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Influence of the tool surface micro topography on the tribological characteristics in metal cutting: Part I experimental observations of contact conditions

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ABSTRACT

The influence of surface micro topography of CVD α-Al_2O_3 coatings, deposited on cemented carbide inserts, on tribological characteristics in sliding contact and in metal cutting has been investigated using quenched and tempered steel as counter/work material. Pin-on-disc and turning tests were carried out and post-test characterization using 3D optical surface profilometry and scanning electron microscopy was performed in order to investigate the tribological response of the coatings. The results show that surface micro topography can have a significant impact on the tribological performance of Al_2O_3 coatings under initial and cutting contact conditions. For both kinds of tests the tendency for transfer of workpiece material strongly increases with increasing coating micro topography. In the pin-on-disc tests, a smooth coating surface significantly reduces the friction coefficient. In the turning tests the contact conditions at the flank face increase with decreasing micro topography. In contrast, no general conclusions can be drawn regarding the influence of coating micro topography on the contact conditions at the rake face. The resulting topography of the turned surface was found to increase with increasing coating topography.

1. Introduction

The characterization of wear and failure modes of metal cutting tools is a research area of great importance for the manufacturing industry. In metal cutting, progressive wear of the cutting tool occurs where the tool is in contact with the workpiece, i.e., on the rake face and the tool flank. The wear process is very complex, involving both mechanical and chemical interaction between the contacting surfaces and is to a large extent governed by the cutting forces, the cutting speed and the chemical composition of the tool and the workpiece materials, respectively [1–3]. Cemented carbide is the dominant tool material for metal cutting operations using indexable inserts. For these, multilayer-coatings of hard refractory materials such as TiC, Ti(C,N), TiN and Al_2O_3, are today used in order to further enhance the performance of the cutting tool insert, and of these Al_2O_3 has so far shown the most success in reducing the wear in the machining of steel (iron based metals). However, in order to further improve the wear resistance of Al_2O_3 attempts have been made to control the wear resistance through the deposition of different types of Al_2O_3 multilayer coatings as well as phase and texture-controlled Al_2O_3 coatings [4–7].

Coating characteristics such as phase composition, texture, defect density, thickness, etc. affect the coating surface topography, which in turn affects the tribological performance of the coating, i.e., friction, wear characteristics and material pick-up tendency of a coated surface [8–11]. In metal cutting, the influence of parameters such as cutting depth, feed, type of workpiece material, etc. on the cutting tool lifetime is well investigated. In contrast, very few studies focusing on the influence of the tool surface topography (surface treatments) on the cutting process [12–16] have been published.

In metal cutting, the contact conditions between the tool surface and the chip/workpiece material varies and the rake and flank faces are usually exposed to different contact pressures and temperatures [14,17–19]. Further, the contact surfaces at both faces are often divided into three contact zones with different contact conditions. These contact zones involve sticking, adhesion and sliding, respectively [17,20,21]. The coating ability to improve and stabilize the adhesion zone during machining is of vital importance for the function of the coating. Thereby, the coating contributes to the minimization of the sliding zone [12].

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In order to increase the understanding of the tribological mechanisms being active in metal cutting, a number of laboratory tribotests have been developed [22–26]. These tests are generally based on standard sliding wear tests but modified in order to let the tool material slide against fresh workpiece material. Nevertheless, test methods such as pin-on-disc testing are still very common and useful since they will give information about the general tribological response of the mating surfaces and promotes post-test microscopy and surface analysis.

In the present paper, the influence of coating surface micro topography on the tribological contact at the flank and rake faces in metal cutting as well as in pin-on-disc testing have been evaluated. Initial metal cutting and pin-on-disc experiments have been performed using CVD α-Al_2O_3 coated cemented carbide tools and quenched and tempered steel as counter material. The influence of the coating surface micro topography on the resulting contact conditions, tendency toward build-up layer formation and prevailing wear mechanisms have been identified and evaluated using optical profilometry, FEG-SEM and EDX analyses.

2. Experimental

2.1. Cutting tool materials

2.1.1. Substrate material

Commercial cemented carbide inserts (ISO geometry TPUN160308) with a composition of 93.5 wt% WC, 0.5 wt% (Nb,Ta)C and 6 wt% Co were used as substrates in the present study. The inserts used for metal cutting studies consisted of two different geometries: an as-received with an edge radius of 20 μm (denoted as "standard") and a geometry with a predefined flank land of 200 μm and an edge radius of 15 μm (denoted as "flank") (Fig. 1).

