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A STUDY OF WEAR CHARACTERISTICS OF DIFFERENT MATERIALS

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Summary

The wear characteristics of different materials including plastics were studied. The variation in mass and linear wear with normal load and speed was determined. An empirical relation was derived for the mass wear of brass sliding against steel in terms of the normal load. The variation in mass and linear wear with material hardness was investigated. Different sliding pairs were studied to assess a minimum wear rate.

1. Introduction

Machine performance and life depend on the wear characteristics of sliding components. For example, the axis of rotation of a shaft with respect to the bearing axis depends on bearing and shaft wear. Bearing wear results in eccentric shaft rotation and vibration. Wear of machine tool components such as guideways affects component accuracy. Tool wear leads to poor surface finish and reduced tool life. Study of the wear characteristics of materials aids the selection of sliding pairs and the working conditions for minimum wear.

Takeuchi [1] studied the mechanism of dry sliding wear of cast iron. Ramaswami [2] discussed tool wear as a metallurgical problem. The presence or absence of a built-up edge (BUE) affects tool wear and surface finish; the influence of different types of BUE was discussed.

Larsen-Badse [3] studied the effects of specimen length on abrasive wear rates for copper abraded dry against silicon carbide abrasive paper. Pal and Basu [4] studied factors affecting the wear resistance of plastic guides on a cast iron bed plate under dry and controlled conditions and established a generalized wear equation for Perspex slides.

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Moore [5] obtained a relationship between abrasive wear resistance and bulk hardness of pearlitic and martensitic ferrous materials.

Gent [6] predicted a discontinuity in frictional sliding as the compressive stress is increased from zero. This occurs at a critical value which depends on the coefficient of friction, the shear modulus of the material and the detailed shape of the contact zone. Corresponding changes in wear behaviour are inferred.

Pai *et al.* [7] measured the wear rates of cast aluminium-base alloys rubbing under lubricated conditions against a rotating hardened steel disc. The variations in groove wear profile and BUE adherence to the machined surface have also been studied [8].

In the present work the wear characteristics of different materials including Perspex were studied under different sliding conditions with and without lubrication. An empirical relation for the mass wear of a brass block has been obtained. Different sliding pairs were assessed for the wear rate and one pair was identified for the minimum wear rate.

2. Description of experiments

Wear tests were conducted with a Timken wear and lubricant testing machine. The test specimens are rectangular blocks 0.485 in square and 0.75 in long and a hardened (61 HRC) steel cup of circumference 6 in and thickness 0.520 in with a tapered internal surface on which it is mounted on the machine. Figure 1 shows a schematic arrangement of the test block, cup and loading arrangement. The materials tested were copper, brass, graphite, Perspex, carbide and hardened steel blocks sliding against a hardened steel cup. The test blocks and cup were weighed with a microbalance before and after the test. The weight loss was regarded as the mass wear and the test block scar width increase as the linear wear. Tests were conducted with the following different sliding pairs of materials.

(i) A brass block was slid against a hardened steel cup at a sliding speed of 152 m min^{-1} under various normal loads with lubrication. The test duration was 0.5 h. Wear tests were also conducted under a normal load of 75.5 kgf at various sliding speeds up to 213 m min^{-1} with lubrication. The test duration was 0.5 h.

(ii) A graphite block was slid against a hardened steel cup at a sliding speed of 152 m min^{-1} under various normal loads without lubricant. The test period was 5 min. Tests were also conducted under a normal load of 53 kgf and at various sliding speeds up to 213 m min^{-1}. The test period was 5 min.

(iii) Wear tests were conducted under a normal load of 75.5 kgf at a speed of 152 m min^{-1} with hardened steel, cast iron, copper, brass, mild steel and aluminium blocks against a hardened steel cup. The test durations used were 0.5 and 1 h.

(iv) Wear tests were conducted on carbide slid at 152.4 m min^{-1} under loads of 198.16 and 226.44 kgf with lubrication.

