INFLUENCE OF COUPLE-STRESSES ON NONLINEAR DEFORMATIONS OF DISPERSELY FAILING FIBER-REINFORCED COMPOSITES

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In the theory of reinforcement, two simple approaches are known for predicting the linear elastic properties of spatially reinforced composites – the methods of Voigt and Reuss. According to them, the composite is viewed as consisting of unidirectionally reinforced bars which are directed along the fibres of the spatial reinforcement and have the same relative content of fibres as the entire composite. The linear characteristics of the bars can be obtained using an appropriate reinforcement theory or found experimentally. Thereafter the linear rigidity (Voigt) or, alternatively, the linear compliance of the composite is calculated by averaging the respective quantities of all the bars. The effective linear characteristics of spatially reinforced composites fall between both predictions nearer to the Voigt one. In order to clarify the prediction accuracy of these approaches for nonlinear characteristics of composites, the case of $\pm\pi/4$ cross-ply epoxy plastic reinforced with glass fibres was considered.

The linear elastic constants of the bars, which we assumed to be transversely isotropic, were calculated from the known linear properties of the fibres and the binder. Their nonlinear characteristics were obtained through approximation of some experimental deformation curves of a corresponding unidirectional composite by an explicitly invertible tensor-linear function specified between the stress and strain tensors. It was found that the linear characteristics of the cross-ply composite calculated by the Voigt method fitted rather well with the experimental data, whereas the nonlinear compliance of the composite, e.g., in the uniaxial tension and compression, turned out to be much higher even that of the Reuss model. One possible reason for this fact is the action of couple-stresses arising in the composite due to relative rotation of fibres, which cause fracture of the matrix layers between the fibres in their intersection nodes and thus reduce the rigidity of the entire composite. So, a refined version of the Voigt model was elaborated with allowance for the couple-stresses. We assumed that the shear strain of the matrix has a critical value at which the matrix fails. In addition, a fourth-rank damage tensor was introduced characterizing the failure of the fibre intersection node as a whole and a constitutive equation for the tensor was defined. The additional constants needed to describe the failure process in the matrix within the nodes and to calculate the components of the damage tensor were found by approximating the experimental uniaxial tension curve of the $\pm\pi/4$ cross-ply composite. Thereafter the theoretical uniaxial compression curve was obtained, which corresponded well with the experimental one. Also, we computed two proportional biaxial loadings of thin-walled tubular specimens in uniaxial tension/compression and torsion. Comparison of these predictions with experiments testifies that consideration of the effect of couple-stresses allows one to improve the description of nonlinear deformation of composite materials.