Arch. Metall. Mater. **66** (2021), 4, 1171-1178

DOI: 10.24425/amm.2021.136433

K. SRAVANTHI[1,2*], V. MAHESH[3], B. NAGESWARA RAO[1]

INFLUENCE OF CARBON PARTICLE IN POLYMER MATRIX COMPOSITE OVER MECHANICAL PROPERTIES AND TRIBOLOGY BEHAVIOR

In this research, the carbon particle dispersions are made in two different levels as carbon nano tube (CNT) and carbon particle in microns range. The mechanical strength is evaluated for the composites developed by axial loading and bending test analysis. In addition, the air jet abrasive particle erosion study is performed for different angle of impingement. The dispersion of carbon particle in the matrix material has reduced the mechanical strength. The sample with 4% of CNT dispersion in the composite has a maximum strength of 143 MPa and a minimum strength of 112 MPa. For the same combination (4% of CNT composite), the maximum flexural strength is 116 MPa. It is clear to infer that the strength of CNT in matrix materials is superior to the increase in length of carbon particle. The dispersion of carbon particle in the matrix material increases the brittleness and the strength is diminished. During the flexural bending, the fiber delamination occurred with severe deformation in the plain composite. When the materials are subjected to impingement of solid particle, the attrition effect on the exposed surfaces is vulnerable towards erosive mechanism. The presence of carbon in the matrix material has significantly increased the surface property. The results are appreciable for 4% of CNT composite. Especially at 30º, the minimum erosive wear 0.0033 g/g has been recorded. Erosive wear is less at minimum impingement angle and the wear is found increasing at higher impingement angle. Therefore, it is recommended not to add carbon particle to a higher weight percentage, since it leads to brittleness.

Keywords: Carbon, epoxy, CNT, Mechanical, Tribological

1. Introduction

Recent contributions towards fiber reinforced polymer composites received ample attention in the scientific community as they exhibited excellent properties such as high strength to weight ratio which are amenable to structural applications. Artificial fibers, such as carbon and glass are often reinforced with various polymeric materials. The growing demand for glass fiber is widespread in applications such as automotive, aerospace, marine and military sectors due to their high Mechanical strength and stiffness [1], which led to the development of various polymer composites. However, the composite reinforced with various man-made fibre shows excellent properties, but with high processing and material costs compared to natural fiber composites.

Researchers made various attempts to improve the mechanical and tribological properties of various fiber-reinforced composites. However, the polymer composite tribological properties could not satisfy the demand in the industry. Hence a novel idea of combining the synthetic fibers with carbon fillers in a common matrix has been introduced and they are referred to as hybrid composites. Introducing reinforcement (filler) such as micro carbon [2,3], Al_2O_3 [4], SiO_2 [5], carbon nanotubes (CNTs) and graphene [6] etc., into polymer matrix composites displayed good mechanical properties such as tensile strength, flexural strength and inter laminar shear strength and thermal properties. Alongside it is also intuitive that addition of short fibers, continuous fibers and ceramic particulates with the fiber reinforced polymer matrix composites will significantly enhance the mechanical and tribological properties of the composites [7]. In general, the properties of composite material are increased with increase in particle reinforcement. Especially the nano fillers such as carbon nanotubes and graphene with polymer matrix material has good mechanical, electrical and dielectric properties [8].

Carbon nanotubes (CNTs) received significant attention by the scientific community to enhance the polymeric properties with the advancement of nano composites, as they exhibit excellent inherent properties [6,9] which has numerous applications in the area of high strength and temperature applications [10,11].

1 DEEMED TO BE UNIVERSITY, DEPARTMENT OF MECHANICAL ENGINEERING, KONERU LAKSHMAIAH EDUCATION FOUNDATION, GREEN FIELDS, VADDESWARAM, GUNTUR 522 502, INDIA
2 MARRI LAXMAN REDDY INSTITUTE OF TECHNOLOGY AND MANAGEMENT, DEPARTMENT OF MECHANICAL ENGINEERING, HYDERABAD, INDIA
3 SR ENGINEERING COLLEGE, DEPARTMENT OF MECHANICAL ENGINEERING, WARANGAL 506371, INDIA

* Corresponding author: reddy.kundurusravanthi@gmail.com

The reinforcement of CNTs in the composite has effectively enhanced properties. In point of fact, due to proper transfer of load from the matrix to the fiber, the matrix and the interfacial fiber bonding often improve and as a result, the delamination resistance of the composite material can be improved [12,13].

