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Experimental investigation on friction coefficient of composite materials sliding against SS 201 and SS 301 counterfaces

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Abstract

In this research, friction coefficients of composite materials such as gear fiber reinforced plastic (gear fiber) and glass fiber reinforced plastic (glass fiber) are investigated and compared. In the experiments, gear fiber and glass fiber slide against different austenitic stainless steels such as stainless steel 201 (SS 201) and stainless steel 301 (SS 301). Experiments are carried out at low loads 2, 4 and 6 N, low sliding velocities 0.2, 0.4 and 0.6 m/s and relative humidity 70%. The obtained results reveal that in general, friction coefficient of gear fiber and glass fiber increases with the increase in normal load and sliding velocity. Results show that friction coefficient of glass fiber-SS 201 pair is the highest and gear fiber-SS 301 pair is the lowest within the observed range of normal load and sliding velocity. On the other hand, it is found that friction coefficient of glass fiber-SS 301 pair is slightly higher than that of gear fiber-SS 201 pair. During the running-in process, friction coefficient of gear fiber and glass fiber steadily increases with the increase in rubbing time and after certain duration of rubbing, it remains constant regardless of the counterface material. The obtained results reveal that for the observed range, the influence of normal load on the frictional properties of gear fibe and glass fiber is greater than that of sliding velocity. At identical operating conditions, the magnitudes of friction coefficient of gear fiber and glass fiber are different depending on normal load, sliding velocity and counterface material.

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Keywords: Friction coefficient; gear fiber; glass fiber; SS 201; SS 301; normal load; sliding velocity; running-in process

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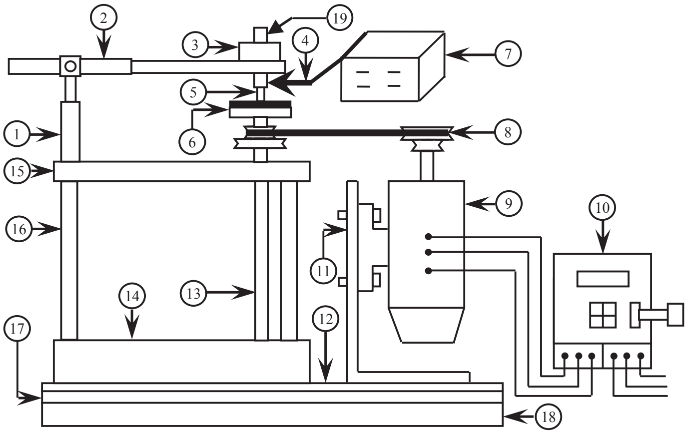
1. Introduction

In the past decade, a number of investigations were carried out on friction and wear of different type materials under different operating conditions. Several researchers [1-7] reported that friction and wear of metals, polymers and composites rubbing against metal depend on several parameters such as normal load, roughness of the rubbing surfaces, sliding velocity, relative humidity, lubrication etc. Among these parameters, normal load and sliding velocity are the most influential parameters that dictate the tribological properties of the materials. Friction coefficient of polymers and its composites sliding against metal increase or decrease depending on the range of operating conditions and sliding pairs. There have been also investigations to explore the influence of type of material, relative motion and frequency, amplitude and direction of vibration [8-10]. It was reported that the influence of velocity on the sliding wear of polymer and its composite is greater than that of applied load [11] although other researchers have different views [12,13]. Tribological performance of polymeric material can be improved significantly by the incorporation of fiber reinforcement or fillers. Friction and wear characteristics of polymers and composite materials sliding against rough steel counterface were investigated [14] and it was reported that frictional values of these polymers and composites are significantly influenced by the applied load and duration of rubbing. Wear rates of these polymers and composites are also greatly influenced by the applied normal load. The influence of sliding velocity on the friction and wear of polymer and composite materials sliding against rough steel counterface were also investigated [15]. The obtained results showed that in general, friction coefficient increases with the increase in sliding velocity for all the tested materials. It was also found that wear rates of these polymer and composite materials are significantly influenced by sliding velocity. After friction process, it was observed that surface roughnesses of these materials are greatly changed depending on sliding velocity. Friction coefficient and wear rate of different composite materials sliding against smooth and rough mild steel counterfaces were investigated [16]. It was found that the friction coefficient and wear rate of these materials are significantly influenced by the applied normal load, sliding velocity and counterface surface condition.

