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Geometric model of nonwoven fabric for homogenization of mechanical properties

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1. Introduction

Light nonwoven fabric Meftex is a functional textile material with various interesting properties, including EMS shielding properties and electrical conductivity. The functional properties of the textile are given by a thin metal surface layer on a polyester fiber core. In our application, Meftex figures a functional layer inside a more complex laminate material for electric car battery boxes. As with other automotive applications, safety requirements exist, especially on mechanical properties, which will be investigated by a computational homogenization approach. The first step for computational analysis of Meftex mechanical properties and homogenization is to create representative geometry. Geometrical modeling of Meftex fabric with different surface density is described in the paper [2], which describes the reconstruction of the geometry of a small section of a similar textile with lower areal density. Textiles with different areal densities exhibit distinct characteristics and require the introduction of different assumptions. In contrast to the mentioned article, this work aims to establish a methodology for constructing a micro-mechanical representative model rather than creating an accurate replica of a small textile segment.

2. Image processing

The structure of the Meftex consists of two layers connected by thermal bonding. In each layer, fibers are almost parallel and perpendicular between layers, which is reflected in the model. Therefore, the proposed model consists of two layers of fibers and thermal bonds. Each of these units is created independently. Image data from scanning confocal microscope were

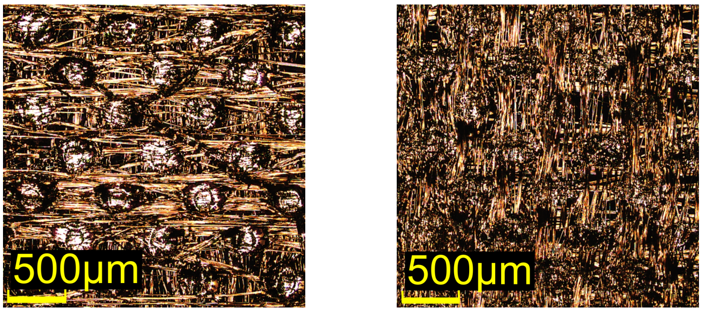

Fig. 1. Images of Meftex fabric obtained by confocal scanning microscope from front and back side

used as input, Fig. 1. The images show uneven fiber placement, where fibers are arranged in periodically spaced clusters. The objective of image analysis is to characterize and replicate this arrangement.

Fibers from the opposite side are visible through both the front and back layers, which could cause distortions in subsequent analyses. The distribution of fibers between layers was determined by orientation analysis in ImageJ software [3]. Each image was then binarized and skeletonized, Fig. 2. Each skeleton was characterized by its length and center coordinates for further analysis. Furthermore, the local mass distribution was obtained by summing over the direction of fiber orientation, Fig. 3.

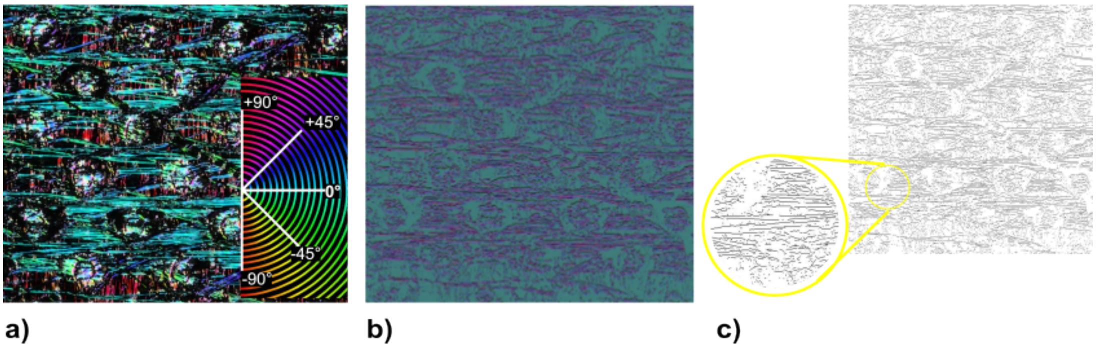

Fig. 2. Image processing procedure–orientation analysis (a), segments with uniform orientation (b), image after skeletonization (c)

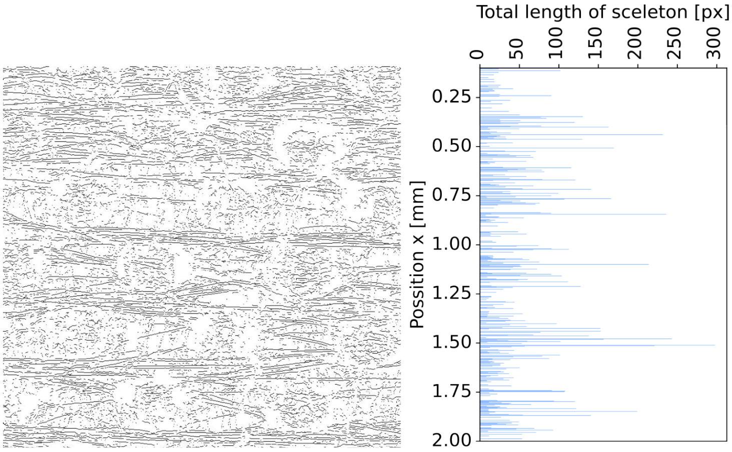

Fig. 3. Example of vertical mass distribution of one side of fabric

3. Identification of fiber placement characteristics

The mass distribution diagram shows two levels of periodicity of the structure. The fibers are arranged in periodically spaced bundles. The next level of arrangement is the distribution of fibers within these bundles. The discrete wavelet transform (DWT) was used to separate these two levels. The main reason for using the wavelet transform is its ability to decompose the signal into frequency components while preserving localization information with minimal distortion [4]. A fifth-order Daubechies wavelet was used as the basis function. Fig. 4 shows the trend and fluctuation components of the signal obtained by the wavelet transform. The fast Fourier transform (FFT) of these components was performed to characterize the periodicity of the fiber distribution.

