

Influence of normal loads and sliding velocities on friction properties of engineering plastics sliding against rough counterfaces

This content has been downloaded from IOPscience. Please scroll down to see the full text.

2016 IOP Conf. Ser.: Mater. Sci. Eng. 114 012112

(<http://iopscience.iop.org/1757-899X/114/1/012112>)

View [the table of contents for this issue](#), or go to the [journal homepage](#) for more

Download details:

IP Address: 103.53.34.12

This content was downloaded on 04/03/2016 at 04:10

Please note that [terms and conditions apply](#).

Influence of normal loads and sliding velocities on friction properties of engineering plastics sliding against rough counterfaces

D M Nuruzzaman¹, M A Chowdhury², M L Rahaman² and A N Oumer³

¹ Faculty of Manufacturing Engineering, University Malaysia Pahang, Malaysia

² Department of Mechanical Engineering, Dhaka University of Engineering and Technology, Gazipur, Bangladesh

³ Faculty of Mechanical Engineering, University Malaysia Pahang, Malaysia

E-mail: dewan052005@yahoo.com

Abstract. Friction properties of plastic materials are very important under dry sliding contact conditions for bearing applications. In the present research, friction properties of engineering plastics such as polytetrafluoroethylene (PTFE) and nylon are investigated under dry sliding contact conditions. In the experiments, PTFE and nylon slide against different rough counterfaces such as mild steel and stainless steel 316 (SS 316). Frictional tests are carried out at low loads 5, 7.5 and 10 N, low sliding velocities 0.5, 0.75 and 1 m/s and relative humidity 70%. The obtained results reveal that friction coefficient of PTFE increases with the increase in normal loads and sliding velocities within the observed range. On the other hand, frictional values of nylon decrease with the increase in normal loads and sliding velocities. It is observed that in general, these polymers show higher frictional values when sliding against SS 316 rather than mild steel. During running-in process, friction coefficient of PTFE and nylon steadily increases with the increase in rubbing time and after certain duration of rubbing, it remains at steady level. At identical operating conditions, the frictional values are significantly different depending on normal load, sliding velocity and material pair. It is also observed that in general, the influence of normal load on the friction properties of PTFE and nylon is greater than that of sliding velocity.

1. Introduction

In the past decade, friction and wear characteristics of different type materials were investigated under different operating conditions and several researchers [1-6] reported that friction and wear of plastics and their composites rubbing against metal depend on several parameters such as sliding velocity, roughness of the rubbing surfaces, normal load, lubrication, relative humidity, etc. Among these parameters, sliding velocity and normal load are the most influential parameters which dictate the frictional properties of the materials. Depending on the sliding pairs and the range of operating conditions, friction coefficient of polymers and its composites may increase or decrease. The influence of type of material, relative motion and frequency, amplitude and direction of vibration have also been

¹ Corresponding author



investigated [7-9]. Sliding friction and wear characteristics of polymer and composite materials were also investigated under different applied load and sliding velocity conditions [10,11].

Recently, engineering plastics and their composites are finding ever increasing usage for a wide variety of industrial applications such as bearing materials, gears, wheels, cams, rollers, clutches, pistons rings, mechanical seals, etc. where their self-lubricating properties are exploited in order to avoid the need for any lubrication. Friction and wear characteristics of these engineering polymers and composite materials sliding against steel counterface were investigated [12] and it was reported that frictional characteristics of these polymers and composites are markedly influenced by the applied load and duration of rubbing. Wear rates of these materials are also significantly influenced by the applied normal load. Friction and wear properties of polymer and composite materials under different sliding velocities were also investigated [13]. Experimental results revealed that in general, friction increases with the increase in sliding velocity. It was also observed that wear rates of these materials are significantly influenced by the sliding velocity. After running-in process, it was observed that surface roughnesses are changed depending on sliding velocity and material pair.