Despite the aforementioned research works, frictional properties of different composites such as gear fiber and glass fiber sliding against different grades of austenitic stainless steels under different normal loads and sliding velocities are yet to be clearly understood. Therefore, in this study, the frictional properties of gear fiber and glass fiber sliding against stainless steel 201 (SS 201) and stainless steel 301 (SS 301) under low load and low velocity conditions are investigated. The influence of rubbing time on friction coefficient of these composite materials is also examined. Nowadays, different composite-steel combinations are widely used for sliding/rolling applications where low friction is required. Due to these tribological applications, different material combinations have been selected in this research study.

2. Experimental

Experiments are carried out using a pin-on-disc set-up which is shown in Fig. 1. A cylindrical pin (both ends flat) can slide on a horizontal surface (disc) which rotates using the power from a motor. A circular test disc is fixed on a horizontal plate which can rotate and this rotation (rpm) can be varied by an electronic speed control unit. A vertical shaft which connects the horizontal plate with a stainless steel base plate. To provide the alignment and rigidity to the main structure of this set-up, four vertical cylindrical bars are rigidly fixed around the periphery to connect horizontal plate with the stainless steel base plate. The whole set-up is placed on a main base plate which is made of mild steel (10 mm thick). The mild steel main base plate is supported by a rubber block (20 mm thick) at the lower side. A rubber sheet (3 mm thick) is also placed at the upper side of the main base plate to absorb any vibration during the friction test. For power transmission from the motor to the stainless steel base plate, a compound V-pulley is fixed with the shaft. A cylindrical pin (6 mm diameter) made of stainless steel can be fitted in a holder and this holder is subsequently fixed by an arm. A load cell (CLS-10NA) along with digital indicator (TD-93A) was used to measure the frictional force. To obtain the friction coefficient, the measured frictional force was divided by the applied normal load. To measure the roughness, A precision roughness checker was used. Each experiment was carried out for 30 minutes and after each experiment, new pin and new test sample were used. Each experiment was repeated five times to ensure the reliability of test results and the average value was taken into consideration. Table 1 shows the detail of the experimental conditions.



1 Load arm holder
2. Load arm
3. Normal load (dead weight)
4. Horizontal load (Friction force)
5. Pin sample
6. Test disc with rotating table
7. Load cell indicator
8. Belt and pulley
9. Motor
10. Speed control unit
11. Vertical motor base
12. 3 mm Rubber pad
13. Main shaft
14. Stainless steel base
15. Stainless steel plate
16. Vertical square bar
17. Mild steel main base plate
18. Rubber block (20 mm thick)
19. Pin holder.

Fig. 1. Block diagram of the pin-on-disc experimental set-up

Table 1. Experimental conditions

Sl. No.	Parameters	Operating conditions
1.	Normal Load	2, 4, 6 N
2.	Sliding Velocity	0.2, 0.4, 0.6 m/s
3.	Relative Humidity	70 (± 5)%
4.	Duration of Rubbing	30 minutes
5.	Surface Condition	Dry
6.	Disc material	(i) Gear fiber (ii) Glass fiber
7.	Average Surface Roughness of Gear fiber and Glass fiber, R_a	0.4-0.5 μm
8.	Counterface pin material	(i) SS 201 (ii) SS 301
9.	Average Surface Roughness of SS 201 and SS 301, R_a	0.2-0.3 μm

