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Friction and Wear Properties of Glass Fiber Reinforced Polyphenylene Sulfide Composites

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Abstract

The aim of this study is the experimental investigate of wear and friction properties of polyphenylene sulfide polymer (PPS) and 20%, 30% and 40% by weight glass fiber reinforced polyphenylene sulfide composites. Tribological tests were done by pin-on-disc test configuration. The disc material is AISI 1040 steel. 50, 100, 200 N normal loads and 1, 2, 3 m/s speeds were applied to the test specimens. Adding fiber decreased the friction values and specific wear rates. Furthermore, increasing load decreased the friction coefficient but increased the specific wear rate, although increasing sliding speed increased both friction and specific wear rate.

Keywords: Friction, wear, polyphenylene sulfide, glass fiber

1. INTRODUCTION

Polymer materials have been used widely in engineering applications. In use generally, polymers have been reinforced with various fibers. Fibers improved the tribological performance of the materials and gained the high wear resistance [1-9]. Mens et al. [1], investigated the tribological properties of different polymer materials and concluded that the increasing load increased the wear amount but decreased the friction coefficient. Yilmaz et al. [2], studied the pomza powder/carbon fiber hybrid composites and stated that the reinforcement and fillers enhanced the wear properties of PPS. Sumer et al. [3], studied the 30 wt% glass fiber (GF) reinforced PEEK composite and concluded that the increasing load increased the friction coefficient and wear. Friedrich et al. [4], studied PTFE with glass fiber composites. They found that adding glass fiber enhanced the wear properties of PTFE polymer. Tewari et al. [5], studied the polyetherimidin with glass fiber composites. They stated that increasing wt % glass fiber ratios decreased the friction coefficient. They also showed that increasing load decreased the friction coefficient. Yousif et al. [6], studied the polyester composites with glass fiber mat. They investigated the wear surfaces and observed the cracks in the matrix, breakage in glass fibers at the major load. Reinicke et al. [7],

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studied different fiber reinforced thermoplastic materials. They used the glass fiber as a reinforcement material in the PA46, PP, PPS and PEI polymers. Cai et al. [8], tested the PEI composites reinforcing with glass and carbon fiber. They stated that both increasing fiber ratios and increasing load decreased the friction coefficient. Voss et al. [9], studied the glass and carbon fiber-PEEK composites. They showed that adding fiber into the matrix enhanced the wear resistance of polymer.

Polyphenlyne Sulfide (PPS) polymer has a widespread usage area such as automotive, electrical and electronical. It has high heat, chemical resistance and high mechanical properties. Its melting point is 285 ^{0}C. These properties make the PPS an alternative of thermosets and metals [10]. Researchers have been using different reinforcements in the PPS polymer to gain the wear resistance [11-15]. Guo et al. [11], studied the molybdenum concentrate and PTFE filled PPS composites. They stated that thickening of transfer film layer on the disc decreased the friction. Uniform location of transfer film layer and less detachment of materials from the surface, ensured the increasing of wear resistance. Jiang et al. [12], studied the carbon fiber reinforced sub micro TiO_2 filled PPS composites. For this composite increasing sliding speed increased the friction coefficient, but increasing carbon fiber ratios improved the tribological behaviour. Lhymn et al. [13], studied the fiber reinforced PPS composites. They stated that increasing of glass and carbon fiber ratios, decreased the wear amount. Unal et al. [14], studied the glass fiber reinforced PPS composites. They found that increasing speed worsen the tribological behavior, while increasing load increased the wear and decreased the friction. Besnea et al. [15], tested the 40 wt % glass fiber + PPS and 10 wt % PTFE+ 20 wt % carbon fiber reinforced PPS composites.

In the light of these literatures it is seen that the studies for PPS polymer composites have been being rarely and more detailed studies are needed such as different fiber ratios, influence of load and speed parameters. The aim of this study is to experimental investigate of friction and wear behavior of chopped glass fiber reinforced polyphenylene sulfide composites with glass fiber reinforcements in 20%, 30% and 40% weight ratios. Tests were carried 50, 100, 200 N normal loads and 1, 2, 3 m/s sliding speed values at room temperatures. In these tests, the counterface disc material is AISI 1040 steel used.

