EGTRIB Journal
JOURNAL OF
THE EGYPTIAN SOCIETY OF TRIBOLOGY
VOLUME 20, No. 2, April 2023, pp. 23 - 34 ISSN 2090 - 5882
(Received January 21. 2022, Accepted in final form January 29. 2023) jest.journals.ekb.eg

ENHANCING THE WEAR RESISTANCE OF GLASS FIBER-REINFORCED PLASTIC COMPOSITES THROUGH THE ADDITION OF BORON CARBIDE AND MULTI-WALLED CARBON NANOTUBES

Naguib G. Yakoub

Faculty of Engineering, Beni-Suef University, Beni-Suef, Egypt.

Abstract
The present study investigated the effect of various reinforcements, including boron carbide (B4C), multi-walled carbon nanotubes (MWCNTs), and a combination of both, on the wear resistance of composite materials made of glass fiber-reinforced plastic (GFRP). Four samples were used in the experiment, namely pure GFRP, GFRP with 0.2% B4C, GFRP with 0.2% MWCNTs, and GFRP with 0.2% B4C and 0.2% MWCNTs. Samples are subjected to various speeds of 1 m/s and 2 m/s as well as weights ranging from 50 N to 150 N. The wear resistance of the composite materials was assessed using weight loss before and after the testing. The outcomes demonstrated that the wear resistance of GFRP was improved by the addition of either B4C or MWCNTs. The composite material that was reinforced with both MWCNTs and B4CNTs additionally demonstrated the highest wear resistance. The aerospace and automobile industries, which demand materials with great wear resistance, can benefit from the information this study offers. The wear resistance of GFRP might be greatly improved by adding B4C and MWCNTs as reinforcement, leading to a longer service life and lower maintenance costs. The study's experimental design and findings may also serve as a foundation for future studies on how to improve the wear resistance of composite materials in various environments.

KEYWORDS
Multi-walled carbon nanotubes, glass fiber-reinforced polymer, tribological behavior, coefficient of friction.

INTRODUCTION

Because of their superior mechanical, physical, chemical, and structural properties, GFRP composites have found widespread application in a variety of industries including automotive, aircraft, ships, and boats. The addition of fillers to composite materials can improve the performance of the composite, [1 - 7]. The mechanical, thermal, and functional properties of epoxy resins can be improved by incorporating inorganic particles such as Al2O3, B4C, SiO2, TiO2, and other nano-

ceramic particles, [8]. The tribological behaviour of composite materials is critical in applications where materials are subjected to sliding conditions, [9]. Polymer composites' tribological properties cannot be predicted and must be evaluated in the specific environment and conditions in which they will be used, [10]. Factors such as matrix material and fibre orientation can improve or degrade the tribological properties of epoxy resin. Furthermore, environmental conditions, applied load, and sliding speed can all have an effect on wear, [11 - 15].Polymer composites reinforced with woven fabric have desirable properties and are simple to manufacture, [16]. Lim et al., [17] investigated the wear properties of carbon/carbon composites and discovered that CNTs improved wear resistance. Bagci et al., [18] investigated the wear behaviour of GFRP reinforced with silicon oxide and discovered that GFRP nano composites were resistant to abrasive particles. Debonding between the fibre and matrix, matrix fracture, delamination, and fibre fracture are all common types of wear in FRP, [19 - 24]. Deshpande et al., [25] investigated the wear resistance and friction coefficient of an HFRP/bone fibre composite and discovered that sliding speed had the greatest influence on wear rate. Jain et al., [26] investigated the effect of MWCNTs on the wear behaviour of GFRP and discovered that MWCNT addition significantly improved the wear rate. Basavarajappa et al., [27] discovered that using 10% graphite as a filler in GFRP/graphite composites reduced wear and friction. Hanumantharaya et al., [28] assessed the wear resistance of epoxy polymer composites reinforced with nanofillers such as fly ash, B_4C, and MoS_2. They concluded that the addition of these nanofillers improved the wear performance of pure epoxy composites. The hand layup method, a simple method for creating GFRP laminates, was used to study GFRP/Glass fibre nanocomposites. Gao et al., [29] previously investigated the effect of various fillers on the wear and friction resistance of epoxy composites, including short carbon fiber, short glass fiber, graphite, and silicon oxide. According to the results, the composite made of epoxy, short carbon fiber, silicon, and graphite had the best wear resistance.

The goal of the study was to determine the effectiveness of nano B_4C, nano MWCNTs, or a combination of the two in improving the wear resistance of glass fiber-reinforced plastic (GFRP). To that end, the tribological properties of GFRP composites containing B4C, MWCNTs, or a combination of the two were determined using a pin on disc testing method under various load and sliding speed conditions.

