Mechanical and Thermal Properties of Epoxy Composites Reinforced with Carbon and Pineapple leaf fiber

A. SURESH BABU[a], T.T. NAGARAJAN[a, b*], K. PALANIVELU[b] AND S.K. NAYAK[b]

[a] *Department of Manufacturing Engineering, College of Engineering, Guindy, Chennai 600 025.*

[b] *Central Institute of Plastics Engineering and Technology (CIPET), Guindy, Chennai 600 032, Tamil Nadu, India.*

ABSTRACT

The mechanical and thermal properties of hybrid epoxy composites reinforced with carbon fiber (CF) and pineapple leaf fiber (PALF) composites depend upon fiber-matrix interfacial properties.

A comparison between the CF composite and hybrid fiber composite was made. Composites were characterized by tensile, flexural and impact, TGA, DMA, and SEM analysis. The results showed that the tensile and flexural strengths are increased with increasing CF content upto 30 wt % in the hybrid composite. CF/PALF fibre can be used for improving the properties of hybrid epoxy composites.

KEYWORDS: Epoxy, Pineapple leaf fiber, Carbon fiber, Mechanical properties, Thermal properties.

1. INTRODUCTION

The mechanical and thermal properties of the reinforced composites are mainly depends on the properties of the fiber and the adhesion between the matrix and fiber. Carbon fiber (CF) possess very high specific properties, in particular, stiffness and strength, which make them attractive as the reinforcing elements in the composite materials [1-2]. Nowadays CF have been used in various fields such as automobiles, communication satellites and aerospace industries, because of their low weight, high fracture toughness, high strength and good insulating properties [3-4]. But, the main disadvantages of CF are low compressive to tensile strength ratio and low strain to failure, and these properties limits the application of CF reinforced polymer (CFRP)

J. Polym. Mater. Vol. **35,** No. 1, 2018, 59-69

Correspondence author e-mail: ttnagarajan85@gmail.com

composites. On the other hand, pineapple leaf fiber (PALF) possess lower fiber content and the fiber extraction processes (scraping, retting or decorticating) which is either labour intensive or problematic to the environment. The main advantages of natural fiber reinforcement in polymer composites are cost effective material, biodegradable, bio-renewable and reduce the fossil fuel consumption by occupying the major portion, which also enhances the mechanical and thermo mechanical properties of polymers [5-11, 29]. Reinforcing two or more types of fibers in a common matrix to form hybrid fiber/polymer composites may produce the combined properties of the fibers [8-12]. There are two possible varieties of natural fiber based hybrid composites were obtained by the combination of natural–natural and synthetic–natural fibers. These hybrid composites present an option of achieving combined properties such as stiffness, ductility and strength, which cannot be achieved by single fiber reinforced composites. Hybrid composites also possess increased fatigue life, better fracture toughness and lower notch sensitivity compared to single fiber reinforced composites [12-13]. Many researchers were studied and analyzed the properties of hybrid composites and reported the positive and negative effects on mechanical properties. The behavior of the hybrid composites was mainly influenced by the properties of their extreme fiber layers. Optimum mechanical properties were found to be obtained by placing high strength fibers as the skin layers [14-16]. Most of the studies on cellulose or plant fiber reinforced composites have been based on thermoplastic resins and very few on thermosetting resins. In addition, the method of mixing the fibers into the resins is usually based on mechanical blending or stirring, a process which does not allow the incorporation of large volume fraction of fibers and the tendency to cause fiber damage, fiber agglomeration or generation of air-bubbles [17].

The stress–strain in the CF/polyimide composites with SiO_2 nano particles yields complex shape, which results a high stress without instantaneous failure [18-22]. Compared to glass/epoxy laminates, the CF/epoxy laminates showed lower flexural modulus, as CF is much stiffer than glass fibers [23-24, 26]. The higher content of CF produces a materials with low density because the density of CF (1.7 g/cm^3) is lower than that of glass fibers (2.5 g/cm^3) [25].

In this work, we discussed the development of CF and PALF reinforced epoxy matrix to investigate the effects of fiber content on the mechanical and thermal properties of the hybrid composites. The prepared hybrid composites were analyzed and characterized by using various techniques such as universal testing machine (UTM) for tensile and flexural modulus, izod impact analyzer for impact strength, dynamic mechanical analysis (DMA) for thermo-mechanical properties, thermo gravimetric analysis (TGA) for thermal stability and scanning electron microscope (SEM) for morphology measurement to evaluate the effects of fiber loading on composites.

