Modelling of thermal residual stresses and fracture in metal-ceramic composites

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Abstract

In processing of metal-ceramic composites thermal residual stresses may result from different CTEs of the constituent materials, variable cooling rates inside the bulk material, or irregular pore shapes causing thermal stress concentrations. This paper investigates the interplay between material microstructure and processing-induced thermal residual stresses (TRS) in particulate bulk metal-matrix composites (MMC) and infiltrated phase composites (IPC) with the main objective to explore the combined effect of TRS and microstructure on the macroscopic mechanical properties (E modulus, bending strength, fracture toughness) of the composite. The main focus is on numerical modelling of TRS, fracture toughness and effective elastic properties, while taking into account the real material microstructure from micro–computed tomography (micro-CT) experiments.

The modelling methodology will be developed on examples of a hot pressed chromium-alumina bulk MMC doped with rhenium and on an IPC obtained by squeeze casting infiltration of an alumina porous preform with molten Al alloy or Cu. Our interest in these particular composites is motivated by their potential applications in transport and energy sectors. The paper will include highlights on the processing technologies used (HP, SPS, ceramic tape casting/squeeze casting infiltration), microscopic analysis of material microstructure with special focus on micro-CT scanning, measurements of TRS by neutron diffraction (ND) method, and numerical modelling of TRS by FEM using micro-CT images of real material microstructure.

A numerical micro-CT based model developed to predict the TRS, Young's modulus with account of TRS-induced damage of the ceramic phase will be shown (cf. Fig. 1). The grain size effect on TRS and Young's modulus will be addressed. A good predictive capability of these TRS models was achieved which may become important considering the cost of beam time for ND experiments at neutron sources.

Another model to be presented is concerned with micro-CT FEM modeling of fracture in infiltrated metal-ceramic composites. The model accounts for crack bridging toughening mechanism, large plastic deformations of metal ligaments, and matrix-ligament decohesion. Here the results on *J integral* in the case of compact-tension test specimen made of real interpentrating phase composite will be discussed.

Finally, the large pool of obtained experimental data and modelling results will be wrapped up and conclusions will be drawn.

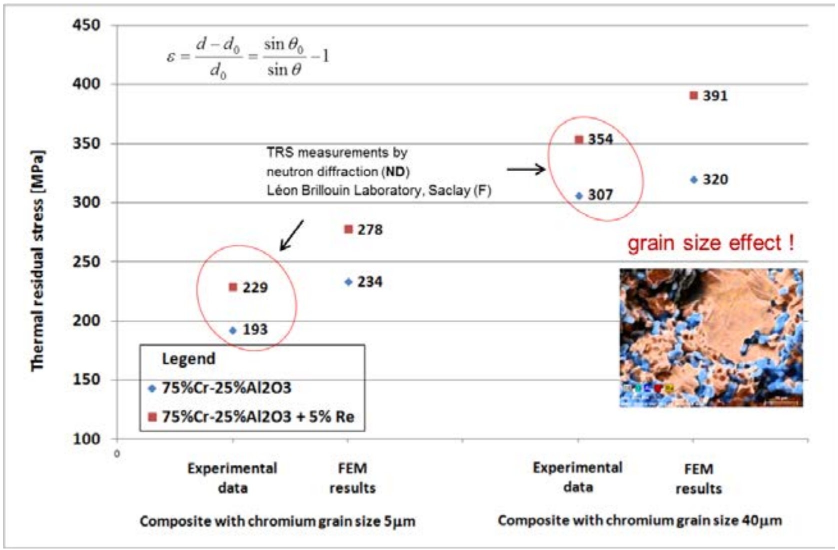

Fig. 1. Thermal residual stresses in $Cr(Re)/Al_2O_3$: experimental data vs. numerical results