EGTRIB Journal
JOURNAL OF
THE EGYPTIAN SOCIETY OF TRIBOLOGY
VOLUME 16, No. 3, July 2019, pp. 26 - 35 ISSN 2090 - 5882
(Received March 11. 2019, Accepted in final form June 25. 2019) www.egtribjournal.com

PROPER SELECTION OF POLYMERIC FIBERS REINFORCING EPOXY

Ali A. S.[1] and Ali W. Y.[2]

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

ABSTRACT

The proper selection of polymeric fibers reinforcing epoxy based on the tribological properties is experimentally investigated in the present work. The effect of reinforcing epoxy matrix by continuous polyamide (PA), Kevlar and polyester (PET) fibers on the friction and wear at dry sliding against steel surface is tested.

It was observed that PA reinforcing epoxy matrix displayed the highest friction coefficient and the lowest wear. The favorite behavior of polyamide can be explained on the basis of the triboelectrification of the tested composites during friction with steel surface. It was found that ESC generated from the friction of PET and steel was higher than that generated from steel and epoxy. The nature of PA fibers influenced the sign of ESC built up on steel counterface, where the resultant ESC showed lower values than that observed for PET fibers.

In the presence of Kevlar as reinforcement, ESC showed higher values than that observed for PET due to the rank of the two sliding materials in the triboelectric series. The attractive force between steel and Kevlar is much higher than that expected for steel and epoxy, where the intensity of ESC controls the strength of the attractive force. Adhesion of Kevlar into steel surface was stronger than the adhesion of epoxy into steel. Consequently, friction force increased with increasing adhesion between the two contact surfaces. As the surface area covered by Kevlar increased, friction increased more than that displayed by the surface area covered by epoxy. Proper selection of fibers in epoxy matrix based on their triboelectrification can control polymer transfer into steel surface and influence both friction and wear.

KEYWORDS

Friction coefficient, wear, epoxy, polyamide, Kevlar, polyester fibers, reinforcement, electrostatic charge.

INTRODUCTION

The increased use of fiber reinforced epoxy composites for the low costs as well as high mechanical and tribological properties accelerates their development. The effect of reinforcing epoxy matrix by polyamide and polyester fibers of different diameters on the friction and wear, at dry sliding against steel surface, was studied, [1, 2], where friction

coefficient displayed by the tested composites drastically decreased as the polymeric content increased and significantly increased up to maximum then drastically decreased with increasing polymeric fiber diameter. Wear increased up to maximum then slightly decreased with increasing fiber diameter. At constant content of polymers, fibers of relatively low diameter showed the lowest wear. Wear mechanism of the tested composites is based on the triboelectrification of the sliding surfaces.

Epoxy composites reinforced by fibers are applied in different industrial applications, [3, 4]. Glass fiber reinforced epoxy resin showed wear increase with increasing load and velocity, [5], where fiber orientation affected wear mechanism. The reinforcements are reinforcing epoxy matrix to develop the strength and increase lifetime, [6, 7]. Carbon fibers (CF) reinforced epoxy composites have lightweight, high mechanical strength and chemical resistance, [8 - 15]. Woven fiber reinforced epoxy was filled by Nano-silica particles, [16, 17] to enhance interfacial stress. Fibers of glass, carbon and Kevlar were commonly used to reinforce epoxy composites, [18 - 21], where Kevlar fibers increased the mechanical property. Besides, multi-walled carbon nanotubes can improve the tensile strength of epoxy, [22 – 24]. The mechanisms of triboelectrification are electron transfer, ion transfer and material transfer, [25 - 27]. For polymers, the electron transfers only happen on their surfaces, [28 – 30]. According to the triboelectric series the polarity of the charge that is transferred from one surface to another can be to predicted, [31]. At relatively higher load, the prevailing mechanism is material transfer, where the sign of ESC charge is frequently changed. Engineering materials including polymers can be arranged in a ‘‘triboelectric series’’ which lists the materials in the order of their relative polarity. In the triboelectric series the higher positioned materials will acquire a positive charge when contacted with a material at a lower position along the series, [32]. The triboelectric series can be used to estimate the relative charge polarity of the materials.

