Araştırma Makalesi / Research Article

Shielding Property of Closed-Cell AlSi7 Foams and AlSi7 Bulk Materials against Gamma Rays

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Abstract

The aim of this paper is experimental comparison of shielding properties against gamma rays among closed-cell AlSi7 foams and bulk materials. These materials were produced by powder metallurgy method. Gamma rays attenuation measurements were performed at photon energies of 88, 511, 662, 1173, 1275 and 1332.5 keV. The obtained results revealed that AlSi7 bulk materials offer better gamma rays attenuation capabilities due to their high density compared to closed-cell AlSi7 foams.

Kapalı Gözenekli AlSi7 Köpükler ve AlSi7 Bulk Malzemelerin Gama Işınlarına Karşı Zırhlama Özelliği

Özet

Bu çalışmanın amacı kapalı gözenekli AlSi7 köpükler ile AlSi7 bulk malzemelerin gama ışınlarına karşı zırhlama özelliklerinin deneysel olarak karşılaştırılmasıdır. Bu malzemeler toz metalurjisi yöntemi ile üretilmiştir. Gama ışınları zayıflatma ölçümleri 88, 511, 662, 1173, 1275 ve 1332.5 keV foton enerjilerinde gerçekleştirilmiştir. Elde edilen sonuçlar AlSi7 bulk malzemelerin kapalı gözenekli AlSi7 köpüklere kıyasla daha iyi gama ışını zayıflatma yeterliliğine sahip olduğunu göstermektedir. Bunun nedeni ise bulk malzemelerin köpüklere kıyasla daha yüksek yoğunluğa sahip olmalarıdır.

1. Introduction

The expected properties in the materials used in the nuclear field are low weight and good levels of radiation attenuation capability due to new criteria which include protecting against dangerous climate change that may occur around the nuclear power plants and nuclear terrorist attacks, radioactive waste storage and processing facilities (Chen et al. 2014, Corner et al. 2011, Watson and Scott 2009). Earlier there have been several studies on materials such as ceramics, polymers, metals and alloys used for this purpose (Grossbeck, 2012, Hobbs et al. 1994, Katoh et al. 2012). Leonard (2012) presented a detailed review of the irradiated properties database for niobium, tantalum, molybdenum, and tungsten refractory

metals and their alloys. For example, martensitic steels are of current interest because of their radiation resistance and low radio activation properties. The irradiation response of the ceramic material is more complicated than metallic materials (Grossbeck, 2012). However, only a few studies have been reported on radiation shielding performance of porous materials.

Today, one of the important porous materials is aluminum foam. Aluminum foams have extremely superior mechanical, physical and acoustic properties (Banhart, 2001). Combination of these properties provides that these structures to be widely used as structural and functional materials in industries such as the automotive, aerospace

and railway (Aguiree-Perale et al. 2012, Ashby et al. 2000, Banhart, 2001, Degischer and Kriszt 2002, Hangai et al. 2014, Khabushan et al. 2013, Lefebvre et al. 2008). Currently, the most commonly used production methods are solid–gas eutectic solidification, high pressure casting method, powder metallurgy method, and melt-foaming method (Baumaster 1992, Kitazono et al. 2002, Ma and Song 1998, Shiomia et al. 2010). In powder metallurgy method, aluminum foams are made by expansion of foamable precursor in foaming moulds. In a study conducted by Xu et al. (2010) the open cell foam structures filled with water and borided water exhibited excellent performance against neutrons. Neutron sources and nuclear reactors release gamma rays with neutrons. Therefore, it is difficult to determine the behavior of neutron-absorbing material against gamma rays. Both open-cell and closed porous metallic foams provide positive contributions as potential material for radiation shielding applications. In a study conducted by Chen et al. (2014) the attenuation performance against gamma rays and neutrons among aluminum A356, closed-cell and open-cell aluminum foams infiltrated with materials such as borated polyethylene, paraffin wax, water and borated water were compared.

In this study, the experimental comparison of shielding properties against gamma rays among AlSi7 foams and bulk materials which were produced by powder metallurgy were studied. For the investigation of the gamma radiation behavior of these materials, Cd-109, Na-22, Cs-137, Co-60 radioisotopes were used as gamma source in the experimental works. Gamma transmission technique was used for the measurements.