3. Results and discussion

Fig. 2 shows the variation of friction coefficient during the running-in process at different normal loads 2, 4 and 6 N. Experiments were carried out at sliding velocity 0.4 m/s. In the experiments, gear fiber was used for disc material and SS 201 was used for counterface pin material. Curve 1 for normal load 2 N shows that at early stage of rubbing, friction coefficient of gear fiber is about 0.025 and after that it increases very steadily up to 0.05. It was observed that friction coefficient becomes steady over a duration of 24 minutes and it remains constant for the rest of the experimental time. It is believed that due to the ploughing effect, trapped wear particles between the contacting surfaces and surface roughening of the disc, friction force increases with rubbing time. After the running-in process for a certain duration, surface roughness and other parameters reached to a steady state value and there is no change in friction with time. Curves 2 and 3 show the results for normal load 4 and 6 N respectively and the trends of variation of friction coefficient are almost similar as that of curve 1. It was observed that gear fiber disc takes different time to stabilize which is 24, 20 and 17 minutes for different normal loads 2, 4 and 6 N respectively. It indicates that time to reach steady friction is less as the normal load is increased. This is because the surface roughness and other parameter attain a steady level at a shorter period of time with the increase in normal load.

Variations of friction coefficient with duration of rubbing are shown in Fig. 3 and in the experiments, glass fiber was used as disc material and SS 201 was used as pin material. It is observed that at 2 N normal load (curve 1), friction coefficient is 0.046 at initial stage of rubbing and after that friction coefficient increases steadily up to 0.071 which remains almost constant till experimental time 30 minutes. For normal load 4 and 6 N (curves 2 and 3), the trends of variation of friction coefficient are almost similar as that of curve 1. It is also observed that glass fiber disc takes about 25, 21 and 20 minutes to stabilize when the applied normal load is 2, 4 and 6 N respectively. During the running-in process, glass fiber disc takes less time to reach steady state friction when higher load is applied.

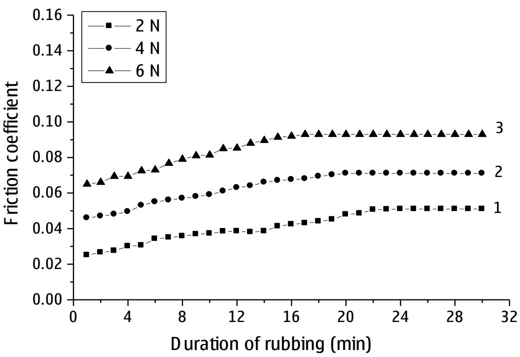


Fig. 2. Variation of friction coefficient with duration of rubbing at different normal loads (Sliding velocity: 0.4 m/s, test sample: gear fiber, pin: SS 201)

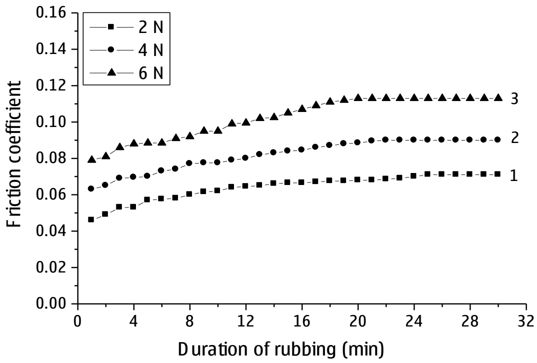


Fig. 3. Variation of friction coefficient with duration of rubbing at different normal loads (Sliding velocity: 0.4 m/s, test sample: glass fiber, pin: SS 201)

Fig. 4 shows the variations of friction coefficient with duration of rubbing at different loads and in the experiments, gear fiber was used as disc material and SS 301 was used as counterface pin material. Curve 1 at 2 N normal load shows that during initial rubbing, friction coefficient is 0.021 which rises for a certain duration of rubbing to a value of 0.035 and then it becomes steady for the rest of the experimental time. Almost similar trends of variation are observed in curves 2 and 3 which are drawn for load 4 and 6 N respectively. From these curves, it can be observed that time to reach steady friction is different for different normal loads. The obtained results show that at normal load 2, 4 and 6 N, gear fiber takes 25, 21 and 18 minutes respectively to reach steady friction. It is apparent that higher the normal load, gear fiber takes less time to stabilize. Experiments were carried out to observe the variation of friction coefficient at different normal loads when glass fiber disc slid against SS 301 pin and the results are shown in Fig. 5. Curve 1 for normal load 2 N shows that during initial rubbing, friction coefficient is 0.034 which increases almost linearly up to 0.055 over a duration of 25 minutes and after that it remains steady. Curves 2 and 3 for normal load 4 and 6 N show similar trends as that of curve 1. During the running-in process, glass fiber disc takes 25, 22 and 18 minutes to stabilize when applied normal load 2, 4 and 6 N respectively.

