ELASTIC PROPERTIES OF CARBON/CARBON COMPOSITES WITH DIFFERENT FIBER DISTRIBUTIONS

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1 Introduction

In carbon/carbon (C/C) composites [1] carbon fibers are embedded in a matrix of pyrolytic carbon (PyC) which is influenced by the CVI parameters [2].
For accurate modeling of the effective elastic properties of these materials it is important to take into account the fiber and pore distributions, and pore shapes.

2 Microstructure characterization

2.1 Fiber distribution

The three dimensional distribution of fibers can be determined by X-ray computed microtomography (µCT) of the non infiltrated preform. An example of such a microstructure characterization is presented for a special case of preform consisting of unidirectional layers (Fig.1a) and felt (Fig.1b) [3]. The unidirectional layers consist of bundles of fibers and separate scattered fibers. The volume fraction of the fibers is much higher in the bundles than in the areas with separate fibers, hence the material properties of these coated fibers of two kinds are different and they are considered two kinds of inclusions in PyC matrix.

2.2 Pore distribution

Porosity is one of the important characteristics of C/C composites. Even though the architecture of the fiber preform is the same, different duration of the infiltration results in a different volume of the pores. µCT analysis was utilized for 3D description of the porosity [4] and the following procedure was used:

- The µCT data was segmented into pores and solid material with a region growing algorithm;
- The pores were labeled and analyzed using the following procedure:

1. The pore surface was extracted as a point cloud;
2. An ellipsoid with the same volume as the pore under consideration was fit using principal component analysis;
3. The Euler angles, principal half axes and the volumes of the pores were tabulated.

Using the described procedure, the 3D information about porosity of the material was gathered. All pores were approximated as oblate and prolate spheroids. The example of the distribution functions of the oblate and prolate pores is presented in Fig.3.

3 Microstructure modeling

For the prediction of the effective elastic properties of C/C composites we propose two homogenization procedures:

I. Two step homogenization procedure [3]:

1. We homogenize the material consisting of the pyrolytic carbon matrix with certain distribution of carbon fibers;
2. We embed the pores in the homogenized material obtained from the previous homogenization step. The pore morphology is taken from µCT studies [4].

II. One step homogenization procedure:

In this procedure we homogenize pores and fibers in the same homogenization step using Mori-Tanaka model [5]:

$$\mathbf{C}^{MT} = \mathbf{C}^{M} + \left(\begin{array}{l} \sum_{i=1}^{n_b} f_i^b \left(\mathbf{C}_b^F - \mathbf{C}^M\right) : \mathbf{B}_i^b + \\ \sum_{i=1}^{n_s} f_i^s \left(\mathbf{C}_b^F - \mathbf{C}^M\right) : \mathbf{B}_i^s - \sum_{i=1}^{n_s} \rho_i^p \mathbf{C}^M : \mathbf{A}_i^p \end{array} \right) :$$
$$\left(\mathbf{I} + \sum_{i=1}^{n_b} f_i^b \left(\mathbf{B}_i^b - \mathbf{I}\right) + \sum_{i=1}^{n_s} f_i^s \left(\mathbf{B}_i^s - \mathbf{I}\right) + \sum_{i=1}^{n_s} \rho_i^p \left(\mathbf{A}_i^p - \mathbf{I}\right) \right)^{-1}$$

where $\mathbf{C}^i$ are the stiffness tensors of the micro constituents, f and ρ are experimentally obtained distribution functions of the virtual fibers and pores, $\mathbf{A}$ and $\mathbf{B}$ are the influence tensors.

4 Numerical results

Effective Properties of the materials with mostly UD fibers (Fig. 1a) and random fibers distribution (Fig. 1b) were calculated using both methods; pore approximations are presented in Table 1.

5 Conclusions

The characterization and modeling procedure is presented for the calculation of effective material properties of C/C composites. The calculations of the effective elastic properties of the composite using one step and two step homogenization procedures give very close results.

The methodology can be used for more complicated fiber and porosity architectures.

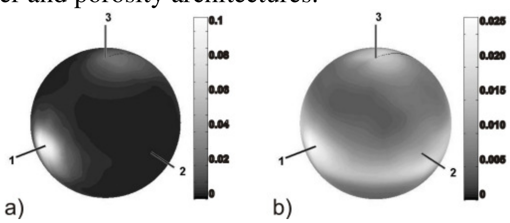


Fig.1. Preform characterization: Probability of the fiber distribution inside the a) UD and b) felt preforms.

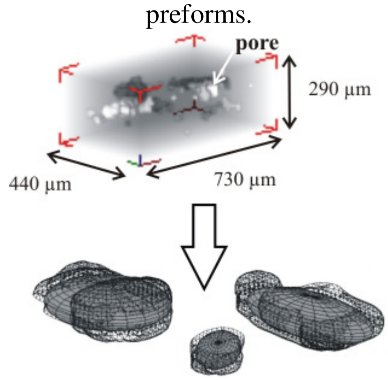


Fig.2. 3D images of the specimen obtained from μCT; approximation of the pore structure by ellipsoids with the same volume (the principal component analysis was used to fit the ellipsoids).

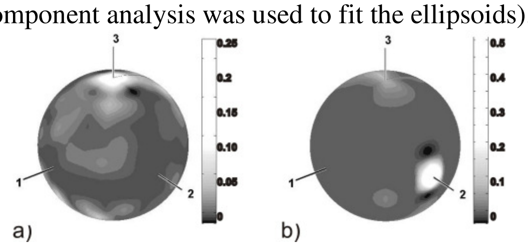
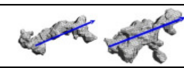
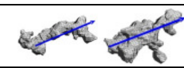


Fig.3. Distribution functions of the a) oblate and b) prolate pores.

Table 1. Effective properties of the materials for 8% pores and 22% fibers in UD specimen and for 20% pores and 11% fibers in felt specimen calculated using different methods.

Pores		E1 [GPa]	E2 [GPa]	E3 [GPa]
UD		61.68	17.78	31.86
	Two step procedure for ellipsoidal pores	61.09	14.54	28.75
	One step procedure for ellipsoidal pores	61.09	14.84	28.93
Felt		23.53	16.27	18.53
	Two step procedure for ellipsoidal pores	24.29	15.36	16.98
	One step procedure for ellipsoidal pores	19.81	18.51	17.37

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