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Texture evaluation in ductile fracture process by neutron diffraction measurement

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Texture evaluation in ductile fracture process by neutron diffraction measurement

H Sunaga [1], M Takamura [1], Y Ikeda [1], Y Otake [1], T Hama [2], M Kumagai [3], H Suzuki [4] and S.Suzuki [5]

Center for Advanced Photonics, RIKEN, Wako, Saitama 351-0198, Japan
Research Reactor Institute, Kyoto University, Kumatori, Osaka 590-0494, Japan
Faculty of Engineering, Tokyo City University, Setagaya, Tokyo 158-8857, Japan
Materials Sciences Research Center, Japan Atomic Energy Agency, Tokai, Ibaraki 319-1195, Japan
Faculty of Science and Engineering, Waseda University, Shinjuku, Tokyo 169-8555, Japan

sunaga@riken.jp

Abstract. A neutron diffraction measurement was performed to reveal microstructural aspects of the ductile fracture in ferritic steel. The diffraction patterns were continuously measured at the center of the reduced area while a tensile specimen was loaded under tension until the end of the fracture process. The measurement results showed that the volume fraction of (110)-oriented grains increased when the texture evolved as a result of plastic deformation. But the mechanism of texture evolution may be changed during necking, decreasing an increase rate of the volume fraction.

1. Introduction

Fracture is one of the most crucial forming defects encountered in manufacturing processes. The classic phenomena of ductile fracture are observed in a tensile specimen subjected to a large amount of plastic deformation showing necking or a reduced area particularly near the fracture itself.

Understanding of the microstructural phenomena occurring during post-uniform elongation will help define numerous criteria expected to be necessary for the establishment of accurate simulation technology[1]. This should reduce the preparation time of the manufacturing processes carried out by trial-and-error method, and enable the realization of high quality and low-cost products with a short delivery period.

Neutron diffraction can be used to measure texture evolution[2]. It has an advantage that the neutrons penetrate more deeply into the bulk than the conventional X-ray diffraction. The neutron diffraction technique has been extended to investigate the evolution of lattice strain and internal stress[3-5]. Therefore, it is used to obtain data under various conditions such as loading or changing temperature by in situ measurements.

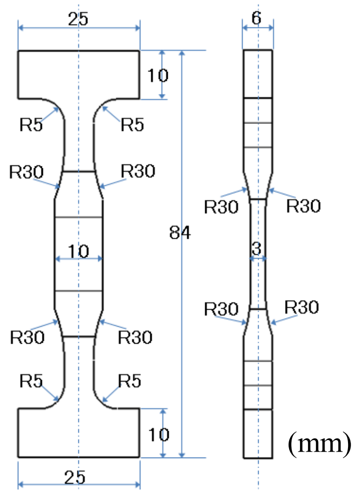
The deformation behavior of a stainless steel is investigated under tensile loading without any interruption to apply a load or displacement. The transformation behavior or volume fraction of the retained austenite under the enhancement of uniform elongation is studied to increase the work-hardening resulting in delaying the onset of necking[6]. The local deformation behavior occurring during post-uniform elongation, which takes place before fracture, is still poorly understood. In this study, a neutron diffraction measurement was performed to reveal the texture evolution in ferritic steel during elongation until the end of the fracture process.

2. Experimental procedure

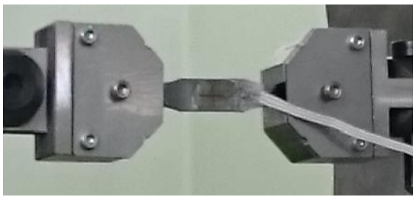
The neutron diffraction measurement was performed using the time-of-flight-type engineering neutron diffractometer TAKUMI at the Material and Life Science Experimental Facility (MLF) of Japan Proton Accelerator Research Complex (J-PARC).

The material used in this study was JIS-SS400, which is a rolled steel used in general structures. The dimensions of the JIS-SS400 steel specimen used in this study are given in Figure 1. The shoulders of the specimen used for gripping are machined to have dimensions fully consistent with the specifications of the tensile testing machine. The most important part of the specimen is the middle section. The cross-sectional area of the middle section was designed to be smaller than that of the other sections, because necking and ductile fracture were expected to occur in the middle section, for which a width of 10mm was determined to provide sufficient area for the diffraction of the incident beam.

The tensile testing machine was oriented at an angle of 45° to the incident beam. The diffraction patterns both parallel and transverse to the loading axis were measured simultaneously by using two detector banks which were oriented at angle of ±90° to the incident beam as shown in Figure 2. A movable crosshead was controlled to move at a constant speed (0.005 mm/s) and the tensile testing machine itself moved to the opposite direction to the crosshead movement to allow the incident beam to be diffracted in the middle section of the specimen during the tensile loading. The neutron data were collected continuously throughout the entire tensile test when the JIS-SS400 steel specimen was loaded under uniaxial tension until the fracture occurred.