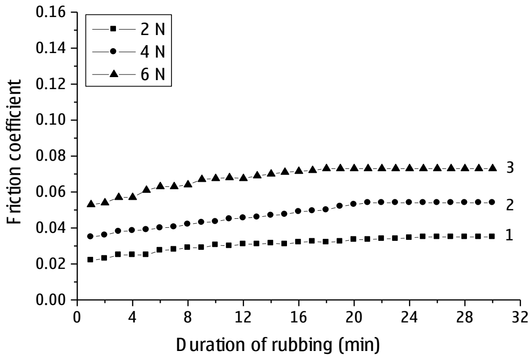


Fig. 4. Variation of friction coefficient with duration of rubbing at different normal loads (Sliding velocity: 0.4 m/s, test sample: gear fiber, pin: SS 301)

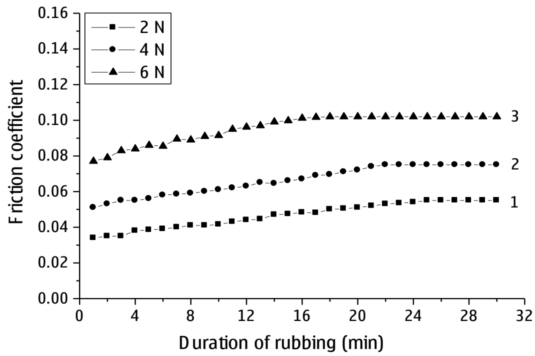


Fig. 5. Variation of friction coefficient with duration of rubbing at different normal loads (Sliding velocity: 0.4 m/s, test sample: glass fiber, pin: SS 301)

Figure 6 shows a comparison of friction coefficient of different composite-stainless steel pairs at different normal loads. Results show that friction coefficient varies from 0.05 to 0.093, 0.071 to 0.113, 0.035 to 0.073 and 0.055 to 0.1 for gear fiber-SS 201, glass fiber-SS 201, gear fiber-SS 301 and glass fiber-SS 301 pairs respectively due to the variation of normal load from 2 to 6 N. These friction results are obtained from the steady values of friction coefficient of Figs. 2, 3, 4 and 5 respectively. It is apparent that friction coefficient increases almost linearly with the increase in normal load for all the material combinations. It is believed that because of more ploughing effect which causes roughening of the disc surface, friction coefficient increases with the increase in normal load. From the figure it is apparent that within the observed range of normal load, friction coefficient of glass fiber-SS 201 pair is the highest and gear fiber-SS 301 pair is the lowest. It is also observed that frictional values of glass fiber-SS 301 and gear fiber-SS 201 pairs are in between the highest and lowest values. On the other hand, glass fiber-SS 301 pair shows higher friction than gear fiber-SS 201 pair. This is because at higher normal load, hardness of SS 201 and glass fiber might have significant role on the friction process. After the running-in process, average surface roughness (R_a) was measured which varied from 1.1-1.45 μm, 1.35-1.7 μm, 0.95-1.25 μm and 1.15-1.57 μm for gear fiber-SS 201, glass fiber-SS 201, gear fiber-SS 301 and glass fiber-SS 301 pairs respectively.

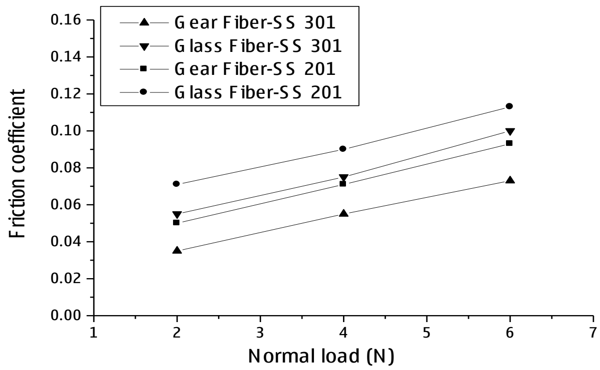


Fig. 6. Comparison of friction coefficient of different composite-stainless steel pairs at different normal loads (Sliding velocity: 0.4 m/s)

