Neutron transmission measurement of neutron shielding material for storage and shipping cask of spent nuclear fuel

Jongyul Kim [a*], Jae Hoon Jang [b], Tae-Ho Lee [b], Hirotaka Sato[c], TaeJoo Kim [a], Baek-Seok Seong [a], Wan Chuck Woo [a]
[a]*Quantum Beam Science Division, Korea Atomic Energy Research Institute, Daejeon*
[b]*Ferrous Alloy Department, Korea Institute of Materials Science, Changwon*
[c] *Faculty of Engineering, Hokkaido University, Japan*
[*]*Corresponding author: kjongyul@kaeri.re.kr*

1. Introduction

Neutron shielding material is important for storage and shipping cask of spent nuclear fuel, and the demand for neutron shielding materials is steadily increasing because there is not enough space in the temporary storage anymore [1]. However, Neutron shielding materials depend entirely on imports. Some research group of Korea have studied and developed Fe based neutron shielding materials for localization [2, 3]. After fabrication of neutron shielding materials, neutron transmission and macroscopic cross section of prepared samples were measured to evaluate neutron shielding ability using neutron imaging.

2. Methods and Results

In this section, samples of neutron shielding material, neutron imaging experiment, and the relationship of neutron transmission and macroscopic cross section are described.

2.1 Fe based neutron shielding materials

The samples of Fe based neutron shielding materials were fabricated and prepared by ferrous alloy research group of Korea Institute of Materials Science (KIMS). Strong thermal neutron absorbers such as Gd, Li, and B should be included in Fe based neutron shielding materials to increase neutron shielding ability. The prepared samples are including 0.2~2.5 wt. % boron, and the composition of samples are shown in Table 1.

Table I: The composition of prepared samples

Sample	Composition (wt %)								
(Stainless Steel)	C	Si	Mn	Cr	Ni	B	Al	Mo	Co
Fe1(B1)	0.056	0.25	1.35	17.7	11.9	0.19	0.024	-	-
Fe2(B2)	0.066	0.26	1.55	18.4	12.3	0.78	0.035	-	-
Fe3(B3)	0.073	0.28	1.57	18.3	12.4	1.76	0.039	-	-
Fe4(S1)	0.056	0.25	1.35	17.7	11.9	0.19	0.024	-	-
Fe5(S2)	0.066	0.26	1.55	18.4	12.3	0.78	0.035	-	-
Fe6(S3)	0.073	0.28	1.57	18.3	12.4	1.76	0.039	-	-
Fe7(B304)	0.11	0.44	1.56	17.68	11.9	2.43	-	-	-
Fe8(B316)	0.13	0.49	1.58	17.73	13.85	2.37	-	2.44	-
Fe9(B4Co)	0.11	0.43	1.57	17.47	11.64	2.49	-	-	4

Fe4, Fe5, and Fe 6 are heat treated samples of Fe1, Fe2, and Fe3.

2.2 Neutron imaging experiment

Neutron imaging experiment is performed to measure neutron transmission intensity of prepared samples using Hokkaido University Neutron Source (HUNS). HUNS is linear accelerator based pulsed neutron source [4]. The photo of prepared samples for neutron imaging experiment is shown in Fig. 1. The neutron transmission image of samples is shown in Fig. 2.

Fig. 1. The photo of prepared samples for neutron imaging experiment

Fig. 2. The neutron transmission image of samples

2.3 Neutron transmission spectrum

Neutron transmission ratios of prepared samples are obtained in accordance with neutron wavelength as shown in Fig. 3. When pulsed neutron source is used, it is possible to obtain neutron transmission spectrum using time of flight detector. It is confirmed that neutron transmission ratio increases as boron wt. % in sample decrease. The heat treatment of sample does not affect neutron shielding ability when sample Fe1, Fe2, and Fe3 are compared with sample Fe4, F5, and Fe6.

