38th Danubia-Adria Symposium on Advances in Experimental Mechanics
20-23 September 2022, Poros, Greece

STRENGTH ANALYSIS OF FIBER ROVING FOR MULTISCALE MODELING OF HYBRID CARBON-ARAMID TEXTILE COMPOSITE

Robert ZEMČÍK[1], Tereza VAŇKOVÁ[2], Tomáš KROUPA[3]

[1] University of West Bohemia, Univerzitní 8, 30100 Pilsen, Czechia, E-mail: zemcik@kme.zcu.cz

[2] University of West Bohemia, Univerzitní 8, 30100 Pilsen, Czechia, E-mail: vankovat@kme.zcu.cz

[3] University of West Bohemia, Univerzitní 8, 30100 Pilsen, Czechia, E-mail: kroupa@kme.zcu.cz

1. Hybrid composite plate

This work focuses on the multiscale modeling of composites made of layers consisting of hybrid fabric reinforcement and polymer matrix. The fabric (HP-P167AC) is a plain-weave textile with carbon (3K, 200 tex) and aramid (Kevlar 49, 158 tex) tows each placed in single direction only [1]. The matrix is made of thermoplastic foil Polyvinyl butyral (PVB). The composite material is made in form of a plate (Fig. 1) by hand lamination of 10 layers of fabric having the same orientation and 20 layers of PVB using autoclave technology (165 °C, 5 bar) with vacuum bagging (approx. –680 mmHg).

The goal is to create a numerical FEA model that can be used for the prediction of mechanical behavior including strength prediction on the macroscale. The material has orthotropic properties caused by the hybrid nature of each layer since the carbon and aramid fibers have different properties and, moreover, the tows have different geometry and spacing (4 carbon tows or 5 aramid tows per 10 mm).

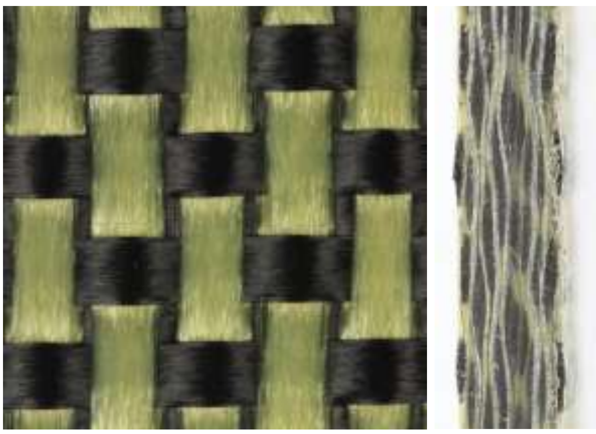

Fig. 1. Detail of hybrid textile composite plate made of 10 layers of plain-weave fabric with carbon and aramid tows and thermoplastic matrix (left – top view ca 10×10 mm, right – side view). Overall thickness is ca 2.5 mm.

2. Microscopic FEA model

The first modelling is performed on the scale of tow where we assume the material to be a unidirectional (UD) composite with parallel fibers arranged in a regular hexagonal periodic pattern [2]. The effective properties of this structure on the mesoscale can be calculated using homogenization techniques [3]. Here, we use an FEA model with exact periodic boundary conditions. The mesh (72 nodes per fiber circumference) is shown in Fig. 2. When calculating the elasticity parameters, the model has to be loaded by 6 individual stress components [4].

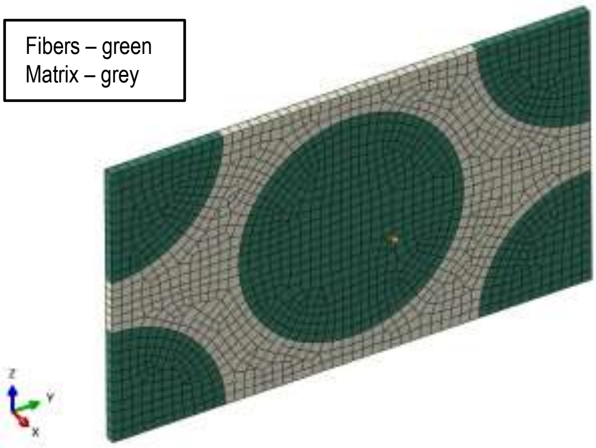

Fig. 2. Mesh of FEA model of UD tow.

3. Strength prediction on mesoscale

To predict the strength, we focus on 2 individual plane-stress problems (*xy* and *yz* planes) where we study the maximum equivalent (von Mises) stress $\sigma_{\max}$ within the matrix elements. For this purpose, we generated $N = 1026$ combinations of the corresponding stress components (σ_x, σ_y, τ_{xy}) and (σ_y, σ_z, τ_{yz}) using a unit sphere in Fig. 3 with vertices (x_n, y_n, z_n) where $\|(x_n, y_n, z_n)\|=1$, $n = 1, \ldots, N$. The vertices are generated by transforming a unit octahedron onto a sphere and then applying 4 subsequent subdivisions for each triangular face. For each combination we can plot a 3D surface generated by multiplying the position of each vertex by the factor $k = \sigma_{\max}/\sigma_{\mathrm{eq}}$, where for the plane-stress (i, $j = x, y$ or $i, j = y, z$) the equivalent stress is

$$\sigma_{\mathrm{eq}} = \sqrt{\sigma_i^2 - \sigma_i\sigma_j + \sigma_j^2 + 3\tau_{ij}^2} \quad (1)$$

Such surface can be utilized in the yield or strength criterion of the homogenized material.

