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Friction Coefficient of Copper Mating with Smooth and Rough Mild Steel Counterfaces

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Abstract

In the present study, friction coefficient and wear rate of copper sliding against mild steel are investigated experimentally. In order to do so, a pin on disc apparatus is designed and fabricated. Experiments are carried out when smooth or rough mild steel pin slides on copper disc. Experiments are conducted at normal load 10, 15 and 20 N, sliding velocity 1, 1.5 and 2 m/s and relative humidity 70%. Variations of friction coefficient with the duration of rubbing at different normal loads and sliding velocities are investigated. Results show that friction coefficient is influenced by 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. The obtained results reveal that friction coefficient decreases with the increase in normal load for copper mating with smooth or rough mild steel counterface. Moreover, friction coefficient increases with the increase in sliding velocity. The magnitudes of friction coefficient are different depending on sliding velocity and normal load for both smooth and rough counterface pin materials.

Keywords: *Friction coefficient; wear rate, copper, mild steel, normal load, sliding velocity*

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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 coefficients of SS 304 mating with smooth and rough couterface are yet to be clearly understood. Therefore, in

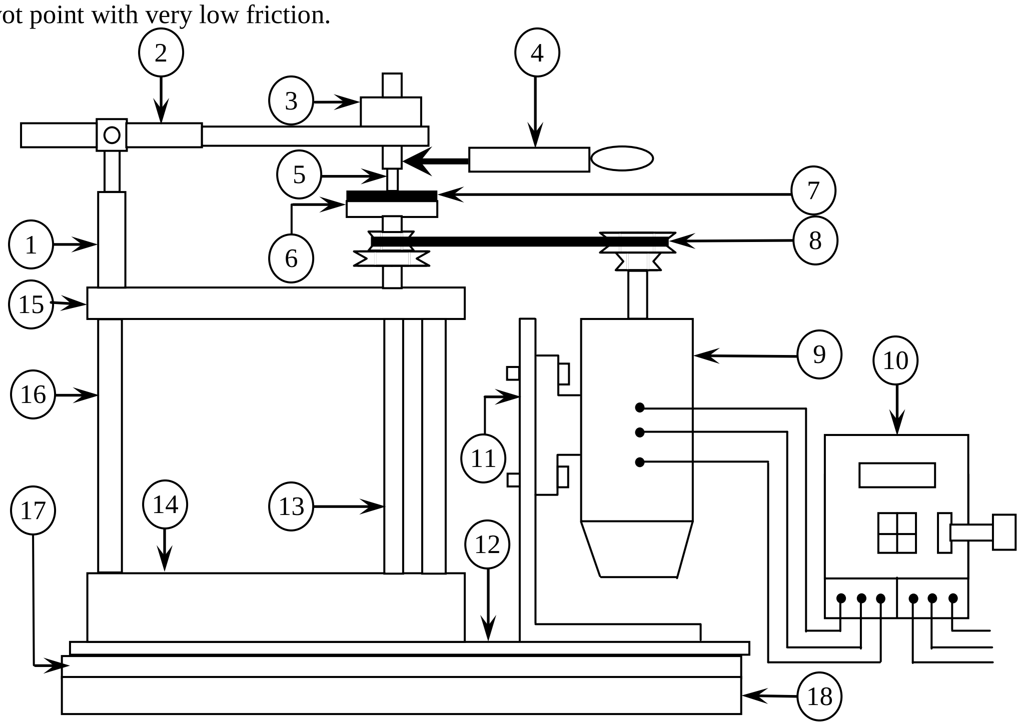
this study an attempt is made to investigate the effect of normal load and sliding velocity on the frictional behavior of SS 304 sliding against smooth and rough mild steel counterface.

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.

Within this research, it is sought to better understand the relation between friction/wear and different types of materials under different normal loads and sliding velocities and to explore the possibility of adding controlled normal load and sliding velocity to a mechanical process as a means to improve performance and quality in industry.

