Stress-strain evaluation of mixed ceramics under thermal and mechanical loads using x-ray diffraction

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Mixed ceramic cutting tools for hard turning applications must withstand high thermal and mechanical loads in order to manifest high wear resistance. In hard turning usually high cutting and radial forces act on small contact areas and thus lead to high compressive stresses [1]. At the same time high thermal loads up to 1500 °C develop in the cutting zone because of high plastic deformation of the workpiece [2]. As a consequence high tool wear occurs. To date characterization of different wear mechanisms is done only in terms of empirical testing or optical examination of wear evolution [3] but not by residual stress analysis. To completely understand wear mechanisms in ceramic cutting tools it is necessary to investigate the superposition of external thermal and mechanical loads with the internal stress / strain distribution. This could be done using high energy synchrotron radiation to determine residual stress states in-situ during friction and turning tests. For these advanced experiments various model tests are required. Therefore, in order to determine the effects of external loads on the macroscopic stress / strain states in mixed ceramics (62 % Al_2O_3, 32 % Ti(O,C), 6 % ZrO_2) first model tests were carried out recording diffraction spectra of the samples at an elevated temperature and under constant loads respectively.

Experiments were performed at the HEMS beamline P07 of Petra III using monochromatic synchrotron radiation with an energy of 100 keV, corresponding to a wavelength of 0.1237 Å. Beam size was defined to 0.4 x 0.4 mm² and 0.2 x 0.2 mm² using an optical lens system. Diffraction pattern were recorded using an image plate detector (mar345, Marreasearch GmbH, Germany) with a sample-to-detector distance of 2050 mm. Two different experimental set-ups (see Fig.1) where 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.

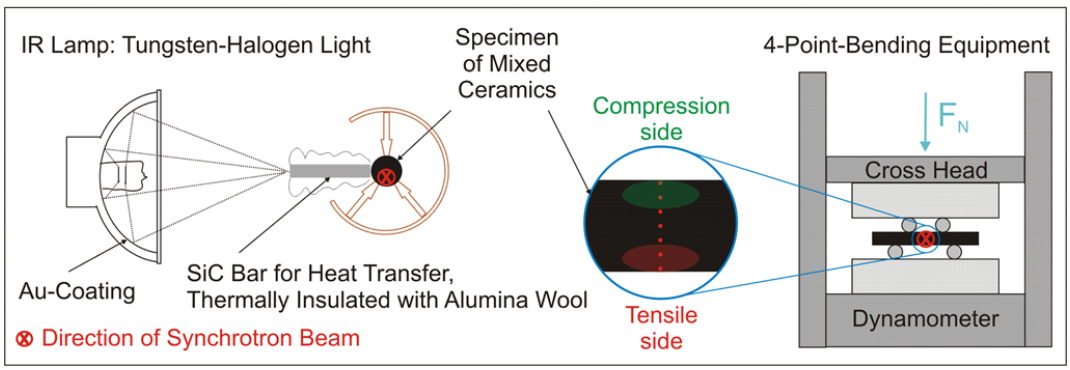

Figure 1: Sketch of experimental setup.

In the first set-up cylindrical samples (9 mm in diameter, 3 mm thick) were heated up to 450 °C using an infrared tungsten-halogen lamp (self-made TUHH). In the second set-up bending bars with dimensions of 3 x 2.5 x 35 mm³ were exposed to normal forces of 300, 400, and 550 N using a 4-point-bending equipment. Various measuring points were placed on the sample in vertical direction

to detect the tensile side and the compression side of the bending bar separately. For the temperature tests peak shifts are obtained which are equal for all ceramic phases (see Fig. 2A). For the bending tests shifts to larger and smaller Bragg angles are observed corresponding to the compression and tensile sides in the bending test specimen (see Fig. 2B).

