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ANALYSIS OF FIBER DISTRIBUTION AND VOLUME RATIO OF UNIDIRECTIONAL
COMPOSITE FOR MICROMODELS

ANALÝZA ROZLOŽENÍ A OBJEMOVÉHO PODÍLU VLÁKEN JEDNOSMĚROVÉHO
KOMPOZITU PRO MIKROMODELY

Abstract

This work focuses on assessment of real fiber and matrix volume ratios of unidirectional fiber composites which will be used while designing corresponding micromodels. Scanning electron microscopy (SEM) was employed on samples with polished cross-sections. Obtained images of various parts of the composite cross-sections are analyzed by convolution with a circular binary mask and a suitably chosen spatial function using *Matlab* and its Image processing toolbox. The output of this analysis are center positions and radii of all fibers. Subsequently, the fiber and matrix volume ratios are easily determined.

Abstrakt

Tato práce je zaměřena na zjištění skutečných objemových podílů vláken a matrice u jednosměrových vláknových kompozitů. Výsledky této analýzy budou dale využity při návrhu geometrie mikromodelu. Snímky naleštěných průřezů kompozitových vzorků byly pořízeny pomocí řádkovacího elektronového mikroskopu. Získané snímky různých částí průřezů jsou analyzovány pomocí konvoluce s binární maskou a prostorovou funkcí s využitím softwaru *Matlab* a jeho Image processing toolboxu. Výstupem této analýzy jsou polohy středů a poloměrů jednotlivých vláken zachycených na snímku. Hledané objemové podíly vláken a matrice jsou následně získány jednoduchým vztahem.

Keywords

image, cross-section, image processing, carbon, fiber

1 INTRODUCTION

All methods of fabricating unidirectional fiber reinforced composites result in a nonuniform distribution of fibers in the matrix (Fig.1 shows a typical cross-section). The fiber distribution affects the mechanical properties of the composite. In [1] the local stress fields and damage initiation in dependence on the fiber distribution are investigated. Although the fiber volume ratio v_f determines the geometry of composite micromodels and subsequently the identified homogenized material

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properties [2], it is a problem to determine it precisely. For example a finished fiber composite article made by transfer molding method typically ranges between approximately v_f =0,5 and v_f =0,6 [3].

2 EXPERIMENT

Five specimens were cut out from five different carbon/epoxy plates using water jet. Each plate was made of different number of autoclaved prepreg layers of different thickness. The specimens were fixed in epoxy and their cross-sections polished on a low speed polishing machine.

Grayscale images of various parts of cross-sections were obtained using a scanning electron microscopy. The composite cross-section was enlarged 1000 times (Fig. 1a) and 4000 times (Fig 1b).

(a) (b)
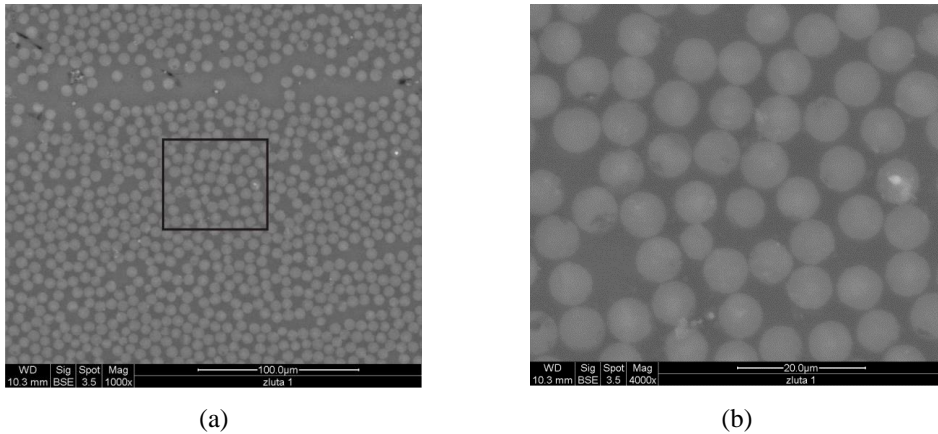
Fig. 1 Cross-section of a unidirectional fibrous carbon/epoxy composite

(a) enlarged 1000 times, (b) enlarged 4000 times

3 IMAGE PREPROCESSING

The grayscale image $f(x, y)$ matrix with pixel intensity values ranging from 0 to 255 is preprocessed by dilation. Dilated image $\overline{f}(x, y)$ is obtained as

$$\overline{f}(x, y) = (f \oplus g)(x, y) = \max\left\{f(x - x', y - y') + g(x', y') \big| (x', y') \in D_B\right\} \quad (1)$$

where:

$g(x, y)$ — binary structuring matrix, (5×5) of ones, with rectangular domain D_B [4],

x, y — pixel coordinates.
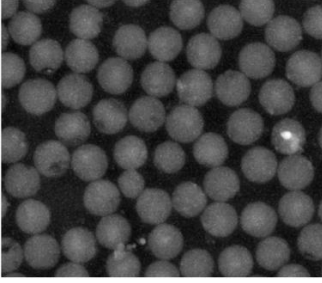
4 FIBER CENTER DETECTION