Variations of friction coefficient with duration of rubbing at different sliding velocities are shown in Fig. 7 and in this case, gear fiber disc slid against SS 201 pin. Curves 1, 2 and 3 show the results for sliding velocity 0.2, 0.4 and 0.6 m/s respectively. Curve 1 shows that at initial rubbing, friction coefficient is 0.036 which increases steadily up to 0.06 over a duration of 23 minutes and after that it remains steady. Curves 2 and 3 show that the trends in variation of friction coefficient are almost same as that of curve 1. It is observed that at 0.2, 0.4 and 0.6 m/s, gear fiber takes 23, 20 and 17 minutes respectively to reach steady friction. Variations of friction coefficient with duration of rubbing are presented in Fig. 8 and in this case, glass fiber disc slid against SS 201 pin. Results show that glass fiber takes 23, 21 and 17 minutes to reach steady friction at 0.2, 0.4 and 0.6 m/s respectively. Variations of friction coefficient are also shown in Fig. 9 and in the experiments, gear fiber disc slid against SS 301 counterface. These results show that for higher sliding velocity, gear fiber takes less time to stabilze. Results of the variations of friction coefficients are shown in Fig. 10 and in this case, glass fiber disc slid against SS 301 counterface. From the obtained results, it is clear that the trends of frictional variation are almost similar but at higher sliding velocity, frictional values are higher and glass fiber takes less time to stabilize.

Figure 11 shows a comparison of friction coefficient of different composite-stainless steel pairs at different sliding velocities. It is shown that friction coefficient varies from 0.06 to 0.082, 0.078 to 0.103, 0.043 to 0.067 and 0.064 to 0.085 for gear fiber-SS 201, glass fiber-SS 201, gear fiber-SS 301 and glass fiber-SS 301 pairs respectively due to the variation of sliding velocity from 0.2 to 0.6 m/s. These results are obtained from the steady frictional values of Figs. 7, 8, 9 and 10 respectively. It can be seen that friction coefficient of all the material pairs increases almost linearly with the increase in sliding velocity. As comparison, frictional values of glass fiber-SS 201 pair are the highest and gear fiber-SS 301 pair are the lowest for the observed range of sliding velocity. It can also be observed that frictional values of gear fiber-SS 201 and glass fiber-SS 301 pairs are in between the highest and lowest values as before (Fig. 6). On the other hand, glass fiber-SS 301 pair exhibits slightly higher friction than gear fiber-SS 201 pair. After the friction process, average surface roughness (R_a) was measured as 1.23-1.42 µm, 1.38-1.61 µm, 1.03-1.27 µm and 1.24-1.45 µm for gear fiber-SS 201, glass fiber-SS 201, gear fiber-SS 301 and glass fiber-SS 301 pairs respectively. Moreover, as comparison of these results (Fig. 11) with the results of Fig. 6, it reveals that within the observed range, the influence of normal load on the frictional properties of the tested material pairs is greater than that of sliding velocity.

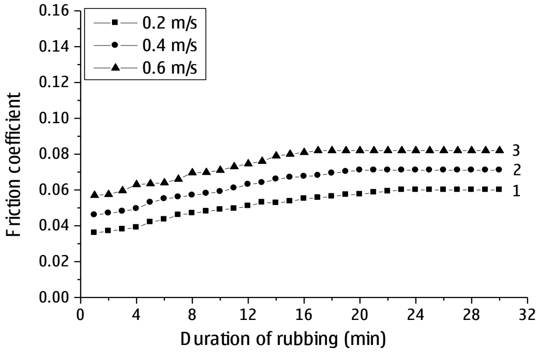


Fig. 7. Variation of friction coefficient with duration of rubbing at different sliding velocities (Normal load: 4 N, test sample: gear fiber, pin: SS 201)

