

Investigation on the Effects of Titanium Diboride Particle Size on Radiation Shielding Properties of Titanium Diboride Reinforced Boron Carbide-Silicon Carbide Composites

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Composite materials have wide application areas in industry. Boron Carbide is an important material for nuclear technology. Silicon carbide is a candidate material in the first wall and blankets of fusion power plants. Titanium diboride reinforced boron carbide-silicon carbide composites which were produced from different titanium diboride particle sizes and ratios were studied for searching of the behaviour against the gamma ray. Cs-137 gamma radioisotope was used as gamma source in the experiments which has a single gamma-peak at 0.662 MeV. Gamma transmission technique was used for the measurements. The effects of titanium diboride particle size on radiation attenuation of titanium diboride reinforced boron carbide-silicon carbide composites were evaluated in related with gamma transmission and the results of the experiments were interpreted and compared with each other.

Keywords: Nanocomposite, Boron Carbide, Titanium Diboride, Silicon Carbide, Cs-137 Gamma Source, Gamma Transmission Technique.

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1. INTRODUCTION

Boron carbide has wide application areas in industry. Some of these areas are nuclear technology, military industry, ceramic industry and air-space industry [1, 2]. Boron carbide has some important properties such as low-density, high hardness and corrosion resistance, chemical stability and high neutron capture feature [2]. Some boron carbide application fields are lightweight ceramic armor, sand blasting nozzles, nuclear reactors, reactor control rods and the radiation shielding materials [2, 3]. However, boron carbide is brittle, has low strength and high temperature sintering properties [3, 4]. Sintering of pure boron carbide to high densities is difficult. So, specific additives such as SiC, TiB₂, AlF₃, elemental boron and carbon have been used as sintering aids to increase the density of composite [2-5].

Silicon carbide has been considered as a candidate material in the first wall and blankets of future fusion power plants because of its safety, environmental and economic benefits [6].

Titanium diboride is one of the candidate materials for high temperature structural applications and also for control rod elements in high temperature nuclear reactors [7].

In this study, titanium diboride reinforced boron carbide-silicon carbide composites which were produced from different titanium diboride particle sizes and ratios were studied for searching of the behaviour against the gamma ray. For the investigation of the gamma radiation behaviour of these materials, Cs-137 radioisotope was used as gamma source in the experiments. Cs-137 gamma radioisotop source has a single gamma-peak at 0.662 MeV and its half life is 30.1y [8]. Gamma transmission technique was used for the measurements.

Different titanium diboride particle sizes and ratios in titanium diboride reinforced boron carbide-silicon

carbide composites were evaluated in related with gamma transmission and the results of the experiments were interpreted and compared with each other. Therefore, the effects of boron carbide particle size in titanium diboride reinforced boron carbide-silicon carbide composites on gamma radiation attenuation were investigated against Cs-137 gamma radioisotope source by using gamma transmission technique.

2. EXPERIMENTS AND MATERIALS

2.1 Gamma Transmission Technique

Gamma transmission technique is based on passing gamma rays through the materials. Detector and gamma source put both sides of the material. Detector material and gamma source are in the same axis. The gamma radiation counts are measured reaching to detector from the source. The counts with material and without material are compared and evaluate [8, 9]. Fig. 1 shows schematic view of gamma transmission technique.

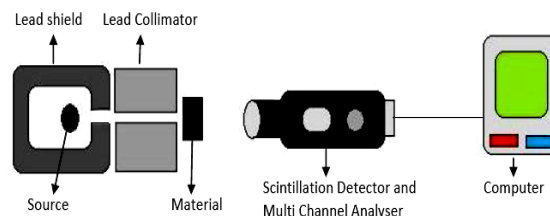


Fig. 1 – Schematic View of Gamma Transmission Technique

The radiation passing through the material is calculated by the following equation: where I and I_0 are the transmitted and initial gamma ray intensities, respectively, μ is linear attenuation coefficient of material at specific γ -ray and x is the thickness of the material.

$$I = I_0 \exp[-\mu x] \quad (1)$$

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2.2 Materials

The materials which were used in the experiments have different boron carbide particle sizes and ratios in the composites. Thus they are coded according to their boron carbide and titanium diboride ratios by volume in composites and particle size ratios. Table 1 shows the materials that used in the experiments and their ratios by volume in the composite materials.

