

RADIATION ATTENUATION PROPERTIES OF ALUMINUM TITANATE-SPINEL COMPOSITES FOR CO-60 GAMMA SOURCE

Gorkem Cevikbas¹, A. Beril Tugrul¹, Umut Onen², Tahsin Boyraz², Bulent Buyuk^{*3}

¹Istanbul Technical University, Energy Institute, Nuclear Researches Department, Ayazaga Campus, Sariyer, Istanbul, 34469, Turkey

²Sivas Cumhuriyet University, Metallurgy and Materials Engineering Faculty, Main Campus, Sivas, 58140, Turkey

³Bandirma Onyedi Eylul University, Engineering and Natural Sciences Faculty, Engineering Sciences Department, Main Campus, Bandirma, Balikesir, 10200, Turkey

Abstract

In this study, the linear and mass attenuation properties of Aluminum titanate (Al₂TiO₅)-Spinel (MgAl₂O₄) composites were investigated for Co-60 gamma source. Aluminum titanate - Spinel ceramics composites which have different Aluminum titanate percentages (0%, 5% and 10%) were produced and performed against Co-60 gamma source. Co-60 gamma source which has mean gamma energy at 1.25 MeV and pair production event also takes place beside the photoelectric event and Compton scattering. Gamma transmission technique was used in the experiments. Linear attenuation coefficients and half value layers were carried out for the studied samples. Increasing Aluminum titanate percentage in the samples caused the higher half value layers of the composites against Co-60 gamma source. The experimental mass attenuation coefficients were compared with the theoretical mass attenuation coefficients resulted from XCOM computer code. Experimental results were compatible with the theoretical results. In conclusion, increasing the Aluminum titanate ratio in the Al₂TiO₅-MgAl₂O₄ ceramics composites decreases the gamma shielding property of the Al₂TiO₅-MgAl₂O₄ ceramics for nuclear shielding applications.

Keywords: Aluminum titanate, spinel, Co-60, radiation attenuation, linear attenuation coefficient, HVL, XCOM

1. INTRODUCTION

Magnesium aluminate spinel (MgAl₂O₄) has good properties such as mechanical resistance, thermal-shock resistance and high corrosion resistance [1-3]. So, magnesium aluminate spinel ceramics have been used in steel-making furnaces, cement rotary kilns, glass furnaces regenerators, steel ladles, and melting tanks. In addition, magnesium aluminate spinel has high radiation resistance (especially to the neutron irradiation) and it has potential to be used in nuclear fission and fusion reactors [4,5]. It could be used in the first-wall or insulators for magnetic coils of the fusion reactors [6]. Also magnesium aluminate spinel ceramics have potential to be used in the radiofrequency heating system of fusion reactors [7].

Aluminum titanate (Al₂TiO₅) is a ceramic material which has good properties such as low thermal expansion coefficient and conductivity, thermal shock resistance, high melting point [8-10]. Aluminum titanate materials have been used in automotive industries, catalytic converters, foundry crucibles, launders, nozzles, riser tubes, pouring spots, thermo couples, master moulds, glass industries and in nuclear fusion reactors [11,12]

In this study, the gamma radiation attenuation properties of aluminum titanate-spinel composite ceramics were investigated against Co-60 gamma source. Radiation shielding properties of aluminum titanate-spinel composites were carried for gamma radiation shielding applications.

2. MATERIALS AND METHODS

2.1. Materials

In the experiments magnesium aluminate spinel-aluminum titanate composite ceramics were used. Magnesium aluminate spinel (MgAl_2O_4) was produced by using alumina (Al_2O_3) and magnesia (MgO). On the other hand aluminum titanate (Al_2TiO_5) was produced by using alumina (Al_2O_3) and titania (TiO_2) powders (99.9 % pure). Samples produced by reaction sintering technique. The resulting mixtures were then sintered at 1550 °C for magnesium aluminate spinel (MgAl_2O_4) and 1600 °C for aluminum titanate in air for 2 h. After than aluminum titanate (0, 5, and 10 wt. %) added to magnesium aluminate spinel to get magnesium aluminate spinel-aluminum titanate (SAT) composites. Samples were coded according to aluminum titanate percentages as in Table 1. After that, mixtures pressed at 200 MPa into 3x3x0.5 cm specimens. The samples were sintered in air using a heating rate of 5 °C/min, and soaked at 1700 °C [13]. The properties of the samples were given in Table 1 as well as figures of the samples were given in Fig. 1.

Sample (Code)	MgAl_2O_4 (wt.%)	Al_2TiO_5 (wt.%)	Density (g/cm^3)
SAT0	100	0	3,46
SAT5	95	5	3,45
SAT10	90	10	3,44

Table 1. The properties of the magnesium aluminate spinel-aluminum titanate composites [13]



Fig. 1. The magnesium aluminate spinel-aluminum titanate composites.

