Radiation Physics and Chemistry 97 (2014) 354–359

Contents lists available at ScienceDirect

Radiation Physics and Chemistry

journal homepage: www.elsevier.com/locate/radphyschem

An investigation on gamma attenuation behaviour of titanium diboride reinforced boron carbide–silicon carbide composites

Bulent Buyuk*, A. Beril Tugrul

Istanbul Technical University, Energy Institute, Nuclear Researches Division, Ayazaga Campus, 34469 Istanbul, Turkey

HIGHLIGHTS

- Linear and mass attenuation coefficients of B_4C–SiC composites were investigated.
- Reinforcing titanium diboride causes higher linear attenuation coefficients.
- Decreasing titanium diboride particle size increases linear and mass attenuation coefficients.
- Nano particle sized samples much closer to the theoretical results than micro sized ones.

ARTICLE INFO

Article history:
Received 17 January 2013
Accepted 22 July 2013
Available online 7 August 2013

Keywords:
Gamma attenuation
Particle size effect
TiB_2 reinforcing
Boron carbide–silicon carbide composites
Cs-137
Co-60

ABSTRACT

In this study, titanium diboride (TiB_2) reinforced boron carbide–silicon carbide composites were investigated against Cs-137 and Co-60 gamma radioisotope sources. The composite materials include 70% boron carbide (B_4C) and 30% silicon carbide (SiC) by volume. Titanium diboride was reinforced to boron carbide–silicon carbide composites as additive 2% and 4% by volume. Average particle sizes were 3.851 μm and 170 nm for titanium diboride which were reinforced to the boron carbide silicon carbide composites. In the experiments the gamma transmission technique was used to investigate the gamma attenuation properties of the composite materials. Linear and mass attenuation coefficients of the samples were determined. Theoretical mass attenuation coefficients were calculated from XCOM computer code. The experimental results and theoretical results were compared and evaluated with each other. It could be said that increasing the titanium diboride ratio causes higher linear attenuation values against Cs-137 and Co-60 gamma radioisotope sources. In addition decreasing the titanium diboride particle size also increases the linear and mass attenuation properties of the titanium diboride reinforced boron carbide–silicon carbide composites.

1. Introduction

Boron carbide (B_4C) is one of the most important materials for nuclear applications, which is mainly used in reactors as a control rod and in neutron shielding systems as a shielding material (Buyuk et al., 2012a, 2012b). Boron carbide has high hardness, wear resistance, chemical stability and thermal neutron cross section value properties (Thevenot, 1990; Akarsu et al., 2010). However, there are some disadvantages of boron carbide such as high sintering temperatures, low mechanical strength, and low fracture toughness. Some additives such as silicon carbide, titanium diboride, tungsten boride and elemental boron are used to increase the density of boron carbide (Akarsu et al., 2010; Buyuk et al., 2012a, 2012b). One of these additives, silicon carbide (SiC), is a candidate material for blankets in future nuclear fusion power plants (Sawabe et al., 2009; Taylor et al., 2001). One of the other additives, titanium diboride (TiB_2), is also a candidate material for control rods for high temperature nuclear reactors (Subramanian et al., 2006) and hard environment applications (Fard and Baharvandi, 2008).

In this study titanium diboride reinforced boron carbide–silicon carbide composites were investigated. Their gamma attenuation behaviors were performed against Cs-137 and Co-60 gamma radioisotopes. Gamma transmission technique was used for the measurements. Experimental geometry and experimental set up were prepared carefully. Scattering effect was minimized. All the measurements were implemented at least three times in the same geometry. The results of the experiments were interpreted and compared with each other. Therefore, the effects of titanium diboride reinforcing ratios and particle sizes on gamma attenuation properties of the titanium diboride reinforced boron carbide–silicon carbide composites were determined using Cs-137 and Co-60 gamma radioisotope sources.

---

* Corresponding author. Tel.: +90 2122853894; fax: +90 2122853884.
E-mail address: buyukbu@itu.edu.tr (B. Buyuk).

0969-806X/$ - see front matter © 2013 Elsevier Ltd. All rights reserved.
http://dx.doi.org/10.1016/j.radphyschem.2013.07.025

2. Experiments and materials

2.1. Gamma transmission technique

Gamma transmission technique is based on penetrating gamma rays through materials (Földiak, 1986). The gamma source and the detector are placed on opposite sides of the material on the same axis. The detector counts the gamma ray intensity which comes from the source (Földiak, 1986; Buyuk and Tugrul, 2009; Kurtoglu and Tugrul, 2003). First, initial baseline intensity in the absence of any material is counted. Then, for each material, the material is placed between the gamma source and the detector, and the gamma ray intensity is counted. The results of the intensity for each material are then compared with the initial baseline intensity. The schematic view of gamma transmission technique could be seen on Fig. 1 (Akarsu et al., 2010).

The absorption of radiation at any small thickness dx is proportional with the incident intensity of radiation.

$$dI/ = -\mu dx \tag{1}$$

Where I is incident radiation intensity and μ is linear absorption coefficient of material at specific γ-ray. Therefore, the radiation intensity which is passing through the material is calculated by following equation (Buyuk and Tugrul, 2009):

$$I = I_o e^{-\mu x} \tag{2}$$

where

I: Transmitted intensity.
I_o: Incident intensity.
μ: Linear attenuation coefficient at specific γ-ray.
x: Material thickness.

