ON THE ANALYSIS OF WEAR PARAMETERS, AN
EXPERIMENTAL STUDY

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ABSTRACT

A detailed experimental study is, herein, presented to demonstrate the effect of most contributing parameters on the trend of wear variation. Results attained show the effects of applied loads, speed and frictional work on wear rate for different interacting materials .

Micrographs are taken to investigate surface changes under various materials combinations at different operating conditions. The results showed that softer materials usually transfer to the harder, and transition from mild to severe wear is affected by the magnitude of load and speed.

Results have shown that wear rate is functionally dependent on the applied load and a proposed speed (sliding/rolling) parameter. A wear rate formula could thus be formulated to identify a basic wear coefficient and a limit beyond which mild followed by severe wear would occur.

INTRODUCTION

Wear, in general, is defined to be loss of material which would occur as a natural consequence when two surfaces interact while being subjected to certain patterns of loads and speeds within specific environmental conditions.

Wear phenomenon has therefore, a complicated nature and represents a problem in classifying it into different types. Early classification considered wear to operate under the mechanism of oxidation [1,2.] In later attempts, wear can be grouped into abrasive [1,2,3,4,7,], adhesive [2,3,4,6,7], corrosive [2,3,4,6], fatigue surface [3,4,6], due to elastic or plastic deformation [2,5,6], erosion [3,7], and fretting [7] .

These types of wear, although describe qualitatively the wear behaviour, seldom occur individually as any of these wear types may spontaneously contribute to another one and so on .

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As regards mechanical wear, the basic mechanisms that govern the wear behaviour have been studied in some details [7,8,9,10]. Of interest to show that the wear mechanisms cannot be fully understood except by analysing wear as a combination of different mechanisms. Archard [10] showed that adhesive is the main contributing factor, proposing a formula

$$Q = \frac{k}{3} \frac{P}{HB} \quad , \quad \left(\text{where : } Q : \text{wear rate per unit travel distance,} \right.$$

P : applied load per unit area, HB : Brinell Hardness and K : a wear coefficient), while Krageleski [5] assumed that fatigue failure is mainly responsible for wear in metals. In a recent approach to wear mechanisms, Suh [11] proposed the delamination theory of wear based on dislocation phenomena and the plastic deformation with fracture of metal near the surface.

These mechanisms, although give qualitatively the wear mechanisms, also give some mathematical models to describe wear rates as a function of operating parameters namely; load, material yield stress [8,10] .

This mathematical analysis has shown some deviations from experimental results [8,10,11] and it looks rather difficult to specify a wear coefficient specific to each metal. The difficulty in specifying a wear coefficient is due to the various parameters that may play a role in defining the wear rate.

Hence, it has been decided to investigate in such extent, the mechanical wear. Two discs describing sliding and/or rolling conditions have been investigated aiming towards specifying a wear coefficient which may be helpful to predict the machine life.

EXPERIMENTAL SET-UP

In the present investigation, tests were conducted on a standard AMSLER wear testing machine, types Al35, Wolbert Machinery LTD, Schaffhausen.

The test specimens are cylindrical disks made of different materials, Table 1. The arrangement of test specimens are shown in Fig.1, to give combined rolling and sliding speeds.

The speeds varied up to about 400 rpm. (41 rad/s.) The applied load varied up to 1500 N. The full range of test scope is shown in Table.2.

Table 1. Specimens materials

Material	Designation	Hardness (B.H.N.)
Alloy steel	41 Cr 4 DIN 17006	288
Bronze	(Cu 91.17% , Sn8.19%, PO.3% Z _n 0.195 %, rest Pb)	165

TEST RESULTS

The wear (loss of weight) varies exponentially with applied load as shown in Fig.2. At relatively high loads the wear increases by a rate higher than that at light loads. This confirms that an increase in the applied loads would eventually lead to a transition from mild to severe wear. However, the critical value of load to determinate this transition could be seen at higher sliding speeds with the range of test herein presented.

The micrographs of the worn surfaces of both test disks are shown in Figs 3,4. It was observed that the general effect of sliding steel on bronze, was the pick-up of the latter by the former, particularly at high loads.