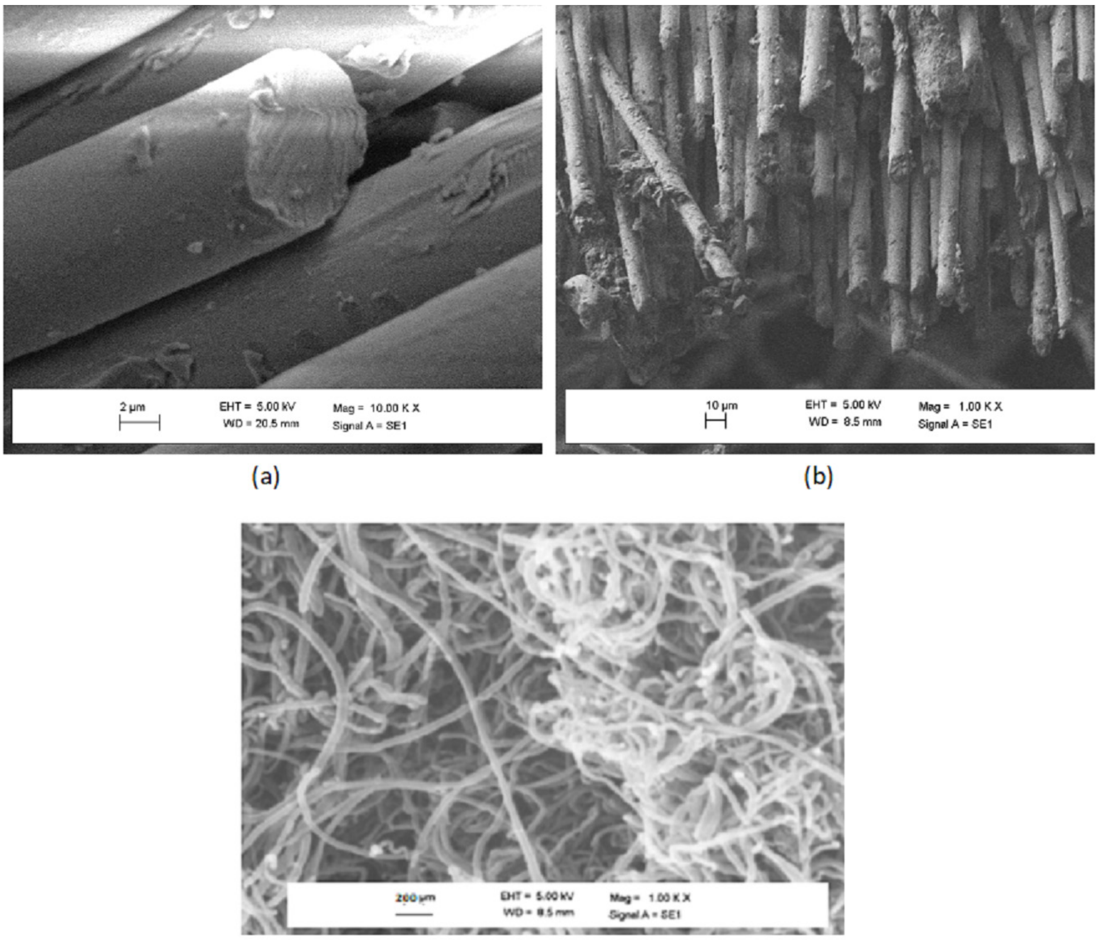
It was found that, the preparation of double wall CNT/ Carbon fiber/epoxy hybrid nanocomposite by resin infusion technique with the addition of small amounts of CNTs to epoxy resin enhanced flexural modulus, flexural strength and impact strength etc., [14]. Experimental and analytical investigations showed that the GFRP composites have superior mechanical properties than woven jute and glass fibre reinforced hybrid polymer composites [15].

The mechanical properties such as stiffness and yield strength are found superior for the nano silicate / glass-fiber / polyamide – hybrid nano composite. It is also observed that these composites possess better interfacial bonding between the fiber and matrix [16]. It is observed that introducing various organic/ inorganic carbon particles, like nano carbon fillers, CNTs, nano clays and epoxy metal oxides, produce a new material with better mechanical and thermal properties [17,18]. However, the epoxy hybrid fiber glass composites in presence of hard powders such as tungsten carbide (WC) and tantalum niobium carbide (Ta / NbC) are tested for improved abrasive wear properties [19]. It is evident from the above literature that the CNTs & micro carbons have induced good mechanical and tribological properties with various processing techniques. From the literature, it is intended to introduce CNTs/micro carbons to GFRPs by hand layup preparation and emphasize the behavior of composite at varying compositions.

Hence, it is proposed that the addition of a small amount of CNTs and carbon particles into the hybrid composite would enhance the mechanical properties and interfacial stress transfer among the fiber and matrix than those of composite made with synthetic fiber. In this paper, a research has been proposed to study the performance of hybrid epoxy composite reinforced with both carbon nanotubes (CNTs) / micro carbon particles. In addition, the tribological properties in terms of erosive wear are evaluated for the hybrid composite.

2. Materials and method

In this research, the influence of carbon in the matrix is studied with reinforcement of glass fibre. The E-glass fiber in the form of woven matrix is used to reinforce with epoxy resin. The matrix material is pre-processed with carbon before composite manufacturing. The carbon particle in the form of nano level and micro level are used in making the composite. Fig. 1 shows



(c)

Fig. 1. SEM image of (a) carbon particles (b) Glass fibre (c) CNT

the SEM image of used carbon particle, Glass fibre and CNT. Hand-layup method is used to make the composite material with a fibre and matrix weight proportion as 40:60. The density of fibre material is 2.56 g/cc and the number of plies used is five. The weight percentage of carbon nano tubes (CNT) and the carbon particles dispersed in the matrix material are given in Table1 with the sample labeling. The size of CNT and the carbon particle in 10-20 microns are used to disperse in the epoxy through mechanical stirring process. The preprocessed epoxy resin and the fiber material are manufactured in the form of flat plate to a dimension of 150 × 60 × 5 mm^3, using a wooden mold box. The curing time for hand laid fiber and matrix material is twenty-four hours using a hardener / catalyst. Figure 2 shows the flow of process involved in composite development followed by the experimental test to evaluate the material quality.