2. MATERIALS AND EXPERIMENTAL WORK

In this study, the materials used were PPS polymer and chopped glass fiber reinforcements. Mechanical and physical properties of PPS and chopped glass fiber were given in Table 1. Specimens were prepared using an extruder. Firstly, the composite materials were produced in granular form in an extruder which temperature ranges from 210 ^{0}C to 240 ^{0}C. Then the test specimens were obtained as cylindrical forms with a 5 mm diameter and 40 mm length by an injection mold. The molding temperature varied from 200 ^{0}C to 240 ^{0}C. Tests were done with pin-on-disc test configuration. ASTM G99 test standard was used in wear tests. Experimental and schematic images of the wear test rigs were given in Figure 1a and 1b respectively.

Figure 1a Experimental image of the wear test rig

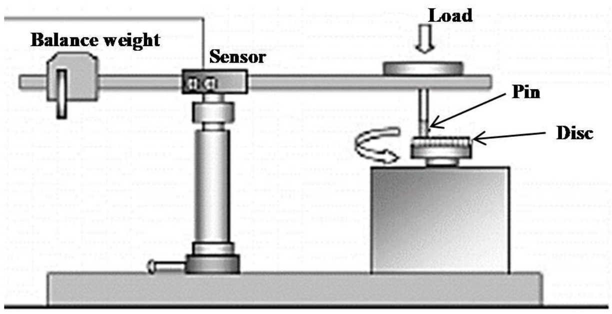

Figure 1b Schematic representation of the wear test rig [16]

Table 1
Mechanical and physical properties of PPS [17] and chopped glass fiber [18]

Properties	PPS	Chopped GF
Tensile strength (MPa)	80	520
Elongation at break (%)	10	4.8
Elasticity modulus (GPa)	2.9	75
Thermal conductivity (W/m.K)	0.2	1.35

Before and after each test, pin specimens and AISI 4140 counterface steel disc with surface roughness (Ra) is 0.29 µm were cleaned with alcohol. Friction force was calculated with a load cell sensor and datas were transferred to the computer. A software calculated the friction forces according to equation (1).

$$\mu = F_F/F_N \quad (1)$$

where F_F is the frictional force and F_N is the normal load. Wear amount was obtained by weight differences which obtained before and after the tests. Applied loads were 50,100, 200 N and sliding speeds were 1, 2, 3 m/s. Tests were repeated three times at room temperature conditions. At the end of the tests, the specific wear rates were calculated, compared and evaluated. Eq. (2) gives the specific wear rate.

$$Wear\ rate = \frac{Wear\ loss}{Density.Load.Sliding\ distance} \quad [mm^3/Nm] \quad (2)$$

3. RESULTS AND DISCUSSIONS

Figure 2 shows the friction coefficient and sliding distance relationship of PPS polymer and glass fiber reinforced PPS composites at 2m/s sliding speed and 50N applied load conditions. It is clear from this figure that PPS polymer showed a small increasing trend up to 1200 m travelling distance and then showed a sharp decreasing behavior and then it continued a steady state behavior. There are some weavings on the PPS line. It is thought that polymer pin could be melt during the rubbing process and detachment particles could make a roughness effect. 20 wt% glass fiber reinforced PPS composites have more waving behavior than the other reinforced composites. Increasing fiber ratio showed more steady state trend and adding of glass fiber decreased the friction coefficient. PPS polymer showed the maximum friction value and 40 wt% glass fiber PPS composite showed the minimum friction with very little weaving trend.

