EGTRIB Journal
JOURNAL OF
THE EGYPTIAN SOCIETY OF TRIBOLOGY
VOLUME 21, No. 2, April 2024, pp. 62 – 70 **ISSN 2090 - 5882**
(Received November 15. 2023, Accepted in final form February 26. 2024) **jest.journals.ekb.eg**

FRICTION AND WEAR DISPLAYED BY THE SCRATCH OF EPOXY REINFORCED BY NATURAL FIBERS

Shaaban S., El-Abden S. Z. and Ali W. Y.

Faculty of Engineering, Minia University, P. N. 61111, El-Minia, EGYPT.

ABSTRACT
The present work investigates the possibility of reinforcing epoxy by natural fibers such as wood, rice straw and palm fibers to be used as floor material. The abrasion resistance of the tested composites was investigated by scratch test where friction coefficient as well wear scar width were determined.

The experiments revealed that friction coefficient increased as the content of the wood fibers reinforcing epoxy matrix increased. Besides, friction coefficient decreased with increasing load, because the stress applied by the indenter exceeded the yield strength of epoxy so that the resistance to scratch decreased. In addition to that, the adhesion of wood fibers into epoxy matrix was relatively tougher compared to rice straw and palm fibers. Rice straw and palm fibers caused friction values lower than that observed for wood fibers.

Wood fibers reinforced composites showed slight wear increase with increasing their content, while composites reinforced by rice straw and palm fibers showed minimum values at certain content of fibers. In addition to that, as the load increased wear increased. The low content of straw and palm fibers strengthened and resisted the abrasion of the matrix. While, the increase of fiber content decreased the strength of the bond between the fibers and the epoxy matrix leading to the increase of the material removal during scratch. Based the above the experimental observation, the abrasion resistance was enhanced at certain content of rice straw and palm fibers, while composites reinforced by wood fibers can be recommended to be applied as floor materials due to their high value of friction coefficient.

KEYWORDS
Friction coefficient, wear scar width, epoxy, natural fibers.

INTRODUCTION
The application of floor materials made of epoxy resins is limited due to their brittleness. Paraffin oil and recycled rubber particles were added to epoxy, [1 - 3]. It was revealed that as the rubber content increased friction significantly increased.

Composites filled by oil and rubber displayed values of friction coefficient that were much higher than the recommended values for safe floor materials. It was suggested that the proposed composites can be used as floor material, where addition of oil into epoxy matrix was intended to decrease the brittleness of the proposed composites.

Although epoxy has several industrial applications, [4], it suffers from brittleness that reduces its use, [5]. The mechanical properties of epoxy matrix filled by butadiene-acrylonitrile rubber were discussed, [6 – 8]. It was found that addition of rubber particles could enhance the ductility of epoxy. Besides, rubber particles could help to concentrate the stress and plastic deformation in epoxy matrix.

Fracture toughness could be enhanced by using block copolymer, [9]. Significant enhancement of the fracture toughness was achieved by block copolymers. They could reduce the effect of voids and shear yielding of the matrix, [10, 11]. The blending process was responsible for cavitation of the rubber leading to the shear deformation of the epoxy matrix and consequently fracture toughness was significantly improved. It was proved that, [12], rubber addition into epoxy matrix was able to overcome the brittleness of epoxy resins.

The tribological and mechanical properties of used polymeric materials were investigated, [13, 14]. Recycled polymers can be applied in applications due to their good mechanical and tribological properties. Toughening of epoxy by blending with waste ground rubber particles was discussed, [15 - 20]. The proposed composites have wide application in automotive industry such as spoilers. Rubber possesses pronounced deformations and higher contact area when loaded on the surface asperities of rigid counterface, then higher values of friction coefficient can be expected, [21 - 23]. Besides, abrasion resistance of epoxy floor surface can be improved by the rubber.