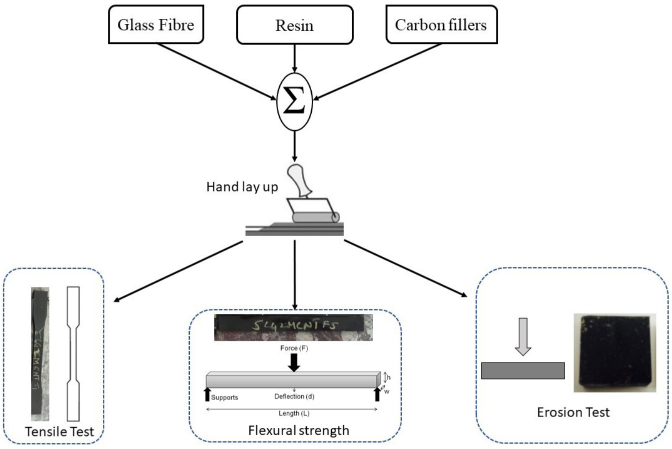


Fig. 2. Flow of process involved in composite development followed by the experimental test to evaluate the material quality

The experimentations on hybrid composite are followed by ASTM standards. The developed composite material is used to evaluate through a standard axial load condition, flexural test and erosive wear. For a tensile testing, the samples are sliced to a dimension following a standard ASTM D638 as shown in Fig. 3. Instron H10KS (cross head speed 2 mm/min) is used to study the axial loading of the composite material, five samples for testing and the average value is used to plot. Similarly, the flexural testing is also done to evaluate the mechanical properties using the standard ASTM D790 as shown in Fig. 4.

TABLE 1

Weight percentage of carbon particle dispersed in the matrix material

Sl. No.	Sample Label	Number of layers of woven glass fibre	Filler	Percentage of filler (wt%)
1	C_1	5	—	—
2	C_2	5	CNT	2
3	C_3	5	CNT	4
4	C_4	5	CNT	6
5	C_5	5	Carbon particle	5
6	C_6	5	Carbon particle	10
7	C_7	5	Carbon particle	15

To perform the mechanical erosion studies, hard silica particle is used to impinge at four different angles over the composite material. ASTM G76 standard is used to follow the erosion test procedure with the process parameter given in Table 2. From the air jet abrasive particle erosion studies, the wear rate is calculated with the following Eq. (1).

$$E_r = \frac{W_m}{W_e} \quad (1)$$

Where 'W_m' is the weight loss of the test sample (g) that can be determined from the difference in weight of the samples before and after each test, and 'W_e' is the mass of the erosion particles (g) that hit the target sample for 10 min (i.e.) the test time. This procedure has been repeated until the rate of erosion has reached constant steady-state value. Further, the worn surface and the fractured samples from the proposed research are examined with the electron microscope.

TABLE 2

Air jet erosion process parameters

Parameter	Units	Range
Erodent particle size	μm	50
Particle velocity	m/s	48, 70, 82
Erodent flow rate	g /min	2
Stand of distance	mm	10
Angle of impingement	Deg	30, 45, 60 and 90

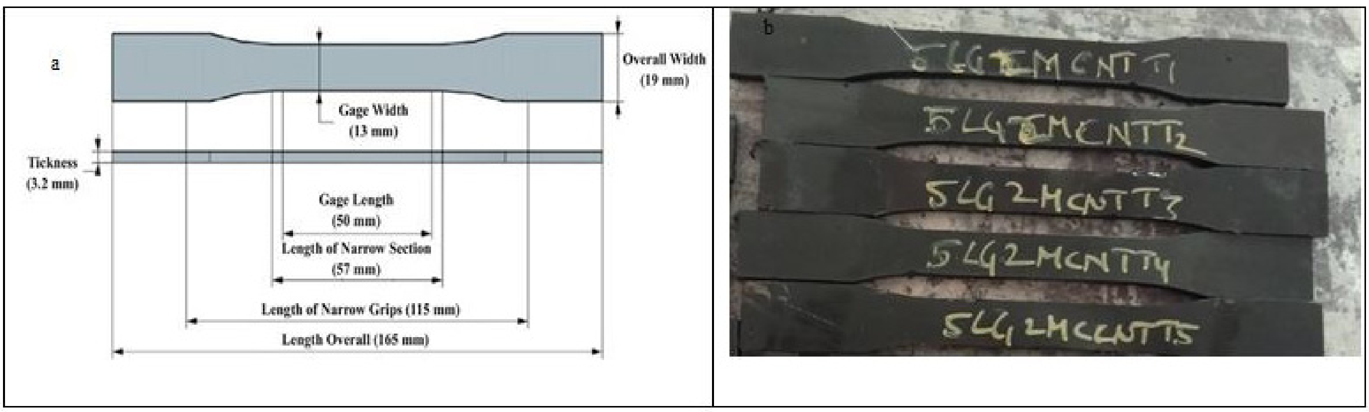


Fig. 3. Dimension for uniaxial loading condition following the standard ASTM D638