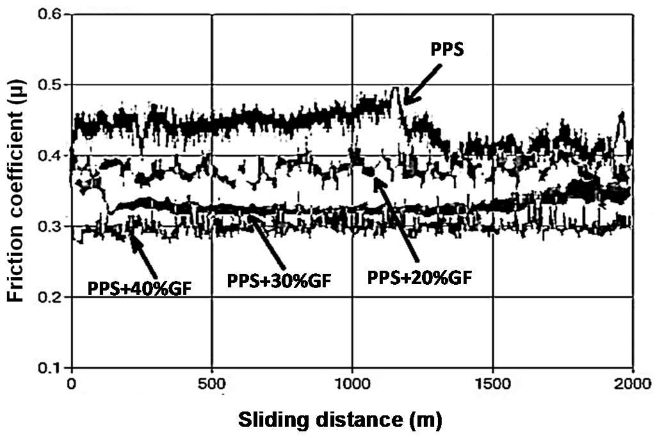

Figure 2 Friction coefficient and sliding distance relationship of pure PPS and PPS composites (speed 2 m/s, load:50N)

Figures 3 and 4 show the friction coefficients of PPS polymer and glass fiber reinforced PPS composites with load and speed, respectively. In the Figure 3 that, adding fiber decreased the friction coefficient and increasing load decreased the friction. Similar situation is seen in the literature [5, 8, 12, and 14]. It is thought that increasing load could shear the surface asperities between pin and disc and it made the pin surface smooth. Therefore, the friction coefficients were decreased. Sarkar et al. [19], explained that as a result of increasing load, it could be a transfer film because of heat generation of rubbing process, thus the friction coefficient decreases because of the increasing load. In the Figure 4, increasing sliding speed caused an increase of friction coefficient. Similar behavior was observed in the literature [13, 14]. It is thought that increasing speed could increase the surface temperature and it could melt and deform the pin surfaces. This could cause the roughness of pin surfaces. And increasing roughness could increase the friction coefficient. It is seen that in the figures 3 and 4, increasing fiber ratio decreased the friction coefficients of PPS polymer. It is thought that adding fiber could decrease the adhesion forces between pin and disc. Also, fibers could decrease the shear forces and thus it could ensure the decreasing of friction forces. Thus, the movement of rotating disc against the pin could be easily. It is seen that in the figures, 40 wt% glass fiber PPS composites have the lowest friction coefficient all the load and velocity conditions.

During the rubbing process, adhesive bonds occurred at the polymer metal contact surfaces and adhesion transfer of polymer material to counterface occurred by molecular and electrostatics forces [20]. Contact region is subjected to shear forces during the rubbing and the forces which effect the contact asperities defined by $F_T = \tau_s . A_r$ equation. A_r is the contact area, τ_s is the shear stress and F_T is the shear force which cuts the adhesive joints at the interface [21, 22]. Polymer – metal adhesion is greater than composite materials. So the F_T tangential forces which necessary to shear the junction points are higher and friction forces are higher than reinforced materials. Adding fiber decreased the adhesion bonds between the contact surfaces and ensured the composites slide easily on the disc so the tangential friction forces decreased as it is seen in the Figures 2-4.

