



Effect of debris size on the reciprocating sliding wear of aluminium



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ABSTRACT

The literature is controversial in relation to the influence of wear debris on tribological behaviour. Some works have shown that the presence of debris is fundamental to the formation of a protective tribolayer, thus reducing friction, whereas others showed that the presence of wear debris could contribute to increase friction coefficient due to the energy spent dragging them into the contact. This work aims to study the influence of the presence of wear debris, simulated by Al_2O_3 particles, on the tribological behaviour of an aluminium-steel pair under reciprocating sliding contact. Special emphasis is given to the particle size (0.05 μm , 0.1 μm , 1 μm and 10 μm). The particles were dispersed in distilled water (2 wt.%) as the source of debris. Reference tests were carried out solely in the presence of distilled water. The addition of alumina particles contributed to a significant reduction in friction coefficient, in particular for the largest particles (diameter $\phi=10 \mu\text{m}$). When the larger particles were added, it was possible to observe the formation of a tribolayer on the sample surface leading to a gain of mass. In opposition, the wear rate of the counter body increased when large particles were added and the wear tracks showed strong evidence of abrasive wear. This suggests that hard and large wear debris, incorporated in the tribolayer formed on the samples, can act as hard protuberances, leading to abrasive wear of the counterbodies. When small particles were added, friction was still reduced when compared with the reference test, but the reduction of the friction coefficient was less significant. Small particles reduced the steel counter body wear rate and did not affect significantly the wear rate of the aluminium samples. It is proposed that small debris can get entrapped in the surface irregularities of the specimens and therefore participate less in the formation of the tribolayers.

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1. Introduction

The rubbing of two surfaces leads to the formation of wear particles, or debris, where some are removed from the contact after their genesis, but some stay in the contact and retransformed by further sliding, modifying contact stresses because they act as load-bearing areas and affecting the formation of protective tribolayers [1]. For that reason, the genesis and role of wear debris on the tribological behaviour of moving surfaces in contact has been in focus for many years [2].

Blau [3] distinguishes between two types of debris: passive debris, which are removed from the contact zone immediately after genesis and are larger in size; and active debris, which have further involvement in the wear phenomena and are substantially smaller.

In particular, the relevance of the presence of wear debris in the contact has been investigated in the case of fretting wear

conditions [4], since during fretting the amount of active debris that remain in the contact is substantially larger than under normal sliding conditions.

However, the role of the debris on tribological performance has been reported as both beneficial and deleterious in the literature. As an example of deleterious effects, in lubricated systems, the contamination of the lubrication oil is generally regarded as detrimental, where friction increases due to the force necessary to drag the particles into the contact and wear can increase mostly due to ploughing action of the wear debris [5], in particular in the case of rolling elements [6,7]. The presence of wear debris can also cause blocking of the lubrication system and form a type of “pollution” when mixed with the lubricant oil that can affect negatively the downstream performance of some manufacturing processes, such as the cold rolling of stainless steels strips [8].

Under dry sliding conditions, negative effects of wear debris have also been claimed. During sliding of a Cu-Zn alloy, monitoring of friction coefficient with time showed a sharp friction transition (from 0.35 to 1.1), which coincided with the detection of debris around the contact. This was attributed to a transition from sliding wear to three-body abrasive wear as a large amount of debris accumulated in the contact [3]. A similar analysis was proposed for

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dry wear tests of steels [9]. In those tests, intentional removal of wear debris from the contact was carried out by a felt wheel, so that wear debris removal occurred at periodical distances of 30 m. They observed that the periodical removal of wear debris caused periodic abrupt fall in friction coefficient, which were attributed to a possible abrasive action of the wear debris.

In another work regarding the effect of debris on wear behaviour of various ceramics (silicon carbide, SiAlON, alumina and partially stabilized zirconia), dry and lubricated tests were conducted, based on the premise that the dry tests favour entrapment of debris within the sliding contact and that lubricated tests help the debris to escape from the contact [10]. They found that conditions that favoured debris elimination from the contact, which were the use of a liquid flow (water and lubricant oil) and the use of very high sliding speeds led to considerably lower friction and wear. They attributed this to the fact that wear debris may act as abrasive particles. However, they did not consider the effects of the sliding speed and the presence of water on possible tribochemical reactions that could be involved in the wear process.

