



Contribution ID : 56

Type : Oral

Evaluation of micro-strain, dislocation density and crystallite size from broadening of multiple Bragg-edges observed by pulsed neutron transmission imaging

Monday, 3 September 2018 14:30 (20)

It is recognized that Bragg-edge neutron transmission method can deduce crystal structure, crystalline phase, crystallographic texture, crystallite size (from the primary extinction effect) and macro-strain in the imaging mode. In this study, further material information, micro-strain, dislocation density and crystallite size, were deduced by broadening analysis of multiple Bragg-edges.

So far, we have investigated that Bragg-edge broadening (FWHM of d-spacing distribution) is same as diffraction peak FWHM [1], and proportional to ferrite/martensite ratio and the Vickers hardness [2]. However, the FWHM can be separated to the crystallite size component and the micro-strain component relating to dislocation density [3]. In addition, the dislocation density is very important information for material strength characterizations. For this reason, we tried to separate these broadening components, and deduce micro-strain, crystallite size and dislocation density by using the Williamson-Hall (WH) method. The WH method needs line-broadening information of various diffraction indices.

Pulsed neutron transmission and diffraction experiment [1,4] was performed at J-PARC MLF BL19 "TAKUMI". During a tensile test of a low-carbon ferritic steel plate, both data of transmission (by 256-pixels Li-6 glass-scintillator detector) and diffraction (by TAKUMI) were measured. As a result, Bragg-edges and diffraction peaks of various diffraction indices were obtained.

We firstly checked the classical WH (cWH) plots [3] of both transmission data and diffraction data. This shows relation between Bragg-edge broadenings and diffraction peak broadenings for various diffraction indices. As a result, it was confirmed that Bragg-edge broadenings corresponded to diffraction peak broadenings. In addition, it was correctly observed that the cWH plots did not have linearity due to the anisotropic elasticity. Thus, Bragg-edge broadening is consistent with diffraction peak broadening for multiple diffraction indices. This means that the same data analysis procedure as the diffraction method can be applied to the Bragg-edge transmission method.

For dislocation density analysis, various high-reliability methods have been proposed in X-ray/neutron diffractometry; modified WH plot, modified Warren-Averbach method, CMWP fitting etc. For a low-carbon steel (only ferrite phase) under cold deformation like this experiment, Akama et al. found the best method; the corrected cWH plot and a dislocation density estimation method using a slope of the plot [5]. By using this method, the Bragg-edge neutron transmission imaging method can quantitatively deduce the dislocation density. As a result, it was found that the dislocation density after the tensile test was about $2\sim 3 \times 10^{14} \text{ m}^{-2}$, and this value was consistent with a similar X-ray diffraction study [5]. Since the corrected cWH model is usable, we are now developing a new fitting program for Bragg-edge neutron transmission spectra by using this model. Owing to this, it is expected that reduction of the analytical error is achieved in the imaging mode.

The authors are thankful to Dr. S. Harjo, Dr. S. Takata, Dr. T. Ito and Dr. K. Aizawa for experimental assistances at TAKUMI.

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Session Classification : Speaker Sessions and Seminars

Track Classification : Methods