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Establishment of in situ Observation of crack initiation and propagation in Carbon Fiber Reinforced Plastic using Synchrotron Radiation X-ray Computed Tomography

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1 Introduction

Structural materials such as composites are commonly subjected to multiple directional loads that can cause critical damage. Carbon fiber reinforced plastic (CFRP) composites have multiple components which are strong but brittle anisotropic carbon fibers and a ductile isotropic plastic. Therefore, CFRP has the properties of lightweight and high stiffness and is extensively used to reduce the weight of structural materials in the aerospace industry.

The mechanisms of crack initiation and propagation in CFRP composites have been investigated using various modelling and experimental techniques. However, owing to recent advances in the production of CFRP composites through microscopic design, observation with even a smaller spatial resolution of less than a micrometer is required to understand the mechanism of crack initiation and propagation.

In this study, we non-destructively observed crack initiation and propagation in CFRP using nanoscopic synchrotron radiation X-CT (SR X-CT).

2 Experiment

The CFRP specimens consisted of T800H carbon fiber/epoxy (fiber areal weight of 190 g/m^2, resin content of 35 wt%). The specimens the size of 1 mm long with a diameter of 60 µm were prepared by mechanical cutting.

X-CT measurements were carried out by nanoscopic SR X-CT installed at the NW2A of the Photon Factory Advanced Ring (PF-AR) in IMSS (KEK, Tsukuba, Japan). The apparatus can measure by Zernike phase-contrast imaging method using a phase ring to observe the boundary of carbon fiber and resin. A focused monochromatic X-ray beam of 8 keV irradiated to the specimen and the transmitted X-ray beam was detected using a CCD camera. The detected image of a 20 × 20 µm^2 field of view and a voxel size of 39 nm was measured.

In situ nanoscopic measurements were performed using a nanomechanical test stage [1]. A pyramidal diamond indenter was used to apply the stress and initiate cracks in the specimen (Fig. 1). In situ CT measurements were performed by rotating the stage. 151 radiographs were collected using exposure time of 10 s during rotating of 151°. The collected radiographs were reconstructed to a 3D image (20 µm diameter, 20µm height) by a filtered back projection method.

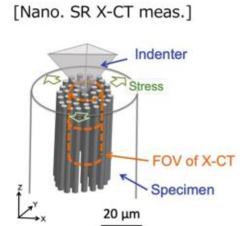

Fig. 1 Schematic image of the part of the CFRP specimen for the nanoscopic SR X-CT measurements [2].

3 Results and Discussion

Fig. 2 shows a series of X-Y cross sections of 3D volume data from lower to upper of specimen along Z-direction. In other words, the from lower to upper series of Z-direction is corresponding to increase strains. The crack initiation occurred by competing two processes of fiber/resin interface debonding and in-resin crack initiation. In the fiber/resin interface debonding process, the cracks initiated by opening the fiber/resin interfaces and propagated along the fiber/resin boundary (red triangles in Fig. 2b–e). These cracks observed at positions with short distances between neighboring fibers. In in-resin crack initiation process, the small void and cracks were observed (blue triangles in Fig. 2c, d, and f). These cracks were propagated with plastic deformation.

We observed crack initiation and propagation process in an early stage using nanoscopic SR X-CT with a high resolution of < 50 nm and phase contrast imaging when mechanical load was applied to CFRP specimen by inserting pyramidal indenter. This observation suggested that the crack initiation in CFRP did not simply result from local stresses but instead occur mainly through two competing nanoscale mechanisms (fibre/plastic interface debonding and in-plastic crack initiation). The mechanisms of crack initiation and propagation are strongly location dependent on parameters such as the distances between neighboring fibers and the bonding strength at the fiber/resin interface under similar applied local stresses. These inhomogeneities have been suggested to be corresponded to a lot of factors such as fiber alignment irregularities, surface morphologies, and the size of carbon fibers. Such information is expected to contribute to the design of CFRPs with reasonable safety margins for use in airplanes.

The developed techniques have been applied to in situ observation of CFRP under a stress applied with a wedge [3].

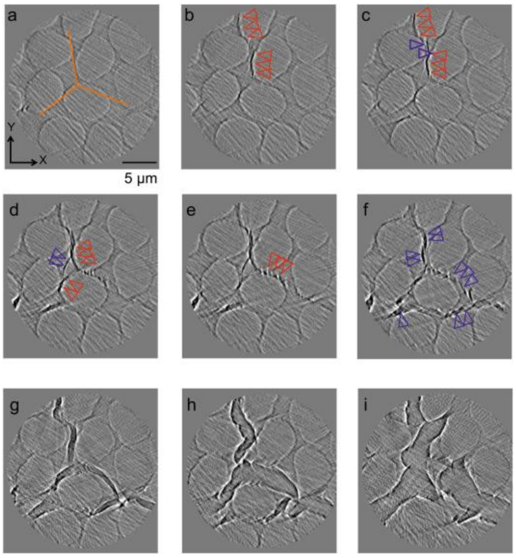

Fig. 2: X-Y cross sections of the 3D volume data from lower to upper of specimen [2].

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