In some works, the role of debris have been found to be both beneficial and deleterious, depending on the tribological conditions. For example, for a gray cast iron/alumina pair, when air flow was used to remove wear debris from the contact, the wear coefficient reduced when the debris were removed under dry conditions, which was explained by the abrasive role of the debris [11]. However, under high humidity conditions, the removal of wear debris increased wear. In another work, for an alumina-zirconia ceramic composite, wear debris were thoroughly characterized and their impact on friction and wear was analysed [12]. The authors proposed various mechanisms to occur due the debris found. Very small alumina debris underwent tribochemical reactions forming aluminium hydroxides and alumina. Under low contact pressure conditions, the debris resulted in a beneficial effect. Zirconia debris were transformed from tetragonal to monoclinic due to the contact stresses. The debris agglomerated and formed a continuous and smooth tribolayer and surface porosity was drastically reduced. However, under high contact pressure conditions, where chipping wear prevailed, debris had both positive and negative effects. In some cases, the plastic deformation of the zirconia debris absorbed most of the input energy, reducing the energy available for microcracking to occur and the spherical alumina debris distributed the stresses resulting in bearing action. On the other hand, sometimes freshly formed alumina debris had irregular and sharp shapes and acted as free abrasive particles, increasing friction and wear.

In a review on the genesis and role of wear debris on the tribology of ceramics, Fisher et al. [1] point out the main differences in relation to metals. Regarding the formation of debris, it mainly occurs involving fracture on different scales. After their genesis, they are strongly fractured and comminuted into a very fine powder. Without humidity, those very fine debris have little effect on wear. With humidity, tribochemical reactions lead to the formation of compact layers, which sometimes, but not always (depending on its nature and morphology) can reduce friction and wear.

When investigating the role of wear debris and transfer films on the tribological behaviour of Ni-Co electrodeposits, it was found a negligible effect of oxidized wear debris. It was proposed that the amount of debris was insufficient to separate the two sliding surfaces and did not result in the formation of effective tribolayers [13].

However, the literature is abundant in works where the presence of wear debris in the tribological contact improves tribological performance. One pioneering work carried out by Halliday and Hirst [14] showed how the removal of wear debris from a fretting contact resulted in a drastic increase in friction. The

authors claimed that while in the contact the debris could act as micro bearings, reducing friction.

One work investigated the role of debris on the tribological behaviour of polytetrafluorethylene (PTFE) composites [15]. They varied the amount of debris available in the contact by varying the surface topography of the counterbody, in particular the alignment of parallel grooves on the surface, based on the premise that grooves parallel to sliding would remove debris from the contact. A substantial wear reduction was found when the grooves were aligned perpendicular to the sliding direction. They postulated that the retention of transferred material and the recirculation of debris are necessary for the formation of a uniform protective transfer film on the metal counterbody.

Another interesting way of assessing the positive effect of debris was by changing the geometry of the pins used in pin-on-disk tests of tool steels. With curved pins, recirculation of the debris was claimed to occur, contributing to the formation of a protective tribolayer. On the other hand, for flat-ended pins, all debris ejected from the contact were definitively lost and no protective tribolayer was formed [16].

Some works also analysed the effect of debris on tribological performance by adding debris particles before the tests. In the important work by Iwabuchi et al. [17], iron oxide particles were added during dry sliding of carbon steels to simulate the effect of debris on friction and wear. They found that in the presence of iron oxide particles the time necessary to achieve a steady-state wear regime was substantially reduced, besides a reduction in wear within the steady-state region. However, they could not find a correlation between the specimen roughness and the reductions in wear rates. In Kato's work [18], similar reductions in the running-in period and wear rates were found. Also, they found that fine particles were more effective to promote the transition to mild wear, in particular for particles with diameters between 0.5 and 1 μm . However, they did not correlate the size of the debris used with the surface topography of the sliding surfaces.

For the sliding wear of aluminium, wear debris have been thoroughly characterized by Rigney's group [19] in terms of structure and chemical composition both experimentally and by quantum molecular simulations. They found that the wear debris are not merely composed of Al_2O_3 , but instead consist partly of an aluminium-oxygen solid solution and partly of hydroxylated material.

This work aims to study the influence of the presence of wear debris on the tribological behaviour of aluminium. For that, Al_2O_3 particles are dispersed in distilled water, in order to simulate the intense hydration of the wear debris observed in [19]. This work also aims to investigate how the size of the debris and its correlation with the surface topography of the surfaces in contact affect the tribochemical processes involved during sliding and, therefore, tribological performance.

2. Materials and methods

The material of the specimens used in this work was a commercial aluminium alloy with the chemical composition shown in Table 1. The chemical analysis was performed using different equipment to improve the precision of the results. Carbon (C) was detected by Infrared Absorption in a Leco CS444[®] equipment,

Table 1
Chemical composition of the aluminium specimens.

C	N	Al	Ti	Cu	Fe	Si	Zn	Mn
0.0015	0.0032	98.6	0.032	0.018	0.202	0.77	0.009	0.355

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