MODELLING OF EFFECTIVE ELASTIC PROPERTIES AND CRACK BRIDGING IN METAL-CERAMIC INTERPENETRATING PHASE COMPOSITES

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1. Introduction

The metal-ceramic interpenetrating phase composites (IPC) are usually processed by pressure assisted or pressureless infiltration of molten metals into porous ceramic performs. They have characteristic microstructure different than typical MMC or CMC with particulate or fiber reinforcement. The main difference is that both metal and ceramic phases are spatially continuous forming complementary 3D skeletons of non-zero stiffness. The uniform microstructure, enhanced mechanical and thermal properties are the main advantages of IPC. A state-of-the art in fracture and damage modelling of IPC can be found in [1], while models of effective properties in [2] and [3].

The objective of this paper is twofold: (i) to model the effective elastic properties of IPC, and (ii) to model the fracture in IPC with the crack bridging being the major toughening mechanism. The developed models are verified on the example of Al_2O_3-Cu infiltrated composites.

2. Modelling of effective elastic properties

The effective elastic constants of IPC can be determined using a number of different methods. Firstly, simple estimates of Voigt, Reuss and Hashin-Shtrikman were computed. Secondly, analytical models of Tuchinskii and Feng [2] based on the cross unit cell (Fig. 1) were implemented since the models based on the Eshelby's solution are inapplicable for IPC. Here the original authors' contribution was the correction and extension of the generic Tuchinskii's model (curves denoted as "extended bounds" and "extended model" in Fig. 3). Thirdly, numerical methods accounting for a real composite microstructure were developed and used for Al_2O_3-Cu microstructure acquired from the computer micro-tomography (CT) images (Fig. 2a). The following numerical approaches were compared: the 3D cross microstructure model (Fig. 1), and two models based on the real microstructure obtained from the micro-CT scans: a voxel model, and a model with smoothed interfaces obtained with Simpleware ScanIP/FE software. With the +ScanFE software a FEM mesh was created and smoothing of material interfaces and optimizing the size of elements was done (Fig. 2b). Three effective elastic constants were modelled: Young's modulus (Fig. 3), Poisson's ratio and the shear modulus (here only *E* modulus is shown for brevity).

3. Modelling of crack bridging

One of the main toughening effect occurring in metal-ceramic IPC during fracture is the crack bridging by metal ligaments, [4]. These ligaments deform plastically contributing to the composite's fracture toughness. The J-integral, or energy release rate *G* in this case, can be expressed as $J = G = \int_0^{u^*} \sigma(u)du$, where σ is the nominal stress in the bridging ligament at stretch u ($\sigma \to 0$ at $u = u^*$, with u^* being the crack opening displacement *COD* at rupture). A non-trivial problem is to determine the physical relation $\sigma(u)$. In this paper this problem was solved numerically. Fig. 4 shows the FEM solution of an elasto-plastic cylindrical ligament in an elastic matrix undergoing delamination from the surrounding material and large strains due to necking. The normalized ($\sigma - u$) relation, which was sought here, is shown in Fig. 5 together with the analytical solution of Mataga [4] based on purely geometrical considerations.

4. Conclusions

A set of analytical estimates and numerical models have been employed to determine the effective elastic constants of the IPC. The micro-CT images can easily be incorporated in the developed FEM models leading to the most realistic estimates. A problem of crack bridging with ligament undergoing delamination and necking has been solved by FEM for an idealized ligament geometry.

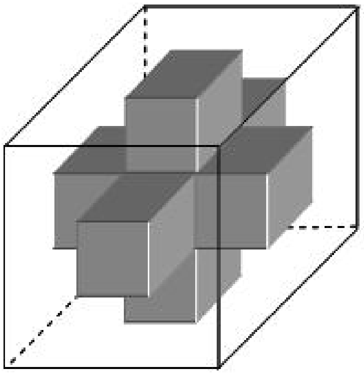

Fig. 1. Cross model of interpenetrating microstructure of IPC.

