Microstructure dependent damage mechanisms in 3D using X-ray tomography

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Introduction:

X-ray Computed tomography (XCT) has established as well-accepted method for non-destructive testing. More and more laboratory XCT devices are put into operation for scientific and industrial applications. For short fibre composites, methods were developed to determine fibre features [1, 2] but also information about damage mechanisms. [3] Digital volume correlation was applied on 3D data to get local strain information using additional fillers as features. [4]

The combination of microstructure, damage and strain information was not yet shown.

This contribution deals with the determination of fibre orientation, defect classification together with the local strain field from one XCT dataset using the fibres as features.

Methods:

For this study Polypropylene filled with 32 wt% glass fibres produced by injection moulding was analysed. Miniaturised dog bone shaped specimens were machined out of sheets. The smallest cross section is ca. 6 mm². A variation of the preferred mean orientation was taken into account by testing specimens with 0° and 90° fibre orientation.

The scans were performed at a laboratory XCT device Nanotom applying 2 µm voxelsize. A Deben CT500 tensile testing stage was mounted onto the turntable and interrupted tensile tests were performed until final fracture.

Microstructure was fully characterized by determination of fibre orientation and length. Additionally, quantification and classification of damage micro-mechanisms was carried out. The calculation of the fibre orientation was performed on a single fibre basis [1], which was additionally used to improve the classification of defects. After binarization of defects, each defect was classified into one of four different types: fibre fracture, fibre pullout, matrix fracture or fibre/matrix debonding (lateral detachment).

The displacement from one loading step to the other was calculated using the fibre arrangement as features. 3D patches with (100 µm)³ were analysed and compared. This leads to displacement values in each Cartesian direction.

Results and discussion:

First results are shown for a 0° specimen, meaning that the majority of fibres are aligned in tensile direction. The images shown in Figure 1 were generated shortly before final fracture.

Since the investigated volume contains a few 100.000 fibres, only a cut out is shown. Fibre orientation is visualized by glyphs that are colour coded according to direction. Only a few slices are shown in this figure to be able to compare it with the slice image in the middle of Figure 1. This slice image shows fibres and associated classified damage. Fibre pullouts are orange, fibre fracture is red and matrix damage blue. In the case of 0° no lateral detachment was observed. Since matrix fracture has developed intensively already, some of the former single pullouts have grown together forming a local crack network.

The displacement shown on the right figure was calculated between the initial state (reference) and the measured state. The image shows the Z- component which is in the direction of force. The contour of the displacement nicely follows the trace of the main crack through the sample.

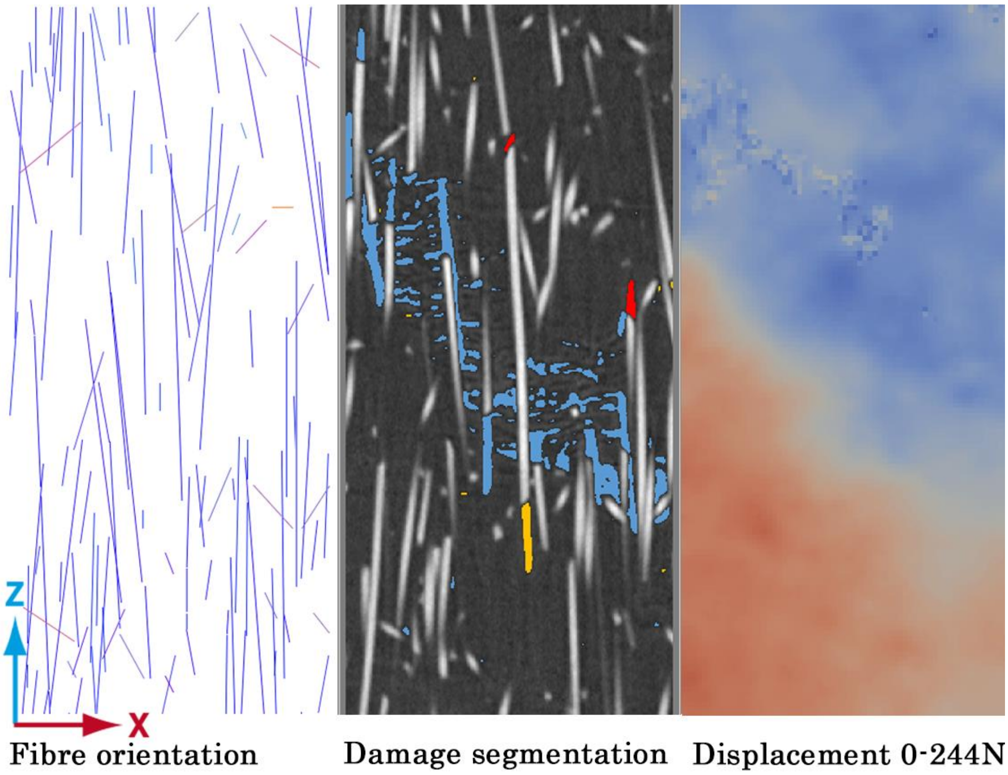

Figure 1: Visualisation of fibre orientation (colour coded glyph for each fibre), damage segmentation in slice image, displacement calculated from 0 to 244 N data.

The methods for quantification of microstructure, damage and displacement and the visualisation techniques provide in-depth understanding of the materials behaviour until final fracture and therefore facilitates further material development.

References

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