Nuclear Instruments and Methods in Physics Research A 833 (2016) 61–67

Contents lists available at ScienceDirect

Nuclear Instruments and Methods in Physics Research A

journal homepage: www.elsevier.com/locate/nima

Prospect for application of compact accelerator-based neutron source to neutron engineering diffraction

Yoshimasa Ikeda [a,*], Atsushi Taketani [a], Masato Takamura [a], Hideyuki Sunaga [a], Masayoshi Kumagai [b], Yojiro Oba [c], Yoshie Otake [a], Hiroshi Suzuki [d]

[a] *Center for Advanced Photonics, RIKEN, Wako, Saitama 351-0198, Japan*
[b] *Faculty of Engineering, Tokyo City University, Setagaya, Tokyo 158-8857, Japan*
[c] *Research Reactor Institute, Kyoto University, Kumatori, Osaka 590-0494, Japan*
[d] *Materials Sciences Research Center, Japan Atomic Energy Agency, Tokai, Ibaraki 319-1195, Japan*

ARTICLE INFO

Article history:
Received 7 March 2016
Received in revised form
12 May 2016
Accepted 28 June 2016
Available online 29 June 2016

Keywords:
Compact accelerator-based neutron source
Neutron engineering diffraction
Time-of-flight
Resolution
Moderation time

ABSTRACT

A compact accelerator-based neutron source has been lately discussed on engineering applications such as transmission imaging and small angle scattering as well as reflectometry. However, nobody considers using it for neutron diffraction experiment because of its low neutron flux. In this study, therefore, the neutron diffraction experiments are carried out using Riken Accelerator-driven Compact Neutron Source (RANS), to clarify the capability of the compact neutron source for neutron engineering diffraction. The diffraction pattern from a ferritic steel was successfully measured by suitable arrangement of the optical system to reduce the background noise, and it was confirmed that the recognizable diffraction pattern can be measured by a large sampling volume with 10 mm in cubic for an acceptable measurement time, i.e. 10 min. The minimum resolution of the 110 reflection for RANS is approximately 2.5% at 8 μs of the proton pulse width, which is insufficient to perform the strain measurement by neutron diffraction. The moderation time width at the wavelength corresponding to the 110 reflection is estimated to be approximately 30 μs, which is the most dominant factor to determine the resolution. Therefore, refinements of the moderator system to decrease the moderation time by decreasing a thickness of the moderator or by applying the decoupler system or application of the angular dispersive neutron diffraction technique are important to improve the resolution of the diffraction experiment using the compact neutron source. In contrast, the texture evolution due to plastic deformation was successfully observed by measuring a change in the diffraction peak intensity by RANS. Furthermore, the volume fraction of the austenitic phase in the dual phase mock specimen was also successfully evaluated by fitting the diffraction pattern using a Rietveld code. Consequently, RANS has been proved to be capable for neutron engineering diffraction aiming for the easy access measurement of the texture and the amount of retained austenite.

1. Introduction

Neutron diffraction is known as the only method which can measure internal strains inside crystalline materials non-destructively [1,2]. This is also a useful technique to quantitatively measure microstructural factors of metals [3] such as microstrain, texture and dislocation density in bulk-average, which are strongly related to its mechanical properties such as materials strength and deformability. Quantitative evaluation of these microscopic parameters may bring advanced understanding of the mechanical behavior of metals by investigating the relationship with macroscopic behavior. Neutron engineering diffraction has been well established to evaluate such parameters for a design of advanced metals with outstanding properties and for development of the industrial products with high reliability and low environmental impact. Development of advanced high strength steels is one of the most critical issues to meet above social demands in a variety of industrial fields such as an automotive industry, which urgently requires novel technologies to measure the texture evolution and the amount of retained austenite. Such materials engineering studies using neutron diffraction typically require a neutron engineering diffractometer [2,4–10] installed in large experiment facilities such as a research reactor and a large accelerator to obtain high flux neutrons. Therefore, we have only few chances in a year to carry out challenging neutron experiments using their facilities because of highly competition of the beam

---

[*] Corresponding author.
E-mail address: yoshimasa.ikeda@riken.jp (Y. Ikeda).

http://dx.doi.org/10.1016/j.nima.2016.06.127

time. In contrast, an important demand from industrial users is a lot of opportunities to be able to use neutrons anywhere at any time like commercial X-ray equipment available at their own locations.