EXPERIMENTAL

Materials

The material used in the study was a combination of reinforcement E-glass fiber woven fabric with a surface weight of 600 GSM and matrix unsaturated epoxy resin (LY556). The hardener used was Araldite (HY951). The composite contained nanofillers in the form of 0.2% weight of B4C (50 nm) and 0.2% weight of MWCNTs (15 nm x 10 microns).The wet-hand lay-up method [30] was used to create three types of GFRP composites: GFRP/0.2% MWCNTs, GFRP/0.2% B_4C, and GFRP/0.1% B4C/0.1% MWCNTs. The procedure began with the creation of 170 x 170 mm^2 fiber mats. The matrix was then created by combining the

unsaturated epoxy and hardener in a 10:1 ratio.Table 1 describes the process of incorporating nanofillers into epoxy resin. The mixture was stirred for 15 minutes with a magnetic stirrer to ensure that the nanofillers were evenly distributed. As shown in Fig. 1, the composites were created using a flat wooden mould that was positioned horizontally and coated with wax to make removal easier. The composite was created by rolling out the first layer of epoxy resin on a roller, followed by laying a layer of E-glass fiber woven fabric on top.After that, the E-glass fibers were attached to the mould surface. A stainless-steel roller was used to remove any air pockets from the layers, ensuring that the epoxy resin was distributed evenly. Over the glass fiber sheet, another layer of epoxy resin was applied. The remaining GFRP/nanofiller composites were created using the same steps, but with the nanoparticles pre-incorporated into the resin. The thickness of all composites was kept constant at 5mm. The composites were allowed to sit at room temperature for 24 hours after the process was completed.

Fig. 1 Hand layup method.

Table 1 Percentage of nanofillers in GFRP composites.

Sample no.	GFRP wt.%	*Nano* B_4C wt.%	MWCNTs wt.%
1	100	0	0
2	99.8	0.2	0
3	99.8	0	0.2
4	99.6	0.2	0.2

Testing

Wear Test

In a dry sliding environment, the wear behaviour of GFRP composites with varying percentages of nanofillers was evaluated using an ASTM G99-05 compliant pin-on-disc wear testing machine (DUCOM, TR 20LE). Before and after testing, the specimens were cleaned, shaped into 10mm x 10mm x 35mm pins on a CNC milling machine, and their initial weights were measured with a high precision electronic balance. At room temperature, the tests were performed with a rotating disc made of hardened steel with a hardness of 60 HRC and a surface roughness of 1.8 micrometres.The pin was attached to it with a wear path diameter of 100mm. Normal loads of 50, 75, 100, 125, and 150 N were applied, with sliding velocities ranging between 1 and 2 m/s. The total sliding distance was 1180 m, and the wear rate was determined using the equation below.

$$Ws = \frac{\triangle m}{L\rho F}$$

Where,

ΔM = sample weight loss (kg)

ρ = Specimen density (kg/mm^3)

F = Applied Load at normal direction (N)

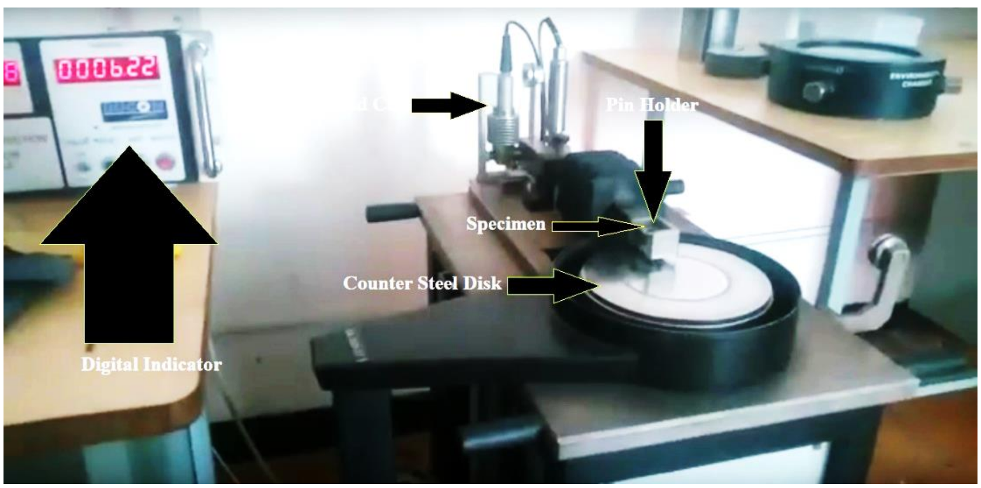

Fig. 2 pin-on disc wear tester

RESULT AND DISCUSSION

Weight loss

The wear characteristics of GFRP composites were investigated using weight loss measurements under varying loads and sliding speeds, with temperature, roughness, and lubrication also taken into account. Figures 3 and 4 show the results of tests with loads of 50 N, 75 N, 100 N, 125 N, and 150 N and sliding speeds of 1 m/s and 2 m/s. These findings demonstrate the effect of applied load and sliding speed on the weight loss of GFRP composites containing various nanoparticles. Temperature was found to play a role in surface wear, as increasing the temperature caused the polymer sample to soften. As the sliding speed and normal load increased, so did the temperature, resulting in increased wear on the sample

surface. While load and sliding speed increased the weight loss, the wear rate decreased due to the formation of a thicker, softer surface layer. As the temperature rose, the sample's epoxy matrix layer softened and separated from the glass fiber, resulting in increased weight loss as the load and sliding speed increased. The wear rate of the GFRP composite without nanofillers was the highest of the composites tested, as measured by weight loss, while the wear rate of the GFRP/B4C/MWCNT composite was the lowest. Fiber dilution, breakage, and peeling were identified as the three primary wear modes for all composite materials. The presence of a chemical bond between the epoxy and the filler material strengthens the composite overall, with the fiber bearing the majority of the load. Three-body abrasive wear is a major factor in composite wear, resulting in increased wear and higher coefficients of friction as the fiber breaks down.

