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A methodology for the prediction of standard steady-state wear coefficient in an aluminium-based matrix composite reinforced with alumina particles

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Abstract: An integrated adhesive wear model was proposed and wear coefficient equations were successfully formulated by using the transient wear data obtained from pin-on-disc wear tests performed with aluminium-based matrix composites reinforced with alumina particles. A methodology was developed to predict the standard steady-state wear coefficient with its corresponding sliding distance with a F_A value of 0.99. This methodology has also the potential to save time and resources to obtain more accurate results in wear testing.

Keywords: Metal-matrix-composites (MMCs), Transient wear, Steady-state wear, Adhesive wear, Wear-coefficient.

1. INTRODUCTION

A wear volume versus distance curve can be divided into at least two regimes, the transient wear regime and the steady-state wear regime. The volume (or weight) loss is initially curvilinear and the rate of volume loss per unit sliding distance in the transient wear regime decreases until it has reached a constant value in the steady-state wear regime. Hence the standard wear coefficient value obtained from a volume loss versus distance curve is a function of the sliding distance. Due to the higher initial running-in wear rates, it has a higher value initially and will reach a steady-state value when the wear rate becomes constant. This is because the standard method to calculate the wear coefficient is to make use of the total volume loss and the total sliding distance covered [1]. This practice would also give a higher standard steady-state wear coefficient value since the higher wear rate from the transient wear is included in the computation. In order to overcome this problem, an integrated adhesive wear model was proposed in the previous studies whereby an exponential equation was used to model the transient wear; and the Archard's wear equation to model the steady-state wear [2, 3]. Two standard wear coefficient equations were developed by Yang [4, 5] for modeling the standard transient and steady state wear coefficients of an Al-Al_2O_3(P)/steel system. The first wear coefficient equation was based on the transient wear volume equation proposed by Zhang et al [6] while the second wear coefficient equation was based on the simpler exponential transient wear volume equation proposed earlier [2, 3].

Wear testing is a time consuming process, as the test has to be repeated with different sliding distance until a steady-state wear condition is achieved. Furthermore, it may also be difficult to judge whether a steady-state wear condition has actually been attained. It was found in the previous investigations [4,5] that the F_A value was a useful factor used to evaluate the wear test condition and to determine whether the steady-state wear regime had been reached. Hence different F_A values ranging from 0.99 to 0.9999 were used to study their suitability for predicting the sliding distance to achieve the steady-state wear and their steady-state wear coefficient values. It was found that the most suitable F_A value for the prediction of net standard steady-state wear coefficients was 0.999 or 0.9999 [7]. In this study, this methodology was further extended to predict the standard steady-state wear coefficient and its corresponding sliding distance as well. This is because the standard steady-state wear coefficient will have a slightly higher value as compared with the net steady-state wear coefficient. It will therefore give some extra margin of safety for wear control design and prediction purposes. Furthermore, the standard steady-state wear coefficient will also take a shorter time to measure, as the sliding distance required is shorter.

2. PREDICTION METHODOLOGY DEVELOPED IN THE PREVIOUS STUDY [7]

Both Eqs.1 and 2 were developed previously for determining standard wear coefficients [4, 5] for aluminium-based MMCs reinforced with alumina particles. However Eq.2 has only two parameters, A and B, as the other parameters such as H, P and L are known. With the use of a commercial software, the values of A and B, that is the shape of the transient curve, can be determined more accurately as all the transient data points are fully utilized to obtain the 'best-fit' curve. Hence Eq.2 will be chosen to illustrate the methodology to be used for predicting the standard steady-state wear coefficient values. For prediction purposes, Eq.2 can be re-written as shown in Eq.3, in which K_P is the predicted steady-state wear coefficient, L_P is the predicted sliding distance, and the F_A value is indicated by the term $\left[1-\exp^{-BL_P}\right]$, whose value, ranging from 0.99 to 0.9999, will be assumed in this study.

$$K_S = \frac{3Hm_A d(1-f_v)}{PLg_3 f_v}\left[1-\exp\left(\frac{-g_3 f_v L}{d(1-f_v)}\right)\right] \tag{1}$$

$$K_S = \frac{3HA}{PL}\left[1-\exp^{-BL}\right] \tag{2}$$

$$K_P = \frac{3HA}{PL_P}\left[1-\exp^{-BL_P}\right] \tag{3}$$

The F_A value depends on the sliding distance (L) used to calculate it. Hence, to obtain a F_A value of 0.99, the sliding distance ($L_{P0.99}$) can be determined from Eq.4. However, Eq.5, in which C is a constant that is equal to 4.605, 6.908 and 9.210 for an F_A value of 0.99, 0.999 and 0.9999 respectively, is the general equation that can be used to determine the predicted sliding distance L_P. By substituting Eq.5 into Eq.3, one gets Eq.6, in which D is equal to 0.215, 0.145, and 0.109 for a F_A value of 0.99, 0.999 and 0.9999 respectively. It should also be noted that D is approximately equal to 1/C.

