Non-destructive Texture Measurement of Steel Sheets with Compact Neutron Source "RANS"

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

Center for Advanced Photonics, RIKEN, Wako, Saitama 351-0198, Japan
Materials Sciences Research Cente, Japan Atomic Energy Agency, Tokai, Ibaraki 319-1195, Japan
Faculty of Engineering, Tokyo City University, Setagaya, Tokyo 158-8857, Japan
Graduate School of Energy Science, Kyoto University, Sakyo-ku, Kyoto 606-8501, Japan
Research Reactor Institute, Kyoto University, Kumatori, Osaka 590-0494, Japan

takamura@riken.jp

Abstract. Neutron diffraction is well known to be a useful technique for measuring a bulk texture of metallic materials taking advantage of a large penetration depth of the neutron beam. However, this technique has not been widely utilized for the texture measurement because large facilities like a reactor or a large accelerator are required in general. In contrast, RANS (Riken Accelerator-driven Compact Neutron Source) has been developed as a neutron source which can be used easily in laboratories. In this study, texture evolution in steel sheets with plastic deformation was successfully measured using RANS. The results show the capability of the compact neutron source for the analysis of the crystal structure of metallic materials, which leads us to a better understanding of plastic deformation behavior.

1. Introduction

Sheet forming technologies for high strength steel sheets are becoming more and more important in automotive body parts with the aim of weight reduction, but their use urgently requires further improvement by analyzing the behavior of plastic deformation. On the other hand, recent advances in numerical analyses have enabled the practical application of advanced sheet metal forming simulation technology using finite-element methods (FEM), e.g., simulations of shearing processes performed by authors [1]. It is obvious that the crystal plasticity FEM is one of the most powerful numerical tools to model microscopic deformation mechanisms and to predict macroscopic plastic behavior [2], which is often performed in conjunction with texture measurement techniques such as Electron backscatter diffraction (EBSD) or X-ray diffraction (XRD). However, these methods can provide information only from localized area or surface with the thickness of μ m or 10μ m.

In contrast, neutron diffraction is well known to be a useful technique to quantitatively measure microstructural factors of metals [3] such as texture in bulk-average taking advantage of a large penetration depth of the beam, which is strongly related to its formability in metal forming processes, bringing advanced understanding of the mechanical behavior of metals by investigating the relationship with macroscopic behavior. Such studies using neutron diffraction typically require a neutron engineering diffractometer [4-11] installed in large experiment facilities such as a reactor and a large

accelerator to obtain high flux neutrons. Therefore, we have only few chances in a year to use their facilities because of high-level competition of the beam time. However, investigations of plastic deformation require much more opportunities to measure the texture anywhere at any time like commercial X-ray equipment available at their own locations.

In contrast, Riken Accelerator-driven Compact Neutron Source (RANS) [12, 13] has been developed as a neutron source which can be used easily in laboratories. If we can evaluate microstructural factors easily by neutron diffraction using a compact neutron source at our own laboratory, it is expected to achieve effective analyses of metal forming processes more efficiently. Authors have recently shown diffraction patterns of ferritic steels obtained by RANS and evaluation results of retained austenite volume fraction [14]. In this study, the neutron diffraction experiments are carried out using RANS and plastically deformed mild steel samples to clarify a capability of the compact neutron source for the analysis of the texture evolution, which leads us to a better understanding of plastic deformation behavior.

2. Experimental method

Figure 1 shows an entire view of RANS [12-14], which consists of a proton accelerator, a neutron production target and instruments for the neutron experiment. Protons are accelerated with a proton liniac to 7 MeV, and injected to a beryllium (Be) target [15]. Neutrons with the maximum energy of about 5 MeV are generated via the Be (p,n) reaction. The fast neutrons are moderated in a polyethylene moderator, and the thermal neutrons with approximately 0.01 eV (0.1 nm in wavelength), which is a suitable energy for the diffraction experiment, can be extracted from the moderator surface. Neutrons with 10^4 $s^{-1}cm^2$ in flux are provided to the camera box installed at approximately 5 m far away from the moderator.

Figure 1. Entire view of RANS. This is about 15 m in total length, consists of an ion source, a proton accelerator, a target station, a neutron beam pipe and a camera box.

Figure 2 shows the experimental setup for measuring diffraction from steel samples [14]. A neutron detector, which consists of a ZnS(Li) scintillator and a position sensitive photo multiplier tube RPMT, were installed inside the camera box. Diffraction patterns were measured based on the time-of-flight (TOF) principle. Energy range from 0.05 to 0.5 nm in wavelength is used to measure the diffraction pattern from the steel in this study.