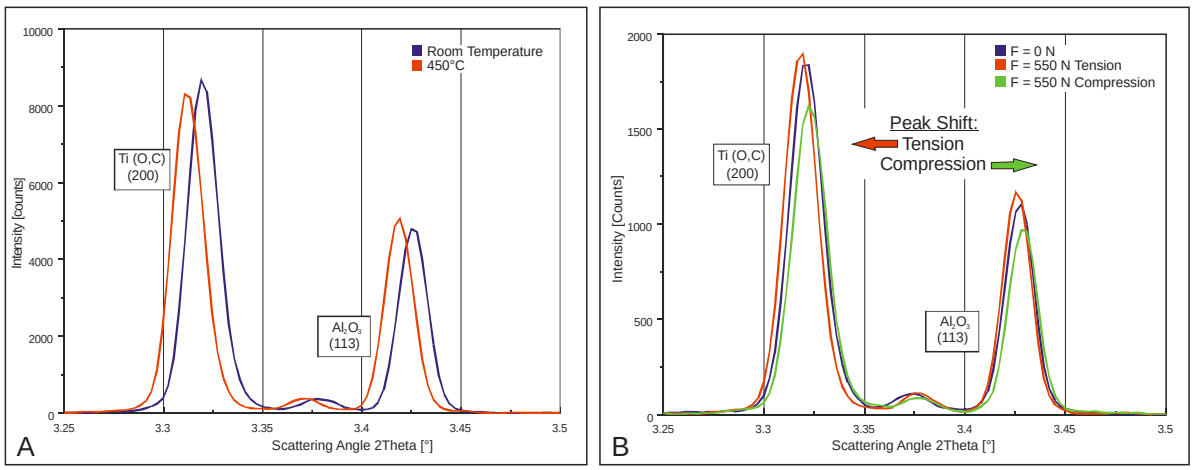

Figure 2: Diffraction spectra of mixed ceramics (A) at elevated temperature, (B) during bending.

Also a variation of lattice strains in different crystallographic directions due to the lateral contraction could be measured. Fig. 3 gives an overview of the crystallographic strains of the phases Al_2O_3 and Ti(O,C) depending on increasing bending stresses. These results can be explained on the basis of a simple Voigt-type polycrystalline stress / strain state, i.e. the elastic strains for all constituent phases are roughly equal.

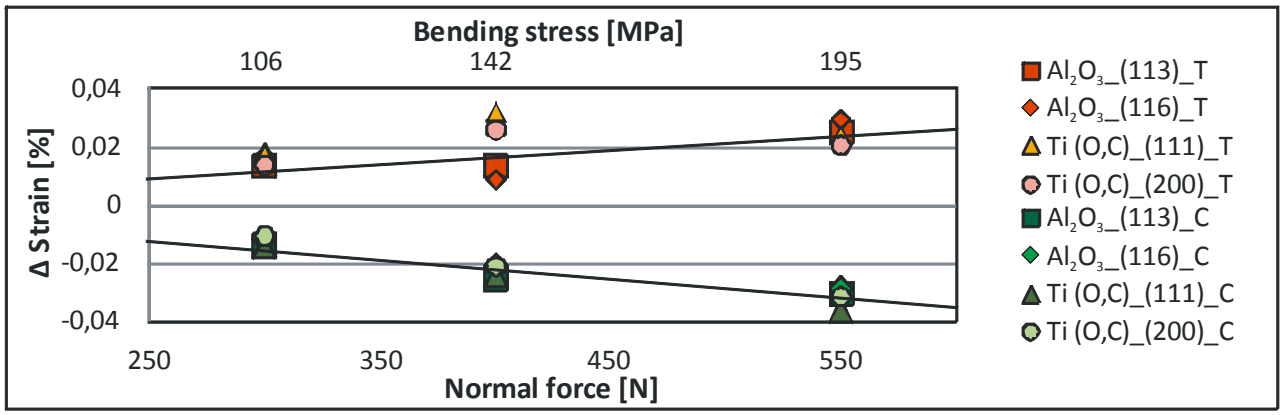

Figure 3: Strain distribution under different loads of compression (C) and tension (T).

This is only a first result that has to be improved by more accurate measurements of the lattice strains which are needed for a precise calibration of the lattice strains with the macroscopic stress. Beyond that, the microscopic stress / strain distribution between the two constituent phases could be investigated. Thus, further experiments will be carried out at P07 soon.

References

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