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Effect of surface topography on the dynamics of the abrasive particles during micro-abrasion ☆

H.L. Costa *, M.A.N. Ardila, W.S. Labiapari, W.M. Silva, J.D.B. de Mello

Laboratório de Tribologia e Materiais, Universidade Federal de Uberlândia, Uberlandia, MG Brazil

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ABSTRACT

During abrasive wear, the wear mechanism has been shown to be associated with the movement of the active particles present at the wear interface: rolling, evidenced by indentations on the worn surface, and sliding, which produces scratching and/or ploughing. Particle dynamics can vary with tribological parameters such as different combinations of ball and specimen materials, applied load, slurry concentration, abrasive material, ball condition and equipment configuration (fixed or free-ball). In this article, the effect of surface topography of both the ball and the specimen on the dynamics of the abrasive particles and micro-abrasion wear is investigated for SiO_2 abrasive particles. The effect of the ball surface topography was investigated using a fixed-ball rig, zirconia balls (S_a=0.06, 0.34, and 0.54 μm) and stainless steel specimens (S_a=0.10 μm). When the roughness of the ball increased, the wear mechanism changed from sliding to mixed and then to rolling and the micro abrasion coefficient k increased substantially, the difference between the smoothest and the roughest ball being around 510%. The effect of the specimen surface topography was investigated using a free-ball rig, AISI 52100 steel balls (S_a=0.82 μm) and tool steel specimens (S_q=0.025 μm and 0.414 μm). The influence of the directionality of the specimen surface finish was also analyzed by conducting tests parallel and perpendicular to the grinding marks using three slurry concentrations. The effect of the topography of the specimens on wear coefficients and mechanisms was much less pronounced than that found for the ball topography. For the highest slurry concentration (20 wt%), k increased for the rougher specimens (around 23%) and a slight change in mechanism occurred from mixed (sliding in the center and rolling at borders of craters), to sliding. This effect was less significant for lower concentrations. The influence of surface directionality on abrasive wear was negligible.

1. Introduction

Micro-abrasion tests, also known as ball-cratering tests, have been used for over twenty years. They were originally proposed to characterize the intrinsic mechanical quality of thin coatings when a commercial dimple grinder, conventionally used in thinning of transmission electron microscopy (TEM) samples, was adapted to grind craters into the surfaces of coating/substrate composites [1]. Later, a rotating sphere apparatus [2] was proposed, which is today commercially available and widely used. In the free-ball version, the ball rotates freely driven by friction at the contact with a notched drive shaft. The normal load results from the weight of the ball resting on the test sample, which can be varied by changing the dimensions and material of the ball and/or by altering the angle of the sample holding plate, and depends on the friction coefficient between the ball and the test surface. In the fixed-ball version, the ball is driven directly by clamping the ball in a split drive shaft and the sample is loaded against the ball with the desired normal force by a lever arm arrangement. This version allows a much wider range of normal loads to be used [3].

Microabrasion wear mechanisms and wear coefficients can vary significantly with the operating conditions used in the tests [4–7]. Grooving wear mechanism occurs when a significant proportion of the abrasive particles embed in the surface of the ball and slide acting as fixed indenters, producing a series of fine parallel grooves in the specimen surface. A rolling mechanism is produced when the abrasive particles do not embed, but roll between the two surfaces, producing a heavily deformed, multiply indented surface, with no surface directionality. A mixed mechanism may also occur, producing grooving in the center and three-body rolling at the edges of the wear craters [4,5].

A model proposed by Williams and Hyncica [8] shows that an abrasive particle between two surfaces undergoes a transition from rolling to grooving at a critical value D/h, where D is the particle major axis and h is the separation of the surfaces. When D/h is only

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* Corresponding author. Tel.: +55 34 3239 4036.
E-mail address: ltm-henara@ufu.br (H.L. Costa).

