8th. World Congress on Computational Mechanics (WCCM8)
5th. European Congress on Computational Methods in Applied Sciences and Engineering (ECCOMAS 2008)
June 30 – July 5, 2008, Venice, Italy

MODELLING DAMAGE AND FAILURE OF MINERAL POLYCRYSTALLINE MATRICES IN FIBROUS COMPOSITES

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Key Words: *Composites, Mineral Matrices, Fracture, Computing Methods.*

ABSTRACT

Recent decades were characterized by intensive development of new fibrous composites. Particularly, the composites of mineral fibers and matrices (oxides, borides, ceramics, etc.) were developed for medical applications (for instance, to replace biodegradable polymer composites for bones repair), for construction industry (fireproof parts of building, environment-proof parts of bridges, etc.), to enhance working temperature of structural materials for hot parts of machines, and so on [1].

Mineral matrices are typically polycrystalline substances. The sizes, shapes, and orientations of the crystallographic axes of crystallites (grains) are usually random. So, the mineral matrices are heterogeneous materials consisted of anisotropic components with stochastic structure. Often mineral matrices consist of different types of crystallites, i.e. they are multicomponent materials itself. The stochastic structure of the matrix yields fluctuating microstresses and stochastic fractures of individual grains. Due to anisotropy, the grains can fracture or become partially damaged via several fracture modes with different probabilities, depending on the stress state of the material.

We model the matrix on the basis of micromechanics and consider it as homogeneous medium with effective properties. Micromechanical boundary value problem for the elastic stochastic medium has usual form [2]

$$\begin{aligned} &\nabla_j \sigma_{ij}(\vec{r}) = 0 \\ &\sigma_{ij}(\vec{r}) = C_{ijkl}(\vec{r})\varepsilon_{kl}(\vec{r}) \\ &\varepsilon_{ij}(\vec{r}) = [\nabla_j u_i(\vec{r}) + \nabla_i u_j(\vec{r})]/2, \quad u_i(\vec{r})\big|_{\vec{r}\in\Gamma} = \varepsilon^*_{ij} r_j, \quad \nabla_i \equiv \frac{\partial}{\partial r_i}, \end{aligned} \qquad (1)$$

where $\varepsilon_{ij}(\vec{r})$, $\sigma_{ij}(\vec{r})$ –strain and stress tensors, $C_{ijkl}(\vec{r})$ - elastic moduli tensor, $u_i(\vec{r})$ – displacement vector, ε^*_{ij} – constant tensor of macro strains, Γ – external surface of the medium. Tensor $C_{ijkl}(\vec{r})$ is a random function of $\vec{r}$, it is constant within each crystallite and changes stepwise when goes to another crystallite due to change of crystallite type and rotation of crystallographic axes.

There are several methods to obtain approximate solutions of the problem (1) [2]. These solutions allow to calculate random stresses in grains and, upon usage some fracture criterions, fracture probabilities of the grains. The homogenization of the problem (1) gives the effective elastic moduli of the medium.

In proposed model it is assumed that the stress state of the matrix at given macrostrain results from a stepwise increasing of the macrostrain from zero to given value with small step. At each step boundary value problem (1) is solved, fracture probabilities and volume fractions of all crystallites are calculated. At initial (strainless) state matrix consists of randomly distributed non-damaged crystallites and pores. At certain macrostrain first partially damaged crystallites appear, then damaging processes progress, some later fully destroyed crystallites are generated, and eventually mechanical resistance of the matrix deteriorates. The matrix model is implemented as an iterative algorithm. The algorithm generates dependence of macrostresses $\langle \sigma_{ij} \rangle$ on macrostrains $\langle \varepsilon_{ij} \rangle$ for arbitrary deformation path in a 6-dimensional strain space.

Fig.1 represents an example of the modeling of a full deformation curve for matrix with hexagonal grains. Fig.2 shows the results of the modeling of a bending experiment of a composite specimen. The specimen is modeled by standard finite elements method and the above described algorithm is used as the constitutive equations for the matrix. The non-linear parts of the curves on both figures correspond to matrix damaging processes.

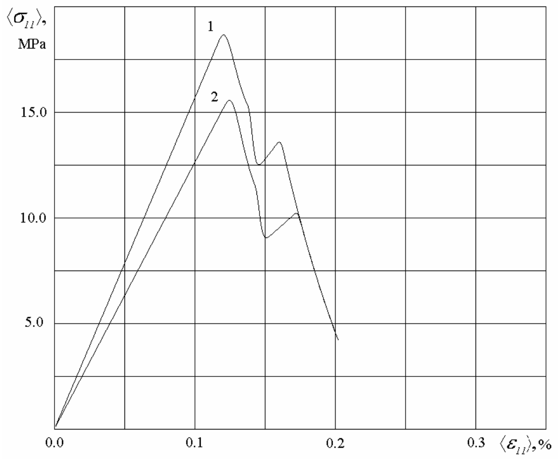

Fig.1. Simple tension of matrix sample.

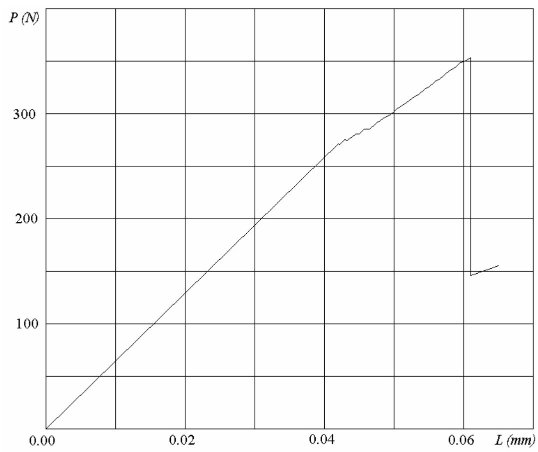

Fig.2. Three-point short beam bending of a unidirectional composite specimen.

This work was supported by Russian Foundation for Basic Research grant 07-01-97619.

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