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MECHANICAL AND THERMO–MECHANICAL PROPERTIES OF BI-DIRECTIONAL AND SHORT CARBON FIBER REINFORCED EPOXY COMPOSITES

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Abstract

This paper based on bidirectional and short carbon fiber reinforced epoxy composites reports the effect of fiber loading on physical, mechanical and thermo-mechanical properties respectively. The five different fiber loading, i.e., 10wt. %, 20wt. %, 30wt. %, 40wt. % and 50wt. % were taken for evaluating the above said properties. The physical and mechanical properties, i.e., hardness, tensile strength, flexural strength, inter-laminar-shear strength and impact strength are determined to represent the behaviour of composite structures with that of fiber loading. Thermo-mechanical properties of the material are measured with the help of Dynamic Mechanical Analyser to measure the damping capacity of the material that is used to reduce the vibrations. The effect of storage modulus, loss modulus and tan delta with temperature are determined. Finally, Cole–Cole analysis is performed on both bidirectional and short carbon fiber reinforced epoxy composites to distinguish the material properties of either homogeneous or heterogeneous materials. The results show that with the increase in fiber loading the mechanical properties of bidirectional carbon fiber reinforced epoxy composites increases as compared to short carbon fiber reinforced epoxy composites except in case of hardness, short carbon fiber reinforced composites shows better results. Similarly, as far as Loss modulus, storage modulus is concerned bidirectional carbon fiber shows better damping behaviour than short carbon fiber reinforced composites.

Keywords: Composites, Mechanical properties, Bidirectional carbon fiber, Thermo-mechanical analysis.

Nomenclatures

E'	Storage modulus
E''	Loss modulus
E'_{10}	Value of storage modulus at 10wt. % fiber reinforcement
E'_{20}	Value of storage modulus at 20wt. % fiber reinforcement
E'_{30}	Value of storage modulus at 30wt. % fiber reinforcement
E'_{40}	Value of storage modulus at 40wt. % fiber reinforcement
E'_{50}	Value of storage modulus at 50wt. % fiber reinforcement
$\tan\delta$	Damping factor
wt. %	Percentage by weight of fiber reinforcement

Abbreviations

CF	Carbon Fiber
CFRE	Carbon Fiber Reinforced Epoxy
DMA	Dynamic Mechanical Analysis
FS	Flexural Strength
FWHM	Full Width Half Maxima
GSM	Gram per Square Meter
ILSS	Inter Laminar Shear Strength
IS	Impact Strength
LCF	Long (bidirectional) Carbon Fiber
SCF	Short (chopped) Carbon Fiber
TS	Tensile Strength

1. Introduction

Newer manufacturing techniques were invented and introduced during the last few decades; some of them were increasingly popular due to their enhanced advantages and ease of manufacturing over the conventional processes. Polymer composite material such as glass, carbon and Kevlar fiber reinforced composite are popular in high performance and light weight applications such as aerospace and automobile fields. Carbon fiber reinforced polymer is an extremely strong and light fiber reinforced polymer which contains carbon fibers [1]. For composite manufacturing a suitable resin either thermoplastic or thermosetting is needed to blend with. Thermoplastic and thermosetting resins have their unique properties but generally thermosetting resins are preferred to mix with glass, carbon and kevlar due to their higher strength and easily curing properties at room temperature. Thermosetting polymers are insoluble and infusible after cure because the chains are rigidly joined with strong covalent bonds. Typical examples of thermoset include epoxies, polyesters, phenolics and polyamide. Epoxy is the most popular among the available thermosetting polymers due to its high strength, low viscosity, low volatility and lower shrinkage rates over other thermosetting polymers [2, 3].

Plasma treatment to carbon fiber (C.F) proved beneficial for improvement in fiber matrix adhesion resulting in significant enhancement in all mechanical and tribological properties [4]. Yunus et al. [5] investigated the mechanical properties of carbon fiber reinforced polypropylene composites. It has been observed that the highest tensile strength was obtained for 10wt. % fiber loading. Also the best properties are obtained for tensile and flexural strength. Water absorption behaviour and flexural strength properties of carbon fiber reinforced plastics

(CFRP) under hot and wet environments were examined. Weight gain of CFRP and epoxy resin both increases with increasing water temperature. It has been observed that after immersion for 180 days at 90 °C, the weight gain of CFRP becomes 3.3 times higher and that of epoxy was 2.2 times higher than normal. Flexural strength of CFRP decreases with the increase in temperature [6]. Szuecs [7] while investigating the mechanical properties of carbon fiber containing bulk metallic glass composites noticed no heterogeneous nucleation at the carbon/BMG interface. Sulaiman [8] investigated the effect of hardener on mechanical properties of carbon reinforced phenolic resin composites for hardener contents ranging from 5-15%. Composites with 15% hardener content show an increase in flexural strength, tensile strength and hardness. Tensile strength and thermal stability of vulcanized silicon rubber were improved significantly due to the incorporation of grafted carbon fiber [9].