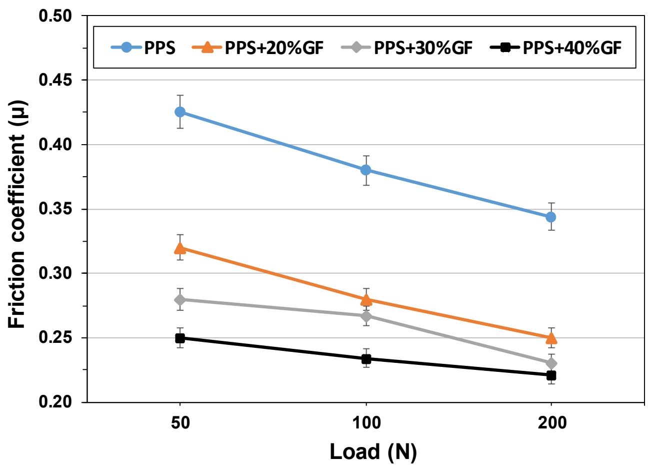

Figure 3 Friction coefficients of materials with load at 1 m/s sliding speed

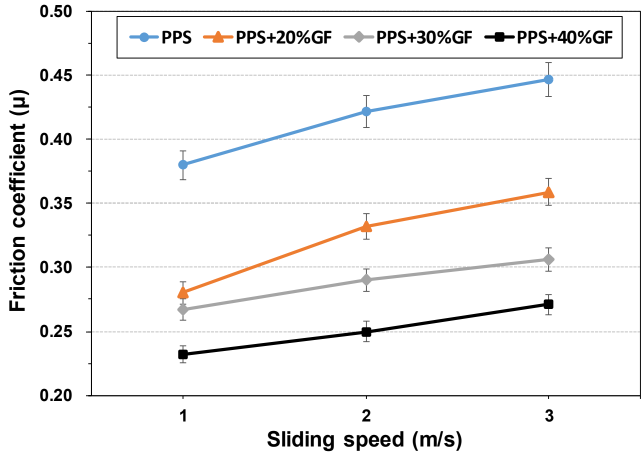

Figure 4 Friction coefficients of materials with speed at 100N load

Figures 5 and 6 show the specific wear rates of PPS polymer and glass fiber reinforced PPS composites with load and speed, respectively. In the Figure 5, it is shown that increasing load increased the wear rates of PPS and glass fiber PPS composites. These results are agreement with the literature [1,3,14]. Increasing fiber ratios strengthened and made the polymer surface harder and so fibers decreased the deformations on the polymer surface and amount of detachment particles decreased. Thus the wear rates of composites decreased. It is seen in Figure 5 that specific wear rate of 40 wt% PPS composite is higher than that of 30 wt% PPS composite at 200N load condition. It is stated in the literature, glass fibers were broken at the high loads [6, 23]. It is thought that it could be a fiber breakage in the PPS polymer at high fiber ratios and higher load. It is seen in the Figure 5 that increasing normal load caused an increase of wear amount and increase of specific wear rate, according to the formula given by equation (2).

Figure 6 shows increasing speed increased the wear rate. This is in a good agreement with the literature [14,19,24,25]. PPS polymer showed the highest wear rate, while 40 wt% reinforced PPS composite showed the minimum specific wear rate. In the literature, increasing speed increased the contact surface heat [19]. It is thought that increasing speed could cause the increasing of surface temperature of pin specimens due to the frictional heating and it could be result of melting the pin contact surfaces and it could increase the wear amount. Furthermore, the work which performed by friction force is given by equation (3) at below,

$$Q_{(t)} = \mu(t).W.v \quad (3)$$

where the $Q_{(t)}$ is the work which generated by friction force by over time, μ is the friction coefficient, W is the load and v is the speed [26]. It is clear in this formula, load and speed are effective on the friction force. Increasing sliding speed increased surface temperature and it caused a high adhesion between the contact surfaces [14,19,24]. High adhesion caused an increase of friction force, thus, increasing friction forces increased the wear rates as it is seen in Figures 4 and 5.

