CALIBRATION OF AN IMAGE PROCESSING TOOL FOR ANALYSIS OF FIBRE ORIENTATION IN FIBRE REINFORCED COMPOSITES

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Summary: *This paper deals with calculation of fibre orientation distribution (FOD) in fibre reinforced composite. The calculation was based on image analysis algorithm applied on image acquired by scanning electron microscope. A composite with oriented fibres was selected to be enable calibration of the algorithm by comparison of the obtained results with FOD declared by the manufacturer.*

Keywords: *C/PPS, fibre orientation, SEM, composite*

1 Introduction

Fibre orientation distribution (FOD) in composites is a crucial factor of the anisotropic properties in both long–fibre and short–fibre composites. While in the long–fibre composites the orientation of fibres may be easily controlled during the fabrication process, the short–fibre composites exhibit a non–uniform FOD [1]. Hence analysis of FOD in the manufactured short–fibre composites provide and resulting predominant directions in mechanical properties. An image processing procedure was developed and calibrated on specimens of Carbon fibre reinforced polyphenylene sulfide (C/PPS). Selected material is a long–fibre composite with geometrical properties declared by the manufacturer.

2 Materials and methods

2.1 Specimen preparation

The specimen for the image acquisition was extracted from C/PPS [2] using a precise saw and the surface was finalised using a series of grinding using diamond grinding discs and suspensions. To achieve a lowest possible roughness an optimised grinding procedure described in detail by Dudíková [3] was used.
As the analysed composite exhibits orthotropic properties there was an crucial requirement for the prepared plane not to follow the principal directions of the fibres. Hence a plane with declination angle $45\,^\circ$ and $45\,^\circ$ xz and xy planes (z is normal to the composite's plies) was selected and prepared for the analysis. To ensure parallelism of the selected plane with the operation plane of Scanning electron microscope (SEM) a custom support was designed and manufactured (see Fig. 1).

2.2 Image acquisition

To acquire high resolution data with a proper contrast capable for a precise segmentation and subsequent analysis, SEM (MIRA LMU II, Tescan, Czech republic) was used. As the specimen contains conductible carbon fibres, there was no need to special preparation procedures to raise the specimen's conductivity. The scanning was performed in high vacuum (the chamber pressure was $3 \cdot 10^{-2}\,\mathrm{Pa}$), and the accelerating voltage was $5\,\mathrm{kV}$. As high contrast of the acquired image data was required, cathodoluminiscence mode was used

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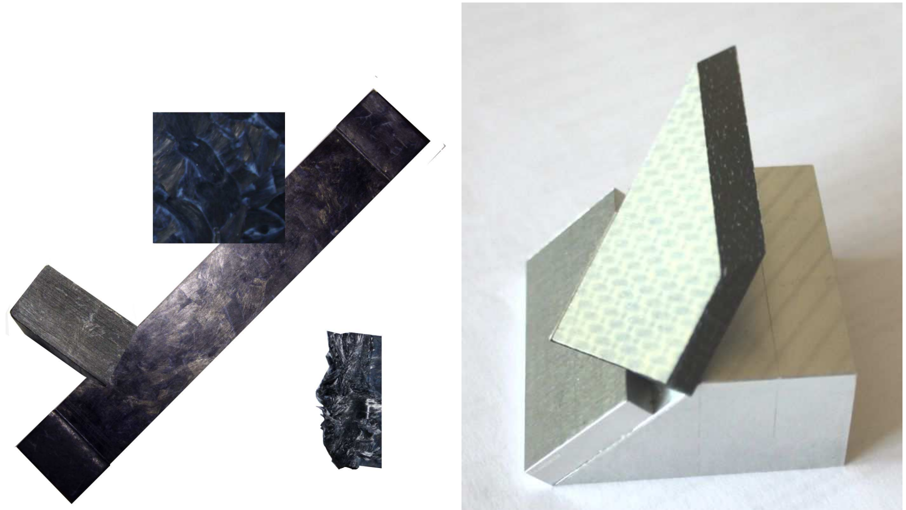
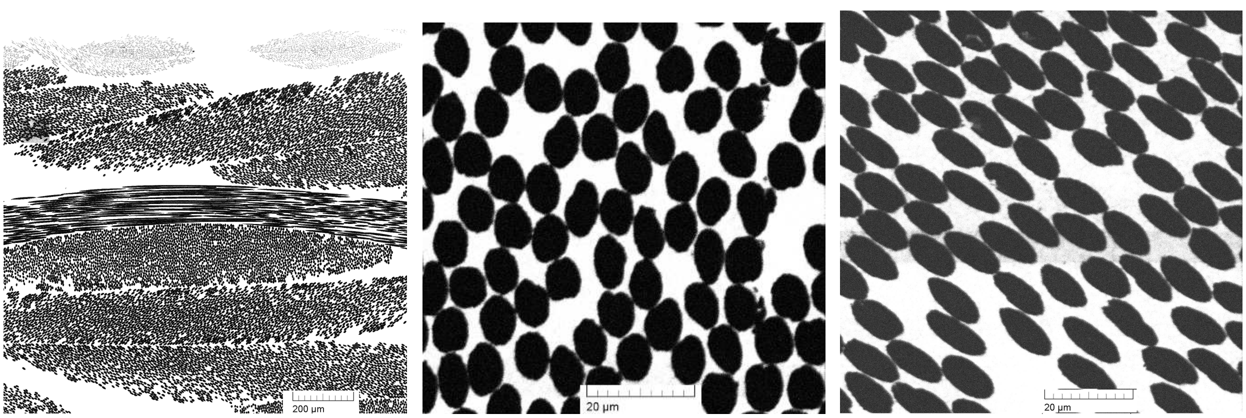