The literature mentioned above relates mechanical and thermal properties of carbon fiber reinforced epoxy composites with limited fiber loading conditions. Therefore, based on the above literature the present work studies both physical and mechanical properties at room temperature for the entire five different fiber loading. At the end, the authors also studied the above said composites thermo-mechanical analysis (i.e., loss modulus, storage modulus and tan delta) to observe the materials behaviour at high temperature.

2. Experimental Procedure

2.1. Materials selected

Bi-directional carbon fiber (200 G.S.M, 3k-plain weave) and short carbon fiber (200 G.S.M. and 5 mm length) supplied by The Hindustan Technical Fabrics Limited, India are used as a reinforcing material as shown in Figs. 1(a) and 1(b). Fiber reinforced polymer composites of bi-directional and short carbon fiber are separately weighed for each weight percent (wt. %) composition and then mixed with epoxy resin chemically belonging to epoxide family used as a matrix material (chemical description is Bisphenol A Diglycidyl ether). The low temperature curing epoxy resin (LY556) and corresponding hardener (HY951) are mixed in the ratio of 10:1 by weight as recommended. The epoxy resin and corresponding hardener are supplied by Ciba Geigy India Ltd. Carbon fiber and resin has Young's Modulus of 123 GPa and 3.42 GPa respectively and possesses densities of 1450 kg m^{-3} and 1100 kg m^{-3} respectively.

The bidirectional carbon fiber composite are prepared by a simple hand-lay-up technique by piling individual layers of fabric and resin one above the other until required composition by weight of fibers are used. However short carbon fibers are uniformly mixed with epoxy resin and then poured in separate mold for each weight percent fiber composition (i.e., 10wt. %, 20wt. %, 30wt. %, 40wt. % and 50wt. %). Prepared mold boxes are then placed for 24 hours to get the proper curing. After that all the composites are removed from the mold and dried in furnace at a temperature of 50 °C for 15 min only to remove moistures from the composites, Fig. 1(c).

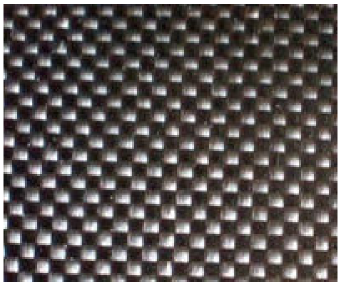

Fig. 1(a). Bidirectional Carbon Fiber (200 G.S.M, 3k-Plain Weave).

Fig. 1(b). Short Carbon Fiber (200 G.S.M., 5 mm Length).

Fig. 1(c). Prepared CFRE Composite Slab.

Fig. 1(d). Universal Testing Machine (Instron 1150).

2.2. Test for mechanical properties

Tests for mechanical properties include the hardness, tensile strength (T.S.), flexural strength (F.S.), Inter laminar shear strength (I.L.S.S.) and Impact strength (I.S.) respectively were done as shown in Fig. 1(d).

Micro hardness measurement is done as per Leitz micro hardness tester. A diamond indenter with a square shaped pyramidal base (angle 136°) between opposite faces is used to make an impression on the composite specimen [10]. The tensile test is generally performed on a rectangular shaped specimen with the narrow gauge length in the middle and broadened end tabs. During the test a uniaxial loads acting outwards from both the ends measures the tensile strength of the test specimen using UTM Instron 1195 [11]. The ASTM standard test method for tensile properties of fiber resin composites has the designation D 3039-76. The flexural strength of the composite is the maximum bending stress that it can be subject to before bending.

A three point bend test is conducted on universal testing machine Instron 1195 to find out the flexural strength of the composite sample with span length of 30 mm and a crosshead speed of 10 mm/min is maintained for the loaded specimen subjected to failure. Inter laminar shear strength tests are conducted as per ASTM D 2344-84 test standards on universal testing machine Instron 1195. Span length of 50 mm and cross head speed of 10 mm/min is maintained [12]. The Impact strength is the capability of the material to withstand a suddenly applied load and is expressed in terms of energy. These tests are being carried out on the impact tester at low velocities. The charpy V-notch impact tests are done as per ASTM D 256 test standards [13]. Dimensions for the specimen taken for impact test are 75 mm × 15 mm × 3.2 mm with a V-groove of 2.5 mm depth at the centre of the specimen. The specimen is then fixed in the slot such that the groove of the specimen faces the opposite side to the striking end of the hammer.

3. Results and Discussion

3.1. Physical and mechanical properties

Mechanical properties are measured to notice the effect of prepared compositions on the overall performance. Effect of increase in percentage by weight of fiber/fabric composition on mechanical properties of composites is discussed. Analysis also includes comparison in properties of bidirectional CFRE composites to that of chopped CFRE composites.