MATERIALS AND METHODS

Materials

Diglycidyl Ether of Bisphenol-A (DGEBA) epoxy resin and cross linking agent (Triethylene tetraamine) was supplied by Araldite®, Petro Araldite Pvt. Ltd., Chennai, and the PALF was supplied by Vibrant Nature, Chennai.

Sodium hydroxide (NaOH) was obtained Fisher Scientific for surface treatment of PALF. Carbon fiber (CF, T300) was supplied by Sakthi industries – Chennai, as reinforcement material.

Fiber Treatment

PALFs were washed and immersed in NaOH solution (5% w/v) in water bath at room temperature for 4 h. Then the fibers were treated with acetic acid to neutralize the remaining hydroxide with distilled water until it was rid of alkali. Finally the fibers were dried in an oven at 70 °C for 24 h.

Composites preparation

The components of the epoxy resin were mixed with CF in a uni-directional arranged like a mat with various weight percents of 5, 10, 15, 20 and 25 wt % in a mild steel mold. The length of the CF is 250 mm x 300 mm and the thickness of CF is 0.5mm. The prepared CF composites were referred as CF5%, CF10%, CF15%, CF20% and CF25% respectively. The hybrid fibers of PALF and CF of same length were arranged like a mat in uni-directional with various weight ratios of (15:10, 15:15, 15: 20, 15:25 and 15:30) with the help of flat surface compression mold under the load 5 kN for 15 min. The prepared hybrid fiber composites were referred as CF15% + PALF10%, CF15% + PALF15%, CF15% + PALF20%, CF15% + PALF25%, CF15% + PALF30% respectively. The epoxy resin and hardener were mixed in the ratio of 90:10 at room temperature for 5 min. The composites were fabricated in a mild steel mold (250 mm x 300 mm x 4 mm) by Hand lay-up technique. Silicone spray was coated with a thin layer for releasing agent in the mold. The mold was then closed with another mild steel mold and the resin was left to cure for 24 h at room temperature followed by 24 h post curing at 70 °C.

Mechanical properties

For mechanical tests the tensile, flexural and impact properties of epoxy matrix with CF and hybrid fibers were compared in different fiber contents. The mechanical characterization was performed by longitudinal tension test (ASTM D-3039) and three-point bending flexural test (ASTM D-790) using an Instron 5584 and ASTM D256 method was used to analyze the impact strength.

Thermal Properties

The thermal decomposition of CF composite and hybrid fiber composite were evaluated by TGA using a Perkin Elmer, Model: Pyris 7 TGA. Roughly 10 mg of sample was heated under air from room temperature to 900 °C at a rate of 10 °C/min, to yield the onset decomposition temperature, mass loss and maximum decomposition peak. The dynamic mechanical properties of the composites were determined by DMA at a frequency of 1 Hz, temperature range from 20 to 200 °C, at a heating rate of 10 °C/min.

Surface characterization

Surface morphological studies were carried out on the fractured surfaces of the CF and hybrid fiber composite using ZEISS EVO MA15 SEM analyzer and the used voltages in the range of 10–20 kV.

RESULTS AND DISCUSSION

Mechanical properties

The results indicated that the mechanical properties of the composites are greatly affected by the content of CF in the epoxy matrix. An increase in the CF content improves the tensile and flexural modulus, but decreases the impact strength as shown in figure 1-4.

Tensile Modulus

The tensile properties of the CF reinforced epoxy composites were increased by increasing the CF content upto 15 wt %. The neat epoxy shows 2228Mpa and the values were increased upto 6195MPa for CF 15 wt % shown in fig 1a. Thereafter by increasing the % of CF, the outer layer of the epoxy get shattered off but the CF remain intact and decreased the modulus value up to 3410 MPa with reinforcement of CF 20 and 25 wt. %. The higher percentage of CF content decreased the adhesion between CF and epoxy, due to the hydrophobic nature of CF.

These results exhibited that CF wt. 15% reinforcement in epoxy matrix shows higher modulus value.