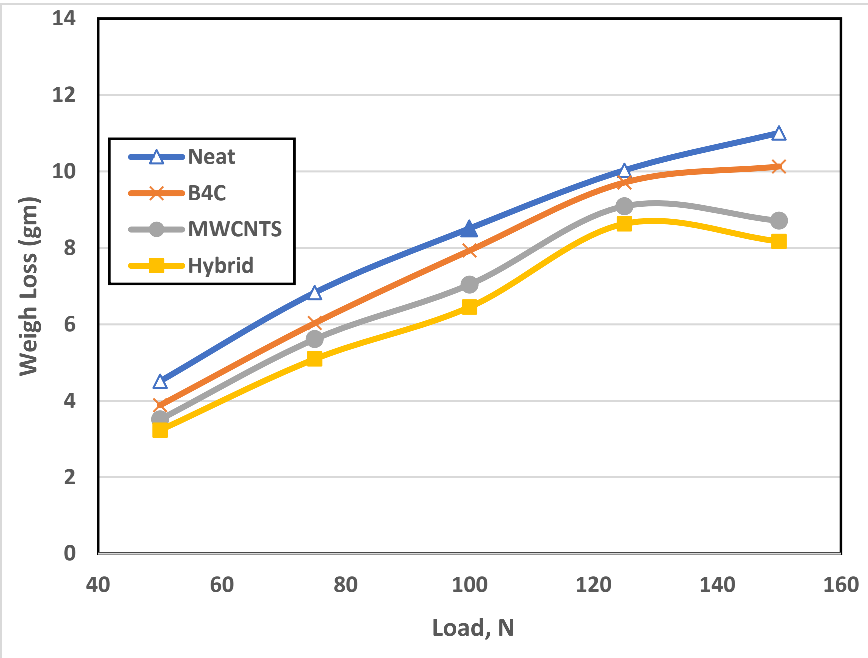

Fig. 3 weight loss versus applied load (sliding speed= 1 m/s, sliding distance=1180 m).

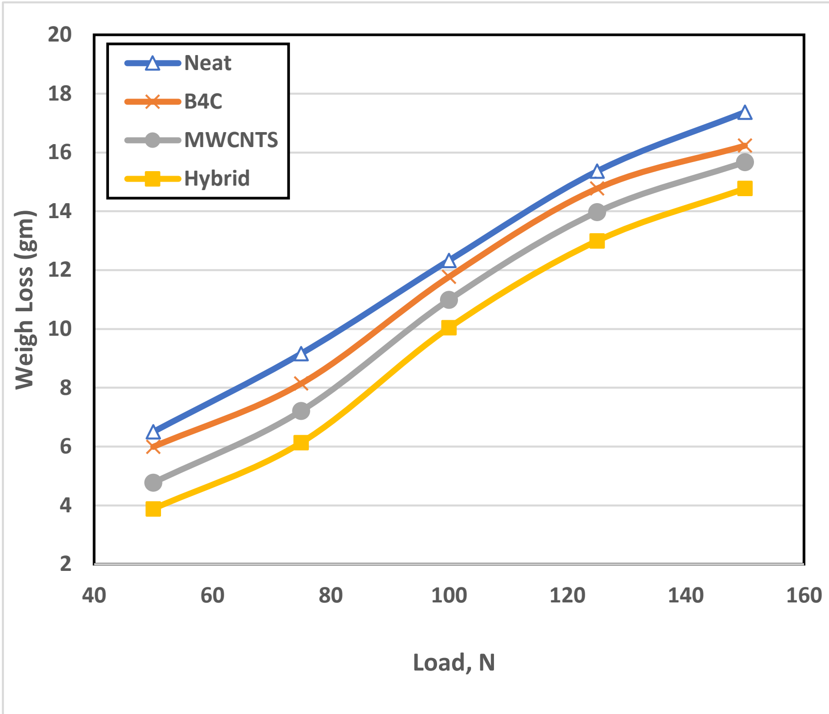

Fig. 4 weight loss versus applied load (sliding speed= 2 m/s, sliding distance=2360 m).

