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Friction Coefficient and Wear Rate of Copper and Aluminum Sliding against Mild Steel

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ABSTRACT

In this research, friction and wear of copper and aluminum are investigated experimentally using a pin-on-disc apparatus. In the experiments, mild steel pin slides on copper or aluminum disc at different normal load conditions 10, 15, and 20 N. Experiments are also carried out at different sliding velocities 1, 1.5 and 2 m/s. The effects of duration of rubbing on the friction coefficient of copper and aluminum are investigated. It is found that during friction process, copper or aluminum disc takes less time to stabilize as the normal load or sliding velocity increases. Time to reach steady friction varies depending on applied normal load or sliding velocity for both copper and aluminum. Within the observed range, friction coefficient decreases when applied load is increased while it increases when sliding velocity is increased for both copper and aluminum. In general, wear rate increases with the increased normal load and sliding velocity. Finally, as a comparison, it is found that friction coefficient and wear rate of copper are much lower than that of aluminum within the observed range of normal load and sliding velocity.

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1. Introduction

In the past few years, numerous investigations have been carried out and several researchers observed that friction and wear depend on several parameters such as normal load, surface roughness, sliding velocity, relative humidity, lubrication etc. There have been also many investigations to explore the influence of type of material, temperature, stick-slip, contact geometry and vibration [1-13]. Normal load and sliding velocity are the two important parameters that dictate the tribological performance of metals and alloys. Copper and copper based alloys are widely used in many engineering applications because of high thermal and electrical conductivity, very good corrosion and wear resistance and self-lubrication property [14,15]. Copper based alloys are used as bearing materials to achieve a high wear resistance [16]. Pure aluminum and aluminum based alloys can be used in applications where corrosion is a problem. Aluminum alloys are used as bearing materials where low friction is required [17]. Wear resistance of Si added aluminum alloys is higher than that of the other aluminum alloys [18]. Aluminum, lead, tin, copper and their alloys can be used as a coating material to steel bearing due to their superior wear properties [19-21].

Bearing materials are expected to have good several properties such as high load capacity, low friction coefficient, high corrosion resistance, high wear resistance and high heat conductivity. All of these properties significantly affect the fatigue and wear life [16]. In the high load regime, friction coefficient decreases with load for many metallic pairs. It is believed that due to a large amount of wear debris and increased surface roughening, friction force decreases [22, 23]. At loads from micro to nanonewton range, friction coefficient may be very low when the contacting surfaces are very smooth [24, 25]. For different material combinations, friction may increase or decrease when the sliding velocity is increased. During friction process, because of increased adhesion of counterface pin material on disc, friction increases with the increase in sliding velocity [13].

In the previous investigations, metals and alloys sliding against different pin materials showed different frictional properties under a range of operating conditions [26-29]. Despite these investigations, friction and wear of copper and aluminum sliding against mild steel are yet to be investigated. Therefore, in this study, the effects of normal load and sliding velocity on the frictional behavior of copper and aluminum sliding against mild steel are investigated. The influence of rubbing time on friction coefficient of these materials is also examined. In addition, wear rates of copper and aluminum under different normal loads and sliding velocities are investigated in this study.

Nowadays, different nonferrous material 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 Detail

Experiments are carried out using a pin-on-disc set-up which is shown in Figure 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 connects the horizontal plate with a stainless steel base plate. The alignment of this vertical shaft is maintained properly through two close-fit bush-bearings in such a way that the shaft can move axially. 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) of mild steel is fitted in a holder and this holder is subsequently fixed by an arm. The contacting foot of the pin is flat so that it can easily slides on the rotating test disc. The arm is pivoted so that it can rotate horizontally and vertically with negligible friction. There are two ways to change the sliding speed, namely, (i) by changing the rotational speed of shaft or, (ii) by changing the frictional radius. In this study, by maintaining constant frictional radius (25 mm), sliding speed was varied by changing the speed of shaft. 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 obtain the wear of the test disc, an electronic balance was used to measure the

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weight before and after the test. 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.

