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## Early stages of sliding wear behaviour of Al<sub>2</sub>O<sub>3</sub> and SiC reinforced aluminium

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### ABSTRACT

Al matrix composites reinforced by 10 vol.% Al<sub>2</sub>O<sub>3</sub> and SiC particles were subjected to dry sliding tests against steel using a slider-on-cylinder tribometer. Damage mechanisms were 'micro-machining' of the steel carried out by ceramic particles, plastic deformation and oxidation of the metal matrix, as well as abrasion. The results were discussed on the basis of the third-body wear model.

### INTRODUCTION

Aluminum metal matrix composites (MMCs) are attractive materials in the mechanical, automotive and aerospace industry, mainly for their light weight, thermal conductivity and energy efficiency, and more recently for their wear-resistant properties. The latter, makes the collection of data on the friction and wear behaviour of these materials very important. Sliding wear of aluminium matrix composites is generally studied using iron alloys as countermaterials. For a good approach to the phenomena occurring in dry sliding of these couples, it is important to investigate not only the effects of different values of load and speed [1-6], but also the early stages of sliding [7,8]. The study of microstructural parameters and mechanisms involved for very short sliding distances, allows a better definition of the selection criteria for materials to be coupled with Al-matrix composites.

### EXPERIMENTAL

Al-matrix composites reinforced with 10% volume fractions of Al<sub>2</sub>O<sub>3</sub> and SiC particles (average size about 13 µm) were produced through powder metallurgy techniques, hot extruded and then subjected to unidirectional dry sliding tests against an AISI 1060 carbon steel heat-treated to 60 HRC hardness. A typical microstructure of the composites is shown in Figure 1; the HV<sub>0.2</sub> microhardness values for the Al<sub>2</sub>O<sub>3</sub> and SiC reinforced composites were 0.43 and 0.41 (± 0.02 kN/mm<sup>2</sup>), respectively.

The sliding tests were carried out using a slider-on-cylinder tribometer, on 20x5x2.5 mm specimens cut normally to the extrusion direction, surface finished with emery papers up to 1200 grit and lapped with 0.25 µm diamond paste. The testing conditions were 5 N normal load, 0.3 m/s sliding speed, room temperature, laboratory air (relative humidity 50-70%), for various sliding distances (0.5, 1, 2, 10 and 20 m). Friction coefficients were continuously recorded as a function of sliding distance.

Morphology and surface chemistry of wear tracks were investigated by means of optical (OM) and scanning electron microscopy (SEM), and electron probe energy dispersive X-ray microanalysis (EDS).

### RESULTS AND DISCUSSION

Figure 2 shows curves of friction coefficients vs. sliding distance for the composite-steel couples. For both composites, the same steady-state value of the friction coefficient (about 1.6) was reached after about 8 m of sliding. The transient parts of the curves, however, were different, the friction coefficient being higher for the Al-Al<sub>2</sub>O<sub>3</sub> composite. These results outline the importance of investigating the early

stages of sliding in order to understand (i) the role of the microstructures, and (ii) the damage mechanisms involved. For comparison, the curves for the same composites sliding against a hard ceramic material are shown in Figure 2.

When the tests were stopped after only 0.5 m of sliding distance, SEM observations showed effects of a 'micro-machining' action on the steel cylinder. According to results reported in literature for higher sliding distances [7, 8], these effects were attributed to abrasive processes carried out by the reinforcing particles. In particular, an iron transfer process occurred from the steel surface into the third body, i.e. the intermediate material whose flow accommodates the velocity differences between the two first bodies (composite and steel) [9,10]. As shown by SEM observations and X-ray maps, the iron fragments were transferred in the form of flakes. Figure 3 shows the presence of iron 'filings' on the Al-SiC composite surface after 0.5 m of sliding. For the same sliding distance, a packing down of such 'filings' was observed on the Al<sub>2</sub>O<sub>3</sub> composite (Fig.4), indicating that the wear of this composite reached a more severe stage. For the SiC reinforced material, this stage was evident after 10 m of sliding (Fig.5). These results are in agreement with those reported by Pan et al. [7,11], who found an iron transfer four times larger for Al-Al<sub>2</sub>O<sub>3</sub> than for Al-SiC 15%vol. composites sliding against an AISI 52100 steel, under lubricated conditions. This difference was attributed to tribochemical reactions between Al<sub>2</sub>O<sub>3</sub> and steel [11]. In all cases the above described packing effects were also observed at the outer sides of the wear tracks, where the damage was lower.