3.2. Specific wear rate

The specific wear rate of polymer composite materials is influenced by several factors, including the density of the specimen, the sliding velocity, and the applied load. The relationship between the specific wear rate and the applied load can be seen in Figures 5 and 6 for different glass fiber reinforced polymer (GFRP) composites at constant sliding speeds of 1 m/s and 2 m/s, respectively. In general, the specific wear rate of the GFRP composites decreases as the load increases from 50 N to 150 N. This is because harder surfaces tend to resist wear better, and as the load increases, the contact pressure between the surfaces also increases, making it more difficult for the softer material to deform and wear away. However, there is an exception in the case of the GFRP/B4C/MWCNT composite, which shows a continuous decrease in specific wear rate as the load increases. This indicates that the addition of boron carbide (B4C) and multi-walled carbon nanotubes (MWCNTs) to the composite has improved its wear resistance, even at higher loads. The B4C and MWCNTs are known to increase the composite material's hardness and toughness, respectively, making it more resistant to wear. Glass fibers, which are commonly used as reinforcing materials in GFRP composites, are brittle and abrasive, which can contribute to greater mass loss during wear tests. This is due to three-body abrasive wear [31-33], which occurs when hard particles (such as glass fibers) become trapped between the sliding surfaces and act as abrasives, causing the softer material to wear more quickly. Understanding the relationship between the specific wear rate and the applied load is therefore critical for selecting and designing wear-resistant polymer composite materials.

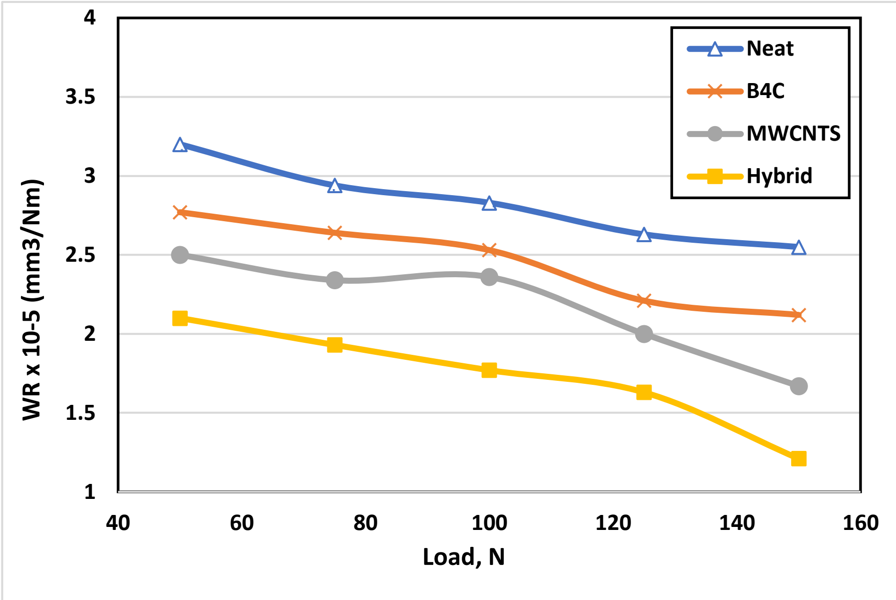

Fig.5 Specific wear versus applied load (sliding velocity 1 m/s, sliding distance = 1180 m).

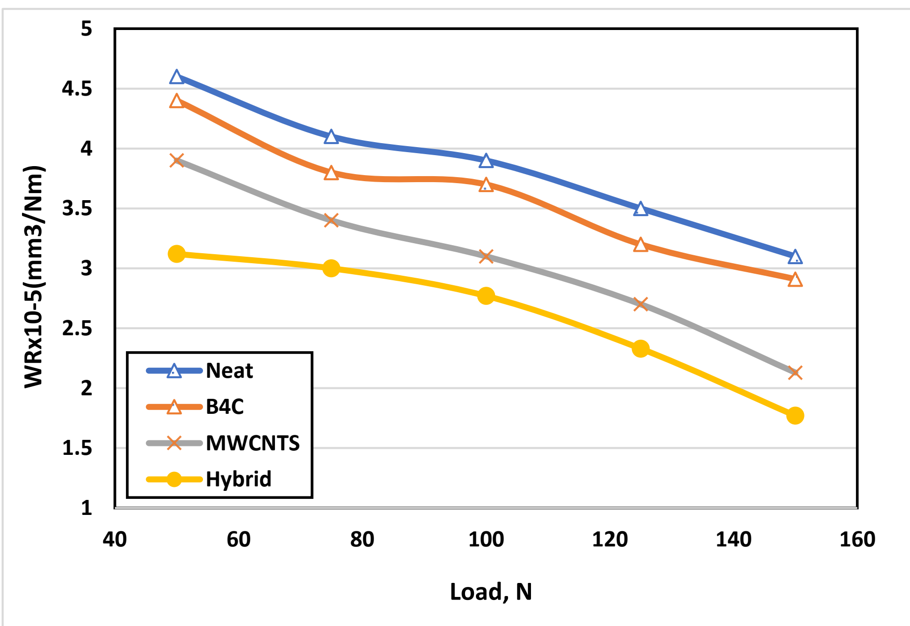

Fig. 6 Specific wear versus applied load (sliding velocity 2 m/s, sliding distance = 2360 m).