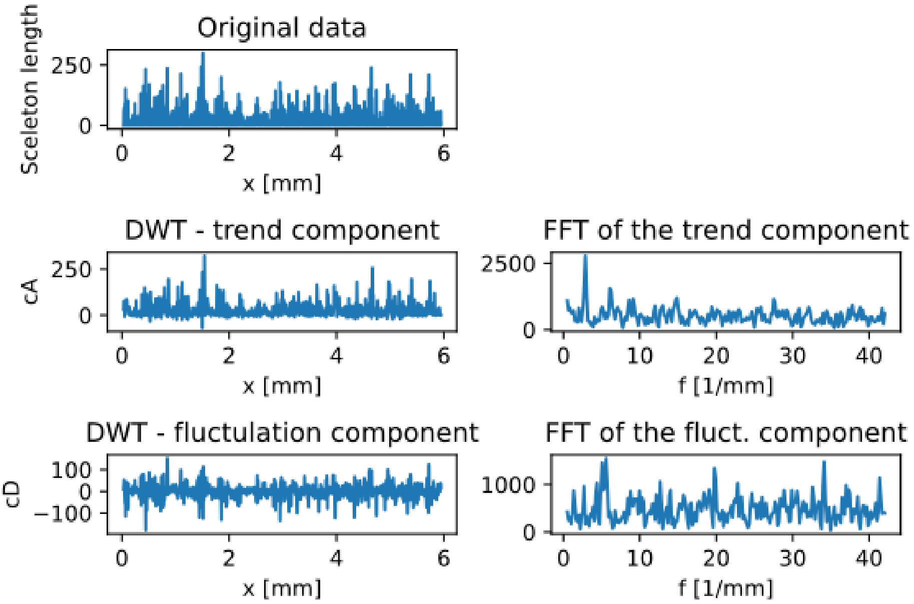

Fig. 4. Decomposition of mass distribution signal by wavelet transform and frequency spectrum of each component

The mass of a single fiber was estimated from its length, diameter, surface density of fabric, and front-to-back side skeleton length ratio. In the next step, the placement of each fiber was determined, and the transversal coordinate was chosen so that no intersections or collisions between fibers would occur. Finally, the representative geometry was built in the multi-scale modeling software MSC.Digimat [1].

4. Application

The developed geometry was used to estimate the effective elastic properties of the laminate with epoxy matrix and Meftex reinforcement. The linear elastic behavior of the material was considered, i.e.,

$$\sigma_{ij} = C_{ijkl}\epsilon_{kl}\,. \tag{1}$$

The representative geometry was discretized using the voxel mesh. Periodic boundary conditions were used. Effective elastic coefficients were computed using linear homogenization

$$\langle\sigma_{ij}\rangle = \frac{1}{V}\int \sigma_{ij}\mathrm{d}V\,. \tag{2}$$

Results are demonstrated by directional dependence of stiffness tensor component E_{11}, Fig. 5b. The FFT solver implemented in MSC.Digimat software was used for the computation [1].

5. Conclusion

The described methodology allows the construction of a geometry based on the characteristics of the periodicity of the fiber placement. Several assumptions were considered. The fibers are treated as straight, arranged in two layers with uniform orientation in one layer. As a result, the geometry is, by default, periodical, which allows the usage of periodic boundary conditions in the homogenization step. Furthermore, a constant fiber diameter is considered, and the vertical position of the fibers is chosen so that the fibers do not intersect. The usage of the developed representative geometry was demonstrated by the homogenization of its mechanical properties.

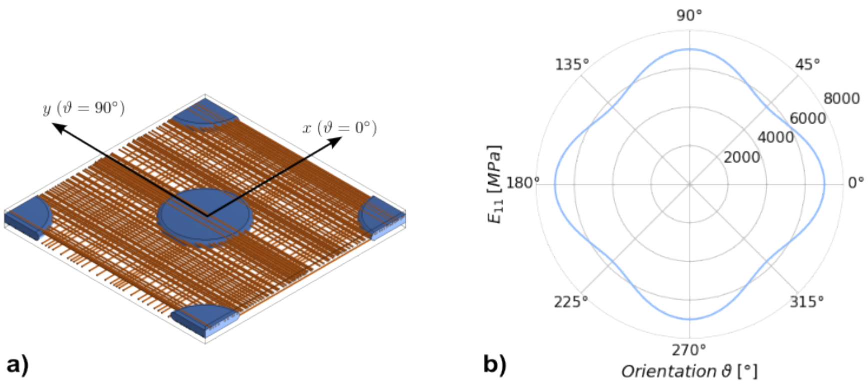

Fig. 5. Representative volume element of reconstructed geometry (a) and directional dependence of stiffness tensor component E_{11} (b)

Acknowledgements

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