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In situ observation of crack initiation and propagation in CFRP using a newly-developed XAFS-CT

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1 Introduction

Carbon fibre reinforced plastic (CFRP) composites are of growing use in aircrafts because of their high specific strength and stiffness. Micromechanism of damages and microscopic chemical properties of CFRPs is a key to understand the mechanical properties and durability of these materials. Recent reports pioneered the micromechanical analysis of fractures under quasi-static stress [1] and fatigue failures [2] in CFRPs from three-dimensional dataset obtained using synchrotron X-ray computed tomography (CT).

2 Experiment

We have developed and installed a new X-ray microscope: Synchrotron Radiation X-ray Absorption Fine Structures – CT (SR-XAFS-CT) at the NW2A beamline of PF-AR in IMSS, KEK. The outline of the SR-XAFS-CT system is illustrated in Fig. 1. A monochromatic X-ray beam is focused onto the sample using an elliptical glass capillary and the image is projected onto the CCD detector by means of a micro - Fresnel zone plate lens. It was confirmed that the system has a high spatial resolution less than 50 nm using a standard test pattern. The sample is mounted on an X, Y, Z, θ stage, and we can perform X-CT measurements by rotating the sample for a specific X-ray energy. By repeating this measurement over an energy range near the absorbing energy of a specific element, we can obtain 3D-mapping of chemical states of the elements. SR-XAFS-CT can provide 3D-imaging information about (a) microstructure, (b) cracks, and (c) chemical states of material with the high spatial resolution.

Furthermore, we have been challenging 'high resolution time-lapse study of in situ crack growth in CFRP'. We utilized a novel nanomechanical test stage, which was designed specifically for the SR-XAFS-CT system (Fig.2). The stage features a high precision piezo actuator and an integrated load cell up to 5000 N, enabling the load-displacement curve to be measured and related to the evolving microstructure observed in the corresponding 3D tomographic reconstructions.

A CFRP specimen was indented with a diamond cone to initiate and propagate cracks in the specimen. Snapshots of initiation and propagation of cracks were successfully obtained with a high resolution less than 50 nm. It was clearly observed that a crack initiates at the interface between a fiber and the resin matrix, and that it branches into cracks that are (a) propagating along the interface and (b) traversing across the resin matrix to a neighboring fiber.

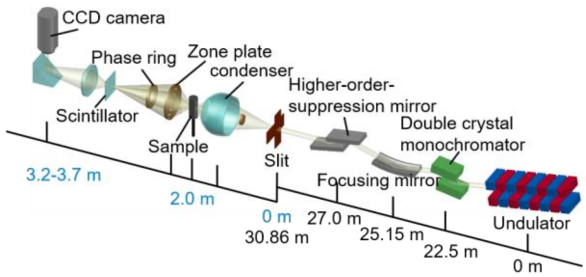

Fig. 1: Outline of SR-XAFS-CT microscope.

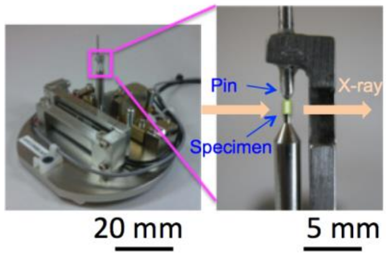

Fig. 2: Nanomechanical test stage.

3 Results and Discussion

Fig. 3 shows typical examples of cross section images of the three-dimensional volume data reconstructed from 151 projections. Interfaces between carbon fibers and epoxy resin were clearly observed. It should be noted the images show features not the surface but inside the specimen and that the crack initiation and propagation is free from surface effects. Cracks propagate along the interface between carbon fibers and epoxy resin in XY slice, and crack branching observed on the tip in XZ slice. We have successfully developed the technique of nanomechanical testing for in situ X-CT observation of crack propagation in CFRP with XRM using synchrotron radiation.

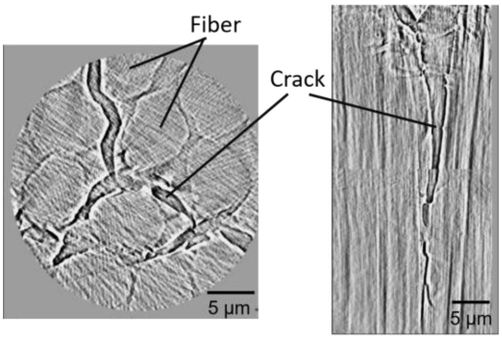

Fig. 3: A cross section image of the volume data obtained by X-CT after the crack propagation.
Left: XY slice and Right: XZ slice.

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References

[1] A. E. Scott, M. Mavrogordato, P. Wright, I. Sinclair, and S. M. Spearing, *Compos. Sci. Technol.*, **71**, 1471 (2011).

[2] S. C. Garcea, I. Sinclair, and S. M. Spearing, *Compos. Sci. Technol.*, **109**, 32 (2015).

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