3.2. Effect of fiber loading on the hardness of bi-direction/ short carbon-epoxy composites

Hardness is the resistance of the material to localized deformation. In polymers, the deformation considered is the plastic deformation of the surface. Figure 2 shows the comparison in the properties of hardness for bidirectional as well as chopped carbon fiber reinforced epoxy composites. For bidirectional composites hardness slightly increases with the increase in fiber loading but for 30wt. % and 50wt. % fiber loading hardness decreases with increase in fiber loading. For chopped fiber reinforced epoxy composites hardness increases with the increase in fiber loading except at 20wt. %, 30wt. % and 50wt. % fiber loading. The exceptional decrease in hardness may be due to the presence of pores and voids. If the void fraction values are more, value of hardness decreases whereas if the void fraction value is less, value of hardness increases. Similar finding were noticed by Gaurav et al. [14] while investigating the mechanical properties of long glass fiber reinforced epoxy composites.

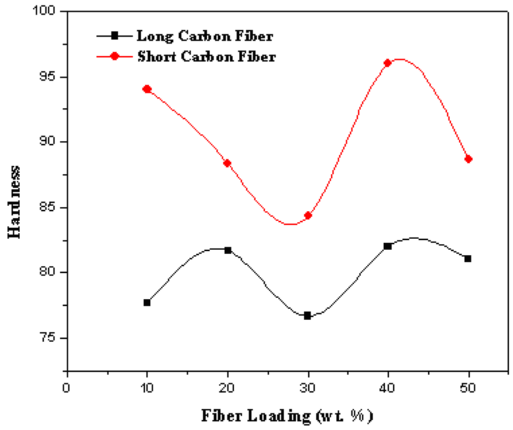

Fig. 2. Effect of Fiber Loading on Hardness of Long and Short CFRE Composites.

3.3. Effect of fiber loading on tensile strength of bi-directional / short carbon-epoxy composites

Figure 3 shows the plotted graph showing change in values of tensile strength with the change in percentage by weight of fiber composition. The tensile strength increases with the increase in fiber loading. An exceptional decrease in tensile strength values is noticed at 40wt. % bidirectional fiber composition. This decrease may be due to improper bonding in between the matrix (epoxy) and the layer of carbon fiber and hence shear stress induced in between the layers of the composite. In chopped CFRE composites lower values of tensile strength are observed than that of bidirectional CFRE composites. This is due to the proper orientation of fibers, loads can effectively be transferred from one end to another resulting in increased tensile strength whereas in chopped fibers, length of fibers are less (5-8) mm which cannot effectively transfer the stresses from one end to another resulting in lower values of tensile strength. Similar observations were noticed by Gaurav et al. [14] and Sua et al. [15] for mechanical properties of carbon fiber reinforced polyetheramide composites. CF reinforcement has improved all mechanical properties of PEI significantly. The extent of improvement of tensile strength however is not proportional to the amount of carbon fiber reinforcement.

Mohit et al. [4] and Hancox and Wells [16] also noticed similar observations in the increase of I.L.S.S. values with the increase in fiber loading. Also it has been established that I.L.S.S. values play an important role in controlling the abrasive wear rate of CFRE composites.

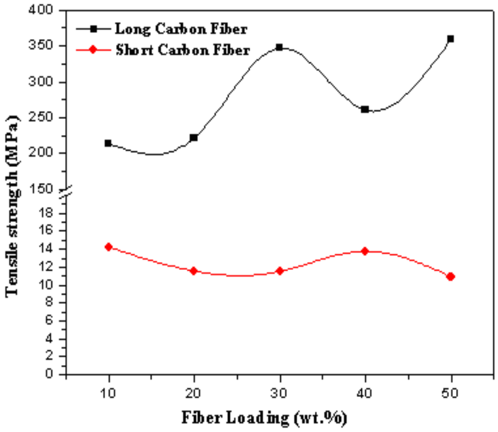

Fig. 3. Effect of Fiber Loading on Tensile Strength of Long and Short CFRE Composites.

3.4. Effect of fiber loading on flexural strength and inter laminar shear strength of bi-directional / short carbon-epoxy composites

Flexural strength which is a mechanical parameter is defined as the material's ability to resist deformation under load. The Flexural strength represents the highest stress experienced within the material at its moment of rupture. Figure 4 (graph) is plotted to notice the effect of change in flexural strength values with the change in fiber loading (wt. %) of the composites. Flexural strength decreases with the increase in fiber loading for bidirectional CFRE composites because when specimen bends only the extreme fiber is at the largest stress and as the wt. % composition increases, number of layers increase and the stresses induced between the layers varies thereby reducing the flexural strength of the composite whereas increase in flexural strength of CFRE composites is due to the homogeneous composition and better bonding in between the fibers and epoxy resin. Bijwe et al. [17] and Wan et al. [18] also reported that flexural strength values increase with the increase in fiber loading of CFRE composites up to some extent and then decreases further. Reduction in flexural strength of the thermoplastic composites may be due to the low interaction and poor dispersion of fiber in the matrix. Inter-laminar shear strength (ILSS) is useful to test for composites where the chances for failure of lamina in layered composite is greater to initiate when subjected to shearing stresses. Figure 5 shows the effect of fiber loading on Inter laminar shear strength (I.L.S.S.) of the composites. I.L.S.S. value increases (bidirectional + chopped) CFRE with the increase in fiber loading of the composites For bidirectional fiber composites I.L.S.S. values at 20wt. % and 40wt. % are marginally lower.