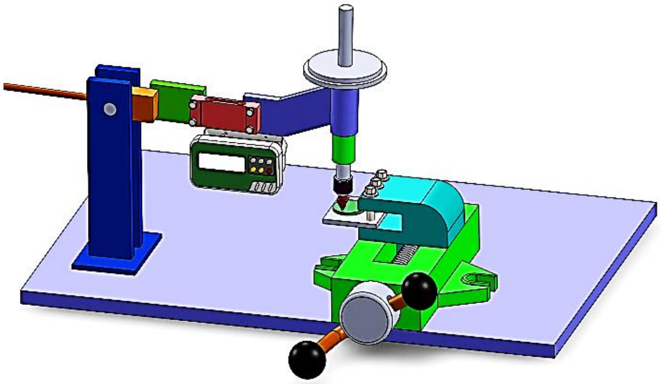
Filling epoxy by oil leads to the trapping of oil inside the matrix in form of infinite number of pores, where they work as oil reservoirs. Oil leaks up to the sliding surface and forms oil film during friction. That behavior is responsible for the friction decrease displayed by composites filled by oil, [24 – 28]. The oil trapped in pores after solidification of the composites is fed into the sliding surface.

The present work proposes epoxy composites used as floor material to withstand the abrasion and reduce the brittleness of epoxy that limits its applications. Wood, rice straw and palm fibers are proposed to reinforce epoxy matrix. The tested composites were investigated by scratch test where friction coefficient and wear scar width were determined.

EXPERIMENTAL

The scratch wear tester was used to carry out by the experiments, Fig. 1. The scratch track was made by an indenter with apex angle 90˚ and tip radius of 0.1 mm. The indenter of TiC insert of 2800 kp/mm^2 hardness is mounted to the loading lever. The values of applied loads were 2.0, 4.0, 6.0, 8.0 and 10.0 N. Load cell connected to digital

monitor was used to measure the scratch force, Fig. 2. The experiments were performed at room temperature. Optical microscope of an accuracy of ± 1.0 µm was used wear scar width, while friction coefficient was determined by the ratio between the friction force and the normal load.



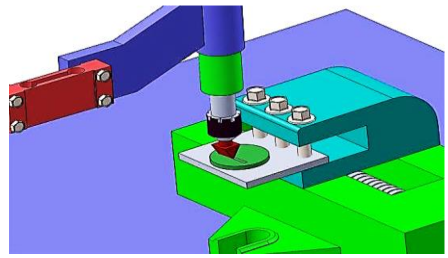


Fig. 1 Arrangement of scratch test rig. **Fig. 2 Details of scratch.**

Epoxy was reinforced by natural fibers of wood, rice straw and palm, where the tested composites were molded of 5.0 mm thickness on the surface of a wooden block of 40 × 40 × 40 mm^3. Tested composites consisted of epoxy filled by wood, (0 - 1.0 mm size), rice straw (0 - 1.0 mm size) and palm fibers of (0 - 3.0 mm size) were added in contents of 2.5, 5.0, 7.5, 10, 12.5, 15, 17.5 and 20 wt. %. Every experiment was repeated five times then the average values were calculated.

RESULTS AND DISCUSSION

The results of friction coefficient displayed by the scratch of the tested epoxy composites are shown in Figs. 3 – 5. Friction coefficient displayed by epoxy composites reinforced by wood fibers showed an increasing trend with the increase of the content of the wood fibers, Fig. 3. Test specimens free of fibers displayed the lowest friction values. As the fiber content increased, friction coefficient increased. The reinforcing action of the fibers was responsible for the friction increase. It was noticed that friction coefficient decreased with increasing load. It seems that the stress applied by the insert exceeded the yield strength of epoxy composites. In that condition, the load increase weakened the epoxy matrix so that the resistance to scratch decreased. The highest value of friction coefficient (1.1) was observed for composites filled by 20 wt. % wood fibers at 2 N load.

Friction coefficient resulted from the scratch of epoxy composites reinforced by rice straw, Fig. 4, displayed relatively lower values than that observed for composites reinforced by wood fibers, where the highest friction coefficient value did not exceed 1.1. It seems that the adhesion of wood fibers with epoxy is relatively stronger than the adhesion between straw fibers and epoxy. As a result of that the abrasion of the tested composites became easier.

