In situ measurement of lattice strains in mixed ceramics under static thermal and mechanical loads

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A complete characterization of the wear behavior of mixed ceramic cutting tools for hard turning applications is important to optimize tool materials and prevent ultimate failure through fracture. Therefore, the inner stress states in mixed ceramics in superposition with external loads during hard turning should be investigated. To determine the internal stresses in the material during machining, lattice strains need to be measured in situ. This can be done via X-ray diffraction using high energy synchrotron radiation. In first model tests internal strain states in mixed ceramics were measured under static thermal and mechanical loads.

Diffraction experiments were carried out at the HEMS beamline P07b of PETRA III using monochromatic synchrotron radiation with an energy of 87 keV, corresponding to a wavelength of 0.0143 nm. Beam size was defined to 0.2 x 0.2 mm^2 with a high precision slit system. The sample was illuminated in transmission at an exposure time of 7 s. Diffraction patterns were recorded using a 2D flat panel detector (Perkin Elmer XRD 1622 AO, US) with a pixel size of 200 x 200 μm^2 and a sample to detector distance of 2000 mm. A self-made testing setup was used to expose samples to thermal and mechanical loads during diffraction experiments (see Fig. 1).

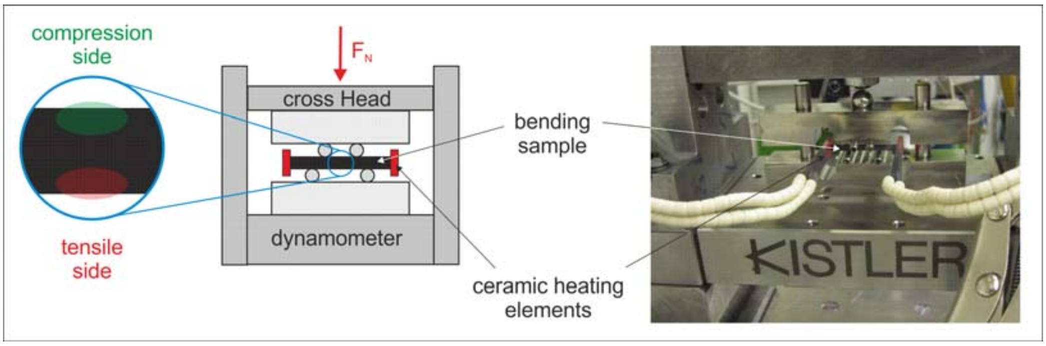

Figure 1: Setup for application of thermal and mechanical loads.

Bending bars of mixed ceramics (65 wt-% Al_2O_3, 30 wt-% Ti(O,C), 5 wt-% ZrO_2) were fabricated with dimensions of 3 x 2 x 35 mm^3 according to standard procedure [1]. Static thermal loads in the range of 490 °C to 670 °C and mechanical loads from 100 to 600 MPa were applied to the samples while lattice strains in the different phases of the mixed ceramic were recorded (see Fig.2). For bending experiments, two measuring positions were placed on the sample, one in the compression zone and one in the tensile zone of the bending bar. Results from temperature experiments show linear expansion of the lattice parameters with increasing temperature for the two main phases of the mixed ceramic. Ti(O,C)-phase shows about ~ 10 % higher thermal expansion of the lattice parameter than Al_2O_3-phase. Coefficients of thermal expansion were calculated from the linear slope (Fig. 2A) and show values of $2.25 \cdot 10^{-6}$ 1/K and $2.05 \cdot 10^{-6}$ 1/K for Ti(O,C) and Al_2O_3, respectively. This leads to the fact, that upon cooling from the sintering temperature Al_2O_3 suffers compression whereas Ti(O,C) suffers tension in the mixed ceramic material [2]. Results from bending experiments show that elastic lattice strains are equal in both phases and for all crystallographic directions (see Fig. 2B). This means that material's behaviour is in accordance to Voigt [1]. By application of thermal and mechanical loads simultaneously, compression and tension curves shift to higher lattice strains because of the superposition of lattice strains from bending with lattice strains from thermal expansion.

