Effect of Sliding Velocity and Relative Humidity on Friction Coefficient of Brass Sliding against Different Steel Counterfaces

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ABSTRACT
The present paper investigates friction coefficient of brass sliding against different steel counterfaces. The effects of sliding velocity and relative humidity on friction coefficient of brass are investigated experimentally. To do so, a pin-on-disc apparatus was designed and fabricated. Experiments are carried out when different types of steel pin such as mild steel (MS) and stainless steel 304 (SS 304) slide on brass disc under sliding velocity ranging from 20 to 100 cm/sec and relative humidity 60% and 80%. During experiment, normal load was kept constant at 10 N. In general, friction coefficient increases for a certain duration of rubbing and after that it remains constant for the rest of the experimental time. Results show that friction coefficient decreases with the increase in sliding velocity and relative humidity. It is found that the magnitudes of friction coefficient are different for different mating pairs. It is also observed that at 60% relative humidity, the magnitudes of friction coefficient of brass-SS pair are higher than that of brass-MS pair. On the other hand, at 80% relative humidity, there is a little difference in the values of friction coefficient of brass-SS and brass- MS pairs.

Keywords: Friction coefficient; Sliding velocity; Relative humidity; Brass, SS 304, Mild steel

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. Several authors [1-16] reported that the variation of friction and wear rate depends on interfacial conditions such as normal load, geometry, relative surface motion, sliding speed, surface roughness of the rubbing surfaces, type of material, system rigidity, temperature, stick-slip, relative humidity, lubrication and vibration. Among these factors sliding velocity and relative humidity are the two major factors that play significant role for the variation of friction coefficient. The third law of friction, which states that friction is independent of velocity, is not generally valid. The coefficient of kinetic friction as a function of sliding velocity generally has a negative slope. Changes in the sliding velocity result in a change in the shear rate which can influence the mechanical properties of the mating materials. The strength of many metals and nonmetals is greater at higher shear strain rates as stated by Bhushan and Jahsman [17, 18] which results in a lower real area of contact and a lower coefficient of friction in a dry contact. On the other hand, Bhushan reported that high normal pressures and high sliding speeds can result in high interface (flash) temperatures that can significantly reduce the strength of most materials [19]. Yet in some cases, localized surface melting reduces shear strength and friction drops to a low value determined by viscous forces in the liquid layer. Fridmen and Levesque [20] suggest that part of the observed friction reduction is due to negative slope of the dependence of the friction force upon velocity. The friction force is a function of velocity and time of contact. For most materials when the velocity increases, friction decreases and when duration of contact increases, friction increases. The dependence of friction on velocity may be explained in the following way. When velocity increases, momentum transfer in the normal direction increases

producing an upward force on the upper surface. This results in an increased separation between the two surfaces which will decrease the real area of contact. Contributing to the increased separation is the fact that at higher speeds, the time during which opposite asperities compress each other is reduced increasing the level on which the top surfaces moves.

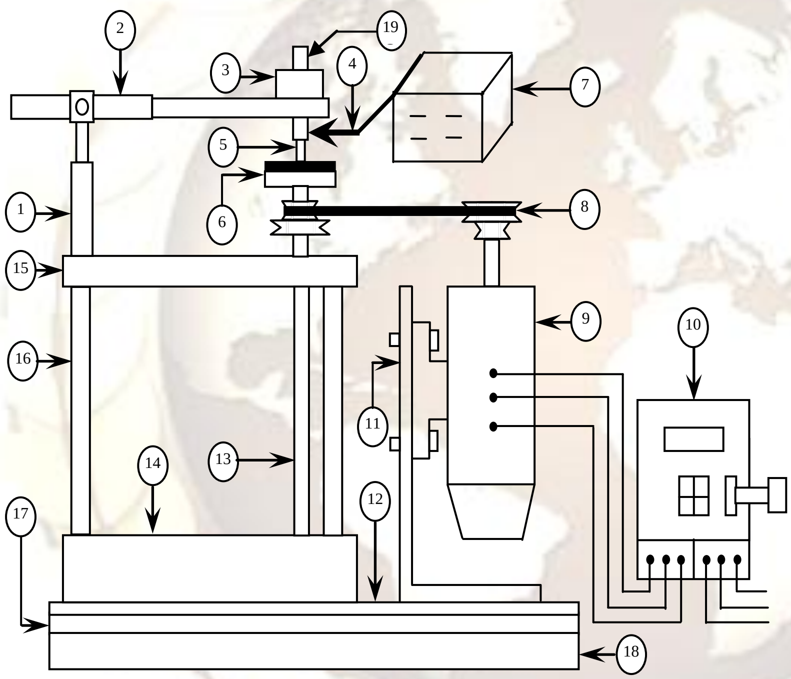
On the other hand friction co-efficient increases with the decrease of relative humidity [21–25].

