Polymer Nanocomposite Based Multi-layer Neutron Shields

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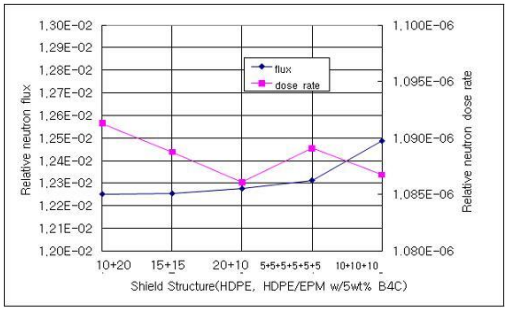
1. Introduction

It is important to shield radiations generated from the various radiation sources including nuclear reactors, transportation and storage systems for the radioactive wastes, accelerator, hospital, and defense systems etc. In this regard, development of efficient, light and durable radiation shielding materials has been an issue for many years [1,2]. High energy neutrons (fast neutrons) can be thermalized by colliding with the light elements such as hydrogen, and thermalized neutrons can be efficiently captured by neutron absorbers such as boron, lithium, or gadolinium, etc. To shield neutrons, it is common to use hydrogen rich polymer based shields containing thermal neutron absorbers. It is also necessary to shield secondary gamma radiations produced from nuclear reaction of neutrons with various materials. Hence, high density elements such as Fe, Pb, or W might be dispersed in the polymer base as well as with neutron absorbers at the same time. However, the particle sizes of these elements are in the range of several tens and hundreds micrometers causing possible leakage of radiation. To enhance radiation shielding efficiency, it is useful to use ultrafine particles to increase collision probability of radiation with the particles. Furthermore, it is theoretically possible to enhance radiation shielding efficiency by using the multi-layer structured shields whose constituents are different for each layer depending upon the shielding purpose under the same overall density. Also, material properties of the nanocomposites can be enhanced compared to the normal composites. This investigation is focused on characterization of the nanocomposite based multi-layer structured radiation shields compared to the conventional radiation shields.

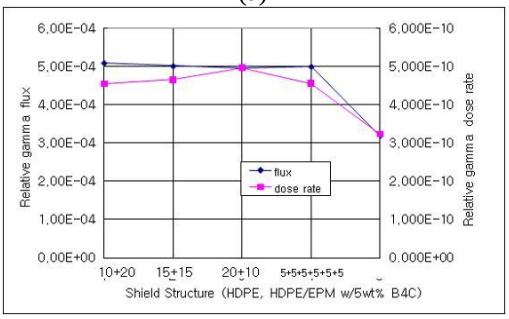
2. Methods and Results

2.1 MCNP Simulations for Multi-Layer Shields

When high energy neutrons enter into hydrogenous shielding material, they have the highest probability to collide with hydrogen atoms and scatter with random directions losing their energy. This means that they travel with random motion and become thermal neutrons, i.e. direction of scattered neutrons are arbitrary. Hence, it is possible to minimize the shielding thickness or filler concentration in the shield by using multi-layer structure. Especially, reduction of secondary gamma radiation by using this type of structure is expected. Figure 1(a) and (b) show the results of MCNP simulation based on the multi-layer structured polymeric shields in terms of dose and flux. X-axis indicates order of the layers in mm, i.e. first layer is pure HDPE (high density polyethylene), second one is 5wt% B_4C dispersed $HDPE_{20}EPM(\text{ethylene propylene monomer})_{80}$ composite, third one is pure HDPE, fourth one is same with the second and so on. As shown in Figure 1, dose and flux for neutrons are varied by the different combinations of the shield layers same as those for secondary gamma radiations. As expected, neutron dose depends strongly on the hydrogen density while flux is more dependent on layer combinations. For secondary gammas, strong dependency of layer combinations on the dose and flux are observed.



(a)

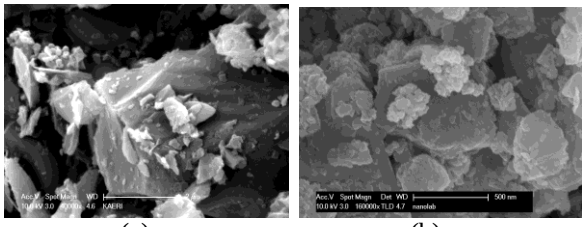


(b)

Figure 1. Shiled layer combinations dependent Dose and flux variations for (a) neutrons and (b) secondary gamma radiaitons

