Vol. 34, No 1 (2012) 18-23

Tribology in Industry

www.tribology.fink.rs

RESEARCH

Friction Coefficient of Different Material Pairs Under Different Normal Loads and Sliding Velocities

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Keywords:

Friction coefficient
Normal load
Sliding velocity
Duration of rubbing

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A B S T R A C T

In the present study, friction coefficients of different material pairs are investigated and compared. Using a pin on disc apparatus, friction coefficients of copper-copper, copper-brass, brass-brass, brass-copper pairs are investigated experimentally. Experiments are carried out when different types of pin slide on different disc materials under normal load 10, 15 and 20 N and sliding velocity 1, 2 and 3 m/s. Variations of friction coefficient with the duration of rubbing at different normal loads and sliding velocities are investigated. Results show that friction coefficient varies with duration of rubbing, normal load and sliding velocity. In general, friction coefficient increases for a certain duration of rubbing and after that it remains constant for the rest of the experimental time. Moreover, the obtained results reveal that friction coefficient decreases with the increase in normal load for all the tested pairs. On the other hand, it is also found that friction coefficient increases with the increase in sliding velocity for all the material pairs. The magnitudes of friction coefficient are different for different material pairs depending on sliding velocity and normal load.

1. INTRODUCTION

Study of mechanics of friction and the relationship between friction and wear dates back to the sixteenth century, almost immediately after the invention of Newton's law of motion. It was observed by several authors [1-13] that the variation of friction depends on interfacial conditions such as normal load, geometry, relative surface motion, sliding velocity, surface roughness of the rubbing surfaces, type of material, system rigidity, temperature, stick slip, relative humidity, lubrication and vibration. Among these factors normal load and sliding velocity are the two major factors that play significant role for the variation of friction. In the case of materials with surface films which are either deliberately applied or produced by reaction with environment, the coefficient of friction may not remain constant as a function of load. In many metal pairs in the high load regime, the coefficient of friction decreases with load. Bhushan [14] and Blau [15] reported that increased surface roughening and a large quantity of wear debris are believed to be responsible for decrease in friction. It was observed that the coefficient of friction may be very low for very smooth surfaces and/or at loads down to micro-to nanonewton range [16, 17]. The third law of friction, which states that friction is independent of velocity, is not generally valid. Friction may increase or decrease as a result of increased sliding velocity for different materials combinations. An increase in the temperature generally results in metal softening in the case of low melting point metals. An increase in temperature may result in solid-state phase transformation which may either improve or degrade mechanical properties [13]. The most drastic effect occurs if a metal approaches its melting point and its strength drops rapidly, and thermal diffusion and creep phenomena become more important. The resulting increased adhesion at contacts and ductility lead to an increase in friction [13]. The increase in friction coefficient with sliding velocity due to more adhesion of counterface material (pin) on disc.

It was reported [18-21] that friction coefficient of metals and alloys showed different behavior under different operating conditions. In spite of these investigations, the effects of normal load and sliding velocity on friction coefficient of different material pairs are yet to be clearly understood. Therefore, in this study an attempt is made to investigate the effect of normal load and sliding velocity on frictional behavior of different material combinations. Moreover, the effects of duration of rubbing on friction coefficient of these materials are examined in this study. It is expected that the applications of these results will contribute to the different concerned mechanical processes.

2. EXPERIMENTAL

A pin-on-disc apparatus was used for conducting frictional tests. Copper (99.90%Cu-0.005%Pb-0.001%Bi-balance O2) and brass (64%Cu-34%Zn-2%Pb) were used as disc and pin materials. To measure the frictional force acting on the pin during sliding on the rotating plate, a load cell (TML, Tokyo Sokki Kenkyujo Co. Ltd, CLS-10NA) along with its digital indicator (TML, Tokyo Sokki Kenkyujo Co. Ltd, Model no. TD-93A) was used. The coefficient of friction was obtained by dividing the frictional force by the applied normal force (load). To measure the surface roughness of the test samples, Taylor Hobson Precision Roughness Checker (Surtronic 25) was used. Before friction tests, the average surface roughnesses of copper and brass test samples were found to be Ra = 0.4-0.5 μm. Each test was conducted for 10 minutes of rubbing time with new pin and test sample. Furthermore, to ensure the reliability of the test results, each test was repeated five times and the scatter in results was small, therefore the average values of these tests were taken into consideration. The detail experimental conditions are shown in Table 1.