The tested composites reinforced by palm fibers showed the same trend of friction observed for composites reinforced by rice straw, Fig. 5. Based on the experimental observation, it can be recommended that composites reinforced by wood fibers can be applied as floor materials to withstand abrasion.

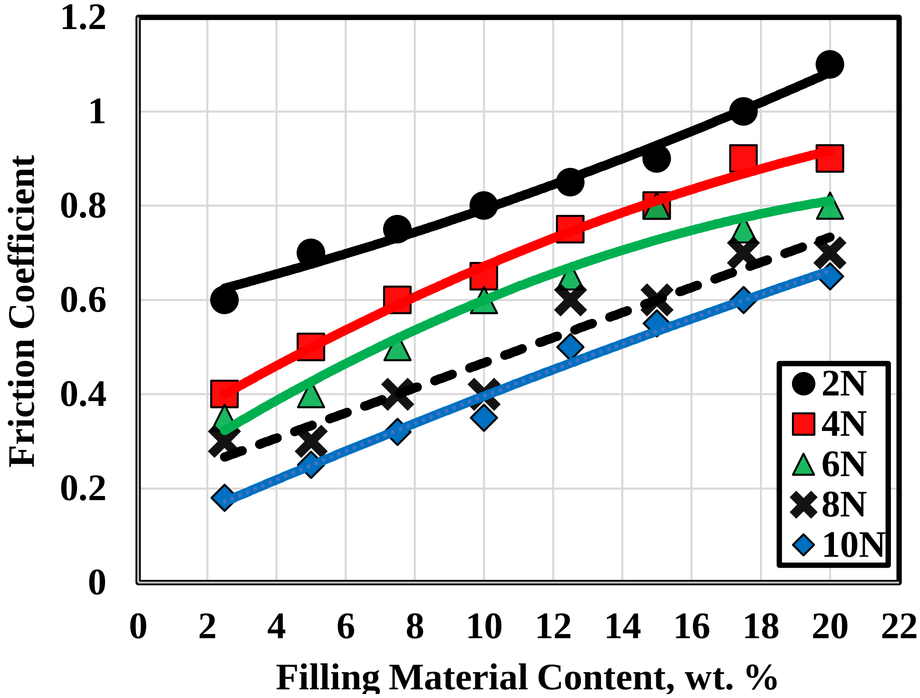


Fig. 3 Friction coefficient displayed by composites reinforced by wood fibers.

