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# Microstructure and wear mechanisms of texture-controlled CVD α-$Al_2O_3$ coatings

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ABSTRACT

In the present study, the microstructure and wear mechanisms of texture controlled CVD α-$Al_2O_3$ layers with (001), (012) and (100) growth textures were investigated in single point turning of C45 carbon steel at low and high cutting speeds. The experimental coatings were investigated by FEG-SEM, EBSD and a combination of FIB and analytical TEM techniques prior to and after machining. Significant texture effects on wear performance of the α-$Al_2O_3$ coating layers were observed, confirming results from previous wear studies in the context of machining AISI 4140 carbon steel. The wear mechanisms of the coating layers were further interpreted in the light of thermal, mechanical and frictional conditions occurring at the tool–chip contact interface. Possible deformation mechanisms of the α-$Al_2O_3$ layers under the conditions of high pressure and temperatures acting on the tool surface are discussed. The high dislocation density revealed by the TEM observations in the subsurface α-$Al_2O_3$ layers was attributed to the activation of a basal slip deformation mechanism resulting from the combined action of the shear stress field and high temperature acting on the tool surface. It is suggested that the enhanced and more uniform near surface deformation capability of (001) α-$Al_2O_3$ is responsible for the improved machining performance.

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## 1. Introduction

Recent advances in nucleation and chemical vapour deposition (CVD) technology have led to the development of highly textured wear- and temperature-resistant protective surface coatings for cemented carbide cutting tool applications. In particular, it has been demonstrated that the performance of α-alumina coatings produced by the CVD technique can be enhanced substantially by controlling crystal orientation and growth texture [1].

Previous investigations of wear behaviour of texture-controlled CVD α-$Al_2O_3$ layers in steel cutting has reported that the failure of the α-$Al_2O_3$ layers was often preceded by a degree of plastic deformation that was dependent on the crystallographic orientation of the thin film [2,3]. The best wear resistance was achieved when the (001) crystallographic planes of the α-$Al_2O_3$ layer were oriented in a direction nearly parallel to the coating surface.

The thermal and tribological behaviour of single and/or multilayer CVD coatings during machining have also been reported in several prior investigations [3–7]. It has been suggested [4] that variations in thermal diffusivity between different coatings are controlling the amount of heat flow from the tool-chip contact zone into the substrate. Another study [5] suggests that an $Al_2O_3$ intermediate layer of a CVD multilayer coating provides a thermally insulating layer due to its low thermal conductivity.

Another investigation [6], however, suggests that the thermal response behaviour of a multi-layer coated tool is controlled both by the microcontact configuration at the tool-chip interface and thermal constriction phenomena taking place at the tool-chip-workpiece interface. It has also been reported that the insulation effect of $Al_2O_3$ is substantially mitigated in continuous turning [7].

In a recent study reporting on the wear and thermal behaviour of texture controlled α- $Al_2O_3$ in steel turning [3], a reduction of heat penetration into the cutting tool was observed when a (001) oriented layer was applied on the tool surface when compared to other orientations such as (104) and (012). It was suggested that since the thermal conductivity of (001) α-$Al_2O_3$ is expected to be highest along the c-axis [001], the variations observed between the different coatings orientations in terms of cutting performance were more likely to be related to differences in tribological conditions and deformation properties of the layers on the tool surface.

The aim of the present investigation is to further investigate the

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**Table 1**
Tool geometry, work material and cutting conditions.

| Test number | Work material | Tool geometry (ISO) | Cutting speed $v_c$ [m/min] | Feed rate $f_z$ [mm/rev.] | Depth of cut $a_p$ [mm] | Time in cut [min.] |
|---|---|---|---|---|---|---|
| | Longitudinal dry turning | | | | | |
| 1 | S355J2 (200HB) | CNMG120408 | 250 | 0.35 | 3 | 25 |
| 2 | 100Cr6 (200HB) | CNMG120408 | 250 | 0.35 | 3 | 15 |
| 3 | 42CrMo4 (230HB) | CNMG120408 | 200 | 0.35 | 3 | 25 |
| 4 | 42CrMo4 (230HB) | TPUN160408 | 180 | 0.3 | 3 | 20 |
| 5 | 42CrMo4 (230HB) | TPUN160408 | 240 | 0.3 | 3 | 8 |
| | Longitudinal dry turning and Orthogonal dry cutting | | | | | |
| 6 | C45 (180HB) | TPUN 160408 | 100 | 0.2 | 3 | 3 |
| 7 | C45 (180HB) | TPUN 160408 | 200 | 0.2 | 3 | 3 |
| 8 | C45 (180HB) | TPUN 160408 | 300 | 0.2 | 3 | 3 |

**Table 2**
Texture coefficient values ($\alpha$-$Al_2O_3$ layers) and coating layer thickness ($\mu$m).

| Coating (*hkl*) reflex | A (006) | B (012) | C (300) | D (422) |
|---|---|---|---|---|
| Ti(C,N) | 1.8 | 2.0 | 1.8 | 12.0 |
| $Al_2O_3$ | 10.4 | 13.5 | 10.9 | – |
| TC(*hkl*) | 4.8 | 5.7 | 6.6 | 5.8 |

wear mechanisms of texture controlled CVD alumina coatings and contribute to the understanding of their deformation behaviour in the context of steel turning applications.