3.3. Friction Coefficient

The coefficient of friction is directly influenced by the applied load and sliding speed, as demonstrated by the data presented in Figures 7 and 8. According to Agrawal et al., [34], there is a positive correlation between the coefficient of friction and the applied load and sliding speed. This trend can be attributed to the wear behavior, viscoelastic properties, and temperature of the polymer. Friction generates heat, which raises the temperature of the contact surface and alters the viscoelastic properties of the surfaces in contact, [35]. GFRP composites containing B4C and MWCNT nanoparticles function as self-lubricants, resulting in reduced friction rates. Conversely, pure GFRP composites exhibit high wear and friction rates, whereas GFRP composites containing B4C and MWCNT have superior wear resistance.

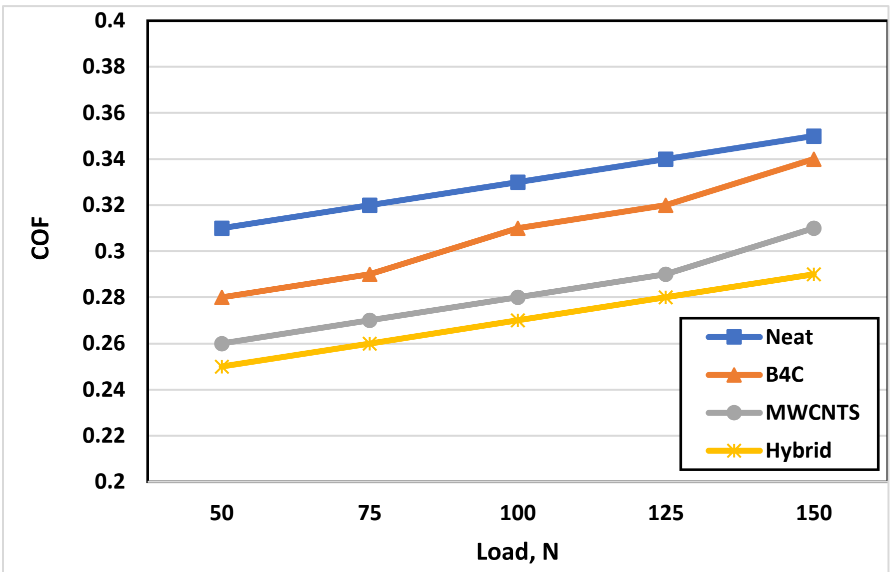

Fig. 7 COF versus applied load (sliding velocity 1 m/s, sliding distance = 1180 m).

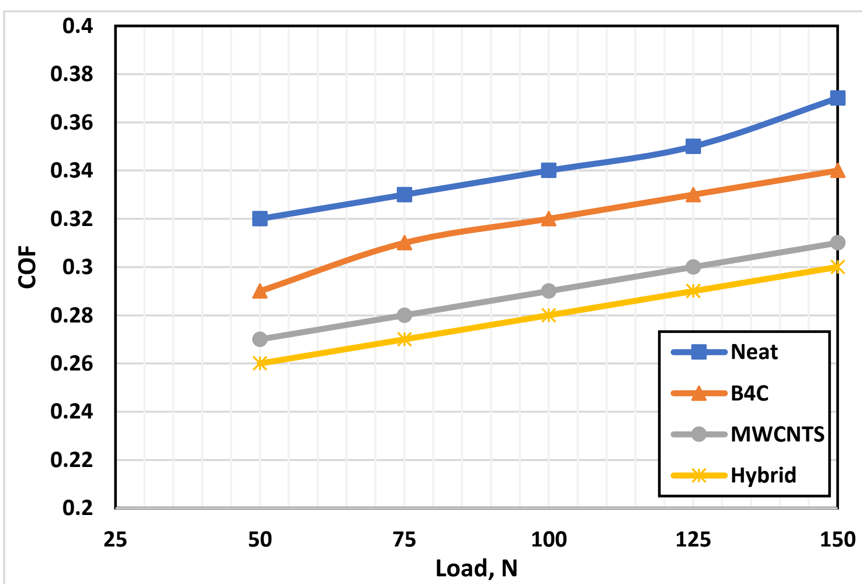

Fig. 8 COF versus applied load (sliding velocity 2 m/s, sliding distance = 2360 m).

