EGTRIB Journal

JOURNAL OF
THE EGYPTIAN SOCIETY OF TRIBOLOGY
VOLUME 21, No. 3, July 2024, pp. 42 - 54 ISSN 2090 - 5882
(Received March 28. 2024, Accepted in final form June 09. 2024) jest.journals.ekb.eg

FRICTION AND WEAR OF SCRATCHED POLYMERIC COMPOSITES

Ali A. S.[1], Al-Kabbany A. M.[2], Zeinab A. H.[2], Ali W. Y.[2] and Atia K. M.[2]

[1]Mechanical Engineering Dept., Faculty of Engineering, Suez Canal University,
[2]Department of Production engineering and Mechanical Design,
Minia University, El-Minia, Egypt.

ABSTRACT

The present study investigates friction and wear of polymeric composites by scratch test. Polymeric composites consisting of polymethyl methacrylate (PMMA) and polyethylene (PE) have been filled by sand, aluminum, copper, carbon fibers and carbon nanotubes. The tribological properties have been determined by scratch test.

The experiments revealed that friction coefficient slightly increased up to maximum then decreased with increasing the applied load. Filling composites by sand increased friction coefficient and decreased wear, while copper and aluminum as fillers did not alter frictional behavior but they increased wear. It was observed that addition of carbon fibers and carbon nanotubes drastically decreased friction coefficient and wear. It seems that they provided low shear layer in the in the contact surface of the tested composites that decreased friction. Besides, their lubricating action decreased wear.

KEYWORDS

Friction, wear, scratch test, polymeric composites, electrically conductive materials.

INTRODUCTION

The frictional behavior of polymeric composites filled by sand and conductive materials to decrease the electrostatic charge (ESC) generated on the surface when sliding on steel surface has been investigated, [1]. It was found the resultant charge gained by composites surface represented minimum values. Electrostatic charges (ESC) generated from sliding of polymeric materials greatly influences their tribological performance. The wide use of polymers raised the need to study that effect, [2]. It was found that ESC generated due to the sliding of aluminum, copper, iron, silicon oxide and aluminum oxide on rubber generated the relatively low ESC, while PTFE showed high ESC one. ESC generated from the sliding of polymers on stainless steel was measured, [3]. ESC of latex rubber sheets slid on PTFE, polyurethane (PU) and stainless steel was measured, [4]. It was revealed that material strain critically affected ESC.

It was observed that the glass fiber allowed the trapping of ESC, [5, 6]. Besides, tribological experiments were performed to investigate the influence of ESC on both friction coefficient and wear. Because polymers have low mobility, therefore strong localization of ESC can occur, [7].

In aeronautical industry, carbon fiber reinforced materials composites provide higher mechanical properties, [8 - 12]. In addition to that, carbon fibers are widely applied in polymer composites for high strength as well as wear resistance, [13 - 16]. Epoxy composites reinforced by carbon fibers and filled by TiO_2 nanoparticles decreased the friction and wear, [17, 18]. Epoxy composites reinforced by parallel unidirectional carbon fibers showed lower friction values, [19 - 21]. That performance recommends the composites to be used in guide ways and antifriction bearings.

In the present work, it is aimed to study the influence of filling the composites incorporating PMMA and PE and filled by sand as well as electrically conductive materials such as copper, aluminum, carbon fibers and carbon nanotubes on their friction and wear during scratch test.

EXPERIMENTAL

The scratch tester shown in Figs. 1, 2 consists of 90° apex angle steel stylus mounted in the loading lever. The loading lever was balanced by counter weight. Load was applied using 2, 4, 6, 8 and 10 N weights. Scratch force was measured by load cell connected to digital monitor. The tested composites were scratched by the stylus. The test was conducted under dry conditions. The details of the scratch test are shown in Fig. 2. After measuring the scratch force the friction coefficient was calculated. The wear scar width was determined by optical microscope of an accuracy of ± 1.0 µm.

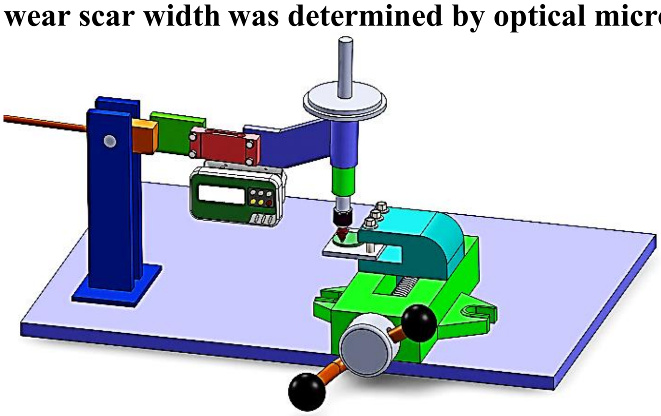


Fig. 1 Arrangement of scratch test rig.

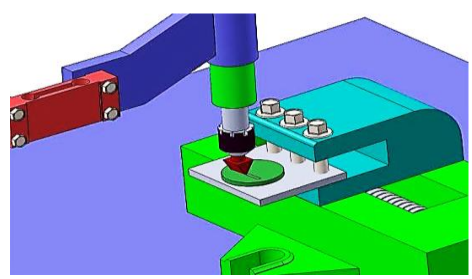


Fig. 2 Details of scratch.

