

EFFECT OF NORMAL LOAD AND SLIDING VELOCITY ON FRICTION COEFFICIENT AND WEAR RATE OF GUN METAL

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ABSTRACT

In this research, variations of friction coefficient and wear rate with the variation of normal load for gun metal are experimentally investigated. Experiments are also conducted to study the effect of sliding velocity on friction and wear. Experiments are carried out by sliding a stainless steel 304 (SS 304) pin on gun metal. To do so a pin on disc apparatus is used. The effects of duration of rubbing on friction under different operating conditions are also investigated in this study. Experiments are carried out for normal load ranging from 10 to 20 N and sliding velocity ranging from 1 to 3 m/s. In each experiment, the duration of rubbing is maintained for 30 minutes. Studies have shown that the values of friction coefficient and wear rate depend on normal load and sliding velocity. It is observed that the values of the friction coefficient of gun metal are decreased with the increase of sliding velocity and normal load. Experimental results also reveal that the wear rate increases with the increase of sliding velocity and normal load for gun metal. In addition, it is found that 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.

Keywords: Gun Metal, Sliding Velocity, Normal Load, Friction Coefficient, Wear Rate.

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 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 speed and normal load are the two major factors whose play significant role for the variation of friction and wear rate. 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.

Gun metal is one of the most important materials which is used for many tribological applications such as bush, bearings, piston rings, valves, gears etc. The strength of many metals and nonmetals is greater at higher shear strain rates as stated by Bhushan and Jahnman [14, 15] 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 [16]. 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 [17] 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.

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 [18] and Blau [19] 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 [20, 21]. In spite of these investigations the effects of sliding speed and normal load are yet to be clearly understood. Therefore in this study an attempt is made to investigate the effect of sliding speed and normal load on friction and wear behavior of gun metal sliding against stainless steel. It is expected that the applications of these results will contribute to the different concerned mechanical processes.

2. EXPERIMENTAL

A schematic diagram of the experimental set-up is shown in figure 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, 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. 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. 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 tests were taken into consideration. The detail experimental conditions are shown in Table 1.

Table 1: Experimental Range and Conditions

Sl. No.	Parameters	Range/Conditions
1.	Normal Load	10, 15, 20 N
2.	Sliding Velocity	1, 2, 3 m/s
3.	Roughness of specimen, R_a	0.5-0.6 μm
4.	Roughness of pin, R_a	0.3-0.4 μm
5.	Relative Humidity	70 (± 5)%
6.	Duration of Rubbing	30 minutes
7.	Surface Condition	Dry
8.	Material Pair (Disc-Pin)	Gun metal-SS 304