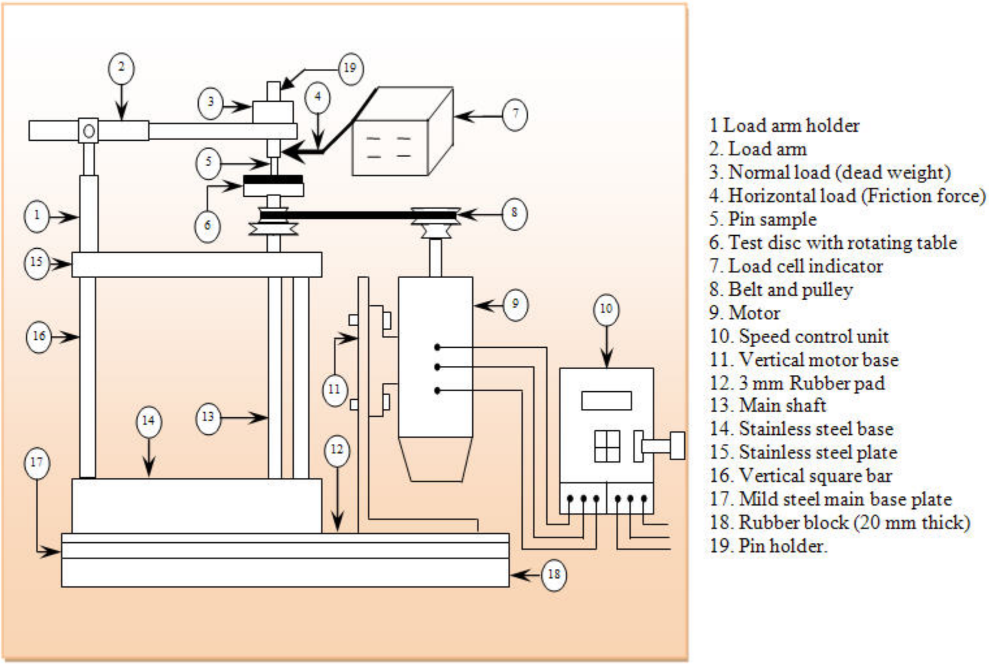

Figure 1: Block diagram of the pin-on-disc experimental set-up.

Table 1: Experimental Conditions.

Sl. No.	Parameters	Operating Conditions
1.	Normal Load	10, 15, 20 N
2.	Sliding Velocity	1, 1.5, 2 m/s
3.	Relative Humidity	70 (± 5)%
4.	Duration of Rubbing	30 minutes
5.	Surface Condition	Dry
6.	Disc material	(i) Copper (ii) Aluminum
7.	Average Roughness of Copper and Aluminum, R_a	0.40-0.50 μm
8.	Pin material	Mild steel
9.	Average Roughness of mild steel, R_a	3.5-4.0 μm

3. Results and Discussion

Friction coefficient of copper varies with duration of rubbing and these variations at different normal loads are shown in Figure 2. Experiments were carried out at sliding velocity

1 m/s and relative humidity 70%. In the experiments, copper disk was sliding against mild steel counterface. Curve 1 for normal load 10 N shows that at the early stage of rubbing, friction coefficient is 0.27 and after that it increases very steadily up to 0.35. Over a duration of 22 minutes, friction coefficient becomes steady and for the rest of the experimental time it remains constant. Friction is low at the early stage of rubbing because of a layer of foreign material on copper disc. This layer generally comprises of lubricating material, metallic oxide and some moisture. At early stage of rubbing, oxide layer separates the contacting surfaces and after initial rubbing, the deposited layer breaks up to make true metallic contact. On the other hand, because of 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, the surface roughness and some other parameters reached to a steady state value and for this reason, there is no change in friction with time. For normal load 15 and 20 N, results are also shown by curves 2 and 3. It is apparent that at different normal loads, copper disc takes different time to stabilize which are 22, 19 and 15 minutes when applied normal load is 10, 15 and 20 N respectively. During friction process, roughness and other parameters may reach to a certain steady level earlier when the applied load is increased. These results are supported by the findings of Chowdhury and Helali [30, 31].

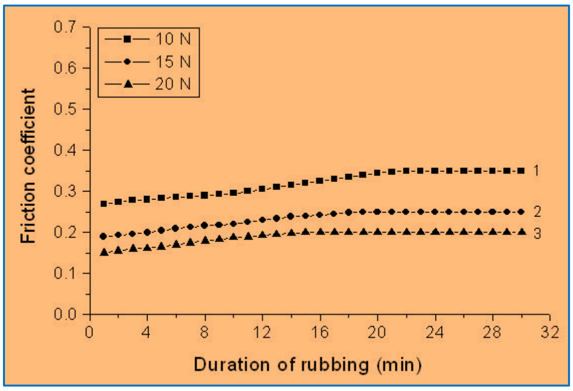

Figure 2: Friction coefficient as a function of duration of rubbing at different normal loads (sliding velocity: 1 m/s, relative humidity: 70%, test sample: copper, pin: mild steel).

