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RESEARCH

Experimental Investigation on Friction and Wear Properties of Different Steel Materials

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A B S T R A C T

Friction coefficient and wear rate of different steel materials are investigated and compared in this study. In order to do so, a pin on disc apparatus is designed and fabricated. Experiments are carried out when different types of disc materials such as stainless steel 314 (SS 314), stainless steel 202 (SS 202) and mild steel slide against stainless steel 314 (SS 314) pin. Experiments are conducted at normal load 10, 15 and 20 N, sliding velocity 1, 1.5 and 2 m/s and relative humidity 70%. At different normal loads and sliding velocities, variations of friction coefficient with the duration of rubbing are investigated. The obtained 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. The obtained results reveal that friction coefficient decreases with the increase in normal load for all the tested materials. It is also found that friction coefficient increases with the increase in sliding velocity for all the materials investigated. Moreover, wear rate increases with the increase in normal load and sliding velocity for SS 314, SS 202 and mild steel. In addition, at identical operating condition, the magnitudes of friction coefficient and wear rate are different for different materials 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 researchers [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 at higher loads. 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.

Friction coefficient and wear rate of metals and alloys showed different behavior under different operating conditions [18-25]. In spite of these findings, the effects of normal load and sliding velocity on friction coefficient of different types steel materials, particularly SS 314, SS 202 and mild steel sliding against SS 314 are yet to be investigated. Therefore, in this study, an attempt is made to investigate the effect of normal load and sliding velocity on the friction coefficient of these materials. The effects of duration of rubbing on friction coefficient are observed in this study. The effects of normal load and sliding velocity on wear rate of SS 314, SS 202 and mild steel are also examined.

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 pin whose contacting foot is flat, made of SS 314, 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). 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, Taylor Hobson Precision Roughness Checker (Surtronic 25) was used. 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.

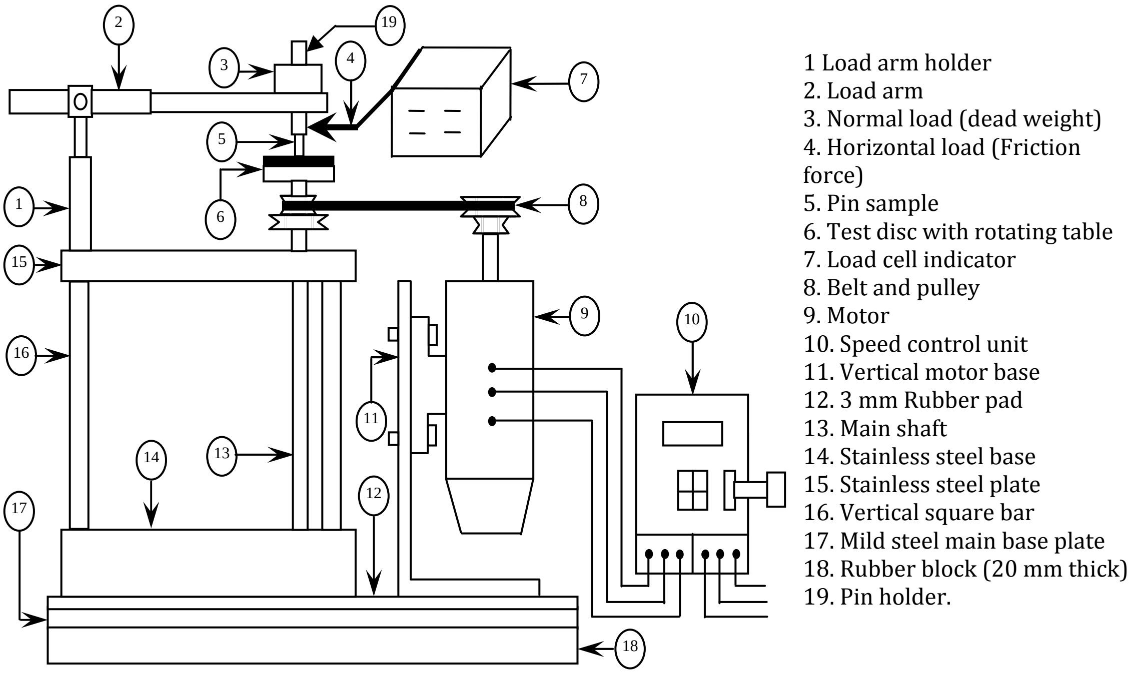

Fig. 1. Block diagram of the experimental set-up.

