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Qualitative comparison of dynamic compressive pressure load and impact of WC/Co composite

Eligiusz Postek[a,*], Tomasz Sadowski[b]

[a] Institute of Fundamental Technological Research, Polish Academy of Sciences, 02-106 Warsaw, ul. Pawińskiego 5B, Poland
[b] Lublin University of Technology, Department of Solid Mechanics, 20-865 Lublin, Nadbystrzycka 40 Str, Poland

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ABSTRACT

Degradation of Cermet Materials (CM) under impact and pulse pressure is not thoroughly investigated. In this study, we qualitatively compare the behaviour of WC/Co samples under these types of loading.

The new models of impact and dynamic compressive load of a WC/Co plate were investigated. We developed two models of the composite plate, namely, a continuous model and a model with crack appearance possibility in the interfaces/binders.

We noted a qualitative difference of the shapes of the deformed structure due to different models and kind of loading. The differences also concern the Mises stress, equivalent plastic strains and damage parameter.

The proposed models are suitable for both impact and pressure load. The possibility of cracks appearance should not be neglected. In case of the model with discontinuities, for both kinds of loads, the grains rotation and sliding is more distinct than in case of the continuous model.

1. Introduction

Modern technologies require an application of complex polycrystalline composites. Monolithic polycrystalline ceramics and ceramic matrix composites (CMC) are described in [1, 2], whereas examples of their modelling are included in [3–7]. However, nanoceramics [8, 9] or multiphase brittle materials [10, 11] and metal matrix composites [12, 13] have more complex internal structures. Functionally graded materials have more important role in many modern practical applications, [14–19] and others. Other widely used advanced materials are CMs, such as tungsten carbide/cobalt (WC/Co) or titanium/molybdenum carbides, [20–22] and others. The basic ideas of the overall properties evaluation of heterogeneous materials were described in [23, 24].

Description of a new composite behaviour at different scales is widely discussed. For example, a two-scale method by decomposition of the problem into a coarse scale and fine scale level is described [25]. The problem in multiscale methods is how to couple the coarse and fine scales that can be used in conjunction with various discretisation methods, like finite element, finite difference or finite volume methods. A variational multiscale method is proposed in [26] and seems to be the most promising for the solution of the multiscale coupling of physical and mechanical properties. The multiple cracking processes in the CM is the partition-of-unity method, [25], where a single cohesive segment in a quadrilateral mesh was applied.

Modelling of the mechanical behaviour of the CM under impact loading, presented in this contribution, is much more complex in comparison to monolithic one phase polycrystalline ceramics. For instance, the WC/Co properties were experimentally investigated in [27, 28]. In our model of impact response of different the CMs, we use meso-mechanical approach for the RVE having grains with very narrow continuous interfaces. Experimental studies of thin metallic interfaces in the two-phase CM have been carried out for example in [29] for WC-Co alloys, for a Pt layer diffusion bonded to Al_2O_3 [30], for Al_2O_3 liquid state bonded with pure Al or Al – 4%wt Mg [31], for TiC-Mo_2C hard phase grains surrounded by tough binder phase Ni [32]. It was proved experimentally in [31] that metal interfaces (Pt, Al or Al – 4%wt Mg) are soft enough for loading conditions and failure in the considered metal matrix composites occurs by a ductile process. For the WC/Co composite, [33], the majority of the fracture energy of CM expends through the ductile failure of the plastic binder Co by two local fracture initiation mechanisms. They are (1) dimple rupture across the binder, [34] and (2) microcracking at the binder/tungsten carbide interface, [27]. Ductile failure of the Co binder can be considered as a primary mechanism manifesting fracture resistance in the WC/Co composite, [33].

Up to now, static models were used for estimation only equivalent mechanical or thermal properties of CMs, [35]. The quasi-static or dynamic loading models describe gradual changes in the RVE, *i.e.,*

* Corresponding author.
E-mail addresses: epostek@ippt.pan.pl (E. Postek), t.sadowski@pollub.pl (T. Sadowski).

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modifications of its internal structure (in relation to a load threshold or time t), *i.e.,* grains rotations and concentration of plastic deformations in thin metallic layers and further micro-cracks growth, [21]. In the cited papers the authors analysed the ductile failure of the plastic Co binder by I fracture initiation mechanisms, *i.e.,* micro-voids coalescence and further inter-granular cracks nucleation and propagation. The secondary fracture initiation mechanism of ductile failure of the plastic binder Co by phenomena developing at the binder/wolfram carbide interface was described in [29]. Interfaces play a significant role in different ways of cracks propagation. It was noticed in case of bi-material interfaces in CMC [36, 37], where cracks can grow along the stiffer grain boundary or can be arrested for a while.

Description of the microcracking process in the WC/Co is essential for impact conditions because this composite is widely used for manufacturing of cutting tools applied in different branches of engineering. It was experimentally monitored for repeated dynamic compressive loading [38] and repeated impact load, [39]. Description of dynamic loading of composites is presented for materials with a layered structure, [40]. High attention is paid to blast load or impact load, [41]. However, in our opinion, we noted lack of references in modelling of WC/Co composite during impact conditions.

We compare qualitatively impact load and sudden increase of pressure that is applied to the edge of a WC/Co sample. In our analysis that is followed up to 10 ns of the load action, we observe the shape of the sample, Mises stress development, equivalent plastic strains and damage variable for a continuous model and a model with cracks appearance possibility.