Table 1. Experimental conditions.

No.	Parameters	Operating conditions
1.	Normal load	10, 15 and 20 N
2.	Sliding velocity	1, 2, 3 m/s
3.	Relative humidity	70 (± 5)%
4.	Duration of rubbing	10 minutes
5.	Surface condition	Dry
6.	Material pair (disc-pin)	(i) Copper-copper (ii) Copper-brass (iii) Brass-brass (iv) Brass-copper

3. RESULTS AND DISCUSSION

Fig. 1 shows the variation of friction coefficient with the duration of rubbing at different normal loads for copper-copper pair. During experiment, the sliding velocity and relative humidity were 1 m/s and 70 % respectively.

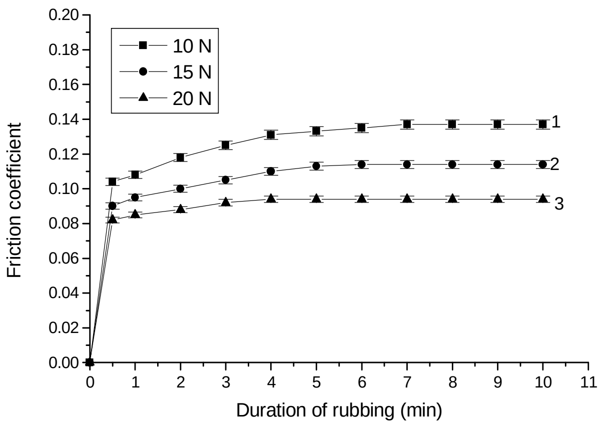

Fig. 1. Variation of friction coefficient with the variation of duration of rubbing and normal load (sliding velocity: 1 m/s, relative humidity: 70 %; pair copper-copper).

Curve 1 of this figure is drawn for normal load 10 N. From this curve, it is observed that at the initial duration of rubbing, the value of friction coefficient is 0.104 and then increases very steadily up to 0.137 over a duration of 7 minutes of rubbing and after that it remains constant for the rest of the experimental time. At the initial stage of rubbing, friction is low and the factors responsible for this low friction are due to the presence of a layer of foreign material on the disc surface. This layer on the disc surface in general comprises of (i) moisture,

(ii) oxide of metals, (iii) deposited lubricating material, etc. Copper readily oxidizes in air, so that, at initial duration of rubbing, the oxide film easily separates the two material surfaces and there is little or no true metallic contact and also the oxide film has low shear strength. After initial rubbing, the film (deposited layer) breaks up and clean surfaces come in contact which increase the bonding force between the contacting surfaces. At the same time due to the ploughing effect, inclusion of trapped wear particles and roughening of the disc surface, the friction force increases with duration of rubbing. After certain duration of rubbing, the increase of roughness and other parameters may reach to a certain steady state value and hence the values of friction coefficient remain constant for the rest of the time. Curves 2 and 3 of this figure are drawn for normal load 15 and 20 N respectively and show similar trends as that of curve 1. From these curves, it is also observed that time to reach steady state value is different for different normal load. Results show that at normal load 10, 15 and 20 N, copper-copper pair takes 7, 6 and 4 minutes respectively to reach steady friction. It indicates that the higher the normal load, the time to reach steady friction is less. 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. The trends of these results are similar to the results of Chowdhury and Helali [22, 23]. Similar trends are observed for copper-brass, brass-brass and brass-copper pairs and these results are presented in Table 2.