Despite the aforementioned research works, friction properties of different engineering plastics such as PTFE and nylon sliding against different rough counterfaces such as mild steel and stainless steel 316 (SS 316) are yet to be clearly understood. Therefore, in this research study, the frictional properties of PTFE and nylon sliding against mild steel and SS 316 under low load and low velocity conditions are investigated. The influence of rubbing time on friction coefficient of these polymer materials is also examined. Furthermore, at identical operating conditions, the friction properties of these polymers are compared.

2. Experimental

Figure 1 shows the pin-on-disc experimental set-up which was used for the friction tests of the specimens. Using the power from motor, a horizontal test disc can rotate and a cylindrical pin (both ends flat) can slide on the test disc. The circular test disc is rigidly fixed on a horizontal plate which can rotate and an electronic speed control unit is used to vary the rotation (rpm) of the disc.

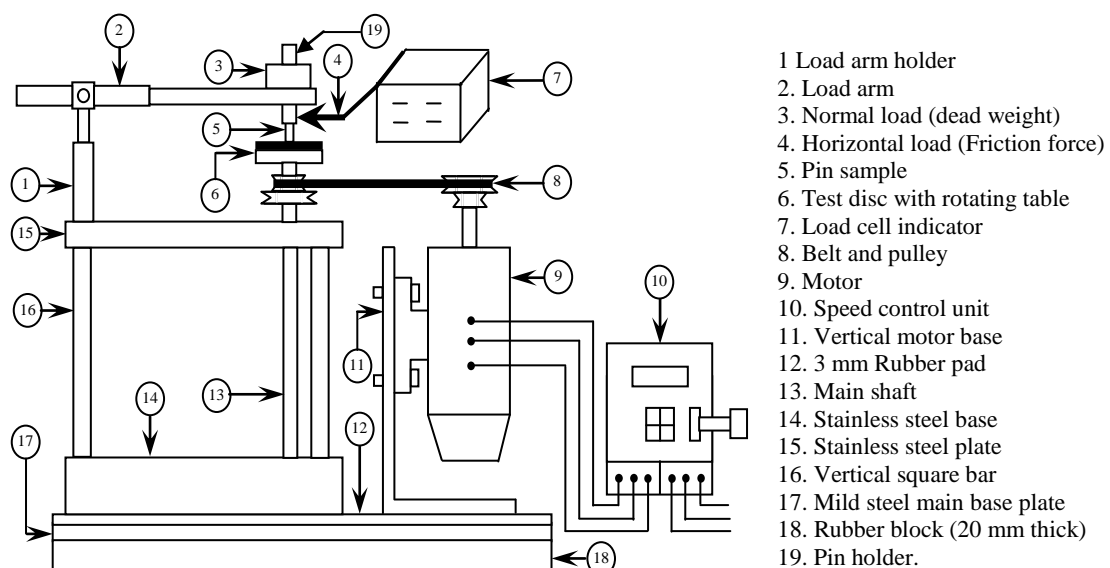


Figure 1. Block diagram of the pin-on-disc experimental set-up

A stainless steel base is connected with the horizontal plate made of stainless steel by a vertical shaft. Four vertical cylindrical bars are rigidly fixed around the periphery to connect the horizontal

plate with the stainless steel base plate to provide alignment and rigidity. The whole set-up is placed on a main base plate made of mild steel (10 mm thick) which is supported by a rubber block (20 mm thick) at the lower side. To absorb any vibration during the friction test, a rubber sheet (3 mm thick) is also placed at the upper side of the main base plate. A compound V-pulley is fixed with the shaft for the power transmission from the motor to the stainless steel base plate. A cylindrical pin (6 mm diameter) made of mild steel or stainless steel 316 (SS 316) can be fitted in a holder and this holder is subsequently fixed by an arm. To measure the frictional force, a load cell (CLS-10NA) along with digital indicator (TD-93A) was used. The measured frictional force was divided by the applied normal load to obtain the friction coefficient. To measure the surface roughness, a precision roughness checker (Taylor Hobson) was used. Each friction test was carried out for 30 minutes and after each test, new pin and new test sample were used. To ensure the reliability of test results, each friction test was repeated five times for identical operating conditions and the average value was taken into consideration. The detail experimental conditions are shown in table 1.

