DETERMINATION OF THERMAL RESIDUAL STRESSES IN ALUMINA REINFORCED WITH CHROMIUM – THE GRAIN SIZE EFFECT

W. Węglewski, M. Basista, M. Krajewski, and K. Bochenek
Institute of Fundamental Technological Research, Polish Academy of Sciences, Pawinskiego Street 5B, 02-106 Warsaw, Poland
e-mail: wweglew@ippt.pan.pl

1. Experimental determination of thermal residual stress in alumina matrix

In ceramic-metal composites thermal residual stresses (TRS) are inherently present mainly due to different coefficients of thermal expansion of the phase materials. Such stresses may trigger microcrack nucleation and growth especially in the ceramic phase. Therefore, determination of TRS is of continuing research interest both in experimental mechanics and materials modelling.

In this communication we present experimental measurements and numerical simulation of processing-induced thermal residual stresses (TRS) in aluminium oxide (alumina) matrix reinforced with chromium particles (60vol.%Al_2O_3/40vol.%Cr). This ceramic-metal composite was manufactured by powder metallurgy route comprising powder mixing in a planetary ball mill and consolidation by hot pressing (HP). Two different chromium powders (mean particle size of 5 μm and 45 μm) were used. The alumina particle mean size (1 μm) was kept constant in all experiments.

The average residual stresses in alumina matrix have been determined applying two optical methods: photoluminescence piezo-spectroscopy (PLPS) and Raman spectroscopy (RS). For comparison the TRS are also measured using two diffraction methods: neutron diffraction (ND) and X-ray diffraction (XRD) [1] and the results are shown in Fig. 1. These four experimental techniques reveal a size effect of chromium particles on the magnitude and sign of the average residual stress in the alumina matrix. When the fine chromium powder (5 μm) is used the average residual stress in the ceramic phase is tensile, whereas for the coarser chromium powder (45 μm) it becomes compressive (Fig.1).

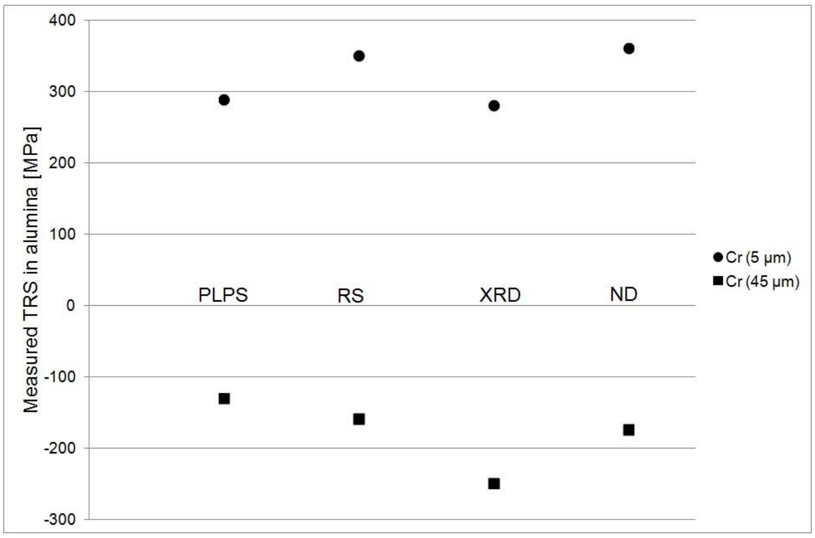
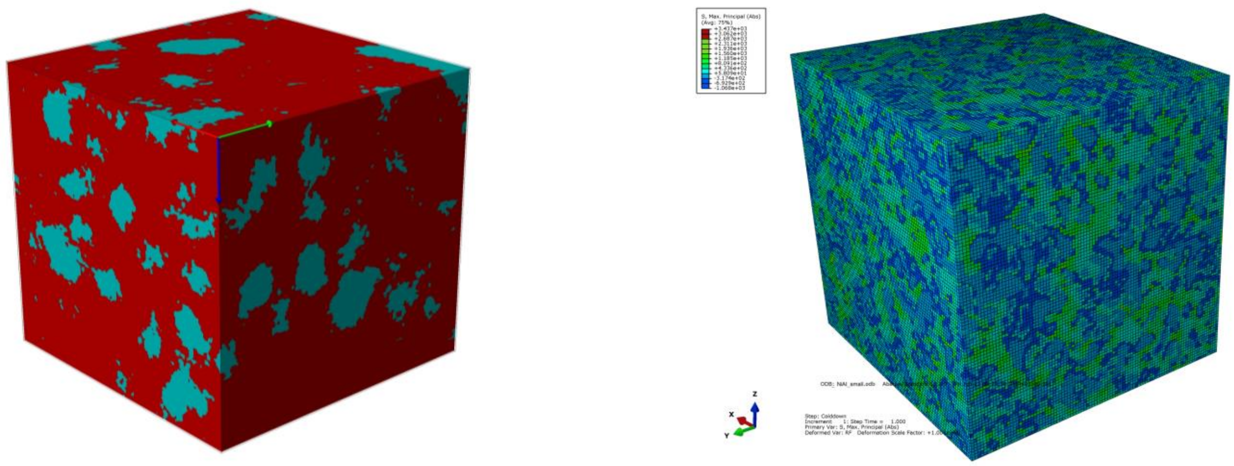


Fig. 1. Experimental measurements of average residual stress in the alumina matrix of 60vol.%Al_2O_3/40vol.%Cr composite as obtained by photoluminescence piezo-spectroscopy (PLPS), Raman spectroscopy (RS), neutron diffraction (ND) and X-ray diffraction (XRD).

2. Discussion of experimental results and modelling approach

The unexpected effect of the sign change of average TRS in the alumina matrix (Fig. 1) has been consistently detected by the four experimental methods and cannot, thus, be deemed as an artefact of any specific measuring technique. Also, by a series of additional PLPS tests and by the neutron diffraction measurements we have ruled out a possibility that the TRS sign change is a surface effect. A plausible explanation of the influence of the size of metal particulates on the TRS in the alumina matrix has been sought using models based on the Eshelby solution of an inhomogeneous inclusion with eigenstrain embedded in an elastic matrix (e.g. [2]). These models allow for determination of the average stresses in ceramic matrix and metal particulates depending on the volume fraction of inclusions, the misfit strains stemming from CTE's difference, and elastic constants of matrix and inclusions. However, using the Taya et al. [2] solutions the average TRS in alumina is compressive, which contradicts our experimental data for 5 μm chromium powder. Apparently, such micromechanical models do not account for the fluctuating stresses caused by complex microstructure that could be a source of the TRS behaviour as shown in Fig. 1.

A more realistic approach seem to be offered by numerical models based on real material microstructures obtained from micro-CT [3], [4]. In such models the inclusions are not approximated by ellipsoids like in the Eshelby solution but micro-CT images of a composite microstructure reflecting the size and mutual position of metal reinforcing particulates are transformed into a finite element mesh using a dedicated software (cf. Fig. 2a). The TRS are then computed by the FEM solving the heat transfer problem of cooling from the high sintering temperature to room temperature (cf. Fig. 2b). This numerical model of TRS in alumina is now in progress. The results will be presented and compared with the experimental measurements.



a) b)

Fig. 2. Micro-CT based FEM model for TRS in alumina-chromium composite: (a) FE mesh obtained from micro-CT images, (b) TRS distribution in ceramic matrix and metal reinforcement computed with Abaqus. .

3. Acknowledgment

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4. References

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