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Wear progressions and tool life enhancement with AlCrN coated inserts in high-speed dry and wet steel lathing

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Abstract

In this paper, the tool life enhancement with a PVD-applied aluminum chromium nitride (AlCrN) coating (named Alcrona) for cemented carbide inserts is investigated. Microstructure wear progressions such as the abrasive wear mechanisms of AlCrN coated cemented carbide tool inserts under dry and wet machining at very high cutting speeds are fully analyzed based on experimental testings. The maximum cutting speed attained in the testing for the turning operations is 410 m/min. Various progressive stages of abrasive wear are observed through the experimental results. These wear results done on AlCrN coated carbide tool inserts are compared with other tool life data reported in the literature. It is found that at 260 m/min, Alcrona performs near 95% better in tool wear than TiAlN coated carbide tool under the same machining conditions. Comparing the performance of Alcrona coated tool inserts with that of TiN coated ones, the former can achieve approximately 33% more depth of cut and can attain higher cutting speed due to better thermal resistance of the coated inserts. This finding verifies the speculation that Alcrona coating enhances tool capability for metal cutting and improves tool life even under harsh cutting conditions. Types of microstructure wear phenomena captured during the course of the experimental study are micro-abrasion, micro-tensile fracture, micro-fatigue, micro-thermal cracks, micro-adhesion, built up edge and micro-attrition. The experimental cutting observations with the underlying tool inserts demonstrate that wear progresses with time and goes through various stages, namely, running into wear, steady state wear, and tool failure wear. It is also evidenced that the use of coolant emulsion increases the tool life proportionally with respect to the cutting speeds and reduces the wear progress considerably. SEM and optical microscope images of the tool wear in progress have been taken at various stages to delve into the morphology of the tool inserts. These are interpreted with reasoning in the paper.

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

1. Introduction

The objective of this research is to understand the micro wear mechanisms of the uncoated and an Alcrona coated inserts for high speed machining under dry and wet conditions. The work concentrates on investigating the performance of uncoated and coated carbide inserts under harsh cutting conditions. This study gives a better idea in understanding the properties of available coatings in the marketplace and hence, helps machining practitioners to choose pertinent coatings for particular machining processes.

Coatings are classified into hard coating and soft coating on the basis of the hardness difference between the substrate and the coating. Hard coatings are proved better and are used more than the soft coatings because of their improved properties [1]. In high speed machining we require to coat the cement carbide tool bits with some type of coating which can reduce material losses, increase the lifetime of tool and machine parts, and most importantly, reduce wear [2]. Several researchers have established that hard coatings deposited on tool and machine parts by different physical vapor decomposition methods can dramatically change the performance of the parts. These coated materials not only help reducing the wear and increasing the tool life but also improve strength and chemical inertness, reduce friction, and make the parts more stable at high temperatures [3]. The use of surface coatings is beneficial in that the substrate material can be designed for strength and toughness while the coating is responsible for the resistance to wear, thermal loads and corrosion [1].

In recent years, TiN-based coatings have been widely used by industry for cutting tools protection. Among various alloying TiN-based coatings applied on tool inserts, TiAlN and TiAlCrN

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are most commonly discussed by many researchers. Some recent relevant works reporting research results in the area can be found in [4–9,18–21]. In particular, Luo et al. [7] investigated the tribological behaviors of TiAlN/CrN and TiAlCrN coatings by different deposition methods. They reported that the wear rate for all these coatings was at least ten times lower than the uncoated tool insert.

More recently, Luo et al. [8] further studied the wear mechanism of low friction superlattice TiAlN/VN coatings. Based on their TEM observations, it was found that the multilayer TiAlN/VN coatings resulted in the formation of tribofilm on the worn surface yielding tribo-oxidation other than traditional isothermal oxidation, better for tool protection. Along the same line, Kovalev et al. [9] looked into the impact of Al and Cr alloying of TiN-based coatings on the final cutting performance. They reported that the addition of Al to TiN coatings drops the chemical reactivity of the coating which in turn, controls the crater wear intensity in turning operations.

