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Three dimensional topographic studies on worn surfaces of coated cemented carbide tools with different workpiece materials

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ABSTRACT

Different worn surfaces were observed when machining different types of workpiece materials using similarly coated cemented carbide inserts. This study focuses on the flank wear within the coating. A clear difference in wear patterns were observed on worn surfaces depending on the workpiece material used. The worn surface was characterized by 3D surface topography using white light interferometry. Additionally, TEM studies were used to increase the understanding between the relations of the workpiece materials to the resulting worn surfaces. The added information from the worn surfaces and TEM investigations can help in better understanding the wear mechanism when machining different workpiece materials.

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Introduction

The topographic characterization of worn insert coating's surfaces is a relatively new field of studies. In literature, very little work has been done for the evaluation with three dimensional (3D) topographic characterizations of different worn surfaces within the same coating type when machining different materials.

In our research we used alumina coated cemented carbide. Alumina has been used as coating for cutting tools since the 1970s [1]. A common concept is a cemented carbide core covered by 3–10 μm Ti(C,N) followed by 2–6 μm Al_2O_3 and with a thin TiN top layer usually deposited using CVD technique. The alumina coating gives the tool a substantial increased tool life thanks to chemical inertness, wear resistance and heat isolation [2]. Common insert wear types during machining are crater wear and flank wear. This paper focuses on methods for characterizing flank wear.

Flank wear occurs when the tool is in contact with the workpiece. It is often suggested to be a result of abrasive wear. While flank wear appears as only a small color difference to the naked eye, groves can often be observed in the flank wear area at higher magnification. By studying the groves, additional information can be obtained about both the workpiece material, and the wear of the cutting tool. Historically, worn surfaces have been characterized qualitatively using Scanning Electron Microscopy (SEM). In later years 3D techniques have been used. Park used confocal laser scanning microscope (CLSM) to evaluate flank wear when turning AISI 1045 (C45E). He related the size of the groves to the size of cementite lamellas in the workpiece material [3]. Wang applied the Phase Shifting Method where four fringes were used to reconstruct a 3D image of the tool for measuring crater wear [4]. Another 3D technique used for wear characterization is white light interferometry, which has been applied for different quantitative wear characterization such as measuring crater wear [5] and wear on CBN edges [6]. White light interferometry was also used in a recent work aiming at better understanding of the wear mechanisms [7]. Here many techniques (SEM, white interferometry, TEM) were combined. It was shown that investigations at high magnification, such as with Transmission Electron Microscopy (TEM), are very valuable for the understanding of the wear mechanism. However, TEM studies are very local (typically at very high magnifications) and should be combined with other methods performed at lower scales.

In this work, we have used SEM and white light interferometry imaging to characterize the flank wear in the alumina coating of inserts having turned five different workpiece materials. Furthermore, the importance of using TEM for increased understanding the wear mechanism is illustrated.

Experimental set up

Turning was performed in an OKUMA LB4000EX lathe using CNMG120408-PM grade GC4325 inserts, using cutting fluid.

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Table 1
Overview of workpiece materials and cutting data (cutting fluid was used in all cases).

	Workpiece material			Cutting data			
	Description	DIN	Hardness HB/HBW	Cutting speed, m/min	Feed rate, mm/rev	Cutting depth, mm	Time in cut, minutes
A	Low alloy steel, non-Ca-treated (SS2541)	34CrNiMo6	300	220	0.2	2	4
B	Ball-bearing steel, spheroidized annealed (Ovako 825B)	100CrMo7-3	214	220	0.2	2	1
C	Austenitic stainless steel, annealed (Sanmac 316L)	X2CrNiMo18-14-3	130	220	0.2	2	2
D	High alloy tool steel, soft annealed (Sverker 21)	X155CrMoV12-1	228	220	0.2	2	1
E	Nickel based superalloy, aged (INCONEL 718)	NiCr19Fe19NbMo3	438	50	0.1	2	4

Cutting data and time in cut have been summarized in Table 1. After machining, the tested inserts were investigated through imaging in scanning electron microscope (Zeiss Supra 55VP) both in backscatter and secondary mode. All investigations of the worn alumina coating were made on the flank face at approximately half depth of cut, as illustrated in Fig. 1. Smearing material was etched away before imaging.

To further study the wear and topography of the wear mark on the flank face, white light interferometry was used to output a 3D topography using a VEECO NT9100. Commercial software were used for topography analysis [8,9]. For sample A (used to turn low-alloy steel) further investigations in micro and nanoscale were performed in TEM using a Tecnai F30ST (FEI Company) operating at 300 kV, with a Tridiem Gatan image filter (Gatan, Inc).

