [1–3]. The incorporation of two or more natural fibres into a single matrix has led to development of hybrid composites. Various researchers have tried blending of two fibres in order to achieve the best utilisation of the positive attributes of one fibre and to reduce its negative attributes as far as practicable [4]. The behaviour of hybrid composites is a weighed sum of the individual components in which there is more favourable balance between the inherent advantages and disadvantages. In an interesting study dynamic mechanical analysis of natural fibre based hybrid composites was performed and observed that the hybridisation of nature fibre improved thermal and dynamic mechanical properties [5]. Glass/banana hybrid polyester composites are subjected to dynamic mechanical analysis over a range of temperature and three different frequencies [6]. Similar work on mechanical and dynamic mechanical properties of sisal/glass hybrid composites reported increase in storage and loss modulus with hybridisation of sisal/polyester with glass fibres [7].

Mixing natural fibres like hemp and kenaf with thermoplastics put Flex Form Technologies [8] on the map and in the door panels of Chrysler's Sebring convertible. In Germany, after authorisation of hemp cultivation led to development of flax/hemp (50:50) needle felt for high-segment cars. A landmark agreement between automobile giant Ford Automobiles supplier Visteon Automotive system and Kafus biocomposites enhanced natural fibre composites applications in interior panels, linings and fittings. It is an important step towards higher performance of hybrid composites in automobiles applications. It is reported that presently, 27 components of a Mercedes S class are manufactured from natural fibre based composites with total weight of 43 kg [9]. The end of life vehicle [10] directive in Europe states that by 2015, vehicles must be constructed of 95% recyclable materials, with 85% recoverable through reuse or mechanical recycling [11].

Present work deals about effect of jute fibre loading on tensile and dynamic mechanical properties of oil palm empty fruit bunch (EFB)-epoxy reinforced composites. Oil palm EFB/jute fibre reinforced epoxy bi-layer hybrid composites fabricated by hand lay-up technique having total fibre loading of 40% by weight. Tensile and dynamic mechanical analysis of oil palm bi-layer hybrid composites was studied. The effect of jute fibre loading on tensile, storage modulus, loss modulus and damping properties of oil palm

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EFB-epoxy reinforced composites will be investigated and compared to pure EFB and pure jute composites.

2. Experimental

2.1. Materials

Oil palm EFB fibres were supplied by Ecofibre Technology Sdn. Bhd., Malaysia. Jute fibres were procured from Indarsen Shamlal Pvt. Ltd., India. The epoxy A331 and hardener A062 was used in this study. Both the epoxy resin and commercial curing agent were obtained from Zarm Scientific Sdn. Bhd., Malaysia.

2.2. Preparation of hybrid composites

Bi-layer hybrid composites were developed by using hand lay-up technique for making test sample. Keeping the different weight ratio of oil palm EFB and jute and total fibre loading at 40% by weight, bi-layer hybrid composites were prepared by hybridizing of oil palm EFB fibres with jute fibres and, both fibres mat were impregnated in epoxy matrix in a mould. Then, the mould was closed for curing and the mould was left to cure at 105 °C for 1 h in a hot press. The mould was compressed at a constant pressure of 275 bars while squeezing out the excess resin. Once the composite was cured, it was removed from the mould and followed by post curing in an oven at 105 °C for 30 min.

3. Characterisations

3.1. Tensile test (ASTM D 3039)

Tensile strength and modulus of bi-layer hybrid composites, and pure composites were measured by using an Gotech Universal Tester-GT-A1-7000L machine. This test was conducted as per the ASTM D 3039 specifications. The rectangular samples of dimension 120 mm × 20 mm × 8 mm were cut by using circular saw. The gauge length was set at 60 mm and testing speed used was 5 mm/min. In each case, five specimens were tested and the average value is tabulated.

3.2. Scanning electron microscope (SEM)

Morphology of the bi-layer hybrid composites were investigated by using scanning electron microscope (Leo Supra, 50 VP, Carl Ziess, SMT, Germany). The samples were mounted onto SEM holder using double sided electrically conducting carbon adhesive tapes to prevent surface charge on the specimens when exposed to the electron beam. The fracture surfaces of the EFB, jute, and, hybrid composites obtained from tensile testing were sputter with gold prior to their morphological observation.