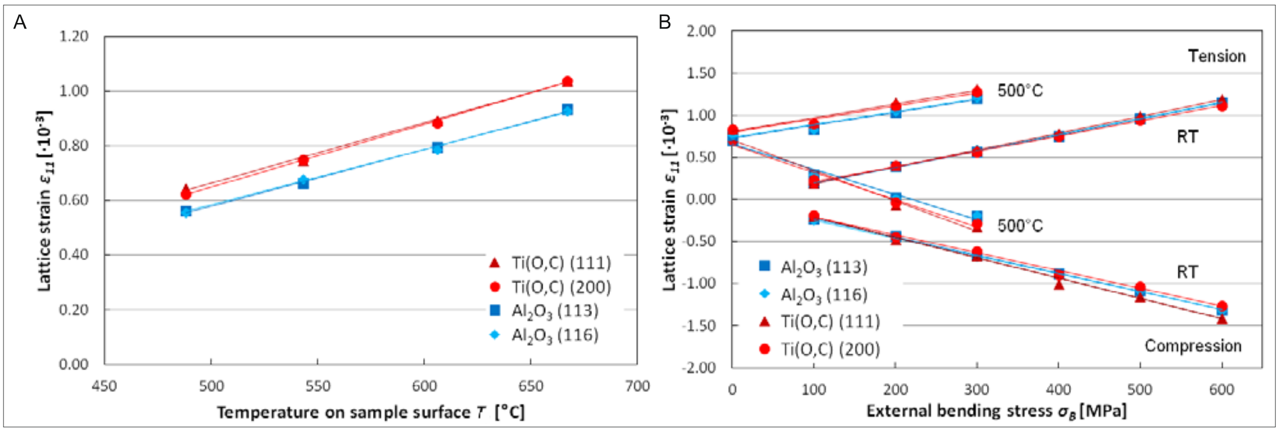

Figure 2: Elastic lattice strain components of the different phases of the mixed ceramic material under (A) thermal, (B) mechanical (RT = room temperature) and thermomechanical (500 °C) load [2].

From measured lattice strain components (ε_{11} and ε_{22}, assumption of a plane strain state $\varepsilon = 0$) the stress states in σ_{11}- and σ_{22}-direction of the Al_2O_3- and the Ti(O,C)-phase can be calculated according to Hooke's law [2]. With increasing external bending stresses also normal stresses increase in both phases in the same order of magnitude (see Fig. 3A). Lattice stresses perpendicular to the external bending stress are lower in value and differ for both phases due to transverse contraction and differences in Poissons' ratio for Al_2O_3- and Ti(O,C)-phases (see Fig. 3B).

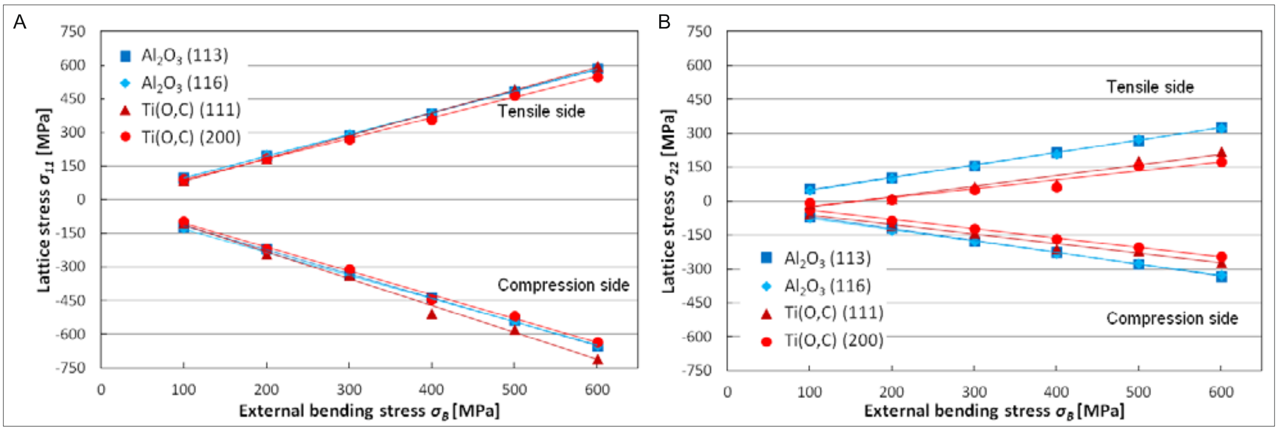

Figure 3: Calculated inner stresses (A: in direction of bending stress, B: in direction perpendicular to bending stress) of the different phases of the mixed ceramic material under bending load [2].

For further details of the results see [2].

References

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