2. Experimental

A schematic diagram of the experimental set-up is shown in Fig. 1 i.e. a pin which can slide on a rotating horizontal surface (disc). In this set-up a circular test sample (disc) is to be fixed on a rotating plate (table) having a long vertical shaft clamped with screw from the bottom surface of the rotating plate. The shaft passes through two close-fit bush-bearings which are rigidly fixed with stainless steel plate and stainless steel base such that the shaft can move only axially and any radial movement of the rotating shaft is restrained by the bush. These stainless steel plate and stainless steel base are rigidly fixed with four vertical round bars to provide the rigidity to the main structure of this set-up. The main base of the set-up is constructed by 10 mm thick mild steel plate consisting of 3 mm thick rubber sheet at the upper side and 20 mm thick rubber block at the lower side. A compound V-pulley above the top stainless steel plate was fixed with the shaft to transmit rotation to the shaft from a motor. An electronic speed control unit is used to vary the speed of the motor as required. A 6 mm diameter cylindrical smooth (roughness, $R_{a,}$ about 0.3 μm) or rough (roughness, $R_{a,}$ about 3 μm) pins their contacting foots are flat made of mild steel, fitted on a holder is subsequently fitted with an arm. The arm is pivoted with a separate base in such a way that the arm with the pin holder can rotate vertically and horizontally about the pivot point with very low friction.



1. Load arm holder 2. Load arm 3. Normal load (dead weight) 4. Spring balance 5. Pin sample 6. Rotating table 7. Test disc 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 bar17. Mild steel main base plate 18. Rubber block (20 mm thick)

Fig..1: Block Diagram of the Experimental Set-up

Sliding speed can be varied by two ways (i) by changing the frictional radius and (ii) by changing the rotational speed of the shaft. In this research, sliding speed is varied by changing the rotational speed of the shaft while maintaining 25 mm constant frictional radius. 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). Wear was measured by weighing the test sample with an electronic balance before and after the test, and then the difference in mass was converted to wear rate. 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 test sample was found to be R_a= 0.5 μm.. Each test was conducted for 30 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 test results were taken into consideration. The detail experimental conditions are shown in Table 1.

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	Copper
7.	Pin material	Mild steel (smooth and rough)

3. **Results and Discussion**

Figure 2 shows the variation of friction coefficient with the duration of rubbing at different normal load for copper mating with smooth mild steel counterface. During experiment, the sliding velocity and relative humidity were 1 m/s and 70% respectively. Curve 1 of this figure is drawn for normal load 10 N. From this curve, it is observed that during the starting, the value of friction coefficient is 0.23 and then increases very steadily up to 0.3 over duration of 20 minutes of rubbing and after that it remains constant for the rest of the experimental time.

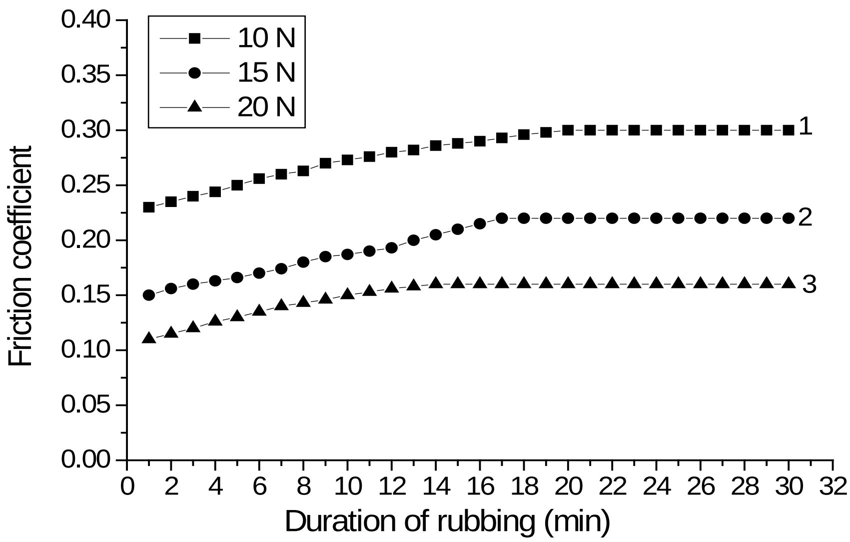


Figure 2: Friction coefficient as a function of duration of rubbing at different normal loads (sliding velocity: 1 m/s, relative humidity: 70%, test sample: Copper, pin: Mild steel,smooth)

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 a 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 a 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 values is different for different normal load. Results show that at normal load 10, 15 and 20 N, copper-mild steel smooth pair takes 20, 17 and 14 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].

