Special issue of the 3rd International Conference on Computational and Experimental Science and Engineering (ICCESEN 2016)

Production of Barite and Boroncarbide Doped Radiation Shielding Polymer Composite Panels

O. Evcin[a], A. Evcin[a,*], N.Ç. Bezir[b], İ. Akkurt[b], K. Günoğlu[b] and B. Ersoy[c]

[a]Afyon Kocatepe University, Department of Materials Science and Engineering, 03200 Afyonkarahisar, Turkey

[b]Süleyman Demirel University, Department of Physics, Faculty of Art and Science, 32260 Isparta, Turkey

[c]Afyon Kocatepe University Department of Mining Engineering, 03200 Afyonkarahisar, Turkey

Developments in nuclear technology in the last century have lead to the use of radiation in different areas of human activity. These are not just the energetics but also food, agriculture, medicine, industry and science. Thus, radiation has become an inevitable phenomenon in our lives. Since we cannot isolate radiation from our life, the radiation protection methods should be available. As alternatives to conventional radiation prevention methods, such as lead and heavy concrete shielding, more functional materials need to become the focus of research. The development of the least harmful to the environment, easily applicable, flexible radiation shields has become very important. In this study, silicon matrix composite panels, doped with different ratios of barite and boron carbide, were produced and characterized by optical and scanning electron microscopy (SEM). Gamma and neutron radiation shielding properties of these materials were investigated. The results have been compared with the lead as the standard shielding material.

DOI: 10.12693/APhysPolA.132.1145

PACS/topics: 87.50.Gi, 94.10.Gb, 28.41.Te, 78.66.Sq, 29.30.Kv

1. Introduction

Radiation is energy in the form of waves or particles. It travels through space and may be able to penetrate various materials in its path. Radiation waves vary in frequency and wavelength and may be described according to their position in the electromagnetic spectrum. The electromagnetic spectrum includes X- and gamma-rays, ultraviolet, visible light, infrared, and radiofrequencies [1, 2].

X, α, β and γ rays, which are known as ionizing radiation can become important threats for living organisms. These rays may cause biological, chemical and physical changes in living organisms [3]. Exposure to gamma rays can occur because of nuclear applications, such as reactors, nuclear research and medical diagnostic centers, and nuclear waste storage sites. It is essential to reduce the intensity of external radiation to the standard acceptable level, and hence the attenuation property of a shielding material is of great importance [4].

Radiation is encountered in the natural environment and is produced by modern technology. The usage areas of radiation, are mainly the medical and the industrial fields. Most of them have the potential for both, beneficial and harmful effects [3, 5].

There are several types of particulate radiation:

- Beta particles (electrical charge of -1),
- Alpha particles (electrical charge of $+2$),
- Positrons (electrical charge of $+1$),
- Neutrons (no electric charge) [2].

Many forms of radiation cause environmental impacts and come from different sources. Protection from these radiation is based on applying three fundamental strategies: [2, 6]

- Minimize the time spent near radiation sources,
- Maximize the distance from radiation sources,
- Use shielding of appropriate type [2].

Radiation shielding is very important in places, where radiation is used. The radioactive area and the vicinity areas are separated by traditional lead or concrete bricks in order to protect the working environment from the harmful effects of radiation [3]. With the increasing use of gamma-ray isotopes in industry, medicine and agriculture, it is an important task to develop better radiation shielding materials. Recently glass and polymer composite materials are one of the possible alternatives to concrete, because of their density and properties [7].

The linear attenuation coefficient (μ, cm^{-1}) can be expressed as the probability of interaction of the radiation with a material per unit path length:

$$I = I_0\,\mathrm{e}^{-\mu x}, \tag{1}$$

where I is the intensity of radioactive beam after passing through an absorber, I_0 is the initial intensity of the beam, without the absorber, μ is linear attenuation coefficient, e is base of natural logarithms and x is thickness of the absorber sample [2, 6, 8].

There are many alternative materials, which can be used directly, or as additives, for these purposes. Heavy

*corresponding author; e-mail: evcin@aku.edu.tr

elements, such as lead, tungsten, bismuth, are materials to be used in radiation shielding, Presence of high atomic munber atoms, such as Fe, Ba, and Pb in concrete composition increases photoneutron production within concrete and the highest value has been reported for Pb-based high density concretes [9–11].

Many different types of materials, which contain light and heavy elements, have been used in building construction for years. The boron atom has a great importance for neutron absorption and interactions in composites. Barite ($BaSO_4$) is an alternative material, which can be used directly, or as an additive, for this purposes. Another point about popularity of concrete is its hydrogen content for neutron shielding. The importance of hydrogen in concrete, in terms of radiation (particularly neutrons) shielding process, is known [9, 11, 12]. There are many studies on concretes containing different non-Pb materials.