Despite the aforementioned investigations, the combined effects of sliding velocity and relative humidity on friction coefficient of brass are yet to be clearly understood. Therefore in this study an attempt is made to investigate the simultaneous effect of sliding velocity and relative humidity on friction coefficient of brass sliding against different steel counterfaces such as mild steel and SS 304. Nowadays, brass is widely used for sliding/rolling applications where low friction is required such as gears, bearings, valves etc. Due to these tribological applications, brass has been selected as test material in this study. .

It is expected that the applications of these results will contribute to the different concerned mechanical processes.

2. Experimental Details

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).



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 experimental set-up

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 pin whose contacting foot is flat, made of mild steel or SS 304, 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. 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). To measure the surface roughness, Taylor Hobson Precision Roughness Checker (Surtronic 25) was used. Each test was conducted for 6 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 N
2.	Sliding Velocity	20, 40, 60, 80, 100 cm/s
3.	Relative Humidity	60%, 80 %
4.	Disc material	Brass (64%Cu-34%Zn-2%Pb)
5.	Pin materials	Mild steel (MS) Stainless steel 304 (SS 304)
6.	Average surface roughness of disk (R_a)	0.4-0.5 μm.
7.	Average surface roughness of pin (R_a)	About 0.3 μm
8.	Surface Condition	Dry
9.	Duration of Rubbing	6 minutes

3. Results and Discussion

Fig. 2 shows the variation of friction coefficient with the duration of rubbing at different sliding velocity for sliding pair brass-MS at 60% relative humidity.

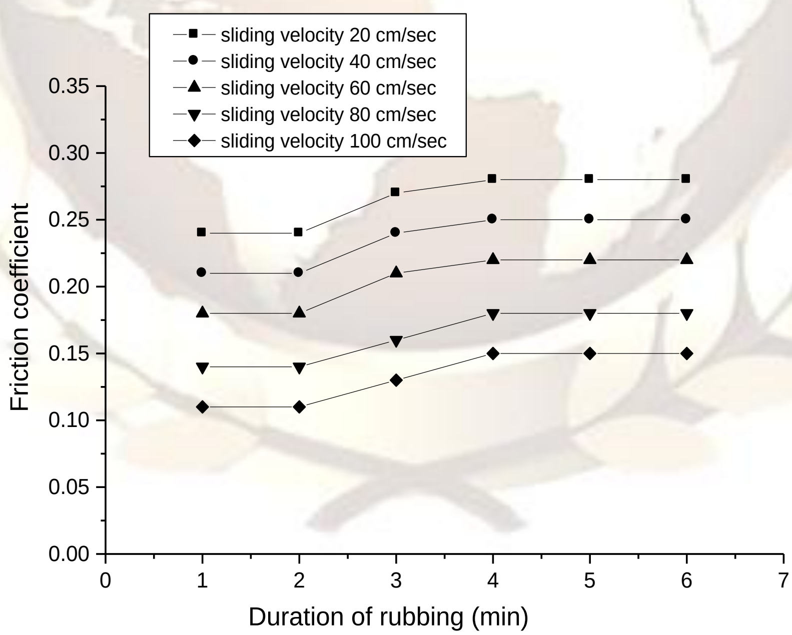


Fig. 2: Variation of friction coefficient with the variation of duration of rubbing at different sliding velocity for brass-MS pair (Normal load=10 N, Relative humidity=60%)