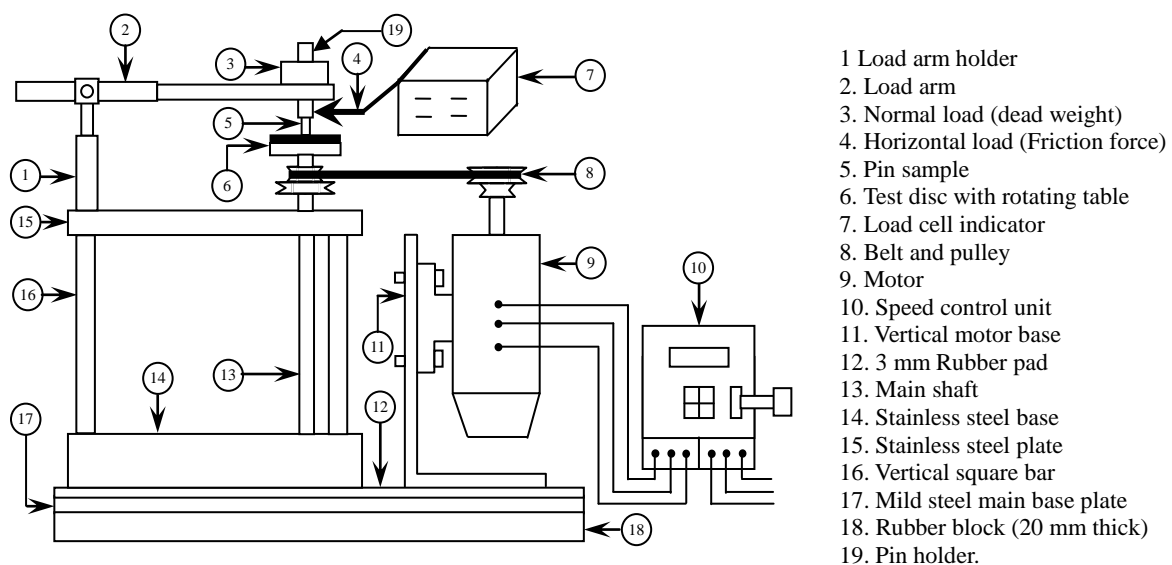


Fig 1. Block diagram of the experimental set-up

3. RESULTS AND DISCUSSION

Figure 2 shows the effect of the duration of rubbing on the value of friction coefficient at different normal load for gun metal at speed of 1 m/s and 70% of relative humidity. Curve 1 of this figure drawn for normal load 10N, shows that during starting of the experiment, the value of friction coefficient is 0.14 which rises for few minutes to a value of 0.17 and after that it remains constant for the rest of the experimental time. At starting of experiment the friction force is low due to contact between superficial layer of pin and disc. Then the friction coefficient increases due to 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 and for this reason the values of friction coefficient remain constant for the rest of the time. Curve 2 and Curve 3 of this figure is drawn for normal load 15 and 20 N respectively and shows similar trend as that of curve 1. From these curves, it is also observed that time to reach steady state values are different for different normal load. The trend of these results are similar to the results of Chowdhury and Helali [22-24].

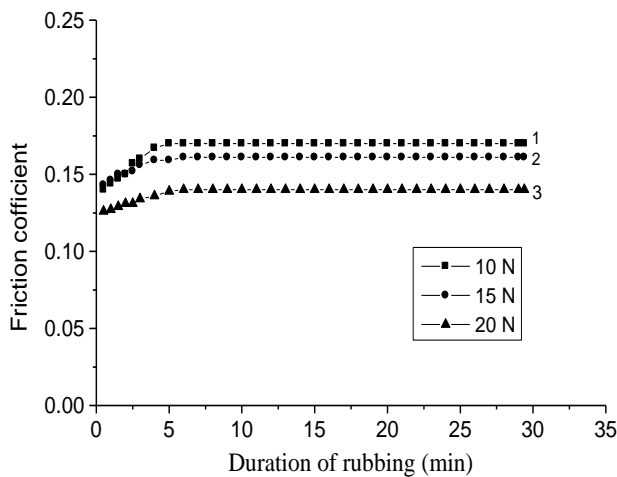


Fig.2: Friction coefficient as a function of duration of rubbing at different normal load (sliding velocity: 1 m/s, relative humidity: 70%, test sample: Gun metal)

Figure 3 shows the variation of friction coefficient with normal load for gun metal. It is shown that the friction coefficient varies from 0.17 to 0.14 with the variation of normal load from 10 to 20 N for gun metal. It indicates that that friction coefficient of gun metal decreases with the increase of normal load from 10 to 20 N. Increased surface roughing and a large quantity of wear debris are believed to be responsible for the decrease of friction [18,19] with the increase of normal load. The increase of transfer of gun metal layer on the pin surface with the increase of normal load may also be responsible for lower friction. The variation of coefficient of friction with applied load follows the equation $\mu = KN^{(n-1)}$. According to this equation, the coefficient of friction decreases with increase in applied load. The materials Al–Stainless steel [25] couples, also show similar

behavior, i.e friction coefficient decreases with the increase of normal load.