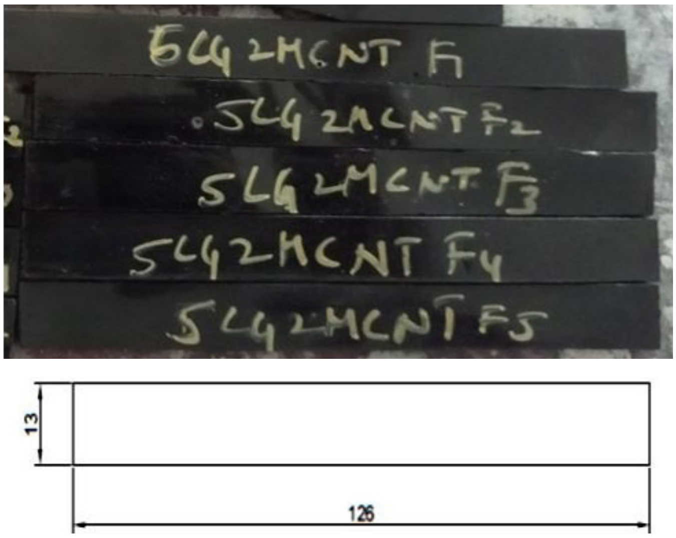


Fig. 4. Dimension for flexural testing following the standard ASTM D790

3. Results and discussion

The tensile strength of the carbon particle dispersed composite material is evaluated through axial loading. The results are compared with plain fiber – epoxy matrix composite for illustration as shown in Fig. 5. The plain fiber – matrix composite (C1) has a tensile strength of 112 MPa. The addition of CNT in the matrix has a maximum strength of 143 MPa for 4 wt. % of CNT compared to other composite materials. While increasing the weight percentage of carbon particle, the tensile strength is found decreasing. The graphite or carbon particle is hard in nature. They do not possess any elongation towards axial loading. Due to the dispersion of carbon particle, the brittle nature increased drastically and less tensile strength is found for 15%

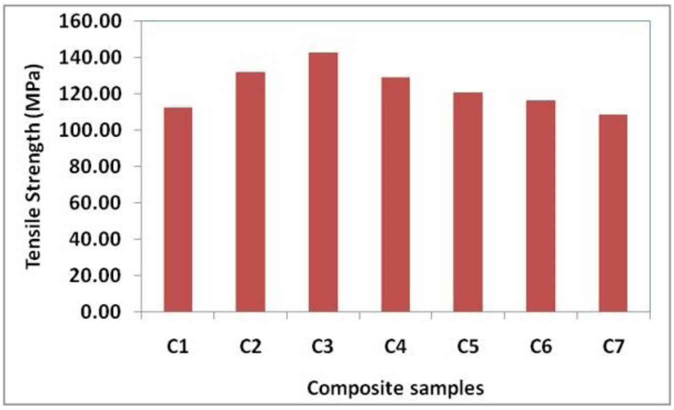


Fig. 5. Tensile strength of the composite with and without carbon particle dispersion in the matrix material