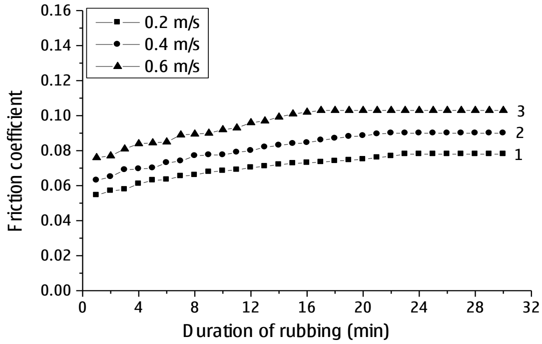


Fig. 8. Variation of friction coefficient with duration of rubbing at different sliding velocities (Normal load: 4 N, test sample: glass fiber, pin: SS 201)

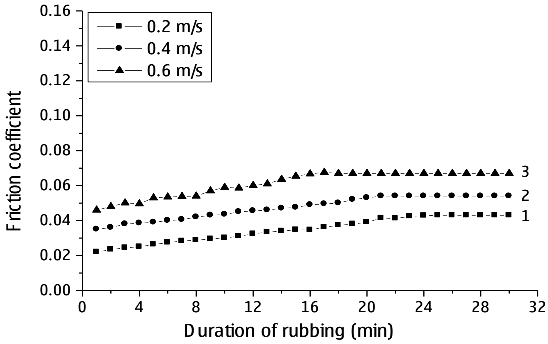


Fig. 9. Variation of friction coefficient with duration of rubbing at different sliding velocities (Normal load: 4 N, test sample: gear fiber, pin: SS 301)

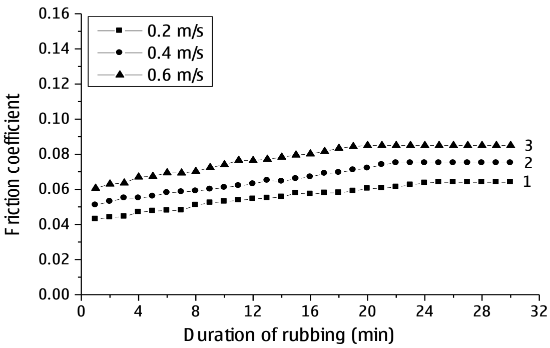


Fig. 10. Variation of friction coefficient with duration of rubbing at different sliding velocities (Normal load: 4 N, test sample: glass fiber, pin: SS 301)

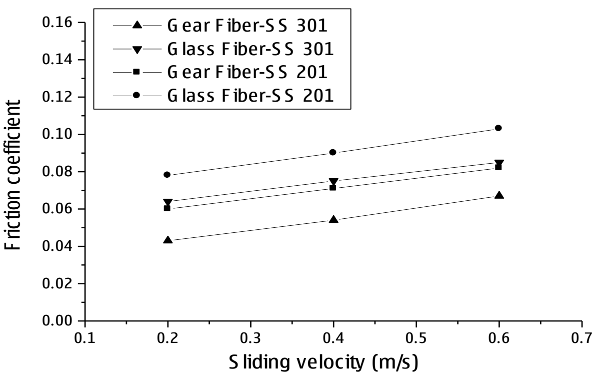


Fig. 11. Comparison of friction coefficient of different composite-stainless steel pairs at different sliding velocities (Normal load: 4 N)

4. Conclusion

From this research study, the obtained results are summarized as:

1. Within the observed range, frictional properties of gear fiber and glass fiber are influenced by normal load, sliding velocity and counterface material. During running-in process, friction coefficient increases with the increase in rubbing time and after a certain duration, it becomes steady for both gear fiber and glass fiber. The obtained results show that during friction process, gear fiber or glass fiber disc takes less time to stabilize as the normal load or sliding velocity increases. Moreover, the time to reach steady friction is different for gear fiber or glass fiber depending on applied normal load or sliding velocity.
2. Under low load and low velocity conditions, in general, friction coefficient increases with the increase in normal load or sliding velocity for all the material pairs. At identical operating conditions, friction coefficient of glass fiber-SS 201 pair is the highest whereas gear fiber-SS 301 pair shows the lowest friction coefficient. Moreover, the frictional values of glass fiber-SS 301 pair are slightly higher than that of gear fiber-SS 201 pair.
3. Regardless of the counterface material, the influence of normal load on the frictional properties of gear fiber and glass fiber is greater than that of sliding velocity.