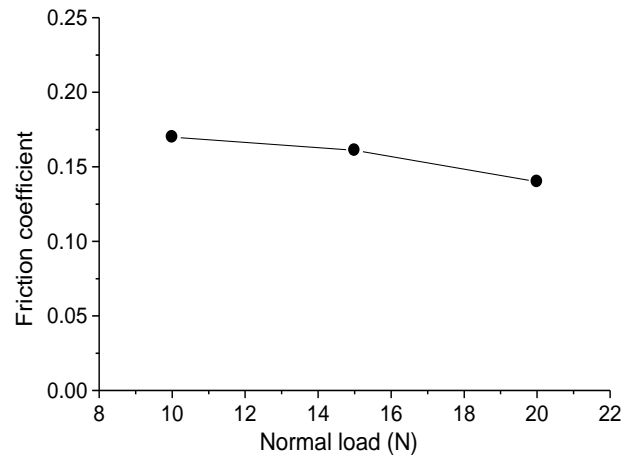


Fig.3: Friction coefficient as a function of normal load for gun metal (sliding velocity: 1 m/s, relative humidity: 70%)

Experiments were also carried out to observe the variation of wear rate with normal load for gun metal. Wear rate is equal to (Initial mass of the disc - Mass after test run)/Rubbing time. These results are presented in figure 4. The experimental results indicate that the curve drawn showing the variation of wear rate from 2.111 to 3.333 mg/min with the variation of normal load from 10 to 20 N for gun metal. From this curve, it is observed that wear rate increases with the increase of normal load for gun metal investigated. The shear force and frictional thrust are increased with increase of applied load and these increased in values accelerate the wear rate. The materials Mild steel–Mild steel [26] couples, also show similar behavior, i.e wear rate increases with the increase of normal load.

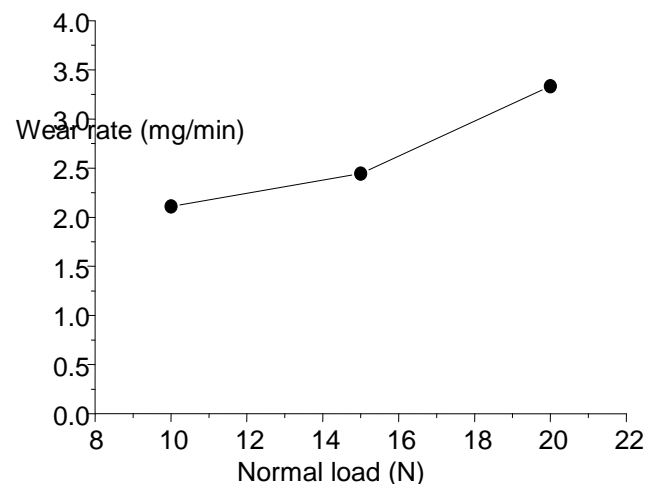


Fig 4. Wear rate as a function of normal load for gun metal (sliding velocity: 1 m/s, relative humidity: 70%)

Several experiments are conducted to observe the effect of duration of rubbing on friction coefficient at different sliding velocity for gun metal. These results are presented in figure 5. Figure 5 shows the effect of the

duration of rubbing on the value of friction coefficient at different sliding velocity for gun metal at normal load 10.0 N and 70% of relative humidity. Curve 3 of this figure is drawn for sliding velocity 3 m/s, shows that during the starting, the value of friction coefficient is 0.106 which then rises for few minutes to a value of 0.14 over duration of 4 minutes of rubbing and after that it remains constant for the rest of the experimental time. Similar trends of variation are also observed in curves 1 and 2 of figure 5.

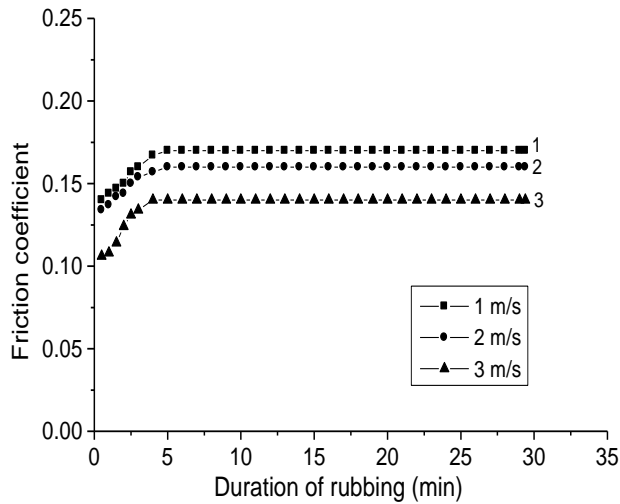


Fig.5: Friction coefficient as a function of duration of rubbing at different sliding velocity (normal load: 10 N, relative humidity: 70%, test sample: gun metal)