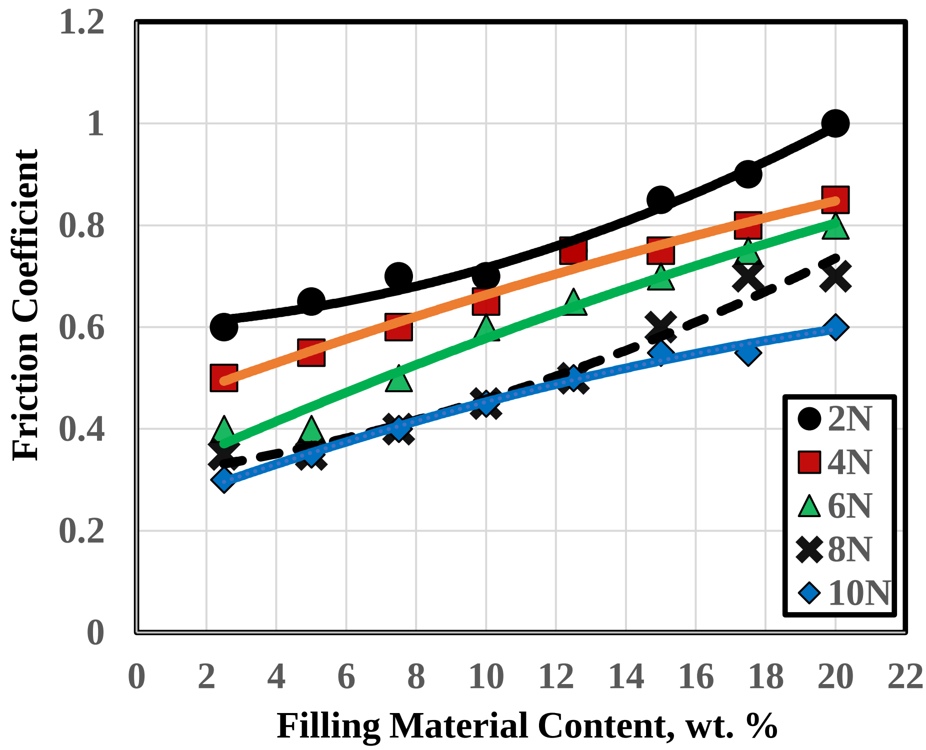


Fig. 4 Friction coefficient displayed by composites reinforced by rice straw fibers.

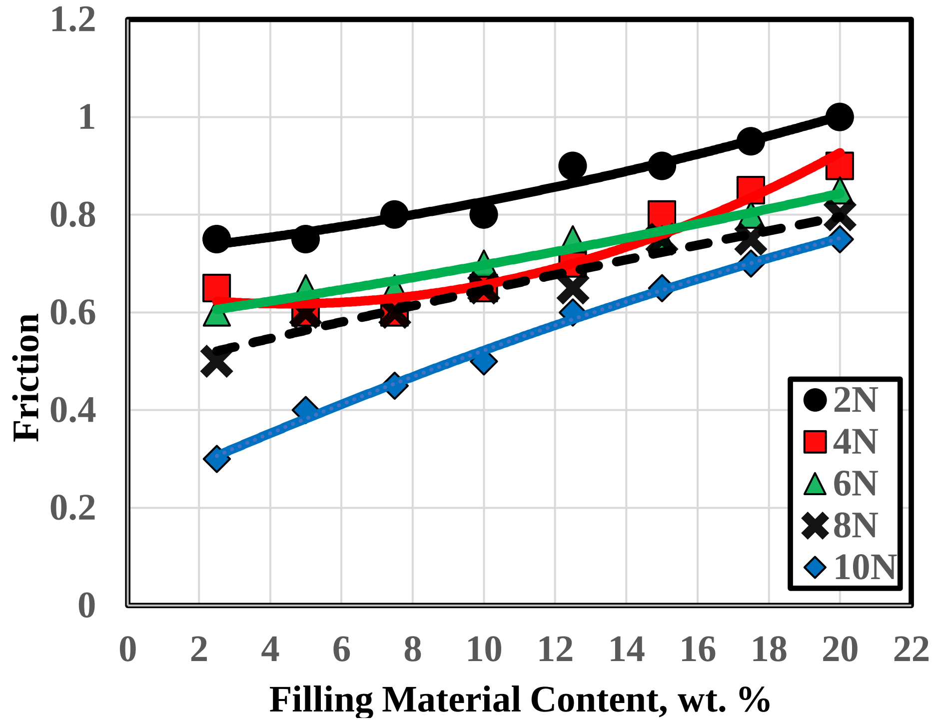


Fig. 5 Friction coefficient displayed by composites reinforced by palm fibers.