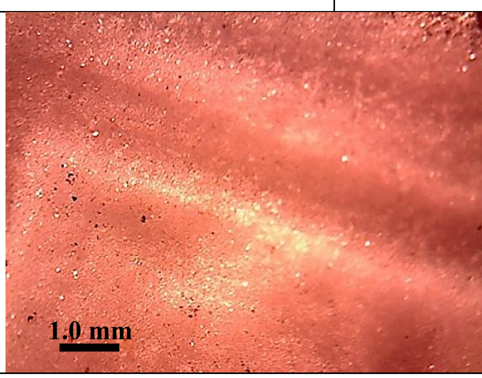
The tested composites containing PE and PMMA. Sand particles of 25 – 50 µm size were added in 5.0 wt. % content. Copper and aluminum particles, of 5 – 10 µm size and 5.0 wt. % content, were filling the tested composites. Besides, carbon fibers of 0.65 µm diameter and 2.0 mm long as well as carbon nanotubes were applied as filling materials in 0.5 wt. % content. The tested composites were (100 wt. % PE), (100 wt. % PMMA), (50 wt. % PE + 50 wt. % PMMA), (50 wt. % PE + 50 wt. % PMMA + 5.0 wt. % sand), (50 wt. % PE + 50 wt. % PMMA + 5.0 wt. % sand + 5.0 wt. % copper),

(50 wt. % PE + 50 wt. % PMMA + 5.0 wt. % sand + 5.0 wt. % aluminum), (50 wt. % PE + 50 wt. % PMMA + 5.0 wt. % sand + 5.0 wt. % carbon fibers) and (50 wt. % PE + 50 wt. % PMMA + 5.0 wt. % sand + 5.0 wt. % carbon nanotubes). The evidence of wear scar in the tested composites is shown in Fig. 3.

50 wt. % PE + 50 wt. % PMMA + 5.0 wt. % Sand + 5.0 wt. % aluminum

50 wt. % PE + 50 wt. % PMMA + 5.0 wt. % Sand + 0.5 wt. % Carbon Fibers

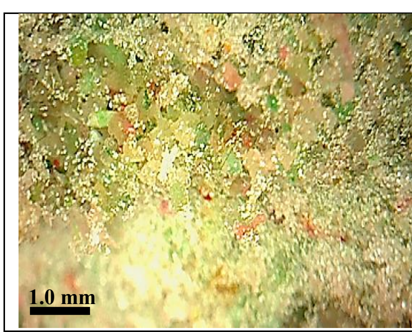
50 wt. % PE + 50 wt. % PMMA + 5.0 wt. % Sand + 5.0 wt. % copper



100 wt. % PMMA

50 wt. % PE + 50 wt. % PMMA + 5.0 wt. % Sand

Fig. 3 Evidence of wear scar in the tested composites.



50 wt. % PE + 50 wt. % PMMA	**50 wt. % PE + 50 wt. % PMMA + 5.0 wt. % Sand**	**50 wt. % PE + 50 wt. % PMMA + 5.0 wt. % Sand + 5.0 wt. % copper**
		
50 wt. % PE + 50 wt. % PMMA + 5.0 wt. % Sand + 5.0 wt. % aluminum	**50 wt. % PE + 50 wt. % PMMA + 5.0 wt. % Sand + 0.5 wt. % Carbon Fibers**	**50 wt. % PE + 50 wt. % PMMA + 5.0 wt. % Sand + 0.5 wt. % Carbon nanotubes**

Fig. 3 Photomicrograghs of the tested composites.

RESULTS AND DISCUSSION

Friction coefficient of the tested polymers slightly increased up to maximum then decreased with increasing applied load, Fig. 4. Test specimens of 100 wt. % PMMA displayed the highest friction values, while specimens of 100 wt. % PE showed the lowest ones. Composites containing (50 wt. % PE + 50 wt. % PMMA) showed the moderate values. It is well known that during rolling, high stresses at the contact area displays insignificant effect on the tribological performance of a polymer. While in sliding, the high shear deformation develops in the surface causing the transfer of polymer to the stylus surface. In that condition, friction coefficient increases with increasing load up to maximum then decreases with further increasing the load. The increase of the friction is due to the increase in the contact area when the load increased. Then the decrease in friction after reaching the maximum value may be attributed to the heat generated during abrasion at loads that are higher than the critical value. Besides, at high temperature, the polymeric layer of low shear strength will be formed at the contact surface leading to the decrease of the friction coefficient.

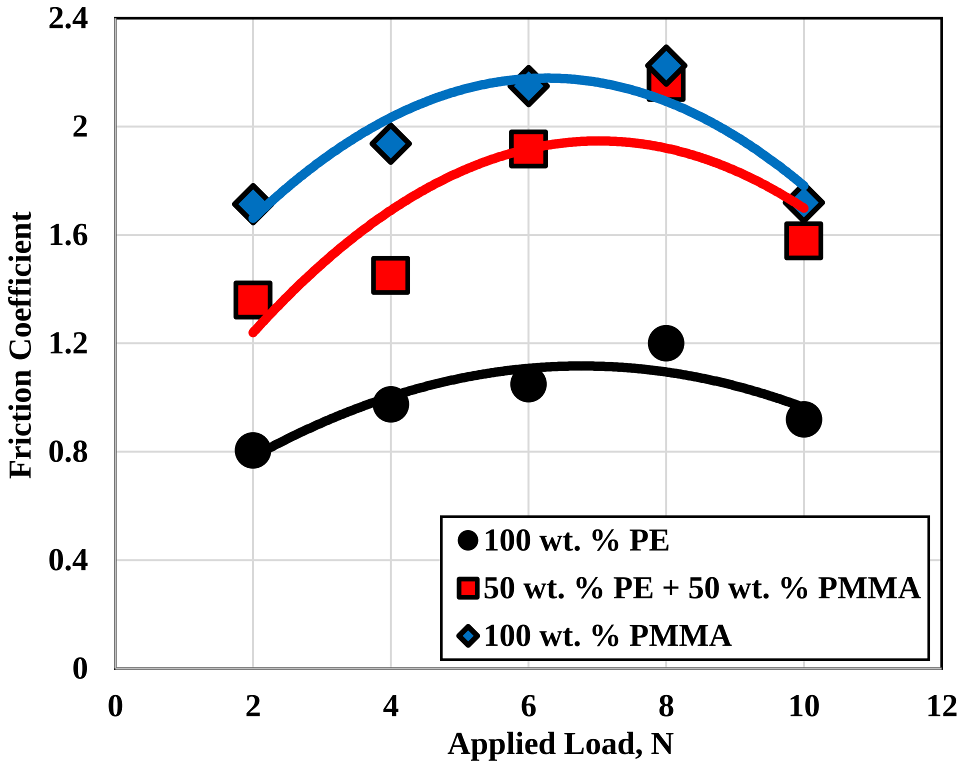


Fig. 4 Friction coefficient of the tested polymers.

