ESRF	**Experiment title:** Analysis of the Triaxial State of Stress in Ceramic – Metal Functional Gradient Materials	**Experiment number**: HS-545
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Report:

Functionally graded materials (FGM) are well-known to improve the properties of technical devices such as thermal barrier systems, because cracking or spalling, which are often observed in conventional two-layer systems, are avoided due to the smooth transition between the components. Nevertheless the differences in the coefficients of thermal expansion (CTE) of the ceramic and metallic components lead to the formation of residual stresses, which may be critical for the integrity of the composite.

The non-destructive analysis of the phase specific residual stresses in FGMs is restricted to the diffraction methods. In comparison with the neutron diffraction, high energy synchrotron radiation offers the possibility to analyse the triaxial stress state within a considerably smaller gauge volume, so enlarging the spatial resolution. Thus, the method is suited for the evaluation of the residual stress distributions in FGMs with even steep compositional gradients.

A microwave sintered Ni/8Y-ZrO_2 FGM with a thickness of 6mm (manufactured at the University of Dortmund, Department Chemical Engineering, Div. Material Sciences) consisting of 11 individual layers with 0, 10, 20,...,100 vol.% Ni was analysed with regard to the phase-specific residual stresses within both, the metal and the ceramic phase.

The experiments were carried out at the beamline ID15/a using the white beam (energy range from 50 to 250keV). The gauge volume was limited to 0.15 x 0.15 x 1.6 mm^3 by slits in the primary as well as in the diffracted beam. The diffracted intensities were recorded by means of an energy dispersive Germanium Detector. To evaluate the stress-free lattice spacings $d_{0,hkl}$, measurement at corresponding powder samples were performed. Using DE BROGLIE's relation as well as BRAGG's law, the shifts of the energy profiles were transformed into the lattice strains $\varepsilon_{hkl} = d_{hkl}/d_0 - 1$. Finally, applying HOOKE's law yields the average values of the phase specific residual stresses $\langle \sigma_\alpha \rangle$.

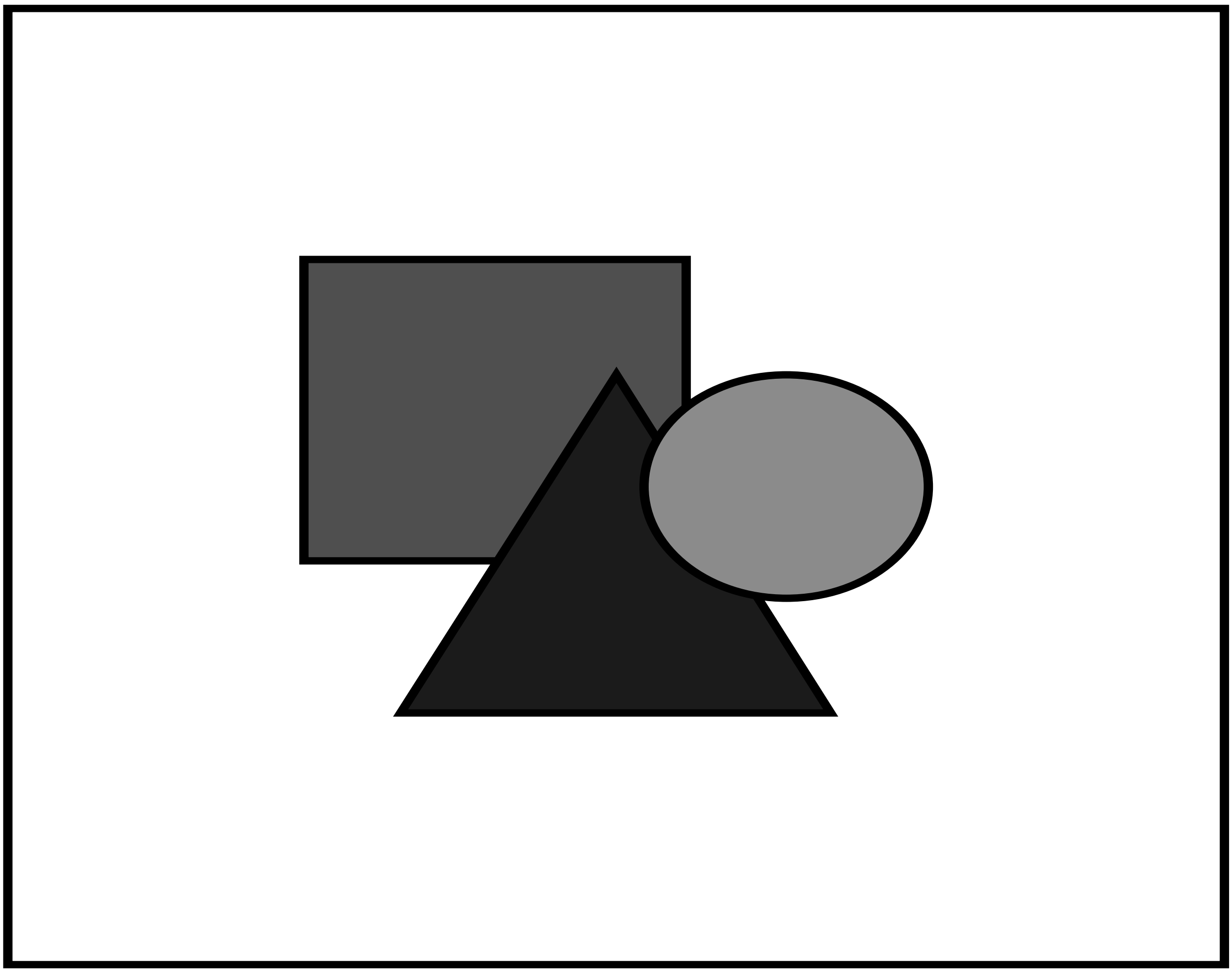

Fig. 1: a) phase specific and macro residual stresses in a Ni/8Y-ZrO$_2$ – FGM as a function of the volume fraction; b) phase specific residual stress distribution of the ceramic in one composite interlayer

Due to the lower CTE of the ceramic phase compressive residual stresses were detected in the Zirconia which are partially compensated by tensile residual stresses in the ductile metal component. On the macroscopic scale two local maxima of compressive residual stresses, one in the ceramic rich area and one in the metal rich area are observed (Fig. 1a)).

Due to the small size of the gauge volume the analysis of the residual stress distribution even in an individual sublayer of the FGM is possible. Corresponding measurements have been performed on the FGM NiCr8020/8Y-ZrO$_2$. Fig. 1b) shows the results obtained for the ceramic component. Here high compressive stresses are observed as a consequence to its small CTE. The measurements show clearly the non-uniform distribution of the stresses even within a composite interlayer.

The experimental results obtained by high energy synchrotron diffraction give clear evidence for the suitability of this method in the field of triaxial residual stress gradient analysis within the bulk of polycrystalline materials. Compared with neutron diffraction methods, considerably shorter exposure times as well as improved spatial resolution are achieved.