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Three-Dimensional Microstructures of Fiber Composite Materials and their Non-destructive Investigation with CMT

Peter Wyss[1], Felix Beckmann[2], Ulrich Bonse[2], Bert Müller[1,3], Jörg Mayer[3], Erich Wintermantel[3], Walter Muster[1]

[1]Eidgenössische Materialprüfungs- und Forschungsanstalt (EMPA), CH-8600 Dübendorf, Überlandstrasse 129

[2]HASYLAB am DESY, D-22607 Hamburg, Notkestrasse 85

[3]Biokompatible Werkstoffe und Bauweisen, Dept. Werkstoffe, ETH Zürich, CH-8952 Schlieren, Wägistrasse 23

Introduction

Computed Micro-Tomography (CMT) allows a non-destructive three-dimensional structural analysis of composite materials. Emphasis is given to biocompatible materials often composed of light elements.

Biocompatibility

For implants the appropriate selection of materials is crucial regarding long term compatibility. A number of polymers and ceramics have been shown to be tolerated or even accepted by living tissues. In order to improve the mechanical properties of transmitting prosthetic devices, carbon fibers, SiO_2- or Al_2O_3 fibers can be incorporated into a matrix, forming a highly stable anisotropic composite.

Mechanical stability

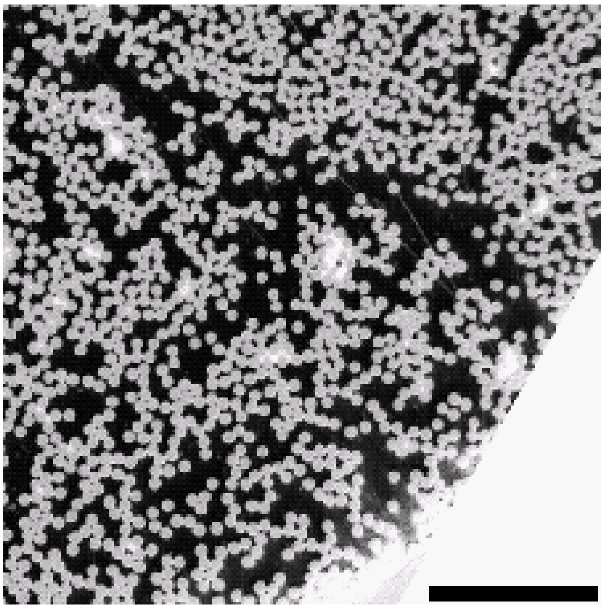
Fiber orientation, density distribution, kind and density of defects determine the mechanical properties of composite materials and, therefore, the lifetime of the devices and implants.

Characterization

Micro-section using electron microscopy delivers the materials structure with a high lateral resolution, but is destructive. The surface preparation of composite materials can result in artifacts. Hence, for 3D imaging of composite materials as well as for the characterization of biologic-prosthetic systems a non-destructive technique with micrometer resolution is highly desirable.

Continuous-fiber metal-matrix composite

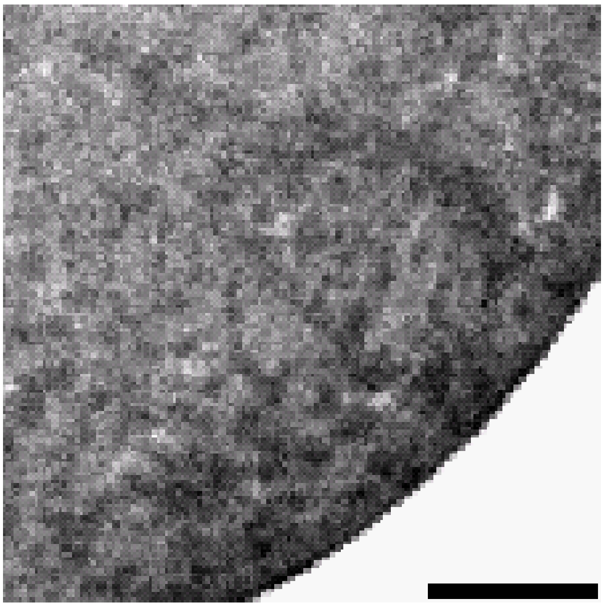
The mechanical properties of a metal can be tailored by the incorporation of ceramic fibers. Continuous fibers are much more effective. A micro-section is helpful to obtain an idea of the fiber distribution and the defects. (Fig.1) But an effective 3D, volume-oriented investigation of the samples is a prerequisite for materials optimization by an adequate modeling.



200 µm

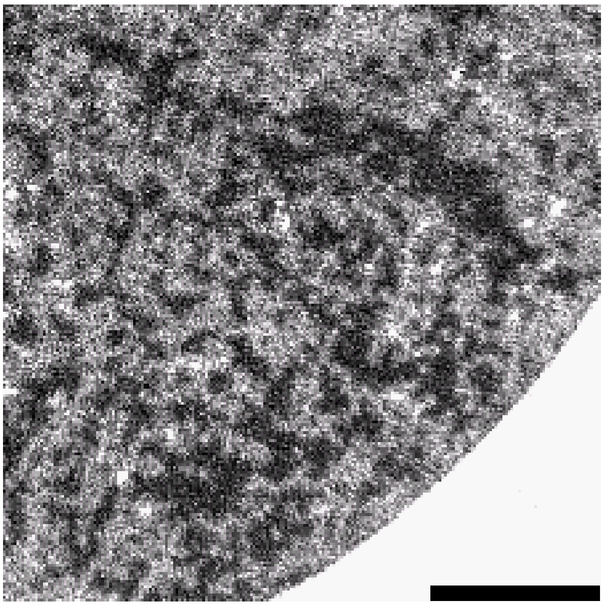
Fig. 1. SEM micrograph of a metal-matrix composite.
Metal: AlZn6Mg1,
Fibers: Altex, diameter 10 µm.
Note, the sample was drawn at the beginning of the run in of the casting machine. Therefore the quality is low. However it is rendering a lot of interesting items for comparing the analytical methods.