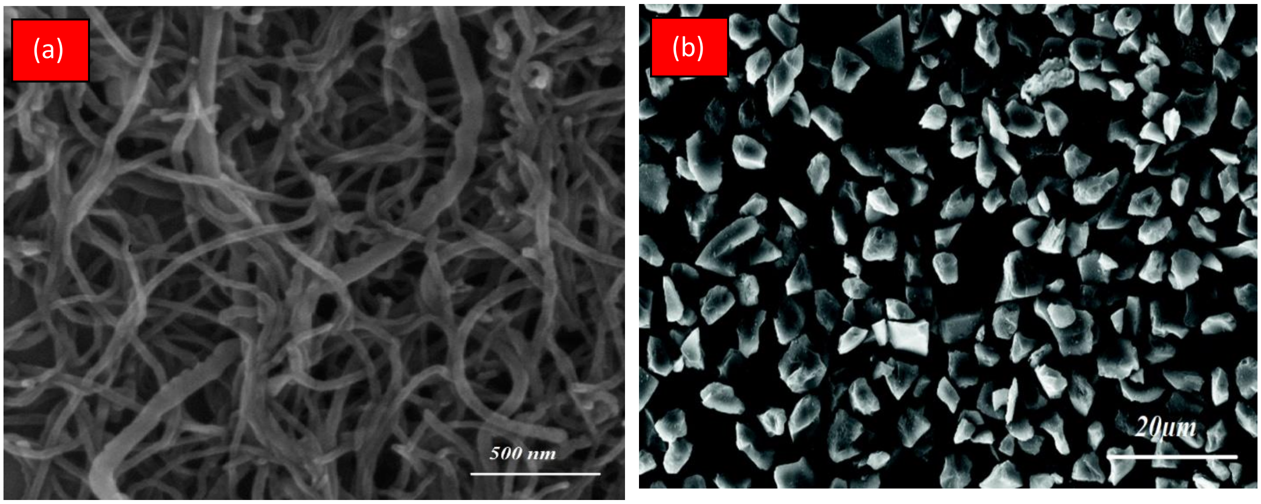

Fig. 9 SEM of nanofillers: (a) MWCNTs; (b) B_4C.

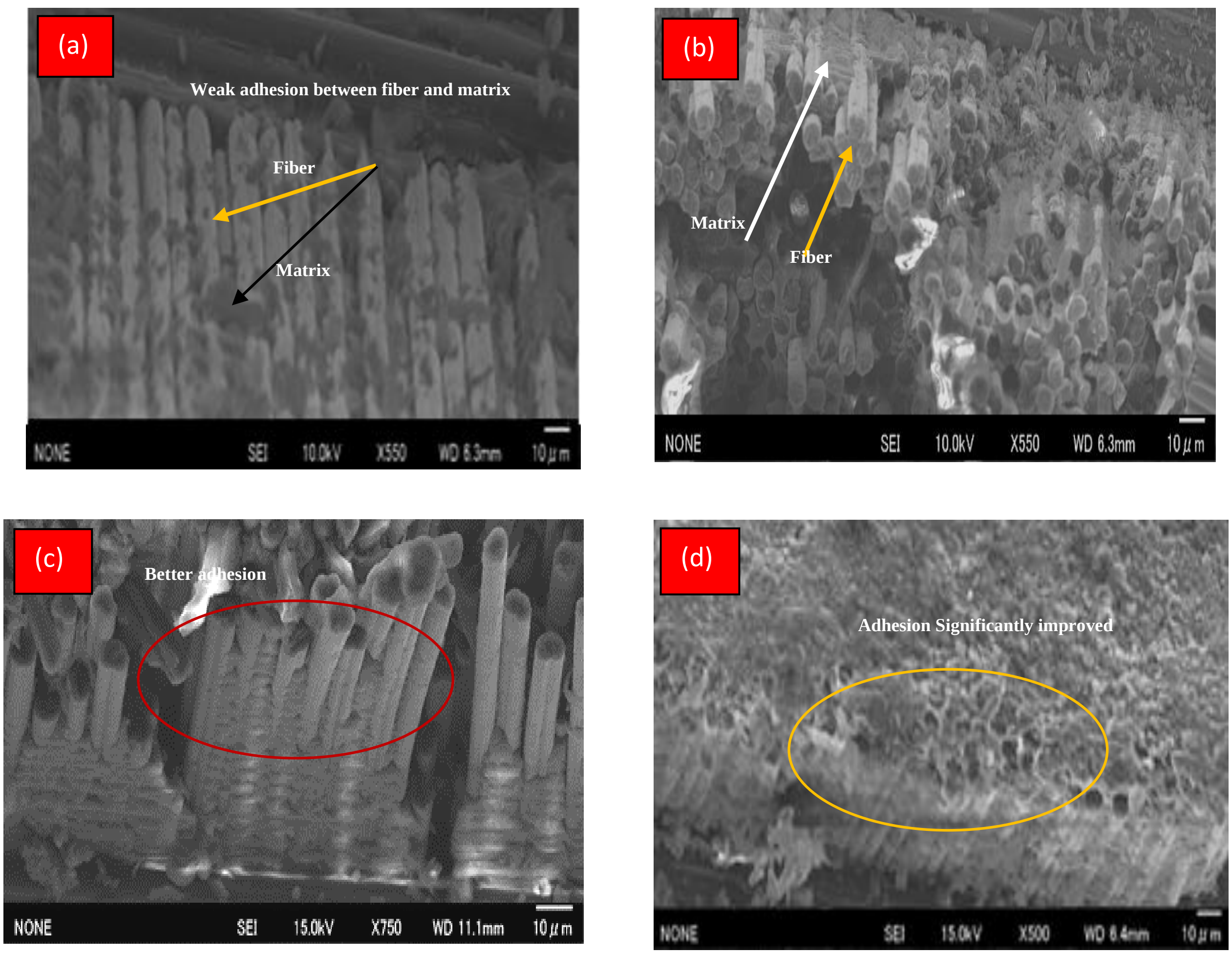

Fig. 10 SEM of worn surfaces: (a) Neat GFRP sample; (b) GFRP sample with 0.2 wt. % B_4C (c) GFRP sample with 0.2 wt. % MWCNT(d) GFRP sample with 0.2 wt. % B_4C + 0.2% MWCNT.

