17th International Conference
ENGINEERING MECHANICS 2011
Svratka, Czech Republic, 9 – 12 May 2011

AIR VOIDS IN MATRIX BASED TEXTILE COMPOSITES

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Abstract: *A two-layer statistically equivalent periodic unit cell with air voids is offered to predict a macroscopic response of plain weave multilayer textile composites. Two different approximations of air voids are considered to properly describe the given material system in accordance with the X-ray microtomography. Numerical predictions of both the effective thermal conductivities and elastic stiffnesses and their comparison with available laboratory data are presented and their limitations are discussed.*

Keywords: ***Textile composites, finite element method, air voids, homogenization.***

1. Introduction

In the last decade, composites have been attracting great attention of many engineers due to the irreplaceable position in a variety of engineering spheres including building, aeronautic, space and automobile industry. Applications range from rehabilitation and repair of concrete and masonry structures to the design of biocompatible medical implants. Nowadays, an increasing number of fiber reinforced composite components are being fabricated with load-carrying fibers, which are woven to form a fabric. This reinforcement system has advantages with respect to fabrication as well as mechanical properties. The weaving and interlacing of the fiber tows produces a self-supporting system that can be manipulated to form complex shapes.

Although woven composites are frequently used in practice, an accurate and reliable thermomechanical analysis of these material systems still presents a non-trivial challenge due to their complex geometry and imperfections displayed at several length scales, e.g. yarn waviness and misalignment of individual tows, porosity of woven composite, etc. In plain weave composites at least three different length scales are recognize, i.e. micro-scale (tow = fiber-matrix-void interaction), meso-scale (individual plies) and macro-scale (sample, component), see Fig. 1. To obtain the macroscopic material properties of such complicated material system the coupled (Sýkora, 2010) or uncoupled (Vorel & Šejnoha, 2009, Sýkora et al., 2010) homogenization technics can be employed.

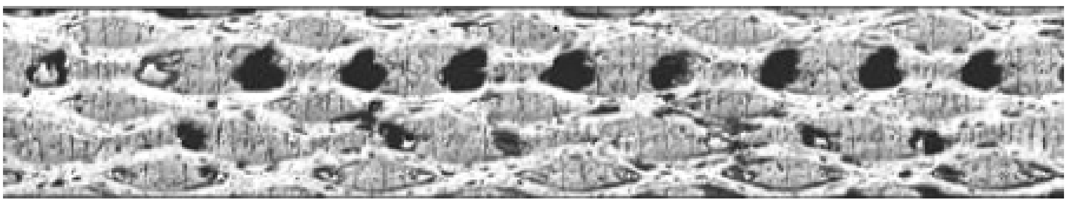

Fig. 1: Real composite system.

Here, the meso-scale level of uncoupled homogenization approach is assumed. In particular, the comparison of influence of pore shape discretization on the effective thermal coefficients and the effective stiffness matrices by means of finite element (FE) simulations is presented. The selection of mechanical and heat conduction problems is promoted not only by available experimental measurements but also by their formal similarity. To support the proposed approach the numerically obtained results for carbon-carbon composites are compared with experimental data.

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2. Numerical approach

The effective properties of a multilayered carbon-carbon (C/C) plain weave composite including the porous phase are derived in this section. The geometrical model of the corresponding representative volume element, here given in terms of the statistically equivalent periodic unit cell (SEPUC), is displayed in Fig. 2. Although the FE analysis is computationally demanding it is adopted in this study as it provides more accurate results and allows an incorporation of various intrinsic imperfections of composites.