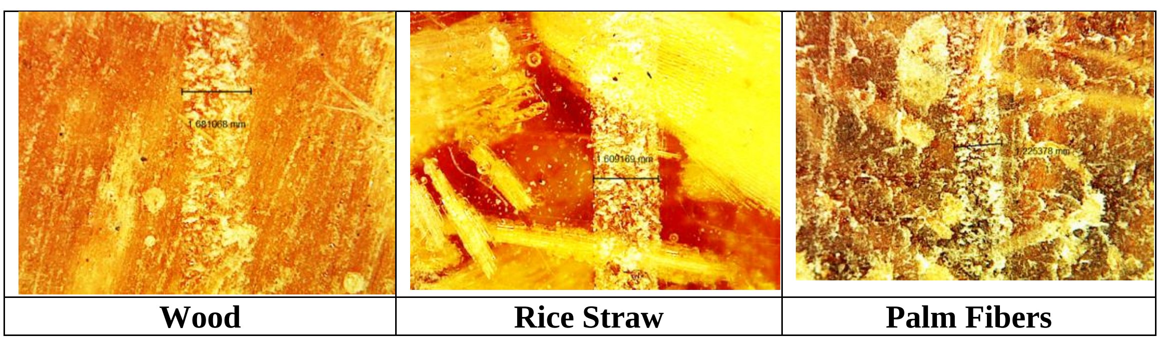


Fig. 6 The evidence of the scratch track on the tested composites.

The track of the wear scratch for the tested composites is illustrated in Fig. 6. The results of wear, measured by the wear scar width after the scratch of the tested composites, are illustrated in Figs. 7 - 9, where composites reinforced by wood fibers showed slight wear increase with increasing the wood content, Fig. 7. It was revealed that as the load increased wear increased.

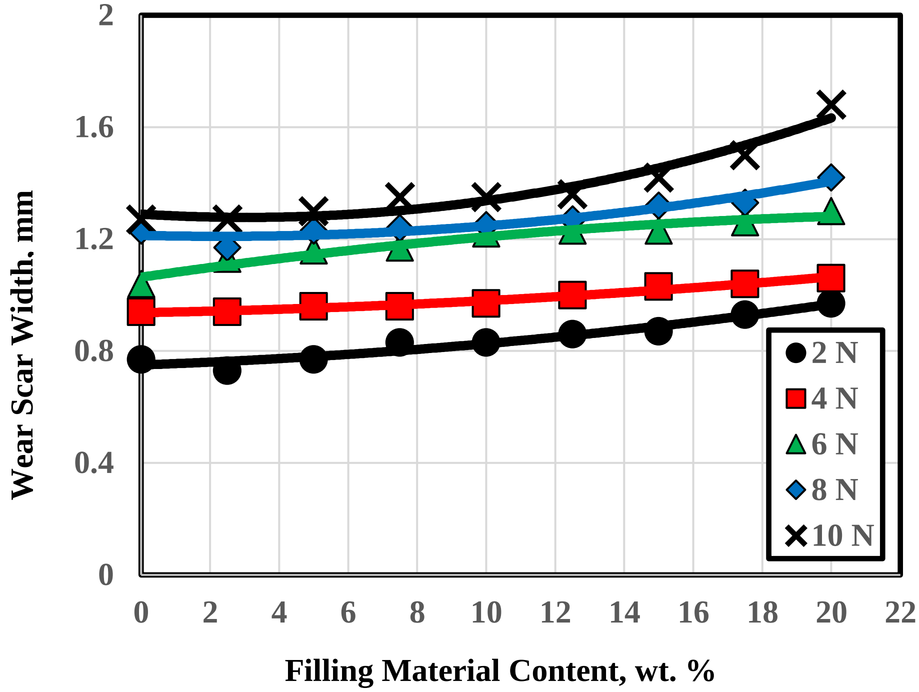


Fig. 7 Wear scar width displayed by composites reinforced by wood fibers.

