Design and fabrication of high density borated polyethylene nanocomposites as a neutron shield

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► ***Technical note***

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ABSTRACT

Background: Polyethylene composites including boron can be used as an effective neutron shield. Our investigation focuses on manufacturing borated polyethylene nano-composite. The purpose of this study is to design a radiation shield for use in both neutron and gamma fields. ***Materials and Methods:*** Borated polyethylene shields containing 2%, and 5% weight percentage of Boron nano-particles were constructed and their neutron attenuation was compared with pure polyethylene. Polycarbonate films were used to find the attenuation of Am-Be neutrons after passing the shields. Mechanical properties of the shields were finally compared. ***Results:*** Mean (± SD) number of α tracks induced by neutrons passing through the shields, were found to be $1.0488\times10^3\pm128.98$, $289.56\pm10^3\times1.1972$ and $1.5340\times10^3\pm206.52$ for polyethylene with 5% by weight, polyethylene with 2% by weight boron nano-particles, and pure polyethylene, respectively. The neutron spectrum after each shield was also obtained by MCNP4C Monte Carlo simulations. On the other hand, borated polyethylene nano-composites showed higher tensile strength compared to that of pure polyethylene. Attenuation of neutrons measured in experiments and the result of MCNP simulation were in good agreement. ***Conclusion:*** A statistically significant difference was found between neutron attenuation by borated polyethylene nanocomposite made of 5% by weight boron and pure polyethylene. However, the difference between borated polyethylene nano-composite with 5% weight and 2% wt boron was not statistically significant.

Keywords: *Nano-composites, neutron shield, borated polyethylene, MCNP.*

INTRODUCTION

External radiation shielding is one of the main radiation protection principles for keeping the working condition safe (1). Shielding design for neutron and gamma radiations are very important, because any shield which attenuates these two rays will be effective for attenuating most of the other nuclear radiations (2, 3). Neutron has no charge and has no interaction with electric fields of electrons or nuclei (2). The main processes by which neutron interacts with material, are non-elastic, and elastic scattering, absorption and neutron activation (4).

Low atomic number materials, i.e. paraffin, water and polyethylene can be used effectively in slowing-down fast neutrons. Materials with high neutron absorption cross sections can also be effectively used in absorption of thermal neutrons. In addition to neutron attenuation properties, low cost, mechanical strength, stability, and easy handling are among the most important factors that must be taken into consideration (5).

Different investigations have been performed on constructing protective materials containing nano-particles in radiation fields [6-9]. The radiation attenuation properties of the shields depend highly on size and concentration of nano -particles [7, 8, 10].

Nowadays, using polymeric composite materials as neutron shield has increased significantly. Several investigators have proposed construction of multi-purpose shields by adding metal structures or synthesis mineral to these composites, so that they can be used in photon fields [11-13]. The polyethylene composites containing boron can be used as effective neutron shields, because of the high neutron absorption cross section of boron [14].

Nano-composites [15] have shown better mechanical performances than micro-size ones; however, the basic challenge in nano-composite production is mono dispersion of nano-particles, into the polymer matrix, as these small particles have high tendencies to agglomerate [16]. The aim of this study was to compare the neutron attenuation, and mechanical properties of pure polyethylene with borated polyethylene.

MATERIALS AND METHODS

Polyethylene is a simple, light, inexpensive and flexible polymer. In this study polyethylene provided by Imam Khomeini chemical company, was used to fabricate borated polyethylene nano-composites. Nano-composite borated polyethylene shields were made with two different concentrations, i.e. 2, and 5% weight of boron carbide (B_4C) were prepared by melt mixing in the internal mixer. B_4C is a low density semiconductor with high melting point, high resistance to chemical attack and high neutron absorption cross section. The properties of materials used in constructing borated polyethylyne are shown in table 1. Cubical slabs of pure polyethylene, and borated polyethylene shields were constructed with dimension of 20 × 20 ×1 cm. Then the scanning electron microscope (SEM) images of the nanocomposite slabs were prepared.

To measure the neutron attenuation of pure and borated HDBPE, they were exposed for 48 hours to neutron beam of ^{241}Am-Be (1.97×10^7n/s) source at a distance of 68 cm in the gamma, radon and neutron calibration laboratory of atomic energy organization of Iran. To measure the neutrons passing through the shield, the polycarbonate film with boron filter were used as a passive dosimeter. Fast neutron detection by using heavy recoils and (n, α) reactions occurred mostly within the track detector. First, the neutron measurements using polycarbonate films were performed without the samples in place and the average of these readings was taken as I_0 (the incoming intensity). Then, the measurements were performed four times for each shield. The average values of the four measurements are considered as the transmitted intensity I.