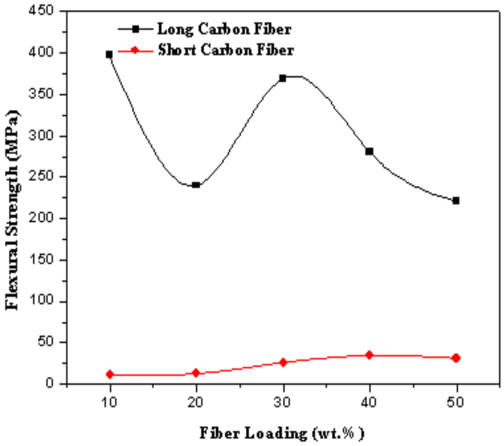

Fig. 4. Effect of Fiber Loading on Flexural Strength of Long and Short CFRE Composite.

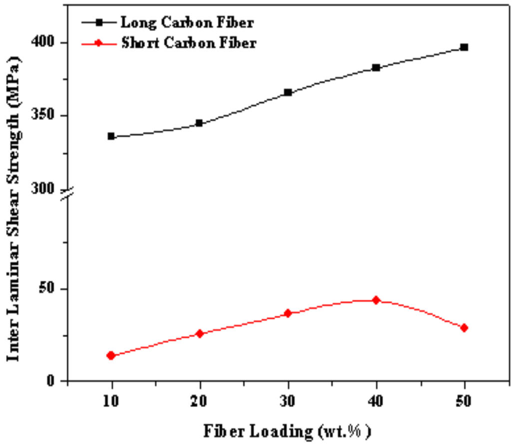

Fig. 5. Effect of Fiber Loading on Inter-Laminar Shear Strength of Long and Short CFRE Composites.

3.5. Effect of fiber loading on impact strength of bi-directional short carbon-epoxy composites

Figure 6 shows the effect of fiber loading on the impact strength of bidirectional and chopped CFRE composites. Impact strength increases with the increase in fiber loading for bidirectional and chopped composites. While comparing the plotted graphs of bidirectional and chopped carbon fiber reinforced epoxy composites (Fig. 6), the values for chopped fiber composites are slightly less than that of bidirectional composites. This is due to the weave pattern and longer length of fibers in bidirectional composites which can effectively transfer loads from one end to another. Therefore the energy consumed due to definite orientation of fibers and longer fiber is more than that of irregular orientation and short fibers. Furthermore low strength of short fibers may be due to of too many fiber ends in between the composite and micro-cracks and induced stresses occurs at fiber ends due to impact [19]. Rezaei et al. [20] also investigated that the fiber length of mechanically reinforced long fibers exhibit more resistance to crack propagation in the matrix compared to short fibers.

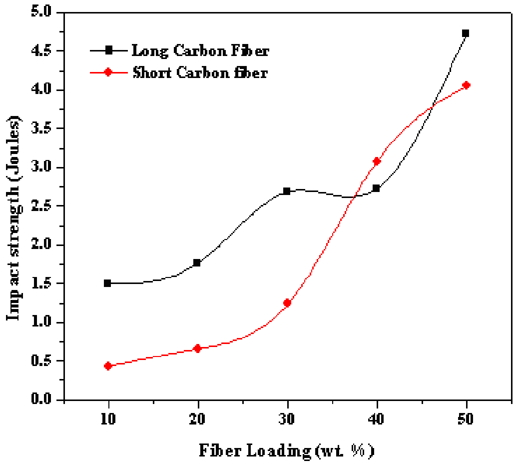

Fig. 6. Effect of Fiber Loading on Impact Strength of Long and Short CFRE Composites.

3.6. Thermo-mechanical properties of composite (Dynamic mechanical analysis)

Dynamic Mechanical Analysis (DMA) is a tool where damping capacity of a material is measured which is dissipated in the material during mechanical vibrations under cyclic loading. Thus high damping materials absorb noise with in turn is used to reduce vibration and stabilises of the structure [21]. Dynamic Mechanical Analysis (DMA) of bidirectional and short carbon fiber reinforced epoxy composite have been carried out in this study to investigate the variation of storage modulus (E´), loss modulus (E´´) and damping factor (tan δ), i.e.,

$$\tan\delta = \frac{E'}{E''} \qquad (1)$$

It is a measure of the energy dissipation of a material. The damping behaviour (tan delta), storage modulus and loss modulus of CFRE composite specimens are studied with varying temperatures in the range of 25-200°C using Dynamic Mechanical Analyser. Figures 7-9 show the behaviour of loss modulus, storage modulus and damping capacity of the material with increase in temperature of the CFRE composite specimen.