3.3. Dynamic mechanical analysis (DMA)

Dynamic mechanical analyser Mettler Toledo was used for the evaluation of storage modulus, loss modulus and damping factor (Tan δ). Three point bending mode was used. The heating rate used was 5 °C/min and frequency was 1 Hz under amplitude control. Liquid nitrogen was used as cooling agent and temperature range was from −150 °C to 150 °C. The amplitude was set at between 7 and 10 mm depending on the thickness of the samples. The sample sizes were a thickness of 4–5 mm, width 9–10 mm and length 50–60 mm.

4. Results and discussion

4.1. Tensile properties

Table 1 shows the tensile strength and modulus of EFB, jute and the oil palm EFB/jute fibre bi-layer hybrid composites having weight ratio of oil palm EFB and jute of 4:1, 1:1, and 1:4 respectively. It can be observed from Table 1 that tensile strength and modulus of oil palm–epoxy composite increases with jute fibre loading in all cases. Composites with weight ratio of oil palm EFB and jute of 1:4 show higher tensile strength and modulus at all fibre loading. Hence, as the weight fraction of jute fibres increased in the bi-layer hybrid system, tensile strength and modulus of oil palm–epoxy composite increased significantly. For oil palm EFB and jute fibre bi-layer hybrid, EFB:jute (1:4) composite at 80% weight fraction of jute fibres, the tensile strength of hybrid composite is 37.9 MPa, which is comparable to tensile strength of jute composite.

Similar study reported on tensile strength of the hybrid composites and it showed a positive hybrid effect when the relative volume fraction of the two fibres was varied, and the maximum tensile strength was found to be in the hybrid composite having a ratio of banana and sisal of 4:1 [12]. When the fibre content and length of the roselle and sisal fibres were increased, the tensile strength of the composite increased [13]. In another research they reported that tensile properties of coir based hybrid increase with increasing fibre content [14]. Researchers studied the tensile behaviour of hybridisation of the oil palm EFB with glass fibres and reported increase in tensile strength, and tensile modulus of the hybrid composites [15]. In an interesting work, researchers reported that mechanical properties of EFB/glass hybrid polyester composite are found to be much higher than those of EFB composite. All these improvements in the hybrid composite properties are mainly due to the high strength and modulus value of glass fibre than the inferior properties of the EFB fibre itself [16].

In case of bi-layer hybrid composites, the load from the failed jute fibre mat not directly transferred to the oil palm fibres. The failed jute fibre mat though, are able to continue to carry the load in the hybrid system and capable of undergoing multiple failures throughout the loading process. Since the failed jute fibre mat are still able to carry the load, the oil palm EFB fibres can effectively transfer the load from the jute fibres without failing catastrophically. As the weight fraction of jute fibre increases in the hybrid composites, jute fibres are able to withstand a higher load while redistributing a lesser load to the oil palm EFB fibres resulting in better tensile strength and modulus of the hybrid composites with the addition of jute fibres. The tensile failure of a hybrid composite though, is mainly depended on the breaking strain and modulus of the individual reinforcing fibres [17,18]. The increase in tensile strength of the hybrid composites is also due to the higher tensile properties of jute fibres (400–800 MPa) compared to the low strength nature of oil palm fibre (248 MPa) [4]. The incorporation of jute fibre into EFB composite also increased the tensile modulus of the hybrid composites. The enhancement in stiffness of bi-layer

Table 1
Effect of jute fibre loading on tensile properties of oil palm EFB composite at 40% fibre by weight.

Composites	Tensile strength (MPa)	Tensile modulus (GPa)
EFB	22.6 ± 0.63*	2.23 ± 0.07*
EFB:Jute (4:1)	25.3 ± 0.26	2.62 ± 0.09
EFB:Jute (1:1)	28.3 ± 0.59	2.90 ± 0.05
EFB:Jute (1:4)	37.9 ± 0.76	3.31 ± 0.02
Jute	45.5 ± 0.14	3.89 ± 0.07

* Standard error.

hybrid composites is attributed to the higher modulus of jute fibre (10–30 GPa) compared to oil palm EFB fibre (3.2 GPa) [4]. The addition of jute fibres into EFB composite increases the load bearing capability of the hybrid composites resulting in an improved stiffness. Therefore, it is well understood that hybridisation of the EFB composite with jute fibre enhances the tensile strength and modulus of the hybrid composites.