(a) Dimensions of a tensile specimen



(b) Specimen fixed to the tensile machine

Figure 1. Tensile specimen used in this study

3. Results and discussion

Figure 3 shows the tensile load vs crosshead displacement obtained by the tensile test during the neutron

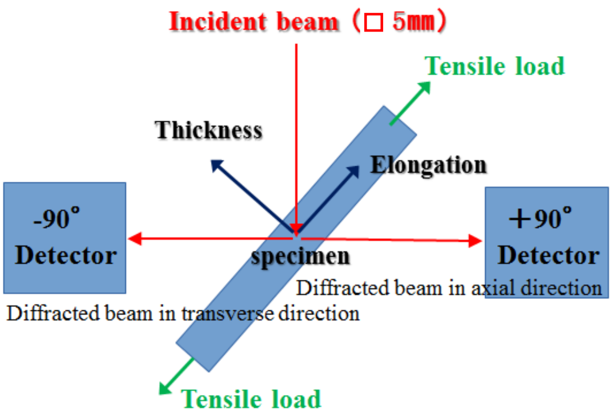


Figure 2. Schematic view of neutron diffraction measurement

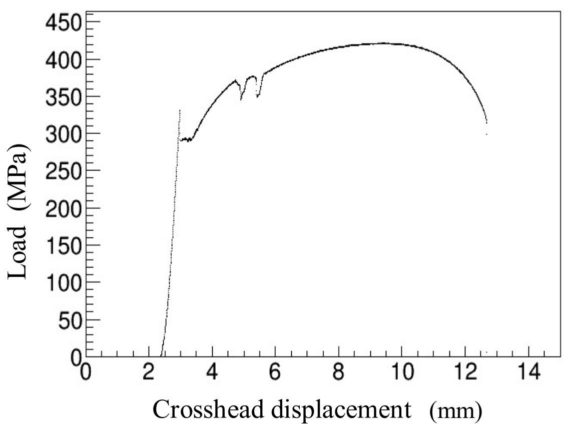


Figure 3. Load-crosshead displacement diagram

diffraction measurement. Figure 4 shows the changes in the thickness and width at the most reduced section of the specimen where the incident beam was diffracted during the tensile loading, as shown in Figure 5. It was measured with the photographs taken from the front and side of the specimen during the tensile test, which was performed under the same condition as the diffraction measurement. Both the width and thickness decrease at the same rate relative to the initial size, and the maximum load corresponds to the point at which the deformation starts to localize in the middle of the specimen. It was also confirmed that neutron diffraction could measure the material elongation during necking and ductile fracture, because necking occurred in an area of the square equal to the incident beam size (□5 mm).

The neutron data were sliced every 30 sec to calculate the diffraction patterns in each detector bank. Figure 6 shows the diffraction patterns for the axial direction parallel to the loading axis taken before deformation. Here, we discuss the texture evolution based on changes in the peak intensity of the 110, 200, 211 and 220 reflections during deformation. The peak intensities were normalized by a sampling volume which was estimated from a change in thickness at the center of the specimen.

Figure 7 shows the change in the diffraction intensity in the axial direction as a function of crosshead displacement. Initially, the intensity of 110 increased while those of 200 and 211 decreased with increasing applied load. A transition from an increase to a decrease in the intensity occurred for 110 prior to the fracture.

The volume fraction of (110)-oriented grains increased when the texture evolved as a result of plastic deformation. But the mechanism of texture evolution may be changed during necking, decreasing an increase rate of the volume fraction.

Figure 8 shows the change in the diffraction intensity in the transverse direction as a function of crosshead displacement. In contrast of the result for the axial direction, the intensity of all the lattice planes including 110 decreased monotonically. No behavior

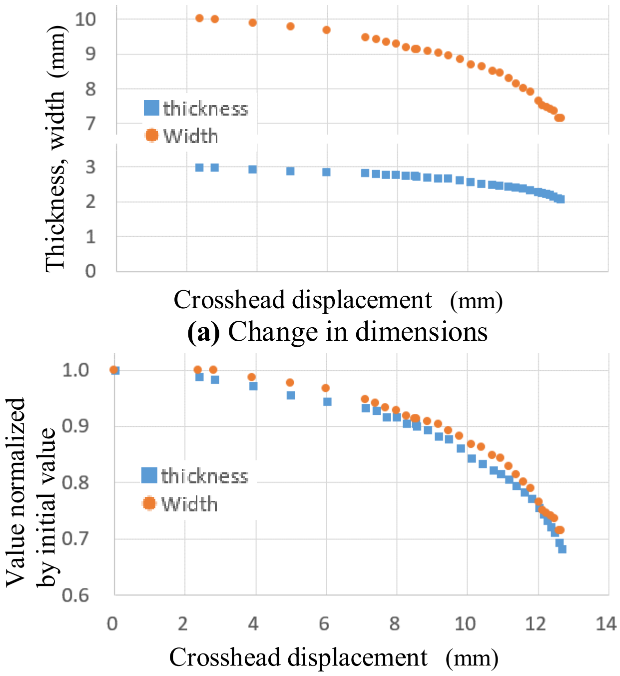


Figure 4. Changes in the thickness and width at the most reduced section of the specimen