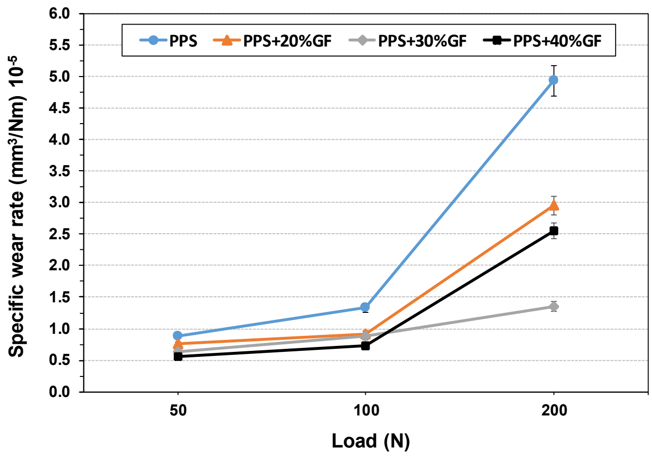

Figure 5 Specific wear rates of materials with load at 1 m/s speed

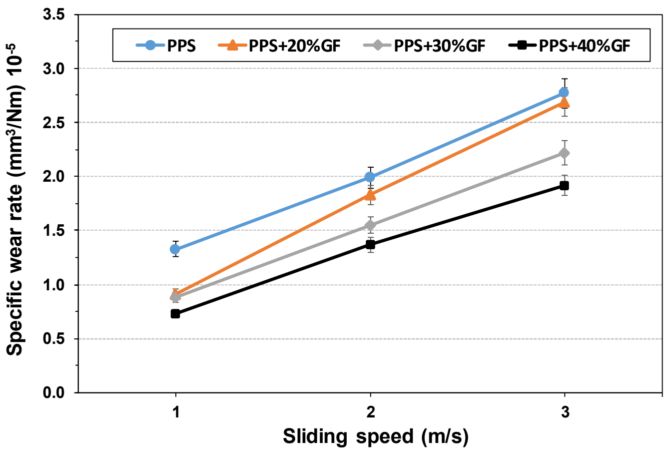

Figure 6 Specific wear rates of materials with speed at 100N load

Figure 7 shows the scanning electron microscopy (SEM) images of disc and pin worn surfaces at 1m/s speed and 100 N applied load value. In Figure 7a, PPS polymer caused the transfer film on the disc surface and is not regular on the disc surface. It caused the waving in friction coefficient values as it is seen in the Figure 1 (friction coefficient vs. sliding distance diagram). In Figure 7b (PPS polymer), micro ploughing lines are more than composite materials. Applied load and sliding speed were caused the softening of PPS contact surface. Besides the shear forces which applied by the disc caused the detachment of particles. In Figures 7c-d-e, it is seen that fibers were broken towards the sliding direction by protecting matrix to the shearing failure. Existing of overlapping layers because of fiber breakage on the material surfaces show the plastic deformation and material losses. Also, 40 wt% ratio of fiber content caused the increase in wear rate at the higher load. It is thought that polymer matrix does not sufficient to bond the fibers at the higher fiber ratios. Some researchers concluded that higher load caused the breakage of the fibers [23, 27]. Wear debris adhered to disc and it makes an abrasive effect on the pin contact surface. Hence, PPS polymer and glass fiber reinforced PPS composites were subjected to adhesive and abrasive wear mechanisms and deformations were seen on the pin surfaces.

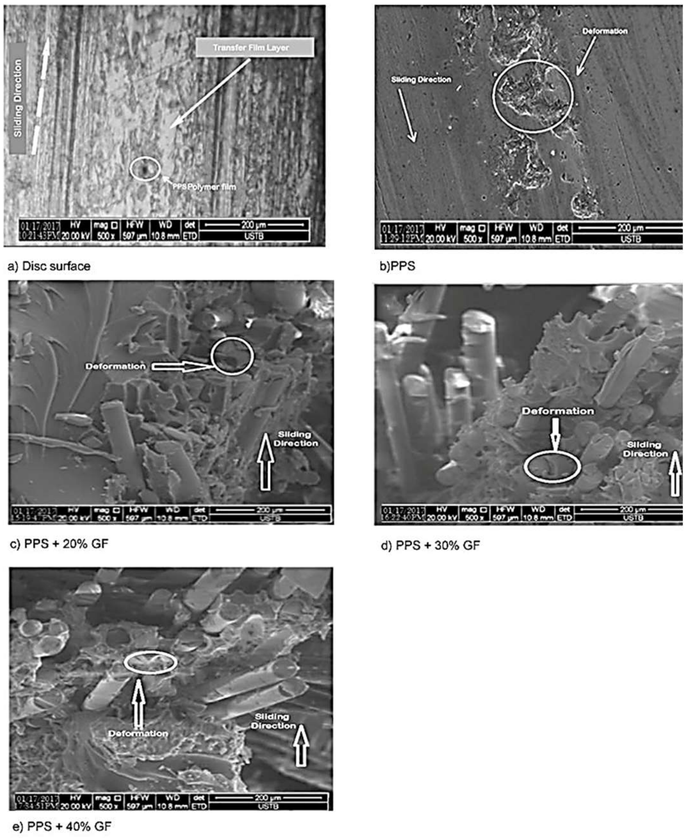

Figure 7 Scanning electron microscopy images of disc and pin worn surfaces at 1m/s sliding speed and 100 N applied load. a) Disc surface, b) PPS, c)PPS+20%GF, d)PPS+30%GF, e)PPS +40%GF

4. CONCLUSIONS

In this study, the following conclusions are reached:

Increasing load from 50N to 200N, decreased the friction values of PPS and glass fiber reinforced PPS composites.