The preprocessed image (Fig. 2a), a circle binary mask of the minimum fiber cross-section size (Fig. 2b) and a discrete spatial matrix (Fig. 2c) are transformed with two dimensional discrete Fourier transform

$$F(u, v) = \sum_{n=0}^{N-1} \sum_{m=0}^{M-1} \overline{f}(x, y) \cdot e^{\left(-2\pi i\left(\frac{nx}{N} + \frac{my}{M}\right)\right)}, \quad (2)$$
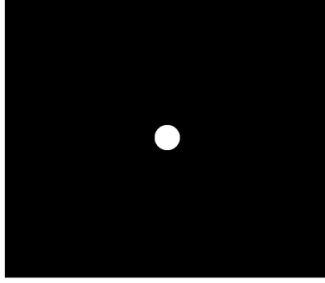
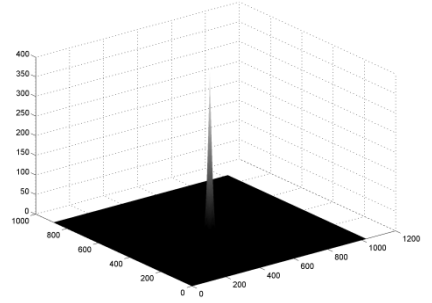where:

$F(u, v)$ — matrix in spatial frequencies u and v,

M, N – matrix dimensions [5].

Fig. 2 (a) Preprocessed image ($M{\times}N = 883{\times}1024$)

Fig. 2 (b) Circular binary mask ($M{\times}N = 883{\times}1024$)

Fig. 2 (c) Bilinear ruled surface function non-zero in square subdomain

Matrix in spatial frequencies obtained by discrete convolution

$$G(u,v) = F(u,v) * \left(H(u,v) \cdot Q(u,v)\right), \tag{3}$$

where $H(u,v)$ is binary mask (Fig. 2(b)) and $Q(u,v)$ is matrix (Fig. 2(c)) transformed by Fourier transform (2) [4] and its local maxima are considered as the fiber center positions.

5 RADIUS AND AREA DETECTION

Further, a cluster analysis was applied on the input grayscale image segmented by thresholding. Cluster analysis is an iterative process where a set of objects (pixels in this case) in one group (cluster) are more similar to each other than to those in other groups. In this case a hierarchical clustering method was used to group the pixels to the initial cluster centroid positions in this case the identified fiber center positions. Fiber area S corresponds to the number of pixels assigned to its center (Fig. 3). Fiber radius r is approximated by
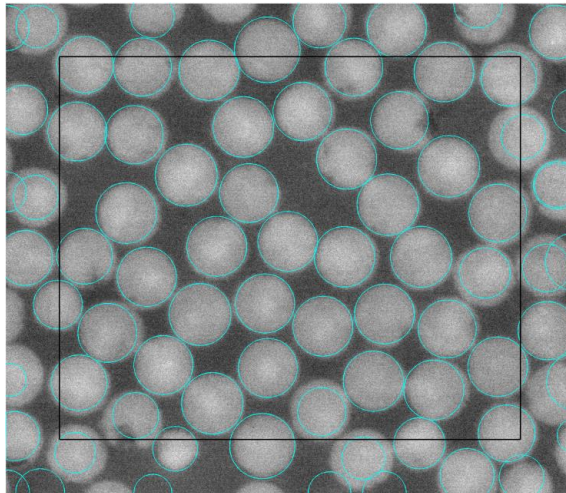
$$r = \sqrt{\frac{S}{\pi}} . \tag{4}$$
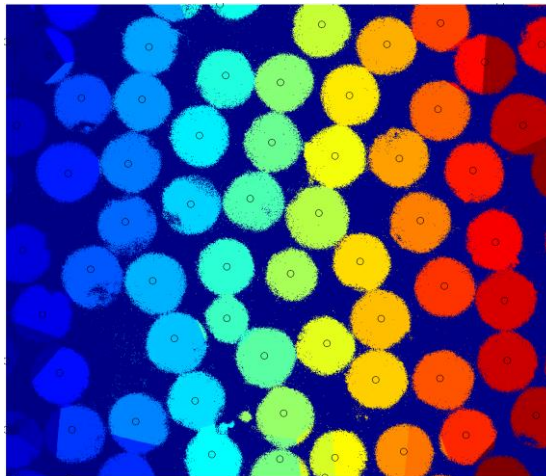
Fig. 3 Clustered pixels and identified fiber centers

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6 RESULTS

Tab. 1 Results of analysed image

Fiber volume ratio	v_f	0.62
Arithmetic mean of fiber radii	$\bar{r}$	51.58 pixels
Fiber radii standard deviation	$\sigma(r)$	5.05 pixels

7 CONCLUSIONS

Fig. 4 Identified fibers and reduced part of image

Figure 4 shows the identified fibers on the input image. The analysis of fiber center position and diameter gives more precise results at the inner part of the cross section image. Therefore, data for further micromodel modeling are taken into account from a reduced part of the image. The fiber area on the reduced part has been divided by the reduced image area to obtain the fiber volume ratio.

ACKNOWLEDGEMENT

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