2.2. Methods

Gamma transmission technique was used in the experiments to figure out the material's gamma attenuation capability. The gamma source is placed on the same axis with the detector. The lead blocks at least 5 cm thicknesses were put in front of the both source and the detector. These lead blocks have holes to get narrow beam conditions. The gamma intensities with and without materials were detected by detector. Attenuation ratios of the samples were carried out and evaluated according to purpose [12,13]. The schematic view of the gamma transmission was given in Fig. 2.

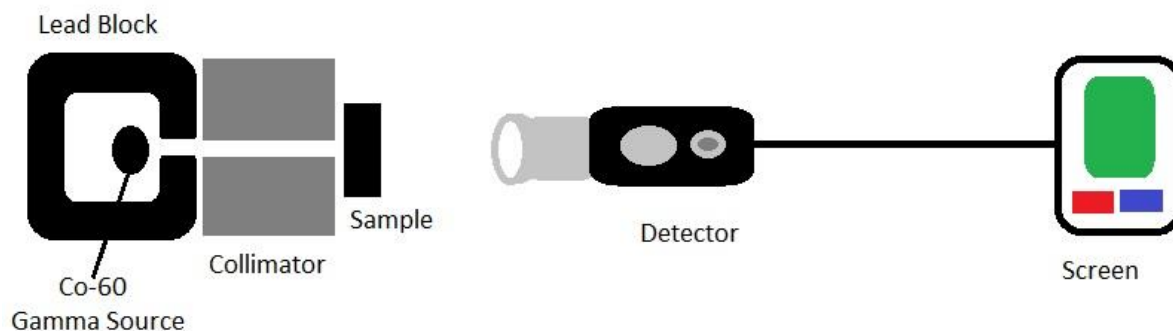


Fig. 2. Schematic view of gamma transmission technique.

In the experiments Co-60 gamma source which has two main energy peaks at 1.17 and 1.33 MeV. The mean energy peak of Co-60 was accepted as 1.25 MeV. This energy level is higher than threshold energy of pair production which is 1.022 MeV. Therefore, pair production events occur beside the photoelectric events and Compton scattering when gamma rays interact with materials' atoms. In addition, the half life of Co-60 is 5.27 years. Gamma ray intensities were detected by PM1401K model scintillation detector. Lead blocks were used for radiation shielding as well as collimator. The collimator has a 0.7 cm diameter hole and 5 cm thickness. At first, the initial gamma intensity without any material (I_0) was measured. Then gamma intensities (I) were measured for each samples at different thicknesses. The accumulation time was 300 s for the samples. Relative intensity (I/I_0) values were carried out for all samples at different thicknesses.

The radiation attenuation can be described by Lambert-Beer's equation;

$$I = I_0 e^{-\mu x}$$

where I and I_0 are incident and transmitted gamma intensity, respectively. μ is linear attenuation coefficient at specific gamma ray energy and x represents material thickness.

Half value layer (HVL) is the minimum material thickness to reduce the gamma intensity to its half value at specific gamma ray energy. HVL is one of the good methods for comparing radiation attenuation properties of the materials. HVL is determined by following equation;

$$HVL = \frac{0.693}{\mu}$$

Mass attenuation coefficient (μ_m) can be determined by the following formula;

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

where μ_m is the mass attenuation coefficient and ρ is the density of the material. Mass attenuation coefficient shows the materials' attenuation capability by eliminating its density.

At first relative intensity-material thickness graphs were drawn for magnesium aluminate spinel-aluminum titanate composites. Then linear attenuation coefficients were carried out by using the graphs. Half value layers and mass attenuation coefficients were determined by using linear attenuation coefficients. The radiation attenuation properties of magnesium aluminate spinel-aluminum titanate composites were evaluated and compared each other for Co-60 gamma source.

3. RESULTS

The relative intensity values of the produced magnesium aluminate spinel-aluminum titanate composites were carried out and given in Table 2. For each sample three different material thicknesses were used to get relative intensities for Co-60 gamma source.

SAT0		SAT5		SAT10	
Thickness (cm)	Relative count	Thickness (cm)	Relative count	Thickness (cm)	Relative count
0,0000	1,000	0,0000	1,000	0,0000	1,000
0,4541	0,919	0,4525	0,930	0,4413	0,935
0,8979	0,855	0,8989	0,864	0,8940	0,869
1,3517	0,790	1,3518	0,809	1,3403	0,820

Table 2. Relative Intensity values of the magnesium aluminate spinel-aluminum titanate composites.