The curve of Fig. 2 drawn for sliding velocity 20 cm/sec shows the variation of friction coefficient of brass-MS pair with duration of rubbing. During the starting, value of friction coefficient is 0.24 which remains constant for 2 minutes then increases almost linearly up to 0.28 over a duration of 4 minutes of rubbing and after that it remains constant for the rest of the experimental time. Other curves of this figure show the values of friction coefficient at 40, 60, 80 and 100 cm/sec sliding speed. All these curves show similar trend as before. Other parameters such as normal load (10 N), surface roughness (R_a= 0.40-0.50 μm) and relative humidity (60%) are identical for these five curves. These findings are in agreement with the findings of Chowdhury and Helali [26,27] for mild steel and composite materials. The friction at the time of starting is low and remains at its initial value for some time and the factors responsible for this low friction are due to the presence of a layer of foreign material. This surface in general comprises of (i) moisture, (ii) oxide of metals, (iii) deposited lubricating material, etc. Brass 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. During 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 inclusion of trapped wear particles and roughening the substrate, the friction force increases due to the increase of ploughing effect. Increase of surface temperature, viscous damping of the friction surface, increased adhesion due to microwelding or deformation or hardening of the material might have some role on this increment of friction coefficient as well. 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 co-efficient remain constant for the rest of the time. In the curves of Fig. 2, it is also seen that the values of friction co-efficient decrease with the increase of sliding velocity. The decrease of friction coefficient of brass-MS couple with the increase of sliding velocity may be due to the change in the shear rate which can influence the mechanical properties of the mating materials. The strength of these materials is greater at higher shear strain rates [17,18] which results in a lower real area of contact and a lower coefficient of friction in dry contact condition. These findings are in agreement with the findings of Chowdhury and Helali [28] for mild steel, ebonite and GFRP sliding against mild steel.

Similar trends of results are obtained for friction coefficient with the variation of sliding velocity and duration of rubbing at 80% relative humidity for brass-MS pair and these results are presented in Fig. 3.

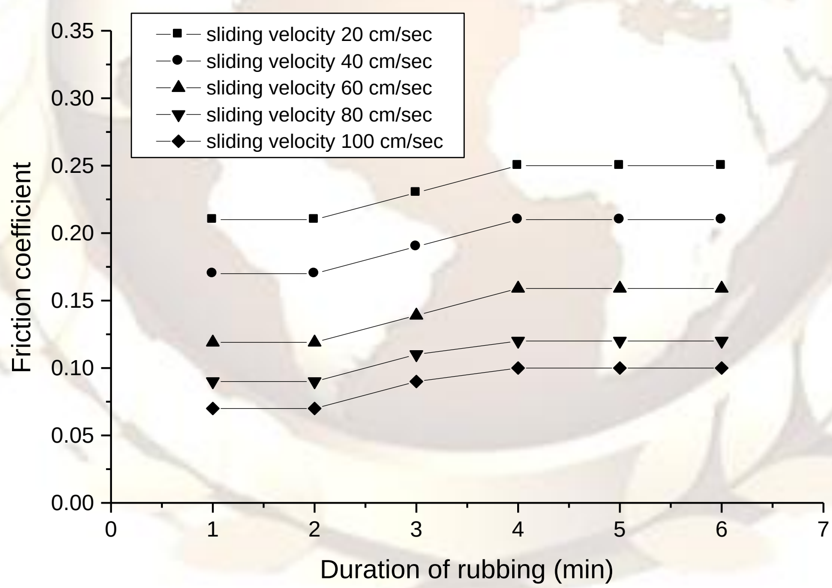


Fig. 3: Variation of friction coefficient with the variation of duration of rubbing at different sliding velocity for brass-MS pair (Normal load=10 N, Relative humidity=80%)

Figs 4 and 5 indicate the variation of coefficient of friction with the variation of sliding velocity and duration of rubbing of brass-SS pair for 60% and 80% relative humidity respectively. Similar behaviors are observed in the curves of Figs. 4 and 5 as that of the curves of Figs. 2 and 3 drawn for sliding pair brass-MS.

