

# MICROMECHANICAL WEAR AND FRICTION MECHANISMS OF COATED SURFACES

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There has been increased interest in the use of coatings on mechanical components, tools in the production industry, disc drives in the computer industry, precision instruments and human replacement organs. The new coating deposition techniques that have been developed during the last two decades have offered a large variety of possibilities to tailor the surfaces with many different materials and structures. In particular, chemical vapour deposition (CVD) and physical vapour deposition (PVD) have made it possible to deposit thin coatings of one micrometre thickness in a temperature range from very high temperatures (about 1000°C) down to room temperature. Coating materials such as TiN, TiC, Al<sub>2</sub>O<sub>3</sub> and more recently diamond, diamond-like carbon (DLC) and MoS<sub>2</sub> and their combinations as multilayers and dopants have been used with great success.

In the best cases, these very thin coatings have decreased the coefficient of friction and the wear rate by one or two orders of magnitude. Super-low friction coefficients down to 0.001 in dry sliding have been registered (Donnet, 1998). The deposition techniques of thin coatings and their tribological behaviour and applications have been described by Holmberg and Matthews (1994, 2000) and Holmberg et al. (1998).

A tribological contact with two loaded surfaces in relative motion is a very complex system that is not easy to understand nor simulate or predict. The system becomes even more complex when coatings are introduced on the surfaces. Studies have been carried out on a macrolevel, that is component level, on microlevel i.e. surface asperity level and on a nanolevel, i.e. molecular level (Singer and Pollock, 1991; Holmberg and Matthews, 2000).

It is natural that, in a situation when our understanding of the contact phenomena is poor, the development of new coatings and their applications have very much been carried out by the trial and error technique. This approach though has by no means been unsuccessful. However, the full advantage of the possibilities that these new techniques offer requires more systematic approaches. Excellent works on the simulation of a coated tribological contact have been reported by Djabella and Arnell (1992, 1993), Diao et al. (1994a), Mao et al. (1995), and Zheng and Ramalingam (1995), but because of the complexity of the problem they are still restricted to necessary simplifications of the complete problem.

A shortcoming is that even the parameters that are used to describe the friction and wear behaviour in coated tribological contacts are not clear. The parameters related to the macrogeometry of the contact and the topography are better defined, but the parameters defining the wear debris and surface layers are not well defined. Parameters related to load and speed are well-controlled, as are the environmental parameters such as temperature, humidity, gases, etc. The material parameters are crucial for the tribological performance, but here there is considerable diversity. Hardness is one crucial material parameter that is much used and well defined by several in depth studies e.g. Rickerby and Matthews (1991). Other parameters that attempt to describe the tribological performance such as the critical load in scratch testing and load-carrying capacity are less well-defined and their role is more unclear.

The contact conditions with a sphere sliding over a plate coated with a very thin (0.1-20  $\mu\text{m}$  thick) coating were analyzed and discussed in the presentation. It is concluded that the most important material parameters that influence the friction and wear performance of thin coated surfaces in sliding contacts are: the shear strength ( $\tau_u$ ) and the decohesion ( $K_u$ ) on the top of the coating; the elastic modulus ( $E_c$ ), the hardness ( $H_c$  or  $\tau_c$ ) and the fracture toughness ( $K_c$ ) of the coating; the fracture toughness at the coating-to-substrate interface ( $K_i$ ); and the elastic modulus ( $E_s$ ), the hardness ( $H_s$  or  $\tau_s$ ) and the fracture toughness ( $K_s$ ) of the substrate material. These material parameters can be measured by the following available test methods: the nanoindentation test, the scratch test and the pin-on-disc test.

It has been observed that hard coated surfaces very often fail due the fracture. However, the fracture behaviour of coated surfaces is not so well understood and there is no adequate technique to measure this performance. There is not even a generally accepted parameter to assess the fracture behaviour of a thin coating or a surface.