The relative intensity-material thickness graphs were drawn and given in Fig. 3. In addition, the graphs fitted exponentially by using Origin 8 computer program. Even though the relative intensities were closed to each other, magnesium aluminum spinel has lower relative intensity values than aluminum titanate added samples. Adding aluminum titanate to spinel material caused to increase on the relative intensities for the studied samples.

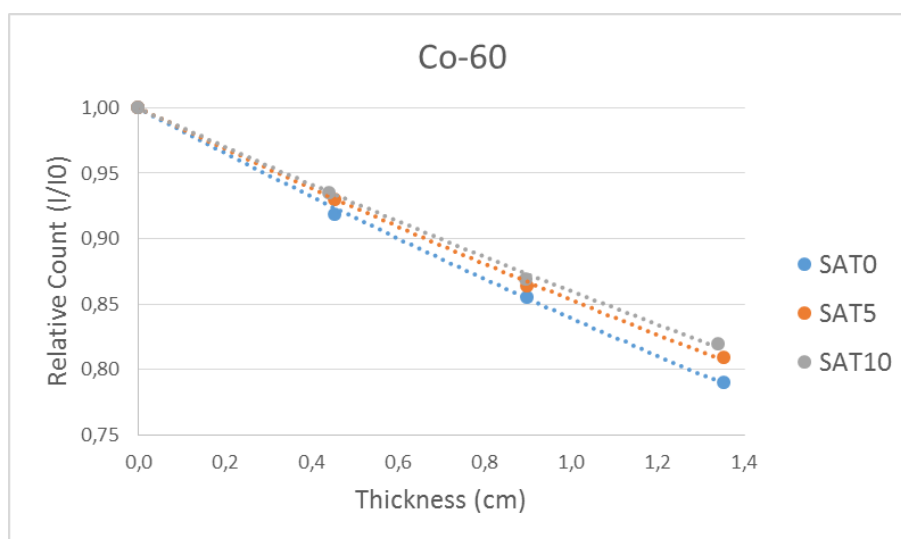


Fig. 3. Relative intensity-material thickness graphs of the samples.

The linear attenuation coefficients (μ) and correlation coefficients (R^2) were figured out for Co-60 gamma source. Linear attenuation coefficients (μ) of the materials were determined by Origin 8 computer program and shown in Table 3.

Material	Linear Attenuation Coefficient		Half Value Layer, HVL (cm)
	μ (cm ⁻¹)	R^2	
SAT0	0,175	0,999	3,960
SAT5	0,159	0,999	4,358
SAT10	0,151	0,998	4,589

Table 3. Linear attenuation coefficients and Half value layers of magnesium aluminate spinel-aluminum titanate composites for Co-60 gamma source

The linear attenuation coefficients were decreased with increasing aluminum titanate ratio in the magnesium aluminate spinel-aluminum titanate composites. It means that radiation attenuation capability was decreased with increasing aluminum titanate ratio. It could be explained by decreasing density values of the samples by adding aluminum titanate to magnesium aluminate spinel materials. In addition, correlation coefficients were over 0.99 which mean the results were well-matched with each other.

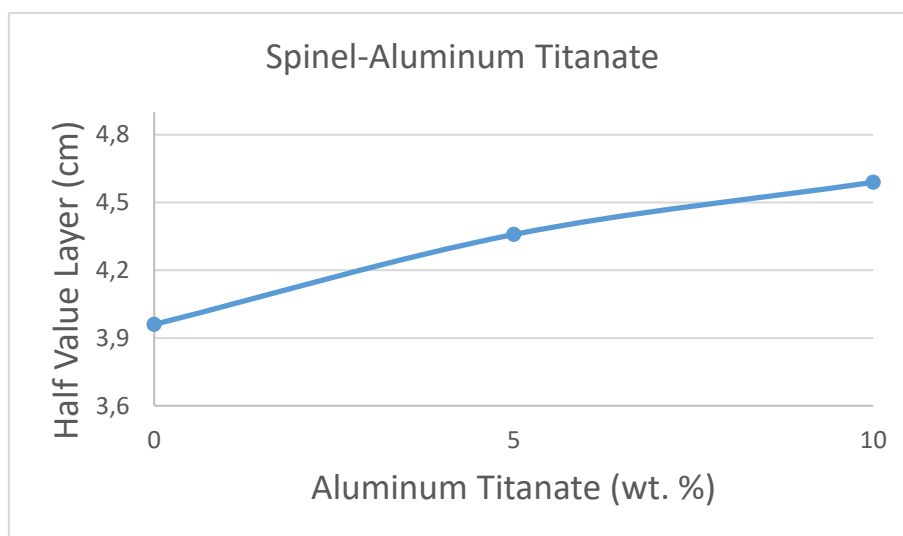


Fig. 4. Half Value Layers of the magnesium aluminate spinel-aluminum titanate composites for Co-60 gamma source.