Increasing speed increased the friction value of PPS and glass fiber-PPS composites.

Friction coefficients of glass fiber-PPS composites decreased with increasing fiber ratio.

Increasing sliding speed and load increased the wear rate. Adding glass fiber ratio decreased the wear rates of PPS composites. PPS polymer showed the maximum increment of wear rate with increment of speed and load.

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No conflict of interest or common interest has been declared by the authors.

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The authors declare that this document does not require an ethics committee approval or any special permission.

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The authors of the paper declare that they comply with the scientific, ethical and quotation rules of SAUJS in all processes of the paper and that they do not make any falsification on the data collected. In addition, they declare that Sakarya University Journal of Science and its editorial board have no responsibility for any ethical violations that may be encountered, and that this study has not been evaluated in any academic publication environment other than Sakarya University Journal of Science.

REFERENCES

[1] J. Mens and Jee. De A., “Friction and wear behavior of 18 polymers in contact with steel in environments of air and water,” Wear, vol. 149, pp. 255-268, 1991.

[2] S. Yılmaz, A. E. Şahin, T. Yılmaz, and T. Sınmazçelik., “Pomza tozu ve karbon elyaf takviyeli polifenilen sülfid (PPS) kompozitlerin adhezif aşınma davranışının incelenmesi,” International

Participation III. Ege Composite Materials Symposium, pp.34-36, Turkey, Kuşadası, 2015.

[3] M. Sumer, H. Unal, and A. Mimaroglu, "Evaluation of tribological behaviour of peek composite under dry sliding and water lubricated conditions," Wear, vol. 265, pp. 1061-1065, 2008.

[4] K. Friedrich and A. Voss, "Sliding and abrasive wear of short glass fibre reinforced PTFE composites," Journal of materials science letters, vol. 5, pp. 1111-1114, 1986.

[5] U.S. Tewari and J. Bijwe, "Tribological Behavior of Polyimides, Polyimides: Fundamentals and Applications," M.K. Ghosh and K.L. Mittal, Ed., Marcel Dekker Inc., p 533–586, 1996.

[6] N.S.M. El-Tayeb, F. Yousif, and T.C. Yap, "An investigation on worn surfaces of chopped glass fibre reinforced polyester through SEM observations," Tribology International, vol. 41, pp. 331-340, 2008.

[7] R. Reinicke, K. Friedrich, W. Beier and C. Liebald, "Tribological properties of SiC and G-fiber reinforced glass matrix composites," Wear, vol. 225-229, pp. 1315-1321, 1999.

[8] C. Cai, "Evaluation of the friction and wear properties of PEI composites filled with glass and carbon fiber," Advanced Materials Research, Vols. 299-300, pp 21-24, 2011

[9] H. Voss and K. Friedrich, "On the Wear Behaviour of Short Fibre Reinforced Peek Composites," Wear, vol. 116, pp. 1- 18, 1987.

[10] Engineering plastics handbook / [edited by] James M. Margolis. McGraw-Hill Education: New York, Chicago, San Francisco, Athens, London, Madrid, Mexico City, Milan, New Delhi, Singapore, Sydney, Toronto, 2006 McGraw-Hill Education

[11] L. Guo, H.Q. Zhu, and Y.B. Sun, "Friction and wear studies on polyphenylene sulfide filled with a complex mixture," Applied Mechanics and Materials, vol. 184-185, pp.1400-1403, 2012.