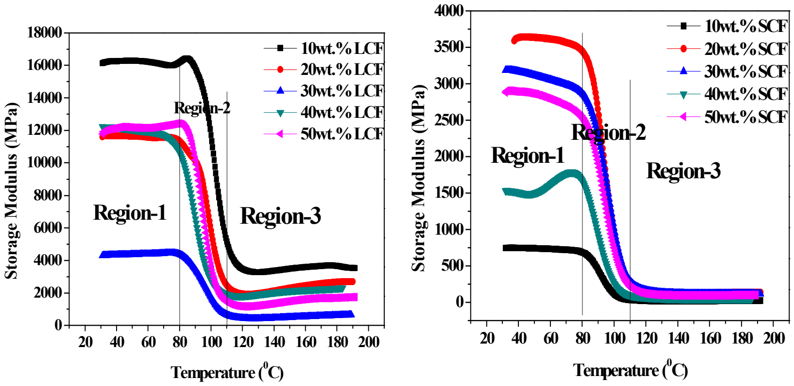

Fig. 7. Variation of Storage Modulus with Temperature for Long and Short Carbon Fiber Reinforced Epoxy Composites.

Figure 7 shows a graph of storage modulus versus temperature for long and short CFRE composites. From room temperature to 80 °C storage modulus values are nearly constant for bidirectional and short CFRE composites, this shows a glassy regime in the range of 0 °C to 80 °C whereas region 2 shows a sharp decline in the values of storage modulus between 80 °C to 110 °C with the increase in the values of temperature, i.e., the material changes from glassy to rubber transition regime from temperature range of 80 °C to 110 °C, region 3 again is a straight line and the values nearly tend to zero, which shows a rubbery regime indicating degradation of the moduli above 110 °C. Values of storage modulus for bidirectional CFRE composites are exceptionally higher than that of short CFRE composites. The higher values in region 1 and sharp decrease in the values in region 2 are due to the fact that in region 1, the material is in glassy state in which the contribution of elastic modulus is more than the viscous modulus whereas in region 2 the material is in glass transition stage in which a change from glass state into rubber-elastic state takes place. When the time scale of molecular motion coincides with that of mechanical deformation, each oscillation is converted into the maximum-possible internal friction and non-elastic deformation, In the glass transition region, the storage modulus falls during heating to a level of one-thousandth to ten-thousandth of its original value [22].

Figure 8 shows the Dynamic Mechanical Analysis (DMA) spectrum of long and short Carbon fiber reinforced epoxy composites. With the increase in the value of temperature in region 1 value of loss modulus slightly increases whereas in region 2 the value of loss modulus attains a peak value which again decreases with the increase in temperature in region 3. For Bidirectional carbon fiber reinforced epoxy composites, values of loss modulus follows a trend, i.e., $E'_{10} > E'_{20} > E'_{50} > E'_{40} > E'_{30}$ whereas values of loss modulus for short carbon fiber reinforced epoxy composite follows a trend that $E'_{20} > E'_{30} > E'_{50} > E'_{40} > E'_{10}$.

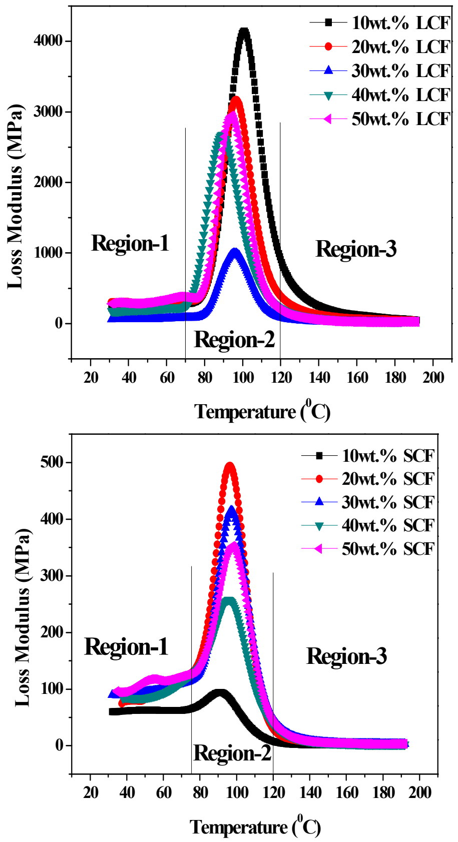

Fig. 8. Variation of Loss Modulus with Temperature for Long and Short Carbon Reinforced Epoxy Composites.