Suppose that the homogenized effective conductivities of the yarn are already known from an independent micromechanical analysis performed on the level of individual fibers, see (Vorel & Šejnoha, 2009). The objective now is to find effective parameters on the mesoscopic level for a multilayered composite. The concept of statistically equivalent periodic unit cell for random or imperfect microstructures is utilized. A lucid presentation of individual steps enabling the substitution of real microstructures by their simplified artificial representatives - the SEPUCs – is available, e.g. in (Zeman & Šejnoha 2007). The three-dimensional structure of SEPUC, shown in Fig 2, is formed by two identical one-layer blocks, relatively shifted in all directions. Afterwards the air voids (inclusions) are introduced into the created unit cell using two different approximations which are in coincidence with the X-ray microtomography presented in Fig. 3:

- Ellipsoidal voids – with the higher level of simplification the air voids on the meso-scale can be seen as the ellipsoidal inclusions placed between the fabric reinforcements, see Fig. 2a. The relative ratio of spheroid axes is chosen as high as possible to fill the space between the tows.
- Distorted voids – this approach follows the real manufacturing process in the sense that the each tow is coated with a layer of matrix of a specific thickness. The resulting inclusions between the layers are then considered as the air voids, see Fig. 2b.

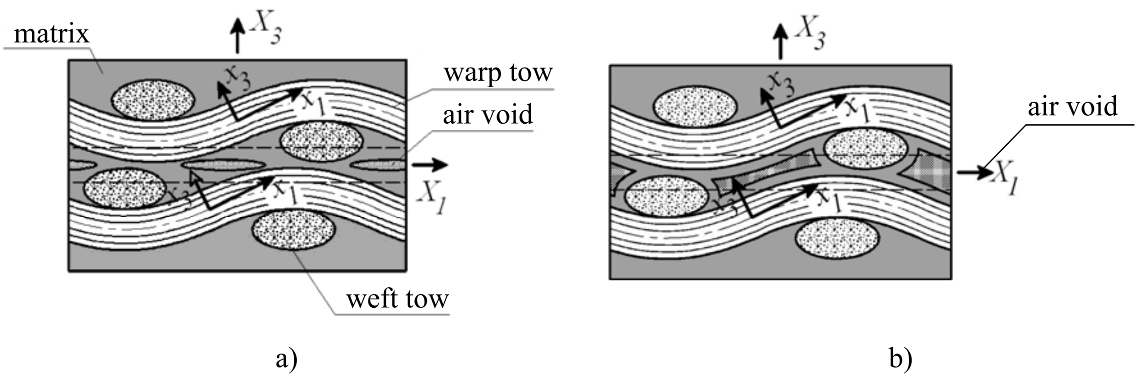
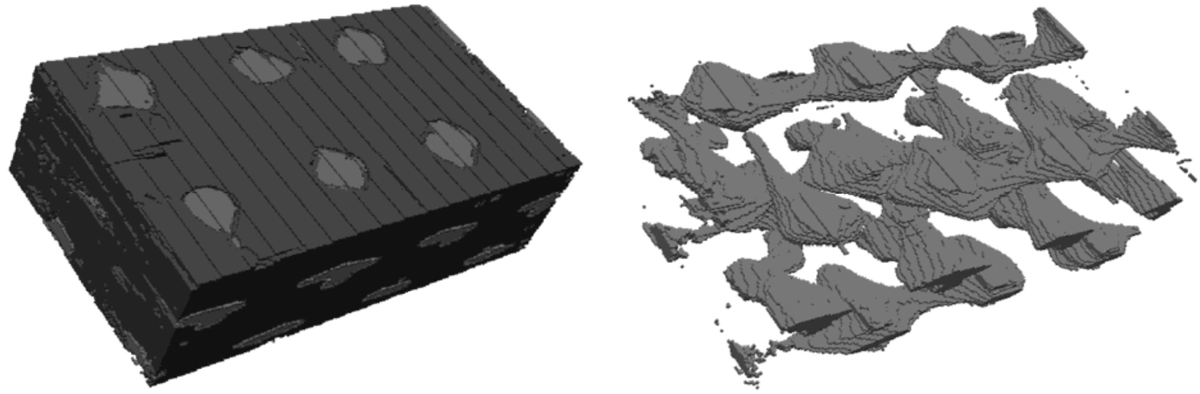


Fig. 2: Geometrical model of two-layer SEPUC: a) Ellipsoidal, b) distorted voids.