Different experiments were carried out to investigate the effect of sliding velocity on the friction coefficient for gun metal. Results of these experiments are presented in Fig. 6. It is shown that the friction coefficient at 10N normal load varies from 0.17 to 0.14 with the variation of sliding velocity from 1 m/s to 3 m/s for gun metal. This indicates that friction coefficient of gun metal decreases with the increase of sliding velocity from 1 m/s to 3 m/s. The decrease of friction coefficient of gun metal with the increase of sliding speed 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 [14,15] which results in a lower real area of contact and a lower coefficient of friction in dry contact condition. The increase of transfer of gun metal layer on the pin surface with the increase of normal load may also be responsible for lower friction. These findings are in agreement with the findings of mild steel, ebonite and GFRP sliding against mild steel [24], copper disc sliding against copper and stainless steel-304 pin [27] and aluminum sliding against stainless steel pin [25].

Experiments were also carried out to observe the variation of wear rate with sliding velocity for gun metal. These results are presented in Fig. 7. It is shown that the wear rate at 10N normal load varies from 2.111 to 2.778 mg/min with the variation of sliding velocity from 1 m/s to 3 m/s for gun metal. It indicates that wear rate

increases with the increase of sliding velocity for gun metal. This is due to the fact that duration of rubbing is the same for all sliding speed, while the length of rubbing is more in case of higher speed [27]. The increase of wear rate may also be due to reduced shear strength at higher sliding velocity.

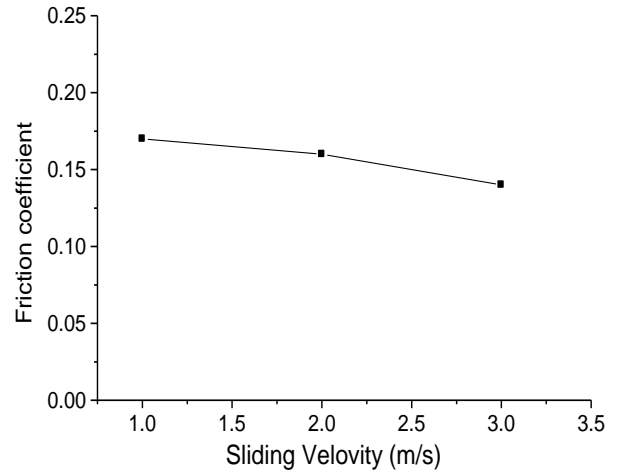


Fig.6: Friction coefficient as a function of sliding velocity for gun metal (normal load: 10 N, relative humidity: 70%)

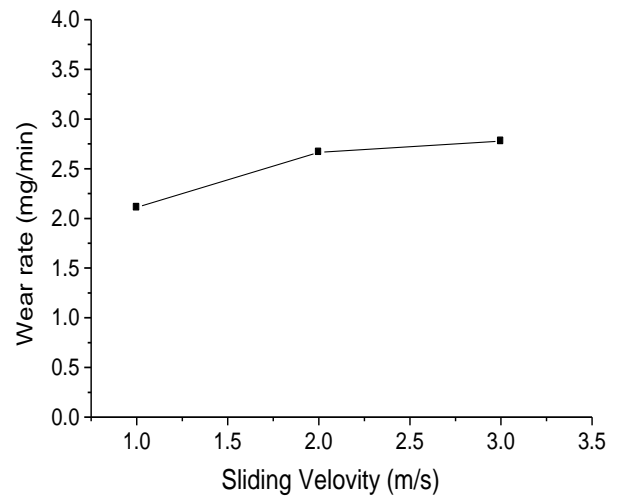


Fig.7: Wear rate as a function of sliding velocity for gun metal (normal load: 10 N, relative humidity: 70%)

4. CONCLUSION

The followings can be concluded from this study:

(1) 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.

(2) The friction coefficient decreases with increase of normal load and sliding velocity for gun metal.

(3) Wear rate increases with increase of load and sliding velocity for gun metal.

Therefore by maintaining an appropriate combination of normal load and sliding velocity friction force as well as wear may be kept to some lower value to improve

mechanical processes.

5. REFERENCES

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