From the optimized composites of CF 15 wt. %, as shown in Figure 1b. The modulus values of the composites were increased from 2228 to 4414 MPa up to CF 15 wt. % and PALF 15 wt. % loading. Lesser hydrophobic nature of PALF can able to make hydrogen bonding with epoxy matrix, which results the enhancement of adhesion between matrix and fibers. But, higher percentage of PALF in epoxy matrix reduces the modulus value from 4414 to 4219 MPa. This effect was due to the volume fraction of epoxy

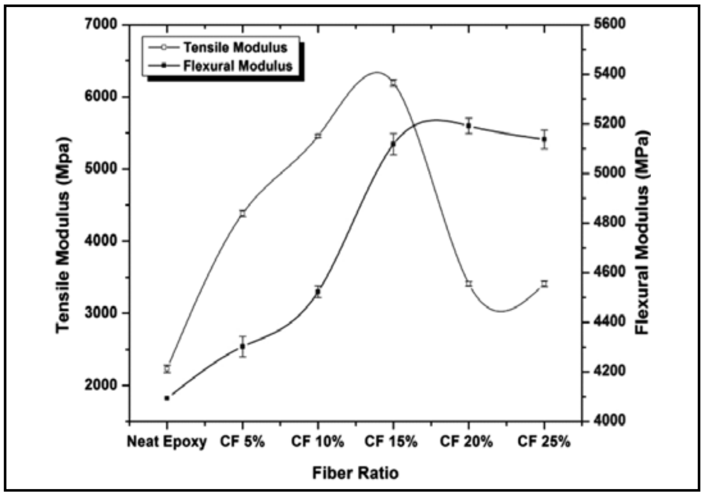

Figure 1a. Tensile and Flexural Modulus of CF Composite

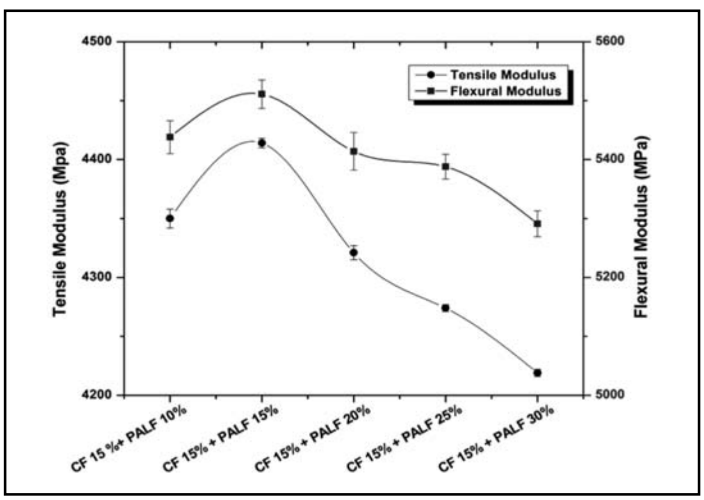

Figure 1b. Tensile and Flexural Modulus of Hybrid Composite

matrix. At higher volume fraction of PALF with the optimized CF, the modulus results are found to fall below the results, the fiber interactions in the form of overlapping reduces the interfacial surface area between fibers and matrix results in the effective fiber volume fraction. It should be mentioned that the use of a hybrid composition can enhance the tension damage tolerance, that is, the residual tension strength of a composite structure.

Flexural Modulus

The flexural modulus of the composite was increased with increase in fiber content. The flexural modulus was linearly increased upto 15 wt. % of CF from the neat epoxy matrix (4098 to 5192 MPa) as shown in figure 1a. In hybrid composites, the flexural values were increased upto 5511MPa for CF 15 wt. % + PALF 15wt. %. Further addition of PALF to the CF 15 wt. %, flexural values were reduced from 5511 to 5291 MPa. The reduction in values after the optimum ratio was due to the volume fraction with the epoxy matrix as shown in figure 1b. This result shows that PALF plays important role in the hybrid composites.

Impact Strength

From the Figure 2a, it can be seen that the addition of CF in epoxy matrix, the impact strength was increased from 39 to 84.6 J/m at CF 25 % when compare to neat epoxy. In this composite is subjected to a high speed impact load, the sudden stress transferred from the matrix and fiber exceeds the fiber can with stand the energy hence resulting in the fracture of the epoxy at the cracks plane without any fiber pull out. This observation indicates that brittle nature of the epoxy. In the hybrid composite (Figure 2b) the impact strength was reduced from 55.4 J/m (CF 15 wt. %) to 53.1 J/m at CF 15 wt.% + PALF 15 wt.%. Compare to CF composites, the impact strength and fiber volume fraction (15 % of the PALF content) was increased for hybrid composites.

