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Hard AlTiN, AlCrN PVD coatings for machining of austenitic stainless steel

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Abstract

The austenitic stainless steels in general are considered to be difficult to machine materials. This is mainly due to the high plasticity and tendency to work-harden of the austenitic stainless steel, which usually results in severe cutting conditions. Additionally, austenitic stainless steels have much lower thermal conductivity as compared to structural carbon steels; this inflicts high thermal impact within the chip-tool contact zone, which significantly increase the cutting tool wear rate. The machineability of austenitic stainless steels can be improved due to application of coated cutting tools. Hard PVD coating with low thermal conductivity and improved surface finish should be used in this case. This can result in enhancement of frictional characteristics at the tool/workpiece interface as well as chip evacuation process. In this study the stainless steel plates were machined using cemented carbide finishing end mills with four high aluminum containing PVD coatings namely: AlCrN, AlCrNbN, fine grained (fg) AlTiN and nano-crystalline (nc) AlTiN. Both AlTiN and AlCrN-based coatings have high oxidation resistances due to formation of aluminum oxide surface layers. The influence of surface post-deposition treatment on tool wear intensity was investigated. The coating surface texture before and after post-deposition treatment was analyzed by means of the Abbot-Firestone ratio curves. Minimal wear intensity after length of cut 150 m was achieved for cutting tools with the nc-AlTiN coating.

Keywords: Hard PVD coatings; Machining; Stainless steel; Cutting tools

1. Introduction

It is known that the austenitic stainless steels have high work hardening even at low deformations rates and low thermal conductivity [1]. These two characteristics make austenitic stainless steels (γ-SS) more difficult to machine than carbon steels, low alloy carbon steels and non-austenitic stainless steels. The high toughness and high ductility of the austenitic stainless steel leads to the formation of long continuous chips and to the intensive sticking of the workpiece material to the cutting tool surface which results in an adhesive wear enhancement. Moreover, high temperatures at the tool-chip interface result in an increase of diffusion and chemical wear [2]. In addition, the build-up edge formation and tearing off during cutting can also lead to the machining forces instability, which results in cutting edge chipping. A severe condition of attrition wear usually occurs during machining of stainless steels [2]. The machineability improvement of γ-SS could be done by optimization of the cutting parameters (such as cutting speed and feed rate).

Some researchers have presented ways to improve machinability of steels by adding oxide-forming elements such as S or Ca [2,3]. This improvement is associated with the plastic behavior of the sulfides during machining. Lubricious compounds accumulate on the tool surface, leading to cutting force reduction and lower heat generation [2,3].

Hard coatings application is another effective way of cutting tool life improvement during machining of stainless steels. Cemented carbide tools are traditionally coated by two methods: chemical vapor deposition (CVD) and plasma vapor deposition (PVD) [4]. Due to high temperature during the CVD process the cemented carbide substrate could lose some fracture toughness [5]. The PVD process offers lower deposition temperatures and a sharp cutting edge could be retained easier, which is very important for machining of stainless steels [2]. A number of PVD coatings have been used for machining of stainless steels [6,7]. Eventually tool life could be significantly increased [8,9]. Numerous studies during the last two decades have shown that the nitride coatings with high aluminum

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content (such as AlCrN and AlTiN) can provide better wear protection than aluminum-free nitride coatings (such as CrN and TiN) at high service temperatures due to their higher hot hardness, oxidation resistance, and lower thermal conductivity [10].

In present research, we are investigating the influence of the AlCrN, AlCrNbN; fg-AlTiN and nc-AlTiN coatings on wear mechanism and tool life of finishing carbide end mills during machining of AISI 316 stainless steel. Previous studies have shown the superior oxidation resistance and hot hardness of AlCrN-based coatings as compared to AlTiN ones. However we demonstrate that a longer tool life can be achieved by tailoring of the surface characteristics (such as crystalline grain sizes as well as surface texture) for specific applications.

2. Experimental

The hard coatings investigated in this research were deposited using a Balzers' Rapid Coating System (RCS) deposition machine in a cathodic arc ion-plating mode. Customized $Al_{70}Cr_{30}$, $Al_{70}Cr_{25}Nb_5$ and $Al_{67}Ti_{33}$ targets in a reactive nitrogen atmosphere were used to obtain stoichiometric AlCrN, AlCrNbN, fine-grained (fg)-AlTiN and nano-crystalline (nc)-AlTiN thin coatings. Cemented carbide 8-mm diameter finishing end mills substrates were used for the coating deposition (Fig. 1).