This may be due to the percentage of fiber content, i.e., as the percentage of fiber content increases, the area under the E´´ curve spreads across a wider temperature range leading to an increase in the peak-width. Further it has also been observed that for the composites with lower fiber content the shift in the loss-peak is more towards higher temperature [22]. This can be clearly verified from Fig. 9, i.e., for 10wt. % bidirectional CFRE composites peak value of loss modulus is 4060.33 MPa at 102.09 °C whereas for 30wt. % CFRE composites peak value of loss modulus is 999.46 MPa at 99.22 °C similar observations are obtained for short CFRE composites where the higher peak is at a temperature of 95.9 °C and lower peak shifted to a temperature of 90.54 °C. While comparing the loss modulus characteristics for long and short CFRE composites, the values for long CFRE composites are exceptionally higher than that for short CFRE composites. This is because for the same amount of fiber content the amount of resin in bidirectional CFRE composites is comparatively less in comparison to that of short CFRE composites as the part of total resin which is entrapped in between the fibers is only used in composite preparation. The remaining part of resin (epoxy) flows out (wasted) during piling and solidification of composite.

However, at elevated temperature region 3 (rubbery region) there is a slight improvement in the value of storage modulus. Figure 9 shows the behaviour of the damping factor for bidirectional and chopped CFRE composites with the increase in the temperature of the composite. While comparing the graphs of long and short CFRE composites, the highest value of tan delta is obtained for 10wt. % fiber loading for short CFRE composites and for long CFRE composites the highest value of tan delta is comparatively less than for short CFRE composites and is obtained for 30wt. % fiber loading. The peak value of tan delta indicates that the material is non elastic whereas the lower value of tan delta indicates that the material is elastic in nature. Highest peak value of tan delta for 50wt. % bidirectional composite shows that the material is non-elastic in nature and the lowest peak value of tan delta for 10wt. % bidirectional composite shows that the material is elastic. This may be attributed to the fact that at 10wt. % fiber loading I.L.S.S. value is less in comparison than that at 50wt. % fiber loading, i.e., as the number of layers in the bidirectional composite increases I.L.S.S. value increases and the material tends towards being non-elastic in nature than that when the numbers of layers in bidirectional CFRE composites are less.

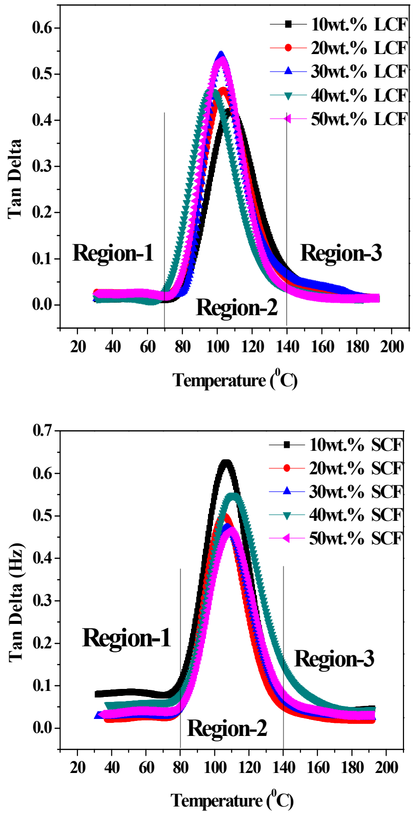

Fig. 9. Variation of tan Delta with Temperature for Long and Short Carbon Fiber Reinforced Epoxy Composites.

3.7. Cole- Cole plot analysis

Figure 10 shows the analysis carried on bidirectional and chopped CFRE composites using Cole –Cole analysis. The dynamic mechanical properties of composites when measured as a function of temperature and frequency are represented on the Cole-Cole complex plane *E=f(E')* [23]. Cole-Cole plot distinguishes between homogeneous and heterogeneous material. A semicircular curve indicates that a polymeric system is homogeneous [24]. A homogeneous system typically exhibits a semi-circular curve whereas a heterogeneous system typically exhibits an irregular curve (imperfect semicircle) also the nature of curvature obtained in Cole-Cole curve determines the adhesion between fiber and matrix. Investigated bidirectional and short CFRE composites represent imperfect semicircles and hence are heterogeneous in nature. Also bidirectional CFRE specially 20wt. %, 30wt. %, 40wt. % and 50wt. % shows better interfacial characteristics than that of short CFRE composites [25].

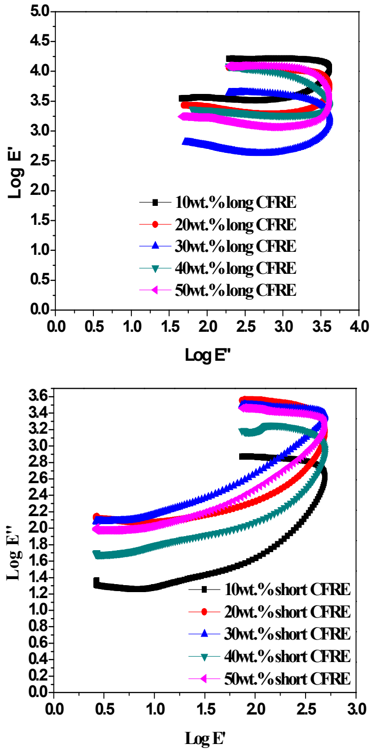

Fig. 10. Cole-Cole Plot for Bidirectional and Chopped CFRE Composites.