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.	Disc materials	(i) Stainless steel 314 (ii) Stainless steel 202 (iii) Mild steel
5.	Pin material	Stainless steel 314
6.	Average surface roughness of disks (R_a)	0.35-0.45 μm
7.	Average surface roughness of pin (R_a)	0.3-0.4 μm
8.	Surface Condition	Dry
9.	Duration of Rubbing	30 minutes

3. RESULTS AND DISCUSSION

Figure 2 shows the variation of friction coefficient with the duration of rubbing at different normal loads for SS 314. During experiment, the sliding velocity and relative humidity were 1.5 m/s and 70% respectively.

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 0.215 and then increases very steadily up to 0.27 over a duration of 24 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.

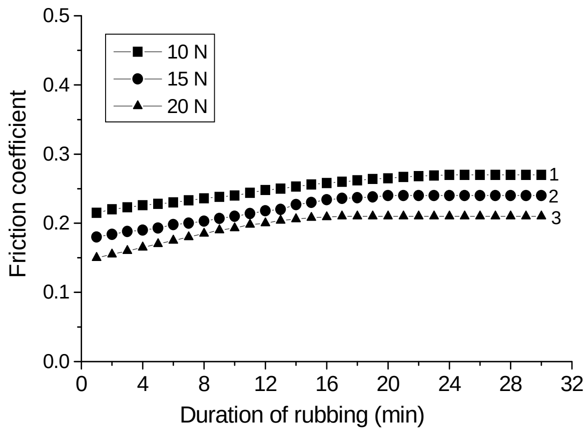

Fig. 2. Friction coefficient as a function of duration of rubbing at different normal loads (sliding velocity: 1.5 m/s, relative humidity: 70%, test sample: SS 314, pin: SS 314).

This layer on the disc surface in general comprises of (i) moisture, (ii) oxide film (iii) deposited lubricating material, etc. 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 loads. Results show that at normal load 10, 15 and 20 N, SS 314 takes 24, 20 and 17 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 [26,27].

Figure 3 shows the effect of the duration of rubbing on friction coefficient at different normal loads for SS 202 at velocity of 1.5 m/s and 70% of relative humidity.

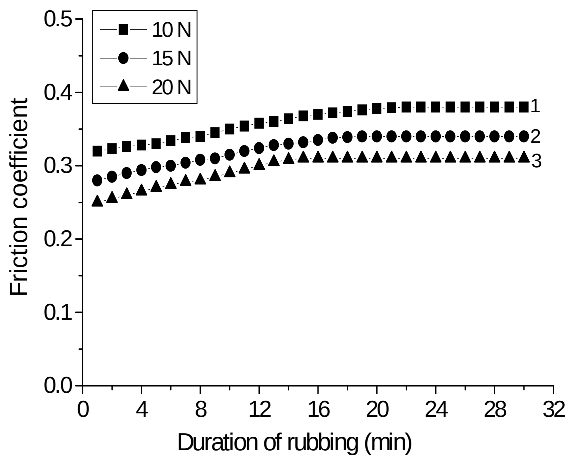

Fig. 3. Friction coefficient as a function of duration of rubbing at different normal loads (sliding velocity: 1.5 m/s, relative humidity: 70%, test sample: SS 202, pin: SS 314).

Curve 1 of this figure drawn for normal load 10 N, shows that during initial rubbing, the value of friction coefficient is 0.32 which rises for few minutes to a value of 0.38 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 loads. At normal loads 10, 15 and 20 N, SS 202 takes 22, 19 and 15 minutes respectively to reach steady friction. It means that higher the normal load, SS 202 takes less time to stabilize.

Experiments are conducted to observe the effect of duration of rubbing on friction coefficient under different normal loads for mild steel and these results are shown in Fig. 4.

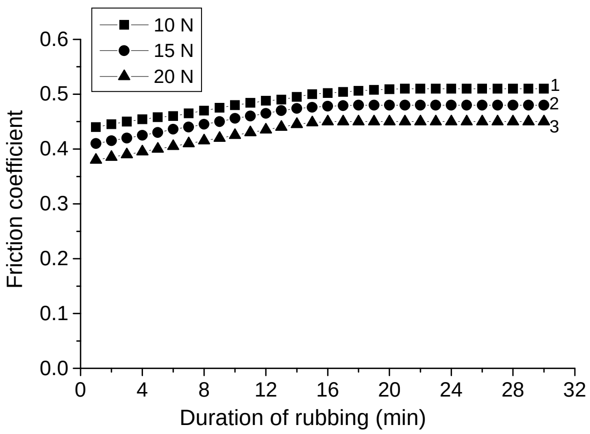

Fig. 4. Friction coefficient as a function of duration of rubbing at different normal loads (sliding velocity: 1.5 m/s, relative humidity: 70%, test sample: mild steel, pin: SS 314).