The tested composites incorporating (50 wt. % PE + 50 wt. % PMMA) filled by 5.0 wt. % sand, showed higher friction values than that displayed by composites free of sand, Fig. 5. It is expected that when sand particles abraded the polymeric layer of low shear value from the stylus surface and interacted in the steel surface of the stylus. Besides, sand particles acted as multiple number of abrasive tips that increased the friction force.

The addition of the copper into the composites (50 wt. % PE + 50 wt. % PMMA + 5.0 wt. % sand) showed the same trend of friction similar to that displayed by the composite free of copper, Fig. 6. The same trend was observed for the composites filled by aluminum, Fig. 7. It seems that addition of copper and aluminum did not affect the frictional behavior.

Reinforcing the tested composites by carbon fibers displayed drastic friction decrease, Fig. 8. The same behavior was displayed by composites filled by carbon nanotubes, Fig. 9. It can be concluded that addition of both carbon fibers and carbon nanotubes into composites matrix can reduce the frictional performance.

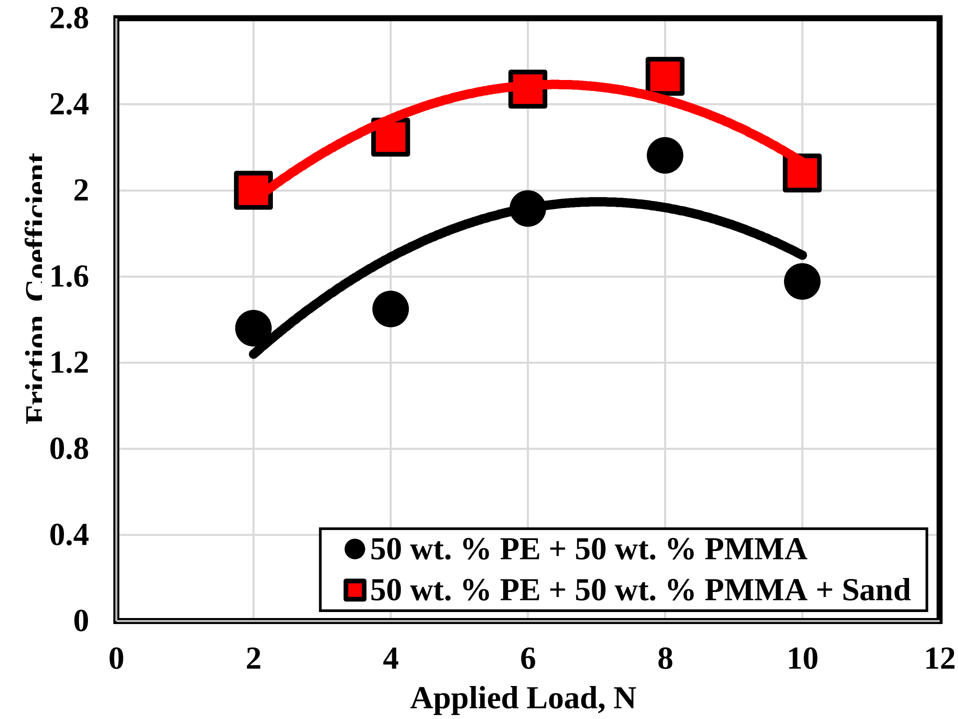


Fig. 5 Comparison of the friction coefficient of the tested polymer composites with that filled by sand.

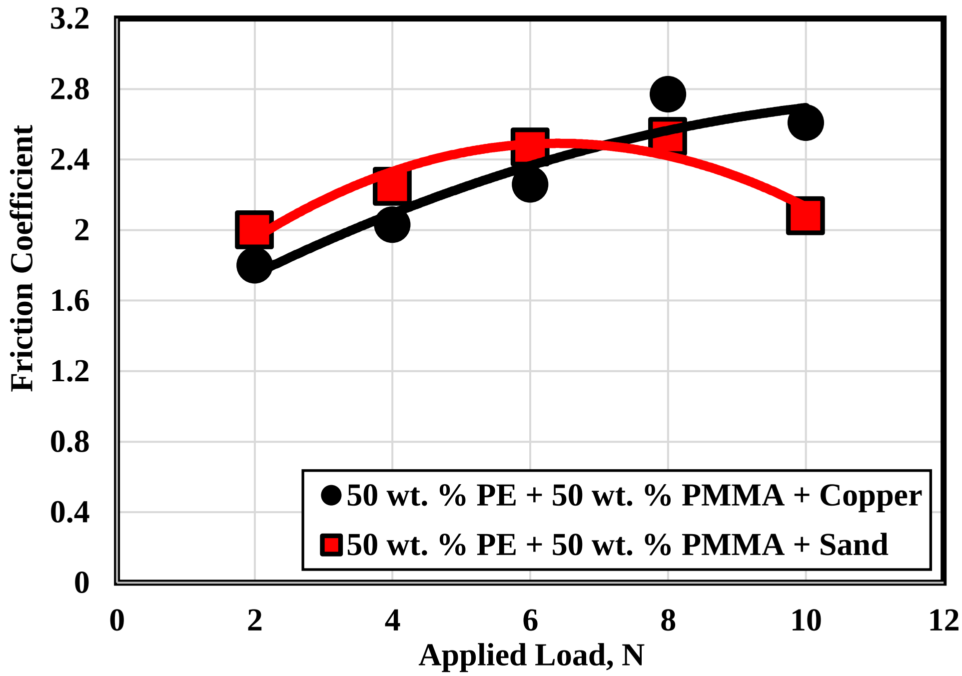


Fig. 6 Comparison of the friction coefficient of the tested polymer composites filled by sand and copper particles.