In addition in [9], it was concluded that the addition of Cr to TiN coatings improved the plasticity of the coating. The authors proved that the simultaneous addition of Al and Cr in the complex TiN-based nitride weaken the long range bonds, further improve the plasticity of the compound and prolong the cutting tool life under heavy wear conditions. Moreover, Koalas et al. reported that the wear rate of TiAlN/CrN was stable while that of TiAlCrN was sensitive to change in cutting speed. Their conclusion stated that both the nitride coatings increased the wear resistance of tool steel by up to 10 times.

Recently, physical vapor decomposition (PVD) is used extensively compared to other coating techniques. It involves the atomization or vaporization of material from a solid source and the deposition of that material onto the substrate to form the coating. The advantages of this process is the possibility to deposit alloy compounds, compositions with multi-layer structure and the ability to vary the coating characteristics continuously to get a functionally graded coating [1]. Also as this process involves temperatures ranging up to 500 °C, it overcomes the problem of depositing brittle layer.

In addition, PVD process produces very smooth surface finish of the coated product, resulting in good sliding of the chips over the cutting inserts. Thus the contact zone temperature is reduced which further reduces the tendencies for thermal cracking [4].

The paper is organized as follows. The coolant properties of the cutting fluid selected for the underlying machining operations are provided in the next section. This is followed by the experimental details of the research work. Then, the results of the experimental testing and the associated analytical discussion are presented. Finally, some concluding remarks are drawn and addressed in the last section of the paper.

2. Tool wear mechanisms

Morphology of the wear mechanisms under high speed machining is discussed in this section. The morphology was investigated and reported for the underlying Alcrona cutting insert material. The intention is to provide valuable insight for understanding, optimizing machining operations and obtaining sufficient knowledge to improve coating materials and coating techniques pertinent to unconventional high speed machining operations.

Che Haron et al. [10] studied the wear phenomenon of coated and uncoated carbides in turning tool for cutting steel under dry and wet conditions. The workpiece material was selected as ISO 95MnCrW1 with hardness 23HRC. Coated carbide tools were tested at four different speeds, 200, 250, 300 and 350 m/min, respectively. The results showed that performance of coated (TiCN) carbide tools under wet cutting was significantly better than under dry cutting for all the selected cutting speeds. The tool life measured was 52, 31, 16 and 14 min under wet cutting for 200, 250, 300 and 350 m/min cutting speed, respectively. The tool lives for dry cutting at the above speeds was measured as 49, 22, 12 and 7 min, respectively.

Jindal et al. [11] studied the performance of PVD applied TiN, TiCN and TiAlN coated cemented carbide tools in turning. The experiment was done at two different speeds, 305 and 396 m/min. For the wear criterion of 0.4 mm, the tool life for TiN, TiCN and TiAlN was measured as 40, 50 and 60 min, respectively, for 305 m/min, and 10, 15 and 28 min for 396 m/min, respectively.

D'Errico et al. [12] studied the influences of PVD coatings on cemented tool life in continuous and interrupted turning. Monolayers of TiN and TiCN thin films were coated on the cemented tool. It was stated that in terms of the tool life coated inserts performed better than uncoated inserts.

3. Coolant properties

Coolant emulsion rapidly affects the temperature of the chips and can sometimes favorably influence chip breaking, particularly when large cross section chips are formed [13,23,24].

In general, most turning and other machining applications use water based coolant emulsions. These contain a microscopic dispersion of the concentrate in water. The microscopic oil globules are homogeneously dispersed throughout the coolant. The basic ingredients of these emulsions are water, oil, and wetting agents [15].

There are many types of cutting fluid available today in the marketplace. The cutting fluid used in the underlying research was water based emulsion. It is mixed with water at a concentration of 10%. Its properties are listed in Tables 1 and 2.

Table 1
The properties of cutting fluid

Appearance – concentrate	Amber liquid
Appearance – dilution	Opaque amber – white
Odor	Bland
Residual film	Soft, Fluid
pH @ 20:1 (5%)	9.1 ± 0.5
Specific gravity @ 60 (F)	0.93 ± 0.03
Lbs/gallon	7.7 ± 0.1
Flash point, PMCC (F)	222