Table 1. Experimental conditions

Sl. No.	Parameters	Operating conditions
1.	Normal Load	5, 7.5, 10 N
2.	Sliding Velocity	0.5, 0.75, 1.0 m/s
3.	Relative Humidity	70 (\pm 5)%
4.	Duration of Rubbing	30 minutes
5.	Contact condition	Dry sliding contact
6.	Disc material	(i) PTFE (ii) Nylon
7.	Average Surface Roughness of PTFE and Nylon, R_a	0.3-0.4 μ m
8.	Counterface material	(i) Mild steel (ii) SS 316
9.	Counterface size	6.0 mm (cylindrical)
10.	Average Surface Roughness of mild steel and SS 316, R_a	3.0- 4.0 μ m

3. Results and discussion

Figure 2 exhibits the frictional variation during the running-in process at different normal loads 5, 7.5 and 10 N. These experiments were carried out at sliding velocity 0.75 m/s. In the experiments, PTFE was used for disc material and mild steel was used for counterface pin material. Curve 1 for normal load 5 N shows that at early stage of rubbing, friction coefficient of PTFE is about 0.027 and after that it increases very steadily up to 0.042. It was observed that friction coefficient becomes steady over a duration of 25 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 7.5 and 10 N

respectively and the trends of variation of friction coefficient are almost similar as that of curve 1. It was observed that PTFE disc takes different time to stabilize which is 25, 21 and 16 minutes for different normal loads 5, 7.5 and 10 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 rubbing time are shown in figure 3 and in the experiments, nylon was used as disc material and mild steel was used as pin material. It is observed that at 5 N normal load (curve 1), friction coefficient is 0.068 at initial stage of rubbing and after that friction coefficient increases steadily up to 0.09 which remains almost constant till experimental time 30 minutes. For normal load 7.5 and 10 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 nylon disc takes about 24, 22 and 19 minutes to stabilize when the applied normal load is 5, 7.5 and 10 N respectively. During the running-in process, nylon disc takes less time to reach steady state friction when higher load is applied.

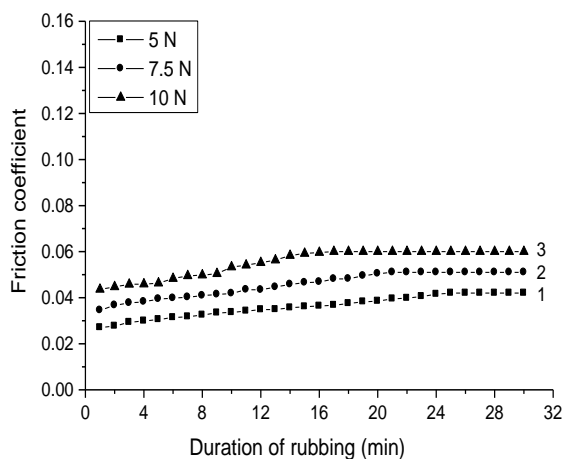


Figure 2. Variation of friction coefficient with duration of rubbing at different normal loads (Sliding velocity: 0.75 m/s, test sample: PTFE, pin: Mild steel)