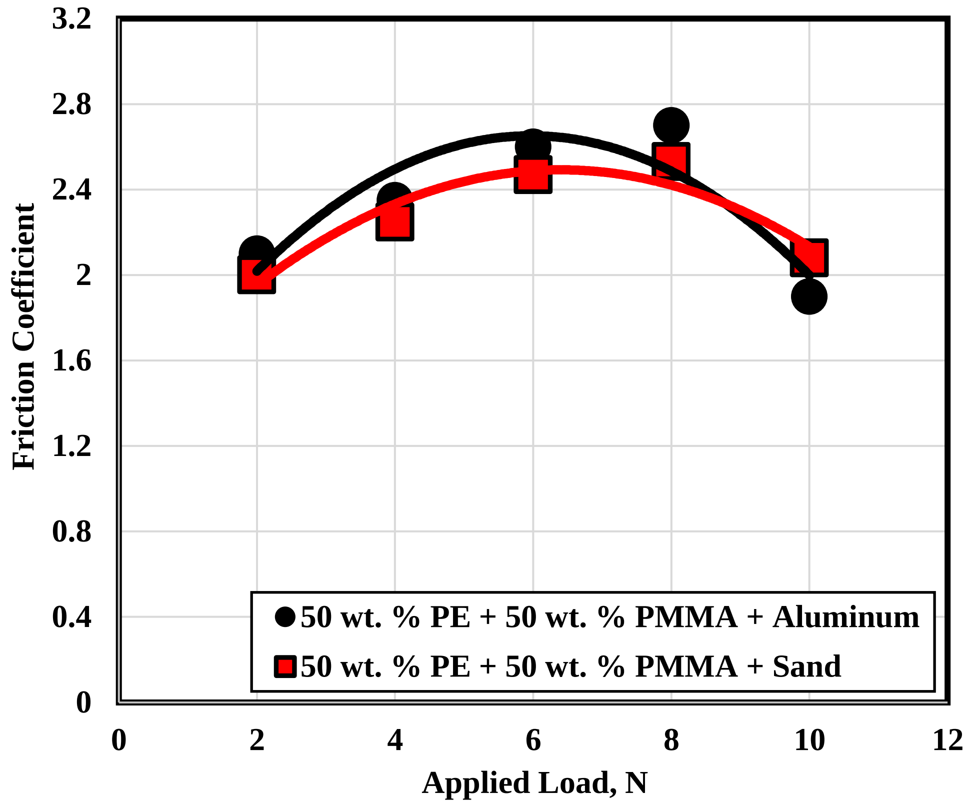


Fig. 7 Comparison of the friction coefficient of the tested polymer composites filled by sand and aluminum particles.

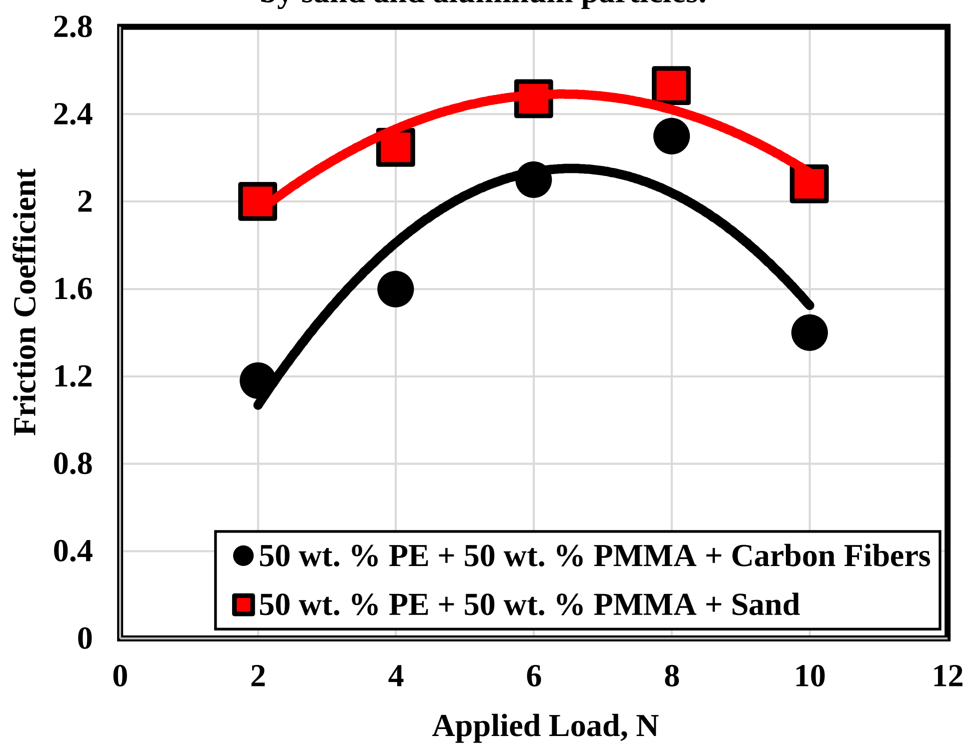


Fig. 8 Comparison of the friction coefficient of the tested polymer composites filled by sand and carbon fibers.