In the present work, effect of reinforcing epoxy by PA, Kevlar and PET fibers on friction coefficient and wear when sliding against steel is investigated.

EXPERIMENTAL

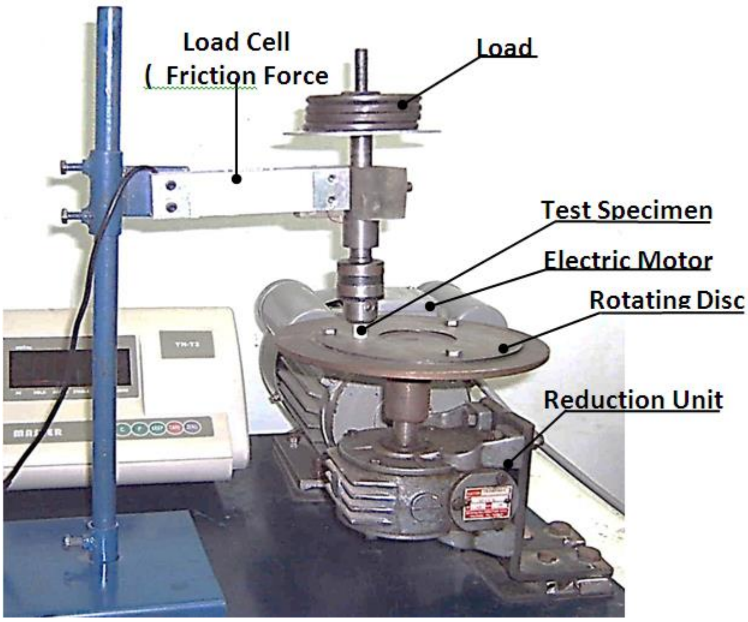

Fig. 1 Arrangement of the test rig.

Experiments were carried out using pin-on-disc wear tester. It consists of a rotary horizontal steel disc driven by variable speed motor. The details of the wear tester are shown in Fig. 1. The pin made of the tested composites is held in the specimen holder that fastened to the loading lever. Friction force can be measured by means of the load cell, fastened to the rotating disc.

Friction tests were carried out under 2.0 m/s sliding velocity. The load values were 8, 10. 12, 14 and 16 N. They lasted for 30 minutes. All measurements were performed at 25 ± 5 ºC and 30 ± 10 % humidity. The test specimen, in the form of a cylinder, is 10 mm diameter and 30 mm height. The diameter is reduced to 6 mm to contact the steel disc. The polyamide, Kevlar and polyester continuous fibers of 0.20 mm diameter and 12.5 vol. % volumetric content were used to reinforce epoxy matrix (KEMAPOXY 150A).

RESULTS AND DICUSSION

The results of friction tests are shown in Figs. 2 and 3. It was observed that a drastic decrease in friction coefficient as the polymeric fiber volumetric content increased, Fig. 2. The highest value of friction coefficient was observed for epoxy reinforced by polyamide fibers. Reinforcing epoxy by Kevlar displayed the lowest friction. Friction coefficient displayed by the tested composites reinforced by the tested polymeric fibers significantly decreased with increasing applied load, Fig. 3. The dependency of friction coefficient on load can be explained considering that as the load increased, the plasticity of the epoxy asperities contacting steel increased, so that the shear strength decreased causing the decrease of friction coefficient. The accumulation of the layers of the transferred epoxy may display the relatively high friction coefficient. It was observed at the beginning of the experiment the tested composites experienced relatively lower values of friction coefficient. As the epoxy transfer film deposited on the steel surface, friction coefficient increased indicating that both epoxy and steel suffered from severe stick-slip.