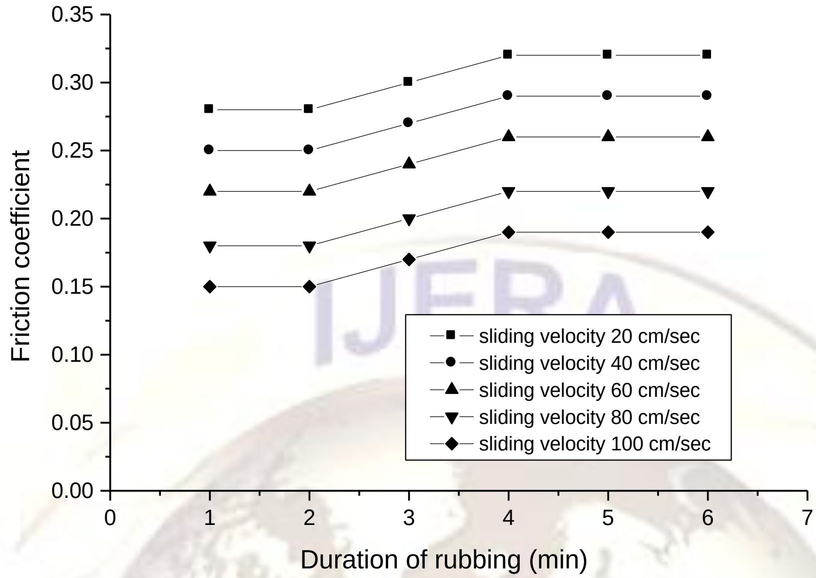


Fig. 4: Variation of friction coefficient with the variation of duration of rubbing at different sliding velocity for brass-SS pair (Normal load=10 N, Relative humidity=60%)

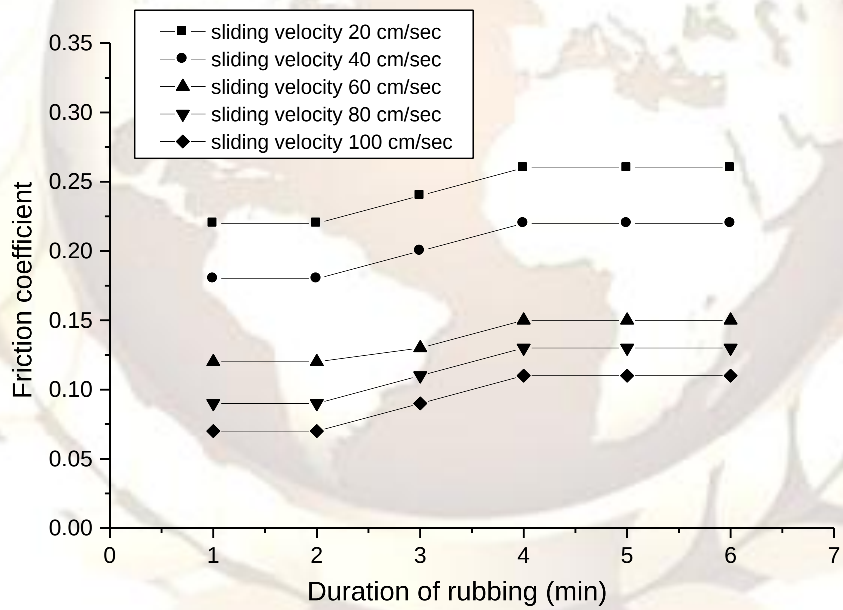


Fig. 5: Variation of friction coefficient with the variation of duration of rubbing at different sliding velocity for brass-SS pair (Normal load=10 N, Relative humidity=80%)