[12] Z. Jiang, A. Schlarb, K. Friedrich, and Z. Zhang, "Study on friction and wear behavior of PPS composites reinforced by short carbon fibers," Article in composites science and technology, vol. 68, pp.124, 2009.

[13] C. Lhymn, "Friction and wear of fiber reinforced PPS composites," Advances in polymer technology, Vol. 7, No. 4, pp. 451-461, 1987.

[14] H. Ünal, U. Şen, and A. Mimaroğlu, "Dry sliding wear characteristics of some industrial polymers against steel counterface," Tribology International, vol. 37, pp. 727-732, 2004.

[15] A. Besnea, D. Trufasu, G. Andrei, and L. Deleanu, "Wear behavior of polyphenylene sulfide composites during dry sliding tests," Mechanical Testing and Diagnosis, vol. 2, pp. 15-20, 2012.

[16] N.A. Emira, H.T. Mohamad, and M. S. Tahat, "Stick-slip detection through measurement of near fieldnoise", Journal of Mechanical Engineering Research Vol. 3(3), pp. 96-102, 2011.

[17] D.I. Chukov, A.A. Stepashkin, V.V. Tcherdyntsev, L.K. Olifirov, and S.D. Kaloshkin, "Structure and properties of composites based on polyphenylene sulfide reinforced with Al-Cu-Fe quasicrystalline particles", Journal of Thermoplastic Composite Materials, Vol. 31, no. 7, pp. 882–895, 2018.

[18] M.A. Abdulrehman, I.I. Marhoon, and A.K AlKamal, "Studying the Effect of Reinforcement with Random Short Fibers and Temperature on the Impact Strength of an Epoxy/Polyurethane Blend Matrix", International Conference on Materials Engineering and Science, IOP Conf. Series: Materials Science and Engineering, vol. 454, pp.1-6, 2018.

[19] P. Sarkar, N. Modak, and P. Sahoo, "Effect of Normal Load and Velocity on

Continuous Sliding Friction and Wear Behavior of Woven Glass Fiber Reinforced Epoxy Composite," Materials Today: Proceedings, vol. 4, pp. 3082–3092, 2017.

[20] W. Wieleba, "The Mechanism of Tribological Wear of Thermoplastic Materials," Archieves of Civil and Mechanical Engineering, Vol: VII, No:4, pp. 185-199, 2007.

[21] V. Quaglini and P. Dubini, "Friction of Polymers Sliding on Smooth Surfaces," Advances in Tribology, Volume 2011, pp. 1-8, 2011.

[22] K.V. Shooter and D. Tabor, "The Frictional Properties of Plastics," Proceedings of the Physical Society. Section B, Volume: 65, Number: 9, Pages: 661–671, 1952.

[23] Kishore, P. Sampathkumaran, S. Seetharamu, S. Vynatheya, A. Murali, R.K. Kumar, SEM observations of the effects of velocity and load on the sliding wear characteristics of glass fabric–epoxy composites with different fillers, Wear, vol. 237, pp. 20–27, 2000.

[24] A. Mimaroglu, H. Unal, and T. Arda, "Friction and Wear Performance of Pure and Glass Fiber Reinforced Poly-Ether-Imide on Polymerand Steel Counter face Materials," Wear, vol. 262, pp.1407–1413, 2007.

[25] B. Suresha, G. Chandramohan, P. Samapthkumaran, S. Seetharamu, and S. Vynatheya, "Friction and Wear Characteristics of Carbon Epoxy and Glass-Epoxy Woven Roving Fiber Composites," J. of Rein. Plast. and Comp. vol. 25, pp. 771-782, 2006.

[26] Surface Effects and Contact Mechanics X: Computational Methods and Experiments, WIT Transactions on Engineering Sciences, Vol 71, 2011 WIT Press, UK, page 223, Edited By: J.T.M. DE HOSSON, C.A. Brebbia, ISSN 1743-3533 (on-line)

[27] H. Pıhtılı and N. Tosun, "Effect of load and speed on the wear behaviour of woven glass fabrics and aramid fibre-reinforced composites," Wear, vol. 252, pp. 979–984, 2002.