2. Gamma Rays Measurements

2.1. Theory

Gamma transmission technique is based on the interaction of the material atoms with gamma rays as it passes through materials. Gamma rays lose all or a portion of the energy due to this interaction. Transmission is measured by the radiation intensity passing through the material and coming out of source (Foldiak, 1986). Count value (I) obtained by using different thicknesses of materials is dispensed with the count value (I_o) obtained without the material. Thus, the relative count values (I/I_o) for each material thickness is obtained. For each material, the gamma attenuation curves are generated by drawing thickness-relative count graphs. According to Beer-Lambert's law, the linear attenuation coefficient (μ) of materials (Equation 1) can be derived from these curves (Knoll, 2010).

$$I = I_o e^{-\mu x} \qquad (1)$$

Where; I and I_o denote the attenuated and incident gamma ray intensity, respectively, μ (cm^{-1}) is the linear attenuation coefficient and x (cm) is sample thickness. The mass attenuation coefficient (μ_m) is obtained through the use of linear attenuation coefficient calculated for the material. It is calculated depending on the material density (ρ) by the formula given in Equation 2 (Knoll, 2010, L'Annunziata, 2007).

$$\mu_m = {^\mu}/_\rho \qquad (1)$$

3. Experimental Procedure

Closed-cell AlSi7 foams and AlSi7 materials used in experimental studies were produced by powder metallurgy method (Uzun and Turker 2015). Figure 1 illustrates the macrostructure images of cross-section of samples. The densities of samples are also presented in Table 1. Gamma ray transmission experiments of samples produced in different thicknesses (5, 12 and 15 mm) were performed in vertical beam transmission geometry. Each tests were repeated three times.
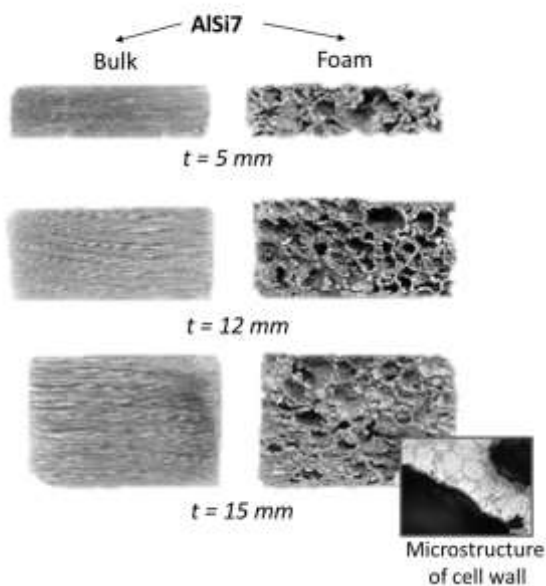
Figure 1. Cross-section of closed-cell AlSi7 foams and bulk materials.

Table 1. Densities of samples.

Thickness (mm)	Density (g.cm^{-3})	
	Foam	Bulk
5	0.68	2.68
12	0.56	2.66
15	0.53	2.63

Gamma detection device is shown schematically in Figure 2. The distance between the radioactive source and the detector is 90 mm. To achieve a narrow parallel beam, the source is positioned using the lead holder with a hole diameter of 2 mm. Samples were placed on collimator at 80 mm distance from the source. Then the photon flux is transported to the detector by passing from the lead holder. Gamma radiation transmission was measured using NaI(Tl) detector. Each sample was measured by photon energies of 88, 511, 662, 1173, 1275 and 1332.5 keV.
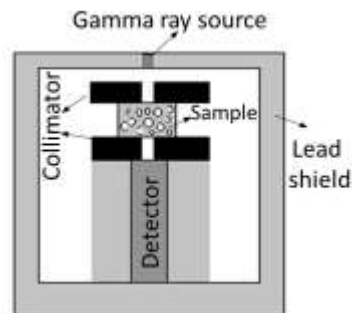