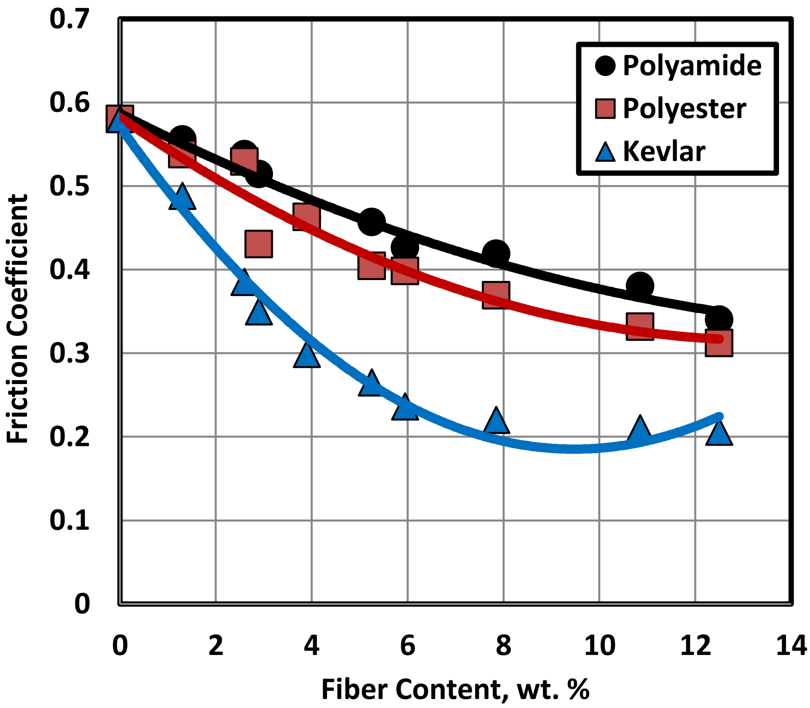

Fig. 2 Friction coefficient displayed by epoxy reinforced by polymeric fibers and sliding against steel at 16 N load.

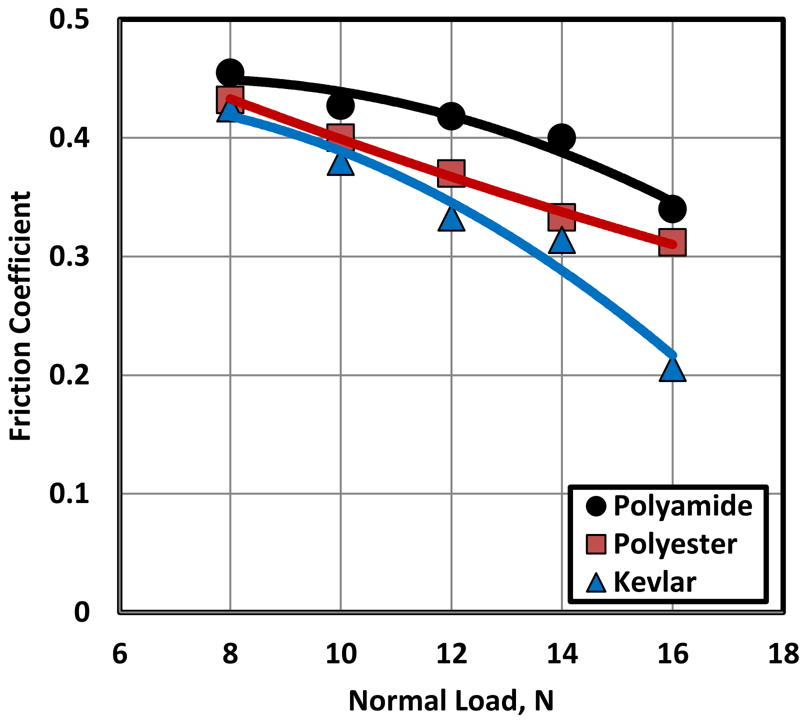

Fig. 3 Friction coefficient displayed by epoxy reinforced by 12.5 vol. % polymeric fibers content and sliding against steel.