Table 2
Friction coefficient at different normal loads for different material pairs (sliding velocity: 1 m/s, relative humidity: 70 %)

Material pairs	Copper-copper			Copper-brass			Brass-brass			Brass-copper		
Normal load, N	10	15	20	10	15	20	10	15	20	10	15	20
Time (min)	Friction coefficient											
0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.5	0.104	0.09	0.082	0.118	0.104	0.083	0.127	0.113	0.098	0.093	0.074	0.062
1	0.108	0.095	0.085	0.123	0.111	0.088	0.132	0.117	0.102	0.1	0.08	0.068
2	0.118	0.1	0.088	0.13	0.118	0.098	0.138	0.12	0.105	0.111	0.088	0.077
3	0.125	0.105	0.092	0.138	0.125	0.108	0.141	0.123	0.108	0.118	0.094	0.083
4	0.131	0.11	0.094	0.146	0.131	0.113	0.144	0.127	0.108	0.122	0.098	0.083
5	0.133	0.113	0.094	0.154	0.135	0.113	0.147	0.127	0.108	0.127	0.098	0.083
6	0.135	0.114	0.094	0.157	0.135	0.113	0.147	0.127	0.108	0.127	0.098	0.083
7	0.137	0.114	0.094	0.157	0.135	0.113	0.147	0.127	0.108	0.127	0.098	0.083
8	0.137	0.114	0.094	0.157	0.135	0.113	0.147	0.127	0.108	0.127	0.098	0.083
9	0.137	0.114	0.094	0.157	0.135	0.113	0.147	0.127	0.108	0.127	0.098	0.083
10	0.137	0.114	0.094	0.157	0.135	0.113	0.147	0.127	0.108	0.127	0.098	0.083

Figure 2 shows the comparison of the variation of friction coefficient with normal load for the above said material pairs. Curves of this figure are drawn for copper-copper, copper-brass, brass-brass and brass-copper pairs. It is shown that friction coefficient varies from 0.137 to 0.094, 0.157 to 0.113, 0.147 to 0.108 and 0.127 to 0.083 with the variation of normal load from 10 to 20 N for copper-copper, copper-brass, brass-brass and brass-copper pairs respectively. These results show that friction coefficient decreases with the increase in normal load. Increased surface roughening and a large quantity of wear debris are believed to be responsible for the decrease in friction [14, 15] with the increase in normal load. Similar behavior is obtained for Al–Stainless steel pair [24] i.e friction coefficient decreases with the increase in normal load.

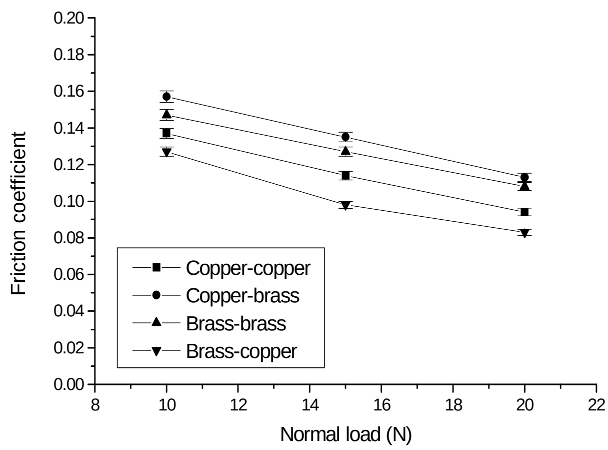

Fig. 2. Variation of friction coefficient with the variation of normal load for different material-pairs (sliding velocity: 1m/s, relative humidity: 70 %).

From the obtained results, it can also be seen that the highest values of the friction coefficient are obtained for copper-brass pair and the lowest values of friction coefficient are obtained for brass-copper pair. The values of friction coefficient of brass-brass pair and copper-copper pair are found in between the highest and lowest values. Moreover, it is apparent that the magnitudes of friction coefficient of brass-brass pair are higher than that of copper-copper pair. It was found that after friction tests, the average roughnesses of copper disc of copper-brass pair, brass disc of brass-brass pair, copper disc of copper-copper pair and brass disc of brass-copper pair varied from 1.4-2.3, 1.1-1.9, 0.9-1.7 and 0.8-1.4 μm respectively.