Dynamic Mechanical Analyzer

Figure 3a represents the storage modulus curves of the neat epoxy, CF and CF + PALF composites. Overall, the storage modulus of epoxy composites increases with the addition of fibers. In the initial glassy state, the composites loaded with hybrid fibers exhibited an enhanced storage modulus compared to pure epoxy polymer and CF composites. At the temperature of 75 °C, the storage modulus of composites containing CF 15 wt % + PALF 15 wt % is 5580 MPa, which is 2.53 times larger than that of neat epoxy resin (2204 MPa) as well as 2.23 times larger than that of composites loaded with CF 15 wt % (2508 MPa). The enhanced storage modulus indicates that in the glassy state, the motion of epoxy matrix chains is constrained by the PALF and CF hybrids have stronger interfacial adhesion with the matrix in comparison with other composite. The highest storage modulus was achieved for CF 15 wt % + PALF 15 wt % (8.217 GPa), which is 258 % higher compared to neat epoxy storage modulus (3.184 GPa). It can be concluded that effect of fiber added in the epoxy matrix acts as a plasticizer, improving the mobility of polymer matrix and diminishing the strengthening effect of CF. But, at around 80 °C the pure epoxy resin as well as fiber composites both are exhibiting almost similar storage modulus. This is due to the matrix softening and loss of fiber–matrix