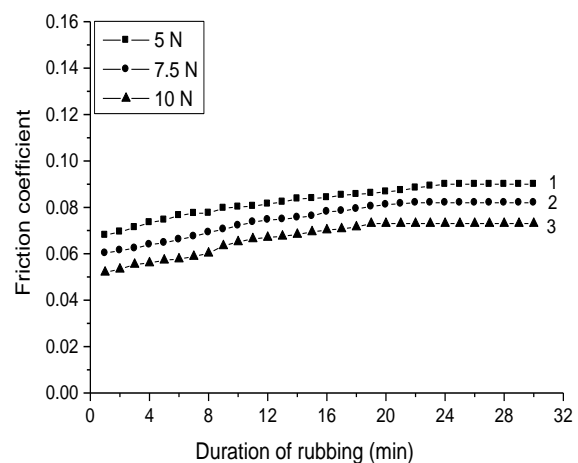


Figure 3. Variation of friction coefficient with duration of rubbing at different normal loads (Sliding velocity: 0.75 m/s, test sample: Nylon, pin: Mild steel)

Figure 4 exhibits the frictional variations with rubbing time at different normal loads and in the experiments, PTFE was used as disc material and SS 316 was used as counterface pin material. Curve 1 at 5 N normal load shows that during initial rubbing, friction coefficient is 0.04 which rises for a certain duration of rubbing to a value of 0.061 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 7.5 and 10 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 5, 7.5 and 10 N, PTFE takes 26, 24 and 21 minutes respectively to reach steady friction. It is apparent that higher the normal load, PTFE takes less time to stabilize. Variations of friction coefficients are observed at different normal loads when nylon disc slid against SS 316 pin and these results are shown in figure 5. Curve 1 for normal load 5 N shows that during initial rubbing, friction coefficient is 0.082 which increases almost linearly up to 0.11 over a duration of 24 minutes and after that it remains steady. Curves 2 and 3 for normal load 7.5 and 10 N show similar trends as that of curve 1. During the running-in process, nylon disc takes 24, 21 and 17 minutes to stabilize for applied normal load 5, 7.5 and 10 N respectively.

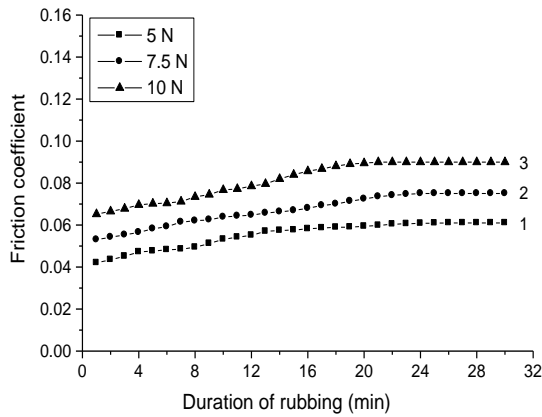


Figure 4. Variation of friction coefficient with duration of rubbing at different normal loads (Sliding velocity: 0.75 m/s, test sample: PTFE, pin: SS 316)

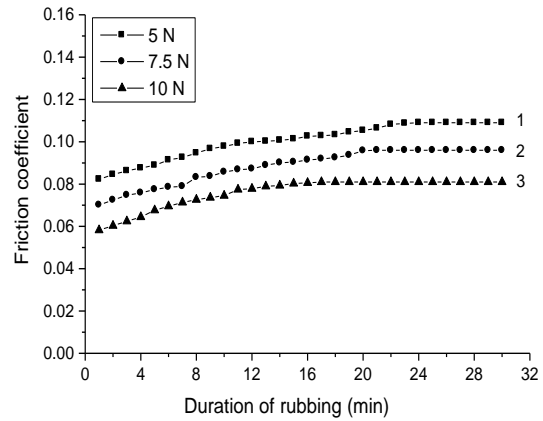


Figure 5. Variation of friction coefficient with duration of rubbing at different normal loads (Sliding velocity: 0.75 m/s, test sample: Nylon, pin: SS 316)