To observe the effect of relative humidity at different sliding velocity on friction coefficient for sliding pairs brass-MS and brass-SS, results are presented in Fig. 6. From this figure it is observed that friction coefficient at 60% relative humidity for sliding pairs brass-MS and brass-SS varies from 0.28 to 0.15 and 0.32 to 0.19 respectively. For 90% relative humidity values of friction coefficient vary from 0.25 to 0.1 and 0.26 to 0.11 for sliding pairs brass-MS and brass-SS respectively. This means that friction coefficient decreases with the increase of relative humidity for both brass-MS and brass-SS sliding couples. From the curves of Fig. 6 it is also found that the magnitudes of friction coefficient are higher for sliding pair brass-SS than that for sliding pair brass-MS at 60% relative humidity. On the other hand, at 80% relative humidity, there is a little difference between friction coefficient for sliding pair brass-SS and brass-MS. The increase of relative humidity might moisten the test disc surface that might have some lubricating effect and hence the friction force was reduced. Therefore, it can be concluded that with the increase of relative humidity, the values of friction co-efficient decrease. These findings are in agreement with the findings of Imada and Nakajima [21]. Similar trends are also observed for different materials [22-25] i.e. friction co-efficient decreases with the increase of relative humidity.

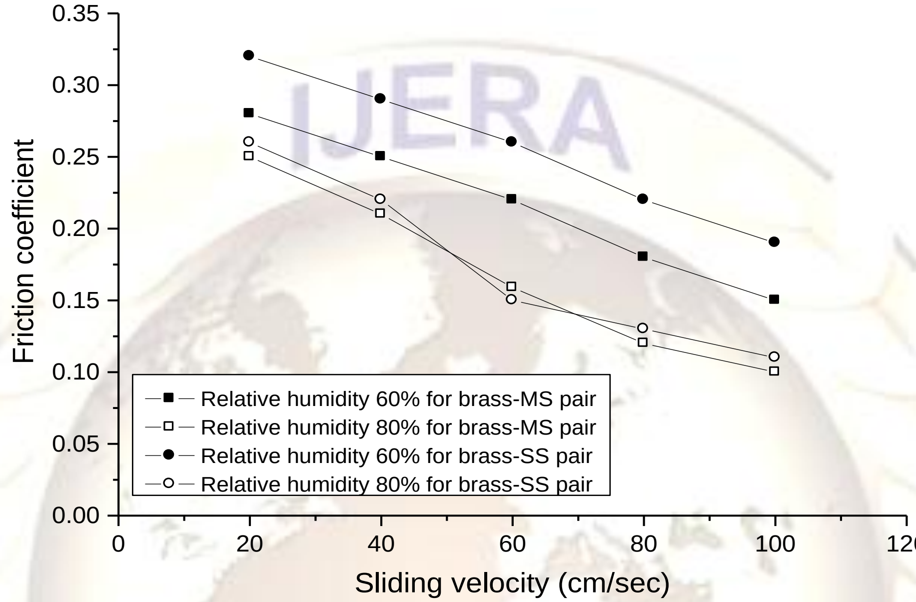


Fig. 6: Variation of friction coefficient with sliding velocity and relative humidity for different material pairs (Normal load=10 N)

4. Conclusions

Within the observed range, the presence of sliding velocity and relative humidity indeed affects the friction coefficient considerably. Friction coefficient varies with the duration of rubbing and after certain duration of rubbing, friction coefficient becomes steady for the observed range of sliding velocity. The values of friction coefficient decrease with the increase of sliding velocity and relative humidity of brass sliding against different steel counterfaces such as mild steel and SS 304. At 60% relative humidity, the magnitudes of friction coefficient of brass-SS pair are higher than that of brass-MS pair while at 80% relative humidity, there is a little difference in the values of friction coefficient of brass-SS and brass-MS pairs

As (i) the friction coefficient decreases with the increase of relative humidity and sliding velocity and (ii) magnitudes of friction coefficient are different for different sliding pairs, therefore maintaining appropriate level of sliding velocity and relative humidity as well as appropriate choice of sliding pair, friction may be kept to some optimum value to improve mechanical processes.

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