3.4. SEM inspection

SEM was used to examine the surface of Glass Fiber Reinforced Polymer (GFRP) composites with and without nanoparticles, as shown in Figures 9(a) and 9(b) .The surface wear of these composites was also studied. Figures 10(a) to 10(d) show SEM micrographs of the worn surfaces of various GFRP composites (d).Figure 10(a) depicts the surface of a plain GFRP sample, revealing that the resin in the first layer has mostly worn away and the fibers have been pulled and broken. It is also possible to see that the bond between the fiber and the epoxy matrix is weak. Figure 10(b) depicts the reduced wear rate on the surface of a sample containing 0.2 wt. % B4C when compared to a neat GFRP sample. Figure 10(c) shows that the surface of a 0.2 wt. % MWCNT sample has significantly less wear damage. Finally, Figure 10(d) depicts the improved interface bond between the epoxy matrix and fiber on the surface of a (GFRP / 0.2 % B4C / 0.2 % MWCNTs) sample under similar loading and sliding speed conditions.

CONCLUSIONS

The study's data suggests the following conclusions:

1. The applied load and sliding speed have a significant impact on the wear rate and friction behavior of GFRP composites, according to the data analyzed in the study.

2. As the load and speed increase, the polymer composite material softens, increasing the wear rate.

3. The coefficient of friction (COF) of GFRP increases as the applied load and speed increase.

4. When subjected to abrasive conditions, the unmodified GFRP composite was found to have the highest wear rate, which can be attributed to the three-body abrasive wear caused by fiber separation. The GFRP composite reinforced with both boron carbide and multi-walled carbon nanotubes, on the other hand, had the lowest wear rate.

5. Adding nano-sized boron carbide and multi-walled carbon nanotubes improves the tribological properties of GFRP composites significantly.

6. When compared to other GFRP composites without reinforcement, the GFRP composite reinforced with both B4C and MWCNTs had the highest wear resistance.

ACKNOWLEDGMENT

The author express gratitude towards Beni-Suef University and Minia University for the assistance and support provided.

REFERENCES

1. Mohan, N. Mahesha, C. R. Raja, R., "Tribo-mechanical behaviour of SiC filled glass-epoxy composites at elevated temperatures, Int. J. Eng., Sci. Technol. 6, pp. 44 – 56, (2014).

2. Shivamurthy, B. Prabhuswamy, M. S., "Influence of SiO2 fillers on sliding wear resistance and mechanical properties of compression moulded glass epoxy composites, J. Minerals Mater. Charact. Eng. 8, pp. 513 - 530 (2009).
3. Nadia, A., "Effect of Al_2O_3 and SiO_2 nanoparticle on wear hardness and impact behavior of epoxy composites, Chem. Mater. Res. 7, pp. 34 – 39, (2015).
4. Lingaraju, D., "Mechanical and tribological studies of polymer hybrid nanocomposites with nano reinforcements, Bull. Mater. Sci. 34 (4) 705 - 712, (2001).
5. Raju, B.R., "Investigations on mechanical and tribological behaviour of particulate filled glass fabric reinforced epoxy composites, J. Minerals Mater. Charact. Eng. 4 160–167 (2013).
6. Asi, O., "An experimental study on the bearing strength behavior of Al_2O_3particle filled glass fiber reinforced epoxy composites pinned joints, Compos. Struct. 92 (2), pp. 354 - 363 (2010).
7. Devendra, K. Rangaswamy, T., "Determination of mechanical properties of Al_2O_3, Mg(OH)2 and SiC filled E-glass/epoxy composites, Int. J. Eng. Res. Appl. 2, pp. 2028 - 2033 (2012).
8. M. Hussain, Y. Oku, A. Nakahira, and K. Niihara, "Effects of wet ball-milling on particle dispersion and mechanical properties of particulate epoxy composites," Mater. Lett., vol. 26, no. 3, pp. 177 - 184, (1996).
9. El-Tayeb NSM "wear and friction characteristics of chopped strand mat of glass fiber reinforced polyester composites" Proceed of the Int Conf on Recent Adv in Mech and Mater Eng; pp. 1006-1013(2005).
10. El-Tayeb, N. S. M., & Yousif, B. F., "Wear and Friction Behaviour of CGRP and WGRP Composites Subjected to Dry Sliding", Proceedings of the World Tribology Congress III. World Tribology Congress III, Volume 1. Washington, D.C., USA. September 12 - 16, pp. 31 – 32, ASME, (2005).
11. Findik F., Misirlioglu M. and Soy U., "The Structural Features of Glass Fiber Reinforced Polyester Matrix Composites" Science and Engineering of Composite Materials, vol. 10, no. 4, pp. 287 - 296 (2002).
12. Findik F., Yilmaz R., Koksal T., "Investigation of mechanical and physical properties of several industrial rubbers" Mater Des, 25 (4), pp. 269 – 276, (2004).
13. Kishore P. Sampathkumaran, Seetharamu S., Murali A., and Kumar R. K., "On the SEM features of glass–epoxy composite system subjected to dry sliding wear," Wear, vol. 247, no. 2, pp. 208 - 213, (2001).
14. Unal H., Findik F., and Mimaroglu A., "Mechanical behavior of nylon composites containing talc and kaolin", J. Appl. Polym. Sci., vol. 88, no. 7, pp. 1694 - 1697, (2003).
15.Vishwanath B., Verma A. P., Kameswara R. C. V. S., "Effect of matrix content on strength and wear of woven roving glass polymeric composites", Compos Sci Technol; 44, pp. 77 – 86, (1992).
16. Agrawal S., Singh K. K., Sarkar P. K., "A comparative Study of Wear and Friction Characteristics of Glass Fiber Reinforced Epoxy Resin, Sliding under Dry, Oil-lubricated and Inert Gas Environments" Tribology International, vol. 96, pp. 217 - 224, (2016).
17. Dae-Soon L., Jeong-wook A., Hwack J., "Effect of carbon nanotube addition on the tri biological behaviour of carbon/ carbon composites., Wear, 252, pp. 512 - 517 (2002).
18. Bagci M. and Imrek H., "Solid particle erosion behaviour of glass fibre reinforced boric acid filled epoxy resin composites," Tribol. Int., vol. 44, no. 12, pp. 1704 - 1710, (2011).