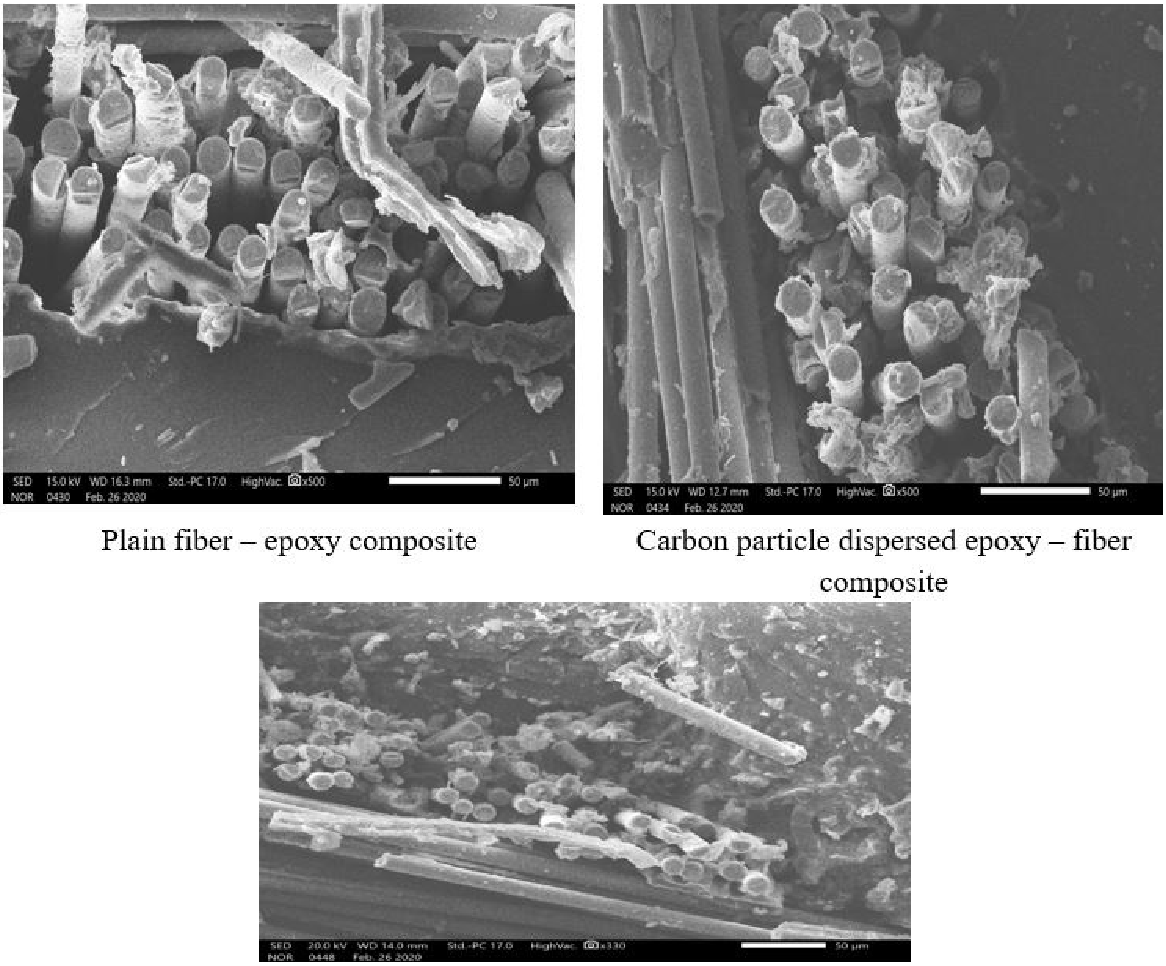


Fig. 6. Fractography analysis on fiber – epoxy with and without carbon particle dispersion in the composite material

dispersion of carbon particle in fiber – epoxy composite material. To discuss in detail, the fractographical analysis on axial load samples are performed. In plain matrix – fiber composite, fracture occurred due to the stretching of weak fiber as shown in Fig. 6. However, the carbon dispersed matrix has good bonding with the matrix and fiber. Simultaneously, the load applied has been uniformly distributed on the material. To confirm the mechanical property, the samples developed with the same proportion are tested with flexural strength and plotted in Fig. 7. As noticed in the axial loading, the sample with nano particle dispersion (4% of CNT in epoxy) has high strength compared to all other composition. Similar to axial loaded condition, when there is an increase in the dispersion of carbon particle (in the matrix), the brittleness increased and their modulus found decreased. Corresponding fractured surfaces are observed with the help of electron microscope to study the nature of failure as shown in Fig. 8. The fibers are pulled and detached in the plain composite material. It is due to the catastrophic nature of matrix and sudden failure of the composite. For carbon dispersed composite, the fiber has a good bonding strength and the fractured layers are uniform. There is no pullout or any loose fibre wandering over the fractured layer as shown in Fig. 8. The significance in the research is that the carbon particle may have super conducting nature and high surface bonding strength. However, while applying the mechanical load, it is does not have superior modulus to resist shear or tear, hence leading to fracture with brittle nature [20].

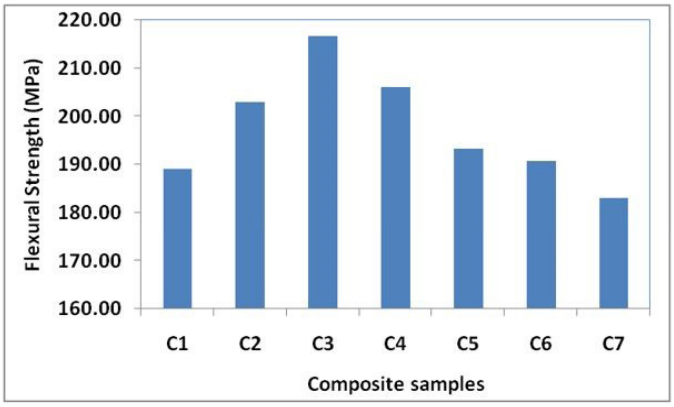
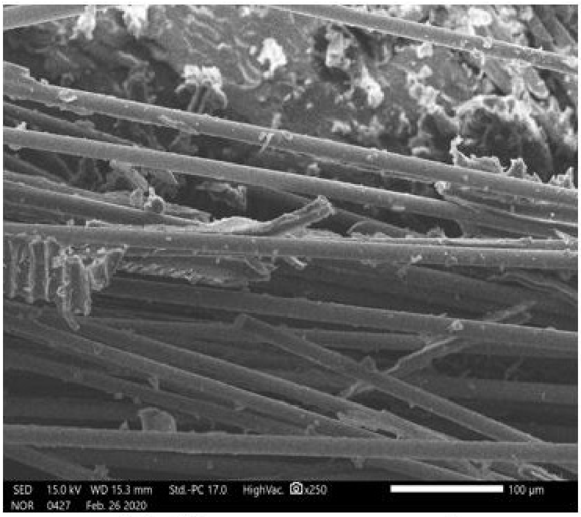
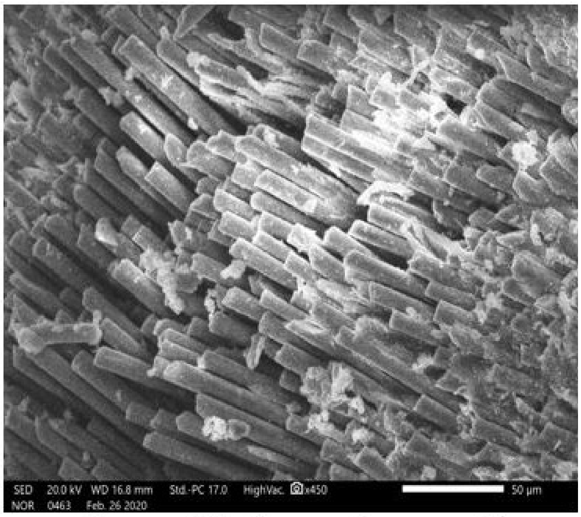


