Development and validation of multiscale micromechanical model for carbon/carbon composites produced by chemical vapor infiltration

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ABSTRACT

Chemical vapor infiltration process used in production of carbon/carbon composites (C/C) results in a material with multiscale hierarchical structure consisting of carbon fibers surrounded by layers of pyrolytic carbon (PyC) with irregularly shaped pores. For accurate modeling, C/C must be considered on several length scales:
- nanoscale (effective properties of nanotextured pyrolytic carbon);
- microscale (effective properties of carbon fibers with multiple layers of PyC);
- mesoscale (effective properties of material with irregularly shaped pores).

An overview of the methods developed within the framework of the project “Materials World Network: Multi-Scale Study of Chemical Vapor Infiltrated Carbon/Carbon Composites” is presented in this paper.

While mechanical properties of carbon fibers are well studied, understanding of mechanical response of PyC is hindered by the fact that this material does not exist in bulk form. Its anisotropic thermoelastic response is determined by manufacturing conditions. In our studies, the properties of the PyC matrix are predicted assuming Fisher distribution of orientations of graphene planes found by processing of high resolution transmission electron microscope data. These predictions are used in the microscale model to evaluate effective thermoelastic properties of unidirectional C/C composites. The approach is based on elastic solutions for basic loadcases including prescribed axial tension, transverse hydrostatic loading, axial and in-plane shear, and unconstrained thermal expansion. The composite cylinder assemblage model is utilized to predict axial elastic properties, transverse bulk modulus and thermal expansion coefficients of the overall composite. The effective transverse shear modulus is evaluated using a self-consistent method.

X-ray computed microtomography is employed to identify pores. They have dimensions on the order of tens of microns (mesoscale) and highly irregular shapes. For irregularly shaped cavities, micromechanical modeling based on the analytical solutions of elasticity becomes inapplicable. Thus, the cavity compliance tensor of an individual pore is found numerically by finite element method, and then used in a micromechanical modeling procedure. Effective properties of C/C with irregularly shaped pores are calculated.

The multiscale approach is validated by experimental measurements of elastic moduli performed on random fiber orientation (felt) material samples as well as laminated configurations of C/C. Strain gage measurement technique for felt, and digital image correlation technique for laminated structures are utilized to determine the overall material properties.

Keywords: carbon/carbon composite, nanotexture, irregular pores, multiscale model