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RESEARCH

PVD-Alumina Coatings on Cemented Carbide Cutting Tools: A Study About the Effect on Friction and Adhesion Mechanism

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A B S T R A C T

Crystalline PVD γ-alumina coatings are interesting for machining operations due to their outstanding characteristics, such as high hot hardness, high thermal stability and low tendency to adhesion. In the present work (Ti,Al)N/γ-Al_2O_3-coatings are deposited on cemented carbide by means of MSIP. Objectives of this work are to study the effects of coating and cutting fluid regarding friction in tribological tests and to study the wear mechanisms and cutting performance of γ-Al_2O_3-based coated cemented carbide cutting tools in machining operations of austenitic stainless steels. Based on the remarkable properties of the coating system the performance of the cutting tools is increasing significantly.

1. INTRODUCTION

The machining of difficult-to-machine materials such as austenitic stainless steels has been the focus of investigations for a long time now [1]. The austenitic stainless steels represent the largest group of stainless steels in use, making up 65–70% of the total for the past several years [1]. The characteristic properties of austenitic steels, such as high strength, low thermal conductivity, high ductility and high tendency towards work hardening are the main factors for their poor machinability. One approach to overcome the difficulties in machining operations of these steels is an appropriate coating system on the cutting tool. In this case, hard PVD coatings with low thermal conductivity and improved surface finish should be used. The application of coatings on the cutting tools can result in an enhancement of the frictional characteristics at the tool-workpiece interface as well as of the chip evacuation process [2]. Crystalline PVD γ-alumina coatings are interesting for the mentioned machining operations due to their outstanding characteristics, such as high hot hardness, high thermal stability and low tendency to adhesion due to their low surface free energy [3, 4, 5, 6].

For cutting and friction tests, (Ti,Al)N/γ-Al_2O_3-coatings were deposited on cemented carbide by means of MSIP (Magnetron Sputter Ion Plating).

In order to improve the adhesion of γ-alumina on the cemented carbide, a (Ti,Al)N bond coat was employed. Objectives of this work are to study the effects of coating and cutting fluid regarding friction in tribological tests and to study the wear mechanisms as well as cutting performance of aluminium oxide based coated tools in continuous turning of austenitic stainless steels. Based on the remarkable properties of the coating system the performance of the cutting tools is increasing significantly.

2. GAMMA-ALUMINA COATINGS

As cutting tool substrate material, fine grained tungsten cobalt based (WC-Co) cemented carbide was chosen. A charge of the cemented carbide cutting tools was coated with the coating system (Ti,Al)N/γ-Al_2O_3. For the deposition, the commercial coating system CemeCon CC800® was used. All coatings were made by the Surface Engineering Institute, RWTH Aachen University. The process parameters for the deposition process are described in [7]. The coating thickness was about 6 µm. The structure of the coatings is exemplarily shown in Fig. 1.

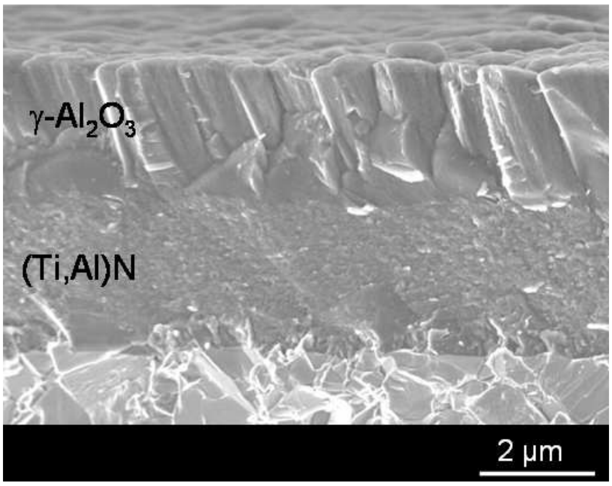

Fig. 1. Structure of the coatings (Source: Central Facility for Electron Microscopy of RWTH Aachen University).

3. WORKPIECE MATERIAL - AUSTENITIC STAINLESS STEEL

As material for the workpiece, the austenitic stainless steel grade AISI 316Ti (X6CrNiMoTi17-12-2) was chosen. His chemical composition is given in Table 1. The austenitic steel has an average Vickers hardness of about 170 HV 30 and an average tensile strength of TS = 510 N/mm^2.