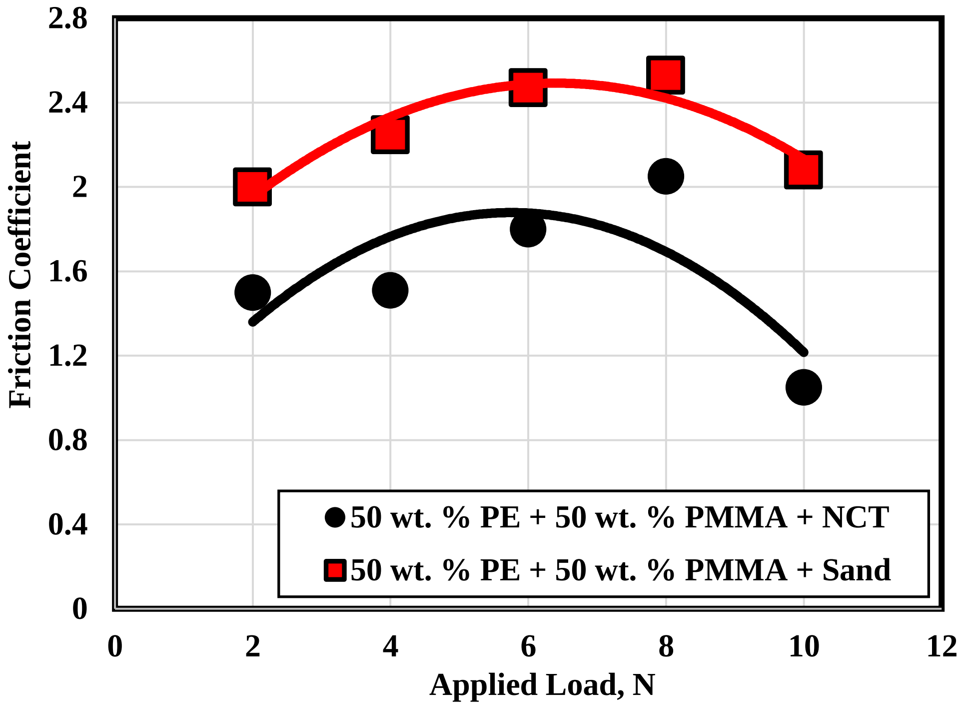


Fig. 9 Comparison of the friction coefficient of the tested polymer composites filled by sand and nanocarbon tubes.

Wear of the tested composites measured by wear scar width increased with increasing the applied load, Fig. 10. Composites containing (50 wt. % PE + 50 wt. % PMMA) displayed the highest wear values followed by the composites (100 wt. % PE) and (100 wt. % PMMA). It seems that the adhesion of the particles of both PE and PMMA was responsible for that behavior. The contact of the steel stylus with the tested composites provided the steel with positive electric charge when contacted PE and negative charge when contacted PMMA. Because steel is conductive material, both positive and negative charge are equalized. Consequently, the worn particles of PE and PMMA weakly adhered into the surface of the steel stylus facilitating the excessive cutting.

Comparing the wear of the tested polymer composites with that filled by sand showed that sand particles drastically decreased the wear. That behavior was clearly observed at relatively higher load, Fig. 11. It seems that sand particles resisted the abrading action of the stylus and removal of the polymeric composites. Using of copper as filler facilitated the interaction of the stylus in the surface of the composites. This performance can be attributed to the lubricating action of copper particle, Fig. 12.

Copper particles as good electrically conductive medium conducted ESC from the surfaces of PE, PMMA and sand to each other and exchanged the negative and positive charges formed on the sliding surfaces. The same trend was observed for aluminum filling the teste composites, Fig. 13.

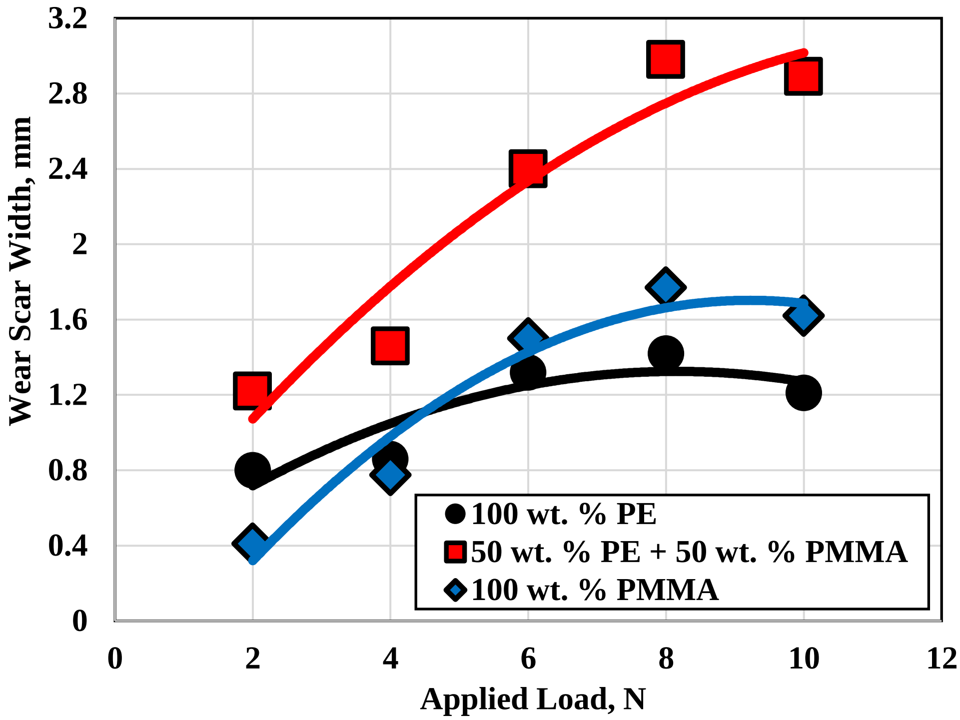


Fig. 10 Wear scar width of the tested composites.

