Neutron shielding characteristics of nano-B_2O_3 dispersed Poly Vinyl Alcohol

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1. Introduction

Neutron is sometimes beneficiary to human beings while they are unwanted for most cases same as the other radiations such as gamma, beta, and alpha, etc. do. Shielding for neutrons therefore is extremely important to keep the radiation environment safe. Especially, it is critical to absorb (or shield) neutrons generated from the spent fuel in a container/storage, nuclear reactor, and cyclotron, etc. In this regard, light materials containing neutron absorbers such as borated-polymers are very useful to shield neutrons in those radiation environments.

This investigation is focused on the development of borated polymer-based materials whose neutron shielding efficiency is greatly enhanced by using nano-sized boron compounds. Boron is well known as a thermal neutron absorber due to its large thermal neutron absorption cross-section (σ_{th} = 760 b, b = 10^{-24} cm^2). Although absorption of neutrons in the medium is mainly dependent on the boron atomic weight concentration, we firstly observed the size of boron particles also has an important role in neutron shielding. Mean free path of neutrons colliding with the smaller particles dispersed in the medium might be decreased when it is compared to the larger particles at the same atomic weight concentration [1-3]. This means that the neutron shielding efficiency of a polymer mixed with the smaller boron compounds is higher than that of a polymer mixed with the larger boron compounds at the same atomic weight boron concentration.

2. Methods and Results

To verify the enhancement of neutron shielding efficiency dependent on the size of the boron compound, micro- and nano-boron compound containing composites were prepared and material properties were analyzed. Neutron shielding tests were also performed.

2.1 Materials Preparation

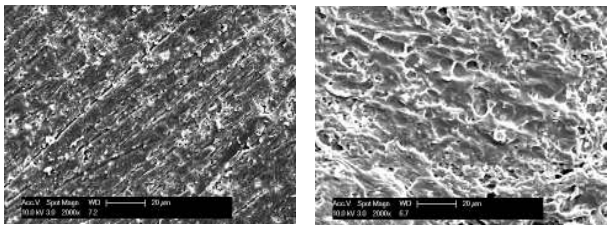
As a neutron absorbing boron compound, B_2O_3 (High Purity Chemicals, Inc., Japan) was used while PVA (Poly Vinyl Alcohol, Aldrich) was used as a polymer base. Nano-B_2O_3 powder was produced by using a MA (Mechanical Activation) process. Initial micro-B_2O_3 powder was grounded by a high energy ball mill under the various experimental conditions including metal ball to powder ratio, jar rpm and duration of jar revolution, etc. Micro-sized (untreated) and nano-sized (MA treated) B_2O_3 powders were mixed homogeneously with PVA powder under the given atomic boron concentrations. Mixed powders were then hot pressed at the preset pressures making various thicknesses of the borated-polymer samples. Table 1 shows the physical and geometrical characteristics of each sample.

Table 1. Characteristics of micro- and nano-B_2O_3 dispersed PVA samples.

Properties	**Micro-B_2O_3**	**Nano-B_2O_3**	**PVA**
Size Distribution	200μ m ~ 300μ m	0.1μ m ~ 1μ m	~ 200μ m
Atomic Weight Concentration of Boron	1.0% & 2.5% in PVA		
Sample Thickness	0.2cm, 0.5cm, 0.75cm, 1.0cm		

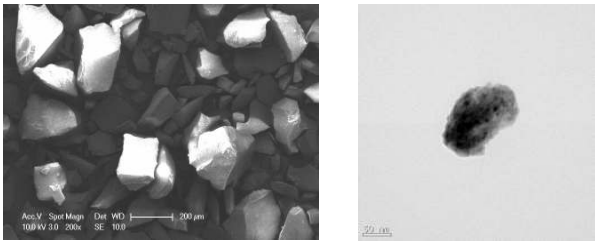
2.2 SEM and TEM Analyses

Degree of dispersion of the boron compounds and the average particle sizes in the prepared samples were observed by the various analytic means including SEM (Scanning Electron Microscope) and TEM (Transmitted Electron Microscope), etc. Images in Fig. 1 and Fig. 2 show that the distribution of the boron particles is homogeneous in the medium, and also the average sizes of the particles are (a) 200 ~ 300μ m for a untreated sample and (b) 0.1μ m ~ 1μ m for a MA treated sample.