2. Numerical model and material properties

The Co interfaces in the CM polycrystal are modelled with an assembly of hexahedral continuous and interface elements, which are introduced into the interfaces between the grains, into the junctions of the interfaces and the structure of the interfaces and the junctions. The WC grains are assumed to be elastic and have a very high strength. The Co intergranular layers are elastic-plastic, *i.e.,* the material model agrees with the experimental studies presented in [31].

The schemes of the structure with the initial conditions are shown in Fig. 1. We qualitatively compare a sudden increase of compressive load on the edge of the structure, Fig. 1a and the impact of the sample against the rigid wall which is perpendicular to the x-axis of the structure, Fig. 1b. The rigid wall is on the left side of the structure. The scheme of the pressure pulse is given in Fig. 2. The discretisation of the sample takes into account separate discretisations of the grains and interfaces, Fig. 3. We consider the edge pressure of the values 200 MPa, 500 MPa and 1000 MPa and the impact velocity 50 m/s.

We use two models, namely, continuous (M1) and with possibility of appearance the discontinuities (M2). The discontinuities are modelled by introducing the interface elements in the regions of binders. The continuous model M1 consists of 34,572 linear bricks and 41,216 nodes. The discontinuous model M2 consists of 18,882 linear eight-node bricks in the grains, 15,690 linear eight-node bricks in the intergranular layers and 47,407 linear eight-node interface elements that are

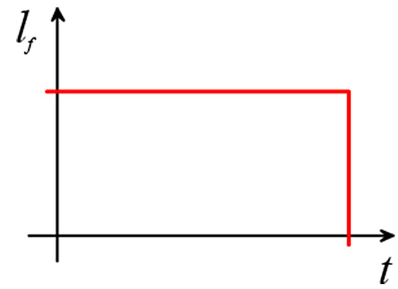

Fig. 2. Pressure pulse.

also placed in the intergranular layers. The scheme of a single cohesive element is presented in Fig. 4a. The discretisation of the whole sample needs 152,169 nodes. An assembly of a brick element that is covered with cohesive elements is shown in Fig. 4b. In this way, we introduced all of the bricks in the binders. The model allows cracks appearance in the binders.

We use Abaqus program for FEA calculations, [42], MSC Patran program [43] for the model creation and GiD program [44] for post-processing and visualisation of the results. We use C3D8 elements and COH8D3 interface elements. We use implicit version of the Abaqus program. The elastic properties of grains are as follows: Young's modulus is 7.1×10^{11} Pa, and Poisson's ratio equals to 0.21. The elastic material properties of the intergranular layers are Young's modulus 2.1×10^{11} Pa and Poison's ratio 0.31. Yield limit of the material reads 2.97×10^{8} Pa.

We will observe field variables in time at the element A in the binder, Fig. 3b, and in the relevant cohesive element A^c that is placed between the element A and the grain, Fig. 4c. The elements are placed in the binder close to the loaded edge. We also observe the x-displacement at the node X in the case of edge pressure load, Fig. 3a.

The above formulated FEA model allows for the possibility of the elements separation in the intergranular layers. Cohesive elements around each brick elements in the interfaces are introduced, see Fig. 4b. Taking into account [45], we set properties of the intergranular layers and assume the traction-separation model of the interfaces, [46, 47].

The elastic behaviour of the interface is assumed uncoupled. Therefore, tractions-strains relation reads:

$$\begin{Bmatrix} t_n \\ t_s \\ t_t \end{Bmatrix} = \begin{bmatrix} E_{nn} & & \\ & E_{ss} & \\ & & E_{tt} \end{bmatrix} \begin{Bmatrix} \varepsilon_n \\ \varepsilon_s \\ \varepsilon_t \end{Bmatrix} \tag{1}$$

where t_n is traction normal to the interface, t_s and t_t are orthogonal tractions in plane of the interface, ε_n is strain normal to interface, ε_s and ε_t are orthogonal strains in plane of the interface, E_{nn} is Young modulus normal to the interface, E_{ss} and E_{tt} are orthogonal shear moduli in plane of the interface.

The elastic properties of the interface elements are as follows: the elastic modulus normal to the interface element (n) is 2.1×10^{11} Pa, the shear moduli in the directions in the plane of the interface element (s, t) are both 1.373×10^{11} Pa. In the formulated FEA model, as a

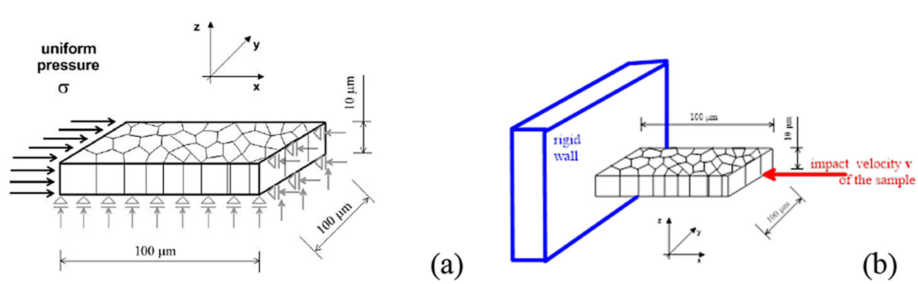

Fig. 1. Loading and boundary conditions: (a) edge pressure; (b) impact into rigid wall.