Table 1 – The contents of the composite materials which were used in the experiments

Material (Code)	Boron Carbide (% Vol.)	Silicon Carbide (% Vol.)	Titanium Diboride (% Vol.)	Nano Titanium Diboride (%Vol.)
8202_b	78,4	19,6	2	-
8202_s	78,4	19,6	-	2
8204_b	76,8	19,2	4	-
8204_s	76,8	19,2	-	4

Table 2 shows the hardness, strength and density properties of the materials which were used in the experiments [5].

Table 2 – The hardness, strength and density properties of the composite materials which were used in the experiments

Material (Code)	Strength (MPa)	Hardness (Vickers)	Density (g/cm ³)
8202_b	261,425±25,60	1902,57±131,8	2,361
8202_s	233,25±36,45	1868,29±96,74	2,394
8204_b	276,125±78,79	1983,67±56,78	2,429
8204_s	279,5±45,51	2211,80±168,17	2,476

The average particle size of unmilled titanium diboride in composite materials is 3,851 μm . Figure 2 shows the particle size distribution of unmilled titanium diboride in the composites.

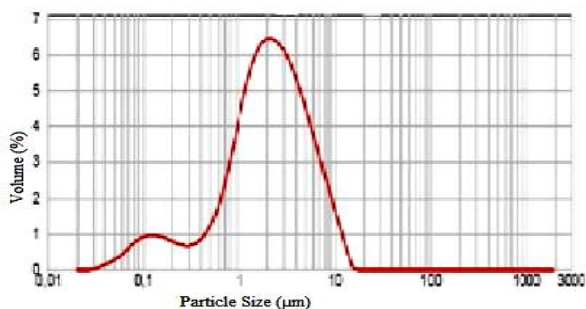


Fig. 2 – Particle size distribution of unmilled titanium diboride

For production of nano scale titanium diboride, titanium diboride materials were milled in Spex 8000 mill for one hour with WC balls. Average particle sizes were decreased to about 170 nm. Figure 3 shows particle size distribution graph of milled titanium diboride particles.

All composite materials were sintered hot pressed method at 2250°C for 2 hours under 130 MPa pressure. Cs-137 Gamma Radiation source which has 8.9 μCi was

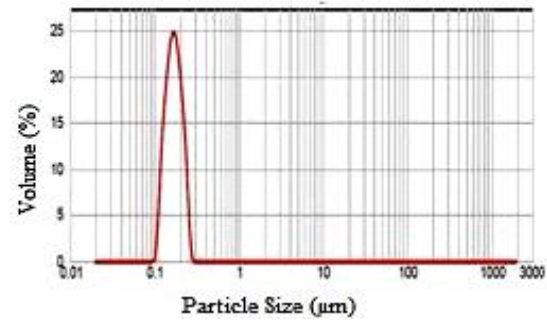


Fig. 3 – Particle Size Distribution of 60 minutes milled titanium diboride

The SEM views of the titanium diboride powders are shown in Figure 4.

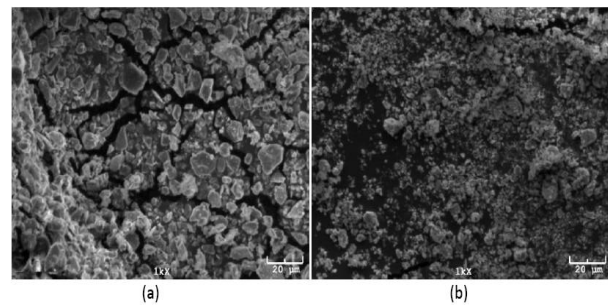


Fig. 4 – SEM views of the (a) unmilled (b) milled titanium diboride

used in the experiments. Lead blocks were used for radiation shielding and collimation. The collimator diameter is 7 mm. The distance between the detector and source is 10 cm.