Wear of the tested composites reinforced by the tested polymeric fiber decreased with increasing fiber content, Fig. 4. The observations in wear tests confirmed the role of reinforcing fibers that have relatively higher wear resistance than epoxy in decreasing wear. The wear mechanism observed in the present work can be explained based on epoxy transfer onto the steel counterface forming an adherent layer. During friction, the relatively softer epoxy and fibers transferred to the steel counterface. The deposit then back transferred fractionally to the tested composites. An equilibrium state appears to reach as far as the amount of transfer in both directions is concerned. The accumulation of the layers of the transferred material may form the layer that was adhered to the counterface by the action of the contacting asperities then removed from the surface when the shear stress exceeds the adherence between the transferred layer and the steel counterface. Transferred materials are mainly epoxy and polymeric fibres contaminated by tiny steel particles.

The relationship between wear of the tested composites and applied load is shown in Fig. 5. Wear remarkably increased with increasing load. Polyamide showed the lowest wear followed by Kevlar and polyester fibers. During wear process, epoxy worn from the tested composites and adhered to the steel counterface formed thin layer. During sliding, relatively hard steel asperities penetrated the surface of the tested composites, where the stresses at the point of contact were high and caused localized plastic deformation. Then, sliding of the contacting materials was accompanied by repeated extensive deformation of the thin surface layer of epoxy leading to the deformation of the surface layer and wear particles. The polymeric material transfers back to the parent composites. It is expected that the transfer film generated from epoxy is considerably thicker than that generated from fibers. The transfer film of epoxy was accumulated to form thicker film

adhered to the steel surface and followed by excessive shear stress that caused considerable plastic flow of the deposited film.

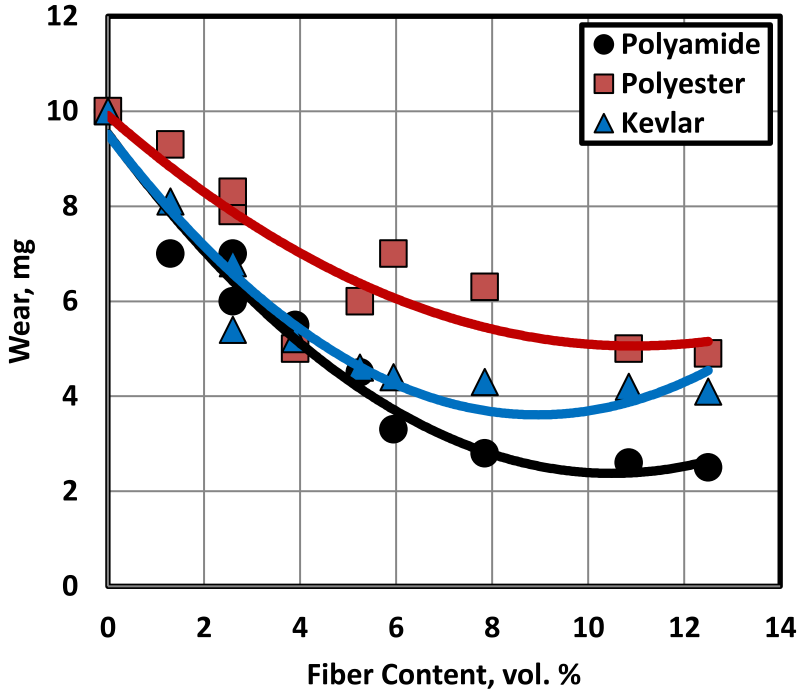

Fig. 4 Wear of epoxy reinforced by polymeric fibers at 16 N load.