Curve 1 of this figure drawn for normal load 10 N shows that during initial rubbing, the value of friction coefficient is 0.44 which increases almost linearly up to 0.51 over a duration of 21 minutes of rubbing and after that it remains constant for the rest of the experimental time. Curves 2 and 3 of this figure are drawn for normal load 15 and 20 N, respectively. These curves also show similar trend as that of curve 1. Results show that at normal load 10, 15 and 20 N, mild steel takes 21, 18 and 16 minutes respectively to reach constant friction. It means that the higher the normal load, the time to reach constant friction is less. The possible reason is the surface roughness and other parameter attains a steady level at a shorter period of time with the increase in normal load.

Figure 5 shows the comparison of the variation of friction coefficient with normal load and curves of this figure are drawn for SS 314, SS 202 and mild steel.

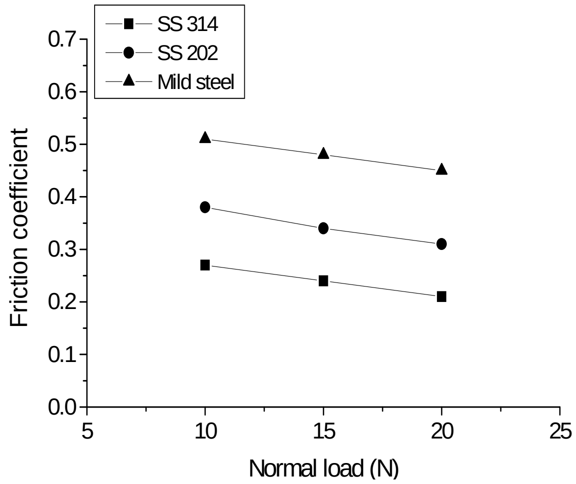

Fig. 5. Variation of friction coefficient with the variation of normal load for different materials (sliding velocity: 1.5 m/s, relative humidity: 70%, pin: SS 314).

These results are obtained from the steady values of friction coefficient of Figs. 2-4. It is shown that friction coefficient varies from 0.27 to 0.21, 0.38 to 0.31 and 0.51 to 0.45 with the variation of normal load from 10 to 20 N for SS 314, SS 202 and mild steel respectively. All of 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 [28] i.e friction coefficient decreases with the increase in normal load. From the obtained results, it can also be seen that the highest values of the friction coefficient are obtained for mild steel and the lowest values of friction coefficient are obtained for SS 314. The values of friction coefficient of SS 202 are found in between the highest and lowest values. It was found that after friction tests, the average roughness of SS 314, SS 202 and mild steel discs varied from 1.15-1.32, 1.45-1.7 and 2.1-2.45 μm respectively.

Figures 6, 7 and 8 show the variation of friction coefficient with the duration of rubbing at different sliding velocities for SS 314, SS 202 and mild steel respectively at 15 N normal load.

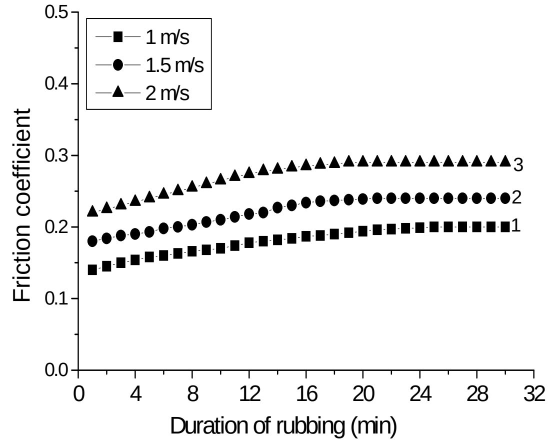

Fig. 6. Friction coefficient as a function of duration of rubbing at different sliding velocities (normal load: 15 N, relative humidity: 70%, test sample: SS 314, pin: SS 314).