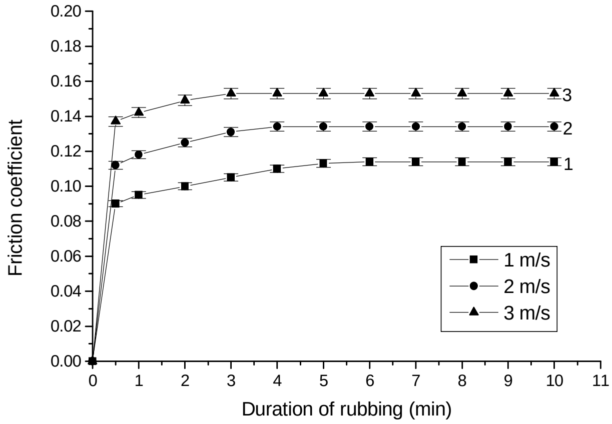

Fig. 3. Variation of friction coefficient with the variation of duration of rubbing and sliding velocity (normal load: 15 N, relative humidity: 70 %, Pair: copper-copper).

Fig. 3 shows the variation of friction coefficient with the duration of rubbing at different sliding velocities for copper-copper pair. Curves 1, 2 and 3 of Fig. 3 are drawn for sliding velocity 1, 2 and 3 m/s respectively. Curve 1 of this figure shows that during initial rubbing, the value of friction coefficient is 0.09 which increases almost linearly up to 0.114 over a duration of 6 minutes of rubbing and after that it remains constant for the rest of the experimental time. The increase of friction may be associated with ploughing effect and because of roughening of the disc surface. After certain duration of rubbing the increase of roughness and other parameters may reach to a certain steady value hence the values of friction coefficient remain constant for the rest of the time.

Curves 2 and 3 show that for the higher sliding velocity, the friction coefficient is more and the trend in variation of friction coefficient is almost the same as for curve 1. From these curves, it is also observed that time to reach steady state values are different for different sliding velocities. From these results it is found that at sliding velocity 1, 2 and 3 m/s, copper-copper pair takes 6, 4 and 3 minutes respectively to reach steady friction. It indicates that the higher the sliding velocity, the time to reach steady friction is less. This may be due to the higher the sliding velocity, the surface roughness and other parameters take less time to stabilize. Similar trends are observed for copper-brass, brass-brass and brass-copper pairs and these results are presented in Table 3.

Table 3. Friction coefficient at different sliding velocities for different material pairs (normal load: 15 N, relative humidity: 70 %).

Material pairs	Copper-copper			Copper-brass			Brass-brass			Brass-copper		
Sliding velocity, m/s	1	2	3	1	2	3	1	2	3	1	2	3
Time, min	Friction coefficient											
0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.5	0.09	0.112	0.137	0.104	0.125	0.14	0.113	0.129	0.143	0.074	0.09	0.111
1	0.095	0.118	0.142	0.111	0.131	0.148	0.117	0.133	0.15	0.08	0.096	0.118
2	0.1	0.125	0.149	0.118	0.142	0.16	0.12	0.139	0.16	0.088	0.106	0.13
3	0.105	0.131	0.153	0.125	0.147	0.166	0.123	0.146	0.16	0.094	0.113	0.13
4	0.11	0.134	0.153	0.131	0.15	0.166	0.127	0.146	0.16	0.098	0.113	0.13
5	0.113	0.134	0.153	0.135	0.15	0.166	0.127	0.146	0.16	0.098	0.113	0.13
6	0.114	0.134	0.153	0.135	0.15	0.166	0.127	0.146	0.16	0.098	0.113	0.13
7	0.114	0.134	0.153	0.135	0.15	0.166	0.127	0.146	0.16	0.098	0.113	0.13
8	0.114	0.134	0.153	0.135	0.15	0.166	0.127	0.146	0.16	0.098	0.113	0.13
9	0.114	0.134	0.153	0.135	0.15	0.166	0.127	0.146	0.16	0.098	0.113	0.13
10	0.114	0.134	0.153	0.135	0.15	0.166	0.127	0.146	0.16	0.098	0.113	0.13

Figure 4 shows the comparison of the variation of friction coefficient with sliding velocity for the above mentioned material pairs.