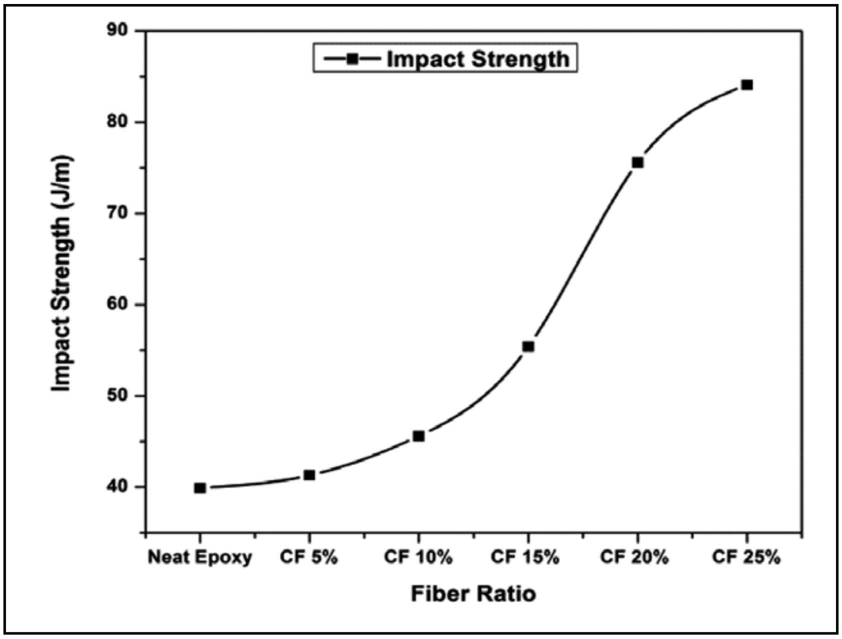

Figure 2a. Impact Strength of CF Composite

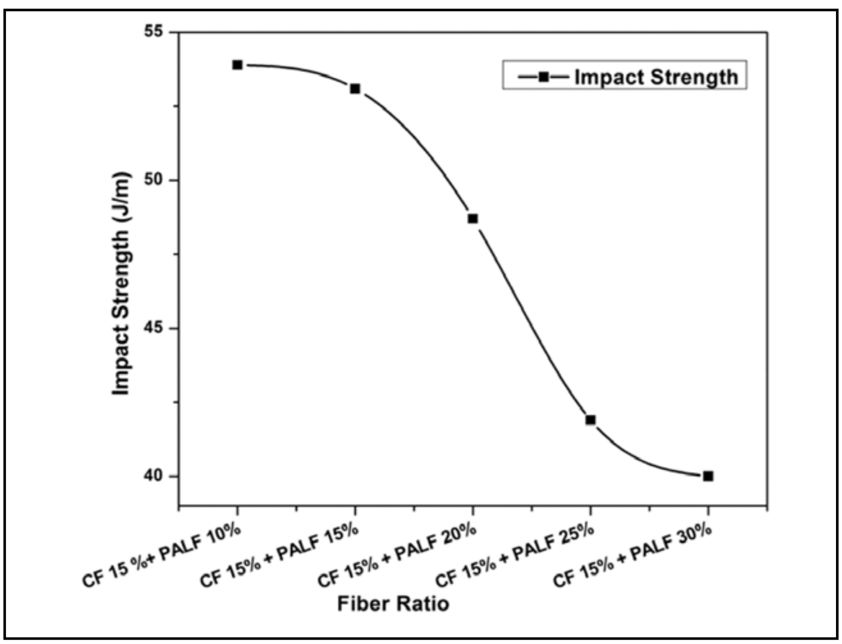

Figure 2b. Impact Strength of Hybrid Composite

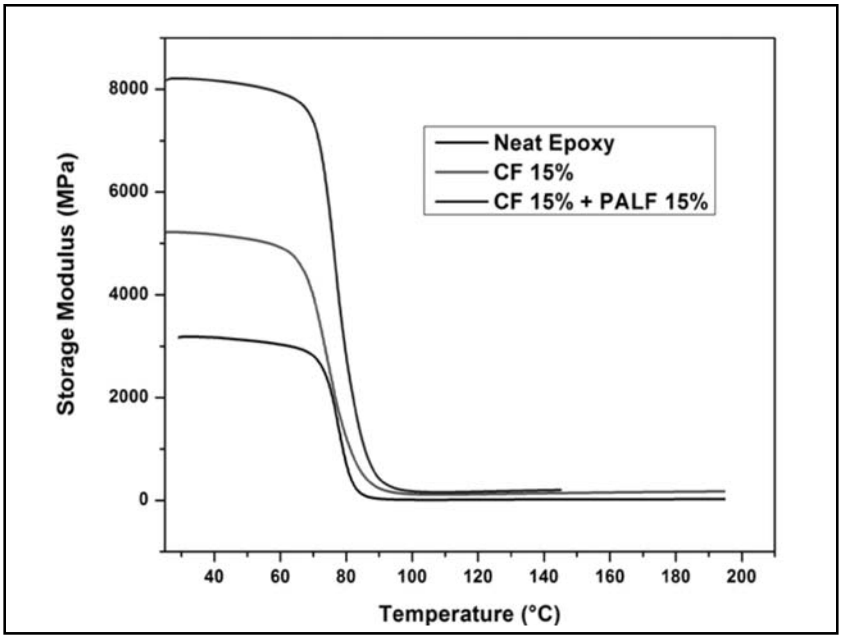

Figure 3a. Dynamic Mechanical Analysis Storage Modulus

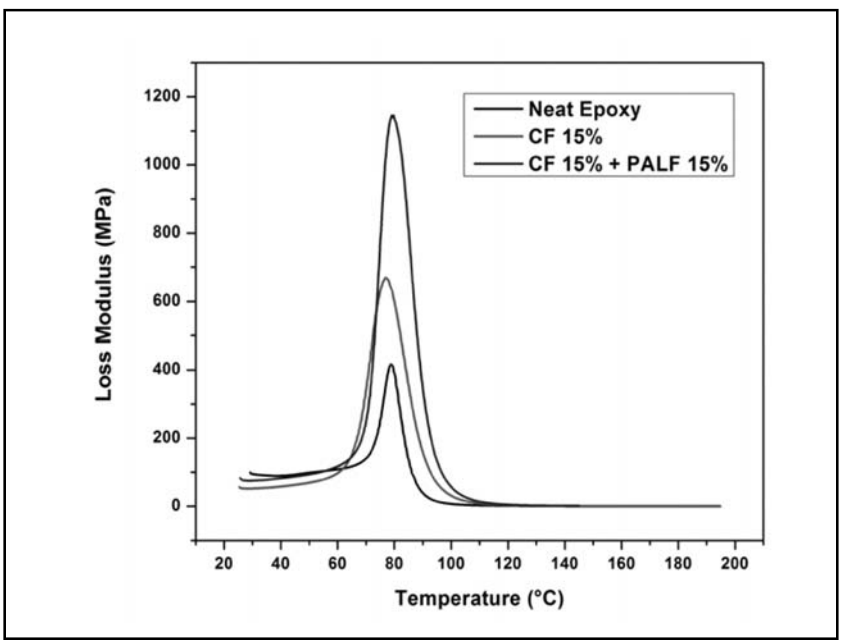

Figure 3b. Dynamic Mechanical Analysis Loss Modulus

adhesion and it was a major factor affecting the strength reduction observed at high temperatures. Similar results were reported by Bosze et al. for carbon fiber composite matrix [30].

The results of loss modulus (Figure 3b) confirmed the plasticizing effect of composites. Loss modulus increased with increasing fiber content however, the differences between the samples were small, especially in CF and CF + PALF. Similar to storage modulus, loss modulus also increased in all types of composites with increasing content of fibers up to twice the time of CF and three times of neat epoxy. The T_g of a pure epoxy resin is 77 °C. The addition of CF decreased the T_g to 74 °C. Further addition to CF + PALF increased the T_g to 82 °C. From this results, the T_g values are not depends on CF or volume of the fibers. The incorporation of the hybrid fiber into the polymer matrix usually improves the interaction between the matrix and fiber and restricts the motion of the molecules, which increases the T_g of the polymer matrix.

Thermal properties

