Low friction and wear resistant coatings

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SUMMARY

Vapour-deposited coatings are often utilised to solve intricate materials problems which are unachievable by bulk materials. The success of surface coatings relies mainly on the possibility of tailoring a material with specific properties. The substrate material can be chosen in order to provide strength and toughness while the other demands, such as friction and wear control are met by the coating. WC/C multilayer is emerging as an interesting coating for tribological applications where a thin high-wear-resistance solid film with low static and dynamic friction against most metals is required. The application of hard TiN coatings to metal cutting tools has been hailed as one of the most significant technological advances in the development of modern tools. Even though TiN coatings have already a dominant position, still considerable efforts are invested in the research and development of multilayer coatings to enhance further the wear resistance of coated components. By alternately depositing two (or more) chemically and/or mechanically different materials, the stress concentration and the conditions for crack propagation can be changed. The multilayer structure may act as a crack inhibitor and thereby increasing the coating fracture resistance. TiN/(Ti,Al)N multilayer coatings takes the advantage of the multilayer properties and the properties of each component. However, despite their undoubted success the coating-substrate composites are often poorly characterised and badly understood. Clearly, if significant input is to be made in the design of improved coatings, a detailed knowledge of microstructure and mechanical properties is essential.

This thesis is aimed at providing a thorough characterisation of the microstructure and mechanical properties, such as hardness and Young's modulus. Additionally, a detailed understanding of the fracture mechanisms is assessed by nanoindentation and rolling contact fatigue tests, allowing to foresee how the coated systems will perform in service. To accomplish this purpose a successful novel technique for cross-sectioning through contact sites of nanometer size indentation was developed.

WC/C MULTILAYERS

As this coating is still under development, a great degree of uncertainty exists regarding the optimal constitution. Different configurations of WC/C multilayer coatings are deposited onto stainless and tool steel substrates. The goal is to probe the influence of each constituent layer on mechanical grounds and assess which will be the most promising ones. They are constituted by a body centred cubic chromium columnar interlayer, amorphous intermultilayers of WC and carbon, an amorphous WC layer, and finally the amorphous interlaminar WC/C structure. The columnar chromium interlayer is deposited to improve the adhesion of the coating to the substrate, whereas the intermultilayers and the amorphous WC layer are employed to provide a composition gradient from the interlaminar WC/C to the chromium interlayer. Defects structures prone to jeopardize the coatings performance have been identified. They are generated by the presence of substrate surface irregularities and by the top morphology of the chromium columns. Both types of defects are mainly composed of carbon. It is shown that the presence of a WC interlayer is beneficial for defect truncation.

Nanoindentation experiments has been utilised to gauge the mechanical properties and fracture mechanisms of coated systems. The WC/C multilayers hardness is found to be ~14 GPa and the effective Young's modulus is ~220 GPa. The deformation mechanism of the coated systems depends on the

substrate plastic properties. For stainless steel substrates, annular cracks are formed, while for tool steel, nested cracks are created. Moreover, a combined analysis of load-displacement and load-displacement squared curves permits a more comprehensive characterisation of the system behaviour. The systems have responded upon unloading to release elastic strain energy by crack propagation in the carbon layers rather than by interfacial fracture. It is outlined that the most promising combination of coating-substrate corresponds to a thin lamellar structure with the intermediate layers deposited onto tool steel substrate. Tribological experiments have revealed that the good performance of the WC/C multilayers is attributed to lower friction and stress levels offered by their ductile properties. The carbon lamellae reduce the friction and most likely the surface temperature. Consequently, the wear rate is also reduced.

TIN AND TIN/(TI,AL)N MULTILAYERS

Gaining a deeper understanding of the microstructure and mechanical behaviour of TiN layers, it is of utmost importance to tailor and envisage the performance of advanced coating concepts formed by superlattice structures within a multilayer like the TiN/(Ti,Al)N coating.

The TiN and TiN/(Ti,Al)N multilayers investigated have a fibrous and columnar microstructure, respectively. The multilayers surface displays pronounced protuberances and craters. The protuberances are found to be droplets of TiN ejected from the nitrogen contaminated titanium source. As they are loosely bonded to the coating, the droplets close to the surface are easily removed because of compressive stresses, leaving behind craters within the multilayer. The mechanical behaviour of TiN coatings are probed by Vickers hardness tests in order to evaluate the performance of coated systems when submitted at high loads, and by nanoindentation to tackle the properties at low loads where the coating should dominate the response. The hardness and Young's modulus of homogeneous TiN and TiN/(Ti,Al)N multilayers are measured using the continuous stiffness option provided with the nanoindenter. The hardness is 31 ± 1 GPa for both coatings, whereas the Young's modulus of the former is ~500 GPa and of the latter is ~480 GPa.

The major failure mode of coated systems under rolling contact fatigue experiments is initiated at the interface region, indicating that the lifetime is very sensitive to the interfacial bonding strength. Moreover, considerable disparity in fatigue durability is found among systems with different substrate surface finishing and roughness. Thus, there is a dependency on the pre-treatment and surface roughness, being a finer polished surface associated with longer lifetime. Another important outcome of these tests is that the coated system can only improve the lifetime in rolling contact if the substrate is hard enough to carry the load. Otherwise, plastic or elastic deformation will take place in the substrate under the contact and failure by fracture will occur in the coating.