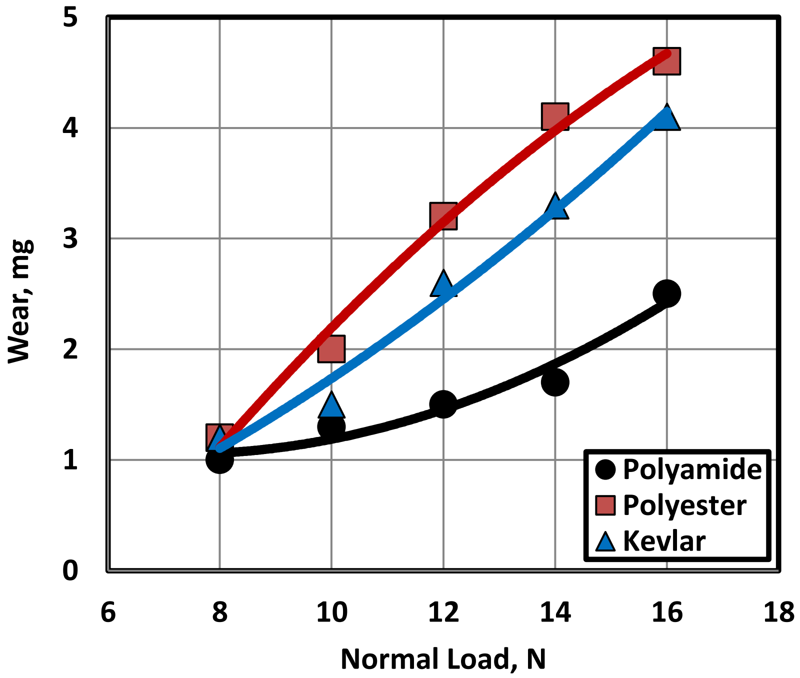

Fig. 5 Wear of epoxy composites reinforced by 12.5 vol. % polymeric fibers.

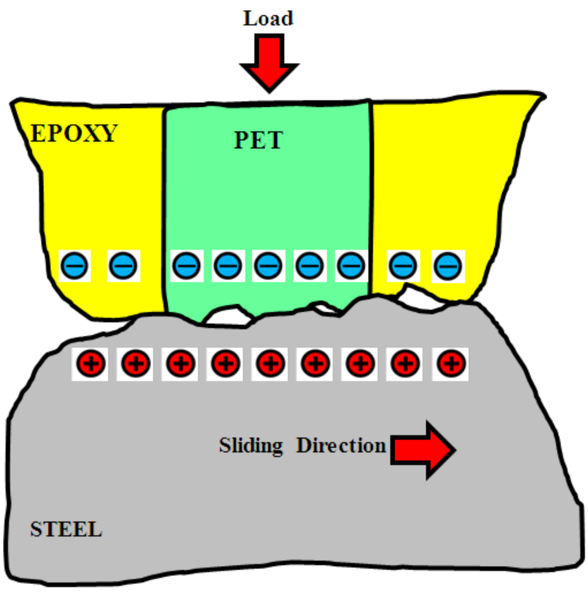

Fig. 6 Distribution of ESC on the epoxy reinforced by PET fibers and sliding against steel counterface.

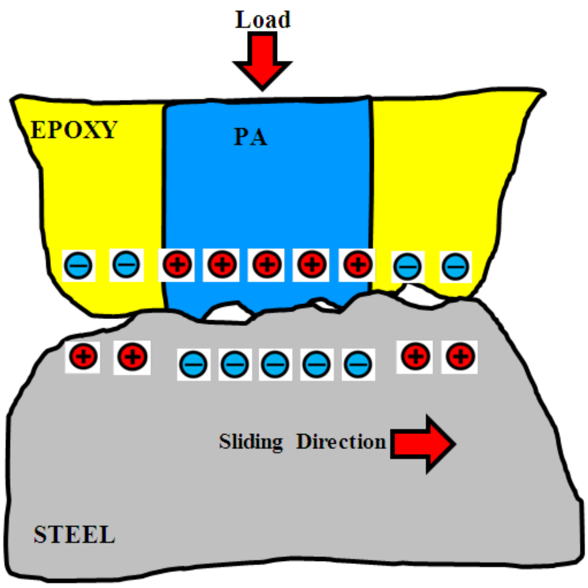

Fig. 7 Distribution of ESC on the epoxy reinforced by PA fibers and sliding against steel counterface.