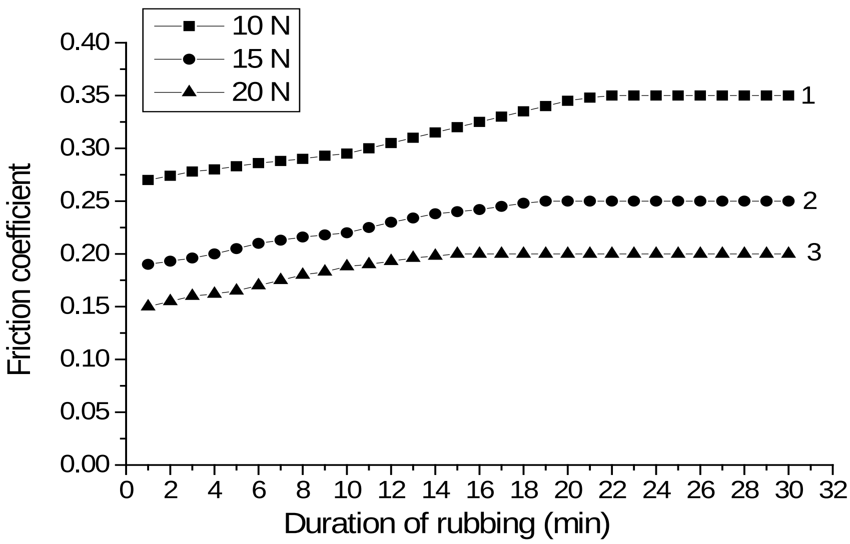


Figure 3: Friction coefficient as a function of duration of rubbing at different normal loads (sliding velocity: 1 m/s, relative humidity: 70%, test sample: Copper, pin: Mild steel,rough)

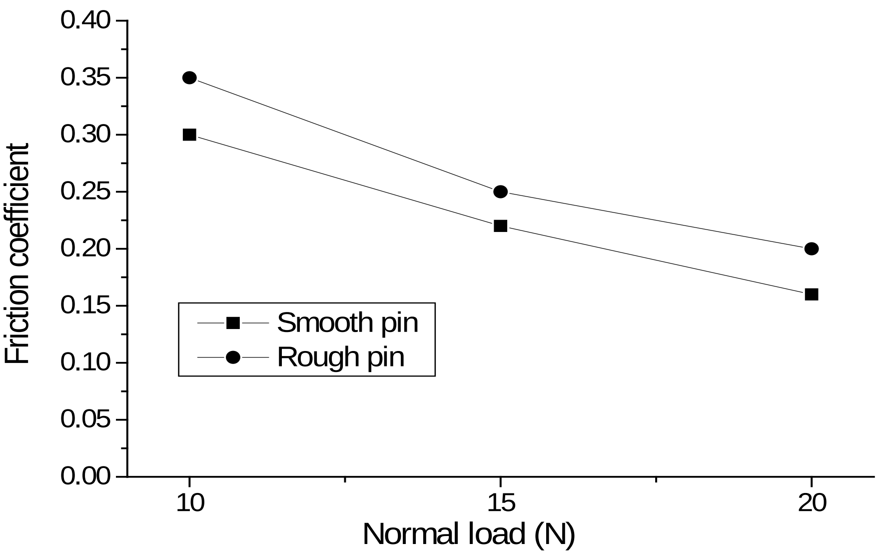


Figure 4: Friction coefficient as a function of normal load for copper (Sliding velocity: 1 m/s, relative humidity: 70%)

Figure 3 shows the effect of the duration of rubbing on the value of friction coefficient at different normal load for copper sliding against rough mild steel counterface at speed of 1 m/s and 70% of relative humidity. Curve 1 of this figure drawn for normal load 10 N, shows that during starting of the experiment, the value of friction coefficient is 0.27 which rises for few minutes to a value of 0.35 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 15 and 20 N respectively. From these curves, it is found that time to reach steady friction is different for different normal load. At normal load 10, 15 and 20 N, copper-mild steel rough pair takes 22, 19 and 15 minutes respectively to reach steady friction That is, higher the normal load, copper-mild steel rough pair takes less time to stabilize.