The MCNP4C Mont Carlo code was used to obtain the neutron spectra after pure polyethylene, and borated polyethylene. Cubical slabs of pure and borated polyethylene with dimension of 20cm×20cm×1cm were simulated at the distance of 68cm from the Am-Be source. Tally type F4 was used to obtain the neutron spectra, after the cubical shields.

The mechanical properties of tensile strength (TS) and elongation at break (EB) were measured on dumbbell specimens according to ASTM D638 in a SANTAM DBBP-500 MODEL machine at test speed of 50mm/min [17, 18].

Table 1. properties of materials used in making neutron shields.

Polyethylene	
Country	Iran
MRF	190)c/2. 16kg)
density	0.967-0.963g/cm^3
Color	milky
B_4C	
Country	Russia
density	2.5g/cm^3
Melting point	^{0} 2400 <)c
thermal extension coefficient	$^{6-}$10 ×5.73k^{-1}
purity	%99
Average particle size	50nm(APS)
specific surface	75m^2/g (SSA>)
color	Dark gray

RESULTS

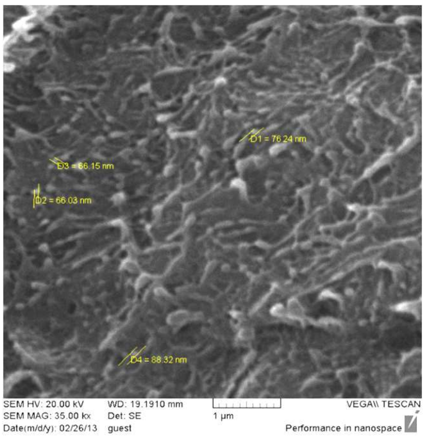
Figures 1a and 1b show the electronic microscope (SEM) images of the nano composites. The figures show fine dispersion of nano-B_4C particles in polyethylene (figure 2). Stress-strain curves obtained in a SANTAM DBBP-500 MODEL machine were used to determine tensile strength (TS) and elongation at break (EB) for borated polyethylene nano-composite and pure polyethylene. The results of mechanical tests TS and EB for borated polyethylene nano-composite and pure polyethylene are compared in table 2. According to the results, boron carbide shows improvement over polyethylene at TS and the values increased with increasing volume percent, while the EB of Borated polyethylene nano-composites was less than pure polyethylene.

In this project attenuation of the borated polyethylene nano-composite and pure polyethylene shields were compared using polycarbonate film dosimetry. Table 3 shows the results of attenuation by measuring the neutron intensity after passing through a layer with 1cm thickness of pure polyethylene, borated polyethylene shields containing 2%, and 5% weight percentage of Boron nano-parcles, i.e. 2wt%, and 5wt%. Figure 2 shows the result of mean number of α tracks induced by neutrons passing through a 1-cm layer of borated polyethylene nano-composites (2wt% and 5wt%) and pure polyethylene. The finding of this study showed a statistically significant difference between mean ± SD number of α tracks induced by neutrons passed through the borated polyethylene nanocomposite included 5wt% boron and pure polyethylene, while the difference between borated polyethylene nano-composite with 5wt% and 2wt% boron was not significant.

Figure 3, compares the Am-Be neutron spectrum with the neutron spectrum after pure, and borated polyethylene obtained by the MCNP simulations. According to figure 3, the average neutron energy after pure and borated polyethylene was reduced compared to the initial neutrons emitted from the Am-Be source.

DISCUSSION

The findings of this study showed that the highest attenuation comes from a borated polyethylene nanocomposite which includes 5% wt boron. The attenuation of 2% wt borated polyethylene nanocomposite was similar to pure polyethylene. Based on MCNP simulation the highest attenuation comes from a borated polyethylene nanocomposite made of 5% wt boron. It was also shown that to have an effective attenuation for fast neutron beams, a thick shield (12cm) is needed. On the other hand, this study showed that boron carbide nano -composites provide higher tensile strengths than the pure polyethylene.