The above mentioned computational models are subsequently used for the finite element based homogenization. This technique implies the use of conforming finite element meshes easily enabling the implementation of periodic boundary conditions, see (Kouznetsova et al., 2001; Michel et al., 1999) for additional details. This might seem daunting in that it requires not only incorporation of an arbitrary shift of the two layers of fabric reinforcement, but also an independent introduction of voids. In the present study these obstacles are overcome by employing the volumetric modeling capacities of the ANSYS package (ANSYS, 2005).

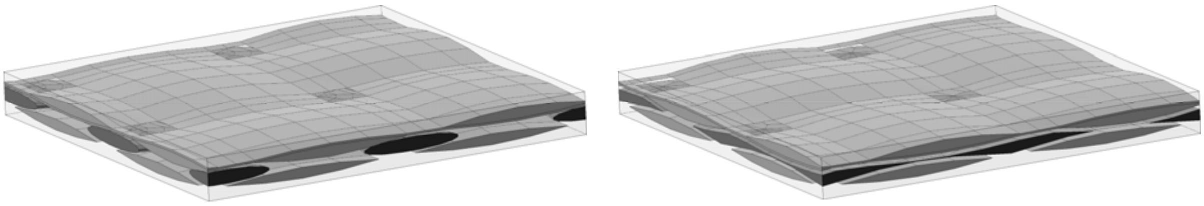
In order to ensure the symmetry of the resulting FEM mesh, a primitive block of the tow is modeled first. Subsequently, using mirroring, copying and merging operations, the whole volume of one reinforcement layer is generated. The second fabric is created by a copying and shifting of the previous layer.



a) b)

Fig. 3: X-ray microtomography: a) Interior distribution and shape of large vacuoles, b) three-dimensional view of the porous composite structure.

The porous phase is introduced next being represented by four identical oblate spheroids or irregular volumes as already mentioned. Their location is assumed to mimic the distribution of large vacuoles that typically appear, as also seen in Fig. 3, in the location of tow crossing.



a) b)

Fig. 4: 3D view of the geometry of a two-layer unit cell model with: a) Ellipsoidal, b) distorted voids.

The volume of pores equal to 5.5% is assumed. Note that this value corresponds to the percentage determined by the image analysis (Tomková & Košková, 2004). Details regarding the construction of the SEPUC from the solution of a certain optimization problem are provided in (Vorel et al., 2010). This step is quite complex and this is also the reason why the porous phase was excluded from the minimization problem and introduced subsequently to address the influence of shape of pores as the main objective of this paper.

Tab. 1: Effective elastic properties and thermal conductivities. Comparison of numerical results and experimental data (Černý et al., 1989; Boháč, 2005).

Parameter	***FEM***		***Experiment***
	Ellipsoidal voids	***Distorted voids***	
$E_{\text{warp, weft}}$ [GPa]	60.3	60.1	65
$G_{\text{warp, weft}}$ [GPa]	8.1	4.1	6
$\chi_{\text{warp, weft}}$ [W/mK]	9.03	9.00	10
χ_{trans} [W/mK]	1.89	1.49	1.6

This goal is achieved by comparing the effective conductivity coefficients χ and elastic moduli of the two geometrical models in Fig. 4. The results are stored in Tab. 1 suggesting reasonable accuracy of Fem predictions when compared to experimental data.

3. Conclusions

In order to realistically model complex plain weave textile laminates with three-dimensional, generally non-uniform texture of the reinforcements and significant amount of porosity on the mesoscopic level, we advocate the use of SEPUC weakened by air voids. Both approaches presented in this paper provide a reasonable agreement with experimental data, see Tab. 1. Each one of the introduced approximations has intrinsic limits which are related to their shapes. The substitution of air voids by ellipsoidal inclusions has mainly the restriction in the limited volume of pores phase introduced in such a manner. This problem is caused by the nonflexible shape of inclusions and the capability to place them between the reinforcement fabrics. On the other hand the distorted pores provide us with higher possibility to grasp the correct volume of pores, but in some cases deliver lower estimates for an in-plane shear modulus because of the separation of layers by the inclusions.

Acknowledgement

The financial support provided by the GAČR grants No. 106/08/1379 and P105/11/0224 and partially also by the research project CEZ MSM 6840770003 is gratefully acknowledged.

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