Figure 6 shows a comparison of friction coefficient of different polymer-steel pairs at different normal loads. The obtained results show that friction coefficient varies from 0.042 to 0.06, 0.09 to 0.073, 0.061 to 0.09 and 0.11 to 0.08 for PTFE-mild steel, nylon-mild steel, PTFE-SS 316 and nylon-SS 316 pairs respectively due to the variation of normal load from 5 to 10 N. It can be observed that these results are obtained from the steady values of friction coefficient of figures 2, 3, 4 and 5 respectively. It is apparent that friction coefficient increases or decreases almost linearly with the increase in normal load for all the material pairs tested in this investigation. It is believed that because of more ploughing effect which causes roughening of the disc surface, friction coefficient of PTFE increases with the increase in normal load. On the other hand, because of lubricating effect of nylon, friction coefficient decreases with the increase in normal load. Moreover, visco-elastic properties of nylon might be influenced by the high temperature generated for the higher load which is responsible for the decrease in friction.

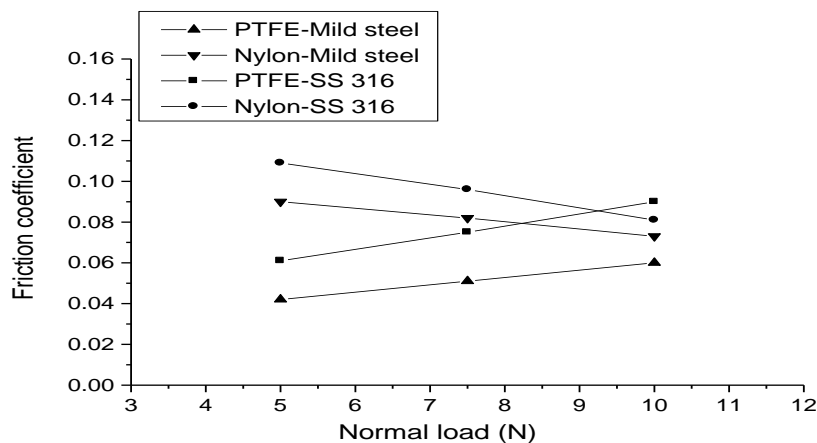


Figure 6. Comparison of friction coefficient of different polymer-steel pairs at different normal loads (Sliding velocity: 0.75 m/s)

The obtained results in figure 6 show that within the observed range of normal load, friction coefficient of PTFE-mild steel pair is the lowest. On the other hand, nylon-SS 316 pair shows highest friction coefficient at 5 and 7.5 N load. At 10 N load, PTFE-SS 316 pair shows the highest friction

coefficient. It is also observed that frictional values of nylon-mild steel and PTFE-SS 316 pairs are in between the highest and lowest values for 5 and 7.5 N load. But as the load increases from 5 to 7.5 N, the difference in frictional values decreases. On the other hand, for 10 N load, nylon-SS 316 pair shows higher friction than nylon-mild steel pair. This is due to the fact that at higher normal load, hardness of SS 316 might have significant role on the friction process. After the running-in process, average surface roughness (R_a) was measured which varied from 1.02-1.2 μm , 1.5-1.33 μm , 1.21-1.5 μm and 1.7-1.41 μm for PTFE-mild steel, nylon-mild steel, PTFE-SS 316 and nylon-SS 316 pairs respectively.

Frictional variations with duration of rubbing at different sliding velocities are shown in figure 7 and in this case, PTFE disc slid against mild steel pin. Curves 1, 2 and 3 show the results for sliding velocity 0.5, 0.75 and 1.0 m/s respectively. Curve 1 shows that at initial rubbing, friction coefficient is 0.028 which increases steadily up to 0.045 over a duration of 24 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 0.5, 0.75 and 1.0 m/s, PTFE takes 24, 21 and 18 minutes respectively to reach steady friction. Variations of friction coefficient with duration of rubbing are presented in figure 8 and in this case, nylon disc slid against mild steel pin. Results show that nylon takes 25, 22 and 20 minutes to reach steady friction at 0.5, 0.75 and 1.0 m/s respectively. Variations of friction coefficient are also shown in figure 9 and in the experiments, PTFE disc slid against SS 316 counterface. These results show that for higher sliding velocity frictional values are higher and PTFE takes less time to stabilize. Variations of friction coefficients are shown in figure 10 and in this case, nylon disc slid against SS 316 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 lower and nylon disc takes less time to stabilize.