$$L_{P0.99} = -\left[\frac{\ln(0.01)}{B}\right] = \frac{4.605}{B} \tag{4}$$

$$L_P = \left[\frac{C}{B}\right] \tag{5}$$

$$K_P = \frac{3HABD}{P} \tag{6}$$

In this study, three different F_A values, 0.99, 0.999 and 0.9999 were again selected. The respective distances $L_{P0.99}$, $L_{P0.999}$ and $L_{P0.9999}$ were determined by using Eq.5 with the respective C values. The predicted wear coefficient values, $K_{P0.99}$, $K_{P0.999}$ and $K_{P0.9999}$ were then calculated by using Eq.6 with the respective D values. By comparing the predicted values with the measured standard steady-state wear coefficient values obtained previously in [5], the best F_A value for the determination of the predicted standard steady-state wear coefficient value could be found.

3. EXPERIMENTAL METHODOLOGY USED IN THE PREVIOUS STUDIES [4, 5]

An Okuma CNC lathe with a fixture to carry a square pin holder and a pneumatic cylinder was used. A Rikadenki Type R-63 multi-pen recorder and a Kistler Type 9121 force dynamometer were used to measure the force between the pin and the disc during wear testing. Wear tests for MMC-A, MMC-B and MMC-C were carried out at distances of 250m, 500m, 1000m, 1500m, 2000m, 2500m, 3000m, 6000m, 9000m and 12000m. Both the moving pin and the conventional pin-on-disc techniques were used. A constant load of 7.5kgf, linear velocity of 4.58m/s and a feedrate of 0.05mm/rev for the moving pin technique were used. A stopwatch was used to time the cycle time. Three repetitions were carried out for each experimental treatment. The discs were made of Assab DF2 tool steel (equivalent to AISI 01) hardened and tempered to 60 HRC (697Hv). The pin materials used in this experiment were composites with A6061 as the matrix material and different nominal volume fraction of alumina particles, MMC-A with 10% alumina, MMC-B with 15% alumina and MMC-C with 20% alumina.

4. RESULTS AND DISCUSSIONS

DataFit Version 6 [9] was used to determine the constants A and B for their transient wear equations. Table 1 shows the predicted sliding distance (L_P) and the predicted wear coefficient (K_P) at different F_A values for MMC-A, MMC-B and MMC-C, estimated from data collected by both the moving-pin and the conventional pin-on-disc methods. It is obvious that the higher the F_A value, the lower is the predicted wear coefficient value. Hence the lowest K_P values are obtained with a F_A value of 0.9999. It can also be seen from the table that, to obtain a higher F_A value, the sliding distance has to be longer. However, with a known F_A value such as 0.99, 0.999 or 0.9999, it is possible to calculate the predicted sliding distance required to attain the steady-state wear regime by using Eq.5; and to obtain the predicted standard steady-state wear coefficient value by using Eq.6.

Comparisons were made between the predicted wear coefficient (K_P) with three types of K_1 (experimental measured) values: (i) the average K_1 value obtained from the steady-state wear at 6km, 9km and 12km; (ii) the lowest K_1 value obtained from the steady-state wear at the same three distances; and (iii) the K_1 value obtained by using the calculated predicted sliding distance (L_P). It was found that the average over-all deviations for $K_{P0.99}$, $K_{P0.999}$ and $K_{P0.9999}$ are respectively 17.3%, 29.7% and 46.9%. Hence $K_{P0.99}$ has given the least average deviation of about 17%. This also indicates that a F_A value of 0.99 should be used to predict the standard steady-state wear coefficient value and the required sliding distance.

Table 1.
Predicted sliding distance (L_P) and wear coefficient (K_P) at different F_A values (MMC-A, MMC-B, MMC-C)

	MMC-A		MMC-B		MMC-C	
F_A	L_P (m)	$K_P(10^{-5})$	L_P (m)	$K_P(10^{-5})$	L_P (m)	$K_P(10^{-5})$
Moving-pin method						
0.99	4920	5.5	4827	3.3	4984	2.8
0.999	7380	3.7	7241	2.2	7476	1.9
0.9999	9840	2.8	9654	1.7	9968	1.4
Conventional pin-on-disc method						
0.99	4382	6.7	6198	3.0	9594	2.9
0.999	6573	4.5	9297	2.0	14391	1.9
0.9999	8763	3.4	12396	1.5	19188	1.5

5. CONCLUDING REMARKS

The proposed methodology was found capable of predicting the sliding distance required to attain the steady-state wear regime; and the corresponding standard steady-state wear coefficient value in an Al-Al_2O_3 /steel system, by using the transient wear loss data and a F_A value of 0.99. The average deviation of the predicted wear coefficient values was found to be about 17%, as compared with the experimental measured values. The proposed methodology would therefore be able to save significant time and resources needed in the determination of standard steady-state wear coefficient values.

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