The typical thermograms was taken for neat epoxy, CF 15 wt. %, CF 15 wt. % + PALF 15 wt. %. as shown in the figure 4. The composites had thermal stability upto 350 °C, thereafter, neat epoxy and fibers reinforced epoxy matrix exhibited single-step thermal degradation. Comparing the weight loss of the composites up to 50 %, there is no considerable variation in the thermal stability between the composites Table 1. The maximum decomposition temperature (T_{max}) of neat epoxy, CF 15 wt % and CF 15 wt % + PALF 15 wt % were 193 (T_{max2} 386), 378 and 375 °C respectively. After the reinforcement of fiber into the epoxy matrix, it reduces the T_{max} values of composites. The

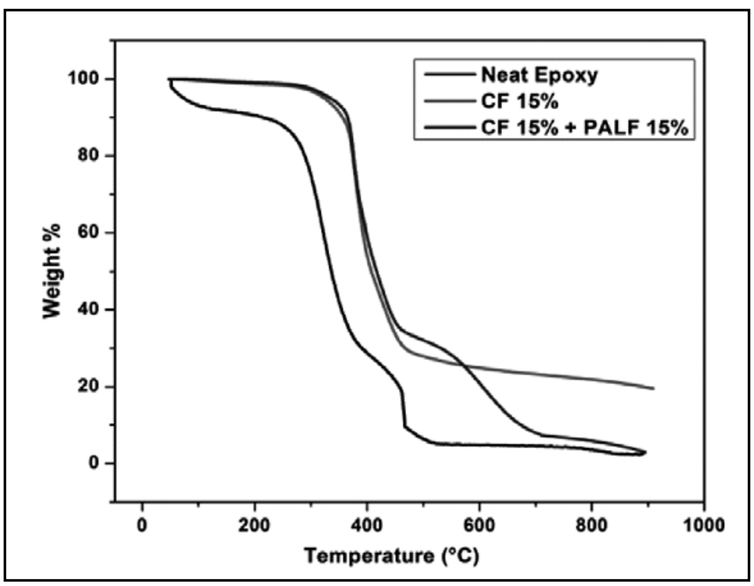

Figure 4. Thermo Gravimetric Analysis of Hybrid Composites

hybrid fiber reinforced epoxy matrix have higher char residue when compared to the neat epoxy matrix. The final residues of the composites were calculated at 800 °C, which was increased from 10.6 to 21.8 percentages with increase in fiber content in epoxy matrix. The absorbed percentage residue in CF 15 wt % + PALF 15 wt % matrix was 21.3 % lesser than the expected residual value. This is due to the chemical composition of PALF. In the case of CF, it is composed of carbon molecules without hydrogen and oxygen molecules. But, the chemical composition of PALF constitutes holocellulose (70–82%), lignin (5–12%), and etc, which is made up of hydrogen and oxygen. At higher temperature, these hydrogen and oxygen constitute present in PAFL enhances the combustion reaction itself as well as CF and decreases the residual mass in hybrid composites. Hence, the CF 15% shows higher residue than hybrid composite (CF15% + PALF 15%).

