

Structural Index of Metal Matrix Composites Evaluated With Computed Tomography

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Abstract

X-ray computed tomography (CT) techniques have been used to evaluate a structural index of high performance metal matrix composites (MMC). Beside of classical features like the determination of number of fibres and eccentricity of fibre bundles an order parameter can be defined and demonstrated for the SiC fibre arrangement in Ti-MMC, which can be used to assess these materials.

The samples for the investigations have been provided by MTU Aero Engines. They consist of a titanium matrix (Ti6242) reinforced by SiC fibres (SCS6).

Keywords: Computed Tomography, Titanium Metal Matrix Composites, Dimensional Control

1. Introduction

X-ray computed tomography (CT) techniques offer a unique potential for non-destructive evaluation (NDE). Established is the detection and localisation of density variations in green components with a density resolution of one percent and lower together with high spatial resolution even in complex shaped samples. This can be used to increase the quality and reliability of ceramic components determining the causes of defects components and following optimisation of the production process^[1]. In the last few years a rapid growing area of CT is the use for dimensional measurements in industry. These results are reached using calibrated reference structures together with procedures to correct some artefacts like beam hardening or scattered radiation.

An intermediate position between density evaluation and dimensional control of geometry is the characterisation of fibre structures. The study of fibre reinforced materials as CFC, FRP, MMC and reinforced concrete are an actual topic of CT to analyse fibre orientation, fibre distances, fibre cracks, matrix cracks, pores and fibre debonding^[2,3,4]. The main approach is the segmentation of single fibres^[5] or in these cases where a separation is not possible an integral method is used^[6]. In MMC materials the number of fibres, their arrangement and other geometrical features governs the properties of such materials. As an example an order parameter can be defined and demonstrated for the SiC fibre arrangement in Ti-MMC, which can be used to assess these materials.

2. Experimental set-up

The versatile experimental set-up of computed tomography developed at BAM is described 2004^[7]. Some improvements are made in respect to dimensional control with CT. Especially in connection with reference structures, calibrated by tactile measurements with coordinate measurement machines (CMM) the uncertainty of CT as an measurement tool could be decreased 2007^[8]. The measurements of the MMC samples are performed with the 225 kV laboratory CT set-up and with the CT set-up of BAM (*BAMline*) at the Synchrotron Facility BESSY in Berlin, Germany.

3. Results

3.1 Fibre cracking

As an example for classical flaw evaluation of MMC samples the following images show some types of MMC samples of different sizes, partially with cracks after loading tests, as visible in the images at right of fig. 1 and 2.

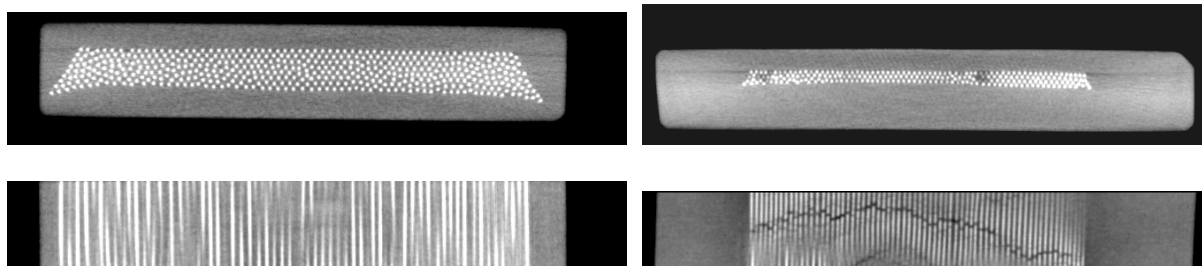


Fig. 1: Two metal matrix structures (cross section $12 \times 4 \text{ mm}^2$) with different number of fibres. For each sample a horizontal slice (top) and a vertical slice (bottom) is shown. The sample (images at right) shows cracked fibres.

