Measurement of neutron diffraction with compact neutron source RANS

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Summary. — Diffraction is used as a measurement technique for crystal structure. X-rays or electron beam with wavelength that is close to the lattice constant of the crystal is often used for the measurement. They have sensitivity in surface (0.01 mm) of heavy metals due to the mean free path for heavy ions. Neutron diffraction has the probe of the internal structure of the heavy metals because it has a longer mean free path than that of the X-rays or the electrons. However, the neutron diffraction measurement is not widely used because large facilities are required in the many neutron sources. RANS (Riken Accelerator-driven Compact Neutron Source) is developed as a neutron source which is usable easily in laboratories and factories. In RANS, fast neutrons are generated by 7 MeV protons colliding on a Be target. Some fast neutrons are moderated with polyethylene to thermal neutrons. The thermal neutrons of 10 meV which have wavelength of 10 nm can be used for the diffraction measurement. In this study, the texture evolution in steels was measured with RANS and the validity of the compact neutron source was proved. The texture of IF steel sheets with the thickness of 1.0 mm was measured with 10 minutes run. The resolution is 2% and is enough to analyze a evolution in texture due to compression/tensile deformation or a volume fraction of two phases in the steel sample. These results have proven the possibility to use compact neutron source for the analysis of mesoscopic structure of metallic materials.

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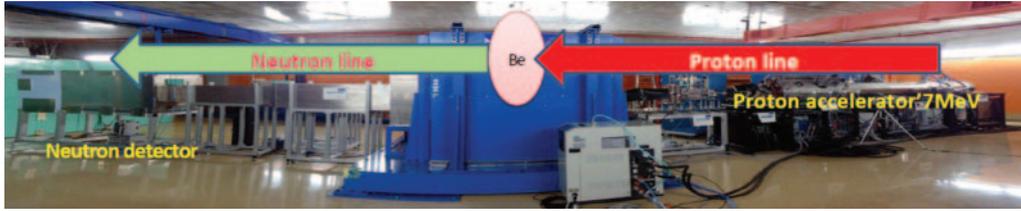
Fig. 1. – RANS entire veiw.

1. – Introduction

X-ray and electron beam are often used to study texture of crystals by diffraction. However, it can be measured for only surface of metal because they have small transmittances for heavy atoms with large electron densities. On the other hands, neutrons which have no interaction with electrons can measure internal structure of metals.

In order to meet the demand of neutron, high intensity accelerator-driven neutron sources have been constructed and operated. Conversely, opportunity of neutron use in the large facility is limited in comparison with that of X-ray or electron although users and demands increase. Compact neutron sources with moderate intensities are developed for increasing needs in neutron community in the world. The compact neutron sources has not been popularly used in diffraction measurement because of their intensity limits. We optimize the compact neutron source for large sample such as a polycrystalline bulk metal from industrial points of view. In this paper, the diffraction of a commonly used IF steel sample is measured with a compact neutron source RANS which is developed for many neutron users, in particular for industrial use [1,2].

