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STRAIN DEPENDENT CONTINUUM DAMAGE THEORY FOR DESCRIPTION OF POLYMER MATRIX COMPOSITES

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ABSTRACT

Experimental assessment and theoretical description of damage state in polymer matrix composite materials subjected to arbitrary mechanical or thermal loading play the important role in practical applications. The objective of this work is to develop a theoretical basis and experimental methodology of damage estimation in polymer matrix composites. In the microscopic scale the damage in polymer matrix composite materials consists of the following types of defects: pores and cracks inside matrix, decohesion at the interface of matrix/reinforcement, local delamination and pulling out of fibers from the matrix. All mentioned defects can be described by introduction of macroscopic damage tensor. For the purpose of this work the second order damage tensor D_{ij} was used in order to reflect changes of composite internal structure due to defects growth.

The idea of the method is to measure experimentally deformations during the several cycles of loading-unloading and further reloading of the composite material sample with increasing stresses σ_{ij} up to the final failure. Let us denote by ε_{ij} a total strain at the beginning of unloading process for the stress level σ_{ij}. At the end of unloading path one can measure a residual ε_{ij}^{r} state of strains. Having estimated an initial elastic compliance tensor C_{ijkl}^{e} it is possible to calculate the elastic strain components ε_{ij}^{e}. Then the damage strains ε_{ij}^{D}, which correspond to the stress level σ_{ij}, are equal to:

$$\varepsilon_{ij}^{D} = \varepsilon_{ij} - \varepsilon_{ij}^{r} - \varepsilon_{ij}^{e} \tag{1}$$

The knowledge of ε_{ij}^{D} allows for assessment of the damage tensor components D_{ij}. In case of two dimensional loading and even in uniaxial one, damage in composite is anisotropic and can be expressed by the following formulas:

$$D_{11} = \frac{\varepsilon_{11}^{D}}{\varepsilon_{11} - \varepsilon_{11}^{r}}; \qquad D_{22} = \frac{\varepsilon_{22}^{D}}{\varepsilon_{22} - \varepsilon_{22}^{r}}; \tag{2}$$

The capability of the above description of the damage state was illustrated by three examples. The polymer matrix composites were built up of epoxy matrix and different number of plies with different volume contents of reinforcing glass fibers. The composite samples were tested under several uniaxial loading-unloading-reloading cycles and the anisotropic damage state was estimated according to the formulas (2).

The main advantages of the proposed method are:

- testing of the material in the controlled deformation process
- estimation of the current global compliance tensor C_{ijkl} by deformation analysis for loading-unloading cycles
- assessment of the anisotropic damage process by tensor $D_{ij}(\varepsilon_{kl})$.