The scanning electron micrograph of oil palm EFB fibre composite show the poor adhesion between the oil palm EFB fibre and epoxy matrix (Fig. 1A). It also evident from SEM micrograph that oil palm EFB fibres pull out and cracks in epoxy matrix which leads to a weak interfacial bonding between the epoxy matrix and the oil palm EFB fibres. Due to weak interfacial interaction between oil palm/epoxy caused failure of oil palm–epoxy composite at a lower load as compared to the jute composite. Fig. 1B–D shows the scanning electron micrograph of the tensile fracture surface of the bi-layer hybrid composite having weight ratio of oil palm EFB and jute of 4:1, 1:1, and 1:4, respectively. Fibre/matrix debonding and fibre pull out is also evident from oil palm EFB:jute (1:1) and oil palm EFB:jute (4:1) hybrid composites (Fig. 1C and D). It is interesting to note down that there is better fibre/matrix interaction in hybrid composites with oil palm EFB and jute with ratio of 1:4 (Fig. 1D), where fibre breakage can be seen in the fracture surface and effective stress transfer between fibres and matrix. Matrix is found to be bonded to the fibre surface.

It is clear from SEM micrograph of tensile fracture of hybrid composites that addition of jute fibre into EFB composites reduced fibre pull out, fibre protruding from the surface as well as holes in the matrix. The high tensile strength of jute fibres able to withstand the tensile stress while the oil palm EFB fibre absorbs the stresses in the hybrid composites and distributes them evenly in the composites. Jute/epoxy interface show better adhesion which