Variations of friction coefficient with duration of rubbing are shown in Figure 3 and in the experiments, aluminum disc mated with mild steel pin. For 10 N normal load (curve 1), friction coefficient is 0.48 at the initial stage of rubbing and after that friction coefficient increases steadily up to 0.55 which remains constant till experimental time 30 minutes. For normal load 15 and 20 N (curves 2 and 3), variations of friction coefficient are almost similar as

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that of curve 1. Also, aluminum disc takes about 23, 21 and 17 minutes to stabilize when the applied normal load is 10, 15 and 20 N respectively. From these obtained results it is clear that aluminum disc takes less time to reach steady state friction as the load increases.

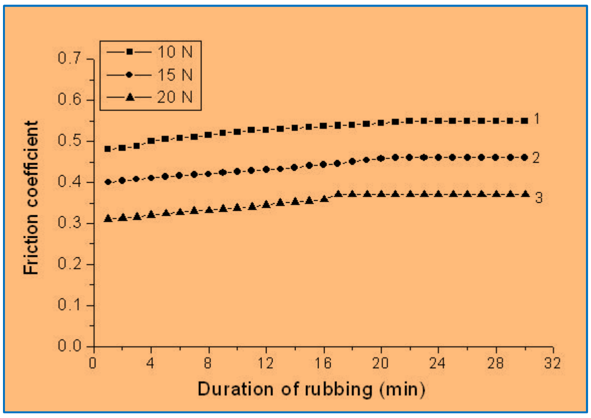

Figure 3: Friction coefficient as a function of duration of rubbing at different normal loads (sliding velocity: 1 m/s, relative humidity: 70%, test sample: aluminum, pin: mild steel).

The effect of normal load on the friction coefficient is shown in Figure 4 and these results show a comparison of friction coefficient of copper and aluminum. Results show that as the normal load increases from 10 to 20 N, coefficient of friction decreases from 0.35 to 0.20 and 0.55 to 0.37 for copper and aluminum respectively. These results are supported by the findings of Chowdhury *et al*. [32] i.e. as the load increases, friction coefficient decreases within the observed range. Moreover, it is apparent that for identical conditions, copper shows much lower friction than aluminum. After the running-in process, average surface roughness (Ra) was measured and it varied from 1.4-1.6 m and 2.2-2.5 m for copper and aluminum respectively.

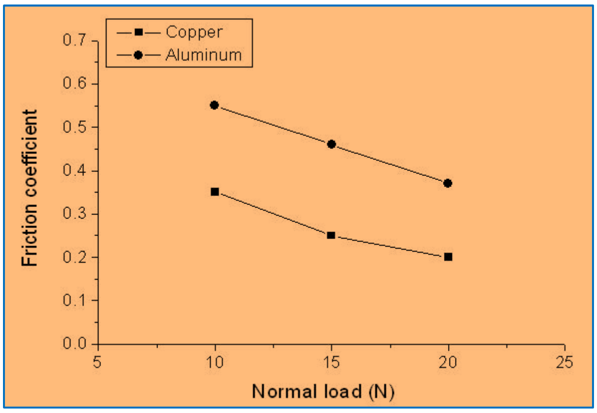

Figure 4: Comparison of friction coefficient as a function of normal load (sliding velocity: 1 m/s, relative humidity: 70%).

Friction coefficient varies with rubbing time and this variation at different sliding velocities is shown in Figure 5. In the experiment, copper disc mated with mild steel pin at normal load 15 N. Results are shown by curves 1, 2 and 3 for 1, 1.5 and 2 m/s respectively. Curve 1 for 1 m/s shows that at the start of rubbing, friction coefficient is 0.19 and after that it increases very steadily up to 0.25. In the experiments, it was found that after 19 minutes of running-in operation, friction became steady. Due to the ploughing effect and surface roughening, friction increases. After a certain duration of running-in process, roughness and other parameters reached to steady state value, and therefore, no change in frictional thrust till the experimental time.