(a) omnidirectional composite (b) directional composite

Figure 1: Specimens of carbon fibre reinforced composites

for the scanning. Two sets of image data were acquired using SEM at two different levels of magnification, $275\times$ and $4000\times$. The overall view and selected regions of interest are depicted in Fig. 2.

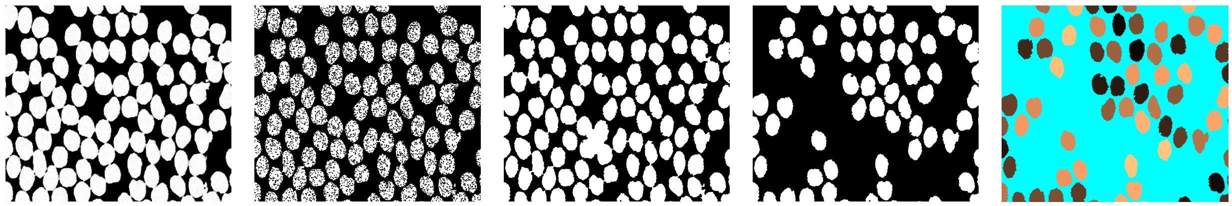


(a) (b) (c)

Figure 2: SEM micrographs of the selected edge of C/PPS specimen, (a) overall view, (b) and (c) detailed views

2.3 Image analysis

The obtained image data were of a sufficient quality both in terms of resolution and contrast. Therefore segmentation procedure based on thresholding and morphological operations was sufficient for the analysis. As the image data were of a homogeneous luminosity, a global threshold value was used. The threshold value was in the first step set automatically based on the original image histogram using Otsu method [4] and subsequently it was manually adjusted (as the absolute areas were used as a secondary parameters only, this fact did not affect the main result, i.e. FOD). Morphological operations (concatenation of binary dilatation and erosion) were used to obtained separated cross–section of the fibres in the binarised images. The morphological operations are characterised by the neighbourhood connectivity and radius of the binary operator



(a) binarization (b) erosion (c) closing (d) nested cross–section removal (e) connected component analysis

Figure 3: Selected detail of the image data in different phases of the image analysis procedure

[5]. The radius was adjusted manually regarding to balance between number of remaining groups of connected cross–sections and preservation of the cross–sections' shapes. An illustrative region of the image data in distinct phases of the segmentation procedure is depicted in Fig. 3. Connected component analysis was applied on the filtered data and following characteristics were extracted (i) area, (ii) perimeter, (iii) centroid coordinates, (iv) minor and major axes and (v) orientation angle. Limit area and area–perimeter ratio were selected for exclusion of the cross–sections indicating nested cross–sections.