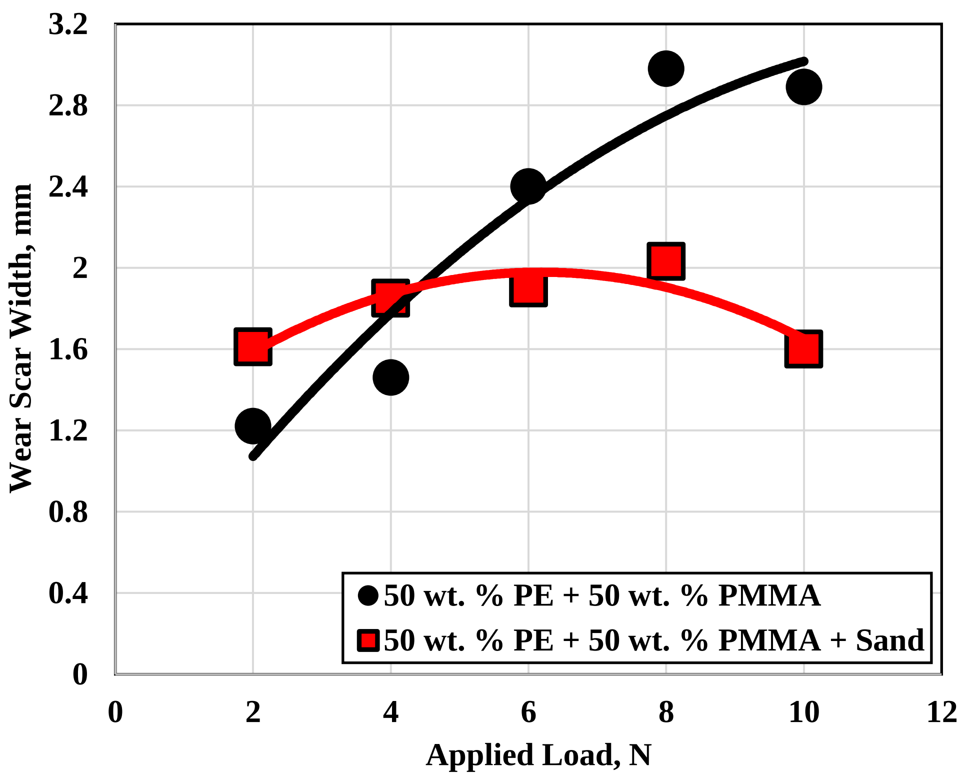


Fig. 11 Comparison of the wear scar width of the tested polymer composites with that filled by sand.

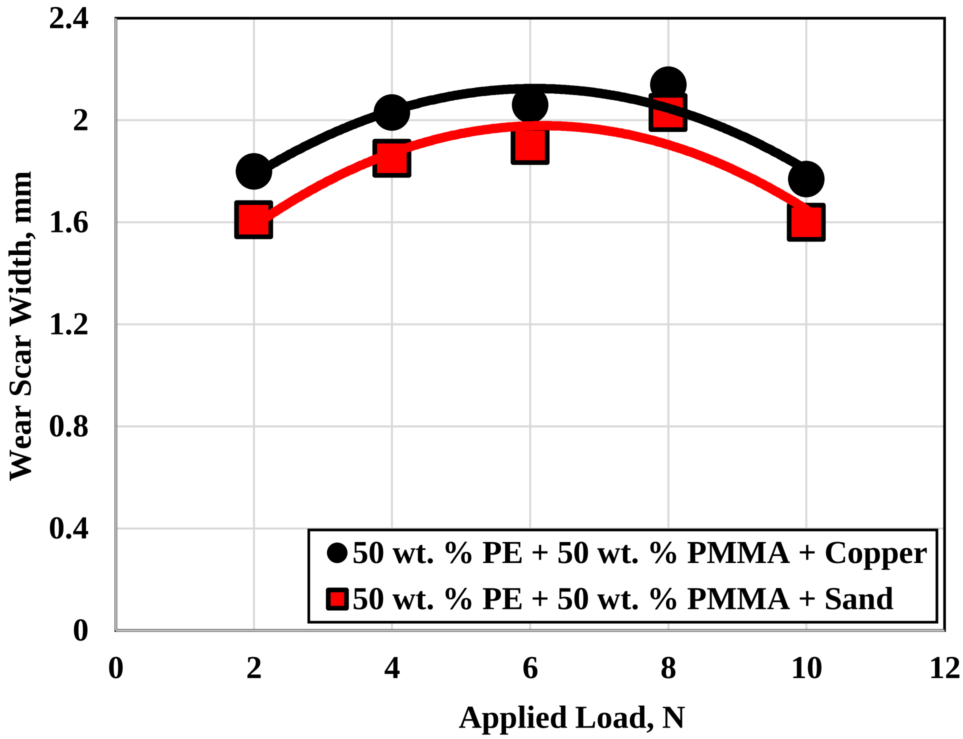


Fig. 12 Comparison of the wear scar width of the tested polymer composites filled by sand and copper.

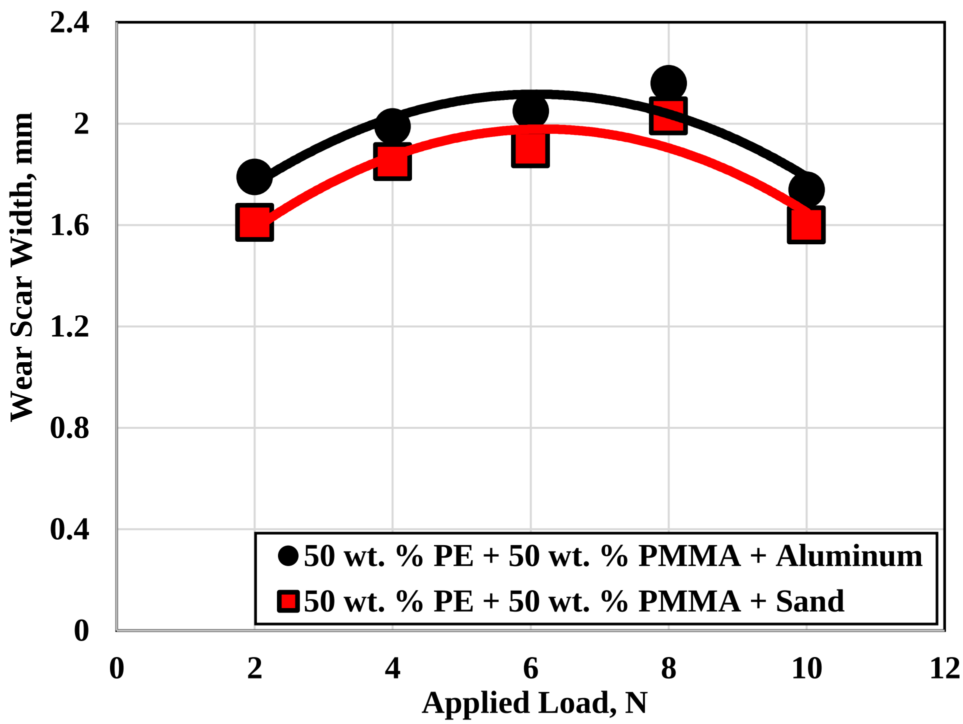


Fig. 13 Comparison of the wear scar width of the tested polymer composites filled by sand and aluminum.

