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Modeling of Nonlinear Behavior of Textile Composites

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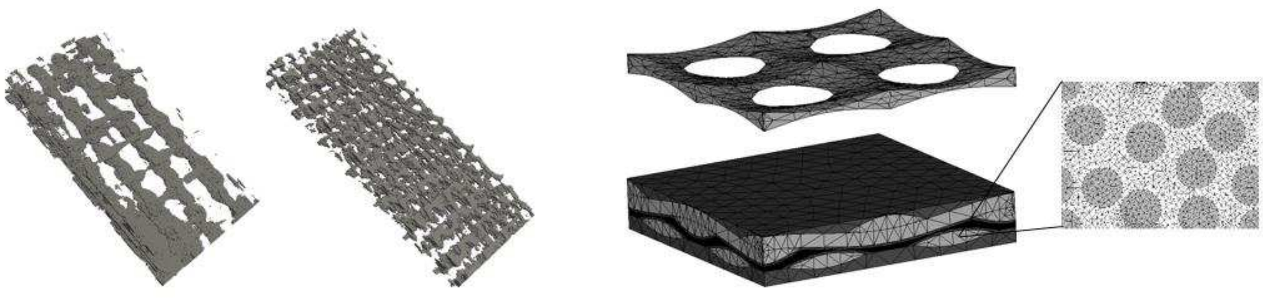
Abstract: This paper deals with the analysis of composite systems reinforced by plain weave textile fabric with attention accorded to the modeling of damage. Solution of this problem requires complex and time demanding preparation consisting of several steps such as formulation of the periodic unit cell exploiting computational microtomography to determine the actual 3D porous structure, meshing the computational model equipped with appropriate boundary conditions and finally evaluating the effective properties of yarns using, e.g. the Mori-Tanaka micromechanical model. Assessing the damage evolution of such systems then requires the solution of the first-order homogenization problem of a periodic unit cell assuming non-liner response of individual phases. Herein an approach based on Hashin-type failure criteria combined with an appropriate damage evolution law is examined.

Formulation of SEPUC

The crucial part of the analysis is the determination of geometrical and material model of statistically equivalent periodic unit cell (SEPUC), see e.g. [1], involving all the technological imperfections developed during the production of the composite including non-uniform layer width and tow undulation, inter-layer shift and nesting, a relatively high-intrinsic porosity as well as disordered arrangement of fibers within the yarn cross-section, which distinctly influences the macroscopic response of the final composite [2]. Therein, the porous phase plays the most important role when predicting the effective properties of the composite. Its volume fraction is obtained from μ-CT measurements. This phase is considerably influenced by the curing temperature as can be seen when comparing its actual distribution plotted in Fig. 1(a) – 9% and Fig. 1(b) – 9.2%. On the other hand, it appears that other imperfections do not evolve much as a function of curing temperature. A scheme of implementation of porous phase to the model of SEPUC is displayed in the Fig. 1(a-c). Figs. 1(c,d) further show the assumed two-level modeling approach.

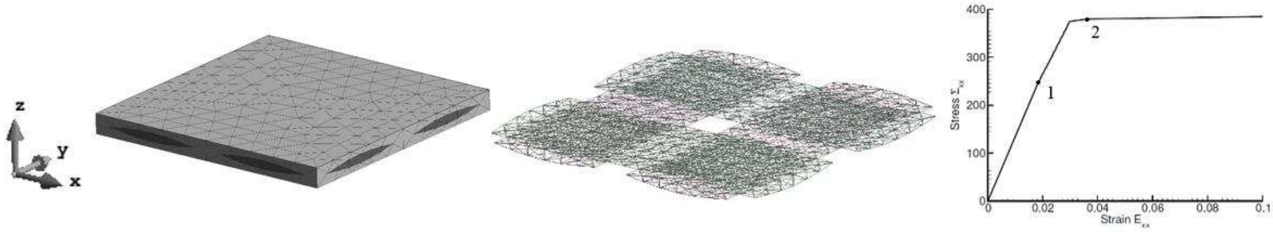


(a) (b) (c) (d)

Fig. 1: (a) porous phase of the sample cured at 200°C in 3D, (b) porous phase of the sample cured at 800°C in 3D, (c) meshed two-layer SEPUC with porous phase (separately shown above) – meso-scale, (d) mesh of yarn – micro-scale

Computational procedure

To assess the damage evolution of micromechanical model of SEPUC a model based on Hashin-type failure criteria reflecting three typical damage mechanisms (transverse matrix cracking, fiber-matrix shearing debond and longitudinal fiber breakage) is introduced. Herein, an improved damage evolution model introduced by Fang et al. [3] is applied. When using this model the tensile and compressive strength of yarn in each direction and full damage equivalent displacement of the examined failure mode are required [3,4]. They are, however, difficult to obtain experimentally. On the contrary, these can be estimated from virtual computational experiments performed at the level of yarns, where properties of individual phases are typically known. In this regard the damage model originally proposed for yarns can be used for the fiber phase on the micro-scale, see Fig. 1(d). A simple maximum stress based criterion is employed for the matrix phase on both scales. This approach falls within the category of uncoupled multi-scale modeling strategies.



(a) (b) (c)

Fig. 2: (a) one-layer SEPUC, (b) example of yarn mesh, (c) tensile stress-strain curve: point 1 - damage initiation, point 2 – full damage of yarns

Example and summary

To validate the implementation of the damage model a one layer SEPUC of textile polymer matrix based composite reinforced by plain weave basalt fabric is considered, see Fig. 2(a,b). The unit cell is subjected to macroscopic tensile stress Σ_{xx}. For the sake of simplicity the porous phase is omitted and only yarns are allowed to undergo progressive damage, whereas the matrix phase is assumed to be elastic. The necessary material parameters are taken from [4]. The resulting macroscopic stress-strain curve is displayed in Fig. 2(c). As expected, upon complete yarn failure the composite stiffness is controlled by the stiffness of the matrix.

At present the research effort is devoted to the determination of meso-scale strength parameters from macro-scale simulations. This will allow us to properly address the effect of curing temperature (effect of the evolving porous phase) on the macro-scale response of the composite.

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References

[1] Šejnoha M, Zeman J, Micromechanics in Practice. WIT Press, Southampton, Boston, 2013

[2] Vorel J, Grippon E, Šejnoha M, Effective Thermoelastic Properties of Polysiloxane Matrix Based Plain Weave Textile Composites. International Journal for Multiscale Computational Engineering, 2015, 13(3):181-200

[3] Fang GD, Liang J, Wang BL, Progressive damage and nonlinear analysis of 3D four-directional braided composites under unidirectional tension. Compos Struct 2009;89:126-33

[4] Zhou Y, Lu Z, Yang Z, Progressive damage analysis and strength prediction of 2D plain weave composites, Composites: Part B 2013, 220-229