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Dynamic pulse sensitivity of WC/Co composite

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ABSTRACT

Cutting tools are manufactured among others from cermet (e.g. WC/Co) having excellent mechanical properties. Geometry of the internal microstructure is complex and mechanical response due to quasi-static or dynamic loading is difficult to be described. Particularly, the dynamic loading is not investigated enough precise up till now.

Experimental evidences, e.g. Siegl and Fischmester (1988), Ravichandran (1994), indicate that the fracture energy of WC/Co is expended through ductile failure of the Co: (1) near the binder/tungsten carbide interface or by (2) dimple rupture across the interphase. Concentrations of stresses around grain boundaries lead to initiation of microcrack system, which is dispersed for dynamic loading.

The aim of the paper is to extend the previously formulated models (Sadowski et al., 2005, 2006, 2007, Dębski and Sadowski, 2014, 2017) of the polycrystalline composite towards more advanced finite element formulation, applicable for description of the cermet behavior under dynamic pulses. The model takes into account: (1) spatial distribution of the cermet constituents, (2) system of grain boundaries/binder interfaces modeled by interface elements, (3) rotation of brittle grains.

The obtained results show that stress distributions and gradual microcracking processes are quite different for quasi-static and dynamic loadings. It was revealed by damage parameter indicating concentration of microcracks.

1. Introduction

Modern polycrystalline materials and composites are one of the most promising types of materials used for different areas of innovative technologies. They can have natural disordered internal structures created by nature or during technological process. However, composition of novel multiphase materials results from specific engineering demands, i.e. artificial structures with different geometries are manufactured, which can:

- have designed regular internal structures build up of uniformly distributed in the matrix nanoparticles, particles, short fibers etc.,
- be formed also as regular or irregular layered material structures,
- have designed functional gradation of physical and mechanical properties.

Conventional polycrystalline ceramics and ceramic matrix composites (CMC) are described in e.g. in [1,2], whereas examples of their modelling are included in e.g. [3–14]. More complicated internal structures have nanoceramic materials, e.g. [15,16] or functionally graded materials, e.g. [17–21]. Other widely used advanced materials are Metal – Ceramic Composites (MCC) such as tungsten carbide/cobalt (WC/Co) or titanium/molybdenum carbide**s**, e.g. [22–28].

Generally, for modelling of the polycrystalline materials behaviour different methods can be used. The basic ideas of the overall properties evaluation of heterogeneous materials were described in [29–36]. Defining of the Representative Volume Element (RVE) and postulating of statistical homogeneity assumption in considered heterogeneous materials one can obtain general results relating to bounds on micro-potentials and on strain energy and complementary energy functionals. Application of the averaging procedure, within micromechanical approach, over the RVE allows for investigation of the material response containing different phases, impurities and types of structural defects (dislocations, pores, cracks etc.) inside the material. An analysis of examples of structural defects is given for example in [64–66].

Various numerical methods for description of a composite behaviour at different scales are discussed in [37–40,63]. De Borst [37] describes two-scale method by decomposition of the problem into a coarse scale and fine scale. The basic problem in multiscale methods is how to couple the coarse and fine scales that can be used in conjunction

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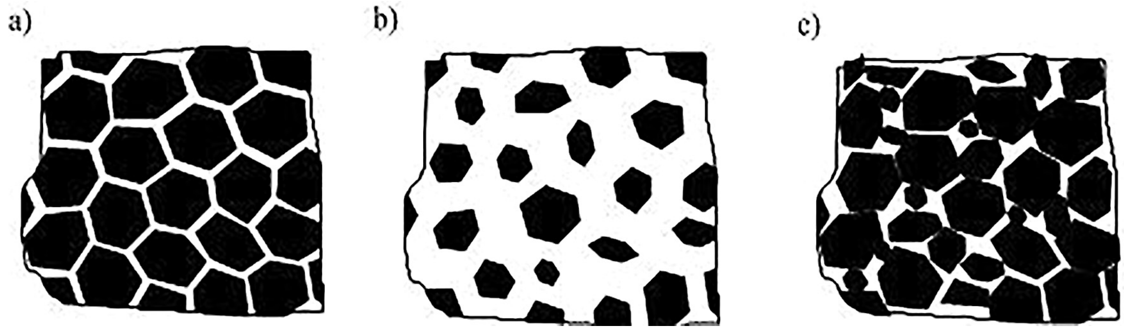

Fig. 1. Different types of two-phase MCC internal structures: (a) with small thickness and continuous interfaces, (b) with dilute distribution of ceramic grains in metallic matrix, (c) with not continuous interfaces.