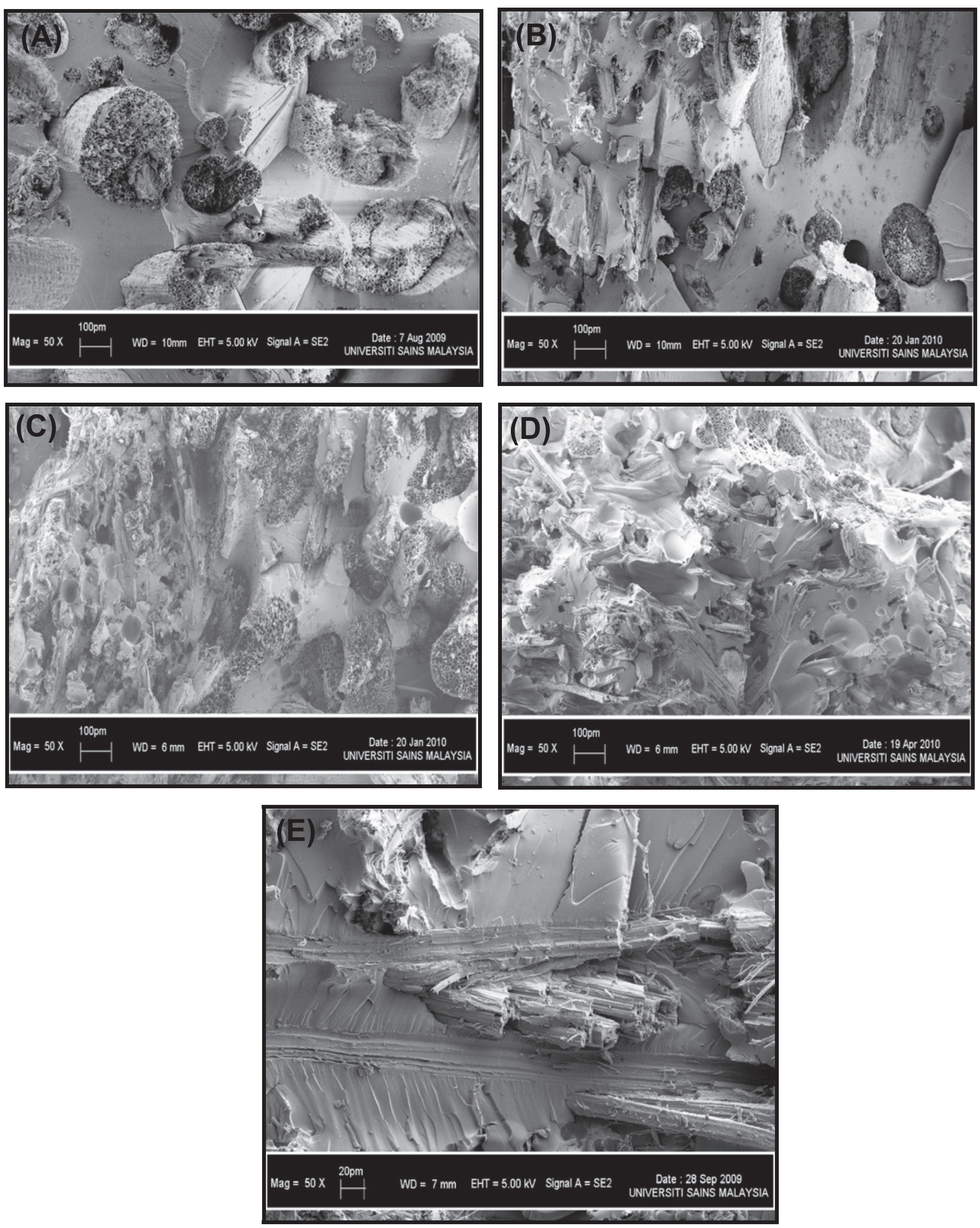

Fig. 1. SEM micrographs of tensile fracture of (A) EFB composite, (B) oil palm EFB:jute (4:1) hybrid composite, (C) oil palm EFB:jute (1:1) hybrid composite, (D) oil palm EFB:jute (1:4) hybrid composite, and (E) jute composite.

may be attributed to the multicellular nature of jute fibre, consequently leading to better mechanical properties [19]. The SEM micrograph of jute composite is shown in Fig. 1E. This micrograph shows that fibre pullout is less than EFB composite. It can be clearly seen that apart from some fibre pulled out from the matrix, some places matrix skin formation on the fibres can be observed. Further, at some places it was observed that some of the fibres broken instead of a pull out. Hence overall bonding between the jute fibres and the matrix was found to be good.

4.2. Dynamic mechanical analysis (DMA)

4.2.1. Storage modulus (E′)

Storage modulus is a measure of how stiff or flimsy a sample. Fig. 2 shows the effect of temperature on the storage modulus of EFB, jute, and hybrid composites having ratio of relative weight fraction of oil palm EFB:jute (4:1), EFB:jute (1:1), and EFB:jute (1:4). Comparing the different hybrid composites, E' value increases with the increase in the weight fraction of jute fibres and a maximum value is obtained for oil palm EFB:jute (1:4) in the glassy region. This is due to fact that modulus of elasticity (Young's modulus) of jute fibres is greater than that of oil palm EFB fibres [4].The storage modulus of EFB:jute (4:1), EFB:jute (1:1) at different temperature is almost the same and slightly higher in EFB:jute (1:1) above the glass transition temperature. The value of storage modulus of EFB:jute (4:1) hybrid composite is lowest. Addition of jute fibres to EFB composite, increases the E' value due to hybrid effect caused by the presence of stiffer jute fibres. Jute fibre as well as hybrid fibre imparts more stiffness to composites.

Below glass transition temperature (T_g), the E' value of EFB, jute, and hybrid composites decrease as the temperature increases. In the vicinity of the T_g, a sharp decrease in E' value was observed, it indicates that material is going through glass/rubbery transition stage [20]. Above T_g, storage modulus of EFB is much lower than that of jute, and hybrid composites, showing increase in molecular mobility in EFB composite. This behaviour occurs due to increases in molecular mobility of the polymer chains above T_g [21]. It was already reported that E' value is directly proportional to the interface bonding [22]. The results show that jute composite and hybrid composites have better interface bonding (Fig. 1B–E) as compared to EFB composite (Fig. 1A). It is due to effective stress transfer between fibre and matrix take place in this composites. Previous work reported that stiffness of the composites is dependent on the inherent stiffness imparted by the fibres that allows efficient stress transfer [23]. It also reported that with increase in oil palm EFB content in oil palm EFB/glass hybrid composites, the storage modulus decreases. In another interesting work on sisal/oil palm hybrid composites, the storage modulus was found to increase with weight fraction of fibres [5].

