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Modeling of effective material properties of pyrolytic carbon with different texture degrees by homogenization method

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Abstract

The elastic properties of pyrolytic carbon material as a function of texture degree were calculated by means of a homogenization method. The material microstructure is modeled as a system of graphite crystals (inclusions) embedded in an infinite homogeneous matrix with unknown effective (overall) parameters. The texture degrees of carbon planes extracted from the experimental selected-area electron diffraction patterns as well as size of coherent domains extracted from high resolution transmission electron microscopy images have been used as reference points for modeling of material properties. The experimental diffraction curves exhibiting a good fitting with the Gauss density function have been used to simulate the spatial orientation of inclusions. After that the overall elasticity tensor is calculated and the influence of the texture degree of pyrolytic carbon material on the engineering elastic parameters is studied.

Keywords: A. Carbon–carbon composites; B. Modeling; C. Elastic properties; D. Transmission electron microscopy; E. Chemical vapor infiltration

1. Introduction

Carbon–carbon (C/C) composites [1,2] exhibit an attractive combination of high fracture toughness and high strength/weight ratio. This unique combination leads to their major application as aircraft brake linings in a variety of extreme aerospace refractory materials.

Chemical vapor infiltration (CVI) is a process to produce the C/C composite. The reinforcing preform material can be used in the form of long carbon fibers, fiber bundles or fiber felts, contributing to strength and stiffness of the bulk composite. During the CVI process a hydrocarbon precursor gas is introduced into the preform where it decomposes, or pyrolyses into hydrogen and elementary carbon. The resulting carbon material deposited on the fiber surface is called pyrolytic carbon [1].

Based on the results obtained by transmission electron microscopy (TEM) and selected-area electron diffraction (SAED), the pyrolytic carbon matrix can be described as a set of graphitic domains having different preferred orientations or textures in relation to the fiber surface, which are classified as: isotropic, low (LT)-, medium (MT)- and high-textured (HT) [3,4]. However, it is not possible to obtain the pyrolytic carbon with different texture degrees in quantity adequate to standard mechanical testing procedures. As a result the correlation between mechanical properties and the texture degree of pyrolytic carbon deposits is poorly studied. The last paper on this topic was written in 1969 by Bokros [5]. Therefore, the prediction of mechanical properties of C/C composites fabricated by CVI of carbon fiber composites is important for their effective industrial applications. The present paper attempts to develop an effective micromechanical approach for the analysis of the

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mechanical behavior of pyrolytic carbon matrices with different texture degree.

Theoretical investigations of heterogeneous materials and structures aim to derive the effective material properties, with respect to imposed loading, known distribution of the material parameters, geometry and characteristic material length scales. The descriptions of the effective properties of heterogeneous materials account for at least two or more length scales. The change from one length scale to another can be visualized as "zooming" into the material to a sufficiently small scale, which is large enough to be presented as a continuum. For this purpose the so called representative volume element (RVE) is defined as a suitably large sample which is a good representative of the material microstructure [6–9]. For the statistically homogeneous RVE, the overall response of this RVE is almost the same for various boundary conditions with a common average stress or strain. In real heterogeneous materials the dimensions of the RVE on the smaller level of the characteristic length l are typically very small in comparison with the dimensions on the length scale L of the higher level. The ratio k of these smaller and larger scales is represented by a very small positive number $k = l/L \ll 1$ [6–9].

The aim of the present contribution is to develop the homogenization method for pyrolytic carbon matrices, to calculate the overall elasticity and the compliance tensors as a function of texture degree, and to apply it for the analysis of mechanical properties of infiltrated carbon fiber composites.

2. Structural analysis

The basic idea of the modeling of the pyrolytic carbon material is to utilize the real physical spatial distribution of carbon structural units obtained directly from experimental microscopical methods.

Fig. 1(a) shows a polarized light micrograph of a polished section of an infiltrated carbon fiber composite. The matrix consists of up to five concentric layers (labeled 1–5) forming well-recognizable interfaces. Fig. 2(b)–(d) are high resolution TEM (HRTEM) micrographs and SAED patterns (insets) taken from

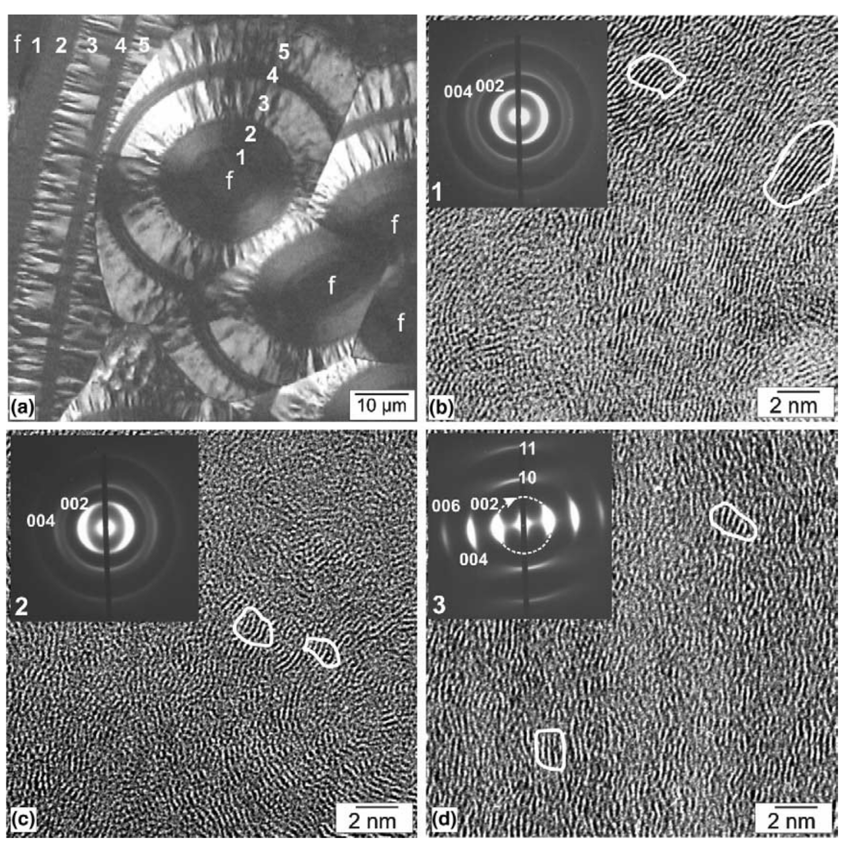

Fig. 1. (a) Polarized light micrograph of a polished section of an infiltrated carbon fiber composite. The carbon fibers (f) are surrounded by five (numbered 1–5) pyrolytic carbon layers. High-resolution TEM images (b), (c) and (d) are taken from layers 1, 2 and 3, respectively. Coherent domains are marked with white bold contours. Insets in (b), (c) and (d): the corresponding selected-area electron diffraction patterns. Dashed white circle in the inset of (d) indicate the direction of the intensity scan.