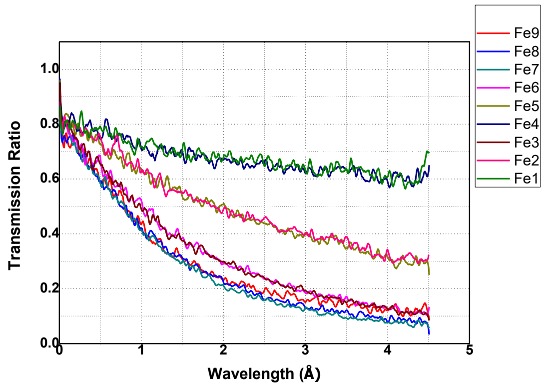

Fig. 3. Neutron transmission ratio of prepared samples in accordance with neutron wavelength

2.4 Thermal neutron macroscopic cross section

Thermal neutron macroscopic cross section can be obtained using the following relationship:

$$I_t = I_o e^{(-\sigma t * n * d)}$$

$$= I_o e^{(-\Sigma t * d)}$$

where I_t is the thermal neutron transmission intensity, I_o is the incident intensity of the thermal neutron, σ t is the microscopic cross section, n is the atom density of the neutron shielding material, d is the thickness of the neutron absorbing material, Σ t is the macroscopic cross section, defined as the probability per unit path length that a neutron will interact as it moves about in a medium [5]. Results of thermal neutron (2.0 Å, 20 meV) macroscopic cross section of prepared samples are shown in Table II.

Table II: thermal neutron (2.0 Å, 20 meV) macroscopic cross section of prepared samples

Sample #	Thickness (cm)	Transmission ratio	Macroscopic cross section Σ_t (cm^{-1})
Fe9(B4Co)	0.3	0.227	4.95
Fe8(B316)	0.3	0.225	4.99
Fe7(B304)	0.3	0.216	5.11
Fe6(S3)	0.3	0.302	4.01
Fe5(S2)	0.3	0.511	2.24
Fe4(S1)	0.3	0.675	1.31
Fe3(B3)	0.3	0.295	4.08
Fe2(B2)	0.3	0.482	2.43
Fe1(B1)	0.3	0.678	1.30

Neutron shielding ability of prepared samples is evaluated quantitatively by obtaining thermal neutron macroscopic cross section. It is confirmed that the values of thermal neutron macroscopic cross section of sample Fe7, Fe8, and Fe9 are about 5 and higher than other samples.

3. Conclusions

Neutron imaging experiment was performed to obtain neutron transmission intensity of prepared samples. Neutron shielding ability of neutron shielding materials was evaluated by measuring neutron transmission ratio and thermal neutron macroscopic cross section. It is confirmed that the higher the boron content, the better the ability to shield thermal neutrons. Therefore, it is necessary to increase boron content while maintaining material properties and stability.

REFERENCES

[1] IAEA Series, Costing of Nuclear Fuel Storage, IAEA-NF-T-3.5, Vienna, 2006.
[2] Y. Choi, Y. Baik, B. M. Moon, D. S. Sohn, Corrosion and Wear Properties of Cold Rolled 0.087% Gd Lean Duplex Stainless Steels for Neutron Absorbing Material, Nuclear Engineering and Technology, vol. 48, (2016), pp. 164-168.
[3] Y. Baik, Y. Choi, B. M. Moon, D. S. Sohn, S. G. Bogdanov, A. N. Pirogov, Effect of Gadolinium Addition on the Corrosion, Wear, and Neutron Absorbing Behaviors of Duplex Stainless Steel Sheet, The Physics of Metals and Metallography, vol. 116(11), (2015), pp. 1135-1142.
[4] H. Sato, T. Sasaki, T. Moriya, H. Ishikawa, T. Kamiyama, and M. Furusaka, High wavelength-resolution Bragg-edge/dip transmission imaging instrument with a supermirror guide-tube coupled to a decoupled thermalneutron moderator at Hokkaido University Neutron Source, Physica B: Condensed Matter, 551(15), (2018), 452-459.
[5] J-S. Choi, J.C. Farmer, C. Lee, L. Fischer, M. Boussoufi, B. Liu, and H. Egbert, Materials Science & Technology 2007 Conference and Exhibition, UCRL-COMF-232503 (2007).