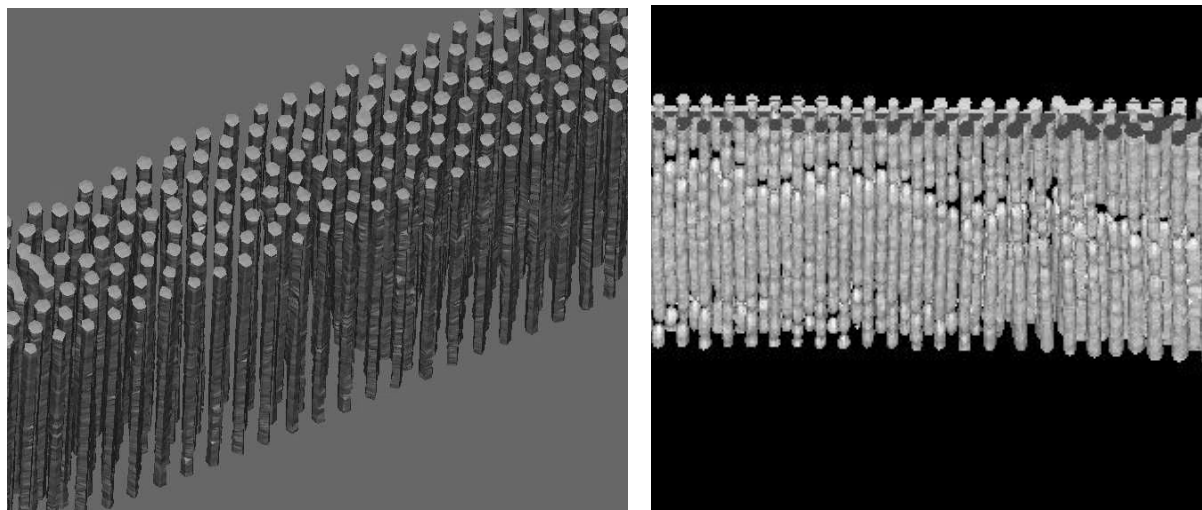


Fig. 2: Iso-surface representation of a cut-out of the corresponding samples of fig. 1.

3.2 Number of fibres

The segmentation of the fibres can be performed analogue to the detection of pores due to the lower density of SiC fibres compared with the Ti matrix. Two methods are applied: a self developed image processing module on the basis of the image processing system AVS (Advanced Visual System Inc., Version AVS 5) and with the commercially image processing software VGStudio Max 2.0. The result, the number of fibres and the coordinates of the centre of the fibres, are listed as a protocol. Fig. 3 shows the different steps of the first method: a cross-section extracted from the CT 3D image data set, the segmentation of the fibres – the success is demonstrated by the different colours - and the centres of the fibres.

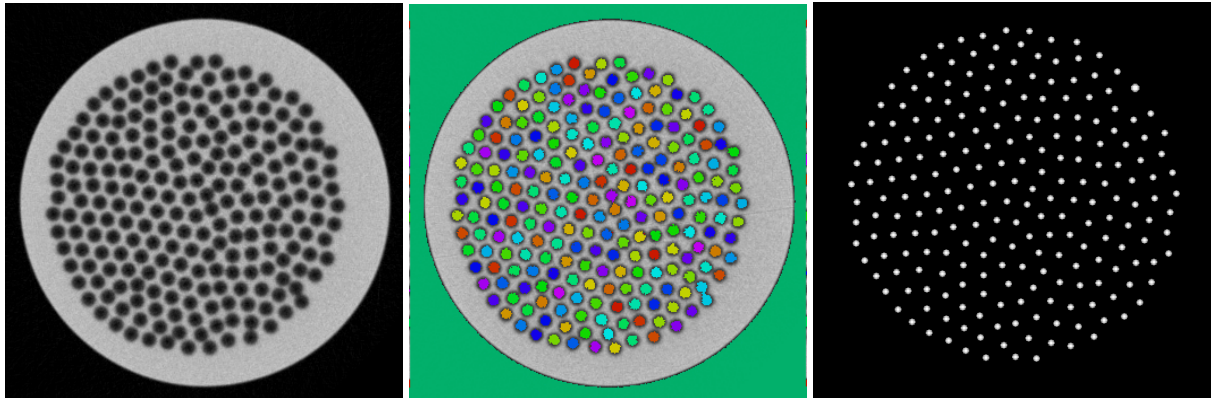


Fig. 3: Cross section of a tensile sample (diameter about 5 mm, left image), measured with Sy-CT at 50 keV, voxel size $(11 \mu\text{m})^3$. The image in the middle shows the segmented fibres and the centres of fibres are given in the image at right.