Based on the experimental observation, it was observed that polyamide fibers exhibited the highest friction coefficient and lowest wear. That behavior can be explained on the triboelectrification of the tested composites during friction with steel surface. Figures 6 - 8 illustrate the distribution of ESC generated on steel counterface and the tested composites surfaces. Figure 6 illustrates the distribution of ESC on the contact area of polyester fibers reinforcing epoxy matrix. It is shown that most of the contact area is charged by double layer of ESC of different charge due to the position of polyester fiber in the triboelectric series, Fig. 9. Consequently, layers of epoxy and polyester can transfer and adhere to the steel counterface, where the contact will be epoxy/epoxy and polyester/polyester rather than epoxy/steel or polyester/steel. That contact condition was

responsible for the friction increase. Polyester is ranked as negative charged material. It is obvious that ESC plays major role in adhesion energy and alters friction by the effect of the trapped charges and, consequently on the presence of surface defects introduced during friction.

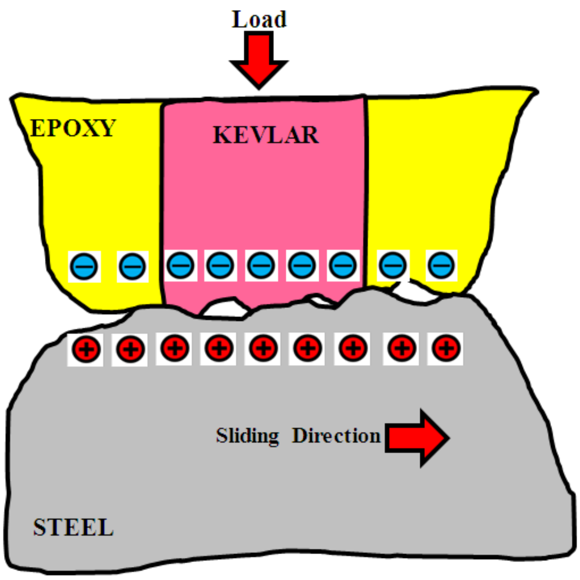

Fig. 8 Distribution of ESC on the epoxy reinforced by Kevlar fibers and sliding against counterface.

Positive Charge	+
Polyamide	
Silk	
Wool	
Glass	
Cotton	
Polyester	
Kevlar	
Polypropylene	
Polyethylene	
Polytetrafluoroethylene	
Negative Charge	-

Fig. 9 Illustration of triboelectric series for tested materials.

On the other side, higher fraction of the contact area of steel will be electrified by negative charge. It is expected that ESC generated from the friction of polyester and

steel will be higher than that generated from steel and epoxy. This behaviour could be attributed to the fact that epoxy, polyester and steel are different materials and according to the triboelectric series, friction between two surfaces causes the object in the upper position of the series to be charged positively (steel) and that in the lower position to be charged negatively (polyester and epoxy). It is known that different polarity means attraction. Besides, it could be attributed to that, the long distance gives higher chance to exchange more electrons between the two different materials rubbing each other. Based on that, polyester wear particles in form of film will be strongly adhered to the steel surface attracting layers of epoxy of negative charge to be accumulated to form thicker polymeric layer. In that condition due to the transfer of polyester and epoxy into the steel counterface both friction coefficient and wear increased.

The distribution of ESC on the contact area of polyamide fibers reinforcing epoxy matrix is shown in Fig. 7. The nature of polyamide fibers influenced the sign of ESC built up on steel counterface, where the resultant showed lower charge than that observed for PET fibers. After sliding, epoxy and PA transferred into steel surface, where friction coefficient depended on the area covered by epoxy and PA as well as the adhesion between both of epoxy and PA and steel surface. When epoxy matrix was reinforced by PA, epoxy transfer into steel would be easier leading to significant increase in the steel area covered by epoxy. In that condition, the contact would be between PET and epoxy, where the ESC would be lower.

In the presence of Kevlar as reinforcement, ESC showed higher values than that observed for PET reinforcing epoxy due to the rank of the two sliding materials in the triboelectric series. The attractive force between steel and Kevlar is much higher than that expected for steel and epoxy due to the position of those materials in the triboelectric series, where the intensity of ESC controls the strength of the attractive force. Adhesion of Kevlar into steel surface would be stronger than the adhesion of epoxy into steel. It is commonly known that friction force increases with increasing adhesion between the two contact surfaces. As the surface area covered by Kevlar increases, friction increases more than that displayed by the surface area covered by epoxy. Proper selection of fibers in epoxy matrix would control polymer transfer into steel surface.