For longer sliding distances, considerable amounts of aluminium and iron oxides were detected as components of the third body. On the oxidized regions observed within the wear tracks produced on the composites, the steel 'filings' displayed a compacted morphology, crack formation (Fig.6), while the reinforcing particles appeared fully fragmented.

In conclusion, a similar damage micro-machining mechanism of the rotating steel cylinder, followed by (i) iron fragments transfer and compacting within the third-body, and (ii) iron and aluminum oxidation, was observed for both Al-Al<sub>2</sub>O<sub>3</sub> and Al-SiC composites sliding against the same steel. The type of reinforcement significantly affected the rate by which the composition of the third-body changed until it reached a steady condition. This was mainly because of transfer and oxidation phenomena of iron and aluminium, and insertion of fragments of reinforcing particles.

The choice of steel as the countermaterial can considerably complicate the study of friction and wear behaviour of Al matrix composites under dry sliding conditions, mainly because of iron transfer and oxidation processes occurring from the early stages of sliding.

## CONCLUSIONS

The following conclusions can be drawn from the dry sliding tests carried out, when coupling stationary sliders of SiC and Al<sub>2</sub>O<sub>3</sub> reinforced aluminium against rotating cylinders of surface hardened steel:

- (1) The first mechanism of damage is a 'micro-machining' action caused by the reinforcing ceramic particles (both Al<sub>2</sub>O<sub>3</sub> and SiC) on the steel counterface, starting from the early stages of sliding. Fragments of iron in the form of 'filings' are transferred into the third-bodies, separating partly or fully the composites from the steel. While undergoing oxidation, these fragments are subsequently compacted into flakes.
- (2) Damage mechanisms of composites involve plastic deformation and oxidation of the Al matrix, with insertion of Al fragments and Al<sub>2</sub>O<sub>3</sub> particles (along with fragments of the reinforcing particles) in the third-bodies. In this way, the abrasive power of the third-bodies increases considerably.
- (3) For both composites, the friction coefficient against steel increases up to a steady-state value of 1.6 after about 8 m of sliding, when the flow properties of the third-bodies become comparable. The transient parts of the friction coefficient vs distance curves are indicative of a tribo-reactivity towards steel being higher for Al<sub>2</sub>O<sub>3</sub> than for SiC reinforcing particles.

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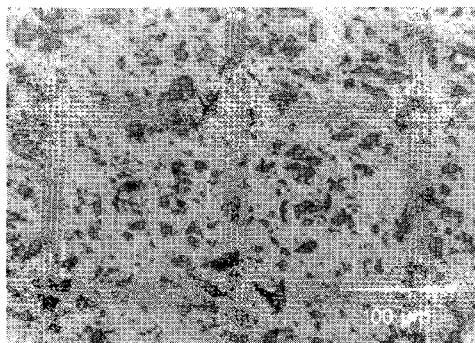


Fig.1 - Microstructure (OM) of the Al-Al<sub>2</sub>O<sub>3</sub> composite.

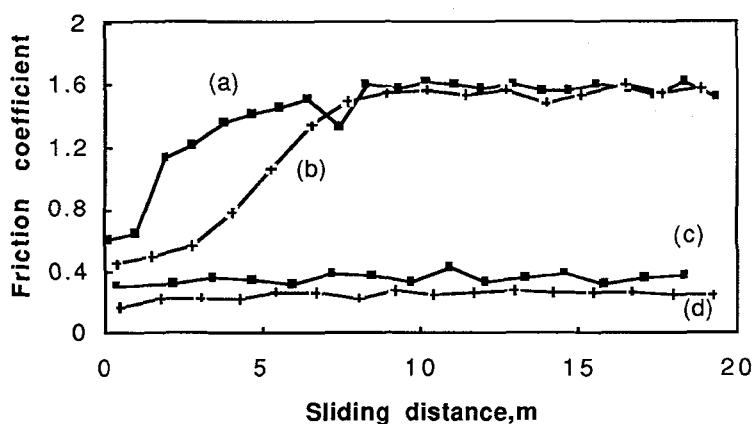


Fig. 2 - Friction coefficient vs sliding distance curves: (a) Al-Al<sub>2</sub>O<sub>3</sub>/steel; (b) Al-SiC/steel; (c) Al-Al<sub>2</sub>O<sub>3</sub>/ceramic; (d) Al-SiC/ceramic.