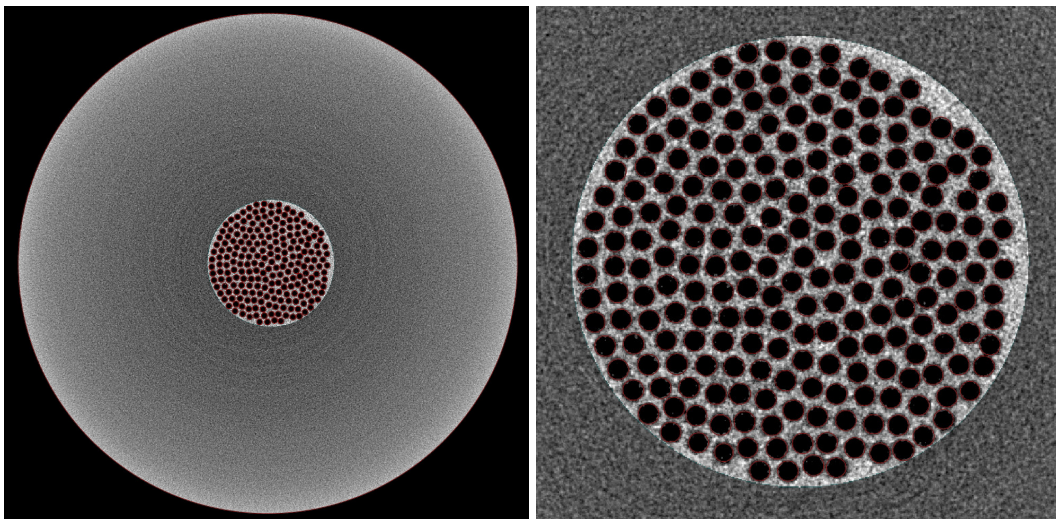


Fig. 4: Cross section of a test sample (diameter 12 mm, left image), measured with laboratory CT at 200 kV, voxel size $(7 \mu\text{m})^3$, and an enlarged cut-out (right image).

3.3 Order parameter

To quantify the regularity of the fibre distribution in a sample or component an order parameter Q_d is defined in 2000^[9]. For an ideal fibre distribution the distances of the centre of mass of the fibres s_{fn} are equal to the average fibre distance s_f and the order parameter Q_d is equal 1.

$$Q_d = 1 + \frac{\sum_{n=1}^n \left| 1 - \frac{s_{fn} - d_f}{s_f - d_f} \right|}{n}$$

- Q_d order parameter of the fibre distribution
- n number of calculated fibre distances
- s_{fn} n^{th} fibre distance
- s_f average fibre distance
- d_f diameter of a fibre

The procedure of calculation of the quality parameter Q_d is performed in the following steps:

- measurement of sample or component with computed tomography
- segmentation of fibres and determination of the centre coordinates
- calculation of the fibre distances and sorting according the distance
- calculation of the order parameter
- validation on simulated test data

For an ideal hexagonal structure the result is shown in fig. 5 and for a real sample (c.f. fig. 3) in fig. 6. The quality parameter Q_d can be evaluated including the distances up to the first maximum in the histogram.