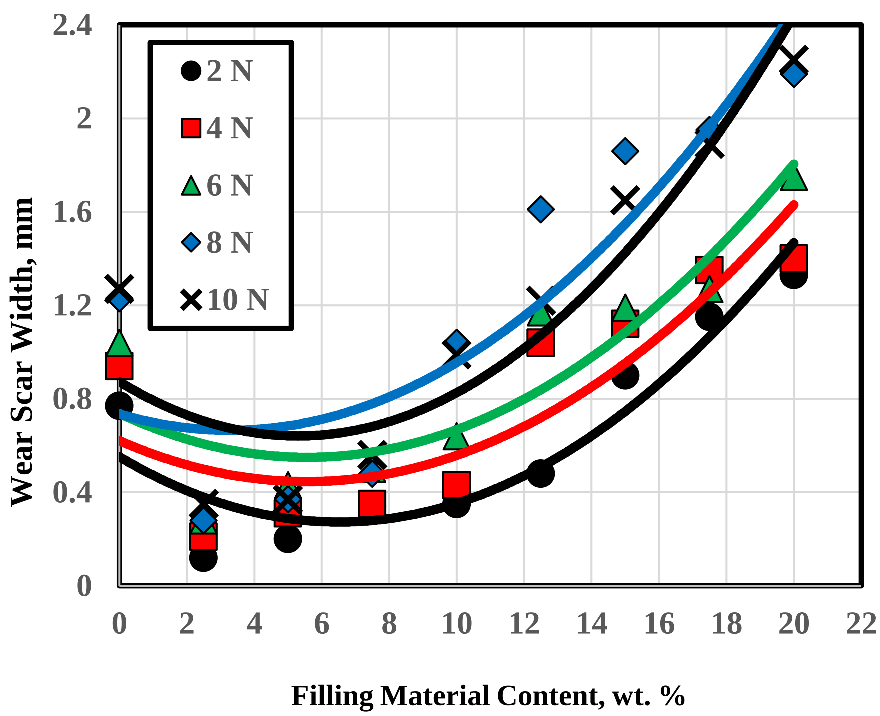


Fig. 8 Wear scar width displayed by composites reinforced by rice straw fibers.

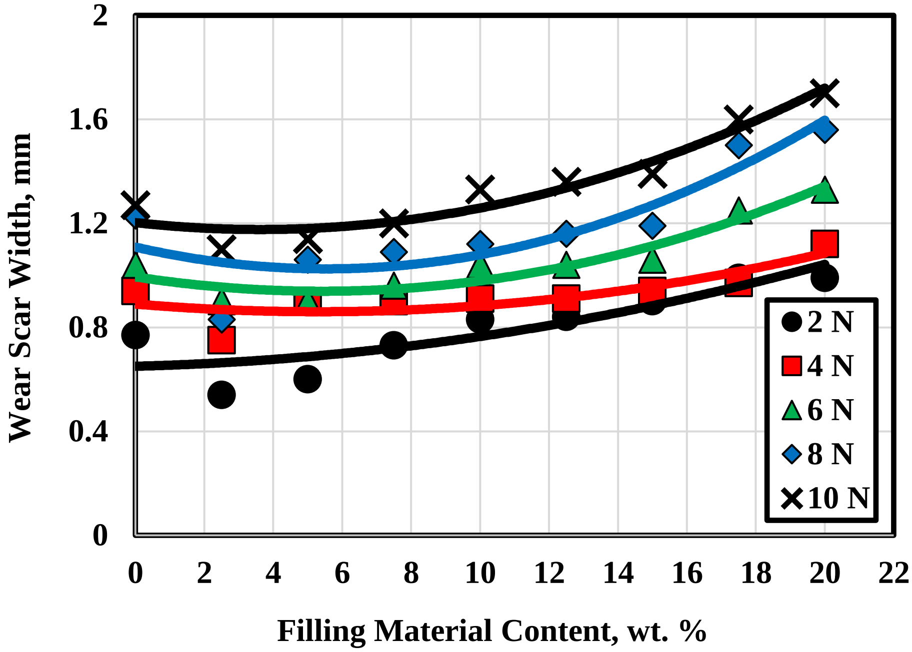


Fig. 9 Wear scar width displayed by composites reinforced by palm fibers.

Wear scar width displayed by composites reinforced by rice straw fibers decreased down to minimum then significantly increased with the increase of the content of rice straw, Fig. 8. The lowest wear values were observed at straw content ranged from 2.0 to 8.0 wt. %. The same trend was displayed by composites reinforced by palm fibers, Fig. 9. It seems that the straw and palm fibers at low content strengthened the epoxy matrix and consequently resisted the abrasion of the matrix. When the fiber content increased, the bond of the fibers inside the epoxy matrix was weakened leading to the increase of the material removal during scratch. Referring to the above observations, the abrasion resistance was enhanced at certain content of rice straw and palm fibers.