CONCLUSIONS

1. Friction coefficient displayed by the tested composites drastically decreased with increasing applied load and fiber content.
2. The highest value of friction coefficient was observed for epoxy reinforced by polyamide followed by PET and Kevlar fibers.
3. Wear of the tested composites decreased with increasing fiber content, while remarkably increased with increasing load. Polyamide showed the lowest wear followed by Kevlar and polyester fibers.
4. Proper selection of fibers in epoxy matrix should be based on their triboelectrification.

REFERENCES

1. Zahraa F. and Ali W. Y., "Friction and Wear of Epoxy Reinforced by Polyamide Fibers", Journal of the Egyptian Society of Tribology, Vol. 15, No. 4, October 2018, pp. 26 - 36, (2018).

2. Zahraa F. and Ali W. Y., "Friction and Wear of Epoxy Reinforced by Polyester Fibers", Journal of the Egyptian Society of Tribology, Vol. 16, No. 1, January 2019, pp. 1 - 11, (2019).
3. Kaw A., "Mechanics of composite materials", Vol. II. London, New York: Taylor and Francis Group; (2006).
4. Valenç S. L., Griza S., Oliveira V. G., Sussuchi E. M., Cunha F. G. C., "Evaluation of the mechanical behavior of epoxy composite reinforced with Kevlar plain fabric and glass/Kevlar hybrid fabric. Compos B Eng, 70, pp. 1 - 8, (2015).
5. Kumar S. T., Shivashankar G. S., Dhotey K., Singh J., "Experimental study wear rate of glass fibre reinforced epoxy polymer composites filled with aluminium powder", Materials Today, Proceedings 4, pp. 10764 - 10768, (2017).
6. Wang Q. H., Xue J., Shen W., Liu W., "An Investigation of the Friction and Wear Properties of Nanometer Si_3N_4 Filled PEEK," Wear, Vol. 196, No. 1 - 2, pp. 82 - 86, (1996).
7. Rao S., Rao G.K., "An Emerging, Energy-Efficient Cure Process for Rapid Composite Manufacture. NAL, Bangalore, (2008).
8. Daniel P. C., Todd C. H., Frank G., Hu R. A., "Interphase mechanical behavior of carbon fiber reinforced polymer exposed to cyclic loading", Compos. Sci. Technol. 151, pp. 202 - 210, (2017).
9. Han W. B., Zhao G. D., Zhang X. H., Zhou S. B., Wang P., An Y. M., Xu B. S., "Graphene oxide grafted carbon fiber reinforced silicon borocarbonitride ceramics with enhanced thermal stability, Carbon 95, pp. 157 – 165, (2015).
10. Zhang Y., Zhang L. T., Liu Y. S., Liu X. Y., Chen B., "Oxidation effects on in-plane and interlaminar shear strengths of two-dimensional carbon fiber reinforced silicon carbide composites", Carbon 98, 144 - 156, (2016).
11. Ning H. M., Li J. H., Hu N., Yan C., Liu Y. L., Wu L. K., Liu F., Zhang J. Y., "Interlaminar mechanical properties of carbon fiber reinforced plastic laminates modified with graphene oxide interleaf", Carbon 91, pp. 224 - 233, (2015).
12. Ma L., Zhu 8.Y., Li X., Yang C., Han P., Song G., "The architecture of carbon fiber-TiO_2 nanorods hybrid structure in supercritical water for reinforcing interfacial and impact properties of CF/epoxy composites", Polymer Testing 66, pp. 213 - 220, (2018).
13. Gao B., Zhang R. L., Wang C. G., "Enhanced mechanical properties of carbon fiber composites by grafting different structural poly(amido amine) onto fiber surface", Polym. Test. 56, pp. 192 - 199, (2016).
14. Dong J. D., Jia C. Y., He J. M., Jiang Z. X., Huang Y. D., "Improved mechanical properties of carbon fiber-reinforced epoxy composites by growing carbon black on carbon fiber surface", Compos. Sci. Technol. 149, pp. 75 – 80, (2017).
15. Lee H., Ohsaw I., Takahashi J., "Effect of plasma surface treatment of recycled carbon fiber on carbon fiber-reinforced plastics (CFRP) interfacial properties", Appl. Surf. Sci. 328, pp. 241 - 246, (2015).
16. Alsaadi M., Bulut M., Erkliğ A., Jabbar A., "Nano-silica inclusion effects on mechanical and dynamic behavior of fiber reinforced carbon/Kevlar with epoxy resin hybrid composites", Composites Part B 152, pp. 169 - 179, (2018).
17. Gay D., Hoa S. V., Tsai S. W., "Composite materials, design and applications", Boca Raton, FL: CRC Press LLC; (2003).
18. Dorigato A., Pegoretti A., "Flexural and impact behaviour of carbon/basalt fibers hybrid laminates", J Compos Mater Apr, 48 (9), pp. 1121–1130, (2014).
19. Singh T. J., Samanta S., "Characterization of Kevlar fiber and its composites: a review. Mater Today, Proceedings, Jan 1, 2, (4 - 5), pp. 1381 – 1387, (2015).

