Simulation of radiation properties of Al(wt. %30 B_4C) and polyethylene-7%B composites used for shield of thermal neutrons

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Abstract

The aim of this study is to compare the neutron absorption properties of composites made of Al(wt.%30 B_4C), fabricated in this study through hot pressing process, with borated polyethylene (PE+%7B). Powders of Aluminum and B_4C were milled by a planetary mill machine. Then mixed powder was sintered by hot pressing machine at different temperatures. The experimental test was carried out through Neutron radiography. The simulation was performed by MCNP code. The results showed that at equal neutron attenuation intensities, Al(wt.%30 B_4C) composite is equivalent to the PE+%7B with half of the thickness. It was found that the composite with uniform distribution of boron carbide particles and higher density has a higher neutron shield property. At low thicknesses, the simulation and practical results confirmed each other and the Al-30% B_4C composite has a better neutron-protective behavior than polyethylene-7%B.

Keywords: Neutron Sheilding, hot pressing process, Monte-Carlo simulation, Neutron Radiography

Introduction

In order to protection against neutrons, ranged from fast to thermal neutrons, proper shielding must be able to slow down the speed of the neutrons by elastic scattering interaction and thus attenuate them through neutrn capture interaction.

B_4C has been used as a neutron absorber composition in nuclear industries, such as dry storage of spent fuel complexes, due to the large thermal neutron absorption cross-section of ^{10}B [1,2]. Boron carbide is a ceramic material with excellent physical properties [3], thermal stability, low density, and high hardness [4,5]. In practice, Al-B_4C composites work at elevated temperatures (250-350 °C) [6]. Al-B_4C composites have been commercially used as a basket of nuclear casks due to their light weight, high thermal conductivity, and high neutron absorbing power [7]–[9]. Due to the neutron protection mechanism in this study, the neutron transmission through neutron absorbers made of Al-30 wt. % B4C and polyethylene-7% B composite is compared.

Experimental

Al-B_4C composite preparation

The process of Al-B_4C composite fabrication consists of milling, forming and sintering. First, the raw material, Al (99.99%, 20 µm, Fluka, Belgic) and B_4C (99.99%, 45 µm, Russia) were mixed. Argon atmosphere was used for preventing of oxidation aluminium during milling. The tungsten carbide balls and cups were used. Then, 5 gr of the composite powder was loaded in a graphite die (10 mm diameter) to form the hot pressed samples, and was sintered at 550, 600, 650°C in a hot-press chamber. Temperature and pressure was changed in a controlled manner, until completing the sintering process. Finally, the applied pressure was removed and the samples were slowly cooled. 5 samples was fabricated with characteristic shown in Table 1.

Borated Polyethylene(PE+%7B)

Polyethylene wighted by %7 Boron (PE+%7B) as an effective and common material is used for neutron shielding [10]. In this study, it was shaped as a step wedge in order to comparing the results of fabricated composites with it.

Neutron radiography test

Neutron Radiography (NR) test of the samples was done by neutron digital imaging facility at Tehran Research Reactor. The neutron flux was about $4.1 * 10^6$ $n.cm^{-2}.s^{-1}$. Results was processed by ImageJ software.

MonteCarlo simulation

Composite samples ware modeled by MCNP code according to the flux of the neutron beam at NR. neutron transmission values were estimeted by calculating the ratio of the neutron flux before and after incident with the samples.

Table 1. Bulk density and thickness of the Al(wt. %30 B_4C) composites

Number of sample	Thickness (mm)	Bulk density (gr/cm^3)
1	2.5	2.2919
2	4.5	2.4844
3	5	2.2919
4	7	2.5011

5	8	2.4844

Results and discussion

Experimental results

Calculations of mean gray value versus thickness of the samples were shown in Figure1. At low thickness (lower than about 1 cm), Al(wt.%30 B_4C) composites attenuate neutrons more effective than polyethylene(wt. %7B) material. Gradually, by increasing the thickness, neutron attenuation properties of Al(wt.%30 B_4C) approaches to that of polyethylene(wt. %7B).

At equal neutron transmission intensities (which are proportional to mean gray values), the Al(wt. 30%B_4C) composite are equal to PE+%7B composite with half of thickness. It is also observed that the composite with highly uniform distribution of boron carbide particles and higher density has a higher neutron shield property. For example, the 650°C sample has the best neutron attenuation properties.

