Influence of the orientation of fibrous structures in a composite material relative to the sample's rotation axis on the local apparent degree of anisotropy derived from micro-CT

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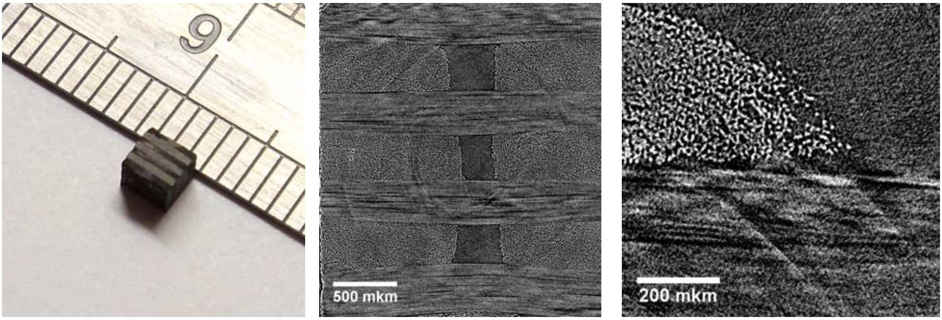
Aims

Textile composites are composites made with interwoven or braided yarns, fixed in the bulk of matrix [1]. Whereas the matrix is usually isotropic, the yarns consist of fibres, arranged approximately parallel to each other. Due to this oriented structure, the impregnated yarns are anisotropic. Modelling of composite materials on the basis of micro-CT data involves the construction of geometry of yarns and the determination of the orientations of the fibres inside them. These orientations can be determined from the 3D micro-CT image with image processing, using the eigenvalue decomposition of the structure tensor [2], which also provides information about the structural anisotropy in the image. The degree of anisotropy is a continuous variable that tends to zero for isotropic domains (matrix) and to one for anisotropic domains (yarns). Correct values of the degree of anisotropy are necessary to separate components of a composite material by their anisotropy. This paper reports on the observed difference in the local degree of anisotropy of yarns with a different orientation relative to the specimen's rotation axis, as determined from the micro-CT image. This difference cannot be explained by physical difference in the yarns, as the yarns of both directions are of the same type and have identical characteristics. The non-physical nature of this difference was confirmed by scanning of the same sample, rotated by 90 degrees, so that the yarns that were oriented along the rotation axis became orthogonal to it and vice versa.

Experimental

A cube sample (Fig. 1a), 2.7 mm^3, was cut from carbon/epoxy non-crimp 3D woven composite plate. The reader is referred to [3,4] for a detailed description of the material. Yarns in the composite are made from the Toho Tenax carbon fibre. The overall fibre volume fraction of the composite is 51.1%. The reinforcement includes three types of yarns: warp, weft (orthogonal to each other) and Z-yarns, binding the warp and weft yarns through the fabric thickness.

The sample was scanned with the SkyScan-1172 microfocus X-ray computed tomography system. Four scans were made, for two different orientations of the sample relative to the rotation axis. In the first two scans the warp yarns were parallel to the rotation axis, whereas the weft yarns were orthogonal to it. In the other two scans the sample was rotated by 90 degrees, so that the weft yarns became parallel to the rotation axis, and the warp yarns – orthogonal to it. The scans were made with the same voltage 59 kV and current 167μA, but with different resolutions and rotation steps, as indicated in Table 1. Reconstruction was done with NRecon 1.6.6.0 by SkyScan (Fig. 1b,c).



a b c

Fig. 1. The sample of carbon/epoxy 3D reinforced composite (a), and micro-CT images of the sample, obtained with SkyScan-1172 (b,c).

The obtained micro-CT images were processed with software, developed at MTM-KU Leuven, that implements the structure tensor method. The images of the image stack are assembled into a single three-dimensional array before the processing. The regions of interest were extracted from yarns that are parallel and orthogonal to the rotation axis, and the degree of anisotropy was calculated in these regions at a set of equidistant regularly arranged points. The mean and standard deviation of the degree of anisotropy were calculated for each region of interest.

Table 1. Parameters of the acquisition

Scan No	Sample orientation as type of yarns parallel to the rotation axis	Resolution, μm	Rotation step, degrees
1	Warp	2.44	0.1
2	Warp	2.44	0.2
3	Weft	1.48	0.2
4	Weft	2.79	0.4

Results

Fig. 2 illustrates the difference in microstructure in the yarns of different orientation. The regions of the micro-CT image inside the yarns, that are parallel to the rotation axis, exhibit the presence of elongated structures. The microstructure of the image inside yarns, that are orthogonal to the rotation axis, is more disordered and discontinuous. This difference is reflected quantitatively by the degree of anisotropy, which is significantly lower in the orthogonally oriented yarns.

Table 2. Degree of anisotropy inside the yarns of different orientation

Scan No	Yarns, that are parallel to the rotation axis; mean (standard deviation)	Yarns, that are orthogonal to the rotation axis; mean (standard deviation)
1	0.92 (0.037)	0.42 (0.130)
2	0.86 (0.054)	0.34 (0.106)
3	0.85 (0.066)	0.44 (0.130)
4	0.91 (0.031)	0.64 (0.113)

Note that the direct optical microscopy observations of the fibrous structure of both warp and weft yarns [4] demonstrate a unidirectional placement of almost parallel fibres with low waviness, with fibre volume fraction quite close for all the warp and weft yarns.