Firstly background radiation measured. Then Cs-137 Gamma source was set. Initial intensity count (I_0) was measured. Then materials were set and intensity counts (I) were measured for different thickness values. All counts were measured three times for 600 seconds. Net counts calculated by reducing background value. Average values and standard deviations were calculated. For rational evaluating, relative intensity (I/I_0) values were calculated. Results were given with tables. Relative intensity-Material Thickness Graph was drawn for each Titanium diboride ratio and particle size. Exponential distribution was shown on graphs and exponential equations were calculated. Then results were evaluated and discussed.

3. RESULTS AND DISCUSSION

Results for 2% titanium diboride reinforced boron carbide-silicon carbide composites (8202_b) at different thicknesses with Cs-137 Gamma source are given on Table 3.

Results for 2% nano titanium diboride reinforced boron carbide-silicon carbide composites (8202_b) at different thicknesses with Cs-137 Gamma source are given on Table 4.

Results for 4% titanium diboride reinforced boron carbide-silicon carbide composites (8204_b) at different thicknesses with Cs-137 Gamma source are given on Table 5.

Results for 4 % nano titanium diboride reinforced boron carbide-silicon carbide composites (8204_s) at different thicknesses with Cs-137 Gamma source are given on Table 6.

Table 3 – Results for 8202_b titanium diboride reinforced boron carbide-silicon carbide composites with Cs-137 Gamma source

Background = 89		8202_b				
Thickness (cm)	Net Count 1	Net Count 2	Net Count 3	Average Count	Standart Deviation	Relative Count
0,000	8135	8128	8211	8158	46	1,000
0,590	7372	7393	7320	7362	38	0,902
1,165	6654	6652	6780	6695	73	0,821
1,725	6147	6121	6073	6114	37	0,749
2,287	5736	5689	5621	5682	58	0,696
2,859	5116	5196	5119	5144	45	0,631

Table 4 – Results for 8202_s titanium diboride reinforced boron carbide-silicon carbide composites with Cs-137 Gamma source

Background = 89		8202_s				
Thick-ness (cm)	Net Count 1	Net Count 2	Net Count 3	Average Count	Standart Deviation	Relative Count
0	8081	8134	8096	8103	27	1,000
0,588	7287	7280	7306	7291	13	0,900
1,184	6630	6644	6640	6638	7	0,819
1,766	6090	6050	6071	6070	20	0,749
2,351	5512	5538	5532	5527	13	0,682
2,937	5004	5024	4980	5003	22	0,617

Table 5 – Results for 8204_b titanium diboride reinforced boron carbide-silicon carbide composites with Cs-137 Gamma source

Background = 89		8204_b				
Thick-ness (cm)	Net Count 1	Net Count 2	Net Count 3	Average Count	Standart Deviation	Relative Count
0,000	8135	8128	8116	8127	10	1,000
0,571	7346	7297	7367	7337	36	0,903
1,119	6718	6696	6725	6713	15	0,826
1,664	6163	6121	6171	6152	27	0,757
2,229	5610	5656	5590	5619	34	0,691
2,763	5209	5198	5192	5200	8	0,640

Table 6 – Results for 8204_s titanium diboride reinforced boron carbide-silicon carbide composites with Cs-137 Gamma source

Background = 89		8204_s				
Thickness (cm)	Net Count 1	Net Count 2	Net Count 3	Average Count	Standart Deviation	Relative Count
0	8178	8093	8085	8118	52	1,000
0,566	7266	7332	7382	7327	58	0,902
1,133	6662	6658	6728	6683	40	0,823
1,700	5996	6184	6052	6077	96	0,749
2,270	5502	5572	5588	5554	46	0,684
2,821	5100	5070	5088	5086	16	0,626

Using the values on the tables Relative Intensity-Material Thickness Graphs were drawn for all titanium diboride reinforced boron carbide-silicon carbide composites. Exponential fitted equations were calculated. Figure 3 shows Relative Intensity-Material Thickness Graphs of 2% titanium diboride reinforced boron carbide-silicon carbide composites.