Table 1. Chemical composition of the austenitic steel AISI 316Ti (wt. %).

Element	C	Si	Mn	P
Chemical composition, %	0.056	0.68	1.88	0.024

S	Cr	Mo	Ni	Ti	Fe
0.020	16.66	2.05	10.68	0.41	balance

4. TRIBOLOGICAL BEHAVIOUR

For a better understanding of the coatings' behavior in machining tasks, friction and machining tests were carried out. A novel set-up was designed for the friction tests. These tests were realized on a conventional NC-turning machine. The friction counterpart was made of the same charge of workpiece material (AISI316Ti) as used in the cutting tests. The relative velocity (friction speed v_f) between tool and counterpart was in the range of conventional cutting speeds when turning austenitic steels. Before every friction test, the counterpart's surface was newly turned off in order to ensure a "new" surface, without any influence due to physical mechanisms like adhesion and diffusion, chemical mechanisms and work hardening as are occurring during previous friction tests. Friction tests were carried out under dry conditions and by using emulsion as cutting fluid. Normal and friction force were measured continuously using a three-component force measuring system. A scanning electron microscope (SEM) was used to study the wear mechanism in friction tests in more detail.

The friction tests could reveal the importance of coating and cutting fluid. Figure 2 shows the measured friction coefficient µ versus friction speed v_f. Under dry frictional conditions, the friction coefficient is relatively high, but is reduced in particular for higher friction speeds by use of the (Ti,Al)N/γ-Al_2O_3 coating. This trend is enforced by the use of flood lubrication. For low friction speed (v_f = 50 m/min) friction is reduced in the case of uncoated tool by use of cutting fluid as well. At higher friction speeds, the coating's significance for the friction reduction is manifested even more.

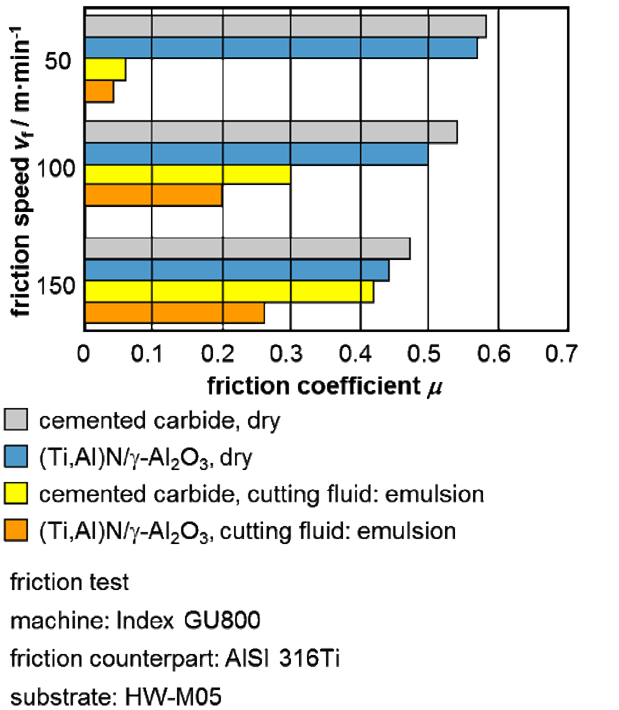

Fig. 2. Friction depending on coating and cutting fluid (counterpart: austenitic steel).

The SEM analyses of uncoated and coated inserts used in friction tests are shown in Fig. 3. The micrographs reveal for both, coated and uncoated tools, zones with sticking particles from the friction counterpart. However, for uncoated cemented carbide the size of the particles is even greater and they are considerably more spread along the contact area between insert and counterpart.

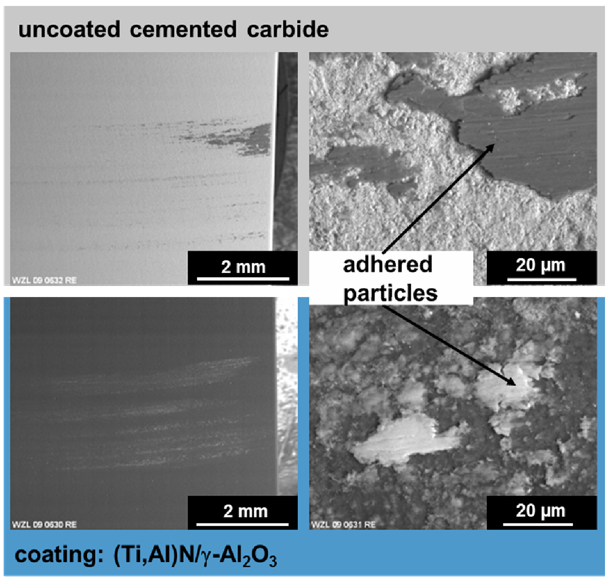

Fig. 3. Effect of alumina coatings on the mechanism adhesion in friction tests.