CONCLUSIONS

1. **As the content of the wood fibers reinforcing epoxy matrix increased, friction coefficient increased, while composites free of fibers showed the lowest friction values.**
2. **Friction coefficient decreased with increasing load.**
3. **Friction coefficient resulted from the scratch of composites reinforced by rice straw and palm fibers displayed relatively lower values than that observed for composites reinforced by wood fibers.**
4. **Wear of composites reinforced by wood fibers slightly increased with the increase of wood content. While wear of composites reinforced by rice straw and palm fibers showed minimum values then increased with further increase of the content of the fibers.**
5. **It was revealed that as the load increased wear increased.**

REFERENCES

1. Eman S. M, Khashaba M. I. and Ali W. Y., "Friction Displayed by the Sliding of Rubber on Epoxy Filled by Recycled Rubber Particle", Journal of the Egyptian Society of Tribology, Vol. 18, No. 3, July 2021, pp. 1 – 10, (2021).

2. Eman S. M, Khashaba M. I., Eyad M. A. and Ali W. Y., "Electrostatic Charge Generated from Sliding of Rubber on Epoxy Filled by Recycled Rubber Granulates", Journal of the Egyptian Society of Tribology, Vol. 18, No. 4, October 2021, pp. 45 – 54, (2021).

3. Eman S. M., Khashaba M. I. and Ali W. Y., "Friction and Wear Displayed by the Scratch of Epoxy filled by recycled Rubber Particles", KGK Kautschuk Gummi Kunststoffe, 2022, 75(6), pp. 35–38, (2022).

4. Kinloch A. J., Lee S. H., Taylor A. C., "Improving the fracture toughness and cyclic-fatigue resistance of epoxy-polymer blends. Polymer 55, pp. 6325 - 6334, (2014).

5. Bray D. J., Dittanet P., Guild F. J., Kinloch A. J., Masania K., Pearson R. A., Taylor A. C., "The modelling of the toughening of epoxy polymers via silica nanoparticles: the effects of volume fraction and particle size", Polymer 54, pp. 7022 - 7032, (2013).

6. Bagheri R., Marouf B. T., Pearson R. A. "Rubber-toughened epoxies: a critical review", Polym Rev 49, pp. 201 - 225, (2009).

7. Liang Y. L., Pearson R. A., "The toughening mechanism in hybrid epoxy-silica-rubber nanocomposites", Polymer 51, pp. 4880 - 4890, (2010).

8. Chen J., Kinloch A. J., Sprenger S., Taylor A. C., "The mechanical properties and toughening mechanisms of an epoxy polymer modified with polysiloxane-based core-shell particles", Polymer 54, pp. 4276 - 4289, (2013).

9. Lorena R. P., Royston G. J., Fairclough P. A., Ryan A. J., "Toughening by nanostructures", Polymer 49, pp. 4475 - 4488, (2008).

10. Liu J., Thompson Z. J., Sue H. J., Bates F. S., Hillmyer M. A., Dettloff M. V., Jacob G., Verghese N., Pham H., "Toughening of epoxies with block copolymer micelles of wormlike morphology", Macromolecules 43, pp. 7238 - 7243, (2010).

11. Declet-Perez C., Francis L. F., Bates F. S., "Deformation process in block copolymer toughened epoxies", Macromolecules 48, pp. 3672 - 3684, (2015).

12. Marouf B. T., Mai Y. W., Bagheri R., Pearson R. A., "Toughening of epoxy nanocomposites: nano and hybrid effects. Polym Rev 54, pp. 56 – 78, (2016).

