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Wear mechanisms and tool performance of TiAlN PVD coated inserts during machining of AISI 4140 steel

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Abstract

The tribological influences of PVD-applied TiAlN coatings on the wear of cemented carbide inserts and the microstructure wear behaviors of the coated tools under dry and wet machining are investigated. The turning test was conducted with variable high cutting speeds ranging from 210 to 410 m/min. The analyses based on the experimental results lead to strong evidences that conventional coolant has a retarded effect on TiAlN coatings under high-speed machining. Micro-wear mechanisms identified in the tests through SEM micrographs include edge chipping, micro-abrasion, micro-fatigue, micro-thermal, and micro-attrition. These micro-structural variations of coatings provide structure-physical alterations as the measures for wear alert of TiAlN coated tool inserts under high speed machining of steels.

Keywords: TiAlN coating; High speed cutting; Microstructure wear; Dry and wet machining; SAE 4140 steel

1. Introduction

It is a common belief that coatings deposited on different substrates improve the wear resistance of the tool and modify the contact conditions between the chip and the tool faces. Ever since Taylor [1] investigated the effect of applying water in big quantities at the cutting area, he found that cutting speed could be increased 33% without reduction in tool life. Tonshoff et al. [2] investigated the wear mechanisms of Al_2O_3/TiC (40% TiC) under dry and wet cutting using coolant emulsion and mineral oil. They discovered that wear mechanisms hard turning under wet condition is different from that under dry cutting. Avial and Abrao [3] studied continuous turning hardened AISI 4340 steel using mixed alumina tools. They observed that the application of a cutting fluid based on an emulsion without mineral oil resulted in longer tool life compared to dry cutting. Smith et al. [4] showed that the performance of coating can be significantly affected by hard thin film of TiAlN. Shaw [5] reported that tool wear increased more when applying coolant than dry cutting with M-2 high-speed-steel cutting tool in machining AISI 1020 and AISI 4340 steels. Seah et al. [6] addressed that coolant had a negative effect on uncoated tungsten carbide inserts' tool life because of the increasing crater wear. However, in general modifying the properties of tool inserts by applying hard or combined hard and soft protective coatings can substantially slow down some wear processes, reduce friction and prolong the tool life. The commercial coatings used most frequently in tools industry for machining of metals are TiC, Al_2O_3 (CVD applied), TiN, TiCN (combined CVD and PVD application), and TiAlN (PVD applied) [7–10].

The aim of this work is to contribute toward better understanding of the positive effects of the PVD-applied TiAlN coating on tool inserts under high cutting speeds for both wet and dry machining of steels. To accomplish the research goal we investigate the type of micro-wear mechanisms activated during machining at high cutting speeds, and coolant emulsion effects on TiAlN coating performance.

The paper is organized as follows. The experimental details of the research work are given in the next section. This is followed by the results of the experimental testing and the associated analytical discussion. Finally, some concluding remarks are drawn and addressed in the last section of the paper.

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Table 1
Workpiece specifications

Description	Hot rolled alloy steel bars, SAE 4140H (UNS H4140)
Dimensions	15 cm diameter × 62 cm length
Heat treatment	Vacuum degassed/processed, Cal-Al treated, annealed and special straightened, conforming to ASTM A322 and A304

Table 2
Workpiece chemical compositions (values in %)

Carbon	0.4
Manganese	0.91
Phosphorus	0.017
Sulfur	0.02
Silicon	0.24
Nickel	0.10
Tin	0.008
Aluminum	0.030
Vanadium	0.002
Calcium	0.0064
Molly	0.2
Copper	0.12

2. Experimental methodology

2.1. Workpiece material

This study was conducted in accordance with ISO 3685 [17]; the work piece material was SAE 4140 steel. Work piece specifications are listed in Table 1. The work piece chemical composition is listed in Table 2. The workpiece was replaced when length/diameter ratio reached 10 in accordance with ISO 3685 [17].

2.2. Cutting inserts and tool holder geometry

Cemented carbide inserts with 6% cobalt were used in the turning tests. Kennametal manufactured the cutting inserts and tool holder. The tool holder used in the test has ISO designation of VBMT 160408. The tool does not have a chip breaker geometry. The cutting inserts assembled geometry is listed in Table 3.

2.3. Cutting conditions

Continuous turning tests of SAE 4140 heat-treated steel bar were performed on (Clausing 1300) variable spindle speed machine with a maximum power of 7.5Hp. The rotational speed of the work piece was measured before every cut by a (HT-5100) handheld digital Techometer to insure the work piece accurately running at the designated cutting speed. The coolant composition includes the listed chemicals shown in Table 4.

An optical microscope with magnification 200 times was used to measure the wear on the flank surface. Scanning electron microscope (SEM) was utilized in obtaining images capturing the initiation and micro-wear mechanisms at different stages of tool life. Five cutting speeds were employed in the test ranging from 210 to the maximum speed of 410 m/min, before the premature insert failure. Depth of cut and feed rate were kept constant during the test period with values of 1 mm, and 0.14 mm/rev., respectively.

Table 3
Cutting tool geometry

Nose radius (mm)	0.8
Bake rake angle	0°
End relief angle	5°
End cutting-edge angle	52°
Side cutting-edge angle	3°
Side rake angle	0°
Side relief angle	5°

Table 4
Coolant chemical compositions

Sulfate	20–30%
Aromatic alcohol	3–5%
Propylene glycol ether	3–5%
Petroleum oil	30–35%
Nonionic surfactant	3–5%
Chlorinated alkene polymer	20–30%

3. Results and discussion

3.1. Tool life testing

Tool life values of coated cemented carbide with one layer of TiAlN for different cutting speeds under dry and wet cutting conditions were plotted in Figs. 1 and 2. It can be seen from the two figures that tool life curves demonstrate three wear stages, namely, running into wear, semi-steady state or gradual wear, and catastrophic wear. These tool wear behaviors were also pointed out by Fang [11] and Chubb and Billingham [12] in their research papers.

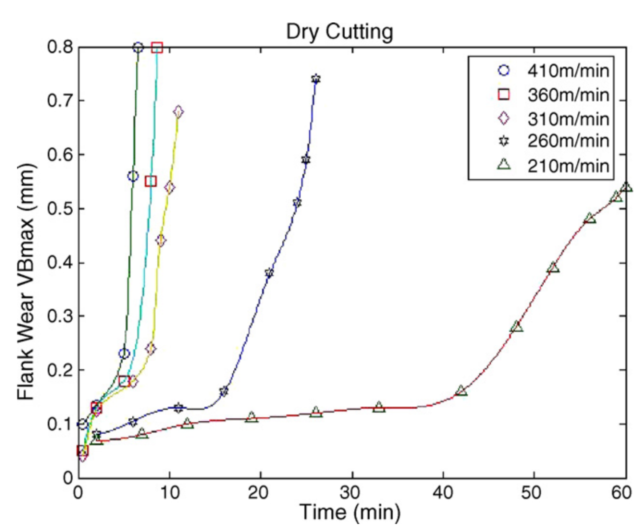

Fig. 1. Tool life vs. cutting time under dry cutting.