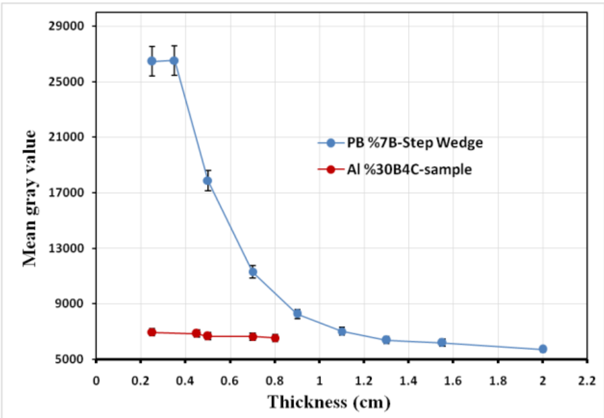

Figure 1. neutron flux attenuation percent of the Al(wt.%30 B_4C) composite and PE+%7B wedges in different thicknesses (<4%).

Results of simulation

B_4C has been used as a neutron absorber composition in nuclear industries. Composites made of Al(wt.%30 B_4C) was fabricated in this article and their neutron absorption properties was studied through experimental NR and MCNP simulation. Simulation and practical results confirmed each other at low thicknesses and Al-B_4C composites have better neutron absorption property (Figure 2).

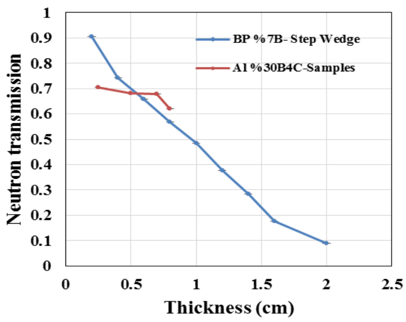

Figure 2. Theneutron transmission value of PE+%7B step wedge and Al(wt.%30 B_4C) composites , (<0.5%)

According to Figure 3, at thicknesses less than 0.5 cm, the protective effect of Al-30 % B_4C composite is better than polyethylene-7%B in the front of the neutrons. As it can be seen, the composite at the same low thickness reduces the neutron dose by about 20 to 25% and polyethylene by about 10%. Then by further increasing of the thickness of the samples, protective effect of composite and polyethylene are same that it can be seen clearly in the Figure 2.

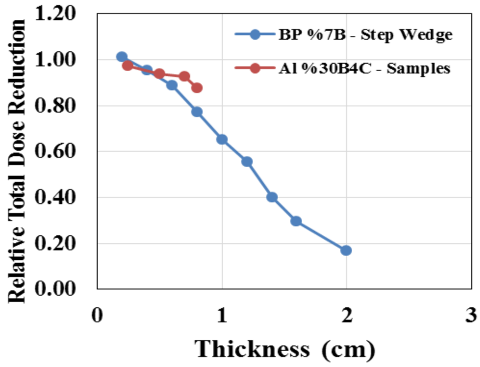

Figure 3. The relative total dose reduction versus the thickness of the polyethylene-7%B and Al-30% B_4C composite.

The dose rate of delayed gammas (emitted gammas which produce through activation process after the end of neutron irradiation) is also calculated for two samples of 0.25 and 0.8 cm thicknesses for polyethylene-7%B and Al-30 % B_4C materials. The results are shown in Table 2. The results show that delayed gamma of polyethylene-7%B is lower than Al-30 % B_4C composite.

Table 2. The delayed gamma dose rate for 0.2 and 0.8 cm of thicknesses for Al-30% B_4C composite and polyethylene wedge

	Thickness (cm)	D(mSv/h)	Relative Error
Polyethylene-7%B	0.2	6.82E-15	0.18
	0.8	1.11E-13	0.05
Al-30 % B_4C	0.25	2.46E-05	0.09
	0.8	2.73E-04	0.03

Conclusions

By increasing the thicknesses of the samples, the amount of relative total dose reduction of the shields will be increased and protective effect of the samples increase.

Also at all thicknesses, Al-30% B_4C composite and polyethylene-7%B have neglect effect on reducing the gamma dose.

Simulation and practical results confirmed eachother up to 0.5 cm of the thickness.

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