5. MACHINING WITH ALUMINA-BASED COATING SYSTEMS

In order to analyse the performance of the γ-Al_2O_3 - based coating systems in machining, turning tests of the austenitic steel AISI 316Ti (X6CrNiMoTi17-12-2) were carried out. The cutting speed v_c was set to 150 m/min (uncoated) and 250 m/min (coated tools), feed f to 0.2 mm and depth of cut a_p to 0.5 mm. The tool life criterion maximum width of flank wear land was fixed to VB_{max} = 0.2 mm. For the measuring of the width of flank wear land a digital optical microscope was used. Additionally, to study the wear formation and mechanism in more detail, some inserts were investigated at the end of tool life time with SEM analysis.

Figure 4 shows the tool life times of uncoated cemented carbide and coated cemented carbide tools. When using the (Ti,Al)N/γ-Al_2O_3 coating in continuous turning of AISI 316Ti, the tool life time T_c was improved from about T_c = 2.4 min (uncoated cemented carbide) to more than 26 min by coating of the cemented carbide tool supplementary increasing the cutting speed from v_c = 150 m/min to 250 m/min.

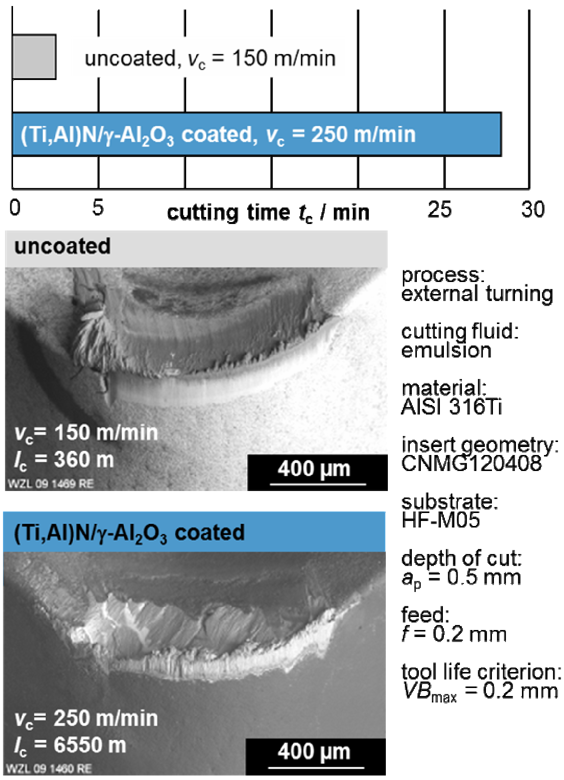

Fig. 4. Effect of alumina coatings on cutting performance of cemented carbide when turning austenitic steels.

The coating seems to have a sealing function; it prevents the direct contact between tool, machined material and chip. As the aluminium oxide can act as barrier for diffusion, the crater wear is avoided [8, 9]. The wear zone at the end of tool life time is homogenously formed, but the tools show large zones with sticking particles from the chip and workpiece.

In order to deeper understand the coatings' behaviour and their wear mechanisms occurring in machining operations of austenitic steels, chips originating from the cutting tests were analysed using SEM and EDX analysis (line scans), Fig. 5. The SEM analysis of the chip underside could reveal sticking coating material particles. EDX line scans could prove the thesis that these particles originate from the coating. Line scans detected particles from the coating top layer (γ-Al_2O_3), left side of Fig. 5. Even more, the line scans revealed particles from the bond coat (TiAlN), right side of Fig. 5.