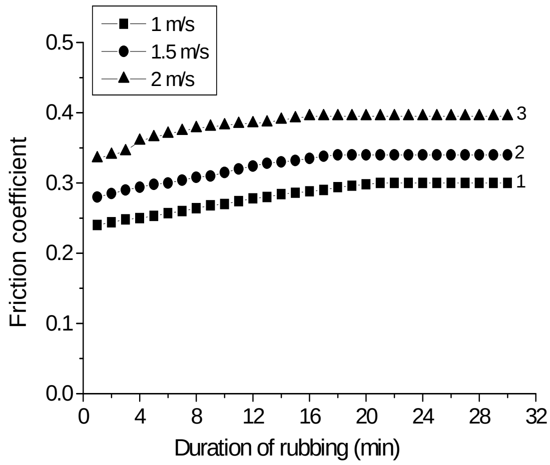

Fig. 7. Friction coefficient as a function of duration of rubbing at different sliding velocities (normal load: 15 N, relative humidity: 70%, test sample: SS 202, pin: SS 314).

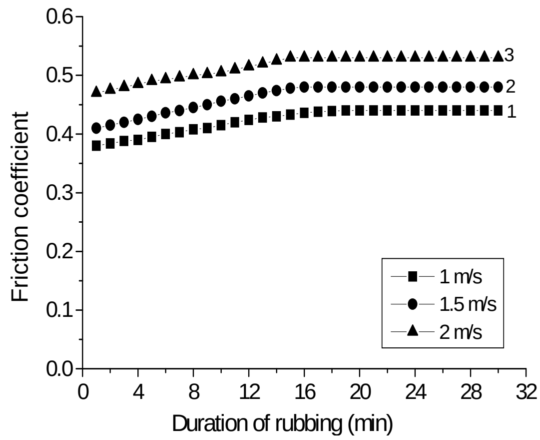

Fig. 8. Friction coefficient as a function of duration of rubbing at different sliding velocities (normal load: 15 N, relative humidity: 70%, test sample: mild steel, pin: SS 314)

Curves 1, 2 and 3 of Fig. 6 are drawn for sliding velocity 1, 1.5 and 2 m/s respectively. Curve 1 of this figure shows that initially the value of friction coefficient is 0.14 which increases almost linearly up to 0.2 over a duration of 25 minutes of rubbing and after that it remains constant for the rest of the experimental 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. The obtained results show that at sliding velocity 1, 1.5 and 2 m/s, time to reach constant friction 25, 21 and 19 minutes respectively. From Figs. 7 and 8, it can be observed that the trends in variation of friction coefficient with the duration of rubbing are very similar to that of Fig. 6 but the values of friction coefficient are different for different disc materials.

Figure 9 shows the comparison of the variation of friction coefficient with sliding velocity and the curves of this figure are drawn for SS 314, SS 202 and mild steel. These results are obtained from the steady values of friction coefficient of Figs. 6-8. It is shown that friction coefficient varies from 0.2 to 0.29, 0.3 to 0.395 and 0.44 to 0.53 with the variation of sliding velocity from 1 to 2 m/s for SS 314, SS 202 and mild steel 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. 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 mild steel and the lowest values of friction coefficient are obtained for SS 314. The values of friction coefficient of SS 202 are found in between the highest and lowest values. After friction tests it was found that the average roughness of SS 314, SS 202 and mild steel discs varied from 1.2-1.34, 1.52-1.85 and 2.23-2.62 μm respectively.

Figure 10 shows the variations of wear rate with normal load for SS 314, SS 202 and mild steel. Results show the variation of wear rate from 2.262 to 3.544, 1.956 to 3.187 and 6.524 to 10.354 mg/min with the variation of normal load from 10 to 20 N for SS 314, SS 202 and mild steel respectively. From these curves, it is observed that wear rate increases with the increase in normal load for all types of materials investigated. When the load on the pin is increased, the actual area of contact would increase towards the nominal contact area, resulting in increased frictional force between two sliding surfaces. The increased frictional force and real surface area in contact causes higher wear. This means that the shear force and frictional thrust are increased with increase of applied load and these increased in values accelerate the wear rate. Similar trends of variation are also observed for mild steel–mild steel couples [29], i.e wear rate increases with the increase in normal load.

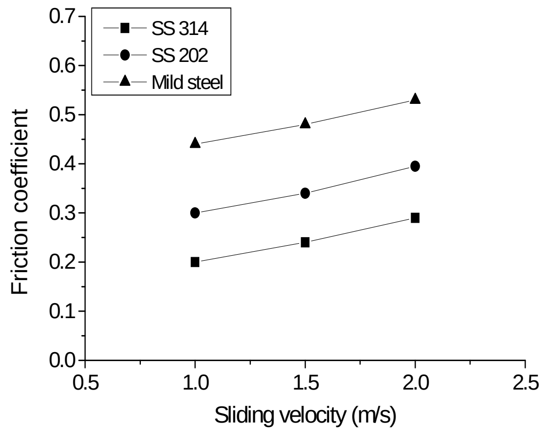

Fig. 9. Variation of friction coefficient with the variation of sliding velocity for different materials (normal load: 15 N, relative humidity: 70%, pin: SS 314).