A new method using the scratch tester for determining the fracture toughness of a thin coating or a surface of a sample was described. A diamond stylus is drawn over the surface and the moment and place for the first transverse tension crack in the groove is observed. At this point, the horizontal and the vertical forces as well as the groove width and depth are measured. Based on geometrical and plasticity analysis, the force with which the stylus pulls the coating or the surface is calculated. Fracture mechanics analysis for a force pulling a thin sheet is carried out to determine the fracture toughness related to the conditions where the first tensile crack in the groove occurred, and this is equal to the critical fracture toughness of the coating.

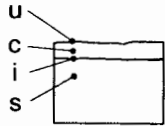
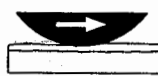

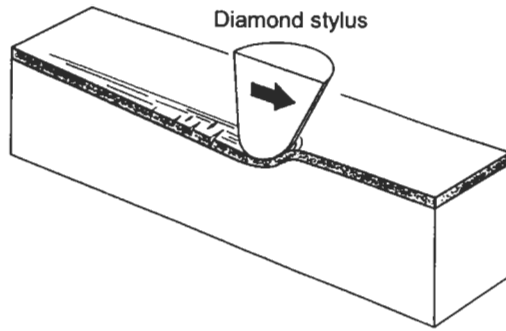
<b>MATERIAL PARAMETERS CONTROLLING FRICTION AND WEAR</b>		
	 <b>RUBBING</b>	 <b>PLOUGHING</b>
	<b>FRICTION</b>	<b>Friction by rubbing:</b> <ul style="list-style-type: none"> <li>- shear strength (adhesion) between coating and counter-surface</li> <li>- decohesion of coating results in debris and changed topography</li> <li>- transfer and reaction layers are important</li> </ul> $\mu = f(\tau_u, K_u)$
<b>WEAR</b>	<b>Wear by adhesion:</b> <ul style="list-style-type: none"> <li>- adhesion to counter-surface and decohesion of coating results in wear debris</li> <li>- decohesion may be fatigue induced</li> <li>- may be of molecular scale</li> </ul> $w = f(K_u, \tau_u)$	<b>Wear by fracture:</b> <ul style="list-style-type: none"> <li>- material stresses influenced by elastic and plastic response of both coating and substrate</li> <li>- fatigue and fracture toughness of coating are important</li> <li>- coating adhesion to substrate is important</li> </ul> $w = f(K_c, K_i, K_s, \tau_s, E_s, \tau_c, E_c)$
E = Young's modulus, K = fracture toughness, $\tau$ = shear strength subscripts: s = substrate, c = coating, i = interface, u = surface		

Fig. 1. Material parameters influencing the friction and wear behaviour for a ball sliding on a coated plate.



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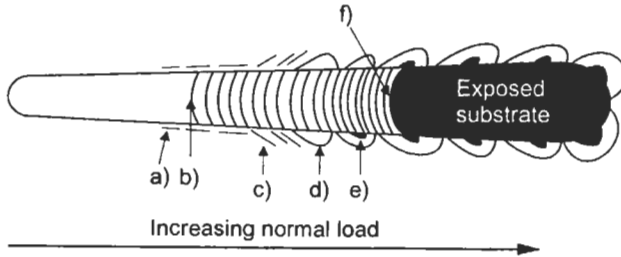


Fig. 2. Schematic illustration of the scratch tester (a) and typical fracture pattern in the groove (b) (after Larsson et al., 1996).

	Test methods	$E_c$	$E_s$	$\tau_u$	$H_c$	$H_s$	$K_u$	$K_c$	$K_i$	$K_s$
	Microhardness indentation test		●				●			
Nanoindentation test	●	●		●	●					
Scratch test								●	(●)	●
Pin-on-disc test				●			(●)			
					$\sim\tau_c$	$\sim\tau_s$				

Fig 3. The most important material parameters influencing friction and wear in sliding contacts with coated surfaces and the available test methods with which the parameters can be measured.

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