4.2.2. Loss modulus (E″)

Loss modulus is a measure of energy dissipated as heat/cycle under deformation or it is viscous response of the materials [21]. Loss modulus also shows similar trend as in the case of storage modulus with variation of relative weight fraction of oil palm EFB fibres (Fig. 3). A highest value of E'' maximum is observed for the hybrid composites having oil palm EFB:jute (1:1). However, oil palm:jute (1:4) hybrid composite showed higher E'' values at higher temperature. Here, the hybrid composites showed an increasing trend in loss modulus upon increasing the jute fibre content and then there is slightly decrease in rubbery stage.Glass transition temperature (T_g) obtained from E' curve is shown in Table 2. It reported that T_g values obtained from the loss modulus were more realistic as compared to those obtained from damping factor [24]. The T_g obtained from loss modulus is found to be lower than that of Tan δ curves. Below T_g, the hybrid composites curve was much closer to EFB composite, where as after this point more closer to jute composite curve. Use of EFB:jute (1:4) combination as fibre reinforcement however causes a lowering in the T_g value. Thus, expectedly infusing an enhanced toughening effect. It is interesting to note that T_g of EFB:jute (1:4) is lower compared to other composites.

4.2.3. Damping factor (Tan δ)

The Tan δ values of EFB, jute and hybrid composites having ratio of relative weight fraction of oil palm EFB:jute (4:1), EFB and jute (1:1), and EFB:jute (1:4) at 40% fibre by weight are shown in Fig. 4. The hybrid composites having weight ratio of oil palm EFB and jute 4:1, 1:1, and 1:4 show better damping factor compare to EFB composite. Fibre/matrix interface effects can be understood to very good extent from damping curves [25]. It was also reported by them that the lower Tan δ values associated with the glass transition temperature reflects the improved load bearing properties of the system. As the fibre/matrix interface bonding increases, mobility of the molecular chains at the fibre/matrix interface decreases and a reduction in damping factor occurs. At the rubbery region, the molecular segments are quite free to move and hence the

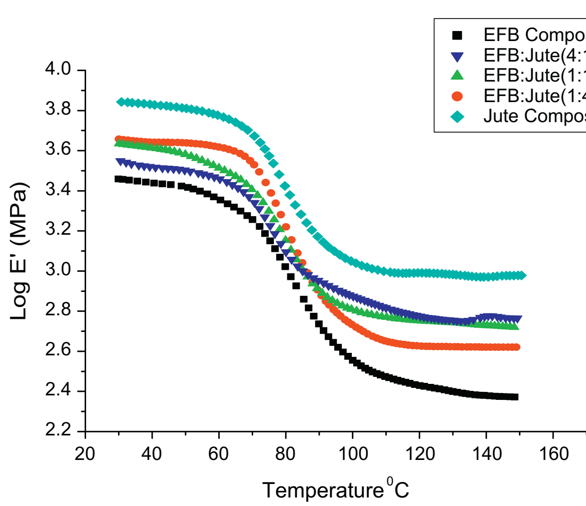

Fig. 2. Effect of varying weight fractions of jute fibre on storage modulus with temperature of oil palm EFB composite.

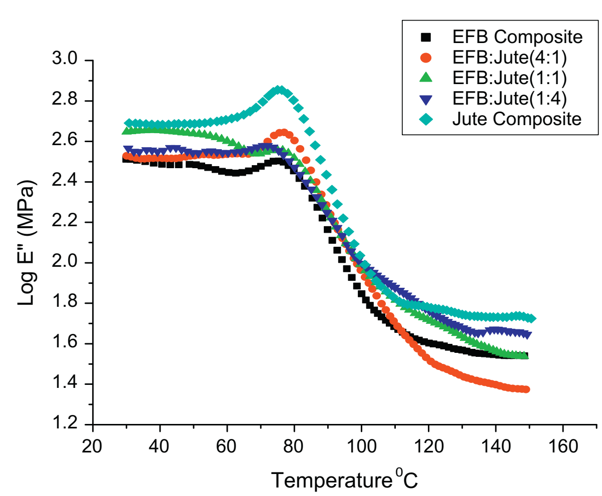

Fig. 3. Effect of varying weight fractions of jute fibre on loss modulus with temperature of oil palm EFB composite.

Table 2
Peak height, Tan δ_{max} (T_g) and E'' max (T_g) of EFB, hybrid, and jute composites.