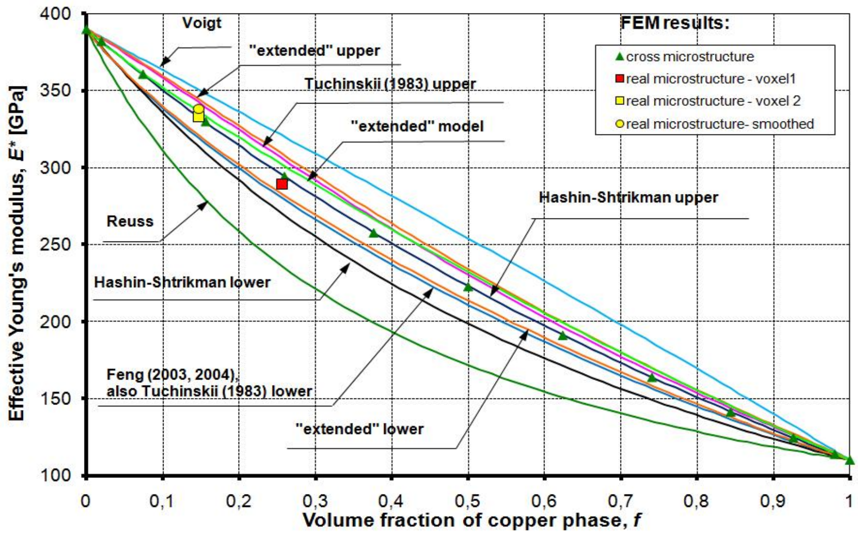

Fig. 3. Effective Young's modulus of Al_2O_3-Cu IPC: Analytical and numerical models and CT measurements results.

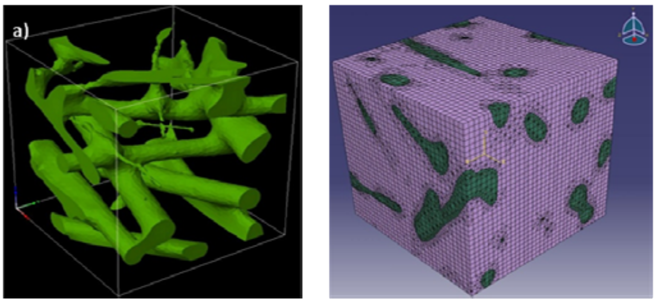

Fig. 2. Real microstructure of Al_2O_3-Cu IPC from micro-CT images (metal phase) (a). FE representation in ABAQUS via Simpleware ScanIP/ScanFE (b).

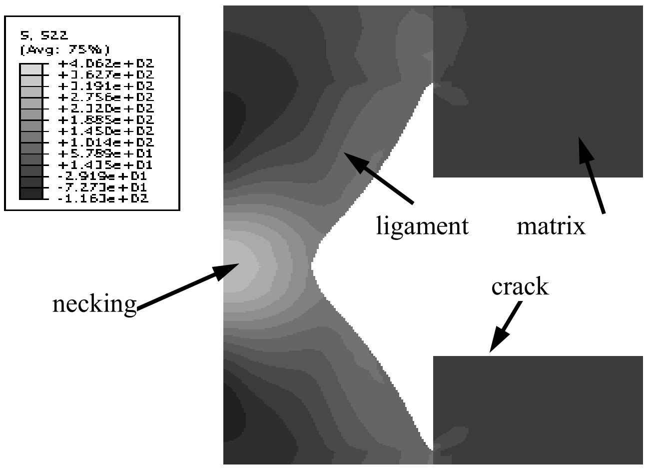

Fig. 4. Axial stress distribution in metal ligament at large plastic deformation (necking) and delamination from the matrix; numerical solution by ABAQUS.

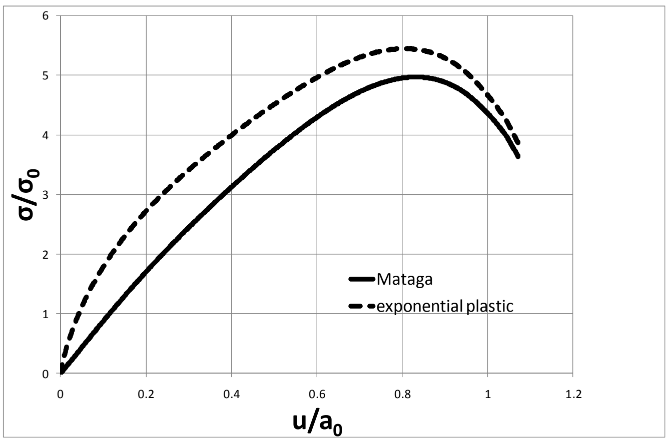

Fig. 5. Normalized $(\sigma - u)$ relationship in metal ligament derived numerically by FEM; σ and σ_0 denote the nominal and the yield stress of the ligament material (Cu); a_0 is the ligament's initial radius. Solid line depicts the analytical solution by Mataga [4].

5. References

[1] Basista M. and Weglewski W. (2006). Modelling of damage and fracture in ceramic-matrix composites - an overview, *J. Theor. Appl. Mech.*, **44**, 455-484.

[2] Feng X., Tian Z., Liu Y. and Yu S. (2004). Effective elastic and plastic properties of interpenetrating multiphase composites, *Appl. Comp. Mater.*, **11**, 33-55.

[3] Poniznik Z., Salit V., Basista M. and Gross D. (2008). Effective elastic properties of interpenetrating phase composites, *Comp. Mat. Sci.*, **44**, 813-820.

[4] Mataga P. A. (1989). Deformation of crack-bridging ductile reinforcements in toughened brittle materials, *Acta Metall.*, **37**, 3349–59.

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