(a) micro-B_2O_3 PVA (b) nano-B_2O_3 PVA

Fig. 1 SEM images showing distribution of the particles in the PVA medium (a) micro-B_2O_3 dispersed PVA. (b) nano-B_2O_3 dispersed PVA



(a) (b)

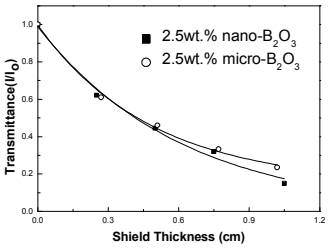
Fig.2. TEM images of the borated polymer with (a) micro-B_2O_3 dispersed PVA and (b) nano-B_2O_3 dispersed PVA.

2.3 Neutron Shielding Tests

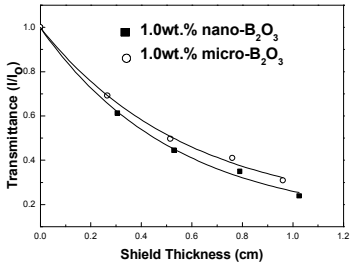
Neutron shielding efficiencies of each borated-PVA samples were tested by measuring the ratios of the incident neutron flux to the shield transmitted neutron flux. Samples with the various thicknesses were irradiated by the thermal neutrons guided from the FCD (Four Circle Diffractometer) beam port installed at HANARO reactor. Neutron wavelength and incident flux were ~ 0.997Å and ~ $6.6x10^5$ n/cm^2/sec at the sample position, respectively. A H-3 gases proportional counter whose effective detection length is 8.8cm was situated at ~ 2m away from the sample. Samples were installed at the outlet of the beam port. The duration of each measurement was 10sec and 10 measurements for each sample were averaged.

2.4 Particle Size Effects on Neutron Shielding

Thermal neutrons are absorbed (or moderated) by the relationship $I(t) = I_o e^{\Sigma_{th} t}$, where I_o is the incident neutron beam flux, t is the thickness of the medium, and Σ_{th} is the macroscopic thermal neutron absorption cross-section expressed by $\Sigma_{th}(cm^{-1}) = n\sigma_{th}$, where n is the number density and σ_{th} is the microscopic thermal neutron absorption cross-section of atomic boron. Usually Σ_{th} can be determined by the experimental measurements. Fig. 3 shows the thermal neutron transmittance in (a) 2.5wt% and (b) 1.0wt% boron dispersed PVA medium. Macroscopic thermal neutron absorption cross-sections are increased about 15% for nano-B_2O_3 PVA compared to the micro-B_2O_3 PVA. Macroscopic thermal neutron absorption cross-sections obtained from Fig. 3 are shown in Table 2.



(a)



(b)

Fig. 3. Neutron shielding efficiencies for micro-B_2O_3 and nano-B_2O_3 dispersed PVA with (a) 2.5 boron wt% (b) 1.0 boron wt%.

Table 2. Macroscopic thermal neutron absorption cross-sections (Σ_{th}) measured for micro- and nano-B_2O_3 dispersed PVA.

Atomic boron weight concentration	**$\Sigma_{th}(cm^{-1})$, micro-B_2O_3**	**$\Sigma_{th}(cm^{-1})$, nano-B_2O_3**
2.5 wt%	1.49	1.72
1.0 wt%	1.25	1.42

3. Discussions

In this investigation, we observed the enhanced neutron shielding efficiency when the smaller sized boron compounds were dispersed in the polymer matrix. Mean free path (l) of the particles, $l \sim (n\sigma_s)^{-1}$, where n is the number density, $\sigma_s = \pi d^2$ is the scattering cross-section, and d is the diameter of the particle, is assumed to be decreased by the factor of 10^3 when the diameter of the particle is 10^3 times decreased. Further research nevertheless is necessary to verify this phenomenon by applying to the other materials and also using a theoretical evaluation such as MCNP simulation in depth. In general, mechanical and thermal properties as well as electrical and optical properties are enhanced by using nano-particles containing polymer [4]. Consequently, it is promising to develop the efficient neutron shielding materials with less boron content or thinner shields maintaining neutron shielding capacity while the material properties are greatly enhanced.

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