Table 2 presents the computed degree of anisotropy for the obtained micro-CT images. The number of data points in all cases was large enough (>10000) to provide a reliable estimate for the mean and standard deviation. The results indicate a significantly higher degree of anisotropy inside the yarns that are parallel to the rotation axis, than for the orthogonal yarns. This difference contradicts the similarity of the fibrous structure of yarns, observed in microscopy.

Discussion

Segmentation of the micro-CT image of a composite material requires a correct determination of the degree of anisotropy. The observed dependence of the apparent degree of anisotropy from the orientation of fibrous structures in a composite material relative to the rotation axis, and therefore from the positioning of the sample inside the micro-CT apparatus, makes the determination of this important parameter of material's microstructure less reliable. An investigation is currently being carried out in order to determine whether this effect is inherent to the reconstruction algorithms or to the X-ray propagation through the fibrous structures.

Acknowledgements

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References:

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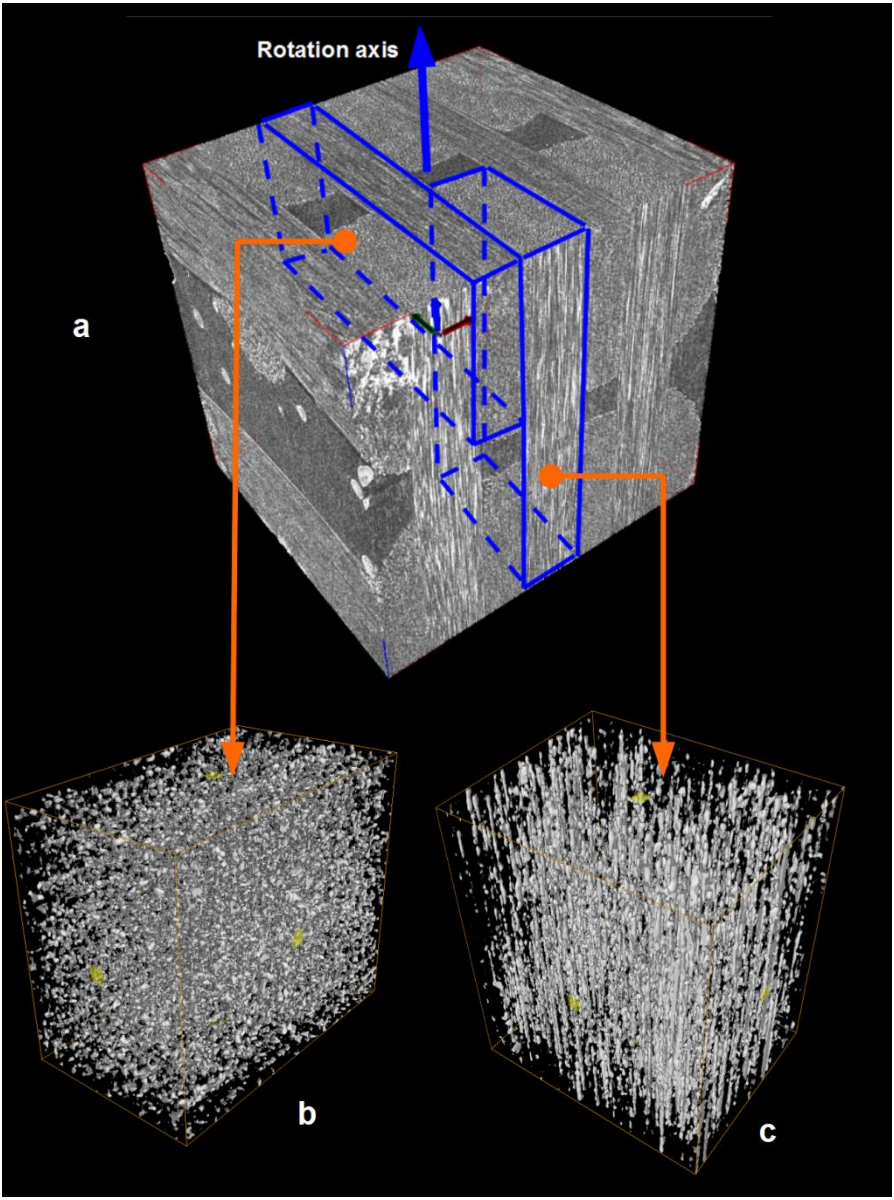

Fig. 2. Microstructure of fibres inside yarns with different orientation relative to the rotation axis. Yarns that are parallel to the rotation axis during scanning, features clearly distinguishable fibrous structure, which results in a higher degree of anisotropy, compared to the yarns, that are orthogonal to the rotation axis. The images were created with VGStudio Max 2.2, using volume rendering (scatter HQ) (a) and isosurface rendering (b,c).