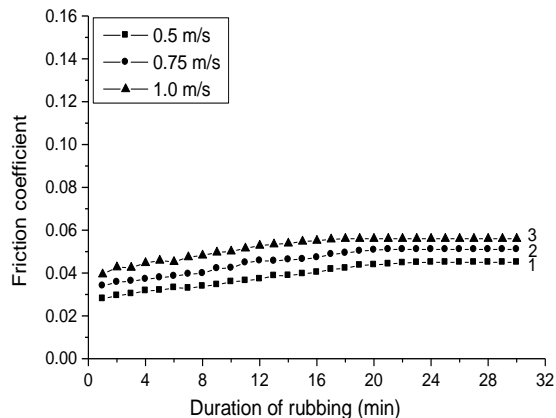


Figure 7. Variation of friction coefficient with duration of rubbing at different sliding velocities (Normal load: 7.5 N, test sample: PTFE, pin: Mild steel)

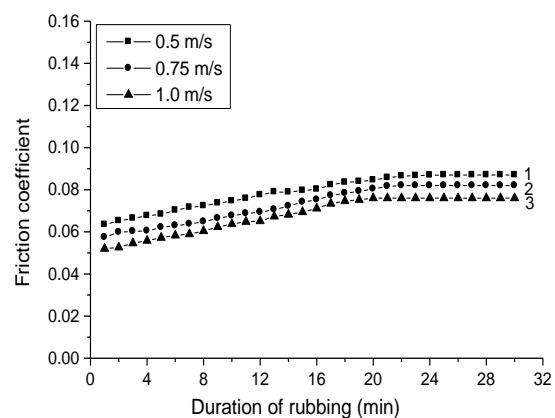


Figure 8. Variation of friction coefficient with duration of rubbing at different sliding velocities (Normal load: 7.5 N, test sample: Nylon, pin: Mild steel)

Comparisons of friction coefficients of different polymer-steel pairs at different sliding velocities are shown in figure 11. It is shown that friction coefficient varies from 0.045 to 0.056, 0.087 to 0.076, 0.07 to 0.079 and 0.102 to 0.091 for PTFE-mild steel, nylon-mild steel, PTFE-SS 316 and nylon-SS 316 pairs respectively due to the variation of sliding velocity from 0.5 to 1.0 m/s. These steady frictional values are obtained from figures 7, 8, 9 and 10 respectively. It can be observed that frictional values increases or decreases almost linearly depending on material pair with the increase in sliding velocity. It is apparent that frictional values of PTFE-mild steel pair are the lowest and nylon-SS 316 pair shows highest frictional values for the observed range of sliding velocity. It can also be observed that frictional values of nylon-mild steel and PTFE-SS 316 pairs are in between the highest and lowest

values. Moreover, nylon-mild steel pair shows higher friction than PTFE-SS 316 pair at sliding velocity 0.5 and 0.75 m/s but the difference in frictional value decreases as the velocity increases. Interestingly, at 1.0 m/s sliding velocity, PTFE-SS 316 pair exhibits slightly higher friction than nylon-mild steel pair. This is due to the fact that at higher sliding velocity, nylon disc exhibits more lubricating effect which causes decrease in friction. Average surface roughness (R_a) was measured as 1.05-1.16 μm , 1.47-1.36 μm , 1.31-1.4 μm and 1.6-1.51 μm for PTFE-mild steel, nylon-mild steel, PTFE-SS 316 and nylon-SS 316 pairs respectively after the friction process. It can be observed that, when these friction results are compared with the results of Fig. 6, it is apparent that within the observed range, in general, the influence of normal load on the frictional properties of the tested material pairs is greater than that of sliding velocity.