The sample used here was IF (interstitial free) steel with the thickness of 1.0 mm, which was plastically deformed by 10 % in uniaxial compression along the rolling direction. A cylindrical-shaped specimen with the height of 10 mm and the diameter of 10 mm (ϕ 10) was prepared by following procedure. The small pieces of the plate with a size of ϕ 10 were, at first, taken from a specimen by milling, and then assembled together into the cylindrical shape, preserving the orientation of the pieces. The diffraction angle 2θ and the distance from the sample to the detector L_2 were set to be 140° and 100 mm, respectively. The diffraction patterns were taken for 10 minutes to get sufficient intensity.
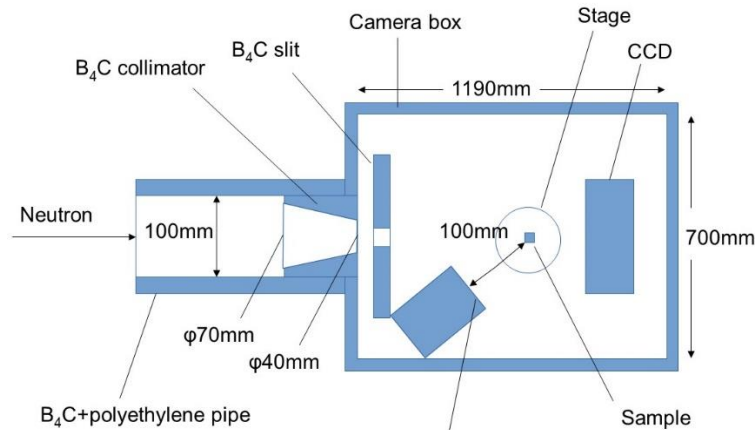
Figure 2. Schematic illustration of the experimental setup.

3. Results and discussion

Figure 3 shows the diffraction pattern in the rolling direction of the deformed specimen, in comparison with that of the undeformed specimen. It can be seen in figure 3 that the undeformed specimen may originally have strong texture even before tensile deformation because the intensity of the 110 reflection is much higher than other peaks. After applying compressive deformation by 10 %, the 110 reflection is the intensity of the 110 reflection is obviously decreased by 0.79 times, while that of the 211 reflections that are perpendicular relation to the 110 reflection is increased by 1.4 times. This is a typical texture evolution for the BCC structure, caused by plastic deformation [16]. Figure 4 shows the variation of diffraction patterns of the deformed specimen with respect to diffraction direction from RD to TD. The variation in the peak intensity shows a possibility of this measurement method for the generation of pole figures. These results suggest that the texture evolution due to the plastic deformation can be observed by RANS. TOF neutron diffraction has an advantage for efficient texture measurement by measuring multiple neutron TOF histograms in various directions of the pole figure, which are simultaneously measured by a wide area detector [17]. For RANS based on TOF neutron diffraction, therefore, it is also expected to measure the texture of material for relatively short time by using similar technique.
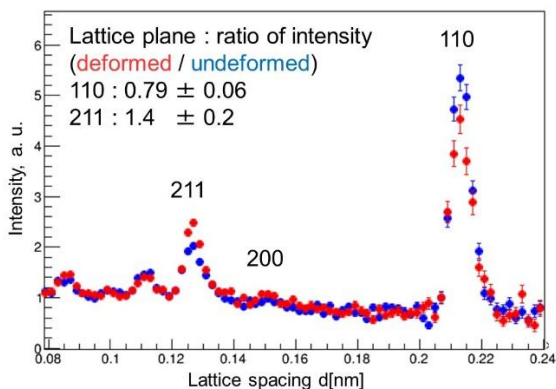

Figure 3. Comparison of the diffraction patterns of the IF steel before and after 10% compressive deformation.
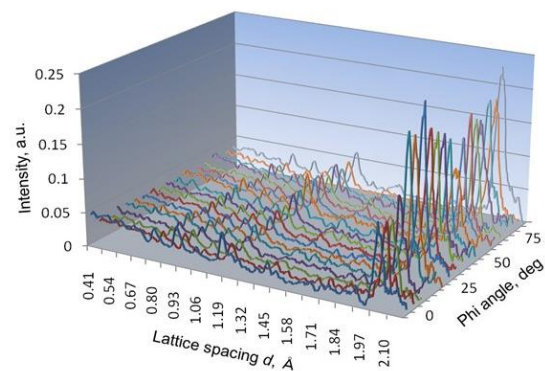

Figure 4. Variation of diffraction patterns with respect to diffraction direction.

4. Conclusions

In this study, the neutron diffraction experiments were carried out using Riken accelerator-driven compact neutron source, RANS. The diffraction pattern of IF steel samples was successfully measured by the TOF method. The texture evolution due to plastic deformation was successfully observed by measuring a change in the diffraction peak intensity. Consequently, RANS has been proved to be capable for neutron engineering diffraction aiming for the easy access measurement of texture evolution.

In the future scene of the metal forming analysis, texture measurement by a compact accelerator-based neutron source can be compared with and can validate the crystal plasticity analysis results and, at the same time, can provide valuable input information for the numerical analyses. Accurate crystal plasticity analysis can make a contribution to the macroscopic material modeling and can improve drastically the accuracy of forming simulations in industrial use.

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