Scanning Electron Microscopy (SEM) of fracture surface

The surface morphological studies were taken from the fracture surface of the epoxy composites as shown in figure 5. From the fracture surface, the epoxy layer was well bonded with the composites. The adhesion between the fiber and the matrix plays an important role in the mechanical performances, which were well proved from the SEM analysis as shown in figure 5a. It is clear that absents of voids and air entrapments in the composite of the fracture that created the good fiber–matrix interface. In the hybrid composite the PALF was debonded, length of pulled-out fibers, (Figure 5) this effect the mechanical properties of the hybrid composite.

CONCLUSION

In this work, the mechanical and thermal properties of CF reinforced epoxy composites

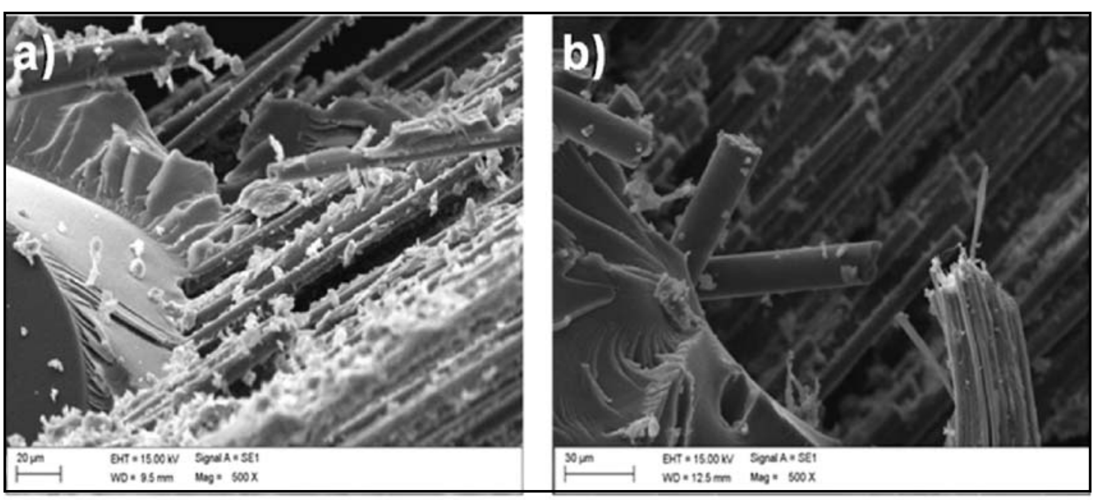

Figure 5. Surface morphology of fracture surface a) CF 15 %, b) CF 15 % + PALF 15%

TABLE 1. Percentage of weight loss and T_{max} of the Composites

Composites	% Wt. loss up to 800 °C					T_{max} (°C)
	10	25	50	75	Residue	T_{max}
Neat Epoxy	370	384	408	464	10.6	193 and 386
CF 15 %	356	378	408	592	21.8	378
CF 15 % + PALF 15 %	356	377	417	656	21.3	375

and CF with PALF reinforced epoxy composites were investigated. The mechanical properties showed that the addition of fibers enhanced the tensile, flexural modulus and impact strength. The tensile test fracture surface morphology of composites analyzed by SEM showed the fractured surface appeared debonded and pull out from of the fibers in matrix. A positive hybrid effect is observed in the elongation property. The storage modulus of the hybrid composite increased and also thermal stability of the epoxy composites increased with the addition of fibers. These composites may find applications as structural materials where higher strength and cost considerations are important.

Acknowledgement

Financial support given from Central Institute of Plastics Engineering and Technology (CIPET) under the scheme of Centre of Excellence for Green Transportation & Network (CoE-GREET) sponsored by Department of Chemicals & Petrochemicals, Ministry of Chemicals and Fertilizer, Government of India is gratefully acknowledged.