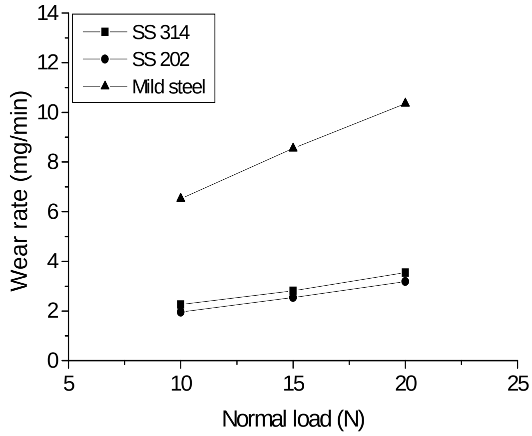

Fig. 10. Variation of wear rate with the variation of normal load for different materials (sliding velocity: 1.5 m/s, relative humidity: 70%, pin: SS 314).

From the obtained results, it can also be seen that the highest values of wear rate are obtained for mild steel and the lowest values of wear rate are obtained for SS 202. The values of wear rate of SS 314 are slightly higher than that of SS 202. It is very clear that within the observed range of normal load, the magnitudes of wear rate of mild steel are significantly higher than that of SS 314 and SS 202.

The variations of wear rate with sliding velocity for above mentioned materials are also observed in this study and the results are presented in Fig. 11. These results indicate that wear rate varies from 2.956 to 4.826, 2.642 to 4.495 and 6.934 to 11.862 mg/min with the variation of sliding velocity from 1 to 2 m/s for SS 314, SS 202 and mild steel respectively. It is observed that wear rate increases with the increase in sliding velocity for all types of materials investigated. This is due to the fact that duration of rubbing is same for all sliding velocities, while the length of rubbing is more for higher sliding velocity. The reduction of shear strength of the material and increased true area of contact between contacting surfaces may have some role on the higher wear rate at higher sliding velocity.

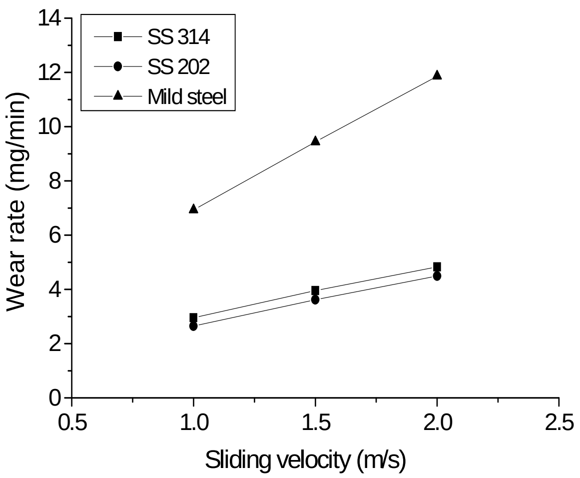

Fig. 11. Variation of wear rate with the variation of sliding velocity for different materials (normal load: 15 N, relative humidity: 70%, pin: SS 314).

At different sliding velocities, the highest values of wear rate are obtained for mild steel and the lowest values of wear rate are obtained for SS 202. Wear rates of SS 314 are slightly higher than that of SS 202. It is apparent that within the observed range of sliding velocity, wear rates of mild steel are remarkably higher than that of SS 314 and SS 202.

4. CONCLUSION

Normal load and sliding velocity indeed affect the friction coefficient and wear rate of SS 314, SS 202 and mild steel considerably. Within the observed range, the values of friction coefficient decrease with the increase in normal load while friction coefficients increase with the increase in sliding velocity. 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. The highest values of friction coefficient are obtained for mild steel and the lowest values of friction coefficient are obtained for SS 314.

The values of friction coefficient of SS 202 are found in between the highest and lowest values. Wear rates of SS 314, SS 202 and mild steel increase with the increase in normal load and sliding velocity. Wear rates of mild steel are significantly higher than that of SS 314 and SS 202. For the observed range, the values of wear rates of SS 314 are slightly higher than that of SS 202.

Therefore, maintaining an appropriate level of normal load, sliding velocity as well as appropriate choice of sliding pair, friction and wear may be kept to some optimum value to improve mechanical processes.

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