Homogenization of the thermoelastic properties of pyrolytic carbon

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Introduction

In order to understand the material properties, we have to investigate the microstructure of the Carbon/Carbon composite (C/C composite). This can be performed by using the method of the, e.g., transmission electron microscopy (TEM) with selectedarea electron diffraction (SAED) [5]. On the submicro scale, the microstructure of C/C composite can be described as a set of coherent domains having different preferred orientations or textures in relation to the surface of the plane substrate. In order to automatically extract the coherent domains, we employ an unsupervised image segmentation technique like the Local Binary Patterns (LBP) [4].

Image Segmentation

Segmentation refers to the process of partitioning a digital image into multiple segments (sets of pixels). The goal of segmentation is to simplify and/or change the representation of an image for an easier and more meaningful analyzation. Generally, we do not know what types of domains exist, how many domains are in an image. In order to reliably distinguish between two domains, representative features must be available. An efficient method for image segmentation based on texture description with feature distributions is the so-called LBP [4].

Local Binary Patterns

The approach of the LBP operator works generally with eight neighbors of a pixel, using the value of the center pixel as a threshold. An LBP code for a neighbor is produced by multiplying the thresholded values with weights given to the corresponding pixels, and summing up the result.

Algorithm

This texture segmentation algorithm using the LBP texture description does not require any prior knowledge about the number of textures or regions in the image, as most existing approaches do. The segmentation method based on the LBP consists of three phases: hierarchical splitting, agglomerative merging, and pixelwise classification.

In the first phase, the image is divided into square regions. Then, based on G-statistics, an agglomerative merging procedure merges similar adjacent regions until a stopping value is reached. In the last phase, the obtained estimates of the different texture regions are completed by a pixelwise classification to improve the exact localization of the segment borders.

The goal of the LBP analysis is to obtain segments with homogeneous textures in a classification step. The dissimilarity of sample and model histograms, which is measured by a nonparametric statistical test, is evaluated as a kind of goodness-of-fit test. The G (log-likelihood ratio) statistic is representative for such a well-known goodness-of-fit test.

Estimation of the Orientation and the Width in TEM image

After the segmentation with the LBP method, we have the segmented regions/areas of the original image. For every individual segmented block, the application of a tool for the evaluation of image information to extract the information about the texture is necessary. We consider an operator – Fourier Analysis – to be applied for every segment in order to extract the dominant features of the homogeneous textures. We employ the correspondence of Fourier transformation to estimate the orientation and the width in the TEM image. In Figure 1 we can see the result of the segmentation.

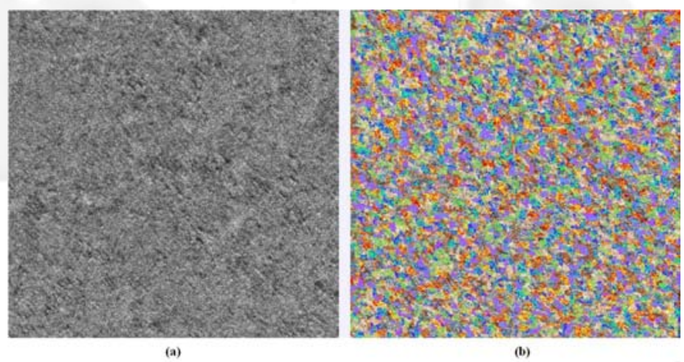

Fig. 1 (a) The original image (b) The result of segmentation

Mechanical Application

Based on these directional information, the stiffness tensor is determined for each domain. The domains have a transversely isotropic material symmetry. The volume fractions of the domains have been estimated with the area fractions assuming an isotropy of the microstructure. With the set of stiffness tensors and corresponding volume fractions, different homogenization schemes for estimating the effective elastic properties of the aggregate of domains can be determined. Here, four bounds are computed. The simple bounds by Voigt and Reuss, which represent the best bounds, that are only based on the one-point statistical information of microstructure, and the Hashin-Shtrikman bounds. Being the best bounds including the two-point correlation functions, which here are approximately isotropic. The mechanical properties like the pole figure (Fig. 2 (a)), Young's modulus [MGPa](Fig. 2 (b)-(d)), the thermal conductivities, etc., can be homogenized by these bounds [2].

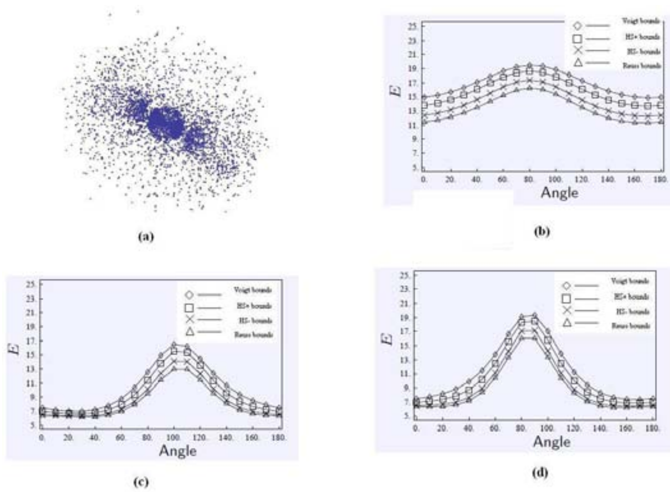

Fig. 2 (a) The pole figure (b) Young's modulus [MGPa] in plane(x, y) (c) Young's modulus [MGPa] in plane(x, z) (d) Young's modulus [MGPa] in plane(y, z).

Conclusions

In this work a method of local binary pattern is presented to analyze the texture on the microscopic level. A solution to unsupervised image segmentation is proposed, in which a method based on comparison of feature distributions is used to find homogeneously image regions and to localize boundaries between regions. The method performed very well in numerical experiments and can be easily generalized. It does not require any prior knowledge about the number of domains or regions in the image. The analysis of Fourier spectra stands on the basis of the 2D-Fourier transform and the sampling theorem. With the help of invariant features, the expected solutions are determined.

Acknowledgment. The authors gratefully acknowlege support by the DFG-NSF joint grant within the "Materials World Network: Multi-cale study of chemical vapor infiltrated C/C composites".

References

[1] T.Böhlke, T.-A. Langhoff, and R. Piat: Bounds for the elastic properties of pyrolytic carbon, Proc. Appl. Math. Mech. (2009).
[2] T.Böhlke, K. Jöchen, T.-A. Langhoff, I. Tsukrov and B. Reznik: Elastic properties of pyrolytic carbon with axisymmetric textures, Technische Mechanik, 30, 4, 343-353 (2010).
[3] E. Fitzer and L. Manocha: Carbon Reinforcements and Carbon/Carbon Composites. Springer (1998).
[4] T. Ojala and M. Pietikäinen: Unsupervised Texture Segmentation Using Feature Distributions Pattern Recognition, 32, 3, 477-486 (1999).
[5] B. Reznik, D. Gerthsen, W. Zhang and K.H¨uttinger: Texture changes in the matrix of an infiltrated carbon fiber felt studied by polarized light microscopy and selected area electron diffraction, Carbon 41, 2 (2003).