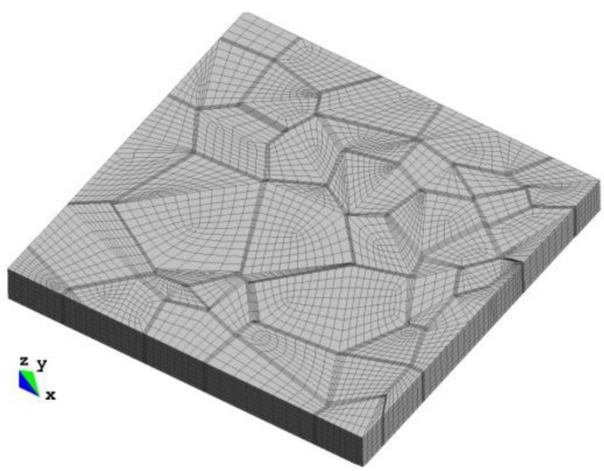

Fig. 2. The RVE FEA model of the WC/Co cermet.

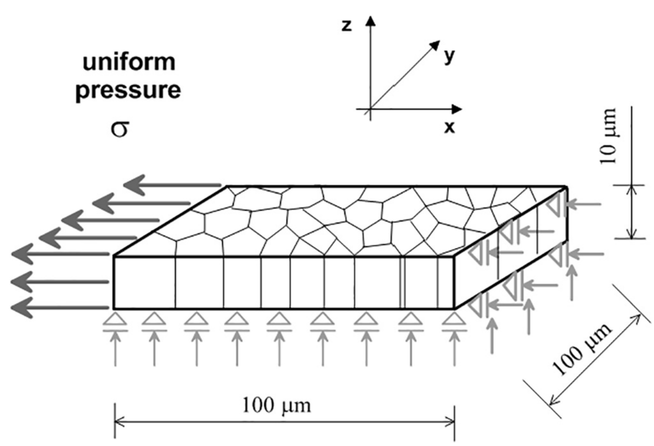

Fig. 3. Loading and boundary conditions of the RVE.

with various discretisation methods, like finite element, finite difference or finite volume methods. The variational multiscale method proposed in [39] is the most promising tool for the proper solution of the multiscale coupled physical and mechanical topics. A very promising method for description of multiple cracking processes in CMC and MCC is the partition-of-unity method, e.g. [37], where a single cohesive segment in a quadrilateral mesh was applied. The other approach, 3D multiphase finite element method [33] is a promising method with application of 8-node hexagonal multiphase finite element with bilinear interpolation.

In this paper we will focus on modelling of the mechanical behaviour of the MMC, which is much more complicated in comparison to single phase polycrystalline ceramics, what was experimentally

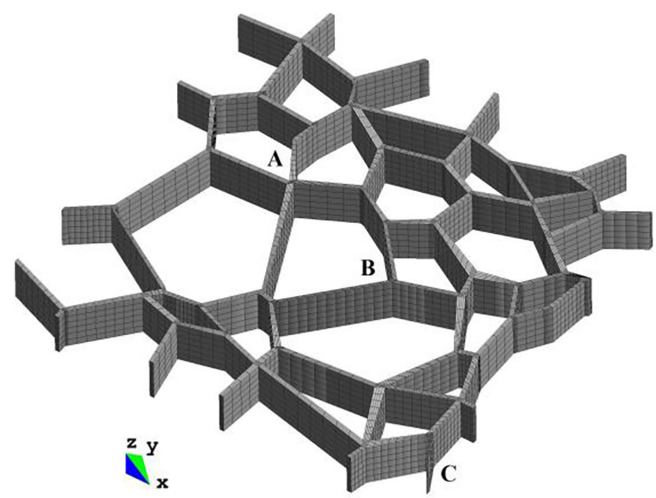

Fig. 4. The discretised binding elasto-plastic interphase system.

investigated e.g. [22,23,41] and many others.

Generally, one can distinguish three types of MCC models of internal structure (Fig. 1):

- composites with metal matrix build up from continuous interfaces of small thickness (volume content V^{in} of ductile second phase is up to a few percent – Fig. 1a),
- with a significant amount of metallic phase – $V^{in} \in (10 \div 90)\%$ – [41], Fig. 1b
- a two-phase composite with discontinuous interfaces, Fig. 1c.

This paper will be devoted to meso-mechanical modelling of MCC with small thickness and continuous interfaces (Fig. 1a). Experimental studies of thin metallic interfaces in two-phase MCC have been carried out for example in: [22,23] for WC-Co alloys; [42] for a Pt layer diffusion bonded to Al_2O_3; [43] for Al_2O_3 liquid state bonded with pure Al or Al – 4%wt Mg and [44] for TiC-Mo_2C hard phase grains surrounded by tough binder phase Ni.

In [43] it was proved experimentally, that metal interfaces (Pt, Al or Al – 4%wt Mg) are soft enough under loading conditions and failure in the considered MCC occurs by ductile process. Ceramic grains of MCC highly constrain the plastic flow in a thin metal layer matrix and give rise to high stress levels under plastic loading.

Similar observations of the WC/Co composite ([23] and [24]) indicate, that the majority of the fracture energy of MCC is expended through ductile failure of the plastic binder Co by:

- fracture mechanisms I – dimple rupture across the binder
- fracture mechanisms II – near the binder/tungsten carbide interface,