Bashter (1997) studied radiation shielding characteristics of different types of concretes and good agreement between the theoretically calculated and practically measured values was discussed [13]. Singh et al. (2004) and Akkurt et al. (2004) investigated building materials, as radiation shielding materials for gamma radiation, both theoretically, as well as practically [14, 15]. Kumar and Reddy (1997) and Yilmaz et al. (2011) discussed atomic numbers of some concretes [16, 17]. Kharita et al. (2008) and Akkurt et al. (2010) investigated radiation shielding properties of concretes, containing barites [9, 17–19]. Effect of addition of boron to different concretes has been studied by many investigations. Boron carbide (B_4C) is an advanced ceramic material, used for neutron absorption in nuclear applications [11, 17, 20, 21]. Boron carbide in the rubber is studied in the nuclear energy field. Celli et al. studied boron carbide in epoxy resin, elastomer [21, 22].

In this work, the radiation shielding properties of composite panels are tested against gamma-neutron radiation, obtained from radioactive sources.

2. Materials and methods

Barite was collected from Sarkikaragac-Isparta region at south of the Sultandagları region, where the purity of barite ore is 90% $BaSO_4$. Boron carbide powder was obtained from a local producer Bor Optik, Nevşehir in Turkey. Composite matrix component is silicon RTV2. RTV2 is a two-component silicone elastomer. RTV2 silicone mold offers a wide range of applications for users.

2.1. Preparation of panels

Firstly mold was cleaned. To suppress the adhesion of polymeric composites to the mold, wax was spread homogeneously over the mold surface. Flexible silicone polymer has been chosen for polymeric composite panels, intended for radiation protection.

Firstly the main component of polymer was poured into a plastic container, according to preparation prescriptions of RTV2 silicone. Then 5 weight % of catalytic component were added and mixed thoroughly to achieve a homogeneous mixture. Then the mixture was poured into the mold in a continuous manner, from a single point. Mixture would reach the final consistency and hardness after about 24 hours, and could be removed from the mold. In this study up to 20%, by weight, of boron carbide and barite were added into the polymer mixture in order to investigate the effects. Same operations have been applied to doped polymers.

2.2. Characterization of samples

2.2.1. XRD analysis

XRD measurements of the samples were performed for crystal phase identification, using XRD 6000-Shimadzu with CuK_α radiation (λ = 1.5418 Å) at 40 kV and 100 mA. The crystal structure of the materials has been determined by the analysis of diffraction patterns and comparison of these with particular standard patterns of compounds.

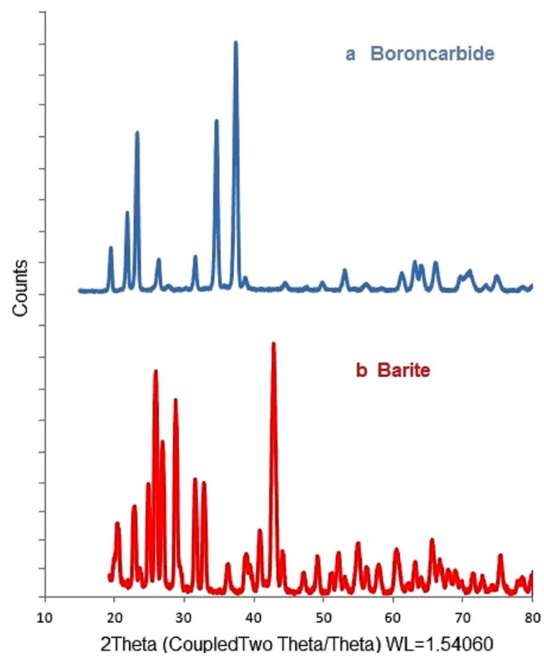

Fig. 1. XRD patterns of powders.

The boron carbide and barite identifications and the patterns, obtained in the XRD analysis, are shown in Fig. 1. Figure 1 shows that patterns of pure boron carbide and barite powders are present in the XRD patterns, similar to the results from literature [23, 24].

2.2.2. Optical microscopy

Microstructural features of cross section of panels were characterized using optical microscope (Leica DM2500 P) at the Department of Geological Engineering of Afyon Kocatepe University.

Figure 2 shows the optical microscope images of samples. It is seen that barite particles and solid boron carbide particles are embedded into the polymer matrix.

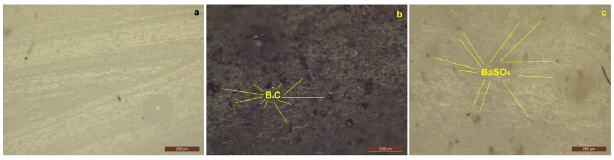

Fig. 2. Microstructure of polymer composite panels (a) polymer, (b) B_4C in composite and (c) $BaSO_4$ in composite.

