Overcoming Challenges in Imaging Carbon Fiber Orientation and Defects for CFRPs

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ABSTRACT | Carbon fiber reinforced polymers (CFRPs) are extremely challenging to image with conventional x-ray techniques, such as microCT, due to the low absorption of carbon fibers and the surrounding polymer matrix. This characterization becomes even more difficult when the diameter of carbon fibers are on the order of single digit micrometers. The Sigray PrismaXRM, through patented innovations, provide access to two new modes of x-ray contrast: Quantitative Phase™ and Subresolution Darkfield™ that are capable of resolving defects (e.g. fiber breaks) and 3D fiber orientations without the need to resolve individual carbon fibers.

INTRODUCTION

Demand for lightweight and strong material in the aerospace industry and for fuel-efficient cars has driven developments in CFRP composites, which provide the strength of steel at 1/5th the weight[1]. Current manufacturing processes of CFRPs are slow and expensive, which limits widespread use in the automotive market. The development of injection molding methods for CFRP composite manufacturing would be revolutionary: passenger car weight would be reduced by 50% and fuel efficiency improved by 35%[2].

Critical to the advancement of manufacturing techniques are defect detection and measurement of 3D carbon fiber orientations, which determines mechanical properties[3-4]. In the case of glass reinforced polymers (GFRPs), x-ray micro computed tomography (microCT) has often been applied extensively for fiber orientation and defect detection. However, due to the low contrast of carbon fibers in polymer matrices and the typical small diameters (e.g. 5-10 µm), conventional microCT has had limited utility for CFRP[3].

Figure 1. Sigray PrismaXRM, which provides a new paradigm in x-ray microscopy with access to two new x-ray phenomena.

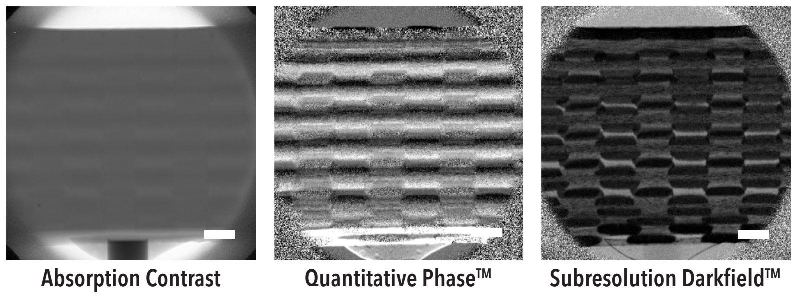


Figure 2. Demonstration of the power of the Quantitative Phase and Subresolution Darkfield capabilities applied to an angle-interlock woven CFRP. All three images were acquired simultaneously in the PrismaXRM. Absorption contrast (what is acquired with conventional microCT) has limited contrast, while the other two images provide information on materials, weaves, and fiber orientations.
Scalebar is 1mm.

A NOVEL APPROACH:

Sigray PrismaXRM 3D X-ray Microscope

The Sigray PrismaXRM features a novel approach to x-ray microscopy for simultaneous acquisition of information that stems from three separate phenomena of x-rays: absorption, refraction and scattering. The approach provides not only standard absorption contrast that microCTs provide, but simultaneously gives access to Quantitative Phase™ and Subresolution Darkfield™. The PrismaXRM is the only commercial system that provides access to these contrast mechanisms and information that is otherwise unattainable using even the leading x-ray microscopes on the market.

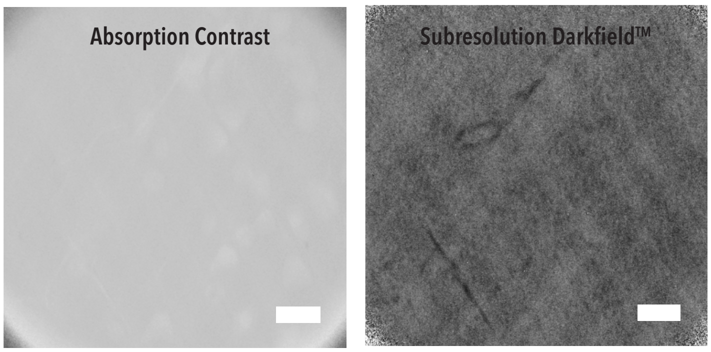
These two new modes of contrast provide complementary information to absorption contrast. In particular, Quantitative Phase™ is exceptional at providing contrast between materials that are similarly absorbing and Subresolution Darkfield™ provides information about microstructures, such as voids and cracks. The PrismaXRM's Subresolution Darkfield™ imaging capabilities also can be used to measure anisotropy of fibers without needing to resolve individual fibers, thus providing powerful insight on fiber orientation without sacrificing field of view or throughput.

RESULTS & DISCUSSION

The Quantitative Phase™ and Subresolution Darkfield™ images acquired with the PrismaXRM were used for measurements of defects and fiber orientation that cannot be observed using high-resolution absorption contrast, due to the low x-ray contrast between carbon fibers and polymers. A number of CFRP samples were imaged: an angle-interlocked woven composite (Fig 2) and a braided CFRP sample (Fig 3).

The results clearly demonstrate the power of Quantitative Phase™ for determining voids and fiber orientations, while Subresolution Darkfield™ provides information on cracks and fiber breaks.

Subresolution Darkfield™ also enables the exciting capability to provide 3D fiber orientations across a large volume, even on short fibers, through an acquisition method called darkfield directional tomography in which at least two tomographies are taken at orthogonal angles. An example of the output of this algorithm is shown in Fig 4.



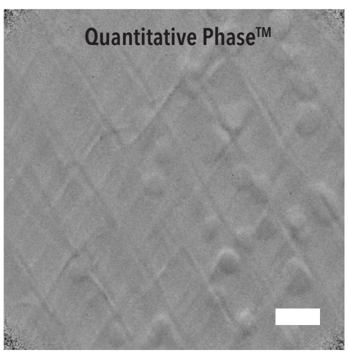


Figure 3. Defect detection in braided composites. Subresolution Darkfield highlights cracks while voids in the polymer substrate are clearly visualized using Quantitative Phase. These details are difficult to detect using Absorption Contrast because of the low absorption of x-rays by soft materials.

Scalebar is 1mm.

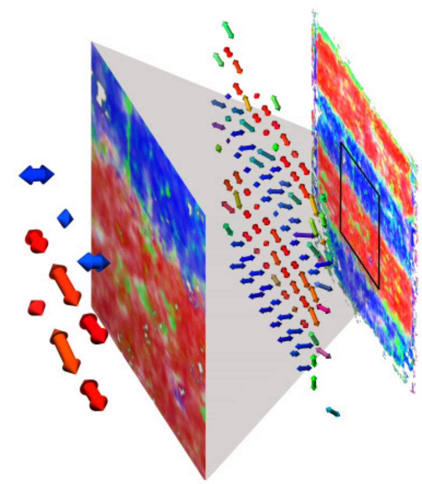


Figure 4. Darkfield directional tomography using the PrismaXRM's darkfield capabilities provides vectors of fiber orientation in three dimensions without needing to resolve each individual fiber.

References

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3. F Prada, et al. "Nondestructive characterization of fiber orientation in short fiber reinforced polymer composites with X-ray vector radiography," *NDT&E International* 86 (2017): 65-72.
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