Wear 328-329 (2015) 563–568

Contents lists available at ScienceDirect

Wear

journal homepage: www.elsevier.com/locate/wear

Effect of abrasive particle size distribution on the wear rate and wear mode in micro-scale abrasive wear tests

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ARTICLE INFO

Article history:
Received 24 December 2014
Received in revised form
16 March 2015
Accepted 18 March 2015
Available online 8 April 2015

Keywords:
Micro-scale abrasion
Particle size distribution
Wear modes
Micro-rolling abrasion

ABSTRACT

In this work, the particle size distribution of two powders was initially analyzed, indicating an approximately normal (Gaussian) distribution with average particle size on the order of 2 μm in one case and 6 μm in the other. Both powders were composed of silicon carbide (SiC) particles. The two original powders were then mixed with different mass fractions, providing a series of SiC powders that were used in micro-scale abrasive tests with fixed-ball configuration. The wear tests were conducted on ASTM 1020 carbon steel and results were analyzed in terms of wear rate as well as wear mode (“rolling abrasion” or “grooving abrasion”). Results have indicated that the mass fraction of the original powders has a significant effect on the wear modes observed at the micro-scale level and that the wear rate does not follow a direct relationship with the mass fraction of the powder with larger average particle size.

1. Introduction

In micro-scale abrasion wear tests, a normal load forces the specimen against a sphere in the presence of an abrasive slurry and wear is analyzed based on the evolution of the diameter of the worn crater as a function of time [1–3]. This type of test is conducted with abrasives with average particle size usually below 10 μm, which, in addition to the selected normal loads, make this type of abrasive test suitable for the analysis of small volumes.

Many works have been dedicated not only to the use of micro-abrasive wear tests in the tribological analysis of engineering materials, but also to a better understanding of the test itself. One of the key issues in this test is the identification of the wear modes at the specimen, which are usually classified into grooving abrasion and rolling abrasion [4–9]. Grooving abrasion refers to the condition in which the abrasive particles slide against the specimen, while rolling abrasion is the wear mode associated with the rolling of the particles in the gap between the sphere and the specimen. Both modes can occur simultaneously and, depending on the test conditions, grooving abrasion may be observed in one area of the worn crater and rolling abrasion in another [4–9]. Moreover, Cozza et al. [10] have defined ‘micro-rolling abrasion’ as a localized mixture of both wear modes, namely for the case where particles rolled along grooves formed previously.

Several wear mode studies are based on the mechanics of particle motion. More specifically, loads and constraints at an abrasive particle are evaluated in order to understand the conditions that would result in its rotation in the gap between the two bodies in contact [4–6,11,12]. Following these ideas, Adachi and Hutchings [4,5] developed a wear mode map for micro-abrasive wear tests, in which it is possible to predict the occurrence of grooving or rolling abrasion based on (i) the ratio between the hardness of the specimen H_s and the hardness of the sphere H_b and (ii) a parameter called severity of contact, which depends on the applied load W, the interaction area A and the volume fraction of abrasive particles υ, as well as H_s and H_b. This map reflects the tendency for grooving abrasion to increase as the separation h between the surface of the specimen and the surface of the ball decreases, or, in other words, as the severity of contact increases. According to those authors [4,5], separation could be calculated based on Eq. (1), in which, besides the terms previously defined, c is a constant of proportionality and H' is dependent only on H_s and H_b. This model was defined assuming spherical abrasive particles with diameter D.

$$h = D\left(1 - \frac{2W}{Ac\upsilon H'}\right) \quad (1)$$

More recently, some works in the literature [7,9,13] have highlighted the fact that the severity of contact may decrease during a given micro-abrasive test, due to the fact that tests conducted with constant normal load are associated with a continuous decrease in contact pressure due to the increase in crater

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http://dx.doi.org/10.1016/j.wear.2015.03.015
0043-1648/

area. Lower contact pressures are associated with lower forces applied to each particle.

The transition between grooving and rolling abrasion was also analyzed by Trezona et al. [6], considering the effect of the parameters selected during micro-abrasive tests. In particular, those authors studied the effect of load, slurry concentration and abrasive material. A nonlinear behavior was observed when wear volume was plotted as a function of the volume fraction of abrasive particles, i.e. as a function of slurry concentration. In this case, maxima in wear volume were observed in curves obtained for different normal loads. Furthermore, at low slurry concentrations, similar wear volumes were obtained for three applied normal loads and a continuous decrease in wear volume with the decrease in the volume fraction of abrasive particles was observed at this portion of the graph.

Despite the significant amount of work dedicated to the study of the wear rates and modes in micro-abrasive wear tests, most of the analyses conducted so far are based on the average value of a given particle size distribution. Thus, at this point, it is not clear if the wear rate in micro-abrasive tests may be affected by the particle size distribution. Similar questionings are possible in terms of the wear modes, including the possibility of considering particle size distribution as one of the reasons for micro-rolling abrasion.

In this work, micro-abrasive tests were conducted with different silicon carbide powders, in order to evaluate the effects of particle size distribution. Each powder was prepared by mixing different mass fractions of two original powders, one with average particle size of 2 μm and another with average particle size of 6 μm.

