Micromodel for failure analysis of textile composites

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ABSTRACT. The failure of textile composites is studied using a microvolume finite element model. The model represents one unit cell that is periodically repeated within the fullscale structure. The unit cell is composed of two interweaved bundles of continuous carbon fibres surrounded by epoxy resin. It is prepared as a parametric model in CAD system NX and transferred to MSC.Marc. The appropriate periodic boundary conditions are applied in the analysis using a custom Fortran subroutine. The calculated results comprise the homogenized Young's and shear moduli, Poisson's ratios, and the strength as a function of loading direction in the case of pure tension.

MATHEMATICAL MODEL OF UNIT CELL AND PERIODIC BOUNDARY CONDITIONS

In order to determine the effective (or homogenized) characteristics of the full scale material using the unit cell (also called representative volume element – RVE) micromodel it is necessary to perform pure tension (for Young's modulus E, Poisson's ratio ν and tensile strength) and pure shear (for shear modulus G and shear strength) tests. For certain structures with complex material structure it is impossible to predict the resulting material type a priori and, therefore, these two types of tests are carried out for arbitrary angle of loading with respect to the unit cell edges (defining the global coordinate system xyz). This situation is depicted in Fig. 1.

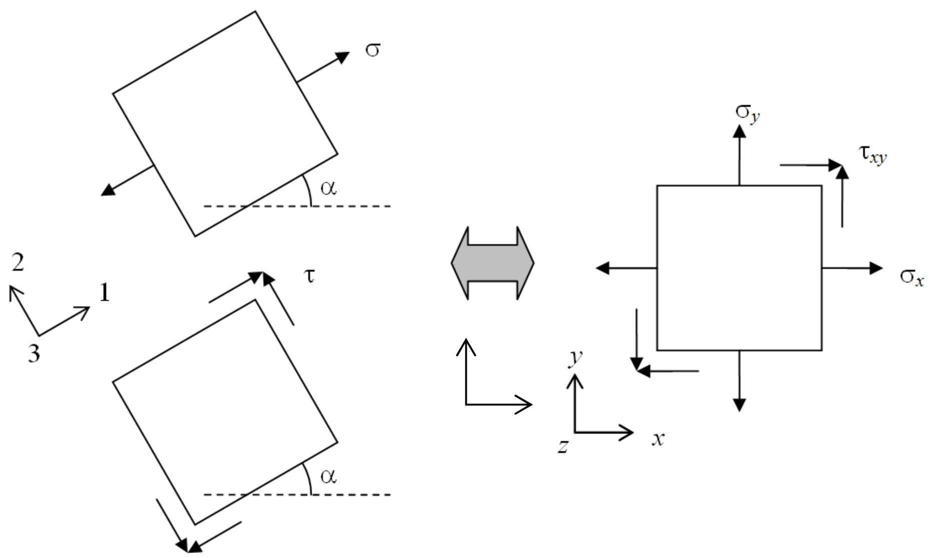

Figure 1: Schema of pure tension and pure shear loading and transformation to global system.

As the unit cell must represent the periodically repeated microvolume even after deformation, the edges (nodes) must fullfil periodic boundary conditions. This is shown in Figure 2 where the displacements for every pair of corresponding nodes on opposite edges must fullfil the following relations [2, 3]

$$u_B - u_A = d_x, \quad v_B - v_A = d_y, \quad w_B - w_A = d_z.$$

Hence, the differences d_x and d_y define the homogenized strains in global system xyz as

$$\varepsilon_x = d_{xV}/l_x, \quad \varepsilon_y = d_{yH}/l_y, \quad \gamma_{xy} = d_{yV}/l_x + d_{xH}/l_y.$$

The indices H and V denote values for horizontal and vertical edges, respectively. After transformation of the strains to the rotated system 12 defined by the angle α, it is possible to derive the desired elastic characteristics (for planar problems) as

$$E = \sigma/\varepsilon_1, \quad \nu = -\varepsilon_2/\varepsilon_1 \quad \text{or} \quad G = \tau/\gamma_{12}$$

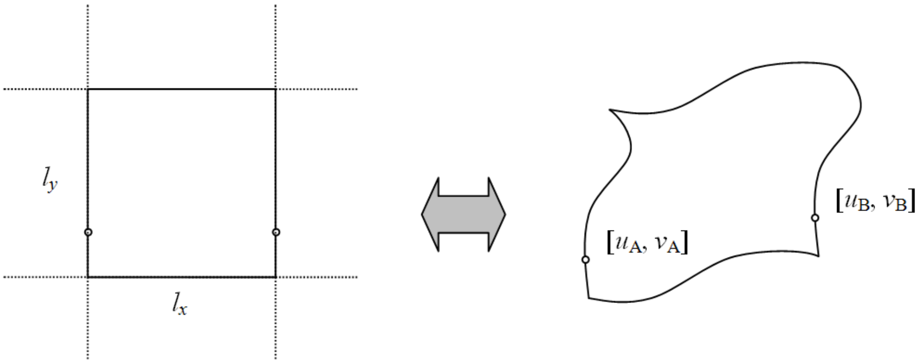

Figure 2: Schema of periodic displacement fields (boundary conditions) on a unit cell.

