An unusual grain size effect in measurements of thermal residual stress in alumina-chromium composites – explanation by modelling

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We present experimental measurements and numerical simulations of processing-induced thermal residual stresses (TRS) in aluminium oxide (alumina) reinforced with chromium particulates (60vol.%Al2O3/40vol.%Cr). This composite was manufactured by powder metallurgy method using two chromium powders (5 µm vs. 45 µm particle mean size), while the mean size of alumina particles (1 µm) remained unchanged in all experiments.

The average TRS in alumina were determined by two optical methods: photoluminescence piezo-spectroscopy (PLPS) and Raman spectroscopy (RS). For comparison the TRS were also measured using two diffraction methods: neutron diffraction (ND) and X-ray diffraction (XRD). The four experimental techniques have revealed a systematic size effect of chromium particles on the magnitude and sign of the average residual stress in the alumina. When the fine chromium powder (5 µm) was used the average TRS in the ceramic phase was tensile what contradicted the predictions of micromechanical models based on the Eshelby solution. When the coarser chromium powder (45 µm) was used the measured average TRS in the ceramic phase was compressive as expected.

Assuming that this unusual size effect was caused by the complex composite microstructure, which cannot be captured by the classical models of micromechanics, a plausible explanation was sought using numerical simulations based on microscopic images of the material microstructure. The effective coefficients of thermal expansion (CoE) of the two composites were computed by FEM using SEM images of the microstructure. The numerical results were compared with the experimentally measured values of CoEs. A significant effect of the composite microstructure on the CoEs was identified as a potential source of the anomalous residual stress behaviour of the composite with small Cr particles.

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