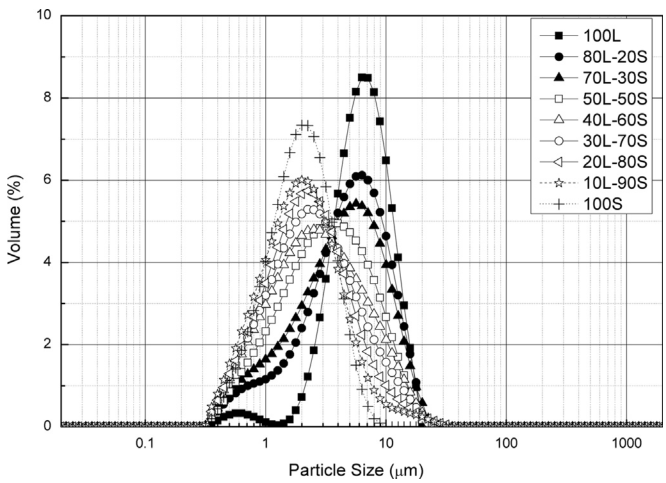

Fig.1. Particle size distribution of the SiC powders.

Table 1
Mass fraction and average particle size of SiC powders.

SiC powder	Mass fraction of the original powders	Average particle size (μm)
0L(or 100S)	100% Small	2.1
10L	90% Small and 10% large	2.6
20L	80% Small and 20% large	3.0
30L	70% Small and 30% large	3.3
40L	60% Small and 40% large	3.7
50L	50% Small and 50% large	4.1
70L	30% Small and 70% large	5.1
80L	20% Small and 80% large	5.4
100L	100% Large	6.6

Table 2
Parameters selected during the micro-scale abrasive wear tests.

Rotation speed of the sphere	150 rpm
Normal loads	0.2 or 0.4 N
Sliding distance	239.4 m
Abrasive concentration	0.1 g/cm^3
Abrasive slurry supply	1 Drop every 3 s

2. Experimental procedure

Micro-abrasive wear tests were conducted in a test rig with fixed-ball configuration (TE 66 from Plint and Partners, Wokingham, UK). The sphere had a diameter of 25.4 mm and was made of AISI 52100 steel. The specimens were manufactured on ASTM 1020 carbon steel, presenting a testing area of 30×30 mm^2. Prior to the tests, all specimens were sanded up to 1200 SiC paper, followed by polishing to a mirror finish with 1 μm alumina paste.

In order to prepare the abrasive slurries, the silicon carbide (SiC) powders with particle size distributions indicated as 100S and 100L in Fig. 1 were initially considered. One of these powders (100S – small) presented an average particle size of 2 μm and the other (100L – large) of 6 μm. Both original powders were mixed with different mass fractions, as indicated in Table 1, providing powders with average particle sizes indicated in Table 1 and particle size distributions shown in Fig. 1. Micro-abrasive tests were conducted with slurries prepared with the powders in Table 1 and Fig. 1 and distilled water, always with a slurry concentration of 0.1 g/cm^3. Table 2 presents other parameters selected during all tests. Three repetitions were conducted for each condition and the entire duration of each test was 20 min (or 300 rotations of the sphere). The worn crater

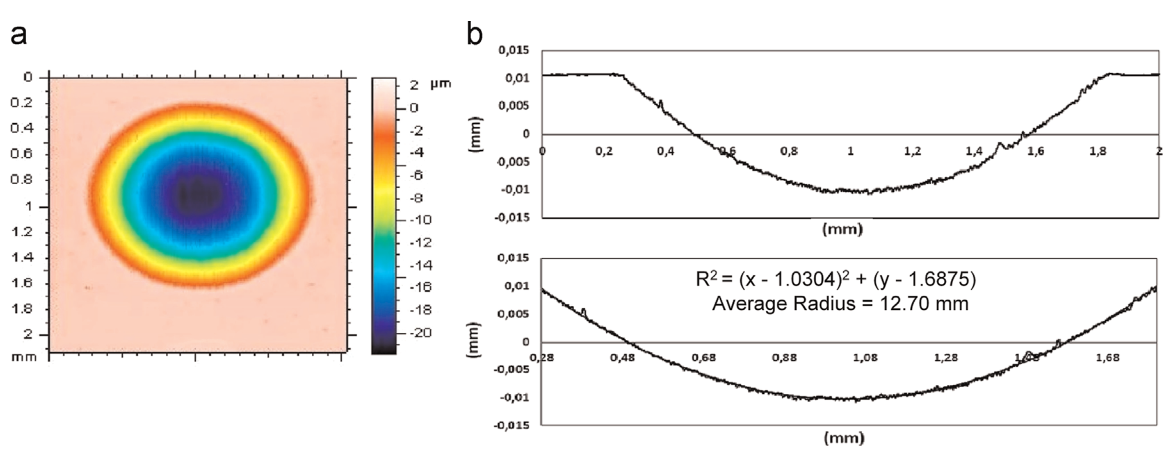

Fig.2. Profilometry analysis of the wear crater obtained with powder 100L and 0.2 N: (a) three-dimensional height data and (b) profile in the center of the crater and crater radius.