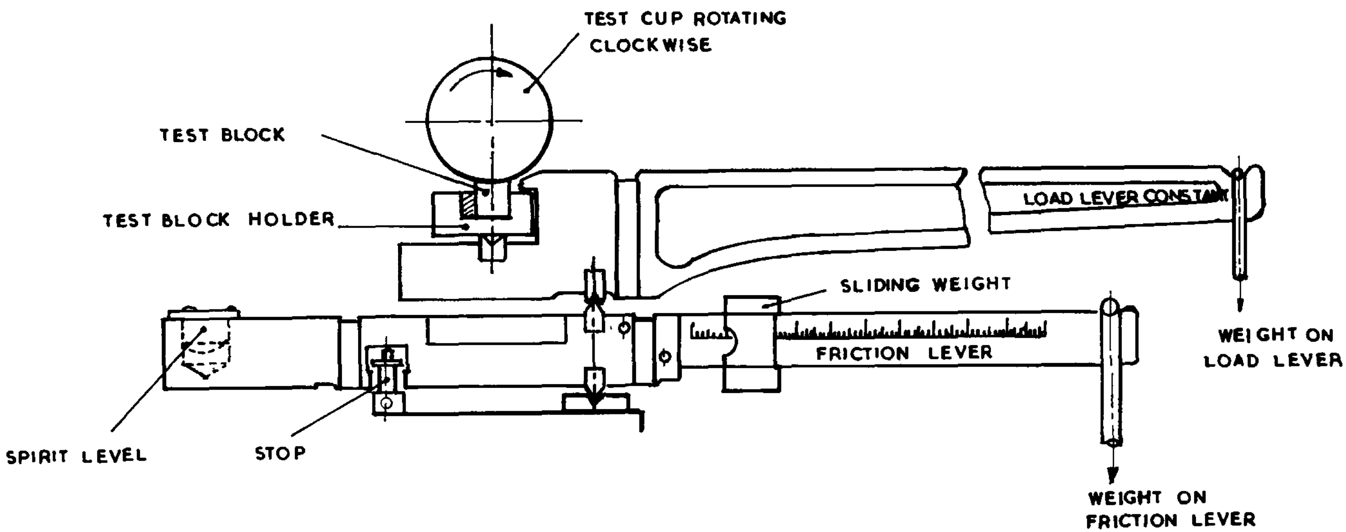

Fig. 1. Schematic arrangement of the test cup and test block.

(v) Wear tests were conducted on Perspex slid at 152.4 m min^{-1} under loads of 30, 53, 75 and 98 kgf with lubrication.

3. Results and discussion

The results of lubricated wear tests with a brass block and hardened steel cup are given in Table 1. The variation in mass wear and linear wear with contact load is shown in Fig. 2. Mass and linear wear increase expo-

TABLE 1

Lubricated wear tests on brass at various loads (speed, 1000 rev min^{-1}; sliding speed, 152.4 m min^{-1}; time, 0.5 h)

Load at the lever end (lbf)	*Load on the block* (lbf (kgf))	*Mass wear* (mg)			*Linear wear* (mm)
		Cup wear	*Block wear*	*Total wear*	
5	66.4 (30)	0.6	2.8	3.4	1.00
10	116.4 (53)	0.8	5.4	6.2	1.74
15	166.4 (75.5)	1.0	8.4	9.4	2.17
20	216.4 (98)	1.7	10.3	12.0	3.43
25	266.4 (121)	2.6	15.5	18.1	4.43

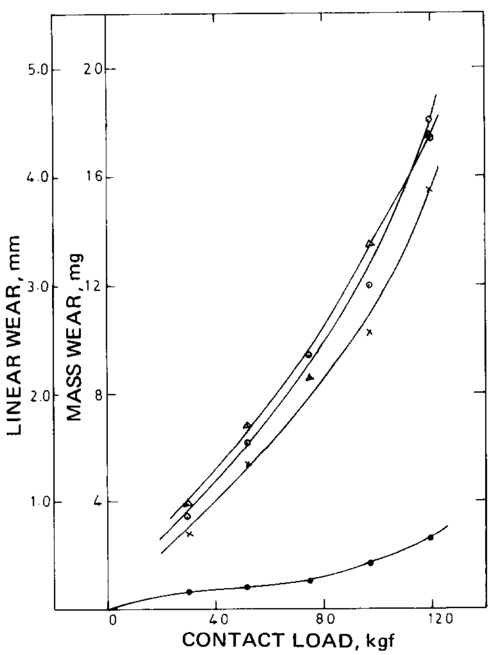

Fig. 2. Variation in linear wear (△) and mass wear (●, cup wear; ×, block wear; ⊙, total wear) with contact load for a sliding pair of brass block and hardened steel cup (with lubrication).

nentially with contact load. Block wear is greater than cup wear owing to the lesser hardness of the block.

A second-order polynomial empirical relation for the mass wear of a brass block sliding against a hardened steel cup was obtained in terms of the normal load:

$$W = A + BP + CP^2$$

where $A = -1.359$, $B = 0.1161$, $C = 1.4942 \times 10^{-4}$, W (mg) is the mass wear of the block and P (kgf) is the normal load. This is valid for a brass of hardness 165 HB when sliding against hardened steel. Figure 3 shows that there is a reasonable correlation between the experimental variation and the proposed variation in mass wear with normal load. This relation can be used to predict the mass wear at any other normal load under similar test conditions.