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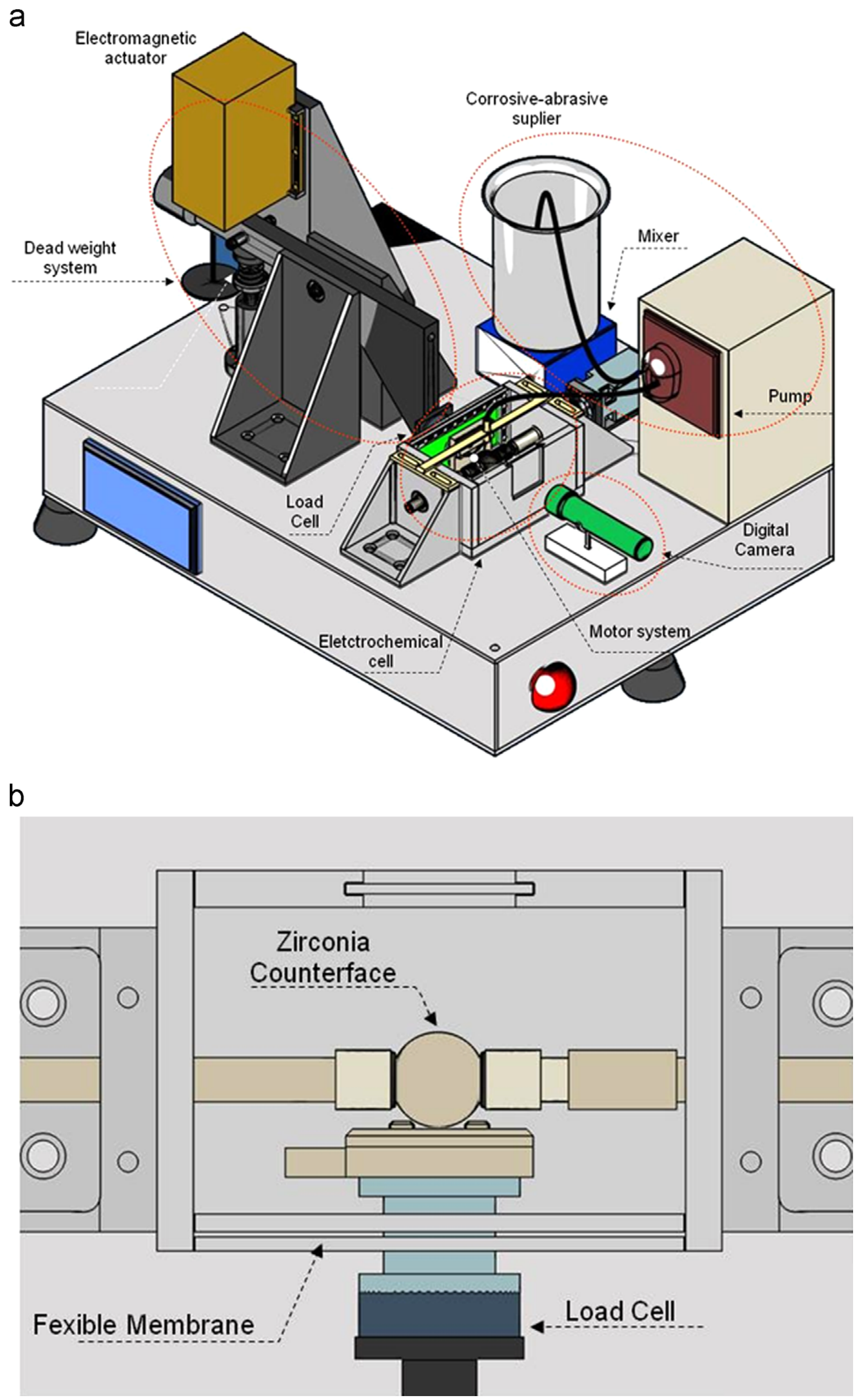

Fig. 1. Test rig details: (a) General view; (b) setup for force measurements.

Table 1
Chemical composition and Vickers hardness (4.9 N, 30 s) of the specimens to evaluate effect of ball topography.

Steel	Chemical Composition [wt%]					Hardness [GPa]
	C	Mn	Cr	Ni	Nb	
AISI 304	0.055	1.15	18.28	8.01	0.01	1.99

slightly larger than 1, the particle indents both surfaces. As there is a similar indentation occurring at the opposite corner of the particle, the two forces acting on the particle, which will not generally be collinear, form a couple tending to rotate the particle. This produces multiple indentations on the surfaces. However, when *D*/*h* increases, the particle initially rotates until eventually the two forces acting on it become collinear. When this happens, there is no impetus to cause further rotation and so the particle will tend to remain at this inclination, producing grooves on the surface. Other authors have adapted this model to associate the transition between the two mechanisms to changes in the severity of the contact. An initial model by Trezona et al. [4] suggests the transition to occur for a certain ratio of normal load to volume fraction of abrasives in the slurry, which varies depending on the type of abrasive. If the contact contains many particles under a low load,