Fig.5 shows the variation of wear with time for a bronze disk rubbing on equal diameter steel disk with normal load 500 N at speeds 200 and 400 r.p.m. The wear rate of bronze, shows speed dependence, increases with increasing speed.

Frictional work done, as being defined by the integration of the frictional resistance along the sliding distance, has shown to display an expected increase with time, load and speed as shown in Fig.6.

Fig.7 demonstrates the effect of applied load on Bronze specimen surface hardness under two different sliding speeds. Increasing applied load and/or running speed shows a higher increase in hardness. However, it should be mentioned that the measured values of hardness comes as an average of several readings along the disk circumference by the end of each test.

DISCUSSION

In general the present results agree well with previous and expected prediction of an increase in the wear rate with load, speed and time. However, by applying available theories of wear predictions and in particular the Archard formula, it can be seen from Fig. 8 that within the range of light loads, the wear rate varies linearly with $\left(\frac{P}{HB}\right)$ whether the hardness has been based on the bulk or the surface hardness after test. At an almost critical value of load of about (48 N/m^2) which comes to a value approximately $0.3HB$, the Archard formula ceases to apply.

It is expected that this behaviour should be a direct result of the effect of either the type of running speed, (whether rolling, sliding or combined rolling and sliding) and the

Fig.1. Arrangement of test specimens

Table.2 Combinations of specimens materials, sizes, and speeds

Case	Upper specimen				Lower specimen				Us
	Material	Size d ₁ (m)	Speed n ₁ (rpm)	Peripheral speed (m/s)	Material	Size d ₂ (m)	n ₂ (rpm)	Peripheral speed (m/s)	
a	Alloy steel	0.038	180	0.358	Bronze	0.038	200	0.399	0.041
	Alloy steel	0.038	360	0.716	Bronze	0.038	400	0.798	0.082
b	Bronze	0.037	180	0.351	Alloy steel	0.041	200	0.429	0.083
	Bronze	0.037	360	0.702	Alloy steel	0.041	400	0.537	0.165

time effect coupled with the applied load .

Actually the present work has shown that the sliding speed component could largely affect the wear rate. By increasing the sliding speed, the wear rate shows a sharp increase at an applied pressure value which is relatively lower than the lower speed. This can be observed with reference to Fig. 8 , in which the wear rate changes its gradient at a stress to hardness ratio of 0.3 when the sliding speed is 0.0399 m/s , and at a stress to hardness ratio of 0.21 when the sliding speed is 0.0798 m/s .

Fig.2 Variation of Bronze disk wear with applied load at different running conditions .

Fig. 3 Micrographs of alloy steel (a) and bronze (b) under applied load of 500 N , and 0.041 m/s sliding speed (test duration : 60 minutes).

Fig. 4 Micrographs of alloy steel (a) and bronze (b) under applied load of 1500 N. and 0.041 m/s sliding speed (test duration: 60 minutes).

In addition to sliding and rolling velocities, experiments carried out on Amsler wear resting M/C showed the peripheral speed of disks is of a prime importance in dictating the final wear rate. When two disks run under rolling/sliding conditions, the wear rate of the disk running at lower peripheral speed is higher than that of the other disk, whether using like or unlike metals.

It has been observed that the wear rate is a function of a proposed speed parameter U_q rather than sliding speed U_s only, to represent different speed combinations in the form :

$$U_q = U_s (U_s + U_r) / U$$

(Where : U_r and U are the rolling and mean running speeds respectively)

The ultimate aim, however, is to develop a reliable and simple wear coefficient to estimate the wear in the sliding systems, which can be used easily and most conveniently in predicting life of engineering components

Fig.5. Variation of Bronze disk wear with time

Fig.6. Variation of the frictional work done with time

Based on the present results, it has been proposed that the speed effect should be considered together with the frictional work done (W) which comprises most of the working parameters.

By several fitting techniques and using π theorem, the following wear criterion Δ has been defined.

$$\Delta = W^{1/3} P^{2/3} U_s (U_s + U_r) / U$$

Where

- W : the frictional work done
- P : applied hertzian pressure
- U : peripheral speed
- $U_{s,r}$: sliding and rolling speeds respectively.