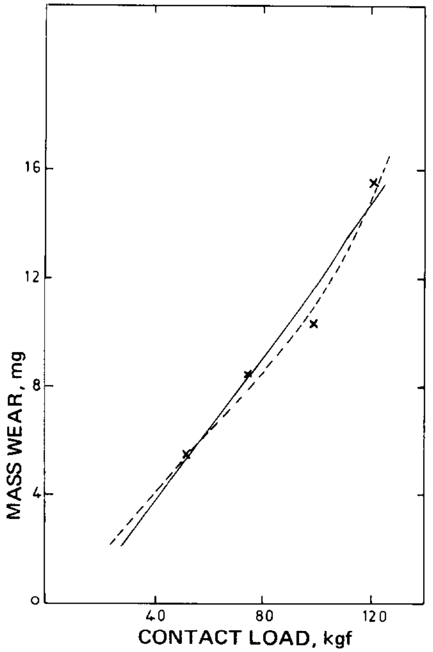

Fig. 3. Variation in mass wear with normal load for a sliding pair of brass block and hardened steel cup (with lubrication): ——, theoretical; – – –, experimental.

Wear test results for dry sliding of a graphite block and hardened steel cup are given in Table 2. The variation in mass wear and linear wear with contact load is shown in Fig. 4. The mass wear and linear wear of the cup and block increase with load. The mass wear of the cup is zero at a load of 75.48 kgf. Under a low load, adhesion of graphite particles on the cup takes place to give negative wear, *i.e.* the weight of the cup increased after the test.

Lubricated wear test results on brass and hardened steel under a load of 52.8 kgf and at various sliding speeds are given in Table 3. The variation in

TABLE 2

Unlubricated wear tests on graphite at various loads (speed, 1000 rev min^{-1}; sliding speed, 152.4 m min^{-1}; time, 5 min)

Load at the lever end (lbf)	*Contact load* (lbf (kgf))	*Mass wear* (mg)			*Linear wear* (mm)
		Cup wear	*Block wear*	*Total wear*	
5	66.4 (30)	−0.6	4.9	4.3	3.38
10	116.4 (53)	−0.3	11.8	11.5	4.38
15	166.4 (75.5)	0.0	19.6	19.6	4.98
20	216.4 (98)	0.8	23	23.8	5.58
25	266.4 (121)	1.8	27.4	29.2	6.10

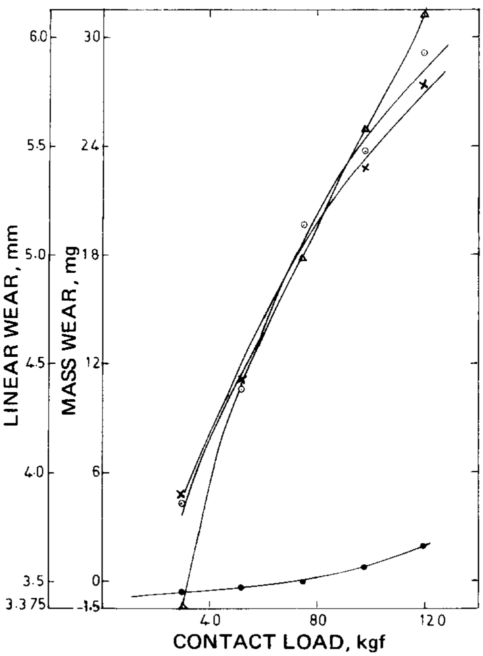

Fig. 4. Variation in linear wear (△) and mass wear (●, cup wear; ×, block wear; ⊙, total wear) with contact load for a sliding pair of graphite and hardened steel cup (without lubrication).

mass wear and linear wear with sliding speed is shown in Fig. 5. The mass wear and linear wear of the block increase exponentially with sliding speed. The mass wear of the block increases rapidly beyond a sliding speed of 152 m min^{-1}. Hence it is advisable to slide below 152 m min^{-1} for this pair.