Fig. 7. Flexural strength of the composite with and without carbon particle dispersion in the matrix material



Plain fiber – epoxy composite



Carbon particle dispersed epoxy – fiber composite

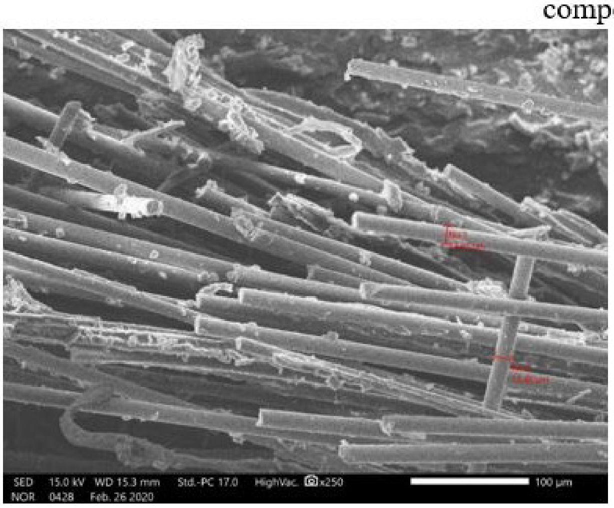


Fig. 8. Fractography analysis on fiber – epoxy with and without carbon particle dispersion in the composite material

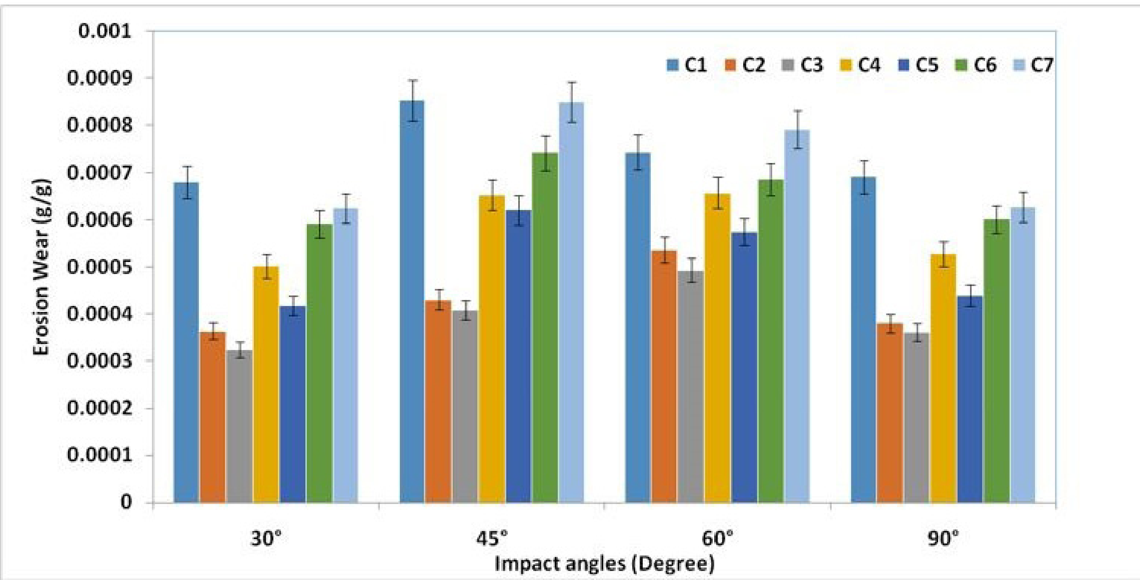
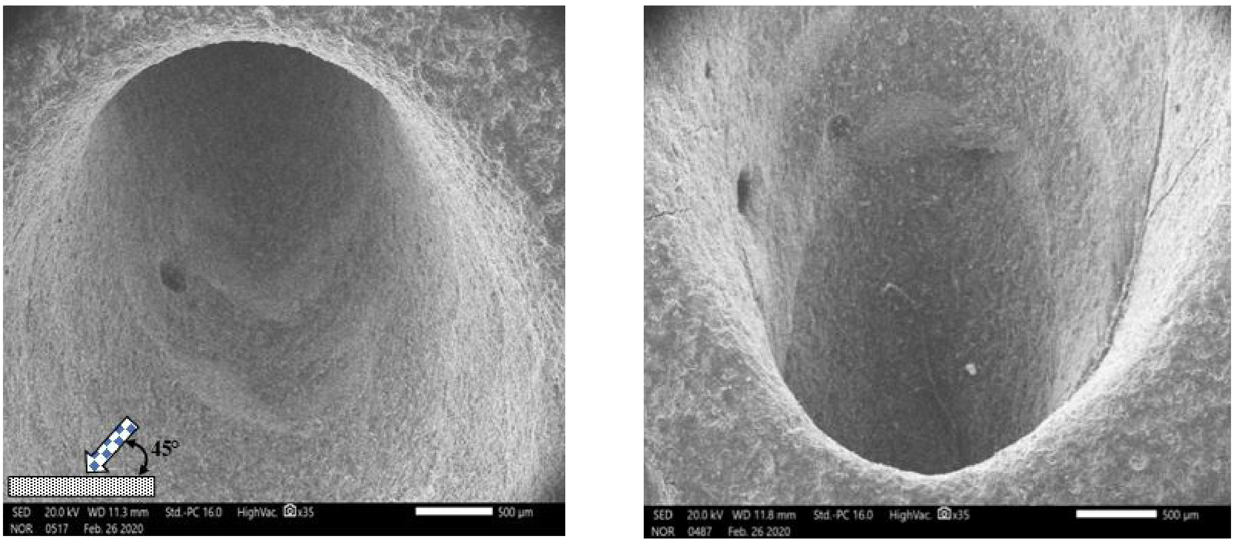


