In situ analysis of inner strains in CBN cutting tool materials under mechanical load

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Cubic boron nitride (CBN) cutting tools must withstand high mechanical and thermal loads in hard machining applications. Due to the low contact area and great forces between work piece and tool very high temperatures and stresses act on the cutting material. CBN cutting materials are composites which contain small CBN grains embedded in a ceramic or metallic binder. Tools with high or low CBN content are fabricated. The composite character of the material contributes to the complexity of inner stress and strain conditions. To investigate the materials response on external thermo-mechanical loading an in situ analysis using high energy synchrotron radiation during external loading was done. This report deals with the results from mechanical loading.

Experiments were performed at the HEMS beamline P07 of PETRA III using monochromatic synchrotron radiation with an energy of 80 keV, corresponding to a wavelength of 0.1555 Å. Beam size was defined to 50 x 50 µm² using an optical lens system at an exposure time of 2 s. Diffraction patterns were recorded using a XRD 1622 flat panel detector (Perkin Elmer, USA) with a sample-to-detector distance of 1932.8 mm. The experimental set-up consisted of a four point bending set-up as described in previous investigations [1]. The bending unit was mounted onto a heavy load hexapod (Physik Instrumente, Germany) which could be moved in x-, y-, and z-direction for alignment of the samples in the incident beam. Three different kinds of CBN materials were investigated (see Fig. 1a): DSC500 was a solid bar made of low CBN content with titanium carbide (TiC) as binder. DCC500 was a bilayer bar with a cemented carbide as substrate that carried a CBN layer which matches the composition of DSC500. DBW85 was a bilayer bar with high CBN content and a metallic binder (AlWCoB). The geometry of all samples was 35 x 2 x 2mm³ (see Fig. 1a), but there was a variation in the CBN layer height. DCC500 had a CBN layer height of 780 µm and DBW85 of 860 µm.

At first, a reference measurement was done without applying any load. Afterwards an external mechanical load was applied and increased in steps of 100 MPa up to 600 MPa. Each load condition for every specimen was investigated with a measurement series respectively. The measurement pattern consisted of a line of single spots every 50 µm across the sample height (see Fig. 1b). The bilayer specimens were placed with the CBN layer facing up. The internal strains were derived from the peak shifts in the diffraction patterns. These peak shifts were directly related to the change of lattice plane spacing [1].

Figure 1: Sketch of specimens (a) and measurement pattern (b).

Results of the solid sample DSC500 show the internal strains in ε₁₁ direction of the two major phases: CBN (see Fig. 2a) and TiC (see Fig. 2b). Strain during loading shows a linear behavior over the sample height. Greater external load causes greater internal strain. Compressive load prevails in
the upper half of the bar which results in negative strain. In contrast, in the lower half of the bar tensile load is predominant and causes positive lattice strains. Comparing the different phases in one composite, different strains can be observed. The TiC phase shows higher strain than the CBN phase at the same loading condition. These results suit a material behavior stated by Reuss, who proposed that all grains are exposed to the same stress but can obtain different strains [2]. Thus, the different strains in the phases can be explained with their different Young’s moduli. CBN (E = 680 GPa) has a greater Young’s modulus than TiC (E = 460 GPa) [3, 4].

Results from the bilayer samples show the internal strains of DCC500 and DBW85 at an external load of 600 MPa (see Fig. 3). Since both bilayer bars were placed facing up with the CBN layer, predominantly negative strain can be seen in the penetrated area. DCC500 also shows different strains in the CBN phase and the TiC phase respectively (see Fig. 3a). The influence of crystallographic orientation is negligible on strain. The strain of TiC close to the interface shows deviation from the linear behaviour. This is related to changes of chemical composition close to the interface. The strain in DBW85 shows a stronger scattering of values than the strain in DCC500 (see Fig. 3b). Tungsten carbide (WC) (E = 690 GPa) and CBN have similar strains which correspond to their similar Young’s moduli [3]. The cobalt nitride phase (Co$_{0.47}$N) expands even more than the TiC. Hence, the Young’s modulus of Co$_{0.47}$N must be smaller than the Young’s modulus of TiC. There is no accurate value reported in literature. In conclusion, in spite of different binder, CBN content, and CBN layer height, similar strain can be determined in the CBN phase.

References