Consequently the wear rate (Q) should read

Fig.7 Variation of surface hardness for Bronze with applied load

Fig.8. The effect of applied pressure on the wear rate per unit travel distance.

$$Q = K (\Delta + \Delta')$$

Where K & Δ' are empirical constants to be evaluated experimentally and are defined as such :

K ... a non-dimensional wear coefficient which is a function of material combination .

Δ' ... wear criterion value at which actual wear starts.

It may be useful to define Δ' as a limiting value for transition from zero (or extremely mild) wear, to mild and severe wear conditions .

With reference to Fig. 6,7,8 the values of the coefficient K can be easily evaluated, as given in Table 3.

In a set of similar wear tests taking various material combinations including different types of steels, the results come in conformity with the proposed wear criterion formula and rendered coefficient K which is thought to be valuable in similar cases to predict wear rate in machine parts. Values of the coefficient K can be referred to in Table 4 .

Conclusions

In conclusion the following points can be drawn :

1. Wear is functionally dependent on: time, velocity, load, and

Fig.9. Wear rate variation of Bronze with proposed wear criterion under different applied loads.

coefficient of friction and material combinations.

- Results indicated that rolling, sliding, and peripheral velocities should be carefully assigned to define wear rate under rolling/sliding condition. An identification of a speed parameter ($U_q = U_s (U_s + U_r)/U$) has shown to accurately represent the type of motion affecting wear.
- Experimental results carried out on different materials combinations under different operating conditions establish a new formulation of wear equation to define a more realistic wear coefficient K . This proposed dimensionless coefficient of wear, show dependency on materials combination. Wear rate has thus shown to be in linear relation with a defined wear criterion term ($\Delta = W^{1/3} P^{2/3} U_q$). The slope of line identifies the wear coefficient K , while the wear criterion value corresponding to zero wear represent a limiting value where mild and severe wear takes place.

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Fig.10. Wear rate Variation of Bronze with proposed wear criterion. under different running distance.

Table 3. K values for Bronze on steel

Combination	r.p.m.	U_s m/s	U_q m/s	K	Remarks
Alloy steel/ Bronze	200	0.0399	0.0419	1.15×10^{-13}	different applied loads.
	400	0.0798	0.0838	2.90×10^{-13}	
Bronze/ Alloy steel	180	0.0828	0.1121	1.2×10^{-13}	different applied loads.
	360	0.1656	0.2242	1.2×10^{-13}	
Alloy steel/ Bronze	200	0.036	0.0376	1.92×10^{-13}	different travelling distances
	400	0.072	0.0752	1.00×10^{-13}	

K is evaluated based on the softer material, (Bronze).

29-31 May 1984, Cairo

Table 4. K values for different materials combinations

Combinations	r.p.m.	Us m/s	Uq	k	Kav.	Remarks
Mild steel/ Mild steel	200 180 400 360	0.042 0.084	0.044 0.049 0.088 0.098	4.17 x 10 ⁻¹³ 2.92 x 10 ⁻¹³ 5.62 x 10 ⁻¹³ 4.17 x 10 ⁻¹³	4.22 x 10 ⁻¹³	different running distances " " " "
Alloy steel/ Alloy steel	200 180 400 360 190*	0.042 0.084 0.796	0.044 0.049 0.088 0.098 0.046	1.86 x 10 ⁻¹³ 1.69 x 10 ⁻¹³ 2.6 x 10 ⁻¹³ 2.26 x 10 ⁻¹³ 1.08 x 10 ⁻¹³	1.77 x 10 ⁻¹³	" " " " different running distances (pure sliding conditions)
Alloy steel/ low carbon steel	200 400 200	0.128 0.256 0.1646	0.1434 0.2868 0.1387	1.61 x 10 ⁻¹² 1.76 x 10 ⁻¹² 4.13 x 10 ⁻¹²	2.5 x 10 ⁻¹²	different applied loads " " " " different running distances
Note k is evaluated for the softer disks (low carbon steel)						

* k is evaluated based on the average of upper and lower disks in pure sliding conditions.