13. Khashaba M. I., Ezzat F. H. and Ali W. Y., "Mechanical and Tribological Properties of Recycled Polymers", Proceedings of The International Conference of Development and Environment, Assiut University, March 26 – 28, Assiut, Egypt, pp. 381 – 390, (2002).

14. Khashaba, M. I. and Ali, W. Y, "Mechanical Properties of Epoxy Filled by Recycled Polymeric Powders", Proceedings of The International Conference of Development and Environment, Assiut University, March 26 – 28, Assiut, Egypt, pp. 373 – 379, (2002).

15. Sridhar V., Xiu Z., Xu D., Lee S., Kim J., Kang D., Bang D., "Fly ash reinforced thermoplastic vulcanizates obtained from waste tire powder", Waste Management 29, pp. 1058 – 1066, (2009).

16. Lee, S. H., Balasubramanian, M., Kim, J.K., "Dynamic reaction inside corotating twin screw extruder. II. Waste ground rubber tire powder/ polypropylene blends". J. Appl. Polym. Sci. 106 (5), pp. 3209 - 3219, (2007).

17. Coran, A.Y., 1987. Handbook of elastomer-new development and technology. In: Bhowmick, A.K., Stephens, H.L. (Eds.). Dekker, New York.
18. Ho, R.M., Wu, C.H., Su, A.C., 1990. Morphology of plastic/rubber blends. Polym. Eng. Sci. 30 (9), 511–518.
19. Jang, B.Z., Uhlmann, D.R., Vander Sande, J.B., “Crystalline morphology of polypropylene and rubber-modified polypropylene”, J. Appl. Polym. Sci. 29 (12), pp. 4377 – 4393, (1984).
20. Montoya, M., Tomba, J.P., Carella, J.M., Gobernado-Mitre, M.I., “Physical characterization of commercial polyolefinic thermoplastic elastomers”, Eur. Polym. J. 40 (12), pp. 2757 - 2766, (2004).
21. Lia K. W., Chang C. C., Chang W. R., “Slipping of the foot on the floor when pulling a pallet truck”, Applied Ergonomics 39, pp. 812 - 819, (2008).
22. Derler S., Kausch F., Huber R., “Analysis of factors influencing the friction coefficients of shoe sole materials”, Safety Science 46, pp. 822 - 832, (2008).
23. Maeda K., Bismarck A., Briscoe B., “Effect of bulk deformation on rubber adhesion”, Wear 263, pp. 1016 – 1022, (2007).
24. Badran A. H., Hasan M. K., Ali W. Y., "Tribological Behavior of Epoxy Reinforced with Carbon Nanotubes and Filled by Vegetables Oils", EGTRIB Journal, Vol. 14, No. 1, January 2017, pp. 51 - 61, (2017).
25. Eatemad H. S., Samy A. M. Khashaba M. I., and Ali Y. A., “Friction and Wear of Polymeric Materials Filled by Oil and Reinforced by Nanocarbon Tubes”, EGTRIB Journal, Vol. 14, No. 4, October 2017, pp. 15 – 26, (2017).
26. Hassan A. El-Sayed M., EiD A. I., El-Sheikh M., Ali W. Y., "Tribological Properties of Low Density Polyethylene and Polyamide 12 as Polymer Matrix Nanocomposites", EGTRIB Journal, Vol. 14, No. 4, October 2017, pp. 40 – 53, (2017).
27. Hassan A. El-Sayed M., Eid A. I., El-Sheikh M., Ali W. Y., "Effect of Graphene Nanoplatelets and Paraffin Oil Addition on the Mechanical and Tribological Properties of Low Density Polyethylene Nanocomposites", Arabian Journal for Science and Engineering, DOI 10.1007/s13369-017-2965-5, Published online: 15 November 2017, (2017).
28. Hassan A. E. M., Eid A. I., El-Sheikh M., Ali W.Y., "Mechanical and tribological performance of polyamide 12 reinforced with graphene nanoplatelets and paraffin oil nanocomposites", Materialwiss. Werkstofftech. 2019, 50, pp. 74 – 85, (2019).