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Determination of gamma ray attenuation coefficients of Al–4% Cu/B_4C metal matrix composites at 662, 1173 and 1332 keV

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Abstract. **Gamma ray attenuation coefficients of metal matrix composites have been investigated. For this purpose, the linear attenuation coefficients of composites containing boron carbide (B_4C) at different rates have been measured using a gamma spectrometer that contains a NaI(Tl) detector and MCA at 662, 1173 and 1332 keV, which are obtained from ^{137}Cs and ^{60}Co sources. The measured results were compared with the calculation obtained using computer code of XCOM for 1 keV–1 GeV gamma energies.**

Keywords. **Gamma ray attenuation coefficient; gamma spectrometer; metal matrix composite; XCOM.**

1. Introduction

Metal matrix composites (MMCs) have high specific stiffness and strength, improved wear resistance and thermal properties. For these reasons, they have been used in advanced structural, aerospace, automotive, electronics and wear applications. The properties of MMCs are directly affected by type and properties of matrix, reinforcement and interface. Matrix materials are usually light weight, especially aluminum and its alloys to give high specific strength. Ceramic reinforcements have been used in the form of particulates, whiskers or continuous fibres. Particulate metal matrix composites (PMMCs) are more attractive than continuous fibre reinforced MMCs because they show higher ductility and lower anisotropy. Moreover, they are much cheaper and need simpler processing methods.

There are some basic principles for radiation protection. These are shielding, distance and time. Shielding is generally preferred due to its efficiency in intrinsically safe working conditions, whereas reliance on distance and time of exposure involves continuous administrative control over workers. The type and amount of shielding required depend on the type of radiation. An effective shield will cause a large energy loss in a small penetration distance without emission of more hazardous radiation. Furthermore, a good shielding material should have high absorption cross section for radiation and at the same time irradiation effects on its mechanical and optical properties should be small. Although standard shielding material is lead and other high-Z materials, owing to their difficulties in use and their price, alternative ways has been subject of research. Thus, this kind of composite is the subject of this work.

A number of experimental and theoretical works have been performed on radiation shielding, which has numerous application areas with different materials, for different building materials (Akkurt *et al* 2004, 2005a; Turkmen *et al* 2008), for concretes (Akkurt *et al* 2006, 2012), for some aqueous solutions (Singh *et al* 2001), for semiconductors and superconductors (Baltaş *et al* 2005; Çevik *et al* 2006), for alloys (Han and Demir 2009) and for steels (Akkurt *et al* 2011).

Experimental study is a vital as every calculation should be confirmed with the experimental results. Thus, in the present work, the γ-ray attenuation coefficients of MMCs for different gamma energies (ranging from 662 to 1332 keV) by using different point radioactive sources (^{137}Cs and ^{60}Co) have been investigated. The measured results have been compared with the calculation.

2. Experimental details

2.1 *Production of composite samples*

Aluminum, copper and B_4C powders were used to produce composite samples. The average sizes of the aluminum, copper and B_4C powders were 37, 33 and 16 μm, respectively. Liquid-phase sintering method was used to produce PMMCs. An electrical furnace was built to fit into a 30-tonne capacity mechanical press to conduct hot uni-axial pressing. First, mechanical alloying of the powders was performed in a 45-mm inner-diameter plastic container in a steel cylinder mixer for 1 h at 70 rpm.

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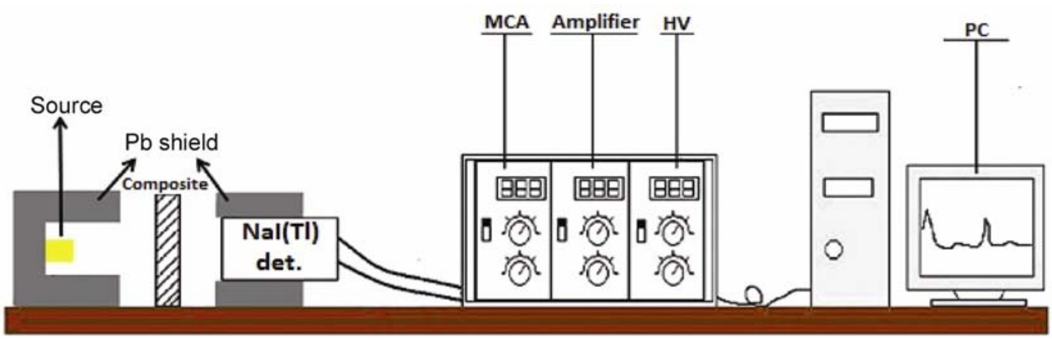

Figure 1. Schematic view of the experimental set-up.