2.1.2. Coating deposition

The CVD coatings investigated were all deposited using a hot-wall CVD reactor. Prior to the deposition of the α-Al_2O_3 layer a 5 μm intermediate Ti(C,N) layer was deposited at a temperature of 860 °C. Finally, a 3 μm thick α-Al_2O_3 layer was deposited at a temperature of 1020 °C.

After coating deposition, the coated inserts were polished using three commercially available surface polishing treatments in order to remove the crystalline facets of the α-Al_2O_3 layer thus improving the surface micro topography of the coated inserts. The coated inserts investigated include one as-deposited coating, denoted A, and three polished coatings, denoted P1, P2 and P3, with decreasing surface micro topography with increasing number.

The surface morphology of the as-deposited and surface polished α-Al_2O_3 coatings were investigated by 3D surface profilometry using a WYKO NT-9100 instrument and scanning electron microscopy using a Zeiss Ultra 55 FEG-SEM equipped with an Oxford Inca Energy 450 energy dispersive X-ray spectrometer.

2.2. Pin-on-disc testing

Sliding wear testing was performed using commercially available pin-on-disc test equipment, (CSM Instruments HT Tribometer®). In the test, a quenched and tempered steel (AISI 4140) pin with a diameter of 10 mm and a polished (R_a=25 nm) hemispherical shaped end surface (radius 5 mm) is loaded against a CVD α-Al_2O_3 coated cemented carbide insert. The pin-on-disc tests were performed under dry conditions in ambient air (21–22 °C, 25–26% RH) using a normal load of 20 N and a relative sliding speed of 0.1 m/s. The tests were run for 1000 s, corresponding to a sliding distance of 100 m, and during testing the friction coefficient was continuously recorded.

2.3. Metal cutting

Orthogonal turning tests were performed on a tube workpiece of quenched and tempered steel (AISI 4140) using the different CVD α-Al_2O_3 coated carbide inserts with the aim to determine the cutting forces. The cutting forces were measured using a standard dynamometer and all turning tests were carried out dry and with

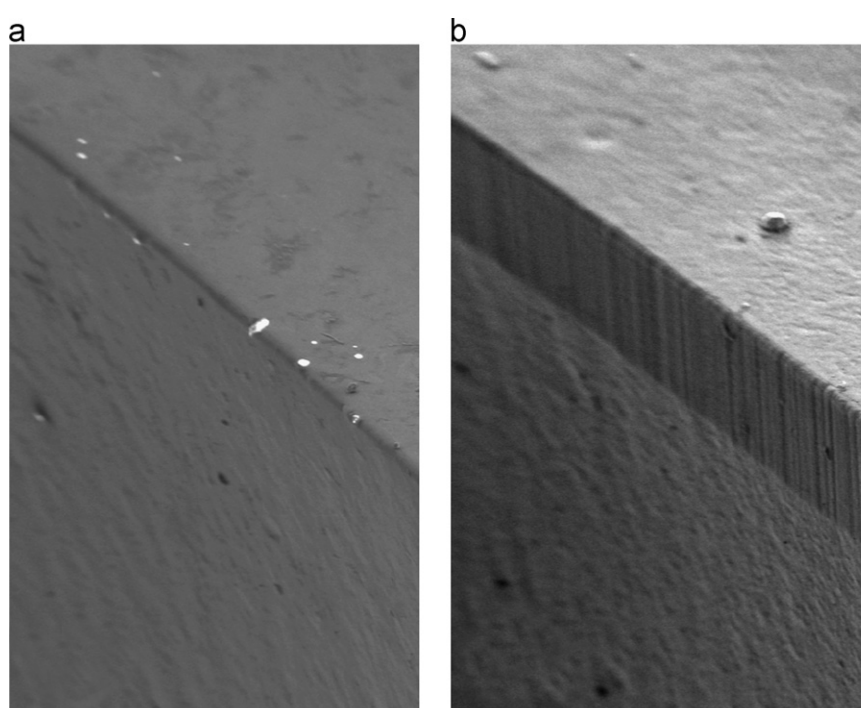

Fig. 1. Two insert geometries investigated: (a) standard insert and (b) flank insert.