2. – Compact neutron source RANS

Figure 1 shows an entire view of RANS. RANS consists of the proton accelerator, neutron production target and instruments for neutron measurement. Protons are accelerated with proton liniac to $7\,\mathrm{MeV}$ and injected to a Be target of $0.3\,\mathrm{mm}$ thickness. A backing of the Be target is V plate of $4\,\mathrm{mm}$ thickness which is cooled by water of $5\,\mathrm{mm}$ covered with a Ti cavity of $5\,\mathrm{mm}$ thickness. Neutrons are generated via the Be(p,n) reaction [3]. The neutron spectrum in forward direction has the maximum energy of $5\,\mathrm{MeV}$ and flux-peak at $1\,\mathrm{MeV}$. The fast neutrons are moderated in a polyethylene of $40\,\mathrm{mm}$ thickness. Neutrons of $0.01\,\mathrm{eV}$ ($0.1\,\mathrm{nm}$ of wavelength) which is suitable energy range for diffraction measurement are emitted from moderator surface. A reflector of $50\,\mathrm{cm}$ thickness consists of graphite blocks placed around the moderator in order to gather neutrons in the moderator. A Shield consists of Pb blocks and B_4C mixed polyethylene blocks placed around the reflector. The shield is a cube of $1.8\,\mathrm{m}$ and weight $10^4\,\mathrm{kg}$. A $10\,\mathrm{cm}$ hole in the shielding, on one side, allows the entrance of proton beam to reach the Be target. The opposite side a $14\,\mathrm{cm}$ hole allows the escape of neutrons from the polyethylene moderator. $10^4\,\mathrm{s}^{-1}\mathrm{cm}^{-2}$ of neutrons are provided to a camera box which leaves $5\,\mathrm{m}$ from the moderator.
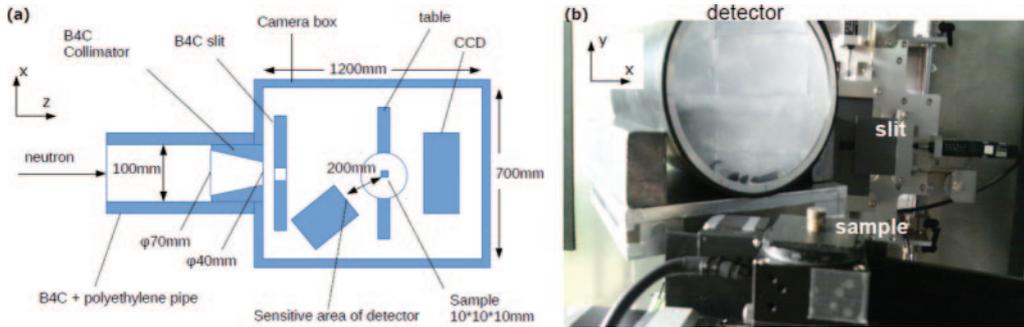
Fig. 2. – Experimental setup of diffraction measurement in RANS.

3. – Experimentally

Figure 2 shows the experimental setup. Neutrons are emitted from moderator surface. The cross-sectional shape of the beam is molded into a square with B_4C collimator and B_4C slit before reaching sample at 5 m downstream from the moderator surface. The shape of beam and shadow of the sample are captured with a CCD which is located downstream from the sample to check the positioning of sample and slit. The sample and detectors are in the Camera box. Diffracted neutrons are detected with a neutron detector. Crystal plane distance of diffraction is calculated with the Bragg function. Wavelength of neutron is estimated with the track length and time of flight.

The neutron detector consists of ZnS(Li) scintillator and position sensitive photo multiplier tube. This detector provides a hit timing and a position for each neutrons. The data are used to estimate a diffraction angle, a wavelength and a diffraction plane distance with Bragg's law for each neutron. In order to estimate track lenght and diffraction angle, we assume that the emission position is the center of the moderator surface and the diffraction position is the center of the sample.

A cubic sample of side 10 mm is made from a test piece IF steel sheet of 1 mm thickness. The sheet is cut and stacked in the same direction. Tensile or compression tests are to be considered in the future.

Walls and ceiling of the camera box and CCD are covered with B_4C sheets to reduce background.

4. – Result

A diffracted neutron spectrum was measured at 20 deg of diffraction angle with 10 minutes counting. The spectrum is calibrated with the Bragg's law and peaks correspond to crystal plane distance were given. Diffraction peaks of 6 crystal planes of the steel are seen. The resolution which is determined as the value of Gaussian dispersion (normalized with the mean value of the peak) of 110 plane is 2%. This resolution is enough to analyze a evolution in texture due to compression/tensile deformation or a volume fraction of two phases in the steel sample. This results have proven the possibility of compact neutron source for the analysis of mesoscopic structure of metallic materials.

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