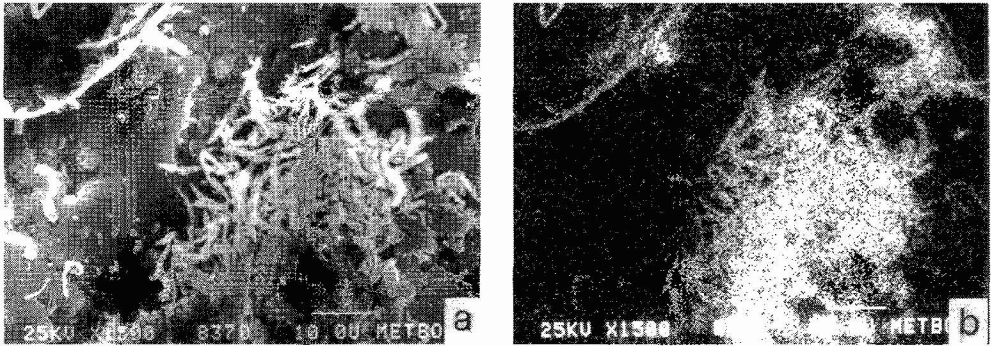


Fig. 3 - SEM micrograph (a) and FeK $\alpha$  X-ray map (b) of the Al-SiC composite after 0.5 m of sliding against steel.

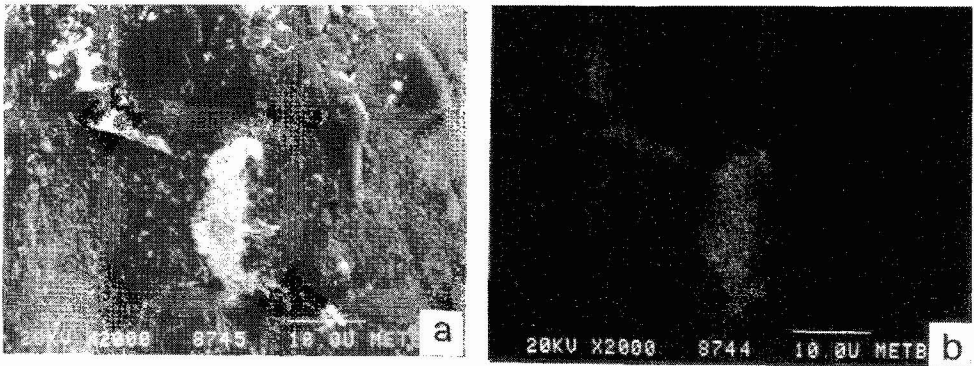


Fig. 4 - SEM micrograph (a) and FeK $\alpha$  X-ray map (b) of the Al-Al<sub>2</sub>O<sub>3</sub> composite after 0.5 m of sliding against steel.

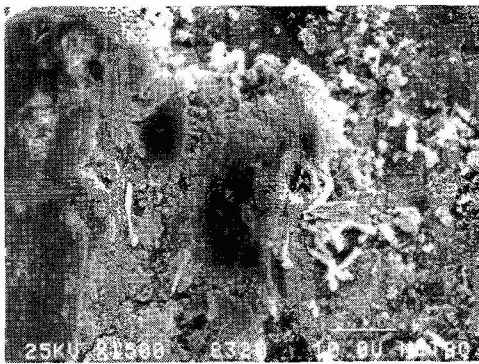


Fig. 5 - SEM micrograph of the Al-SiC composite after 10 m of sliding against steel.

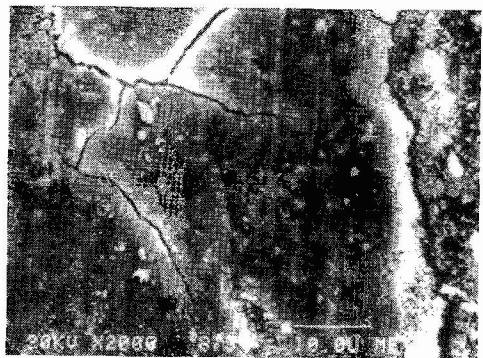


Fig. 6 - SEM micrograph of the Al-Al<sub>2</sub>O<sub>3</sub> composite after 20 m of sliding against steel.