Mass attenuation coefficient (μ_m) of the material is calculated by the following formula (Buyuk et al., 2012a, 2012b):

$$\mu_m = \frac{\mu}{\rho} \tag{3}$$

where, ρ is the density of the material. The mass attenuation coefficients' errors were calculated with following relation (Kurtoglu and Tugrul, 2003):

$$\delta(\mu/\rho)_{\mathrm{exp}} = \left(\frac{-1}{x\rho}\right)\left[\left(\frac{\delta I_0}{I_0} - \frac{\delta I}{I}\right) + x\delta\rho \ln\frac{I}{I_0}\right] \tag{4}$$

where $\delta(\mu/\rho)_{exp}$ is the error of mass attenuation coefficient, δI_0 and δI are the errors of radiation intensities, and $\delta\rho$ is the density error.

In the experiments Cs-137 and Co-60 radioisotopes were used as gamma radioisotope sources. Cs-137 has a single gamma peak at 0.662 MeV and 30.1 years half life (Földiak, 1986). Cs-137 gamma radioisotope has 8.89 μCi activity (Buyuk and Tugrul, 2009). Co-60 has two gamma peaks at 1.17 MeV and 1.33 MeV which has assumed mean energy at 1.25 MeV (Croft, 2006). Co-60 includes pair production events because its gamma peaks are over 1.02 MeV. Co-60 has 5.23 years half life and 14 μCi activity. PM1401K model scintillation detector and Multi Channel Analyzer (MCA) combined system was used to detect gamma ray intensity.

Experimental geometry and set up were prepared carefully. The distances between detector and gamma sources are measured as 10 cm and 14 cm for Cs-137 and Co-60, respectively. Lead blocks were used for radiation shielding and collimating of gamma rays. The collimator has a 7 mm diameter hole. The scattering effect was minimized by using thin hole collimator.

At first background radiation was measured. Then the initial gamma intensity was measured without any material (I_0). Finally for

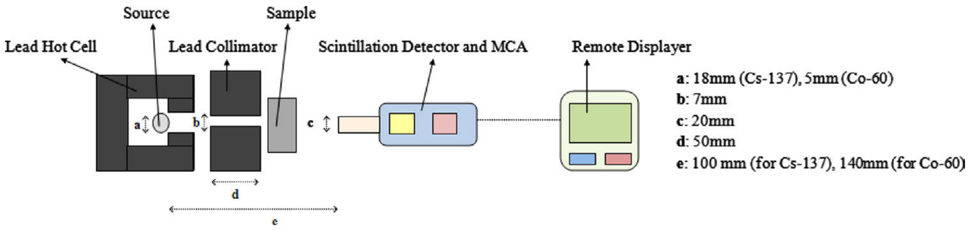

Fig. 1. Schematic view of the gamma transmission technique.

Table 1
The contents of the studied composite materials and their properties (Akarsu et al., 2010).

Material (code)	B_4C (%vol)	SiC (%vol)	Micro TiB_2 (%vol)	Nano TiB_2 (%vol)	Strength (MPa)	Hardness (Vickers)	Density (g/cm^3) ± 0.0001
7300	70	30	–	–	122.733 ± 14.45	1636.0 ± 60.12	2.3934
7302_m	68.6	29.4	2	–	241.75 ± 45.03	1695.2 ± 100.34	2.4156
7302_n	68.6	29.4	–	2	259.825 ± 27.25	1938.25 ± 99.9	2.4210
7304_m	67.2	28.8	4	–	213.93 ± 34.61	1880.87 ± 113.36	2.4871
7304_n	67.2	28.8	–	4	281.5 ± 56.68	2135.62 ± 172.56	2.4961

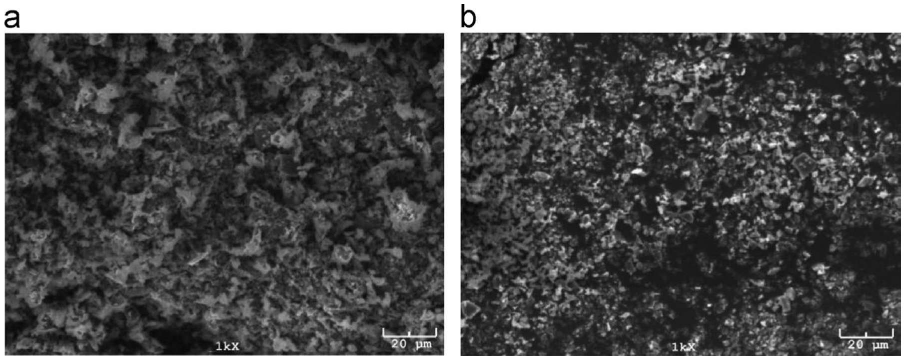

Fig. 2. The SEM views of (a) boron carbide and (b) silicon carbide particles (1000X) (Akarsu et al., 2010).