20. Reddy M. I., Kumar M. A., Raju C. R. B., " Tensile and Flexural properties of Jute, Pineapple leaf and Glass Fiber Reinforced Polymer Matrix Hybrid Composites", Materials Today: Proceedings 5, pp. 458 – 462, (2018).
21. Santos J. C., Siqueira R. L., Vieirad L. M. G., Freire R. T. S., Mano V., Panzera T. H., "Effects of sodium carbonate on the performance of epoxy and polyester coir reinforced composites", Polymer Testing 67, pp. 533 - 544, (2018).
22. Quan D., Urdaniz J. L., Ivankovic A., "Enhancing mode-I and mode-II fracture toughness of epoxy and carbon fibre reinforced epoxy composites using multi-walled carbon nanotubes", Materials and Design 143, pp. 81 – 92, (2018).
23. Xu H., Tong X., Zhang Y., Li Q., Lu W., "Mechanical and electrical properties of laminated composites containing continuous carbon nanotube film interleaves", Compos. Sci. Technol. 127, pp. 113 – 118, (2016).
24. Zheng N., Huang Y., Liu H.-Y., Gao J., Mai Y.-W., "Improvement of interlaminar fracture toughness in carbon fiber/epoxy composites with carbon nanotubes/polysulfone interleaves", Compos. Sci. Technol. 140, pp. 8 – 15, (2017).
25. Lee L. H., "Dual mechanism for metal–polymer contact electrification", J. Electrostat. 32, 1 - 29, (1994).
26. Matsusaka S., Masuda H., "Electrostatics of particles" Adv. Powder Technol. 14, pp. 143 - 166, (2003).
27. Saurenbach F., Wollmann D., Terris B., Diaz A., "Force microscopy of ioncontaining polymer surfaces: morphology and charge structure" Langmuir 8, pp. 1199 - 1203, (1992).
28. Anderson J., "A comparison of experimental data and model predictions for tribocharging of two-component electrophotographic developers", J. Imag. Sci. Technol. 38, pp. 378 - 382, (1994).
29. Gutman E., Hartmann G., Triboelectric properties of two-component developers for xerography" J. Imaging Sci. Technol. 36, pp. 335 - 349, (1992).
30. Yoshida M., Ii N., Shimosaka A., Shirakawa Y., Hidaka J., "Experimental and theoretical approaches to charging behavior of polymer particles", Chem. Eng. Sci. 61, pp. 2239 - 2248, (2006).
31. Park C. H., Park J. K., Jeon H. S., Chun B. C., Triboelectric series and charging properties of plastics using the designed vertical-reciprocation charger", J. Electrostat, 66, pp. 578 - 583, (2008).
32. Meurig W. Williams, "Triboelectric charging in metal-polymer contacts - How to distinguish between electron and material transfer mechanisms", Journal of Electrostatics 71, pp. 53 - 54, (2013).