A compact accelerator-based neutron source (CANS) [11], based on low-energy accelerators and low-energy charged-particle neutron-producing reactions, might be the only way to meet above demand from industry. We have already had seven accelerator-driven compact neutron sources in Japan, and some more plans to build another compact neutron sources are still running [12]. They are expected to be utilized for component developments [13] and materials engineering researches [14–17], as well as medical irradiation [18]. The compact neutron sources for materials engineering are especially designed to be applied for transmission imaging, small angle scattering and reflectometry [14–17], only for cases that speed of measurement is minor consideration. However, nobody considers using CANS for the neutron diffraction experiment because of its low neutron flux. Nonetheless, nobody has been demonstrated actually so far that CANS is really not applicable for neutron diffraction. If we can evaluate microstructural factors easily by neutron diffraction as well as neutron imaging and small angle scattering using a compact neutron source at our own laboratory, it is expected to achieve efficient developments of industrial products and advanced metals more economically. In this study, therefore, the neutron diffraction experiments are carried out using Riken Accelerator-driven Compact Neutron Source (RANS) [16,17], to clarify a capability of the compact neutron source for neutron engineering diffraction aiming for easy access measurement of the texture and the amount of retained austenite. Furthermore, we discuss the optimum optical system, especially in terms of the moderation time, to realize the high resolution neutron diffraction.

2. Accelerator-driven compact neutron source RANS

Fig. 1 shows an entire view of RANS, which consists of a proton accelerator, a neutron production target and instruments for the neutron experiment. Fig. 2 shows a cross-sectional drawing of a shield box around the target. Protons are accelerated with a proton liniac to 7 MeV, and injected to a beryllium (Be) target with 0.3 mm in thickness [19]. A backing of the Be target is a vanadium (V) plate with 4 mm in thickness, cooling with water flowing in a titanium (Ti) cavity with 5 mm in thickness. Fig. 3 shows a neutron spectrum at the camera box, which was simulated by PHITS code [20]. Neutrons with the maximum energy of about 5 MeV are generated via the Be (p,n) reaction, and the flux-peak appears around 1 MeV. The fast neutrons are moderated in a polyethylene moderator with 40 mm in thickness, 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. A graphite blocks are placed in a box

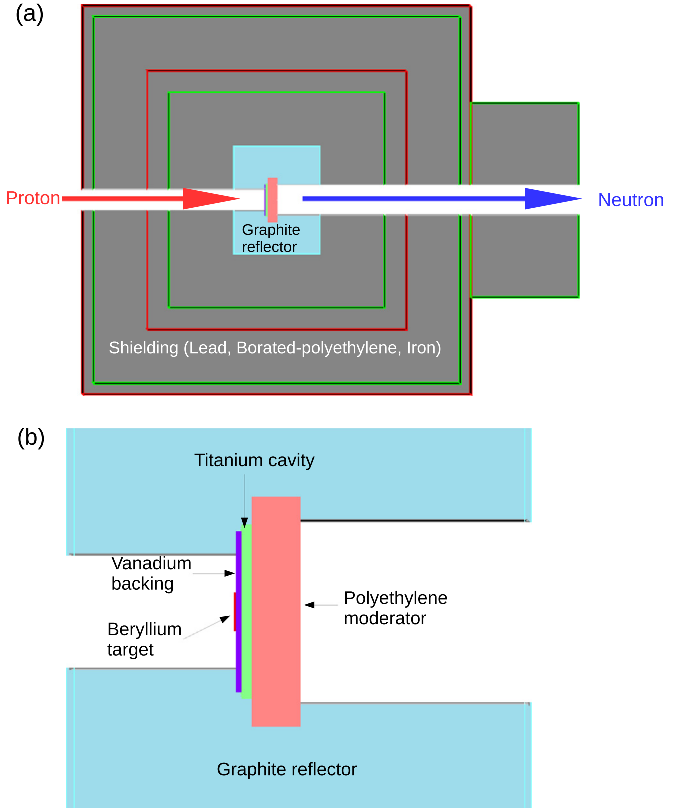

Fig. 2. (a) A schematic of the cross-sectional view of the target station of RANS, and (b) an enlarged detail drawing around the beryllium target.

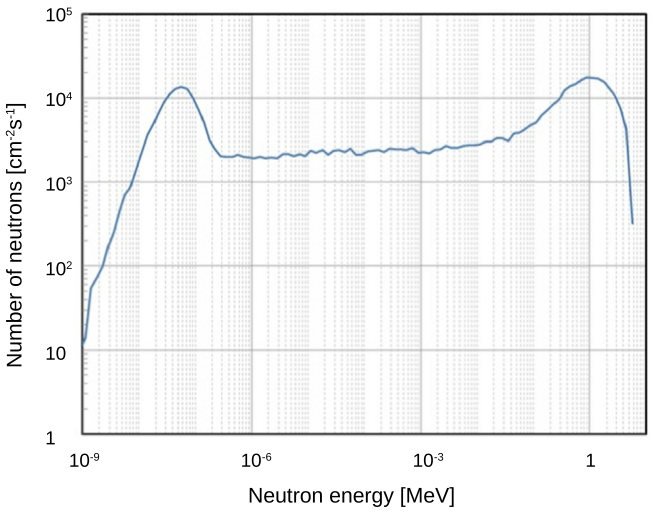

Fig. 3. Energy spectrum of RANS at 5 m far away from moderator simulated by PHITS code.

Fig. 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.