Detection of wear mechanism by friction coefficient variation in mixed lubrication conditions

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Abstract  

Lubricated friction and wear tests were carried out in an Optimol SRV device, using a high pressure cylinder in disk contact. Disk samples were 100Cr6 steel and SAE 1045 steel coated with: Ni-Mo-Al by plasma and flame spraying, Ni, Ni20Co80 and Cr by electroplating. The relation between the variation in time of friction coefficient \( \mu \) and the surface morphology was studied and the possible wear mode inferred.

Key words: friction coefficient, wear, adhesion, abrasion, metallic coatings.

Results and Discussion  

During the wear tests carried out with steel and coated samples, different patterns of \( \mu \)-time diagrams were recorded. The three principal patterns are presented in Fig. 1.

It is worth to note that the different \( \mu \)-time traces patterns randomly appeared in similar wear test conditions, and no evident relation could be established between these patterns and test parameters such as: temperature, contact pressure, metallurgical characteristics of samples and/or formulation of the oils. Nevertheless, morphological studies carried out on 94 from 227 tested samples showed, in all the cases, marked relations between wear scar surface topography and the patterns of the corresponding \( \mu \)-time traces (1, 3, 4).

Free-of-peaks \( \mu \)-time diagrams  
Polished wear scars, free of surface fracture evidences were observed in the test samples were \( \mu \) was low and constant or with slow variations. In the most of the cases, the quasi constant \( \mu \)-time traces and polished surfaces were...
related with low wear intensity. In all samples characterized by constant \( \mu \)-low wear, either steel made or coated, evidences supporting the theory of a partially adhesive-lubricated wear process were found.

Direct evidences on the metal transfer by adhesion were given by the EDX analysis of the worn surfaces of relatively hard coatings, i.e. Ni-Mo-Al sprayed deposits and Cr plated coatings. In these cases, a sensible amount of iron was found, probably produced by the transfer of the cylinder material on the coated disc surface. Beside, it was observed the preferential fluid attack (erosion-corrosion) in the pre-existing discontinuities, i.e. "hair-line" micro-cracking in hard chromium and inter-connected pores in sprayed deposits.

When the tests were performed with steel samples, the two bodies in contact had similar metallurgical characteristics. Therefore, direct evidences on adhesive wear were not obtained by the experimental techniques used in the present work. However, the presence of this wear mode is supposed based on relation between chemical and morphological features of the surface. On the wear scars, nonmetallic deposits rich in iron sulfides, probably corresponding to the nucleation sites of the additive reaction film were detected by AES and DIO; they are supposed to be statistically coincident with the adhesive junctions, due to similarity between thermodynamic conditions required for both processes (adhesion and additive film nucleation). Also, in some steel samples, fluid attack (erosion-corrosion) was observed in reduced areas on the borders of the wear scars, where contact pressure is lower than in the center, therefore, metal-metal contact is less probable.

Transitory Peaks in \( \mu \)-Time Diagrams

Transitory peaks in the \( \mu \)-time traces were recorded during 26 tests with steel and coatings of sprayed Ni-Mo-Al and electroplated Cr; a typical pattern of the m-time diagram is shown in Fig. 1b. The analyses by SEM of the corresponding samples showed in all the cases, severe metal damage, probably produced by transitory rupture and restoration of lubricant film during running-in or steady-state, which induced metal-metal contact reflected in high \( \mu \) values.

Steel samples presented polished abrasive grooves alternating with rough areas (Fig. 2). The latter, more extensive in the center of the scar, are probably fracture surface by delamination. The fracture surfaces appears to cover a greater area when initial peaks are higher, more extensive and/or more frequent in time. Abrasion grooves were also observed in the Ni-Mo-Al sprayed coatings and Cr hard plating where \( \mu \)-peaks were recorded. For these coatings, \( m \)-peaks and abrasion marks tended to be more frequent at higher loads, producing plastically impressed grooves on the surface already modified by preferential fluid attack in discontinuities.

Oscillating \( \mu \), tending to stabilize in upper values

For the relatively soft coatings of Ni and Ni-Co the mean values of the friction coefficient were much higher than in the former cases, variation between 0.3 and 0.5 being recorded. At low normal loads, a great diversity of \( \mu \)-variation pattern was found. Increasing the load, after such
initial oscillations, a high and constant $\mu$ value tended to stabilize during large time intervals; in some cases this value was reached and kept almost constant during the whole test.

The morphological analysis of the corresponding samples showed that, even at the lowest loads, large volumes of material were detached from the coating and adhered on the cylinder surface, indicating near seizure conditions. Due to the reciprocal movement of the cylinder, the adhered material appeared distributed in a relatively regular form; also rounded debris frequently appeared on both surfaces (Fig. 3). At higher loads the adhesion on the major contact area is expected and the friction coefficient probably reflects the almost uniform shear stress of the softer material.

### Figura 2.
Abrasion on the steel sample corresponding to $\mu$-time trace in Fig. 1b. SEM, 1200X.

### Figura 3.
Ni-Co transfer on the steel cylinder (near-seizure condition). SEM, 1000X.

**Conclusion**

In reciprocal sliding wear tests, using lubricated high pressure contacts (cylinder on disk), the variation pattern of the friction coefficient appears to give reliable information about the dominant wear mode. Low constant values of friction coefficient appears to reflect a mixed lubrication and adhesive mechanism. Slow increments of m-values during running-in stage, associated with smooth but deep wear scar possibly reflects a corrosion enhanced wear process. High transitory peaks which appears in $\mu$-time diagram are related with abrasion grooves on the wear scar surface; therefore associated with severe wear due to metal-metal contact. For ductile materials, oscillating m tending to stabilize in the upper value possible indicate a massive transfer to the harder metal, finally leading to the collapse of the fluid film.

**References**