REFERENCES

1. Y. Yueping, C. Haibin, Jingshen Wu, and Chi Ming Chan, *J. Compos Part B-Eng.* **42**, 2145–2150 (2011).
2. J. Lee, D. Bhattacharyya, M.Q. Zhang, and Y.C. Yuan, *J. Compos Part B-Eng.* **78**, 515 (2015).
3. A. G. Zestos, M. D. Nguyen, B. L. Poe, C. B. Jacobs, and B. Jill Venton, *J. Sensor Actuat B-Chem.* **182**, 652 – 658 (2013).
4. E. Omrani, B. Barari, A. D. Moghadam, P. K. Rohatgi, and K. M. Pillai, *J. Tribol Int.* **92**, 222–232 (2015).
5. N. Oya, and H. Hamada, *J. Sci Eng Compos Mater.* **5**, 105–129 (1996).
6. N. Oya, and D.J. Johnson, *J. Carbon.* **39**, 635–645 (2001).
7. M. Shioya, and M. Nakatani, *J. Compos Sci Technol.* **60**, 219–29 (2000).
8. F.Z. Arrakhiz, K. Benmoussa, R. Bouhfid, and A. Qaiss, *J. Mater Design.* **50**, 376–381(2013).
9. Z. Zhao, X. Chen, and X. Wang, *J. Mater Design.* **82**, 130 (2015).
10. V. Fiore, T. Scalici, G. Vitale, and A. Valenza, *J. Mater Design.* **57**, 456 (2014).
11. Abhishek K. Pathak, Munu Borah, Ashish Gupta, T. Yokozeki and Sanjay R. Dhakate, *J. Compos Sci Technol.* 135, 28(2016)
12. A. Shahzad, *J. Reinf Plast Compos.* **30**, 1389–1398 (2011).
13. P. Niedermann, G. Szebenyi, and A. Toldy, *J. Compos Sci Technol.* **117**, 62 (2015).
14. N. Srinivas, P.R. Chandra, S. Shrivastava, and A.K. Jalan, *J. Reinf Plast Comp.* **31**, 759–769 (2012).

15. R.A. Braga, P.A.A. Magalhaes Jr., *J. Mater Sci Eng.* **56**, 269 (2015).

16. W. Li, A. Dichiara, J. Zha, Z. Su, and J. Bai, *J. Compos Sci Technol.* **103**, 36 (2014).

17. I.M. Low, M. McGrath, D. Lawrence, P. Schmidt, J. Lane, B.A. Latella, and K.S. Sim, *J. Compos Part A-Appl S.* **38**, 963–974 (2007).

18. N. Kimiyoshi, *J. Mater Sci,* **48**, 4163–4176 (2013).

19. N. Kimiyoshi, Y.J. Ming, and K. Yutaka, *J. Mater Sci.* **654**, 2620-2623 (2010).

20. Ricardo Baptista, Ana Mendão, Mafalda Guedes and Rosa Marat-Mendes, *J. Proc Struct Int.* 1, 74 (2016)

21. Z. Ying, L. Xianggao, C. Bin, C. Fei, and F. Jing, *J. Compos Struct.* **132**, 44 (2015).

22. S. Chen, and J. Feng, *J. Compos Sci Technol.* **101**, 145 (2014).

23. D. Chensong, and I.J. Davies, *J. Compos Part B-Eng.* **72**, 65–71 (2015).

24. A.R. Alian, S.I. Kundalwal, and S.A. Meguid, *J. Compos Struct.* **131**, 545 (2015).

25. T.T.M. Tan, and N.H. Nieu, *J. Macromol Mater Eng.* **234**, 53-58 (1996).

26. Z. Zhai, L. Feng, Z. Liu, S. Zhou, H. Lou, and G. Li, *J. Prog Org Coat.* **87**, 106 (2015).

27. N. Weidonge, L. Jie, L. Wenbin, J. Wang, and T. Tang, *J. Polym Degrad Stabil.* **111,** 247–256 (2015).

28. H. Alamri, I.M. Low, and Z. Alothman, *J. Compos Part B-Eng.* **43**, 2762–2771 (2012).

29. T. T. Nagarajan, A. Suresh Babu, K. Palanivelu, S. K. Nayak, *J. Macromol. Symp.* **361**, 57-63 (2016).

30. E.J. Bosze , A. Alawar, O. Bertschger, Yun-I. Tsai, and S.R. Nutt, *J. Compos. Sci. Techno.* **66**, 1963-1969 (2006).

Received: 02-01-2018

Accepted: 09-03-2018