3.8. Visco-elastic co-relation to abrasive wear performance

Figure 11 shows the correlation between fiber loading and FWHM of loss modulus values for bidirectional and short carbon fiber reinforced epoxy composites. Such a plot is necessary to find the effect of fiber loading for which loss modulus is minimum. An interrelation between the full-width half-maxima (FWHM) of loss modulus peak and fiber loading has emerged indicating the loss modulus to be mainly controlled by the fiber-matrix interfacial characteristics.

Such an optimization for bidirectional and short composites for minimum loss modulus may also be evident from visco-elastic loss related correlation curve for fiber loading versus FWHM of the loss modulus (E'') peak as a function of fiber concentration. The plotted graph (Fig. 11) between fiber content and FWHM reveals a striking correlation between FWHM, and fiber loading. Theoretically a lower FWHM value corresponding to loss modulus peak indicates a better relaxation behaviour than that of a higher peak value [26, 27]. A smaller FWHM value indicates a larger relaxation time distribution for the system involved in the correlation and thereby leads to higher inhomogeneity of the amorphous phase; the same aspect is also evident from the values of Cole-Cole plot (Fig. 10).

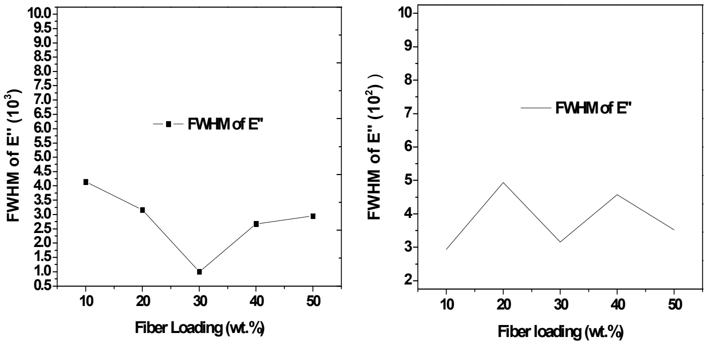

Fig. 11. Correlation between FWHM and Fiber Loading for Bidirectional and Short CFRE Composites.

4. Conclusions

A comparative study was carried out on long and short carbon fiber reinforced epoxy composites to notice the effect of three body abrasion (based on several factors) on the specific wear rate of composites. Based on the above observations, following points may be concluded as under.

- Mechanical properties such as tensile strength, flexural strength, Inter laminar shear strength, impact strength and hardness increases with the increase in fiber loading from 10wt. % to 50wt. % except for I.L.S.S. of short CFRE composites and flexural strength of bidirectional CFRE composites. This may be due to the weak bond strength between the fiber and the matrix due to which the strength decreases.
- Bidirectional carbon fiber reinforced epoxy composites show better mechanical properties, i.e., tensile strength, inter laminar shear strength, flexural strength and impact strength except for that of hardness where values for short carbon fiber reinforced epoxy composites are higher than that for bidirectional composites. Increase in values for bidirectional carbon fibers may be due to the uniform fiber orientation in all the directions.
- Damping properties for bidirectional carbon fiber reinforced epoxy composite are better than that for short carbon fiber reinforced epoxy composites. Highest damping factor value is obtained at 10 wt. % fiber loading for chopped carbon fiber reinforced epoxy composites.

- On investigation of homogeneous and heterogeneous behaviour of bi-directional and short CFRE composites, graphs represent imperfect semicircles and hence are heterogeneous in nature. Also bidirectional CFRE specially at 20wt. %, 30wt. %, 40wt. % and 50wt. % shows better interfacial characteristics than that of short CFRE composites.
- Future study can be extended to new fiber/ matrix combinations and the resulting experimental findings can be further analysed similarly.