Tool and workpiece material

The insert grade used is a commercially available grade for steel turning consisting of an cemented carbide substrate with an average Co content of 7.2 wt% coated with 9 μm Ti(C,N) followed by 5 μm alumina (α-Al_2O_3) and a thin TiN top layer on the flank face (Sandvik Coromant GC4325). The used insert had a textured α-phase alumina CVD layer.

Five inserts, named A-E, were used on different workpiece materials. Machining time was stopped when the wear was around the middle of the alumina coating, as summarized in Table 1.

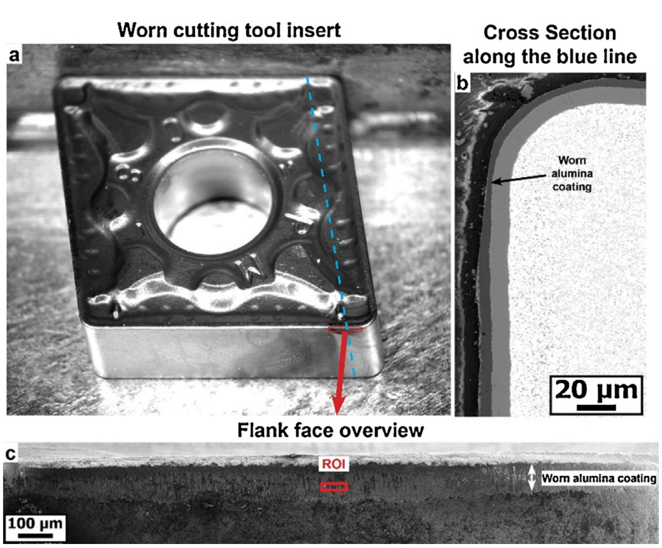

Fig. 1. (a) A worn cutting tool insert. (b) Cross section along the blue dotted line in (a). (c) The investigated worn alumina coating Region Of Interest (ROI). (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

Results and discussion

White light interferometry was used to further study the grooves found on the flank side in the middle of the depth in cut, at the ROI (Fig. 1). The study was made under different scales to check for any repetition occurring at different orders of magnitude. The results obtained for samples A–E are presented in Figs. 2–6 and discussed in the sections below.

Wear surface on flank when machining low alloy steel, non-Ca-treated (sample A)

Fig. 2(a) shows clearly a parallel groove pattern. Some of the grooves are deeper and wider than the others. The same deep groove can be seen in Fig. 2(b) at higher magnification. The groove depth was measured to be around 2 μm. The workpiece material was characterized and alumina particles with an average diameter of 3.3 μm were found. Therefore, the observed grooves fall within the same range of scale as the average alumina particle. The grooves can be the result of the abrasion of the hard particles [7]. The surface area roughness average S_a for Fig. 2(a) was measured to be 225 nm and the filtered groove in Fig. 2(b) has an S_a of 166 nm.

One important feature inside the large groove shown in Fig. 2(a) is a pattern of repetition of grooves. When this same large groove is analyzed on a smaller scale, one can observe smaller grooves inside this larger groove as illustrated in Fig. 2(b). This repeating pattern has similarities to a fractal curve. Accordingly, a fractal dimension D_f with one level of replication can be assigned using Eq. (1):

$$D_f = \frac{\log_n}{\log s^{-1}} \quad (1)$$

where n represents the repeating number of grooves in the larger one and s is the scaling factor. n was determined by counting to be 8 and s^{-1} was determined to be 5.7, yielding a fractal dimension of 1.2.

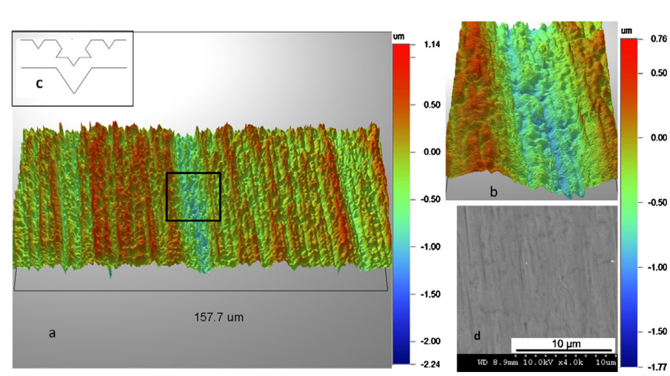

Fig. 2. (a) Topography on the flank side on sample A after turning low alloy steel, (b) enlarged box in (a), (c) Kosh curve [10], (d) SEM on the flank side.

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