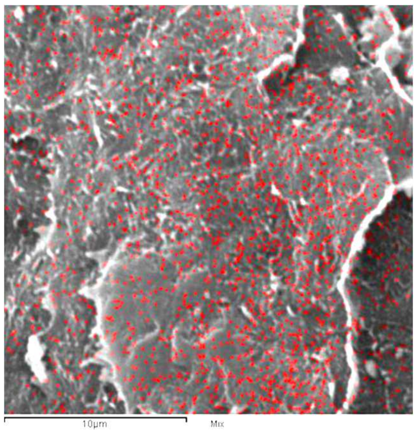


Figure 1. SEM images of boron carbide nano-composites, a) the magnified image to show the size of nanoparticles with 1 µm magnification, b) homogeneous distribution of nano particles (red points) with 10 µm magnification.

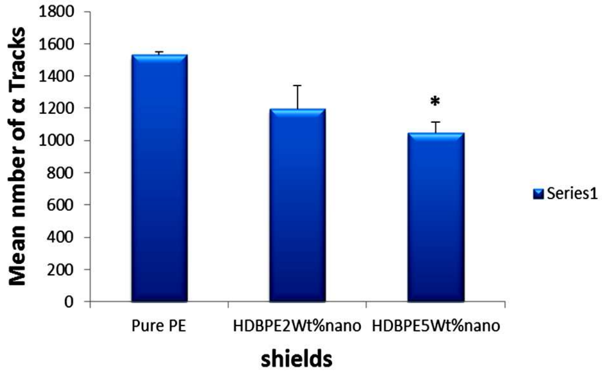


Figure 2. Mean number of α tracks in different shields. Error bar shows the Standard Error.

*Mean± SD of pure polyethylene and borated polyethylene nanocomposite there are significant differences.

Table 2. The results of mechanical tests of the shields.

Composites	Tensile strength (MPa)	Elongation at break
Pure PE	21.9	%232
HDBPE 5wt%	26.9	%4
HDBPE 2wt%	26.3	%4.6

Table 3. The measured values of attenuation (I/I_0) for neutron.

Shield	Pure PE	HDBPE 2Wt%	HDBPE 5Wt%
I/I_0	0.85	0.67	0.58

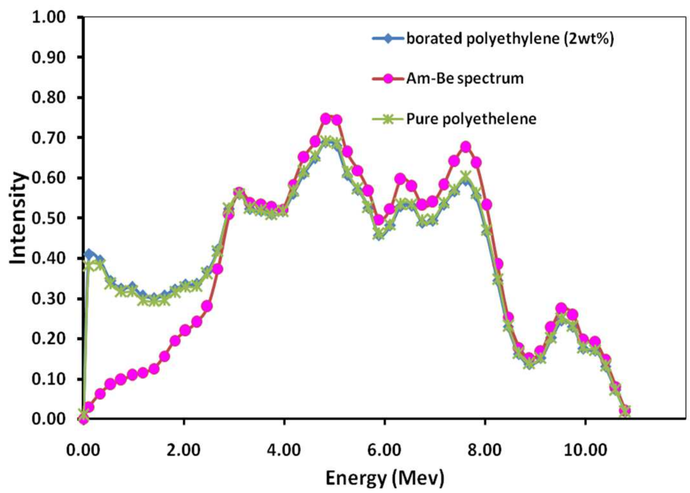


Figure 3. Comparison of the spectrum after pure and borated polyethylene with the initial Am-Be neutron spectrum.

The results of our previous investigations on photon shielding showed that using nano-sized materials in radiation shielding can provide better attenuation results only in very specific circumstances (such a limited range of photon energy, or a limited concentration of nanomaterials in the matrix). It is worth mentioning that according to the results obtained in our previous study the smaller size of nano-structured WO3 particles could guarantee a better radiation shielding property only for low energy photons [13].

The above mentioned limitation in the use of nano-sized shielding materials are also in line with those reported by Botelho *et al.* who compared the X-ray transmission through microsized and nanosized materials. These researchers showed that the radiation beams generated at 26 and 30 kVps were more attenuated by the nanostructured CuO plates by a factor of at least 14%. However, they confirmed that for high energy beams (X-ray generated at 60 and 102 kVps), radiation transmission through the microsized and nanosized CuO was almost the same [19]. These findings are also in line with the results obtained by Künzel and Okuno in 2011 [20] who showed that nanostructured materials absorb more radiation than the microstructured samples for both material concentrations in the resin. It is worth mentioning that they had used CuO microparticles with a mean particle size of about 56 μm while the size of nanoparticles were in the range 10 – 100 nm. They had separately incorporated these particles into a polymeric resin in proportions of 5% and 30% relative to the resin mass.

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***Conflict of interest**: Declared none.*

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