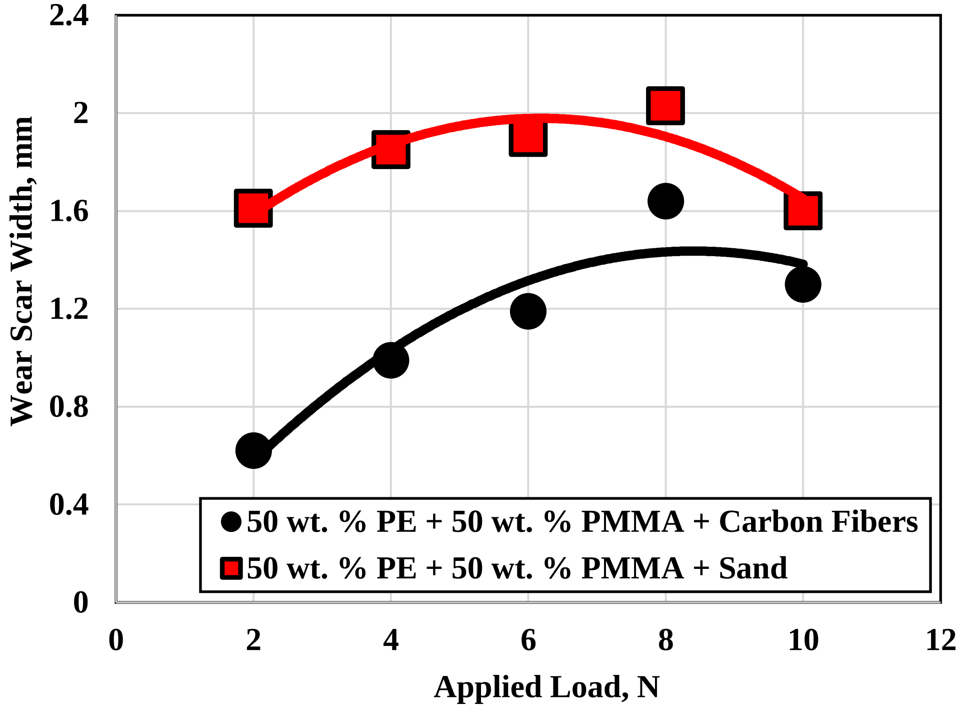


Fig. 14 Comparison of the wear scar width of the tested polymer composites filled by sand and carbon fibers.

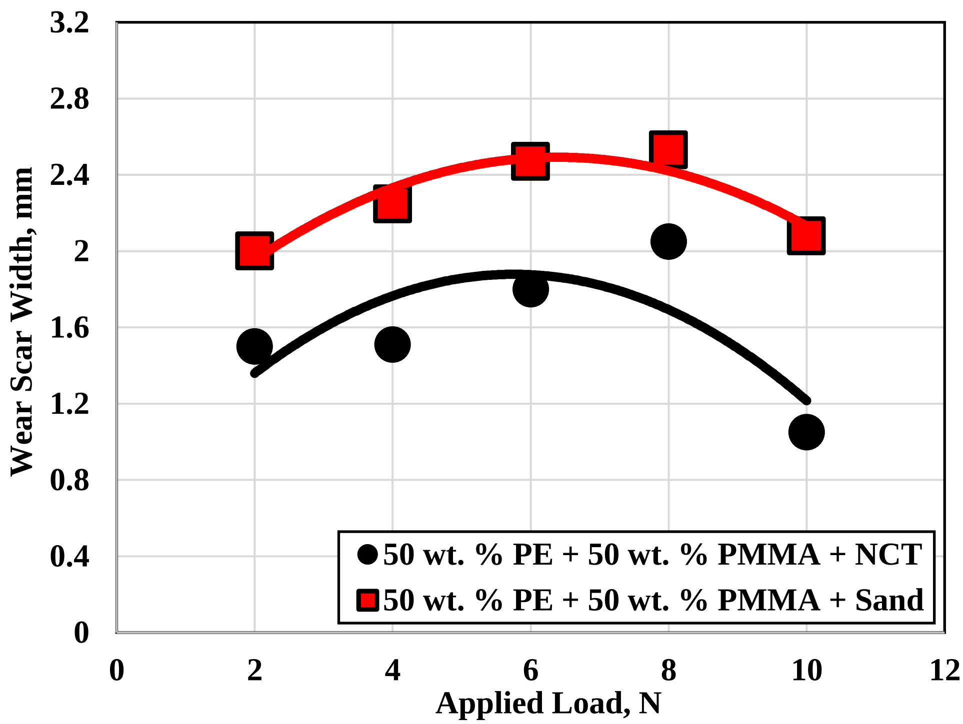


Fig. 15 Comparison of the wear scar width of the tested polymer composites filled by sand and carbon fibers.

Using carbon fibers and carbon nanotubes as filling materials showed significant reduction in wear due to their lubrication action, Figs. 14, 15. Their mechanism of action depends on providing low shear zones in the matrix of the composites limiting the abrading of the surface.