Fig. 9. Erosion wear (g/g) is calculated for different samples and the average value is plotted in the graph

The carbon particle dispersed matrix composite is further evaluated with air jet abrasive particle erosion studies. The Fig. 9 indicates that the calculated erosive wear measure for different angle of impingement is varied and the input process parameters are kept constant. The wear and metallurgical behavior of the composites are significantly revealing to the mechanical properties of the material evaluated. The plain fiber reinforced composite has a maximum wear at an angle of 45° and a decrement in wear with an increase in impact angle. The matrix material with dispersion of 4% CNT yields good strength to resist the erosive wear. At 30° the minimum wear is recorded (0.00033 g/g) and sensitively increasing with slight changes to a maximum of 0.0005 g/g. The composites with an increase in dispersion of carbon particle has lost the material strength and incited to yield severe in wear. In comparison, 4% of CNT has 0.0003 g/g wear and 15% of carbon particle dispersion has 0.00087 g/g wear, at angle of 45°. It is clear to understand that the dispersion of carbon particle in the matrix has drastic physical changes and bulk properties. For the same material, with an increase in impact angle, the severity in material wear is found decreased. This is due to reduced elongation at higher impact angle. At lower angle, the material is subjected to sliding / tangential force which induces the material to deform in ductile. The composites are brittle in nature, thus leading severe erosion. On other hand, at higher angle (at 90°), the shock load induced over the surface, as the composite resisted maximum wear and revealed with minimum erosion.

In-depth discussion is performed on the samples after air jet erosion studies on the composites developed. Fig. 10 shows the dimple mark on the tested composite material. At 45° of impinge-



(a) (b)

Fig. 10. SEM image to represent the erosive wear (a) impact angle and (b) dimple

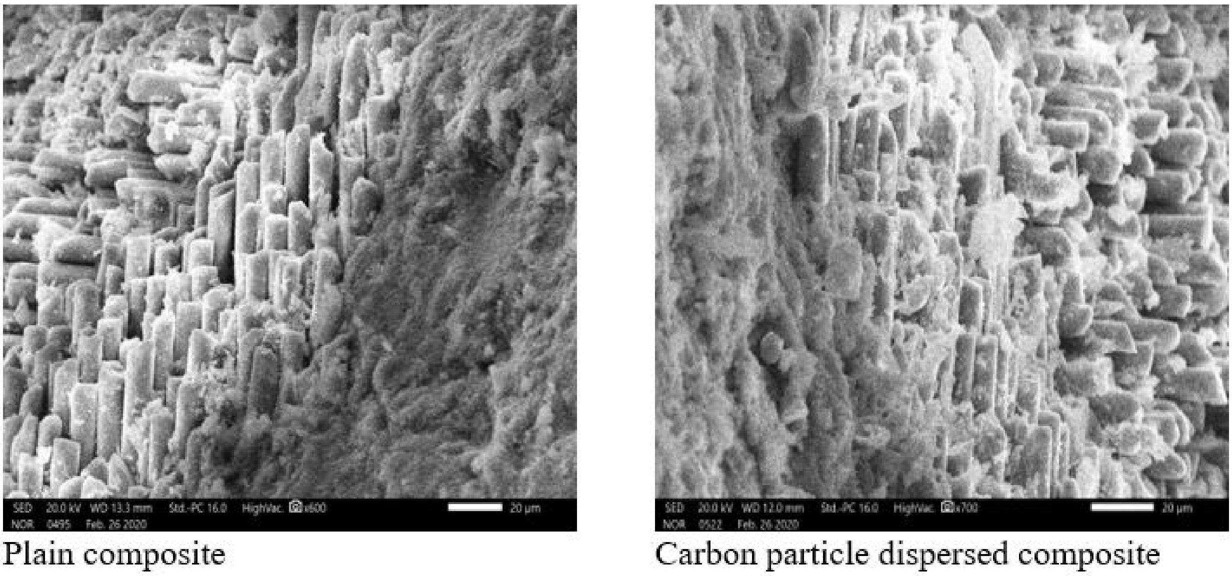


Fig. 11. Electron image to represent the fiber matrix bonding on worn surface

ment, the material floated made the surface to reveal a deep hole. Further, the surface at higher magnification is observed to read the material and fiber bonding. Fig. 11 shows the worn surface of the composite material. In the plain composite material, the shear fiber particle is found over the worn surface with more gaps indicating failure due to weak bonding. However, for the composite with carbon particle, dispersed material has good bonding strength compared to others. In addition, the erodent particles are found scattered over the worn surfaces. This is due to the clinging of hard particle over the matrix material. It is therefore confirmed that the composite with carbon dispersion has week bonding.