Adding and increasing aluminum titanate to spinel increased the half value layers for Co-60 gamma source. The spinel composites have lower half value layers which means better radiation shielding properties than aluminum titanate-spinel composites. In addition, the experimental mass attenuation coefficients were calculated for the SAT0, SAT5 and SAT10 composites (Table 4). On the other hand, theoretical mass attenuation coefficients were calculated by using XCOM computer code [14]. XCOM computer code is one of the most used codes for determining theoretical mass attenuation coefficients of different materials and mixtures [15-19]. The difference percentages between theoretical and experimental results were carried out and given on Table 4 and Fig. 5.

Material	Mass Attenuation Coefficient, μ_m ($\times 10^{-2}$ cm ² /g)		
	Experimental	Theoretical (XCOM)	Difference (%)
SAT0	5,057	5,603	9,73
SAT5	4,609	5,598	17,67
SAT10	4,390	5,594	21,53

Table 4. Linear and mass attenuation coefficients of magnesium aluminate spinel-aluminum titanate composites for Co-60 gamma source

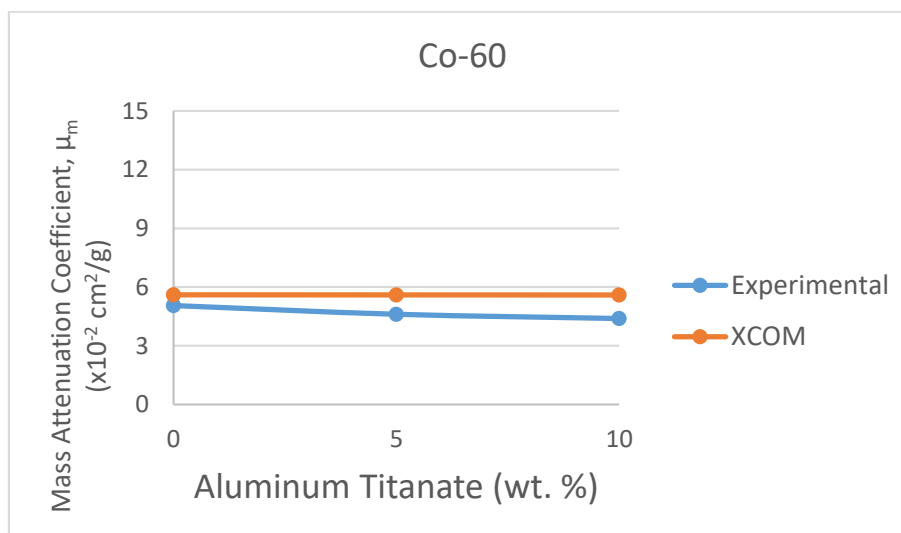


Fig. 5. Mass attenuation coefficients of the magnesium aluminate spinel-aluminum titanate composites for Co-60 gamma source.

Magnesium aluminate spinel material has bigger mass attenuation coefficient than aluminum titanate-spinel composites for Co-60 gamma source. The same tendency could be seen on theoretical mass attenuation coefficients resulted from XCOM code as seen on Fig 5. On the other hand, the difference percentages between experimental and theoretical results were in a range of 9.73-21.53. These differences were propagated by experimental set up errors, material impurities, material production method and the voids in the composites.

4. CONCLUSIONS

Magnesium aluminate spinel-aluminum titanate composites were investigated against Co-60 gamma source. Linear and mass attenuation coefficients of the samples were carried out at 1.25 MeV. Adding aluminum titanate to magnesium aluminate spinel slightly increases the relative intensity values of the materials. SAT0 has the biggest linear attenuation coefficient and the smallest half value layer for Co-60 gamma source. Therefore it could be said that magnesium aluminate spinel has better radiation attenuation capability than the aluminum titanate added composites. Experimental mass attenuation coefficients were compared with the theoretical results and same decreasing tendencies were shown on the mass attenuation coefficients. The difference percentages were over 9.7 % which were combination of various application errors such as experimental set up errors, material impurities, material production method and the voids in the materials. On the other hand, it has been reported that adding aluminum increase the hardness and thermal shock resistance of the magnesium aluminate spinel [13]. In conclusion, adding aluminum titanate to magnesium aluminate spinel composites increase the hardness whereas decrease the radiation attenuation capability for Co-60 gamma source. Therefore, an optimization is necessary when the magnesium aluminate spinel planned to be used for both gamma protective and hard-thermal resistant material needed applications.

ACKNOWLEDGMENTS

This work was supported by Scientific Research Projects Coordination Unit of Bandirma Onyedi Eylül University. (Project No: BAP-19-1009-026)

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