BL20XU
Medical and Imaging II

1. Introduction

BL20XU, which is the only medium-length (250 m) beamline with an undulator source in SPring-8, is designed for application to various imaging techniques. A liquid-nitrogen-cooled Si double-crystal monochromator (DCM) is used to choose the X-ray energy [7.67–37.7 keV with Si(111) reflection and 12.4–61.5 keV with Si(220) reflection]. To transport a clean and coherent X-ray beam, no X-ray optical devices except the DCM and X-ray windows are installed. There are two experimental hutches; experimental hutch 1 (EH1) is located 80 m from the source and experimental hutch 2 (EH2) is located 245 m from the source. Various types of X-ray projection imaging, such as X-ray microcomputed tomography (μ-CT), X-ray high-speed imaging, and coherent X-ray imaging, are available. By using both EH1 and EH2, two types of experiment unique to BL20XU, both of which require a long sample-to-camera distance (165 m) are available; one is ultrasmall-angle X-ray scattering (USAXS) and the other is high-energy X-ray nanotomography (nano-CT). Multiscale CT measurement combining two or more CT systems with different fields of view (FOV) and spatial resolutions is available. Two types of system are in operation. One is a combination of nano-CT and micro-CT, which enables the observation of a sample with a diameter of around 1 mm with a spatial resolution of 200 nm. The other is based on using a large beam size at EH2 that realizes an FOV of up to 6 mm and a spatial resolution of 1 μm. A combination of the multiscale CT and X-ray diffraction CT (XRD-CT), called integrated CT, is also available. They are selected depending on the sample size and requirement of experiments. By using the system, it is possible to find important portions (region of interest, ROI) of a sample nondestructively.

X-ray diffraction (XRD)-based tomography is capable of identifying mineral phases, which is impossible with conventional absorption- or phase-contrast imaging. There are several methods for X-ray diffraction-based tomography in accordance with the requirements. The XRD-CT method [1,2], which is already included in the integrated CT system, is a method of identifying the distribution of mineral phases in a sample that comprises a mixture of multiple mineral phases and many crystal grains of those mineral phases.

As part of activities in this beamline, a new method of XRD-based tomography, called diffraction contrast tomography (DCT) [3], which is a method for the identification of crystal grains in a polycrystalline sample of a single mineral phase, has been developed and included in the integrated CT system.

2. Development of DCT system

Unlike conventional CT methods that observe the intensity distribution of transmitted X-rays, XRD-based tomography acquires diffracted X-rays using a detector. In the DCT method, an X-ray beam with an area of approximately 1 mm × 1 mm irradiates a sample of about 1 mm × 1 mm × 1 mm during its full rotation. In this case, the crystals within the sample that satisfy Bragg's condition undergo extinction, allowing the measurement of diffracted

X-rays. This enables the back-calculation of the positions of the grains that caused diffraction at that rotation angle. Furthermore, the shape of the diffracted X-ray reflects the shape of the crystal grains, and by acquiring this simultaneously, the positions and shapes of the crystal grains can be investigated. This process is performed for all crystal grains and converted into the volumetric information of a sample (Fig. 1).

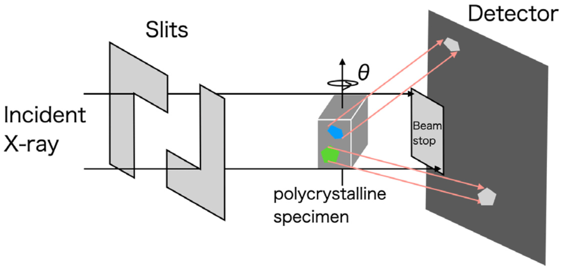

Fig. 1. Schematic illustration of DCT imaging setup.

The DCT method was originally developed at ESRF, where its data analysis software is continuously developed. The latest version of this software is available as an open source. In this development, the software developed at ESRF was modified into an appropriate form for operation at BL20XU after obtaining permission from the development group of ESRF. The development includes data preprocessing, determining reference parameters, setting up for the required database system, avoiding unnecessary processes, and fixing critical bugs.

Including the above developments for the data analysis software, the setup for the DCT analysis was also constructed to combine the integrated CT system. Slits and a beam stop were newly developed and included in the integrated CT system.

Figure 2 shows the result of DCT imaging for β-Ti alloy (Ti-12Mo). Experimental parameters are as follows: the X-ray energy is 30 keV, the pixel size for the DCT analysis is 3.08 μm, the exposure time is 50 ms, the number of images during the full rotation of the sample is 3600, the number of pixels and FOV of the detector are 2048 × 2048 (6.308 mm × 6.308 mm), and the distance between the sample and the camera is 8 mm. The X-ray beam was trimmed to 1mm x 1mm using slits and fixed to the center of the FOV of the X-ray detector.

Absorption contrast CT for the sample was also conducted with the same setup, but without a beam stop. In the image of absorption contrast CT (Fig. 2(a)), the inside of the sample shows no structure and appears almost uniform. However, the DCT image (Fig. 2(b)) clearly shows crystal grains of Ti alloy with their orientations.

By combining the DCT and existing multiscale CT, it is possible to confirm the relationship between the fine structures observed in the high-resolution absorption X-ray CT and the distribution and properties of crystal grains.

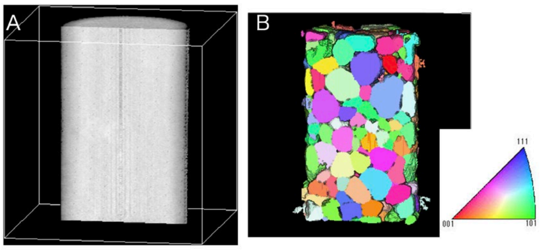

Fig. 2. 3D bird's-eye-view images of vertical cross section of Ti-12Mo alloy by (A) absorption contrast CT and (B) DCT. The diameter of the sample was 600 μm. Colors in the DCT image show inverse pole figure (IPF) colors of the crystal grains against the vertical direction.

UESUGI Masayuki and TAKEUCHI Akihisa
Japan Synchrotron Radiation Research Institute (JASRI)

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