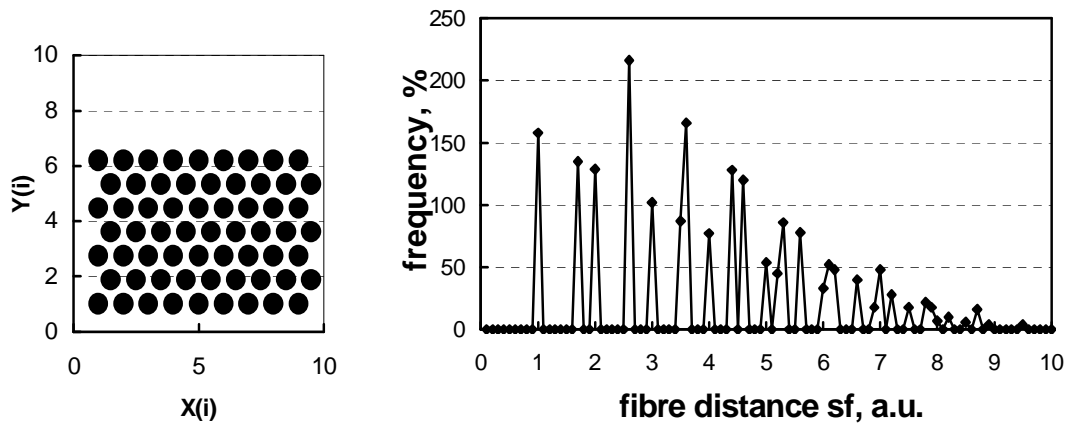


Fig. 5: Coordinates of the centre of fibres (left image) and histogram of the distances between all fibres for an ideal hexagonal fibre distribution

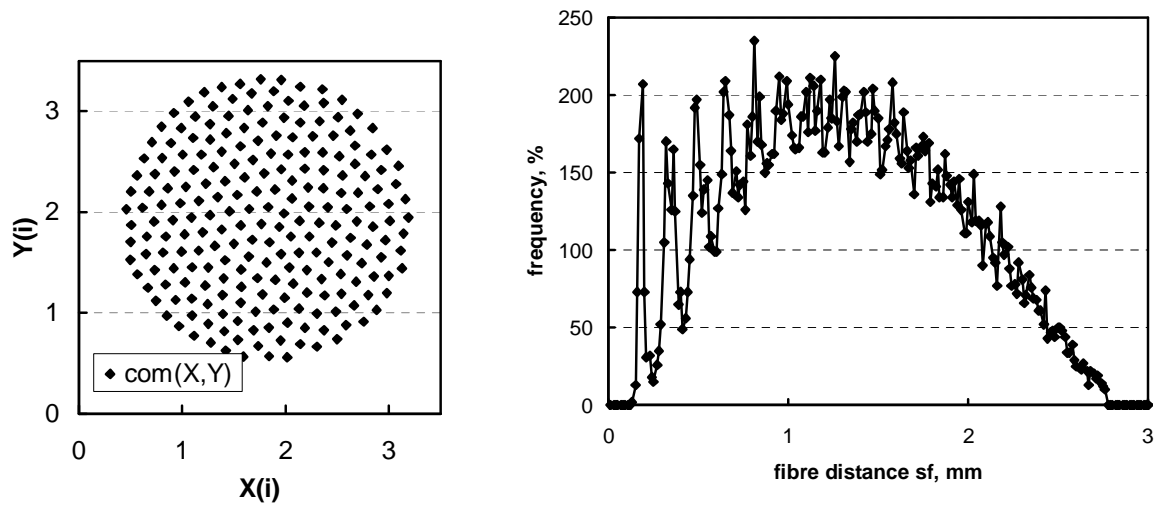


Fig. 6: Coordinates of the centre of fibres (left image) and histogram of the distances between all fibres of the sample, shown in fig. 3.

Using the diameter of the fibres, $d_f = 0.128$ mm, an order parameter of 1.258 is calculated for the sample shown in fig 3. For ten test samples similar as shown in fig.4, the order parameter varies between 1.2 and 1.5 and demonstrates the sensitivity of the order parameter.

4. Conclusion

X-ray computed tomography techniques are applied to the characterisation of MMC samples. With classical absorption CT structural information can be evaluated and quantified, which is demonstrated calculating an order parameter for such materials.

5. References

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