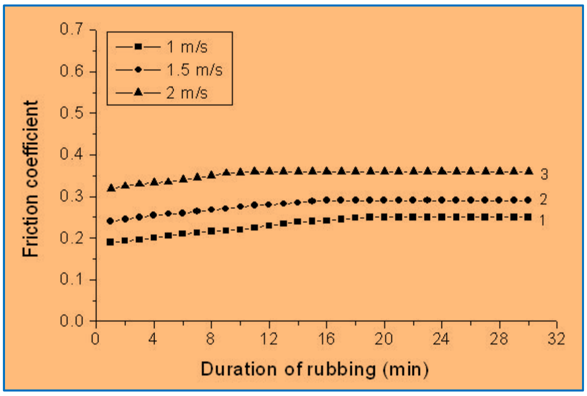

Figure 5: Friction coefficient as a function of duration of rubbing at different sliding velocities (normal load: 15 N, relative humidity: 70%, test sample: copper, pin: mild steel).

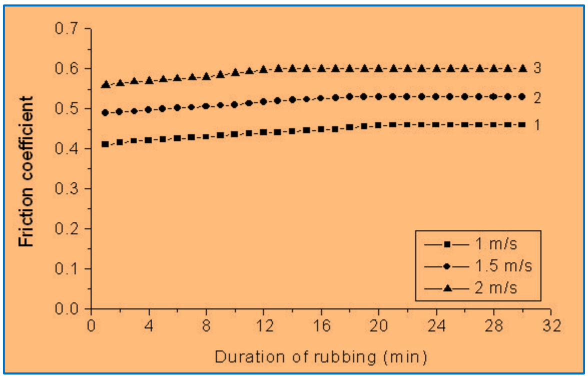

Figure 6: Friction coefficient as a function of duration of rubbing at different sliding velocities (normal load: 15 N, relative humidity: 70%, test sample: aluminum, pin: mild steel).

Figure 5 (curves 2 and 3) it is apparent that friction coefficient is higher for increased sliding velocity but the trend is almost same as before. From the obtained results it can be noticed that time duration is different to reach steady friction depending on the sliding velocity. In the experiments, it was found that copper disc takes 19, 16 and 11 minutes to stabilize for

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sliding velocity 1, 1.5 and 2 m/s respectively. From these results it is understood that roughness and other parameters became steady earlier as the sliding velocity increased. Variations of friction coefficient with duration of rubbing at different sliding velocities are shown in Figure 6 and in this case, aluminum disc mated with mild steel pin. In the experiments, it was found that aluminum disc takes 21, 18 and 13 minutes to stabilize for sliding velocity 1, 1.5 and 2 m/s respectively. From the obtained results it is observed that in general, the values of friction coefficient are much higher as compared to that shown in Figure 5 but the trends of variation in friction coefficient are almost similar.

The influence of sliding velocity on the friction coefficient is presented in Figure 7 and these results show a comparison of friction coefficient of copper and aluminum. In the experiments it was found that as the sliding velocity increases from 1 to 2 m/s, friction coefficient of copper increases from 0.25 to 0.36. On the other hand, friction coefficient of aluminum increases from 0.46 to 0.60 as the sliding velocity increases from 1 to 2 m/s. Due to the interaction of the asperities of two contact surfaces, frictional heat generation occurs and hence temperature increases at the contact surfaces. Due to more adhesion of pin material on the disc with the increase in sliding velocity, friction increases [13]. These findings are supported by the previous findings of Nuruzzaman and Chowdhury [33] i.e. friction increases with the increase in sliding velocity. As a comparison, it is very clear that for identical condition, copper shows much lower friction coefficient than aluminum. After the experiment, the average surface roughness (Ra) was measured as 1.5-1.7 m for copper disc and 2.4-2.65 m for aluminum disc. It is concluded that after friction test, the roughness of both copper and aluminum much increased as compared to the roughness of copper and aluminum before the test (Table 1).