CALCULATION OF EFFECTIVE CHARACTERISICS

A finite element model of unit cell of a typical plain weave textile composite was designed using parametric model in CAD system NX. The geometry was discretize using tetrahedral elements and exported to MSC.Mentat/Marc system. The resulting mesh is shown in Fig. 3 with a detail of the weave pattern. The geometry in this study corresponds to fiber volume ratio of 50%. Material characteristic of the constituents, i.e., the fiber bundles and the epoxy resin, are presented in Tab. 1. For simplicity, both materials are considered homogeneous and isotropic in this study. The dimensionless size of the model is 100×100×18.

The system MSC.Marc, like many other commercial codes, does not allow for straightforward definition of the periodic boundary conditions. Therefore, special custom Fortran subroutine had to be engaged using so-called user defined tie (type 10001) with implemented appropriate relations. Moreover, spring elements had to be used in order to enforce constant dx and dy values on the opposite edges. The applied boundary conditions (ties, springs and appropriate zero displacements in selected nodes needed for static analysis) are shown also in Fig. 3.

Carbon fibres (bundles)		Epoxy matrix	
E_f [GPa]	ν_f	E_m [GPa]	ν_m
135	0.3	3	0.37

Table 1: Material characteristics of textile composite constituents.

RESULTS AND DISCUSSION

An example of results is presented in Fig. 4. The contours of equivalent (Von Mises) stress are shown separately for matrix and fiber elements in case of pure tension with two loading angles. The angle was varied from 0 to 180 degrees with 1 degree steps and the resulting effective quantities are shown in Fig. 5 and 6.

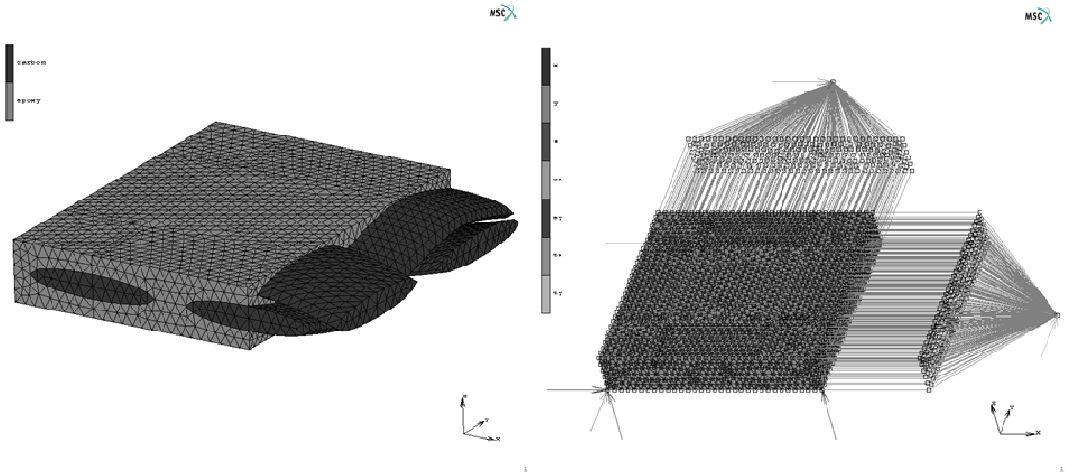

Figure 3: Mesh of FEM model with partially revealed bundles (left) and boundary conditions using links and springs (right).