Figure 4 shows the comparison of the variation of friction coefficient with normal load for copper mating with smooth and rough mild steel couterface. Curves of this figure are drawn for copper under mild steel smooth and rough counerface conditions. It is shown that friction coefficient varies from 0.3 to 0.16 and 0.35 to 0.2 with the variation of normal load from 10 to 20 N for copper-mild steel smooth and copper-mild steel rough pairs respectively. These results show that friction coefficient decreases with the increase in normal load. Increased surface roughing 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. From this figure, it is also found that at identical conditions, the values of friction coefficient of copper mating with smooth counterface is lower that that of copper with rough counterface.

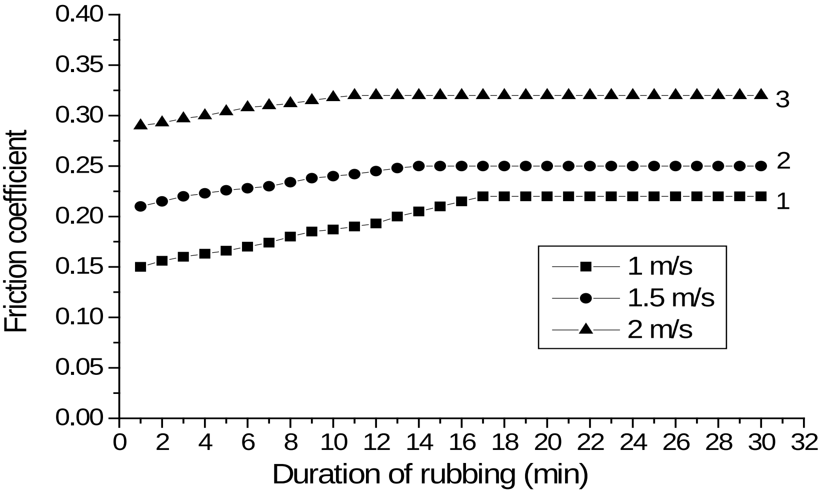


Figure 5: Friction coefficient as a function of duration of rubbing at different sliding velocities (normal load: 15 N, relative humidity: 70%, test sample: Copper, pin: Mild steel,smooth)

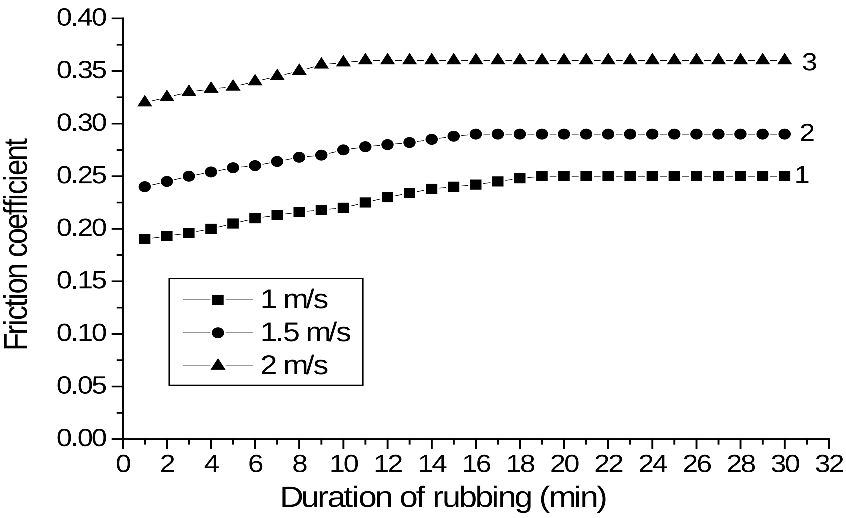


Figure 6: Friction coefficient as a function of duration of rubbing at different sliding velocities (normal load: 15 N, relative humidity: 70%, test sample: Copper, pin: Mild steel,rough)