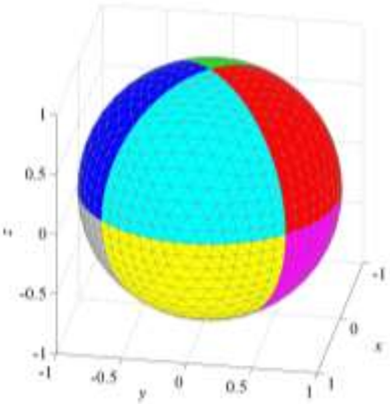

Fig. 3. Unit sphere with 1026 vertices representing load stress components for FEA models. The colored areas depict the 8 primary faces of the octahedron.

4. Results and conclusions

Example of equivalent stress distribution in one calculated model of UD tow is shown in Fig. 4. Note that only the values in matrix are considered for the calculation of k in (1). The resulting surfaces with k values for each plane-stress case are then shown in Fig. 5 and Fig. 6. The triangular faces are used for interpolation of k values from neighboring vertices.

We plan to generalize this concept for a general state of stress and to use the precalculated data in meso-macro homogenization of the textile weave. Approximation of the data by 6D surfaces will be needed for quick prediction of strength or yielding.

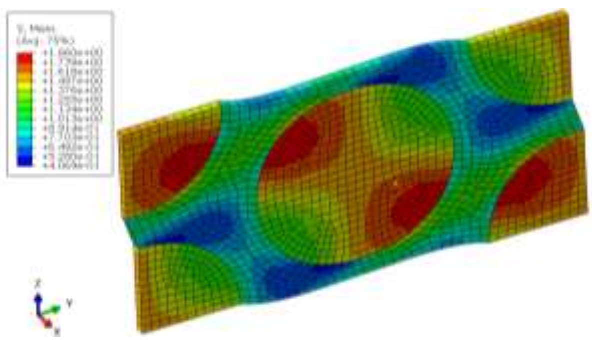

Fig. 4. Example of equivalent stress distribution on one calculated FEA model of UD roving.

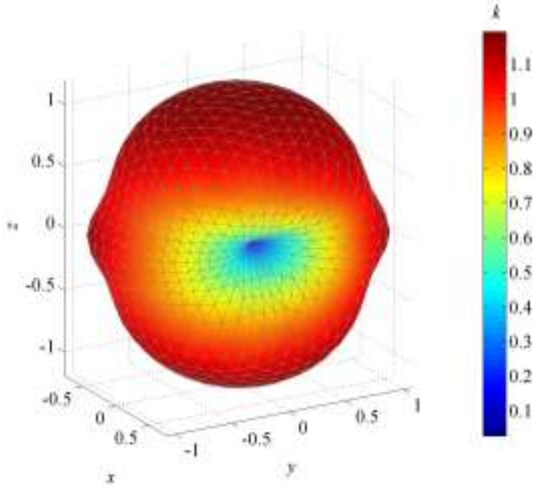

Fig. 5. Contours of stress factor k calculated for plane-stress in xy-plane of UD fiber composite.

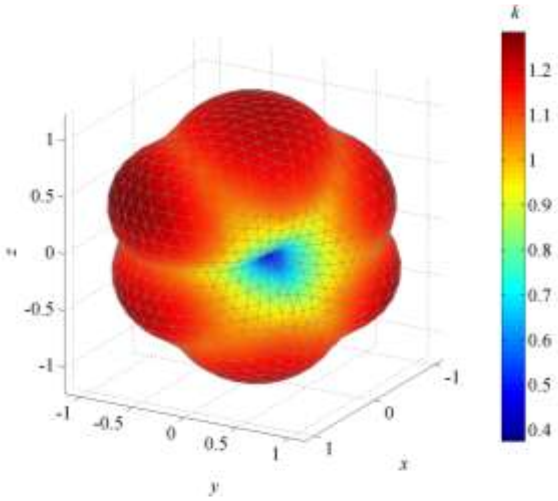

Fig. 6. Contours of stress factor k calculated for plane-stress in yz-plane of UD fiber composite.

Acknowledgements

This publication was supported by project SGS-2022-008 of University of West Bohemia in Pilsen.

References

[1] 165g/m² Hybrid Fabric Plain - Carbon/Kevlar HP-P167AC, HP-Textiles, https://www.hptextiles.com/
[2] Zemčík R, Zemčík H, Kroupa T. Anisotropy of periodic microstructure in models of unidirectional composite materials. Materials Today: Proceedings 12 (2019), 367–376.
[3] Srbová H, Kroupa T, Lukeš V. Comparison of homogenization approaches used for identification of material parameters of unidirectional composite. Materials and technology 51 (2017) 3, 373–378.
[4] Zemčík H, Kroupa T, Zemčík R, Bureš L. Influence of fiber spatial distribution in unidirectional composite cross-section on homogenized elastic parameters. Composite Structures, 203 (2018), 927–933.