Composite	Peak height of Tan δ curve	Temperature (°C)	
		T_g from Tan δ_{max}	T_g from E''_{max}
EFB	0.29	85.37	73.82
EFB:Jute(4:1)	0.26	83.31	76.22
EFB:Jute(1:1)	0.25	83.96	75.25
EFB:Jute(1:4)	0.24	81.26	72.67
Jute	0.24	80.10	76.44

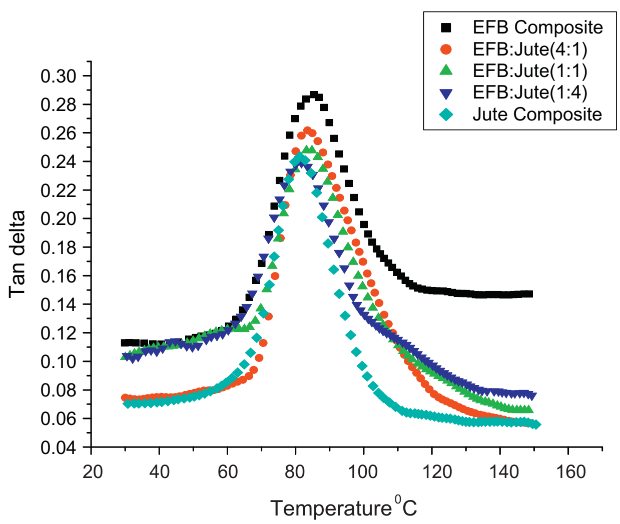

Fig. 4. Effect of varying weight fractions of jute fibre on damping factor with temperature of oil palm EFB composite.

damping is low and thus, upon increasing the jute fibre content damping factor slightly decreases in rubbery stage.

The values of Tan δ peak and T_g from Tan δ max of hybrid and unhybridized composites are given in Table 2. Tan δ peak height is lower in jute composite, and hybrid composites as compared to EFB composite, which shows lower damping and good fibre/matrix adhesion in it. The Tan δ peak height is minimum in oil palm EFB:jute (1:4) which indicate that as weight fraction of jute fibres increases in the composites, the stress transfer between fibre/matrix is increased and fibre/matrix interfacial bonding is also increased (Fig. 1D). Therefore, higher the Tan δ peak value, greater is the degree of molecular mobility [26]. Researchers reported that incorporation of small amount of glass fibre to oil palm/phenol formaldehyde composite enhances the damping characteristics of the oil palm composites [23]. In another study on damping effect of jute/glass fibre reinforced epoxy composite, researchers found that use of jute fibre contributes to a lowering in damping factor of the composite [27].

4.2.4. Cole–Cole plots

Fig. 5 shows Cole–Cole plot where the loss modulus (E'') data are plotted as a function of storage modulus (E') for EFB, hybrid, and jute composites. The nature of the Cole–Cole plots is reported to be indicative of the homogeneity of the polymeric system [28]. Semicircle diagram indicates that polymeric system is homogeneous [29]. It can be seen that jute fibre loading to EFB composite changes the shapes of Cole–Cole plot. For EFB, jute, and oil palm EFB:jute (1:1) composites, the Cole–Cole plot is imperfect semicircular, while for oil palm EFB:jute (1:4), and oil palm EFB:jute (4:1), the form of Cole–Cole plot changes from imperfect semicircular to an irregular shape. Imperfect semicircular shape indicates that,

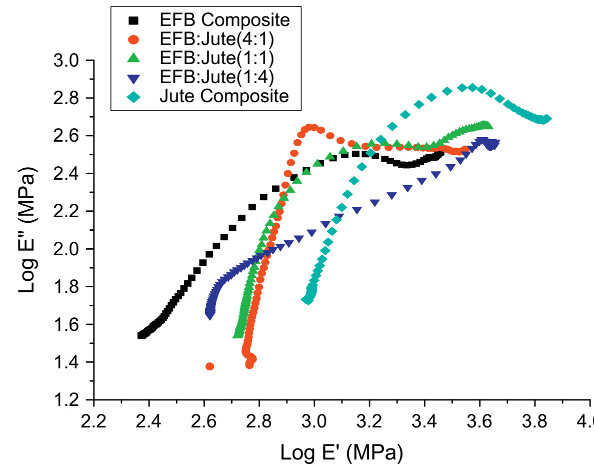

Fig. 5. Cole–Cole plots of the hybrid, EFB, and jute composites.

there is heterogeneity among EFB, jute and hybrid composites. It is seen that the amount and type of fibres will affect the shape of Cole–Cole plot, thereby influencing the dynamic mechanical properties of EFB, jute, and hybrid composites.

