

# NUMERICAL MODELING OF FRACTURE TOUGHNESS OF METAL-CERAMIC INTERPENETRATING PHASE COMPOSITES WITH ACCOUNT OF MATERIAL MICROSTRUCTURE

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## Introduction

The motivation for research on interpenetrating phase composites and possible applications of these novel materials were given in [1]. A rationale behind designing an IPC is to achieve a highly durable material that would combine the most desirable properties of the constituent phases: the high hardness and wear resistance of ceramic and improved fracture toughness and thermal conductivity due to the metal content. The interpenetrating metal-ceramic composites may have remarkable applicability in different sectors of industry, e.g. automotive and aerospace. They should, thus, be carefully investigated in terms of processing routes, material properties and modeling of material response to service conditions.

A 3D FEM model in ABAQUS of the fracture parameters and crack growth in bi-continuous metal-ceramic composites with interpenetrating microstructure (IPC) is proposed. The crack is modeled using the extended finite element method (XFEM) [4]. The  $J$ -integral and fracture toughness  $K_{Ic}$  are determined for a real IPC microstructure obtained from micro-CT images. The fracture parameters (i.e. fracture toughness  $K_{Ic}$ ,  $J$  integral, crack opening displacement) are key mechanical characteristics of IPC composites because of the brittleness of the ceramic phase. The main effects occurring in metal-ceramic IPC during fracture are described (cf. [2], [3]).

## Modeling of fracture toughness $K_{Ic}$ of metal-ceramic IPC

The real IPC microstructure obtained via computed microtomography (micro-CT) (Fig.1c) was incorporated in the present model to give the most accurate microstructure representation. The microstructure images obtained with micro-CT were transformed into a finite element mesh using Simpleware ScanIP/FE software. A scheme of the Compact-Tension (C-T) test model (Fig. 1b) created with ABAQUS for a copper-alumina IPC with the real microstructure in the vicinity of the crack, is depicted in Fig. 1. The effective properties of the composite without a crack were obtained with earlier developed analytical models [5] (Fig. 1a). The IPC microstructure was introduced into the model of the C-T specimen in front of the crack tip. The alumina preform was modeled as isotropic elastic, while the copper infiltrating phase as isotropic elasto-plastic with isotropic hardening.

In computations 730322 (outer part) + 216000 (real material part) solid C3D8 finite elements were used. Large strains locally occurring in the metal ligament necking zone were determined by an incremental algorithm. The surface interaction between copper and ceramic was modeled as cohesive, using the results of [6]. Since large microstructure data was involved, only a small volume near the vicinity of the crack tip was modeled using the micro-CT scans, with the remaining part taken as an effective elastic medium. Submodeling was used to combine the calculations for both subdomains of the specimen, with results from the outer part transferred onto the real material part through the layer of common nodes. Moreover, only a slice of the CT specimen of approx. 0.5mm thickness was considered in the ABAQUS calculations. A displacement-controlled quasi-static loading was applied to make the crack growing.

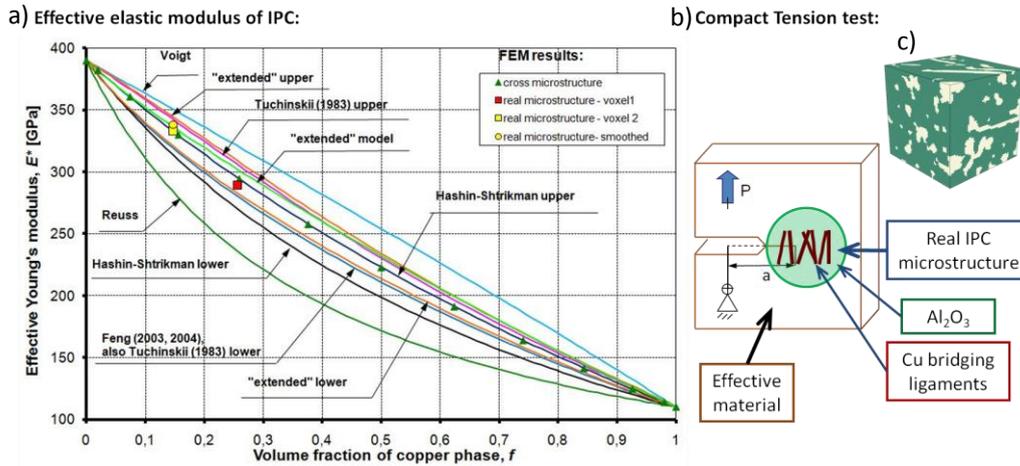


Figure 1. Model of a compact tension test of Cu- $Al_2O_3$  IPC specimen (b) with real material microstructure (c) ahead the crack front and effective elastic properties (a) elsewhere.

The  $J$  integral was calculated along the crack front at 25 contours. The fracture toughness  $K_{Ic}$  was derived from the obtained values of  $J$  integral. Besides the fracture parameters the crack growth was also modelled. In Fig. 2 the predicted crack front at a chosen time point is presented.

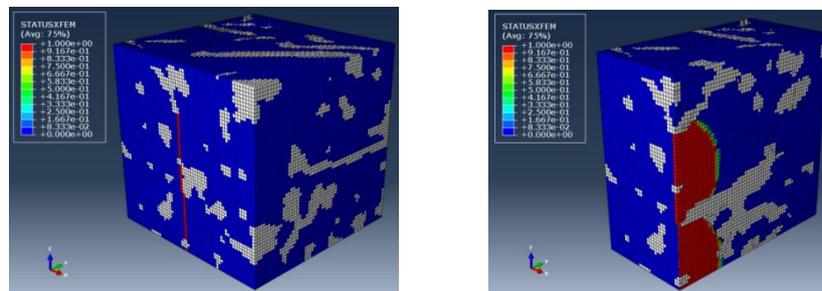


Figure 2. Growing crack front (in red) as predicted by the present model: front view (left) and cut-through along the crack path (right)

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## References

- [1] M. Basista and W. Węglewski (2006). Modelling of damage and fracture in ceramic-matrix composites - an overview, *J. Theor. Appl. Mech.*, **44**, 455-484.
- [2] D. Gross and T. Seelig (2006). *Fracture Mechanics with an Introduction to Micromechanics*, Springer, Berlin.
- [3] P. A. Mataga (1989). Deformation of crack-bridging ductile reinforcements in toughened brittle materials, *Acta Metall.*, **37**, 3349-59.
- [4] T. Belytschko and T. Black (1999). Elastic Crack Growth in Finite Elements with Minimal Remeshing, *Int. J. Num. Meth. Eng.*, **45**, 601-620.
- [5] Z. Poniznik, V. Salit, M. Basista and D. Gross (2008). Effective elastic properties of interpenetrating phase composites, *Comp. Mat. Sci.*, **44**, 813-820.
- [6] Z. Poniznik, Z. Nowak and M. Basista (2015). Numerical modeling of deformation and fracture of reinforcing fibers in ceramic-metal composites, *Int. J. Damage Mech.*, DOI: 10.1177/1056789515611945, 1-24.