2.2.3. Scanning electron microscopy

The morphology of panels was determined from SEM (Leo 1200 LV) images of the samples.

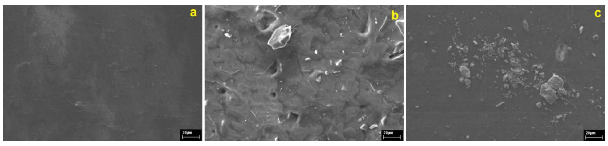

Fig. 3. SEM images of polymer composite panels (a) polymer, (b) B_4C in composite and (c) $BaSO_4$ in composite.

As seen in Fig. 3, solid powders, present inside the polymer, have been distributed heterogeneously. Such distribution has occurred due to the difference in densities of the polymer and the boron carbide/barite powders.

2.2.4. Radiation tests

Experimental and theoretical study of three produced panels has been carried out. Experimental study was performed at Gamma Spectroscopy Lab, at Department of Physics, Faculty of Art and Science, Isparta. The photon attenuation coefficients μ of the samples were measured at the photon energies of 662, 1173 and 1332 keV, obtained from ^{137}Cs and ^{60}Co γ-ray sources, respectively.

Boron carbide- and barite-added polymer composite materials can provide efficient γ-ray shielding, when compared to ordinary polymer. The obtained results are summarized in Table I and are also displayed in Fig. 4, where they are compared with the results of calculations.

TABLE I

Gamma ray linear attenuation coefficients, measured at several gamma energies.

Sample	Gamma ray linear attenuation coefficients [cm^{-1}] 662 keV	1173 keV	1332 keV
Undoped polymer	0.242134829	0.188857606	0.175595102
Boron carbide	0.241738737	0.17979522	0.171897171
Barite	0.197027918	0.14174109	0.129880174

It is clearly seen from this figure that the linear attenuation coefficient is higher in undoped composite panel than in other panels. It can be seen from this figure that the attenuation coefficients strongly depend on the photon energy. The value of the measured linear attenuation coefficient decreases with increasing photon energy.

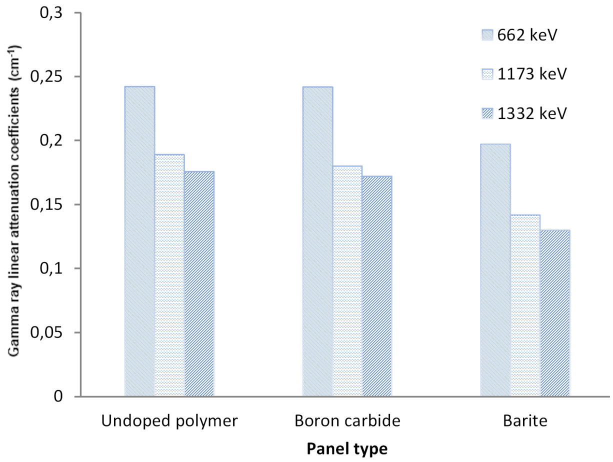

Fig. 4. The linear attenuation coefficients of composite panels, as functions of photon energies.

This is due to the different interaction mechanism between photons and the atomic medium. In the comparison of polymer panels it can be seen that the highest value of attenuation coefficient has been found for undoped polymer and the lowest value for barite-doped polymer panel. Barite-doped polymer panel can provide more efficient γ-ray shielding, when compared to others [4, 25].

The radiation shielding properties of different types of panels have been also tested against neutron rays and the results are given in Table II and Fig. 5.

TABLE II

Measured neutron attenuation coefficients.

Sample	Neutron attenuation coefficients [cm^{-1}]
Undoped polymer	0.407655004
Boron carbide	1.144656227
Barite	0.920989253

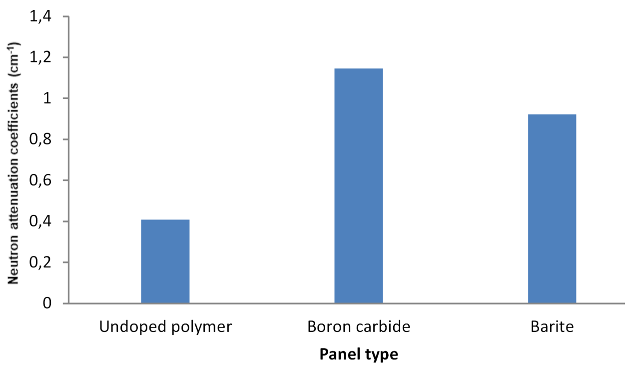

Fig. 5. Neutron absorption coefficients of the investigated panels.