2.2 Materials Preparation and Mechanical Properties

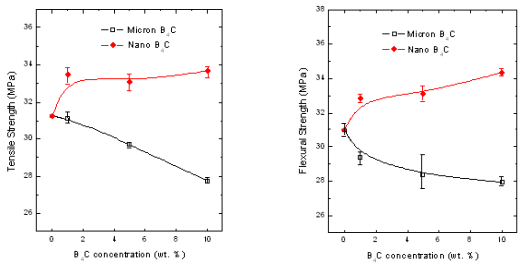
Based on the MCNP simulations, multi-layer structured shields were prepared by using micro- and nano-B_4C dispersed HDPE/EPM composites. Prior to fabricate the composites, nano-B_4C powder was produced by ball milling micro-B_4C (~10 μm, Kojundo Chem., Japan) powder. Figure 2 shows the SEM images of micro- and nano-B_4C particles used in the experiment. As shown in the images, average size of the nano-B4C powder was ~200 nm.



(a) (b)

Figure 2. SEM images of the (a) micro-B_4C particles and (b) nano-B_4C particles

Raw micro-B_4C and produced nano-B_4C powders were then mixed with pure HDPE and also $HDPE_{20}EPM_{80}$ hybrid matrix by using twin screw extruder. Prior to mixing, the surfaces of both powders were coated by polyethylene to enhance the degree of dispersion in the polymer matrix. Thickness of each composite was set at 3 mm. To evaluate mechanical properties of micro- and nano-composites, dumbbell shaped specimens for tensile and flexural strength tests were prepared based on ASTM D638-08 specifications. Figure 3 shows enhanced tensile strength and flexural strength for nano-B_4C dispersed HDPE composite compared to micro-B_4C dispersed HDPE composites. This might be due to better particle surface adhesion with polymer base for nano-B_4C.



(a) (b)

Figure 3. (a) Tensile and (b) flexural strengths for micro-B_4C and nano-B_4C dispersed HDPE composites

Multi-layered shields were fabricated by hot pressing the stack of each pure and composite as shown in Figure 4. Top layer (white) is pure HDPE/EPM hybrid matrix, and 5wt% B_4C (black) and PbO (yellow) dispersed HDPE/EPM composites respectively.

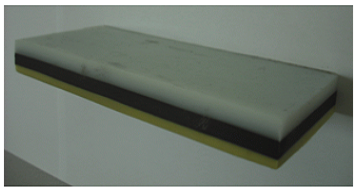


Figure 4. Multi-layer structured neutron shield (sample)

2.3 Neutron Shielding Tests

Neutron shielding tests for prepared multi-layered neutron shields were performed by using Cf-252 source (medium neutron energy ~ 1.4 MeV). Table 1 shows the results of the neutron shielding tests. Neutron shields used in this experiment constitute with 15 mm pure $HDPE_{20}EPM_{80}$ hybrid matrix and micro- and nano-B_4C dispersed $HDPE_{20}EPM_{80}$ composite whose thickness was 3 mm. As shown in the table, nano-B_4C dispersed composite have higher neutron shielding efficiency.

Table 1. Neutron shielding tests for multi-layer structured micro- and nano-B_4C dispersed $HDPE_{20}EPM_{80}$ composites

Shields	count/s	CPS	I/I_0	Σ_{th}
HDPE/EPM (I_0)	17.7	12.93	-	-
Corrected	4.76			
HDPE/EPM + Micro-B_4C (I)	17.47	12.89	0.997	0.010
Corrected	4.58			
HDPE/EPM + Nano-B_4C (I)	16.07	11.51	0.890	0.388
Corrected	4.56			

3. Conclusions

Enhancement of neutron shielding efficiency of the multi-layer structured neutron shield based on nano-B_4C dispersed $HDEP_{20}EPM_{80}$ composite was observed by MCNP simulation and direct measurements. Also, it was clearly shown that the mechanical properties of the nano-B_4C/HDPE composites are higher than those for micro-B_4C/HDPE composites. This type of neutron shields might be applicable in the various nuclear, medical, and defense systems.

Acknowledgement

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REFERENCES

[1] Y. Sakrai, A. Sasaki, and T. Kobayashi, Development of neutron shielding material using metathesis-polymer matrix, Nuc. Inst. Meth. Phys. Res. A, **522**, 455 2004.
[2] J. Jung, J. Kim, Y.R. Uhm, J.-K. Jeon, S. Lee, H.M. Lee, C.K. Rhee, Preparations and thermal properties of micro- and nano-BN dispersed HDPE composites, Thermochimica Acta, **499**, 8, 2010.