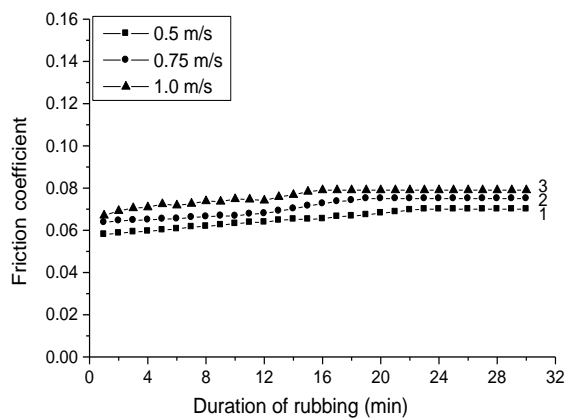


Figure 9. Variation of friction coefficient with duration of rubbing at different sliding velocities (Normal load: 7.5 N, test sample: PTFE, pin: SS 316)

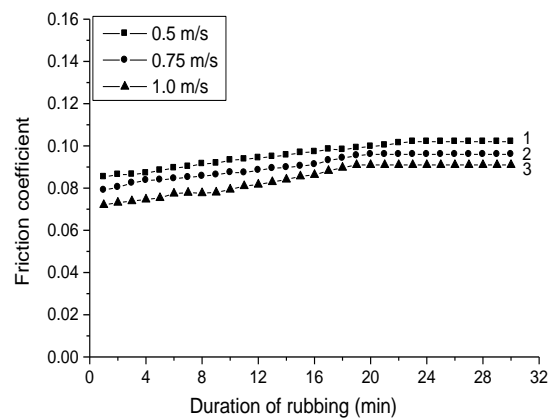


Figure 10. Variation of friction coefficient with duration of rubbing at different sliding velocities (Normal load: 7.5 N, test sample: Nylon, pin: SS 316)

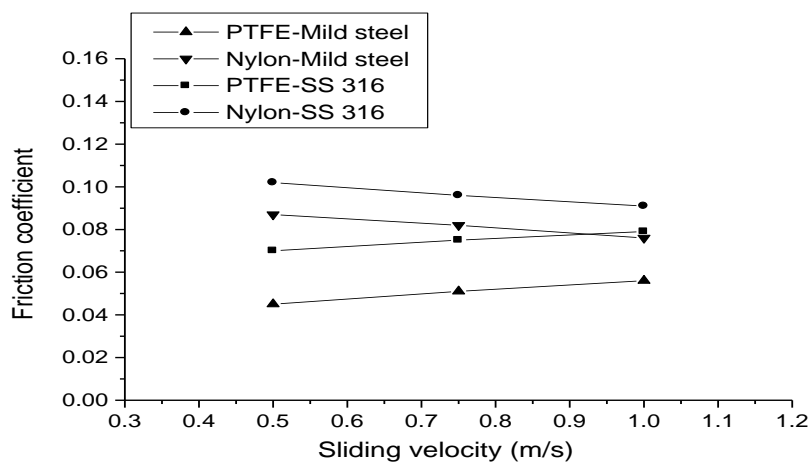


Figure 11. Comparison of friction coefficient of different polymer-steel pairs at different sliding velocities (Normal load: 7.5 N)

4. Conclusion

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

1. Within the observed range, friction coefficient of PTFE increases with the increase in normal load whereas friction coefficient of nylon decreases with the increase in normal load regardless of the

counterface material. At identical operating conditions, friction coefficient of PTFE-mild steel pair is the lowest. On the other hand, nylon-SS 316 pair shows highest friction coefficient at 5 and 7.5 N load. At 10 N load, PTFE-SS 316 pair shows the highest friction coefficient. At 5 and 7.5 N load, nylon-mild steel pair shows higher friction than PTFE-SS 316 pair. Furthermore, at 10 N load, nylon-SS 316 pair shows higher friction than nylon-mild steel pair.

