EXTRACTION OF FIBRES ORIENTATION IN COMPOSITE MEDIA FROM X-RAY MICRO-TOMOGRAPHY: A COMPARATIVE STUDY

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Summary: This study aims at characterizing the fibre orientation measurements from 3D images acquired via X-ray micro-tomography. Synthetic images were generated with controlled microstructures and image quality. Therefrom the calculated local and global measurement errors with varying parameters, it is possible to choose for the most suitable numerical approach in each experimental case.

1. INTRODUCTION

Among other microstructural parameters, the local orientation field plays a major role in the mechanical behaviour of composites by acting on its anisotropy directions, its stiffness and strength but also on its thermal and electrical properties. The orientation of fibres is determined by the flow characteristics of the melt in case of short fibres' reinforced plastics and the deformability of a fabric in case of long fibres' reinforced plastics.

The last decade has seen the rise of X-ray computed micro-tomography as a powerful 3D characterization technique for composite media. Whether the acquisition is performed on classical laboratory systems or at synchrotron sources to exploit the phase contrast enhancement, the measurement of the orientation of fibres in 3D images remains a key issue of the image analysis, especially for dense fibrous media.
Several methods and algorithms were proposed, however little is known about their characteristics and their performances according to the 3D image of a specific type of fibrous reinforcement, e.g. chopped fibres' mats, technical fabrics; a specific type of fibres, e.g. glass, carbon, natural fibres; that was imaged in a specific way, e.g. with or without the matrix.
The purpose of this work was to implement several numerical method to extract the orientation fields from a 3D image, and to calculate the uncertainty of a fibre's orientation measurement as a function of the fibrous microstructure parameters and the image quality.

2. EXPERIMENTAL METHOD

A fibrous media can be mathematically modelled as anisotropic randomly oriented system in the 3D real space. Advani and Tucker [1] proposed a second order orientation tensor **A** that macroscopically describe the orientation of straight fibres within a given volume, it is written as:

$$\mathbf{A} = \oint \mathbf{p} \otimes \mathbf{p}\ \psi(\mathbf{p})\ \delta\mathbf{p}$$

where **p** is a unit vector describing fibre's orientation and ψ the orientation distribution function.

We propose a systematic comparison of the accuracy of measurement of **A** with various numerical methods tested on the same fibrous media images. It is not straightforward to get a wide variety of microstructures with known orientation fields. To fill this gap, a 3D image generator was developed, it gives a 3D segmented image together with the orientation field voxel per voxel. The synthetic images were then used to test three methods/algorithms for the measurement of the orientation of fibrous media with (i) various fibre geometries, diameter, cross section form factor

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and slenderness, (ii) various microstructures with different fibres content and macroscopic orientations, (iii) and various image qualities with different noise and spatial resolution. Finally, the 3D orientation field measured with each method were compared to the real orientation given by the image generator and then errors could be calculated voxel per voxel.

3. RESULTS

Mostly three algorithms were implemented and tested: 3D gradients [2, 3], 3D oriented distance maps [4, 5] and skeletonizing [6, 7]. Our results show that the skeletonization algorithm gives the lowest orientation errors for low fibres content (V_{fibres} /V_{total} < 0.15, Figure 1a) and a wide range of microstructures but errors dramatically increase when image quality decreases. The gray level gradient algorithm gives rather good results which are less sensitive to image quality if the contrast between the gray levels of the fibers and the matrix within the images is sufficient. The presentation shall also focus on the results obtained for the fiber orientation in several real and representative composite media: injected short fibers (Figure 1b), fiber bundles mats and woven fabrics with acquisition performed both in absorption and phase contrast modes using synchrotron radiation.

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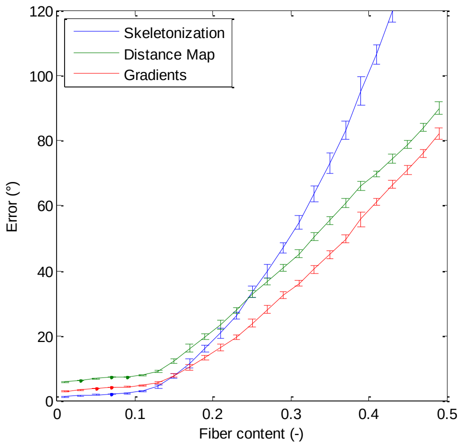
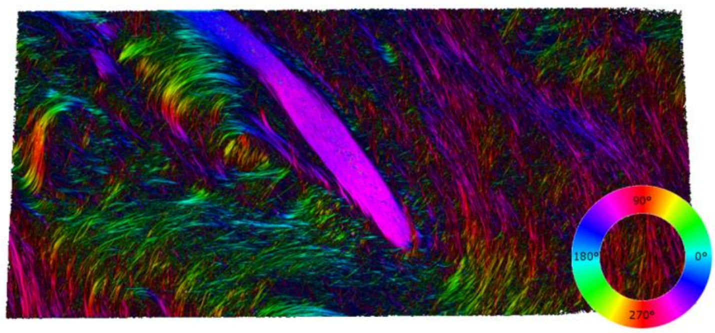


(a)



(b)

Figure 1: (a) Fibre content influence on the quality of the orientation characterization with different methods. (b) 3D orientation map obtained by 3D gradients method on injected short glass fibers in real sample. Each color is correlated with one orientation of the fibrous phase.