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Original Article

Effect of sliding distance on abrasive wear modes transition

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ABSTRACT

This work presents a study on the effect of sliding distance on abrasive wear modes transition in micro-abrasive wear. Ball-cratering wear tests were conducted with specimens of P20 cemented carbide (WC-Co) and M2 tool steel, balls of 52100 steel and abrasive slurry prepared with SiC particles and distilled water. Results were analyzed in terms of A_g (area with grooving abrasion) and A_r (area with rolling abrasion) as a function of sliding distance and pressure; they have indicated that with the increasing of sliding distance and, a consequent decreasing of pressure, there is the transition from grooving abrasion to rolling abrasion.

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1. Introduction

In micro-abrasive wear tests (ball-cratering wear tests), a rotating ball is forced against the tested specimen, in the presence of an abrasive slurry (Fig. 1) and the wear behavior is analyzed based on the dimensions of the crater formed during the test. This test has been applied in the study of the abrasive wear of metallic [1–4] and non-metallic [5–9] materials and, depending on the equipment configuration, it is possible to apply normal forces (N) from $N = 0.01$ N [10] to $N = 5$ N [11].

The test is usually conducted in one of two basic configurations [12]: (i) free-ball and (ii) fixed-ball. In the literature [9–11], fixed-ball equipment usually adopts dead weight systems to apply normal forces, but Cozza [13–15] developed a fixed-ball equipment where the normal force is applied by two compact modules [16], which, in theory provide a system that is stiffer than those with dead weight loading. Analysis on the results obtained with this equipment raised a question [5] on the ability of the abrasive particles to enter between the ball and the specimen as the depth of penetration (h) of the ball gradually increases (Fig. 1). Another point related to this increase in depth of penetration is the evolution of the pressure (P) throughout one of the tests. Since tests are conducted with constant normal force [1–15] and the total area of the crater gradually increases, it is possible to anticipate a variation on the pressure developed along the test, which may affect the abrasive wear modes [14].

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Nomenclature

A_g	projected area fraction with grooving abrasion (mm^2)
A_r	projected area fraction with rolling abrasion (mm^2)
A_t	total crater projected area (mm^2)
b	diameter of the wear crater (mm)
C	abrasive slurry concentration
D	diameter of the ball (mm)
E_b	Young's modulus of the ball (GPa)
E_s	Young's modulus of the specimen (GPa)
E^*	reduced Young's modulus (GPa)
h	depth of the wear crater (mm)
H	hardness (GPa) (HV)
n	ball rotational speed (rpm)
N	normal force (N)
P	pressure (MPa)
P_{Hertz}	Hertz contact pressure (MPa)
R	radius of the ball (mm)
S	sliding distance (m)
v	tangential sliding velocity (m/s)
V	volume of the wear crater (mm^3)

Greek letters

ν_b	Poisson's coefficient of the ball
ν_s	Poisson's coefficient of the specimen

Two abrasive wear modes are usually observed during micro-abrasive wear: rolling abrasion (Fig. 2a) results when the abrasive particles roll between the ball and the specimen, while grooving abrasion (Fig. 2b [14]) is observed when the abrasive particles slide on the surface of the wear crater [2,10,17].

In 2003 and 2005, Kochi Adachi and Ian M. Hutchings published two important researches [10,17] analyzing the influence of the normal force (N), abrasive slurry concentration (C) and other test parameters on abrasive wear modes transition. However, they did not consider the importance of the sliding distance (S) on this transition. Then, with the intent to collaborate with the understanding of the conditions, which cause that phenomenon, the motivation and purpose of this work is to present a study of the effect of sliding distance on abrasive wear modes transition observed in micro-abrasive wear.

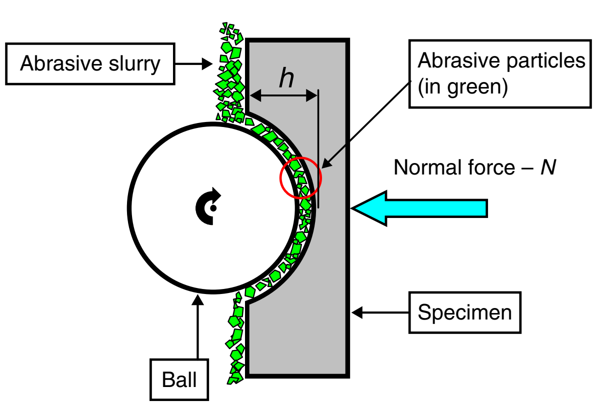

Fig. 1 – Micro-abrasive wear test: representative figure of the operating principle and the abrasive particles between the ball and the specimen.

Table 1 – Hardness of the materials used in this work.

	Material	Hardness – *H* (GPa)	(HV)
Specimens	Commercial ISO P20 cemented carbide (WC-Co)	11.7	(1193)
	AISI M2 tool steel	6.4	(652)
Ball	AISI 52100 steel	8.4	(856)
Abrasive particles	SiC	18.5–19	(1886–1937)

2. Experimental procedure

2.1. *Micro-abrasive wear equipments*

Two equipments were used in the micro-abrasive wear tests: (i) a fixed-ball configuration equipment (Fig. 3a [13,14]), which was designed and assembled with differences from commercial fixed-ball equipment [12] and (ii) a free-ball configuration equipment (Fig. 3b).

In the first case (fixed-ball mechanical configuration), balls with a hole were used and the nut shown in Fig. 3a was responsible for fixing the ball onto the shaft and transferring movement to the ball. This configuration eliminates the relative movement between the shaft and the ball and, theoretically, imposes mechanical restriction for ball movement in the direction parallel to the normal load [5,13].

2.2. *Materials*

Two materials specimens were analyzed in the micro-abrasive wear tests: commercial ISO P20 cemented carbide (WC-Co) and AISI M2 tool steel. Balls made of AISI 52100 steel were used as counterbody and presented a diameter of $D = 25.4$ mm ($D = 1''$). Fig. 4 presents the microstructures and the nominal chemical compositions of the ISO P20 cemented carbide (WC-Co) (Fig. 4a), AISI M2 tool steel (Fig. 4b) and AISI 52100 steel (Fig. 4c).

The abrasive used was black silicon carbide (SiC), from Alcoa, with average particle size of 5 μm and angular shape [18]. Fig. 5 [18] presents a scanning electron micrograph of this abrasive (Fig. 5a) and its particle size distribution (Fig. 5b). The abrasive slurry was prepared as a mixture of 25% of SiC and 75% of distilled water, by volume. This mixture results in 1.045 g of SiC per cm^3 of distilled water.

Table 1 presents the hardness (*H*) of the materials used in this work (specimens, balls and abrasive particles). To determine the hardness of the SiC, liquid-phase sintered SiC samples were tested with ten Vickers indentations (per specimen) under a load of 50 N and a loading time of 15 s [18]. With the same values of load and time adopted by Izhevskyi et al. [18] of 50 N and 15 s, respectively, the hardness of the specimens were measured; the values in Table 1 refer to an arithmetic average of three macro-hardness Vickers measurements. The hardness of the balls was obtained from the manufacturer.

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