## 2. Experimental details

### 2.1. Layer deposition

Four experimental coatings were deposited. Three were bilayer coatings with an inner Ti(C,N) layer followed by an $\alpha$-$Al_2O_3$ layer of either (001), (012), or (100) growth texture, referred to as coatings A, B and C, respectively. The fourth coating, reference coating D, consisted of a single layer of Ti(C,N).

All the coatings were deposited on identical cemented carbide tools. The Ti(C,N) layers were deposited at a temperature of about 860 °C from a gas mixture of $CH_3CN$-$TiCl_4$-$H_2$-$N_2$. The $\alpha$-$Al_2O_3$ layers were deposited from the $AlCl_3$-$CO_2$-$CO$-$H_2S$-$H_2$ system at 1000 °C. The growth textures in the $\alpha$-$Al_2O_3$ layers were obtained by process adjustments during deposition [2].

### 2.2. X-ray diffraction (XRD) and texture analysis for $\alpha$-$Al_2O_3$ layers

Texture for the $\alpha$-$Al_2O_3$ layers were evaluated using texture coefficients, TC, calculated using the following equation:

$$TC(hkl) = \frac{I(hkl)}{I_0(hkl)} \left\{ \frac{1}{n} \sum \frac{I(hkl)}{I_0(hkl)} \right\}^{-1} \quad (1)$$

where I (*hkl*) are the measured intensities of the (*hkl*) reflection, $I_0$ (*hkl*) are the powder diffraction intensities according to the JCPDS card no 46-1212 and n is the number of reflections used in the

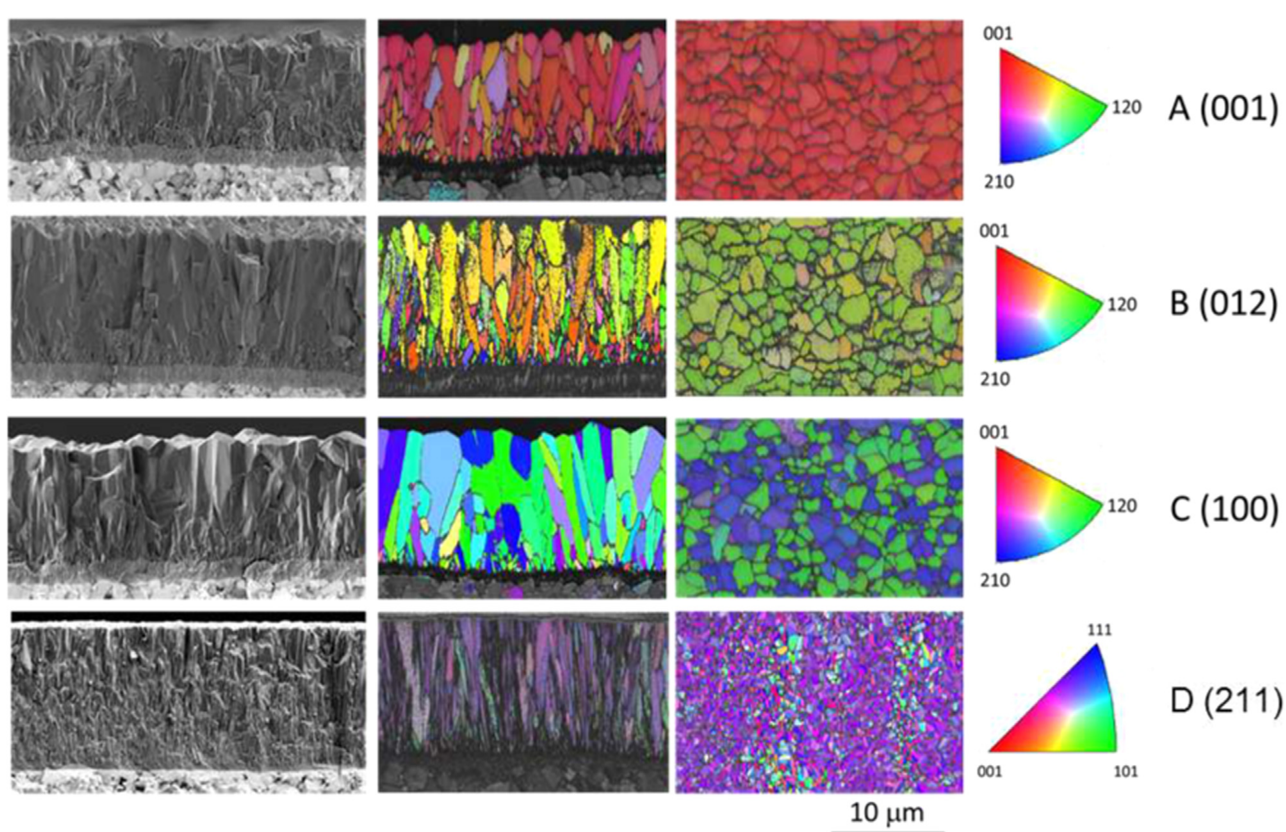


**Fig.1.** SEM images of fractured cross-sections (left), corresponding EBSD cross section (middle) and EBSD top surface (right) maps for coating sample A, B, C and D.

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