As seen in Table II and Fig. 5, composite panels proved to be more efficient for attenuation of the flux of thermal neutrons.

3. Conclusions

In the current study the effect of addition of boron carbide and barite minerals to polymers and some radiation shielding properties and engineering outcomes of these materials were studied.

The results of characterization analysis of boron carbide and barite powders were compared with the results from literature. As it can be observed from the XRD results, all of the peaks from our analysis coincide with the characteristic peaks of boron carbide and barite.

Experimental measurements have been carried out to study the attenuation properties of polymer composites with respect to thermal neutrons and gamma rays.

The photon attenuation coefficients increase linearly with the increasing barite proportion in the composite panel.

It is known that boron carbide is a good thermal neutron absorber material. Therefore, we recommend that boron carbide should be added to polymers as a promising shielding material for the fast neutron applications.

References

[1] H. Dickson, *Radiation and Risk: Expert Perspectives*, Health Physics Society, USA 2013.

[2] *Radiation Safety Handbook*, Northwestern University, 2010.

[3] S. Akbulut, A. Sehhatigdiri, H. Eroglu, S. Celik, *Radiat. Phys. Chem.* **117**, 88 (2015).

[4] E.-S.A. Waly, M.A. Bourham, *Ann. Nucl. Energy* **85**, 306 (2015).

[5] H. Matis, *Radiation in Environment, Nuclear Science-A Guide to the Nuclear Science Wall Chart*, California 2003.

[6] I. Akkurt, K. Gunoglu, *AIP Conf. Proc.* **1476**, 241 (2012).

[7] C. Bootjomchai, J. Laopaiboon, C. Yenchai, R. Laopaiboon, *Radiat. Phys. Chem.* **81**, 785 (2012).

[8] I. Akkurt, H.Akyildirim, B. Mavi, S. Kilincarslan, C. Basyigit, *Radiat. Measurem.* **45**, 827 (2010).

[9] J.P. McCaffrey, F. Tessier, H. Shen, *Med. Phys.* **39**, 4537 (2012).

[10] B. Oto, N. Yildiz, F. Akdemir, E. Kavaz, *Progr. Nucl. Energy* **85**, 391 (2015).

[11] A. Mesbahi, G. Alizadeh, G. Seyed-Oskoee, A.-A. Azarpeyvand, *Ann. Nucl. Energy* **51**, 107 (2013).

[12] O. Gencel, A. Bozkurt, E. Kam, T. Korkut, *Ann. Nucl. Energy* **38**, 2719 (2011).

[13] I.I. Bashter, *Ann. Nucl. Energy* **24**, 1389 (1997).

[14] C. Singh, T. Singh, A. Kumar, G.S. Mudahar, *Ann. Nucl. Energy* **31**, 1199 (2004).

[15] I. Akkurt, S. Kilincarslan, C. Basyigit, *Ann. Nucl. Energy* **31**, 577 (2004).

[16] T.K. Kumar, K.V. Reddy, *Radiat. Phys. Chem.* **50**, 545 (1997).

[17] I. Akkurt, H. Akyildirim, B. Mavi, S. Kilincarslan, C. Basyigit, *Ann. Nucl. Energy* **37**, 910 (2010).

[18] M.H. Kharita, M. Takeyeddin, M. Alnassar, S. Yousef, *Prog. Nucl. Energy* **50**, 33 (2008).

[19] I. Akkurt, H. Akyildirim, B. Mavi, S. Kilincarslan, C. Basyigit, *Prog. Nucl. Energy* **52**, 620 (2010).

[20] D. Sariyer, R. Kucer, N. Kucer, *Procedia – Social Behavioral Sci.* **195**, 1752 (2015).

[21] A. Seyhun Kipcak, P. Gurses, E.M. Derun, N. Tugrul, S. Piskin, *Energy Conv. Manag.* **72**, 39 (2013).

[22] M. Celli, F. Grazzia, M. Zoppia, *Nucl. Instrum. Methods A* **565**, 861 (2006).

[23] F. Farzaneh, F. Golestanifard, M.Sh. Sheikhaleslami, A.A. Nourbakhsh, *Ceram. Int.* **41**, 13658 (2015).

[24] Jiaguo Yu, Shengwei Liu, Bei Cheng, *J. Crystal Growth* **275**, 572 (2005).

[25] I. Akkurt, B. Mavi, H. Akyildirim, S. Kilincarslan, C. Basyigit, in: *6th Int. Conf. Balkan Physical Union*, American Institute of Physics, 2007, p. 533.