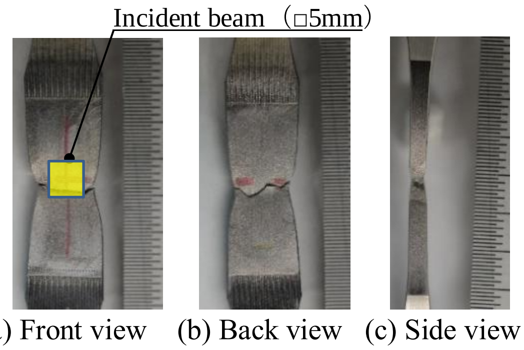


Figure 5. Photographs of specimen after fracture

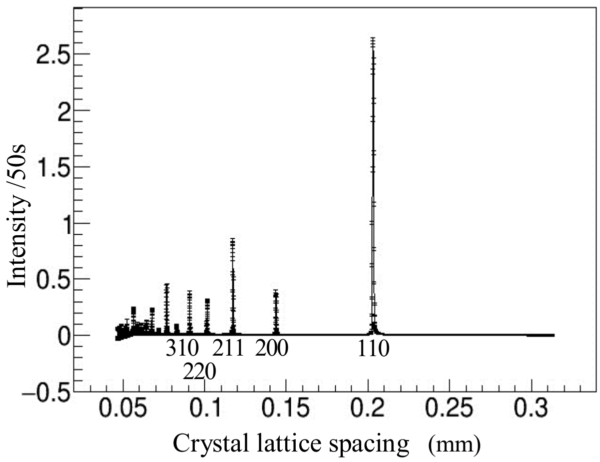


Figure 6. Diffraction pattern in the axial direction taken before deformation

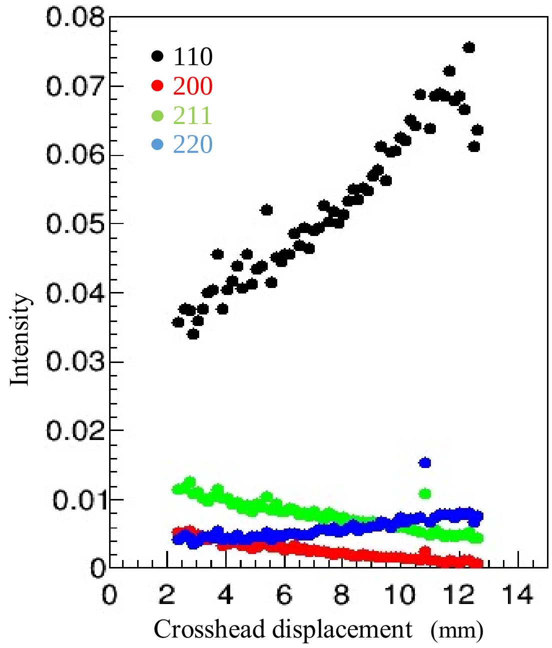


Figure 7. Change in diffraction intensity in the axial direction

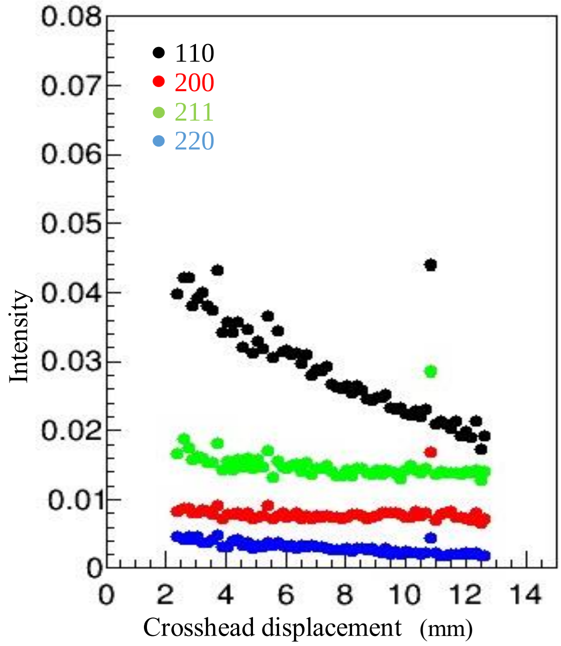


Figure 8. Change in diffraction intensity in the transverse direction

that could be ascribed to the effect of fracture was observed.

4. Conclusion

The local deformation behavior that occurs before fracture was studied by neutron diffraction measurement. The results of a change in the peak intensity of the diffraction pattern supposed that the mechanism of the texture evolution may be changed during necking.

Acknowledgments

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