2.4 FOD calculation

The calculated cross–section characteristics were transformed into fibre orientation angles. The orientation angles of the cross–section ellipses was considered as angle ψ (inclination to the y axis). Angle ϕ was calculated using ratio between major and minor axes of the cross-section ellipse (denoted as i_M and i_m, respectively) using relationship (1). The nomenclature of the angles and axes relatively to a fibre is schematically depicted in Fig. 4.

$$\phi = arcsin\frac{i_m}{i_M} \tag{1}$$

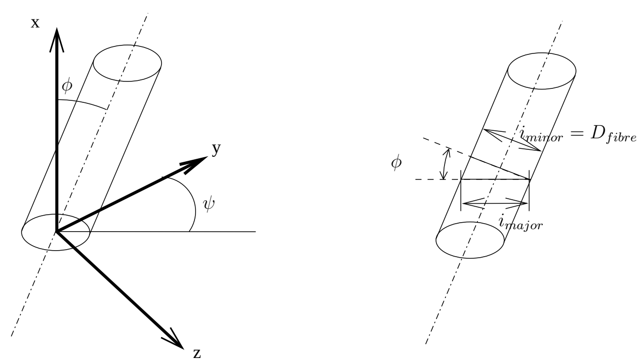


Figure 4: Definition of angles and axes for the FOD calculation.

3 Results

Using described image analysis procedure FOD of directional C/PPS was estimated. Results for both ϕ and ψ are presented in Fig 5. As the tested composite had a woven structure of the fibres, the distribution of the orientation angles in distinct layers of fibres were uniform with variation $\pm 20^o$ along the mean value, which was considered as the principal direction of each layer.

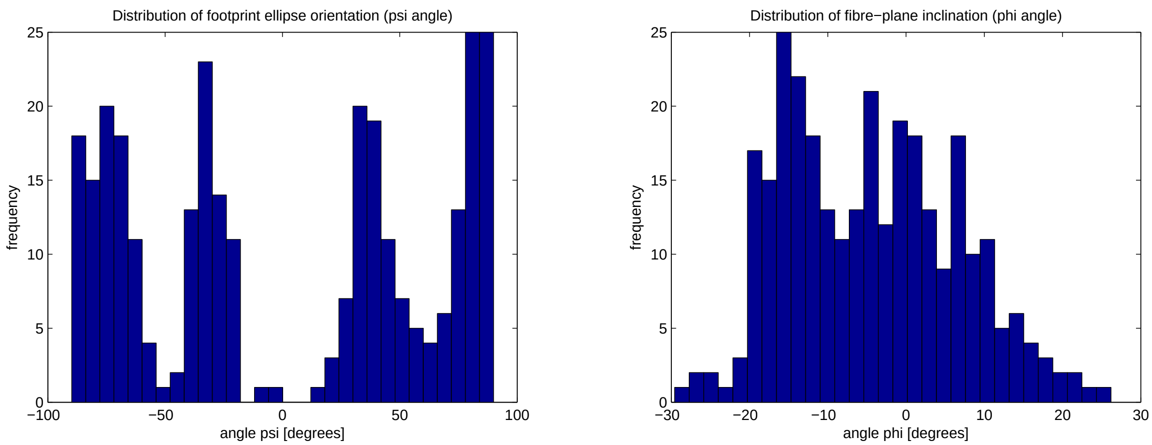


Figure 5: Definition of angles and axes for the FOD calculation.

4 Conclusions

Based on image analysis of the cross–section FOD of C/PPS was estimated. Obtained distribution of ψ exhibits predominant directions with angular step 45° which is in accordance with the datasheets of the tested composite. Distribution of the ϕ is uniform along the principal directions due to the wowen nature of the tested composite. The analysis might be improved and more automated by a better segmentation technique (e.g. region growing may help to overcome the issue with nested ellipses). The analysis of the fibre orientation distribution will provide a base for representative volume element estimation and homogenisation techniques in the further development.

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References

[1] Hine, P. J., Lusti, H. R., Gusev, A. A.: *On the possibility of reduced variable predictions for the thermoelastic properties of short fibre composites*. Composites Science and Technology, 64 (7-8), 1081-1088 (2011).

[2] Airbus: AIMS - Airbus Material Specification, Airbus S.A.S, 2007

[3] Dudíková, M., et al.: Chemické Listy 105, s790-s791 (2011).

[4] Otsu, N.: *A Threshold Selection Method fram Gray-Level Histograms*, IEEE Transactions on Systems, Man and Cybernetics, Vol. 9 (1), 1979, pp. 62-66

[5] Shapiro, L., Stockman, G.: *Computer Vision*. Prentice Hall, Upper Saddle River,2001.