Detection of Cracks due to SCC in Ni-base Alloys by Synchrotron Radiation CT Imaging

Stress corrosion cracking (SCC) is an intergranular failure that takes place in structures such as austenitic stainless steels and nickel-base alloys exposed to high-temperature and high-pressure water. SCC is an important engineering issue for the structural integrity of light water reactors.

For the inspection of cracking in structural components, ultrasonic testing (UT) is recognized as an important and useful technique. However, it is generally not easy to detect the defects and obtain correct information on cracks in the welding metal by UT. This is due to the fact that the anisotropic and inhomogeneous microstructure of the welding metal leads to direction-dependent sound propagation, which is related to sound velocity, polarization, sound reflection and absorption at interfaces. The accuracy of crack size and depth data obtained by UT are sometimes evaluated by other methods such as a cross-sectioning examination. As the cracks due to SCC are complex with a 3-dimensional (3D) distribution, the numerical data obtained by 2-dimensional (2D) techniques such as the cross-sectioning method may results in errors. A numerical simulation technique to interpret the UT signal and data is under development [1].

In this study, we aimed to demonstrate the applicability of X-ray computer tomography (CT) with refractive contrast to the 3D imaging of minute cracks produced in weld metals of nickel-base alloy caused by SCC. Whilst the X-ray CT technique has already been applied to fatigue cracks of light metals such as Al alloys, no trial has yet been performed to evaluate the SCC in steels or Ni alloys [2]. Although X-ray attenuation is high for the Ni alloy specimen due to its large mass absorption coefficient, 3D images are successfully reconstructed by the X-ray CT technique using highly parallelized brilliant X-rays from SPring-8. Accurate crack size and depth data were obtained.

The SCC test specimens were prepared from a weld metal of nickel-base alloy (Ni-15Cr-7Fe-0.15C) after it was exposed to tetrathionic acid solution for few days. The crack depth was fixed by controlling the corrosion potential. The specimen employed was rod-shaped with a diameter of about 0.7 mm, as shown in Fig. 1, and was made so that the top of the rod was on the original material surface. The CT imaging experiments were performed at beamline **BL19B2**. The experimental setup is schematically shown in Fig. 2. The X-ray energy was adjusted to 37 keV using a Si double-crystal monochromator. The distance between the bending magnet (X-ray source) and the sample was about 110 m. The area detector (cooled CCD camera) was set 0.41 m or 0.8 m behind the specimen to obtain refractive contrast imaging. Projection data of 1024 × 1024 pixels was recorded every 0.5° from 0 to 180°. The effective pixel size of the detector was about 6 μm. Slice images were reconstructed by a standard algorithm used for filtered-back projection.

Reconstructed slice images for a crack due to SCC in the Ni-base weld metal obtained at a camera length of 0.41 m are shown in Figs. 3 and 4. A typical bent or twisted crack with a complex structure is observable in Fig. 3. The width of the crack is narrow. The crack propagation is considered to depend on the orientation of the crystal and solidified structures. On the other hand, another type of crack with a flat or plane structure similar to a fatigue crack can be observed in Fig. 4. Although the SCC conditions were the same, it is clear that the crack structure and distribution may change depending on the base-metal condition such as its grain orientation, grain boundary and precipitates. The resolution of the crack image is about 10 μm near the surface.

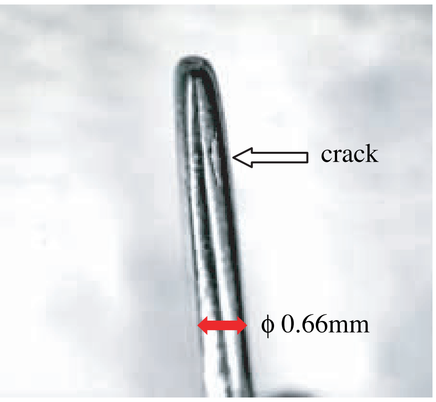

Fig. 1. Appearance of test sample.