Figure 2. Schematic diagram of gamma spectrometry system

4. Results and Discussion

The transmission values of three samples with different thicknesses at six different photon energies are shown in Figure 3. As shown in the graphs, the transmission values decreased with increase in sample thickness. Transmission in the same kind of samples under all sources (energies) is similar slope. It is clear that the bulk materials have better absorbing and radiation attenuation characteristics due to their high density compared to foams. Chen et al. (2014) observed that closed-cell foams demonstrate an effective shielding property compared to bulk aluminum for energies below 0.662 MeV. However, researchers infiltrated in close-cell and open-cell foams variety of second phase materials. An increased attenuation of 2, 6, and 10% can be observed at a lower energy of 88 keV in foam materials with thickness of 5, 12 and 15 mm, respectively. However, the bulk materials with same thickness were attenuated about 14, 31 and 40% at a lower energy of 88 keV. The slope of the transmission curve of the bulk and foam materials is quite different. This condition is related to the density and structural qualities of the materials (Mavi et al. 2014).
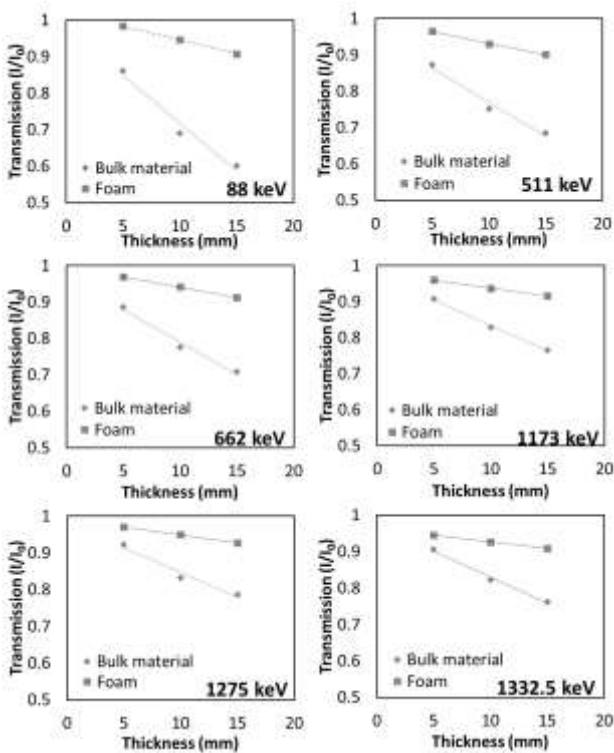
Figure 3. Attenuation of bulk and foam samples at six different photon energies

For AlSi7 samples, the mass attenuation coefficient obtained experimentally was decreased due to the increase in photon energy as seen in Table 2. Initially, the mass attenuation coefficient had a maximum value, and then it decreased. But, a similar situation is difficult to say for AlSi7 foams. Because they have non-homogeneous pore structure, their mass attenuation coefficient is a complex correlation. It is also observed that the mass attenuation coefficient of aluminum foam is slightly higher than that of the bulk material for energies above 88 keV. According to the study by Gedik and Baytas (2015), the linear attenuation coefficient and porosity of the foams was non-uniform locally.

Table 2: Experimental values of mass attenuation coefficients (cm^2/g) for aluminium foams and bulk materials

Energy(keV) (Experimental)	Thickness (mm)	Mass attenuation coefficients (cm^2/g)	
		AlSi7 bulk	AlSi7 foam
88	5	0.111	0.047
	12	0.116	0.081
	15	0.128	0.122
511	5	0.101	0.106
	12	0.090	0.108
	15	0.096	0.165
662	5	0.090	0.094
	12	0.080	0.089
	15	0.087	0.116
1173	5	0.072	0.119
	12	0.059	0.098
	15	0.068	0.110
1275	5	0.061	0.089
	12	0.058	0.078
	15	0.061	0.095
1332.5	5	0.074	0.141
	12	0.061	0.114
	15	0.069	0.121

5. Conclusion

In this study, gamma rays shielding properties of AlSi7 bulk materials and closed-cell foams were investigated using Cd - 109, Na - 22, Cs - 137, Co - 60 radioisotopes. Bulk materials have shown a clearly advantageous behavior, when comparing gamma attenuation against the same thickness of foam materials because, the bulk materials have a higher density compared to aluminum foams. The bulk materials with same thickness were

attenuated about 14, 31 and 40% at a lower energy of 88 keV. However, the mass attenuation coefficient of aluminum foam is slightly higher than that of the bulk material for energies above 88 keV. This condition is related to the density and structural qualities of the materials.

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