Therefore, maintaining an appropriate level of normal load, sliding velocity as well as appropriate choice of material pair, friction can be kept to some lower value to improve the mechanical processes in order to ensure performance and quality in industry.

References

[1] A. Mimaroglu, H. Unal, T. Arda, Friction and wear performance of pure and glass fiber reinforced poly-ether-imide on polymer and steel counterface materials, Wear, 262 (2007) 1407–1413.

[2] B. Suresha, G. Chandramohan, P. Samapthkumaran, S. Seetharamu, S. Vynatheya, Friction and wear characteristics of carbon-epoxy and glass-epoxy woven roving fiber composites. J. Reinf. Plast. Comp. 25 (2006) 771-782.

[3] N.S.M. El-Tayeb, B.F. Yousif, T.C. Yap, Tribological studies of polyester reinforced with CSM 450-R-glass fiber sliding against smooth stainless steel counterface. Wear 261 (2006) 443–452.

[4] Yu. Sirong, Yu. Zhongzhen, Yiu-Wing Mai. Effects of SEBS-g-MA on tribological behavior of nylon 66/organoclay nanocomposites. Tribol. Int. 40 (2007) 855 – 862.

[5] J. Wang, M. Gu, S. Bai, S. Ge, Investigation of the influence of MoS2 filler on the tribological properties of carbon fiber reinforced nylon 1010 composites. Wear 255 (2003) 774–779.

[6] J. Wang, M. Gu, Wear properties and mechanisms of nylon and carbon-fiber-reinforced nylon in dry and wet conditions. J. Appl.Polym. Sci. 93 (2004) 789–795.

[7] M.A.Chowdhury, D.M. Nuruzzaman, Experimental Investigation on Friction and Wear Properties of Different Steel Materials. Tribol. Ind. 35 (2013) 42-50.

[8] M.A. Chowdhury, M.M. Helali, The effect of amplitude of vibration on the coefficient of friction for different materials. Tribol. Int. 41 (2008) 307 – 314.

[9] M.A. Chowdhury, M.M. Helali, The frictional behavior of materials under vertical vibration. Ind. Lubr. Tribol. 61 (2009) 154 – 160.

[10] M.A. Chowdhury, M.M. Helali, The frictional behavior of composite materials under horizontal vibration. Ind. Lubr. Tribol. 61 (2009) 246 – 253.

[11] A. Mimaroglu, H. Unal, T. Arda, Friction and wear performance of pure and glass fiber reinforced poly-ether-imide on polymer and steel counterface materials, Wear, 262 (2007) 1407–1413.

[12] H. Unal, A. Mimaroglu, U. Kadioglu, H. Ekiz, Sliding friction and wear behaviour of polytetrafluoroethylene and its composites under dry conditions, Mater. Des. 25 (2004) 239–245.

[13] H. Unal, U. Sen, A. Mimaroglu, An approach to friction and wear properties of polytetrafluoroethylene composite, Mater. Des. 27 (2006) 694-699.

[14] D.M. Nuruzzaman, M.A.Chowdhury, M.L. Rahaman, Effect of duration of rubbing and normal load on friction coefficient for polymer and composite materials, Ind. Lubr. Tribol. 63 (2011) 320-326.

[15] D.M. Nuruzzaman, M.L. Rahaman, M.A. Chowdhury, Friction coefficient and wear rate of polymer and composite materials at different sliding speeds, Int. J. Surf. Sci. Eng. 6 (2012) 231-245.

[16] M.A. Chowdhury, D.M. Nuruzzaman, B.K. Roy, S. Samad, R. Sarker, A.H.M. Rezwan, Experimental Investigation of Friction Coefficient and Wear Rate of Composite Materials Sliding Against Smooth and Rough Mild Steel Counterfaces. Tribol. Ind. 35 (2013) 286-296.