Chip with adhered particles originating from the coatings top layer:

Chip with adhered particles originating from the coatings bond coat:

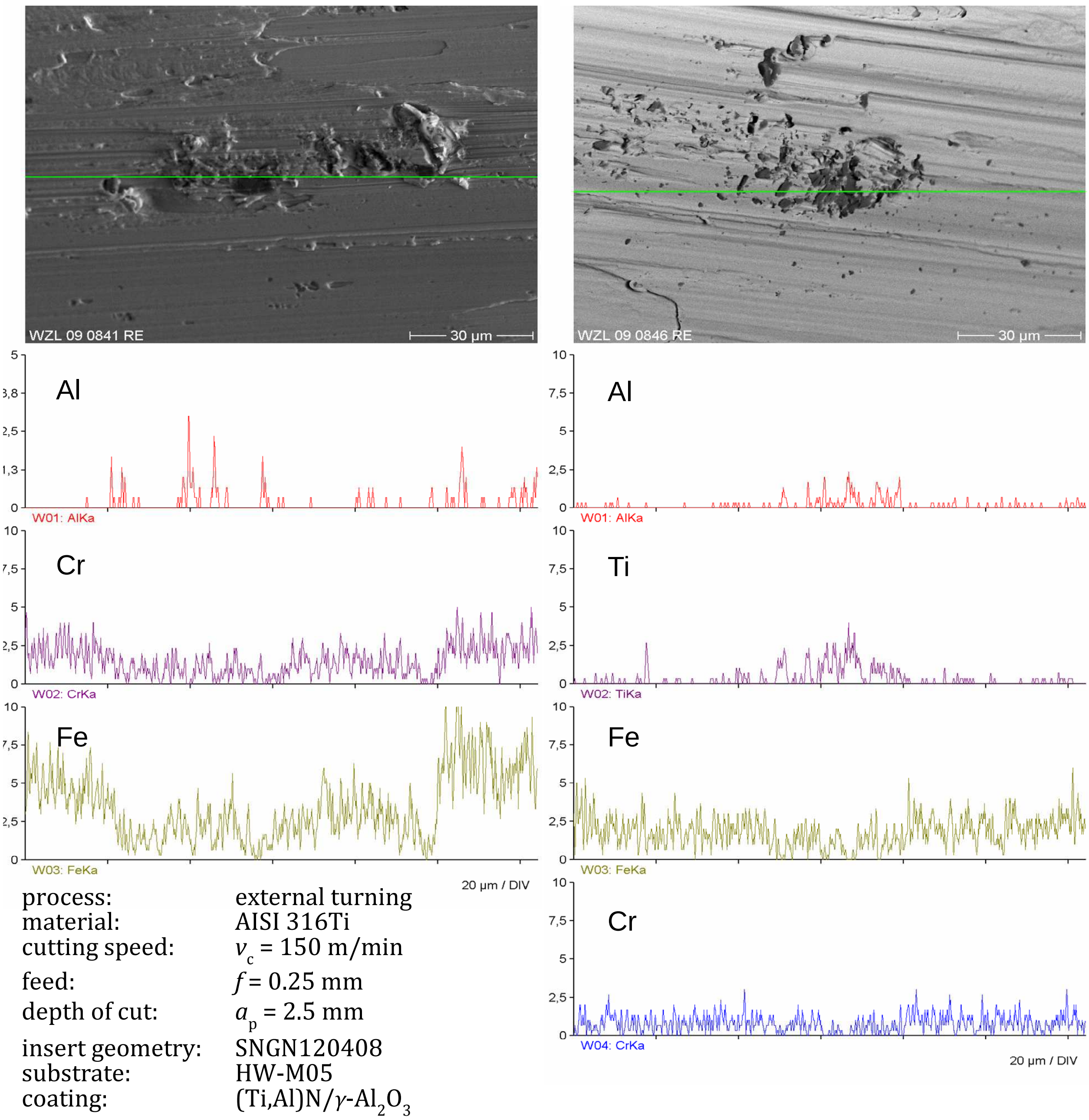

Fig. 5. EDX-line scans of adhered material particles on the chip underside

6. CONCLUSION

In the present work, γ-alumina based coatings systems were deposited on cemented carbide cutting tools. Their behaviour in friction tests as well as in cutting tests was investigated. The friction could be reduced by alumina based coating systems, even more in combination with cutting fluids like emulsion.

In cutting operations, such as machining of austenitic steels, the (Ti,Al)N/γ-Al_2O_3-coating system could significantly effect tool life time and wear formation. Adhesion is one central problem when machining austenitic steels. The coatings bond must be enhanced in order to improve tool life time even more.

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