19. Collyer A. A., "Rubber Toughened Engineering Materials". 1st ed. London: Chapman and Hall, (1994).
20. El-Tayep N. S., Gadelrap R. M., "Friction and wear properties of E-glass fiber reinforced epoxy composites under different sliding contact conditions", Wear, 192, pp. 112 - 117 (1996).
21. Findik, F., "Latest progress on tribological properties of industrial materials" Mater Des; 57: pp. 218 – 244, (2014).
22. Kishore Sampathkumaran P., Seetharamu S., Vynatheya S., Murali A., Kumar, R. K., "SEM observations of the effect of velocity and load on the slide wear characteristics glass-fabric-epoxy composites with different fillers", Wear, Vol. 237, pp. 20 - 27 (2000).
23. Kukureka S. N., Hooke C. J., Rao M., Liao P., Chen Y. K., "The effect of fibre reinforcement on the friction and wear of polyamide 66 under dry rolling–sliding contact", Tribol. Int., Vol. 32, pp. 107 - 116 (1999).
24. Srivastava V. K., Pathak J. P., "Friction and wear properties of bushing bearing of graphite filled short glass fiber composite in dry sliding", Wear, 197, pp. 145 - 150 (1996).
25. Deshpande S., and Rangaswamy T., "Sliding Wear Characteristics of Bone Powder Filled Hybrid Fiber Reinforced Epoxy Compos ites, IOSR Journal of Mechanical and Civil Engineering (IOSR-JMCE), pp. 68 – 78, (2016).
26. Jain, A., Rawat, P., Singh K. K., "Wear and Frictional Behavior of Three Phased Glass/Epoxy Composite Laminate Reinforced with MWCNTs", Materials today proceedings, 5, pp. 8112 - 8120, (2017).
27. Basavarajappa S., Ellangovan S., Arun K.,"Studies on dry sliding wear behaviour of Graphite filled glass–epoxy compos ites; Materials and Design, pp. 2670 - 2675 (2009).
28. Hanumantharaya R., Vaisha, N. L., Davanageri, B. M., Quadros, J. D., Premkumar B. G., "Mechanical and Tribological Wear Behavior of Epoxy Hybrid Composites", Materials Today: Proceedings, pp. 7947 – 7953, (2018).
29. Gao C., Gou, G. Zhao, F. Wang, T. "Tribological behavior of epoxy composites under water lubrication conditions", Tribology International 95, pp. 333 – 341, (2016).
30. EI-Tayeb N. S. M., Yousif B. F., Yap T. C., "Tribological studies of polyester reinforced with CSM 450-R-glass fiber sliding against smooth stainless steel counterface", Wear, 261, pp. 443 - 452 (2006).
31. Friedrich, K., "Friction and Wear of Polymer Composites", Composite Materials Series, Elsevier, Amsterdam, Vol. 1, pp. 233 - 287(1986).
32. Bahadur S., Fu Q., and Gong D., "The effect of reinforcement and the synergism between CuS and carbon fiber on the wear of nylon," Wear, vol. 178, no. 1–2, pp. 123 - 130, (1994).
33. Suresha B., Kumar K. S., Seetharamu S. and Kumaran P. S., "Friction and dry sliding wear behavior of carbon and glass fabric reinforced vinyl ester composites," Tribol. Int., vol. 43, no. 3, pp. 602 - 609, (2010).
34. Agrawal S., Singh K. K., Sarkar P. K., "A comparative Study of Wear and Friction Characteristics of Glass Fiber Reinforced Epoxy Resin, Sliding under Dry, Oil-lubricated and Inert Gas Environments", Tribology International, vol. 96, pp. 217 - 224, (2016).
35. Mimaroglu A., Unal H., Arda T., "Friction and wear performance of pure and glass fiber reinforced polyetherimide on polymer and steel counterface materials", Wear, Vol. 262, No. 11–12, pp. 1407 - 1413, (2007).