References

1. Soboyejo, W. (2003). Mechanical properties of engineered materials, *Marcel Dekker Inc.*, New York.
2. Nielsen, L.E.; and Landel, R.F. (2004). Mechanical properties of polymers and composites, *Marcel Dekker Inc.*, New York.
3. Friedrich, K. (1985). Micro structural efficiency and fracture toughness of short fiber/thermo plastic matrix composites. *Composite Science and Technology*, 22, 43-74.
4. Sharma, M.; Bijwe, J.; and Mitschang, P. (2011). Abrasive wear studies on composites of PEEK and PES with modified surface of carbon fabric. *Tribology International*, 44, 81-91.
5. Yunus, R.; Zahari, N.H.; Salleh, M.A.M.; and Ibrahim N.A. (2011). Mechanical properties of carbon fiber reinforced polypropylene composites, *Composite Science and Technology*, 471-472, 652-657.
6. Katogi, H.; Takemura, K.; and Shimmer, Y. (2011). Mechanical properties of carbon fiber reinforced plastics under hot-wet environment, *Fracture and Strength of Solids VII*, 462-463, 207-212.
7. Szuecs, F.; Nyun, P.K.C.; and Johnson, W.L. (2001). Preparation, microstructure and mechanical properties of carbon fiber containing bulk metallic glass composites, *Journal of Metastable and Noncrystalline Materials*, 10, 43-48.
8. Sulaiman, S.; Yunus, R.; Ibrahim, N.A.; and Rezai, F. (2008). Effect of hardener on mechanical properties of carbon fiber reinforced phenolic resin composites. *Journal of Engineering Science and Technology*, 3(1), 79-86.
9. Kim, E.S.; Lee, T.H.; Kim, E.J.; and Yoon, J.S. (2012). Surface modification of carbon fiber and the mechanical properties of the silicon rubber/carbon fiber composites, *Journal of Applied Polymer Science*, 126(2), 410-418.
10. Agarwal, B.D.; and Broutman, I.J. (1990). *Analysis and performance of fiber composites*. 2nd ed, Wiley New York.
11. ASTM D 3039-3076. (1976).*Tensile properties of fiber-resin composites*. American National Standard.
12. ASTM D2344-84 (1984). *Standard test method for apparent inter-laminar shear strength for parallel fiber composites by short beam method*, American Standard for Testing and Materials,15-17.
13. ASTM D256-97 (1999). *Standard test methods for determining the pendulum impact resistance of notched specimens of plastic*, American Standards for Testing and Materials, 8(1), 1-20.

14. Agarwal, G.; Patnaik, A.; and Sharma, R.K. (2013). Thermo-mechanical properties of SiC filled chopped glass fiber reinforced epoxy composites. *International Journal of Advanced Structural Engineering*, 21(5), 1-8.
15. Sua, F.; Zhang, Z.; Wang, K.; Jiang, W.; and Liu, W. (2005). Tribological and mechanical properties of the composites made of carbon fabrics modified with various methods. *Composites Part A: Applied Science and Manufacturing*, 36, 1601-1607.
16. Hancox, N. L.; and Wells, H. (1977). The effects of fiber surface coatings on the mechanical properties of CFRP. *Fiber Science Technology,* 10, 9-22.
17. Bijwe, J.; Rattan, R.; and Fahim, M. (2007). Abrasive wear performance of carbon fabric reinforced polyetheramide composites: Influence of content and orientation of fabric. *Tribology International,* 40, 844-854.
18. Wan, Y.Z.; Lian, J.J.; Huang, Y.; Wang, Y.L.; and Chen, G.C. (2006). Two-step surface treatment of 3D braided carbon/Kevlar hybrid fabric and influence on mechanical performance of its composites. *Material Science Engineering: A,* 429(1–2), 304-311.
19. Biswas, S.; Debnath, K.; and Patnaik, A. (2012). Mechanical behaviour of short bamboo Fiber reinforced Epoxy Composites filled with Alumina Particulate. *Kathmandu Symposia on Advanced Materials*.
20. Rezaei, F.; Yunus, R.; Ibrahim, N.A.; and Mahdi, E.S. (2007). Effect of fiber loading and fiber length on mechanical and thermal properties of short carbon fiber reinforced polypropylene composites. *The Malaysian Journal of Analytical Sciences*, 11(1), 181-188.
21. Jinmin, Z.; Perez, J.; Catherine, R.R.; and Earique, J.L. (1994). Effects of secondary phases on the damping behaviour of metals, alloys and metal matrix composite. *Materials Science and Engineering*, 325-390.
22. Kumar, S.; Satapathy, B.K.; and Patnaik, A. (2011). Visco-elastic interpretations of erosion performance of short aramid fibre reinforced vinyl ester resin composites. *Journal of Material Science,* 46, 7489-7500.
23. Jawaid, M.; and Abdul, K.H.P.S. (2011). Effect of layering pattern on the dynamic mechanical properties and thermal degradation of oil palm-jute fiber reinforced epoxy hybrid composites. *Bio-Resources,* 6(3), 2309-2322.
24. Agarwal, G.; Patnaik, A.; and Sharma, R.K. (2013). Parametric optimization of three body abrasive wear behaviour of long and short carbon fiber reinforced epoxy composites. *Tribology Material, Surface and Interfaces*, 7(3), 150-160.
25. Kumar, S.; Satapathy, B.K.; and Patnaik, A. (2011). Thermo-mechanical correlations to erosion performance of short carbon fibre reinforced vinyl ester resin composites. *Material and Design,* 32, 2260-2268.
26. Ornaghi, H.L.; Bolner, A.S.; Fiorio, R.; Zattera A.J.; and Amico, S.C. (2010). Mechanical and dynamic mechanical analysis of hybrid composites molded by resin transfer molding. *Journal of Applied Polymer Science*, 118, 887-896.
27. Pothan, L.A.; Thomas, S.; and Groeninckx, G. (2006). The role of fiber matrix interactions on the dynamic mechanical properties of chemically modified banana fibers/polyester composites. *Composites Part A: Applied Science and Manufacturing,* 37, 1260.