Quantitative X-Ray Phase Imaging of Impact Damaged Carbon-Fiber-Reinforced Polymers

M. Hildebrand, M. Leck, M. Korth, Department of Analytical Measurement Technology, Faculty of Natural Sciences and Technology, University of Applied Sciences and Arts, Göttingen, Germany (October 2013)

Application Note

Introduction

Carbon-fiber-reinforced polymers (CRFP) have a wide range of applications. Particularly in the automotive and aerospace field, they play an increasingly important role. In the course of this process, methods for investigation of defects in CRFP gain more and more importance.

In general, x-ray imaging is a powerful tool for non-destructive investigations of optical nontransparent materials. Despite the good penetrability of x-rays, the contrast between the carbon fiber and the surrounding resin in CRFP's is very low due to their similar absorption coefficients. In recent years, phase contrast imaging was advanced, promising a higher contrast between such materials. In this context, different phase imaging techniques where developed with and without optical elements. The former provides good results but requires intricately designed optical elements. The latter, however, is often imprecise and bases on complex reconstruction algorithms. In this application note, an efficient and precise quantitative phase imaging method is presented, requiring a microfocus x-ray source, a high resolution and sensitive x-ray camera and precise collimation slits.

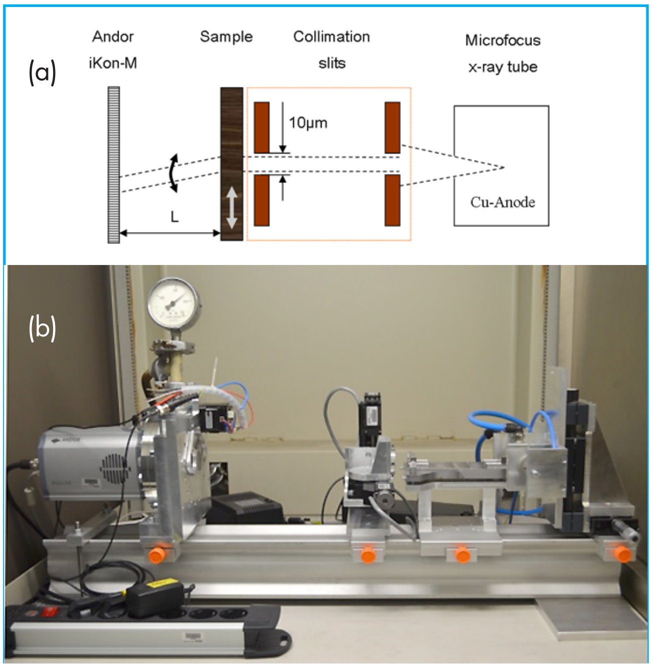

Fig. 1: A Schematic view of the experimental setup is depicted in (a). T
he corresponding photograph is shown in (b).

Experimental Setup

Unlike to diffraction experiments, the angles to be detected are in the range of μrad. To detect theses small angular deviations, it is necessary to generate a very fine collimated x-ray beam. In the used setup, this is achieved by collimating the divergent x-ray beam of a micro focus x-ray source by two 10μm high consecutive slits to a divergence of 70μrad(s. Fig. 1). The line-shaped x-ray beam impinges on the sample at a selected area. Due to phase differences in the penetrated volume, the beam is refracted and exits the sample at a small angle θ relative to the direction of the reference beam.

It is important to note that only deflection in y-direction can be detected. Since the absorption of the illuminated volume is considered to be homogenous, the x-ray CCD camera (iKon-M DO934P-BR-DD from Andor Technology) can be used to detect the displacement vector $s_y = L\,\lambda/2\varpi\,(\nabla\varphi)_y$ of the refracted beam as shown in Fig. 2. So, the phase gradient in the y-direction of the selected row can be calculated. In order to get the entire image, the sample is moved through the collimated beam and all rows are stitched together.

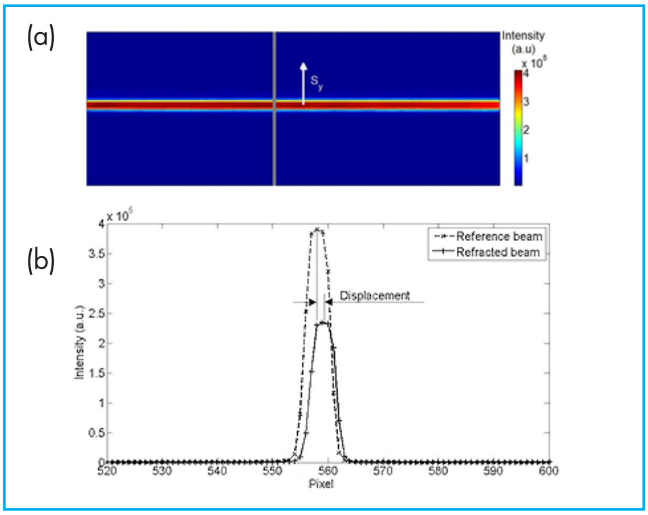

Fig. 2: (a) shows a picture from the Andor iKon-M of the reference beam. The cross section of the beam profile indicated by the gray bar is depicted in (b). By comparing the unaffected beam profile (reference beam) with the refracted beam profile the displacement vector s_y can be calculated.

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Results

Several CFRP specimen with a rectangular section of 100mm x 10mm and overall thickness of 0.5mm were analyzed. They were fabricated by the Resin Transfer Molding process. In order to damage the samples, a falling tool with weights and a spherical head was constructed. The impact energies vary from 1.1J to 4.6J. Different impact energies were achieved by changing the weights of the falling tool at the same height. The introduced damage was examined with the method described before.

In turns out that the phase image offers a much better contrast for the investigation of damaged CFRP specimens as the conventional x-ray transmission method does (s. Fig. 3). Even impacts with the lowest energy can be detected well. Furthermore, the extend of the impact does reveal exactly.

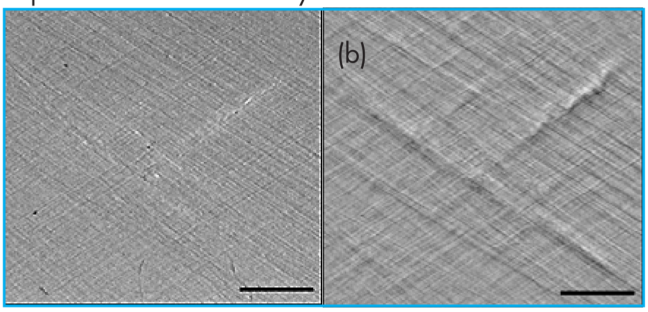

Fig. 3: Example of a 1.1 J impact damaged CRFP-sample. The same image section is depicted. (a): Conventional x-ray transmission image. (b): Phase contrast image. Scale bar: 0.5mm

Conclusion

For the described phase contrast imaging method, a high resolution x-ray camera is needed, which allows to detect these small angle deviations. The achieved angular resolution is in the range of 1µrad. Due to the fact that only a small portion of the light is provided by the collimation, a sensitive x-ray camera is needed. The sensitive iKon-M CCD camera for direct x-ray detection matched our demands perfectly.

Contact

Martin Hildebrand
Department of Analytical Measurement Technology
Faculty of Natural Sciences and Technology
University of Applied Science Göttingen
Von-Ossietzky-Str. 99
37085 Göttingen
Germany

Phone: +49 55 1 / 37 05 - 347
Email: hildebrand@hawk-hhg.de
Web: www.hawk-hhg.de/naturwissenschaften