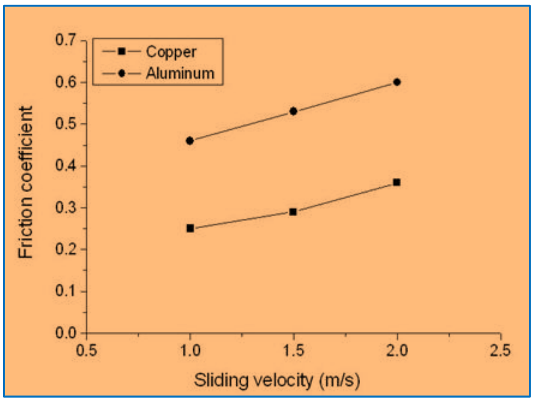

Figure 7: Comparison of friction coefficient as a function of sliding velocity (normal load: 15 N, relative humidity: 70%).

The effect of normal load on the wear rate of copper and aluminum is shown in Figure 8. It is observed that for the increase in normal load from 10 to 20 N, wear rate of copper increases from 0.85 to 1.45 mg/min. On the other hand, aluminum shows the increased wear rate from 2.5 to 3.15 mg/min as the load increases from 10 to 20 N. Because of the increase in normal load, frictional thrust is increased and real surface area is also increased, hence causes higher wear. These results are supported by the findings of Chowdhury and Helali [34]. As a comparison, it is apparent that copper disc shows much lower wear rate than aluminum disc for the range of applied normal load.

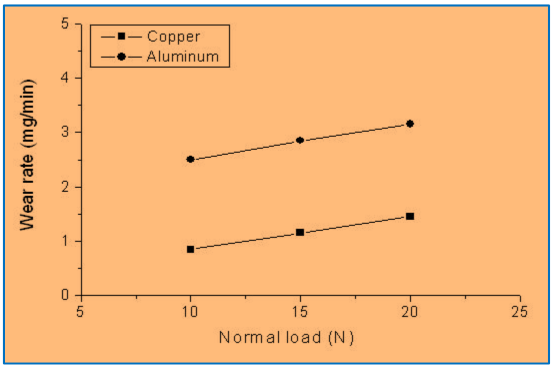

Figure 8: Comparison of wear rate as a function of normal load (sliding velocity: 1 m/s, relative humidity: 70%).

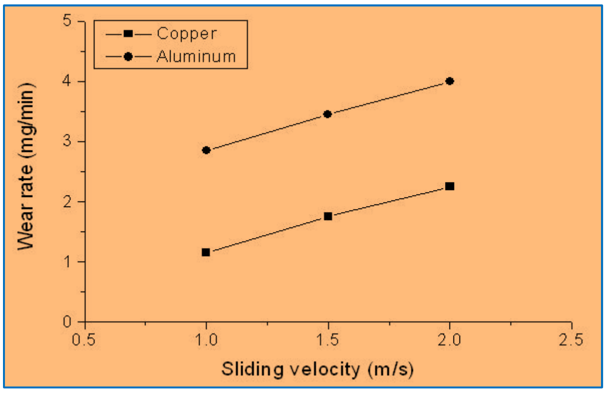

Figure 9: Comparison of wear rate as a function of sliding velocity (normal load: 15 N, relative humidity: 70%).

The influence of sliding velocity on the wear rate of copper and aluminum is shown in Figure 9. It is observed that for the increase in sliding velocity from 1 to 2 m/s, wear rate of copper increases from 1.15 to 2.25 mg/min. On the other hand, wear rate of aluminum increases from 2.85 to 4 mg/min as the sliding velocity increases from 1 to 2 m/s. Because of the higher sliding velocity, the length of rubbing is more for a fixed duration of rubbing. Moreover, as the material shear strength reduces and the true area of contact increases with the increase in sliding

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velocity, hence wear of material increases [13]. As a comparison, it is apparent that wear rate of copper is much lower than that of aluminum for the range of sliding velocity.

4. Conclusion

From this study, the obtained results are summarized as:

1. Within the observed range of normal load and sliding velocity, friction coefficient increases with the increase in rubbing time and after that it becomes steady for both copper and aluminum. It is found that during friction process, copper or aluminum disc takes less time to stabilize as the normal load or sliding velocity increases. Moreover, the time to reach steady friction is different for copper or aluminum disc depending on applied normal load or sliding velocity.

2. Friction coefficient decreases with the increase in normal load while it increases with the increase in sliding velocity for both copper and aluminum. At identical condition, friction coefficient of copper is much lower than that of aluminum within the observed range of normal load and sliding velocity.

3. Wear rate increases with the increase in normal load and sliding velocity for both copper and aluminum. At identical condition, wear rate of copper is much lower than that of aluminum for the observed range of normal load and sliding velocity.

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