5. Conclusions

The tensile properties increased with the increase in ratio of jute fibre in the hybrid composites. As the weight fraction of jute fibre increases in the hybrid composites, jute fibres are able to withstand a higher load while redistributing a lesser load to the EFB fibres resulting in better tensile strength and modulus of the hybrid composites with the addition of jute fibres. It is interesting to note down that there is better fibre/matrix interaction in EFB:jute (1:4), where fibre breakage can be seen in the fracture surface and effective stress transfer between fibres/matrix. The value of storage modulus of EFB and jute (4:1) hybrid composite is lowest. It shows that when jute fibre loading is increased, the effectiveness of stress-transfer is increased. Hybrid composites showed an increasing trend in loss modulus upon increasing the jute fibre content but there is slightly decreasing trend in rubbery stage in case of EFB:jute (4:1) hybrid composite. The T_g obtained from loss modulus is found to be lower that of Tan δ curves. Tan δ peak height is lower in jute composite, and hybrid composites compared to EFB composite, which shows lower damping and good fibre/matrix adhesion in it. It can be seen that jute fibre loading to EFB composite changes the shapes of Cole–Cole plots.

This new family of hybrid composite materials exhibits unique properties as compared with EFB and jute composite, which can explore potential applications of oil palm–epoxy composite with jute fibres. Now most of automobile manufacturer try to replace synthetic fibres with natural fibres but it is not comparable in properties while fabricating hybrid composites by the combination of two natural fibres give them advantage to replace synthetic fibre. So, Hybrid composites consist of oil palm/jute also possible to compete with synthetic composites if it properly design. The automotive and aerospace sectors have been identified as future industries for oil palm based hybrid composites. Challenges still exist in the development of more suitable cost-effective fabrication techniques as well as composites having superior mechanical properties using natural fibres as reinforcement. Nevertheless, the progress so far obtained in this field has allowed the application of natural-fibre based hybrid composites in many sectors such as in construction, automotive and aerospace industries.

