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Neutron diffraction measurements of thermal neutron attenuation coefficients in borated stainless steels

Wanchuck Woo[a],*, Hobyung Chae[a], In-Whan Oh[a], Hyungsup Kim[a], Myung-Kook Moon[a], Eunjoo Shin[a], Jongyul Kim[a], Taejoo Kim[a], Jae Hoon Jang[b], Sang Woo Song[c]
[a] *Neutron Science Division, Korea Atomic Energy Research Institute, Daejeon, 34057, Republic of Korea*
[b] *Department of Materials Analysis, Korea Institute of Materials Science, Changwon, 51508, Republic of Korea*
[c] *Department of Joining Technology, Korea Institute of Materials Science, Changwon, 51508, Republic of Korea*
**Corresponding author: chuckwoo@kaeri.re.kr*

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1. Introduction

Borated stainless steels (BSS) has been known as an effective thermal neutron shielding alloy for the storage racks and transportation casks in spent nuclear fuel applications [1]. Although the thermal neutron absorption and shielding capacity has been known to be proportional to the boron contents, it difficult to include the high percentage of boron in the stainless steel because of its solubility limit more than 2.25 wt. % [2]. The ASTM standard A887 registered eight types of the BSS according to the boron contents of 0.2 - 2.25 wt.% [3].

One of the key issue is the absorption and shielding capability of the thermal neutrons in the BSS. It relies on the very high absorption cross-section (3840 barn) of ^{10}B isotopes contained ~ 20% in the natural boron (B). Thus, the relationship between boron content (w_B, wt. %) and thermal neutron attenuation coefficient (μ_a, cm^{-1}) was examined in BSS.

2. Methods and Results

2.1 Neutron diffraction measurements

Neutron diffraction experiment was applied for the determination of the μ_a in the BSS. Residual Stress Instrument (RSI) was used at HANARO reactor in KAERI [4]. The diffractometers provide the mono chromatic neutron beam having the neutron wavelength (λ) of 1.46 Å (38.4 meV). The μ_a was measured by the ratio of the neutron diffraction peak intensity transmitted by the BSS to the initial intensity without transmission.

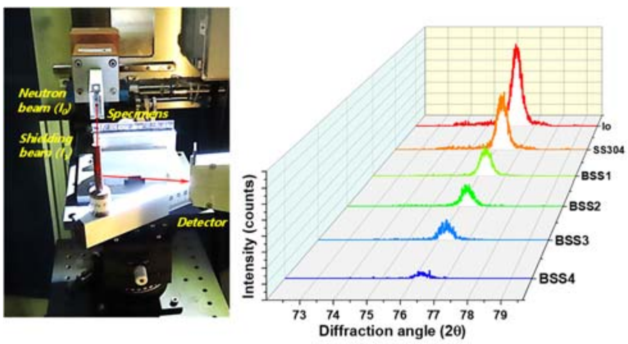

Fig. 1. Neutron diffraction measurements by transmitted beam from the BSS and diffraction peak in initial, stainless, and BSS specimens.

2.2 Comparison between experiments and calculations

The results of experiments and calculation were compared; (i) for experiments, the linear attenuation coefficient (μ_a, cm^{-1}) is defined as the fraction of the neutron beam that absorbed per unit thickness of the specimen [1]. The μ_a can be determined by transmission experiments by following the Lambert-Beer law;

$$\mu_a = (-1/t)\ln(\Phi_t/\Phi_o)$$

where t is the sample thickness (cm), Φ_t is the variation of the neutron flux after transmission (n·cm^{-2}·s^{-1}) and Φ_o is the incident neutron flux.

On the other hand, theoretically it is known that the μa is the sum (Σ) of the macroscopic cross-section (Σ, cm^{-1}) caused by coherent scattering (Σ^{coh}), incoherent scattering (Σ^{incoh}), and absorption (Σ^{abs}), respectively, as bellow;

$$\mu_a = \Sigma = \Sigma^{coh} + \Sigma^{incoh} + \Sigma^{abs}$$

(ii) for calculation in an alloy having more than one element, the macroscopic cross-section ($\overline{\Sigma}$, cm^{-1}) was calculated by the sum (***Σ***) of the weighted contribution from each element as below;

$$\overline{\Sigma} = \boldsymbol{\Sigma}\sigma_i \cdot \left(\frac{\omega_i N_A \overline{\rho}}{M_i}\right)$$

where σ_i is the microscopic cross-section (barn, 10^{-24} cm^2), ω_i is the weight fraction of an element i, $\overline{\rho}$ is the mean alloy density (g/cm^3), and M_i is the atomic weight of an element i (g/mole) [5].

3. Conclusions

The results provides the relationship between the μ_a and w_B as below;

$$\mu_a\,(\text{cm}^{-1}) = 2.404 \cdot w_B\,(\text{wt. \%}) + 1.224 \text{ at } 1.46\text{ Å}$$

Overall it is comparable between the experimental and calculation results. The reason of the proportional relationship between the μ_a (cm^{-1}) and the boron content (w_B, wt. %) and it has been attributed to the high areal density of ^{10}B isotopes, which has a large neutron microscopic cross-section [6].

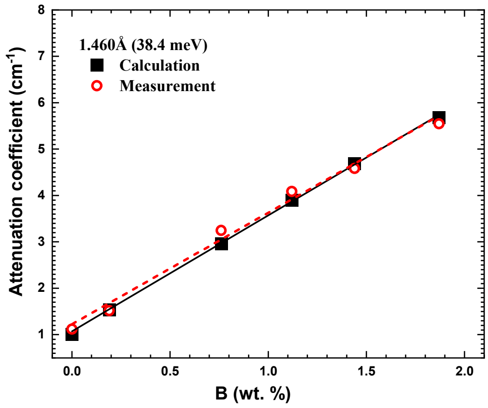

Fig. 2. Comparison of the attenuation coefficient (μ_a, cm^{-1}) measured by neutron experiments and calculations based on the cross-section data [5].

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