4. Conclusions

From the investigation, the fiber composite with and without carbon particle dispersion has been concluded with the following points:

1. The dispersion of carbon particle in the matrix material has reduced the mechanical strength. Sample with 4% of CNT dispersion in the composite has a maximum strength of 143 MPa and a minimum strength of 112 MPa.
2. The dispersion of carbon particle in the matrix material leads to reduced elongation and brittleness. However, the dispersed carbon particle has been supported to increase the bonding strength of the fibre and matrix material.
3. The dispersion of carbon particle in the matrix material increases the brittleness and the strength is found diminished. During the flexural bending, fiber delamination occurred and failure occurred in the plain composite.
4. Erosive wear is less at minimum impingement angle and the wear is found increasing at higher impingement angle. At 45°, 4% of CNT has 0.0003 g/g wear and 15% of carbon particle dispersion has 0.00087 g/g wear.

Therefore, it is recommended not to add carbon particle to a higher weight percentage as it leads to brittleness.

REFERENCES

[1] S. Wu, S. Peng, C. Wang, Polym. **10** (5), 542 (2018). DOI: https://doi.org/10.3390/polym10050542

[2] K. Sravanthi, V. Mahesh, B. Nageswara Rao, Mater. Today Proc. (2020). DOI: https://doi.org/10.1016/j.matpr.2020.06.298

[3] P. Naik, S. Pradhan, P. Sahoo, S.K. Acharya, Mater. Today Proc. **26**, 1892-1896 (2020). DOI: https://doi.org/10.1016/j.matpr.2020.02.414

[4] R.K. Nayak, D. Rathore, B.C. Routara, B.C. Ray, Int. J. Plast. Technol. **20** (2), 334-344 (2016). DOI: https://doi.org/10.1007/s12588-016-9158-z

[5] R.K. Nayak, A. Dash, B.C. Ray, Procedia Mater. Sci. **6**, 1359-1364 (2014). DOI: https://doi.org/10.1016/j.mspro.2014.07.115

[6] J.N. Coleman, U. Khan, W.J. Blau, Y.K. Gun'ko, Carbon N. Y. **44** (9), 1624-1652 (2006). DOI: https://doi.org/10.1016/j.carbon.2006.02.038

[7] G. Zhang, Z. Rasheva, J. Karger-Kocsis, T. Burkhart, Express Polym. Lett. **5** (10), 859-872 (2011). DOI: https://doi.org/10.3144/expresspolymlett.2011.85

[8] C. Lee, X. Wei, J. W. Kysar, J. Hone, Science, **321** (58), 385-388 (2008). DOI: https://doi.org/10.1126/science.1157996

[9] Z. Spitalsky, D. Tasis, K. Papagelis, C. Galiotis, Prog. Polym. Sci. **35** (3), 357-401 (2010). DOI: https://doi.org/10.1016/j.progpolymsci.2009.09.003

[10] B.-X. Yang, K.P. Pramoda, G.Q. Xu, S.H. Goh, Adv. Funct. Mater. **17** (13), 2062-2069 (2007). DOI: https://doi.org/10.1002/adfm.200600599

[11] L. Gorbatikh, S.V. Lomov, I. Verpoest, Procedia Eng. **10**, 3252-3258 (2011). DOI: https://doi.org/10.1016/j.proeng.2011.04.537

[12] S.S. Wicks, R.G. de Villoria, B.L. Wardle, Compos. Sci. Technol. **70** (1), 20-28 (2010).
DOI: https://doi.org/10.1016/j.compscitech.2009.09.001

[13] N. Chisholm, H. Mahfuz, V.K. Rangari, A. Ashfaq, S. Jeelani, Compos. Struct. **67** (1), 115-124 (2005).
DOI: https://doi.org/10.1016/j.compstruct.2004.01.010

[14] T. Peijs, F. Inam, D.W.Y. Wong, M. Kuwata, J. Nanomater. **2010** (2010). DOI: https://doi.org/10.1155/2010/453420

[15] K.S. Ahmed, S. Vijayarangan, A.C.B. Naidu, Mater. Des. **28** (8), 2287-2294 (2007).
DOI: https://doi.org/10.1016/j.matdes.2006.08.002

[16] D.P.N. Vlasveld, P.P. Parlevliet, H.E.N. Bersee, S.J. Picken, Compos. Part A Appl. Sci. Manuf. **36** (1), 1-11 (2005).
DOI: https://doi.org/10.1016/j.compositesa.2004.06.035

[17] B.K. Kandola, B. Biswas, D. Price, A.R. Horrocks, Polym. Degrad. Stab. **95** (2), 144-152 (2010).
DOI: https://doi.org/10.1016/j.polymdegradstab.2009.11.040

[18] T.P. Chua, M. Mariatti, A. Azizan, A.A. Rashid, Compos. Sci. Technol. **70** (4), 671-677 (2010).
DOI: https://doi.org/10.1016/j.compscitech.2009.12.023

[19] N. Mohan, S. Natarajan, S.P. KumareshBabu, Mater. Des. **32** (3), 1704-1709 (2011).
DOI: https://doi.org/10.1016/j.matdes.2010.08.050

[20] S.P. Jani, A. Senthil Kumar, M. Adam Khan, M. Uthaya Kumar. Mater. Manuf. Processes. **31** (10), 1393-1399 (2016).