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References

[1] Rout J, Misra M, Tripathy SS, Nayak SK, Mohanty AK. The influence of fibre treatment of the performance of coir-polyester composites. Compos Sci Technol 2001;61(9):1303–10.
[2] Rana AK, Mandal A, Bandyopadhyay S. Short jute fiber reinforced polypropylene composites: effect of compatibiliser, impact modifier and fiber loading. Compos Sci Technol 2003;63(6):801–6.
[3] Joshi SV, Drzal LT, Mohanty AK, Arora S. Are natural fiber composites environmentally superior to glass fiber reinforced composites? Compos Part A: Appl Sci Manuf 2004;35(3):371–6.
[4] Jawaid M, Abdul Khalil HPS. Cellulosic/synthetic fibre reinforced polymer hybrid composites: a review. Carbohydr Polym 2011;86(1):1–18.
[5] Jacob M, Francis B, Thomas S, Varughese KT. Dynamical mechanical analysis of sisal/oil palm hybrid fiber-reinforced natural rubber composites. Polym Compos 2006;27(6):671–80.
[6] Pothan LA, George CN, John MJ, Thomas S. Dynamic mechanical and dielectric behavior of banana-glass hybrid fiber reinforced polyester composites. J Reinforced Plast Compos 2010;29(8):1131–45.
[7] Ornaghi Jr HL, Bolner AS, Fiorio R, Zattera AJ, Amico SC. Mechanical and dynamic mechanical analysis of hybrid composites molded by resin transfer molding. J Appl Polym Sci 2010;118(2):887–96.
[8] Jon Fox-Rubin DC. Thermoplastic composites. Flex Technologies; 2010.
[9] Sreekumar PA. Matrices for natural-fibre reinforced composites. In: Pickering KL, editor. Properties and performance of natural-fibre composite. Boca Raton: CRC Press LLC.; 2008. p. 541.
[10] Selvin TP, Kuruvilla J, Sabu T. Mechanical properties of titanium dioxide-filled polystyrene microcomposites. Mater Lett 2004;58(3–4):281–9.
[11] Peijs T. Composites for recyclability. Materials Today; 2003. p. 30–5.
[12] Idicula M, Neelakantan NR, Oommen Z, Joseph K, Thomas S. A study of the mechanical properties of randomly oriented short banana and sisal hybrid fiber reinforced polyester composites. J Appl Polym Sci 2005;96(5):1699–709.
[13] Athijayamani A, Thiruchitrambalam M, Natarajan U, Pazhanivel B. Effect of moisture absorption on the mechanical properties of randomly oriented natural fibers/polyester hybrid composite. Mater Sci Eng A 2009;517(1–2):344–53.
[14] Kumar NM, Reddy GV, Naidu SV, Rani TS, Subha MCS. Mechanical properties of coir/glass fiber phenolic resin based composites. J Reinforced Plast Compos 2009;28(21):2605–13.
[15] Hariharan Abu Bakar A, Abdul Khalil HPS. Lignocellulose-based hybrid bilayer laminate composite: Part I – Studies on tensile and impact behavior of oil palm fiber–glass fiber–reinforced epoxy resin. J Compos Mater 2005;39(8):663–84.
[16] Abdul Khalil HPS, Hanida S, Kang CW, Nik Fuaad NA. Agro-hybrid composite: the effects on mechanical and physical properties of oil palm fiber (EFB)/glass hybrid reinforced polyester composites. J Reinforced Plast Compos 2007;26(2):203–18.
[17] Sreekala MS, George J, Kumaran MG, Thomas S. The mechanical performance of hybrid phenol-formaldehyde-based composites reinforced with glass and oil palm fibres. Compos Sci Technol 2002;62(3):339–53.
[18] Mishra S, Mohanty AK, Drzal LT, Misra M, Parija S, Nayak SK, et al. Studies on mechanical performance of biofibre/glass reinforced polyester hybrid composites. Compos Sci Technol 2003;63(10):1377–85.
[19] De Medeiros ES, Agnelli JAM, Joseph K, De Carvalho LH, Mattoso LHC. Mechanical properties of phenolic composites reinforced with jute/cotton hybrid fabrics. Polym Compos 2005;26(1):1–11.
[20] Tajvidi M. Static and dynamic mechanical properties of a kenaf fiber-wood flour/polypropylene hybrid composite. J Appl Polym Sci 2005;98(2):665–72.
[21] Hameed N, Sreekumar PA, Francis B, Yang W, Thomas S. Morphology, dynamic mechanical and thermal studies on poly(styrene-co-acrylonitrile) modified epoxy resin/glass fibre composites. Compos Part A: Appl Sci Manuf 2007;38(12):2422–32.
[22] Keusch S, Haessler R. Influence of surface treatment of glass fibres on the dynamic mechanical properties of epoxy resin composites. Compos Part A: Appl Sci Manuf 1999;30(8):997–1002.
[23] Sreekala MS, Thomas S, Groeninckx G. Dynamic mechanical properties of oil palm fiber/phenol formaldehyde and oil palm fiber/glass hybrid phenol formaldehyde composites. Polym Compos 2005;26(3):388–400.
[24] Akay M. Aspects of dynamic mechanical analysis in polymeric composites. Compos Sci Technol 1993;47(4):419–23.
[25] Idicula M, Malhotra SK, Joseph K, Thomas S. Dynamic mechanical analysis of randomly oriented intimately mixed short banana/sisal hybrid fibre reinforced polyester composites. Compos Sci Technol 2005;65(7–8):1077–87.
[26] Kuzak SG, Shanmugam A. Dynamic mechanical analysis of fiber-reinforced phenolics. J Appl Polym Sci 1999;73(5):649–58.
[27] Ghosh P, Bose NR, Mitra BC, Das S. Dynamic mechanical analysis of FRP composites based on different fiber reinforcements and epoxy resin as the matrix material. J Appl Polym Sci 1997;64(12):2467–72.
[28] Uma Devi L, Bhagawan SS, Thomas S. Dynamic mechanical analysis of pineapple leaf/glass hybrid fiber reinforced polyester composites. Polym Compos 2010;31(6):956–65.
[29] Ferry JD. Viscoelastic properties of polymers. New York: John Wiley and Sons, Inc.; 1980.