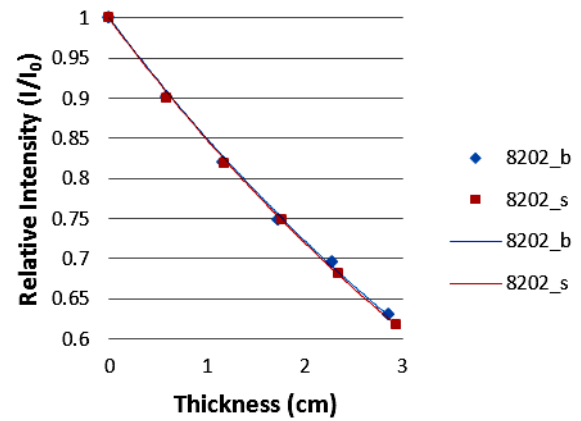


Fig. 3 – Relative Intensity-Material Thickness Graphs of 2 % titanium diboride reinforced boron carbide-silicon carbide composites

Figure 4 shows Relative Intensity-Material Thickness Graphs of 4% titanium diboride reinforced boron carbide-silicon carbide composites.

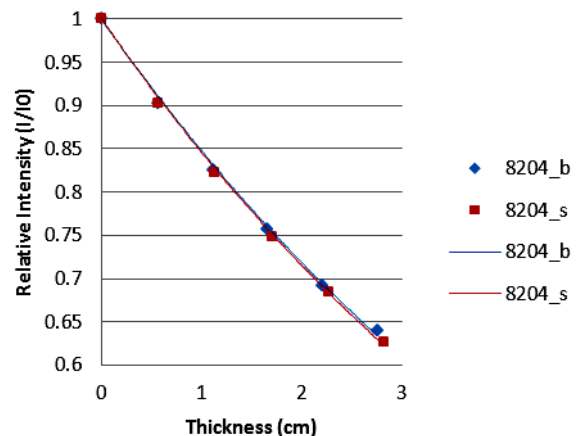


Fig. 4 – Relative Intensity-Material Thickness Graphs of 4 % titanium diboride reinforced boron carbide-silicon carbide composites

Using the graphs on Fig. 3 and Fig. 4 the linear attenuations of the composite materials and correlation coefficients were calculated. The mass attenuation coefficients (μ/ρ) of the composite materials were also calculated. Then mass attenuation coefficient values were compared with the theoretical values which were taken from XCOM computer code which could use for the gamma transmission and gamma absorption techniques [10, 11].

The linear and mass attenuation values and XCOM values of the composites are given on Table 7.

All correlation coefficient values of the linear attenuation coefficients are over 0.99. The linear attenuation coefficients of milled titanium diboride reinforced boron carbide-silicon carbide composites are higher than unmilled reinforced ones. The mass attenuation values

Table 7 – The Linear and Mass attenuation coefficient of the composite materials

Material (Code)	Linear attenuation coefficient (cm ⁻¹)	Mass Attenuation Coefficient (cm ² /g)		
		Experimental (10 ⁻²)	Theoretical (XCOM)	Difference (%)
8202_b	0,162	6,862	7,355	6,710
8202_s	0,164	6,850	7,355	6,867
8204_b	0,165	6,793	7,352	7,605
8204_s	0,168	6,785	7,352	7,712

are closed to theoretical values which were taken from XCOM. The differences of theoretical and experimental values are between 6,71-7,71 %.

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4. CONCLUSION

It could be understood that for 2 % milled titanium diboride reinforced boron carbide-silicon carbide, the linear attenuation coefficient is higher than unmilled one. In addition for 4 % milled titanium diboride reinforced boron carbide-silicon carbide, the linear attenuation coefficient is higher than unmilled one the linear attenuation coefficient is higher than unmilled one. Therefore it can be said that decreasing the titanium diboride particle size in the composites causes higher linear attenuation coefficient values. The experimental values and theoretical values from XCOM are closed to each other with the below difference value at 8%.

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