NON-LINEAR DYNAMIC AND QUASI-STATIC RESPONSES OF TWO-PHASE CERAMIC MATRIX AND METAL MATRIX COMPOSITES SUBJECTED TO COMPRESSION AND DEGRADATION

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Summary The paper presents modelling and experimental testing of non-linear degradation processes developing in two-phase ceramic matrix (CMCs) and metal matrix composites (MMCs) subjected to quasi-static and dynamic compressive loading. Modelling was performed by multiscale approach using both: (1) analytical and (2) numerical methods and selected Representative Volume Elements (RVE) based on SEM observations of composites. Both quasi-static and dynamic experimental tests were done applying standard MTS (100 kN) servo-hydraulic machine and Split Hopkinson Pressure Bar (SHPB) stand for impact tests with loading velocities 20 – 30 m/s. As a results we observed for CMCs in quasi-static loading failure mode by splitting of cylindrical samples, whereas for impact loading dynamic crushing process took place.

INTRODUCTION AND MOTIVATION

Quasi-static and dynamic degradation of semi-brittle ceramic matrix composites (CMCs) or metal matrix composites (MMCs) exhibit different mechanical response under uniaxial tension and uniaxial compression. In this paper we analysed cracking processes and failure under compression of two-phase CMC made of Al_2O_3 and ZrO_2 mixture and two-phase MMC built of WC grains and plastic Co matrix. The importance of these advanced composites results from their applications. The CMC is used as thermal barrier coatings (engines of aircrafts), whereas the MMC with addition nanoparticles is applied for modern cutting tools in different branches of engineering.

MULTISCALE MODELLING

Constitutive modelling of the analysed composites obeys description of: (1) elastic deformations of initially porous material, (2) limited plasticity and (3) cracks initiation and propagation. Description of polycrystalline composites with ceramic or metal matrixes behaviour at microscopic level is related to analysis of set of grains (RVE). The RVE is created with the help of SEM or μCT. In this paper we considered gradual degradation processes due to mechanical: quasi-static or dynamic loading. The basic elements of degradation are different defects growing inside polycrystal structure which includes: (1) dislocations or dislocation bands, (2) micro- and meso-cracks, kinked and wing cracks. To get macroscopic response of the material, one can calculate averaged values of stress and strain over the RVE with application of analytical approach or numerical one.

Analytical approach for quasi-static CMCs response

The constitutive equations for the considered CMC are the following:

$$\varepsilon_{ij} = S_{ijkl}(\sigma_{mn}, p, \omega^{(i)})\sigma_{kl}$$

where S_{ijkl} is the compliance tensor, ε_{ij} is the strain tensor, σ_{kl} is the stress tensor, p is the porosity parameter and $\omega^{(i)}$ are sets of parameters defining the presence of different kinds of defects "i" developing inside the material.
Cracks propagation mechanism is mainly along grain boundaries including defects kinking. It is strongly influenced by grain boundary porosity p_{gb}. Namely, any crack (straight or kinked one occupying grain boundaries) can propagate if the energy release rate G satisfies the following condition

$$G(\sigma_{ij}, \phi, p_{gb}) \geq \gamma_{gb}^{cr}(p_{gb}),$$

where ϕ describes orientation angle of cracks in RVE, γ_{gb}^{cr} is the critical value of the grain boundary surface energy.

Numerical approach for impact response of two-phase composites

Assessment of impact techniques is given in [1]. A basic model of MMCs is presented in [2]. The microstructures of Al_2O_3/ZrO_2 and WC/Co have different grain arrangement and their response is qualitatively different. In numerical models a low velocity impact of the two materials was investigated focusing attention on damage growth associated with microcracks and cracks initiation. We use finite element method (FEM) and meshless non-local peridynamics (PD), [3], Fig. 1. Further, the problems of binder modelling are different in both kinds of materials. In the WC/Co the binders are relatively thick and can be considered as elastic-plastic, while in the Al_2O_3/ZrO_2 the interfaces are thin and brittle. The

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grains in WC/Co are very hard, however, they are ductile as well [4]. The grains in Al_2O_3/ZrO_2 are both brittle. In the case of WC/Co the damage process develops rather along the binders, while in Al_2O_3/ZrO_2 the damage spread in both phases. A significant influence on crack initiation has initial voids, in particular in the CMC samples.

In case of WC/Co, the pulse duration was 10^{-7}s and the applied pressure level - 480 MPa. The proposed numerical model requires advanced FEM formulation including geometrical data and differet phenomena revealing inside of the RVE, like: (1) spatial distribution of the cermet constituents, (2) system of grain boundaries/binder interfaces modelled by interface elements, (3) rotation of brittle grains, (4) initiation and development of microcrakcs during loading process.

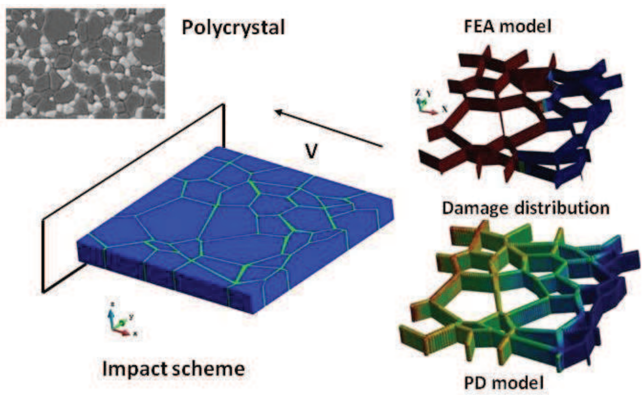

Figure 1. Numerical models in low velocity impact of CMC and MMC: FEM and PD.

RESULTS AND CONCLUSIONS

The obtained numerical results were compared with own experimental data for compression processes: under quasi-static loading using MTS (100 kN) and dynamic loading done with application of SHPB stand, Fig.2. The loading velocities were in the range 20 – 30 m/s.

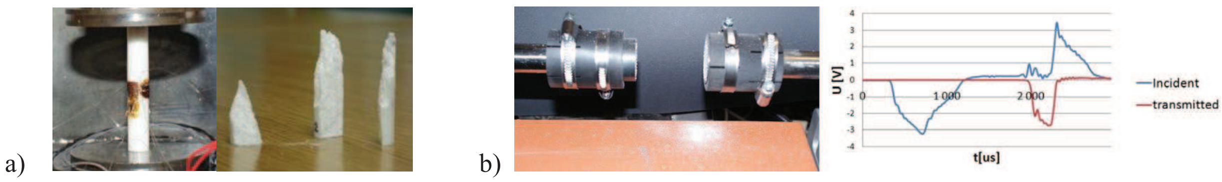

Figure 2. Failure modes of CMC for: a) splitting in quasi-static loading (MTS) and 2) crushing during impact loading with SHPB.

Figure 2 presents qiute different failure modes for quasi-static loading and impact in case of CMC. We obtained splitting of specimens for quasi-static loading, wheras crushing took place during impact.

Similar phenomena were observed for the MMC. Its response due to pulse loading is significantly different in comparison to the quasi-static behaviour, i.e. the stress distributions and microcracking processes are quite different.

Comparison of the proposed models with experimental results lead to conclusion that theoretical models with good quality descrived non-linear behaviour of the two-phase composites under compression.

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