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

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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 2~3×10^14 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.

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