Dry wear test results on graphite and hardened steel under a load of 52.8 kgf and at various sliding speeds are given in Table 4. The mass wear and linear wear increase exponentially with sliding speed as shown in Fig. 6. The mass wear of the cup is zero at a sliding speed of 150 m min^{-1}. Below this speed the mass wear of the cup is negative because the weight of the cup

TABLE 3

Lubricated wear tests on brass at various sliding speeds (load at the lever end, 15 lbf; load on the block, 166.4 lbf (75.5 kgf); time, 30 min)

Speed (rev min^{-1} (m min^{-1}))	*Mass wear* (mg)			*Linear wear* (mm)
	Cup wear	*Block wear*	*Total wear*	
600 (91.5)	0.2	2.2	2.4	1.37
800 (122.0)	0.6	5.4	6.0	1.77
1000 (152.4)	1.0	8.0	9.0	2.20
1200 (183.0)	1.6	18.0	19.6	3.04
1400 (213.5)	2.2	28.0	30.2	3.90

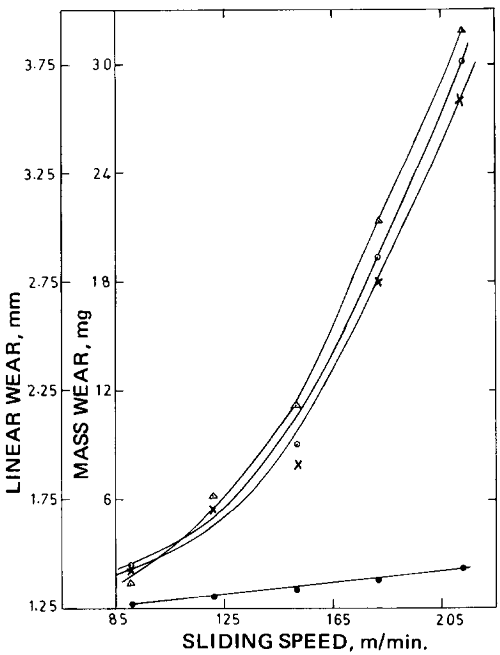

Fig. 5. Variation in linear wear (△) and mass wear (●, cup wear; ×, block wear; ⊙, total wear) with sliding speed for a sliding pair of brass block and hardened steel cup (with lubrication).

increases owing to the adhesion of fine graphite particles. As the sliding speed increases beyond 150 m min^{-1} the built-up layer may be broken and insufficient time is available for the particles of the graphite to adhere to the cup.

Wear test results on materials of various hardnesses are shown in Table 5. The variation in mass wear and linear wear with hardness is shown in Fig. 7. The variation in the mass wear of the block for materials of different hardness for a 1 h test varies and is greatest for brass and least for mild steel. The fact that brass exhibits the greatest wear may be due to low hardness and to brittleness, there being no scope for adhesion. The same trend is also observed for the 0.5 h test. For a Shore hardness greater than 33, cup wear is greater

TABLE 4

Unlubricated wear tests on graphite at various sliding speeds (load on the lever end, 10 lbf; contact load, 116.4 lbf (53 kgf); time, 5 min)

Speed (rev min^{-1} (m min^{-1}))	*Mass wear* (mg)			*Linear wear* (mm)
	Cup wear	*Block wear*	*Total wear*	
600 (91.5)	−1.8	3.5	1.7	4.01
800 (122.0)	−1.2	7.6	6.4	4.48
1000 (152.4)	−0.3	11.7	11.4	5.03
1200 (183.0)	0.5	15.6	16.1	5.69
1400 (213.5)	1.4	21.7	23.1	6.27

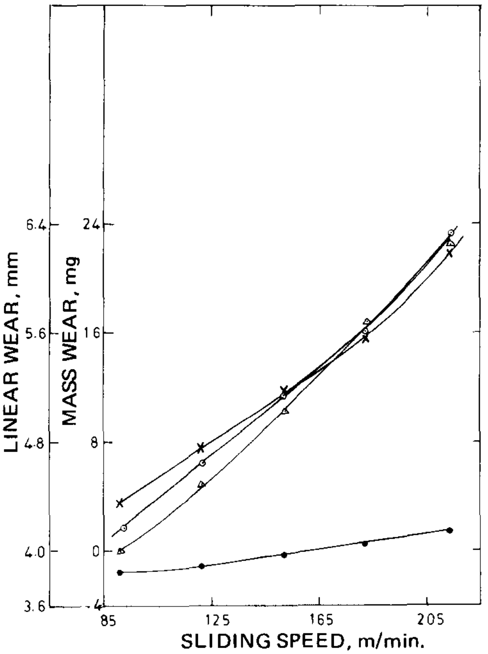

Fig. 6. Variation in linear wear (△) and mass wear (●, cup wear; ×, block wear; ⊙, total wear) with sliding speed for a sliding pair of graphite block and hardened steel cup (without lubrication).

than block wear. This may be due to wear particles that are welded to the block because of the higher contact temperatures that occur with sliding surfaces of higher hardness. It can be concluded that material hardness is not the only factor affecting material wear. Other material properties such as density will also have an effect.

