

ROLE OF THIRD BODIES IN FRICTION AND WEAR

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Friction is usually treated as a two-body problem, in which the two counterfaces move against each other and a “magical” parameter – the friction coefficient – comes into being. Not so. At some scale, from atomically thin surface films to chunks of wear particles, third bodies play an important role in friction. These “third bodies” are often born in the sliding contact and sometimes growing up to be wear particles. They might come about because the tribologist intended to lubricate one or both counterfaces, or they might arise simply from atmospheric gases. Either way, they play a far more important role in friction and wear than you would gather from treatments of friction and wear found in the literature.

For the past fifteen years, our studies at the Naval Research Laboratory have focused on sliding behavior of “low wear” coatings and surface treatments in concentrated contacts. We have been interested mainly in “how” films transfer to the stationary counterface and “what” compositions and phases of films and third body particles form [1,2]. Friction and wear tests have been carried out at relatively low speeds, typically 0.1 - 100 mm/s, with sphere-vs.-flat geometries at high normal contact stresses, 0.5 - 1.5 GPa, in unidirectional or reciprocating sliding. Surface topography, chemistry and microstructure are characterized before and after wear tests [3] and, more recently, by *in-situ* [4] and *in-vivo* studies [5,6]; in the latter, we have focused our sights on the contact itself, watching third bodies form and move in the contact and using Raman microscopy to identify compounds in the sliding interface.

The friction behavior of many surface treatments, such as ion-implanted steels [7] and coatings, such as TiN, TiC and MoS₂ [8], can be traced back to films that form on the surface. Although original films wear away, subsequent films can grow if the environment provides a replenishing material (e.g., oxygen) or the sliding contact replenishes transfer films by forming third body reservoirs [9].

What do we know about coating wear and transfer films? Wear begins as a detachment process. Much of the literature speaks of “adhesive” and “plowing” wear to help us visualize modes by which material can be removed from wear tracks. Recently, we have identified an atomic-scale detachment process, using cross-section TEM, taking place on amorphous, ion-beam deposited Mo-S-Pb coatings. It appears that sliding transforms the amorphous surface to basally-oriented MoS₂ platelets, from one to several layers thick, which subsequently delaminate and transfer to the counterface [10,11]. Transfer films are initially thin, perhaps only a monolayer or so thick, but can be detected on counterfaces by Auger electron spectroscopy and other surface-sensitive spectroscopies long before wear is detected on the track [12]. Although transfer films originate from a “parent” material, they do not always have the same composition or phase as the parent. While sapphire against TiN produces the expected TiO₂ (rutile) phase, more complicated ternary and even quaternary phases can arise due to tribochemical reactions between ambient gases and rubbing counterfaces [8,13]. Compelling evidence for tribochemical control of friction and wear has been demonstrated by carrying out friction tests at controlled gas pressures in a multi analytical UHV chamber [14,15].

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Diamond-like-carbon (DLC) and MoS₂ are, perhaps, the best known and most studied solid lubricant coatings. Unlike the aforementioned hard coatings and implantation treatments that give low friction for relatively short durations, both DLC and MoS₂ can provide up to a million cycles of steady, low friction sliding before failing [16,17]. However, like the aforementioned, both rely on transfer films controlled by solid-solid and gas-solid reactions [18,19]. Friction coefficients, μ , of DLC and MoS₂ coatings are generally lower ($\mu < 0.1$) than those obtained from conventional hard coatings ($\mu \geq 0.1$); moreover, they are very sensitive to contact pressure. In dry environments, friction coefficients of both DLC [20] and MoS₂ [21] depend on the load, L , i.e., they do not obey Amontons' Law; instead, they vary as $\mu \propto L^{-n}$, where $1/3 < n < 1/2$, depending on shape of counterface. This behavior is consistent with the relationship $\mu = s/p$, in which "s" is an interfacial shear strength and "p" is the elastic contact pressure.

For both DLC and MoS₂, friction coefficients also depend on humidity. We have recently studied, visually, the sliding behavior of MoS₂ using a tribometer with a glass hemispherical slider attached to a microscope [5]. In dry air, we observed interfacial sliding between a thin MoS₂ transfer film on the glass and the MoS₂ wear track. In moist air (20 - 60% RH), we observed both interfacial sliding and some extrusion and deformation of transfer material attached to the glass. The friction in moisture was three to four times higher than in dry air. Clearly, changes in third body were responsible for altering the friction behavior.

Similar studies were performed on a boron carbide coating annealed in hot air to oxidize the B₄C surface [6]. The friction coefficient obtained in ambient air (30-60% RH) was correlated with compounds detected in the sliding contact by Raman microscopy. The initial friction coefficient, $\mu = 0.1$, corresponded to H₃BO₃ formed by reaction of B₂O₃ with moisture [22]. With continued sliding, H₃BO₃ disappeared from the contact and the friction coefficient rose to about $\mu = 0.2$; at this value, Raman detected strong "D" and "G" peaks characteristic of nanocrystalline graphite or diamond-like carbon. Again, changes in third bodies -- in this case composition -- were directly correlated with changes in friction coefficient.

In summary, third bodies play an important role in the friction coefficient of low friction, wear resistant materials in dry sliding contact. They can reduce friction by forming transfer films, but increase it by cluttering wear tracks with debris. Transfer films accommodate motion through interfacial sliding and by deformation processes; they also extend life of sliding contacts by forming third body reservoirs and replenishing, thereby healing, wear tracks with slippery material. Third bodies, however, are not simply small pieces of the parent wear track. They are films and particles synthesized at high stress in the contact by tribochemical processes. Perhaps we should be most surprised that they often take on compositions similar to those predicted by equilibrium thermochemical reactions. Hence, if we wish to design long-lived tribomaterials, we must have a more fundamental understanding of third bodies and third body processes.

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