CMT-measurements with bremsstrahlung using a microfocus x-ray tube yields a resolution of 10 µm. (Fig.2) Although many features can be identified, the use of synchrotron radiation (resolution 4 µm) uncovers a more detailed view of sample microstructure (Fig.3). Note, the images displayed in Figs.1-3 are obtained from the same region of the sample and are directly comparable. The resolution given above refer to single defects with very high density gradients, e.g. voids.



200 µm

Fig. 2. Section of a tomogram using bremsstrahlung (Pixel size: 5 µm).



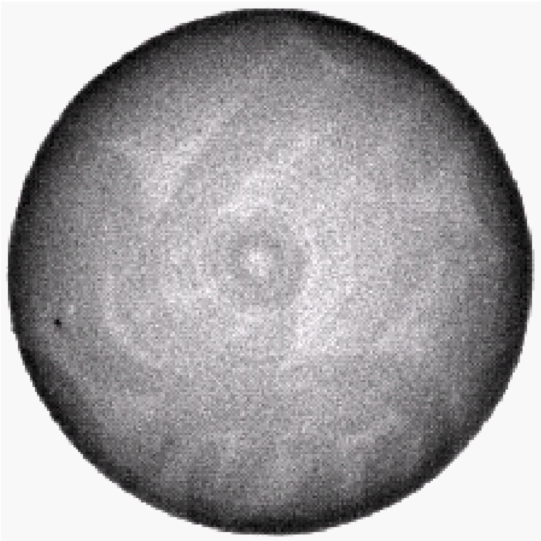
200 µm

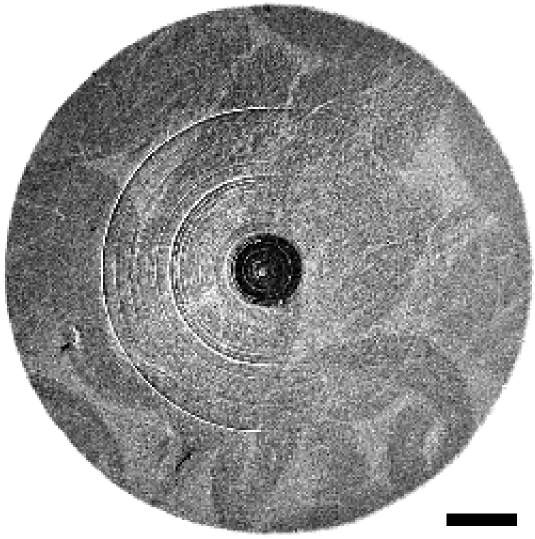
Fig. 3. Section of an absorption tomogram using synchrotron radiation (Pixel size: 2 µm).

Carbon fibre composites

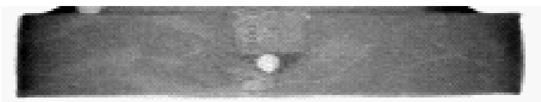
Carbon fiber reinforced polymers are promising materials for implants. The visualization of these composite materials by x-rays on the basis of absorption contrast, however, is difficult or even impossible for these light elements. The same phenomenon is present for organic tissues. The use of the phase contrast is a possibility to get tomograms with sufficient contrast.

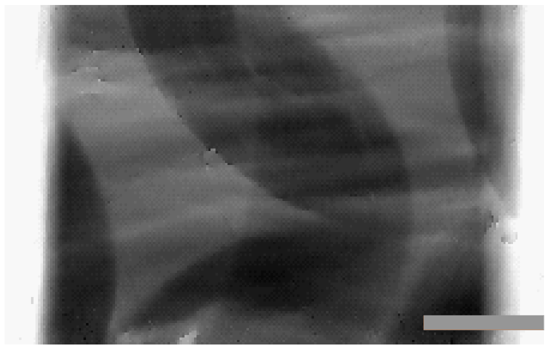
To demonstrate the improved imaging using phase contrast, a projection of a carbon fiber composite is given in Fig.5 b). Fig.4 shows the related images obtained by a conventional X-ray source and Fig 5a) by synchrotron radiation in absorption contrast.


a)



a)


b)



b)

Fig. 4a) section of a tomogram using bremsstrahlung a),
Fig. 4b) axial reclicing.

Fig. 5 a) the same section with synchrotron radiation in absorption contrast,
Fig. 5b) one projection of another piece in phase contrast with synchrotron radiation.

Summary

Fibers used in composites have diameters of several micrometers. This is a typical extension only accessible by synchrotron radiation sources. For composites made of light element materials or organic tissue, phase contrast images give better contrast.

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Corresponding author

Peter Wyss

Tel.: + 41 1 823 43 19, Fax: + 41 1 823 45 79, e-mail: peter.wyss@empa.ch