CONCLUSIONS

1. Friction coefficient of the scratched tested polymers slightly increased up to maximum then decreased as the applied load increased. Composites containing (50 wt. % PE + 50 wt. % PMMA) showed average values relative to (100 wt. % PMMA and 100 wt. % PE) composites.
2. Friction coefficient values increased for composites filled by 5.0 wt. % sand compared to that displayed by composites free of sand.
3. Addition of copper and aluminum did not affect the frictional behavior.
4. Drastic friction decrease was observed for tested composites filled by carbon fibers and carbon nanotubes.
5. Wear of the tested composites was increased with increasing the applied load.
6. Composites containing (50 wt. % PE + 50 wt. % PMMA) displayed the highest wear values followed by the composites 100 wt. % PE and 100 wt. % PMMA.
7. Wear of the tested polymer composites filled by sand showed wear decrease.
8. Copper and aluminum as fillers increased wear.
9. Significant wear reduction was observed for tested composites filled by carbon fibers and carbon nanotubes due to their lubrication action.

REFERENCES

1. Ali A. S., Al-Kabbany A. M., Youssef M. M. and Ali W. Y., "Role of Triboelectrification on the Friction of Sliding Surfaces", Journal of the Egyptian Society of Tribology, Vol. 21, No. 3, July 2024, pp. 1 – 10, (2014).
2. Alahmadi A., "Triboelectrification of engineering materials", Journal of the Egyptian Society of Tribology, Vol. 11, No. 1, January 2014, pp. 12 – 23, (2014).
3. Alahmadi A., Mohamed M. K. and Ali W. Y., "Electric static charge generated from the sliding of polymers against stainless steel", Journal of the Egyptian Society of Tribology, Vol. 11, No. 1, January 2014, pp. 24 – 34, (2014).
4. Sow M., Lacks D. J., Sankaran R. M., "Effects of material strain on triboelectric charging: Influence of material properties", Journal of Electrostatics 71 pp. 396 – 399, (2013).
5. Kchaou B., Turki C., Salvia M., Fakhfakh Z., Tréheux D., "Dielectric and friction behaviour of unidirectional glass fibre reinforced epoxy (GFRE)", Wear 265, pp. 763 - 771, (2008).
6. B. Kchaou, C. Turki, M. Salvia, Z. Fakhfakh, D. Tréheux, "Role of fibre–matrix interface and fibre direction on dielectric behaviour of epoxy composites", Compos. Sci. Technol. 64 (10–11) pp. 1467 - 1475, (2004).
7. Blaise G., "Charge localization and transport in disordered dielectric materials", J. Electrostat. 50, pp. 69 - 89, (2001).
8. Ibrahim A. A., "Friction and Wear of Carbon Fibers Reinforced Epoxy Composites", Journal of the Egyptian Society of Tribology, Vol. 13, No. 4, October 2016, pp. 12 – 27, (2016).

9. Paiva J. M. F., Santos A. N., M. C. Rezende, "Mechanical and morphological characterizations of carbon fiber fabric reinforced epoxy composites used in aeronautical field", Materials Research, Vol. 12, No. 3, pp. 367 - 374, (2009).

10. Soutis C., Smith F. C. and Matthews F. L., "Predicting the Compressive Engineering Performance of Carbon Fibre-Reinforced Plastics", Composites, Part A, 31, pp. 531 - 536, (2000).

11. Zhang Z., Liu Y., Huang Y., Liu L. and Bao J., "The effect of carbon-fiber surface properties on the electron-beam curing of epoxy-resin composites", Composites Science and Technology, 62, pp. 331 - 337, (2002).

12. Guo, Q. B., Rong, M. Z., Jia, G. L., Lau, K. T., Zhang, M. Q., "Sliding Wear Performance of Nano-SiO_2/Short Carbon Fiber /Epoxy Hybrid Composites", Wear 266, 658 - 665, (2009).

13. Zhang, G., "Structure–Tribological Property Relationship of Nanoparticles and Short Carbon Fibers Reinforced PEEK Hybrid Composites", Journal of Polymer Science Part B: Polymer Physics 48, 801–811, 2010.

14. Zhang, G., Sebastian, R., Burkhart, T., Friedrich, K., "Role of Monodispersed Nanoparticles on the Tribological Behavior of Conventional Epoxy Composites Filled with Carbon Fibers and Graphite Lubricants", Wear 292, 176–187, 2012.

15. Friedrich K., Pipes R. B. (Eds.), "Advances in Composite Technology", Vol. 8, Elsevier, Netherlands, pp. 209 - 276, (1993).

16. Zhang Z., Breidt C., Chang L., Haupert F., Friedrich K., "Enhancement of the Wear Resistance of Epoxy: Short Carbon Fibre, Graphite, PTFE and Nano-TiO_2", Composites A 35 (2004) pp. 1385 - 1392; (2004).

17. Chang L., Zhang Z., "Tribological Properties of Epoxy Nanocomposites: Part II. A combinative effect of short carbon fibre with nano-TiO_2",Wear, Vol. 260, No. 7 - 8, pp. 869 - 878, (2006).

18. Cheng B., Kortschot M., "A Study of the Friction Coefficients of Unidirectional and Woven Carbon Fibre/Epoxy Composites", Polymers & Polymer Composites 24.4, pp. 255 - 263, (2016).

19. Berg C. A., Batra S., and Tirosh J., "Friction and Wear of Graphite Fiber Composites", Journal of Research of the Notional Bureau of Standards - C. Engineering and Instrumentation, Vol. 76C, Nos. 1 and 2, pp. 41 – 52, (1972).

20. Cheng B., Kortschot M., "A Study of the Coefficient of Friction and Wear of Unidirectional and Woven Carbon Fiber/Epoxy Composite in Severe Abrasive Conditions", 10th International Conference on Composite Science and Technology ICCST/10 B, (2015).

21. Wan Y. Z., Luo H. L., Wang Y. L., Huang Y., Li Q. Y., Zhou F. G., Chen G. C., "Friction and Wear Behavior of Three-Dimensional Braided Carbon Fiber/Epoxy Composites Under Lubricated Sliding Conditions", Journal of Materials Science (2005).