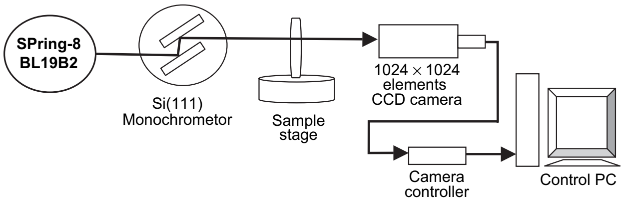

Fig. 2. Schematic illustration of measurement system.

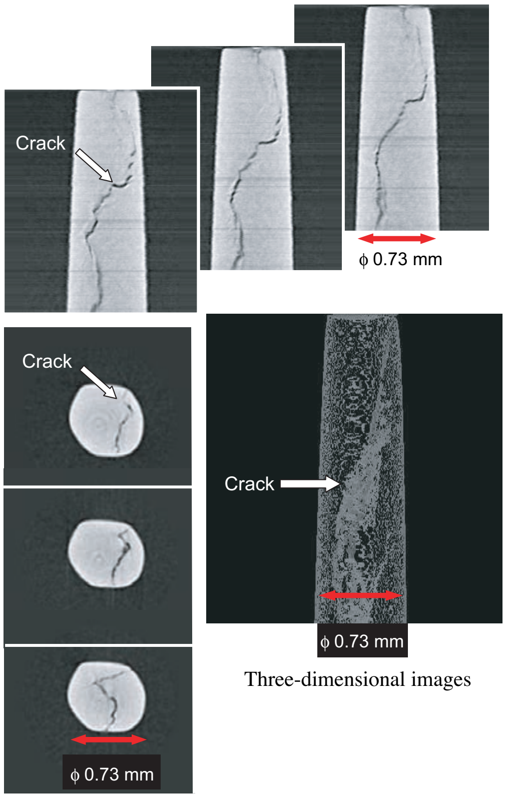

Fig. 3. Reconstructed slice images (sample 1).

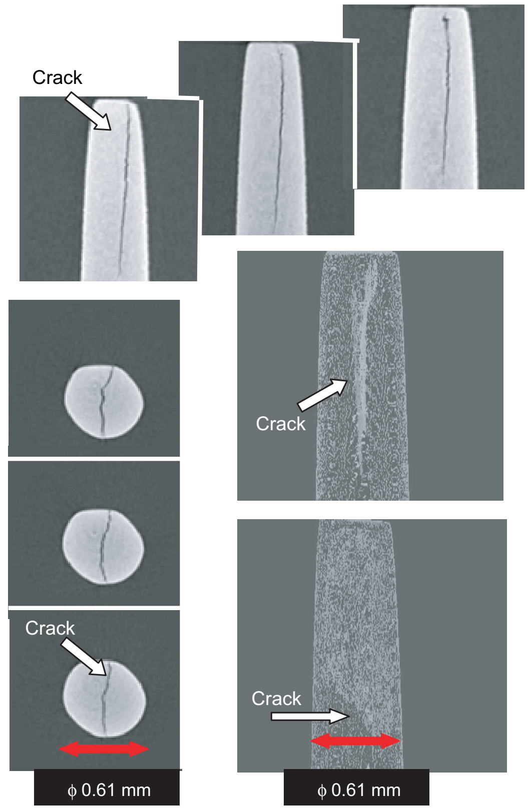

Fig. 4. Reconstructed slice images (sample 2).

The results of crack length measured by a crack depth gage, cross-sectioning examination and CT imaging are compared in Table 1. The values of crack length obtained by cross-sectioning examination are shorter than those obtained by X-ray CT imaging. This is expected since an internal crack cannot be observed by cross-sectioning examination. Although the difference is not large in this case, it should be noted that X-ray CT imaging is a nondestructive technique.

In summary, clear images of fine cracks in nickel-based metal due to SCC were successfully obtained by synchrotron radiation CT imaging.

Table 1. Comparison of the crack depth obtained by crack depth gage, cross-sectioning examination and CT imaging

Sample	Crack depth gage	Sectioning	CT imaging
No. 1	3.2 mm	1.2 mm	1.6 mm
No. 2	1.6 mm	0.7 mm	0.9 mm

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References

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