XRD studies of the coatings under analysis have been performed using cemented carbide insert substrates with mirror-polished surface finish. The temperature of the substrates during deposition was held at approximately 500 °C for the AlCr-based coatings while for the AlTi-based coatings, the temperature was approximately 600 °C. The deposition times were adjusted in order to achieve the thickness of all the coatings within 3.5±0.2 μm. A Siemens D500 diffractometer with a CuK_α tube and the Θ/2Θ mode was used to perform XRD analysis and identify the phases formed.

Surface roughness characterization and the material ratio curves for the deposited coatings before and after surface post-treatment were obtained using a Mahr Perthometer model M1 with the MarSurf XR 20 surface texture analysis software.

Microhardness as well as Young Modulus of the coatings has been measured using a Fischerscope H100C depth sensing indentation instrument. The load used during the indentation was 50 mN and the resulting indentation depth corresponded approximately to 10% of the total coating thickness.

The short-term oxidation tests have been performed in laboratory air. A high vacuum furnace PVA MOV 64 (Pfeiffer GmbH, Germany) was used. The samples were oxidized at 825 °C for the TiAlN samples and 925 °C for CrAlN during 1 h, and then cooled down at a rate of 20 °C/min before the furnace was opened. Depth-profiles of the oxidized layers was studied using a SIMS (FEI Nanotech, USA) instrument, model 4550 equipped with a Cs low energy ion gun. The cutting test was performed on a Mikron VCP 600 milling machine. Cutting conditions were as following: cutting with coolant (Blaser Swisslube: Blasocut 2000 universal, 6% concentration in fluid); cutting speed of 120 m/min, feed rate of 0.05 mm, depth of cut of 10 mm and radial depth of cut of 0.5 mm. The workpiece material was hot rolled AISI 316 austenitic stainless steel, quenched and plasma cut with a hardness 160HB (R_m=550 N/mm^2).

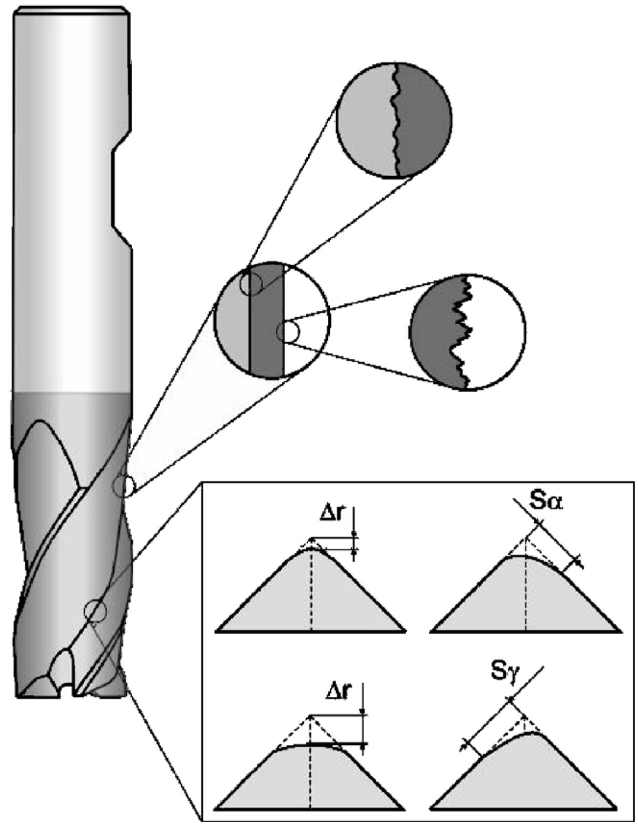

Fig. 1. Drawing of the end mill tool showing the texture features for the substrate and the coating as well as the different configurations of optimized cutting edges. Drawing of an end mill: Δr is the nose radius of the tool, S_α and S_γ correspond to the distances of curvature at the flank and rake surfaces of the end mill cutter, respectively.

LEO 1530 scanning electron microscope (SEM) was used to study morphology of the end mills flank surface after length of cut 7 m (running-in stage of wear). EDX spectra have been obtained to measure the chemical composition of the coating deposited.

To study the coated end mill surface after service morphology, a stainless steel build-up edge has been removed using concentrated HCl solution (37% mol) in ultrasound bath for 30 min at the temperature around 70 °C, and held at this temperature for another 10 min.

3. Results

3.1. XRD patterns

The AlCrN-based coatings and the AlTiN coatings (two types of each) were deposited on the cemented carbide cutting tool substrates (Fig. 1). Fig. 2a shows the XRD patterns for AlCrNbN and AlCrN coatings. These coatings have cubic B1 (NaCl) structure, and their major peaks are located close to the corresponding cubic AlN peaks. Nonetheless, these two