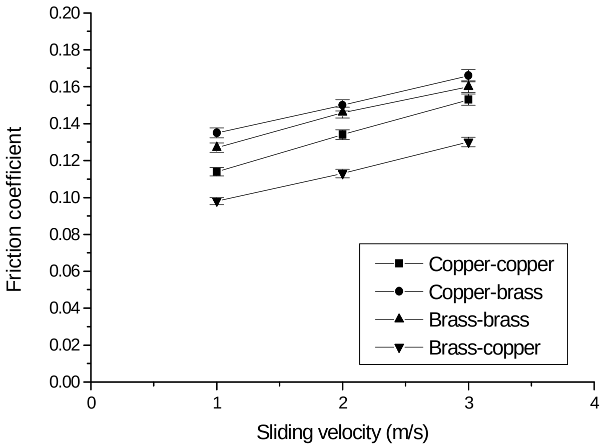

Fig. 4. Variation of friction coefficient with the variation of sliding velocity for different material-pairs (normal load: 15 N, relative humidity: 70 %).

Curves of this figure are drawn for copper-copper, copper-brass, brass-brass and brass-copper pairs. It is shown that the friction coefficient varies from 0.114 to 0.153, 0.135 to 0.166, 0.127 to 0.16 and 0.098 to 0.13 with the variation of sliding velocity from 1 to 3 m/s for copper-copper, copper-brass, brass-brass and brass-copper pairs respectively. These results indicate that friction coefficient increases with the increase in sliding velocity. Sliding contact of two materials results in heat generation at the asperities and hence increases in temperature at the frictional surfaces of the two materials. An increase in the temperature generally results in metal softening in the case of low melting point metals. An increase in temperature may result in solid-state phase transformation which may either improve or degrade mechanical properties [13]. The most drastic effect occurs if a metal approaches its melting point and its strength drops rapidly, and thermal diffusion and creep phenomena become more important. The resulting increased adhesion at contacts and ductility lead to an increase in friction [13]. The increase in friction coefficient with sliding velocity due to more adhesion of counterface material (pin) on disc. From the obtained results, it can also be seen that the highest values of the friction coefficient are obtained for copper-brass pair and the lowest values of friction coefficient are obtained for brass-copper pair. The values of friction coefficient of brass-brass pair and copper-copper pair are found in between the highest and lowest values. In addition, it is observed that the magnitudes of friction coefficient of brass-brass pair are higher than that of copper-copper pair. It was found that after friction tests, the average roughnesses of copper disc of copper-brass pair, brass disc of brass-brass pair, copper disc of copper-copper pair and brass disc of brass-copper pair varied from 1.6-2.5, 1.3-2.1, 1.1-1.8 and 0.9-1.5 μm respectively.

4. CONCLUSIONS

The presence of normal load and sliding velocity indeed affects the friction force considerably. The values of friction coefficient decrease with the increase in normal load for copper-copper, copper-brass, brass-brass and brass-copper pairs. On the other hand, the values of friction coefficient increase with the increase in sliding velocity for the tested material pairs. Friction coefficient varies with the duration of rubbing and after certain duration of rubbing, friction coefficient becomes steady for the observed range of normal load and sliding velocity. It can also be seen that the highest values of the friction coefficient are obtained for copper-brass pair and the lowest values of friction coefficient are obtained for brass-copper pair. The values of friction coefficient of brass-brass pair and copper-copper pair are found in between the highest and lowest values. The magnitudes of friction coefficient of brass-brass pair are higher than that of copper-copper pair.

As (i) the friction coefficient decreases with the increase in normal load (ii) the values of friction coefficient increase with the increase in sliding velocity and (iii) the magnitudes of friction coefficient are different for different sliding pairs, therefore maintaining an appropriate level of normal load, sliding velocity as well as appropriate choice of sliding pair, friction may be kept to some lower value to improve mechanical processes.

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