The variation in linear wear with Shore hardness follows the same trend but the maximum linear wear occurs for aluminium (Shore hardness, 18). This may be due to the low density of aluminium.

From Table 5, the mass wear of the cup is low when it slides on copper.

TABLE 5

Lubricated wear of various materials with time (speed, 1000 rev min^{-1}; sliding speed, 152.4 m min^{-1}; load on the lever, 15 lbf; contact load, 166.4 lbf (75.5 kgf))

Material	*Shore hardness*	*Mass wear* (mg) *for the following test times*						*Linear wear rate* (mm h^{-1})
		Cup wear		*Block wear*		*Total wear*		
		0.5 h	*1 h*	*0.5 h*	*1 h*	*0.5 h*	*1 h*	
Hardened steel	85	2	3	1	1.6	3	5.4	1.41
Cast iron	30	1	2	0.8	1.4	1.8	3.4	1.82
Cu	14	0.8	1.2	1.4	2.4	2.2	3.6	1.77
Brass	24	0.8	1.6	7.6	16.6	8.4	18.2	3.59
Mild steel	33	1	2	0.6	0.9	1.5	2.9	1.28
Al	18	1	2.1	1.7	3.6	2.7	5.7	4.25

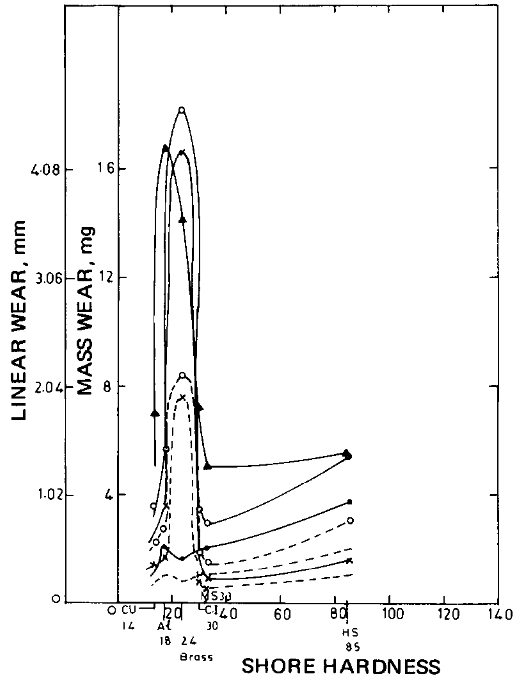

Fig. 7. Variation in linear wear (▲) and mass wear (●, cup wear; ×, block wear; ○, total wear) with Shore hardness for various sliding pairs: ——, 1 h; – – –, 0.5 h.

Sliding wear tests were conducted with brazed carbide against hardened steel at 152.4 m min^{-1} under a contact load of 98.16 kgf for 1 h. There was negligible wear of the carbide material. Under a contact load of 226 kgf there was negligible mass wear on the carbide tip but considerable wear of the cup.

Experiments were conducted with Perspex slid against a hardened steel cup under loads of 30, 53, 75 and 98 kgf and at a constant speed of 152.4 m min^{-1}. During the experiments the sliding speed remained constant under loads of 30, 53 and 75 kgf but under a load of 98 kgf a stick–slip motion developed because of plasticization of the Perspex causing repeated sticking and breaking from the cup. The wear of the cup was negligible compared with cup wear with other materials. The wear of the Perspex block was high and similar for all loads. Under a load of 30 kgf pure wear of the Perspex was observed. Under loads of 53 and 75 kgf, both wear and plastic flow were observed.

4. Conclusions

(1) The mass wear varied exponentially with contact load for all materials tested.

(2) The linear wear increased exponentially with load for some materials.

(3) The mass wear and linear wear increased exponentially with sliding speed for some materials.

(4) The amount of wear (linear or mass) is not only dependent on material hardness but also on other material properties such as density, structure and strength.

(5) Carbide material suffers negligible wear when slid over hardened (61 HRC) steel.

(6) An empirical relation for the mass wear of brass was derived in terms of normal load which may be used for the prediction of mass wear under any required load with reasonable accuracy.

(7) Copper sliding on steel leads to less wear of the steel than other combinations.

(8) Under low contact loads, plastic material may be used satisfactorily for slideways or guides without plastic deformation and with a low wear rate.

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