Figures 5 and 6 show the variation of friction coefficient with the duration of rubbing at different sliding velocity for copper-mild steel smooth and copper-mild steel rough pair respectively at 15 N normal load. Curves 1, 2 and 3 of Figure 5 are drawn for sliding velocity 1, 1.5 and 2 m/s respectively. Curve 1 of this figure shows that during the starting, the value of friction coefficient is 0.15 which increases almost linearly up to 0.22 over a duration of 17 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 a 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 speed, the friction coefficient is more and the trend in variation of friction coefficient is almost the same as for curve 1.

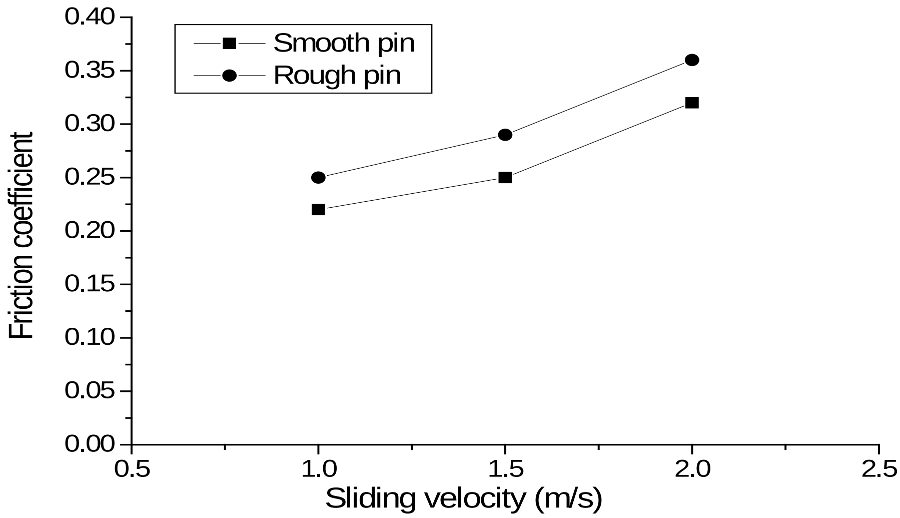


Figure 7: Friction coefficient as a function of sliding velocity for copper (normal load: 10 N, relative humidity: 70%)

From these curves, it is also observed that time to reach steady state values are different for different sliding velocity. From the results it is found that gun metal-mild steel smooth pair at sliding velocity 1, 1.5 and 2 m/s takes to reach constant friction 17, 14 and 11 minutes respectively. It indicates that the higher the sliding velocity, the time to reach constant friction is less. This may be due to the higher the sliding speed the surface roughness and other parameters take less time to stabilize. From Figure 6, it can be observed that the trends in variation of friction coefficient with the duration of rubbing are very similar to that of Figure 5 but the values of friction coefficient are different for copper-mild steel rough pair.

Figure 7 shows the comparison of the variation of friction coefficient with sliding velocity for the above mentioned material pairs. Curves of this figure are drawn for copper-mild steel smooth and copper-mild steel rough pairs. It is shown that the friction coefficient varies from 0.22 to 0.32 and 0.25 to 0.36 with the variation of sliding velocity from 1 to 2 m/s for copper-mild steel smooth and copper-mild steel rough 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 this figure, it is also found that at identical conditions, the values of friction coefficient of copper sliding against smooth mild steel counterface is lower that that of copper sliding against rough mild steel counterface.

4. **Conclusion**

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 mating with smooth and rough mild steel counterfac . On the other hand, the values of friction coefficient increase with the increase in sliding velocity for copper sliding against smooth and rough mild steel pins. 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. At identical conditions, the values of friction coefficient of copper mating with smooth counterface is lower that that of SS 304 with rough counterface.

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 under smooth and rough counterface conditions, therefore maintaining an appropriate level of normal load, sliding velocity as well as appropriate choice of counterface surface conditions, friction may be kept to some lower value to improve mechanical processes.

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