2. Within the observed range, friction coefficient of PTFE increases with the increase in sliding velocity whereas friction coefficient of nylon decreases with the increase in sliding velocity regardless of the counterface material. At identical operating conditions, PTFE-mild steel pair shows lowest friction coefficient whereas nylon-SS 316 pair shows highest friction coefficient. On the other hand, nylon-mild steel pair shows higher friction than PTFE-SS 316 pair at sliding velocity 0.5 and 0.75 m/s but at 1.0 m/s sliding velocity, PTFE-SS 316 pair exhibits slightly higher friction than nylon-mild steel pair.
3. In general, the influence of normal load on the frictional properties of PTFE and nylon is greater than that of sliding velocity. At low load and low velocity conditions, dry sliding friction properties of these polymers are significantly influenced by the rough counterface material.

Therefore, to improve the mechanical processes and to keep the frictional value to some lower level in order to maintain performance and quality in industry, it is very important to maintain an appropriate level of sliding velocity, normal load as well as appropriate selection of material pair.

5. References

- [1] Sirong Yu, Zhongzhen Yu and Yiu-Wing Mai 2007 Effects of SEBS-g-MA on tribological behavior of nylon 66/organoclay nanocomposites *Tribol. Int.* **40** 855–62
- [2] Chowdhury M A and Nuruzzaman D M 2013 Experimental investigation on friction and wear properties of different steel materials *Tribol. Ind.* **35** 42-50
- [3] Chowdhury M A, Nuruzzaman D M, Roy B K, Samad S, Sarker R and Rezwan A H M 2013 Experimental investigation of friction coefficient and wear rate of composite materials sliding against smooth and rough mild steel counterfaces *Tribol. Ind.* **35** 286-296
- [4] El-Tayeb N S M, Yousif B F and Yap T C 2006 Tribological studies of polyester reinforced with CSM 450-R-glass fiber sliding against smooth stainless steel counterface *Wear* **261** 443–52
- [5] Mimaroglu A, Unal H and Arda T 2007 Friction and wear performance of pure and glass fiber reinforced poly-ether-imide on polymer and steel counterface materials *Wear* **262**1407–13
- [6] Suresha B, Chandramohan G, Samapthkumaran P, Seetharamu S and Vynatheya S 2006 Friction and wear characteristics of carbon-epoxy and glass-epoxy woven roving fiber composites *J. Reinf. Plast. Comp.* **25** 771-82
- [7] Chowdhury M A and Helali M M 2008 The effect of amplitude of vibration on the coefficient of friction for different materials *Tribol. Int.* **41** 307–14
- [8] Chowdhury M A and Helali M M 2009 The frictional behavior of composite materials under horizontal vibration *Ind. Lubr. Tribol.* **61** 246–53
- [9] Chowdhury M A and Helali M M 2009 The frictional behavior of materials under vertical vibration *Ind. Lubr. Tribol.* **61** 154–60
- [10] Unal H, Mimaroglu A, Kadioglu U and Ekiz H 2004 Sliding friction and wear behaviour of polytetrafluoroethylene and its composites under dry conditions *Mater. Des.* **25** 239–45
- [11] Unal H, Sen U and Mimaroglu A 2006 An approach to friction and wear properties of polytetrafluoroethylene composite *Mater. Des.* **27** 694-99
- [12] Nuruzzaman D M, Chowdhury M A and Rahaman M L 2011 Effect of duration of rubbing and normal load on friction coefficient for polymer and composite materials *Ind. Lubr. Tribol.* **63** 320-26
- [13] Nuruzzaman D M, Rahaman M L and Chowdhury M A 2012 Friction coefficient and wear rate of polymer and composite materials at different sliding speeds *Int. J. Surf. Sci. Eng.* **6** 231-45