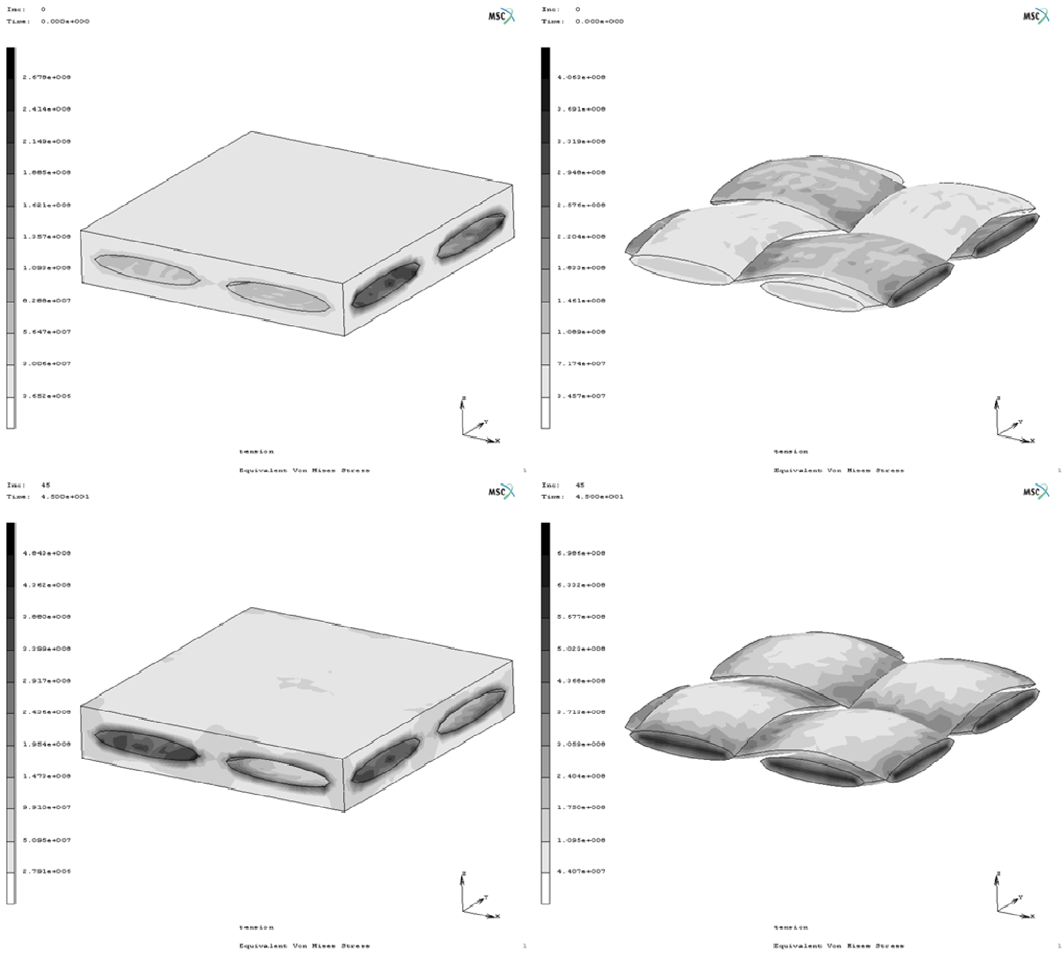

Figure 4: Equivalent stress contours for pure tension for $\alpha = 0^{\circ}$ (top) and $\alpha = 45^{\circ}$ (bottom).

The analysis of these results leads to conclusion that this material model shows cubic symmetry [1]. Nevertheless, there is a certain error in the strength values, most probably due to not perfectly symmetrical mesh. The strength factor *k* represents here the value of maximum tensile stress that can be applied before matrix failure (100%) occurs. The decrease in effective strength to 20-40% is evident. This modelling approach will be further used for the determination of other material properties on more complex structures.

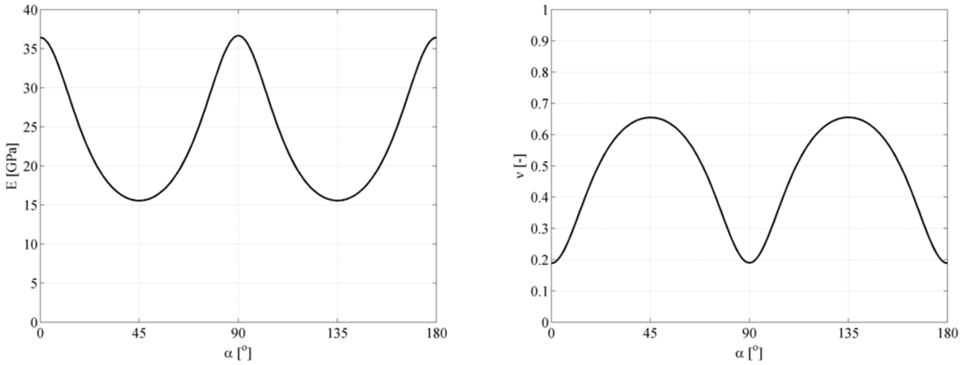

Figure 5: Young's modulus (left) and Poisson's ratio (right) as function of angle α.

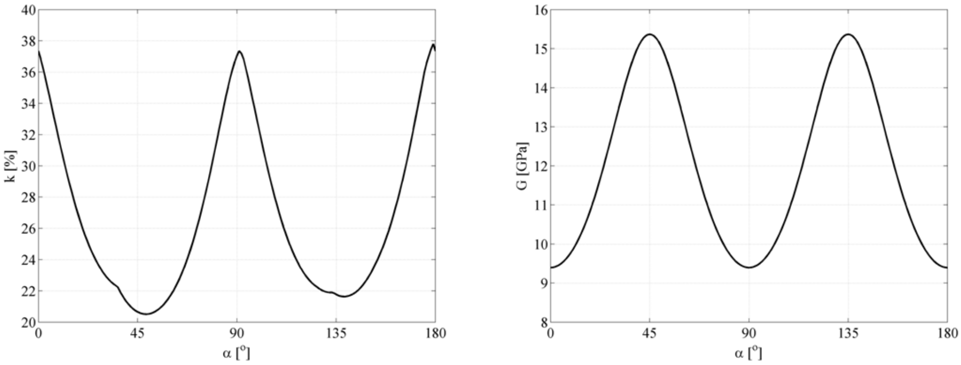

Figure 6: Strength factor for pure tension (left) and shear modulus (right) as functions of angle α.

ACKNOWLEDGEMENT

The work has been supported by the research project of Grant Agency of the Czech Republic GACR 101/08/0299 and research project GA AV IAA200760611.

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