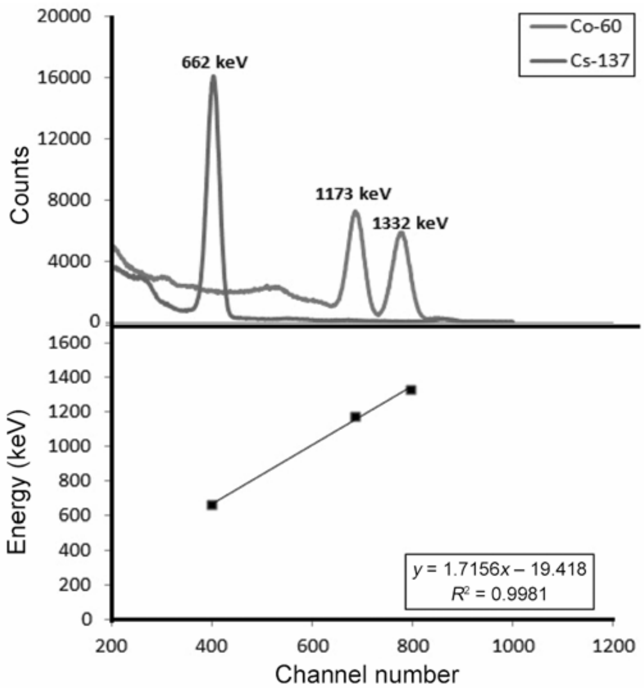

Figure 2. The γ-ray energy spectrum obtained from ^{137}Cs and ^{60}Co sources (upper) and related fit channel vs energy (keV).

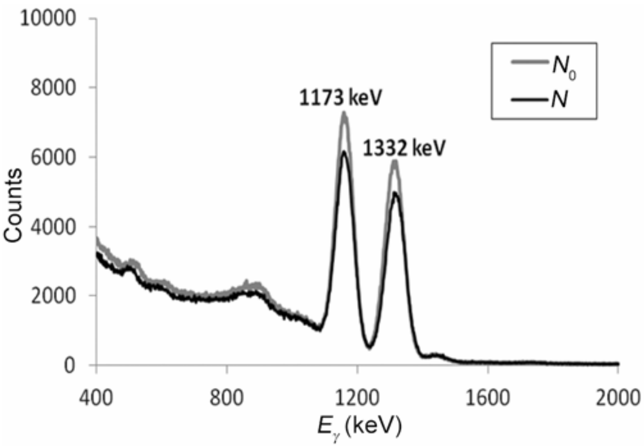

Figure 3. Attenuated and unattenuated γ-ray spectrum obtained from ^{60}Co source.

Then, AISI H13 grade hot work tool steel die with an inner square cross section of 50 mm × 50 mm was manufactured for the cold compaction and sintering of powders. Then, the powders were initially cold compacted at a pressure of 50 MPa. Next, sintering was carried out at 25 MPa and 585 °C for 10 min under an inert nitrogen atmosphere. Finally, after pressure release, the die (along with the specimen) was immediately taken out of the furnace and cooled in air. The final dimensions of the fabricated composites were 50 mm × 50 mm × 10 mm. The B_4C was used in fractions of 0, 10, 20 and 40% in Al–4% Cu, which are tagged as C0, C10, C20 and C40, respectively.

2.2 *Linear attenuation coefficients*

The linear attenuation coefficients of composites were measured at photon energies of 662 keV obtained from a ^{137}Cs source and 1173 and 1332 keV obtained from a ^{60}Co source. The γ-rays through composites were detected using a gamma spectrometer that consists of a 3″ × 3″ NaI(Tl) detector connected to a multichannel analyser (MCA) (Akkurt 2009; Günoğlu and Akkurt 2011). The control of acquisition parameters and analysis of the collected spectra are carried out using MAESTRO-32 software package. The schematic view of the experimental set-up is shown in figure 1. The spectrometer has been calibrated using γ-ray energies of 662 keV from ^{137}Cs source and 1173, 1332 keV from ^{60}Co source. The γ-ray energy spectrum obtained from these sources and the related energy to channel fit are displayed in figure 2.

On the other hand, in the experimental set-up, it is important to take into account multiple compton scattering effects. It has been studied in several works (Kane *et al* 1977; Midgley 2006; Singh *et al* 2006).

If N and N_0 are the measured count rates in detector, respectively, with and without the absorber of thickness, x (cm), the linear attenuation coefficients (μ) can be extracted by the standard equation

$$N = N_0 e^{-\mu x}. \tag{1}$$

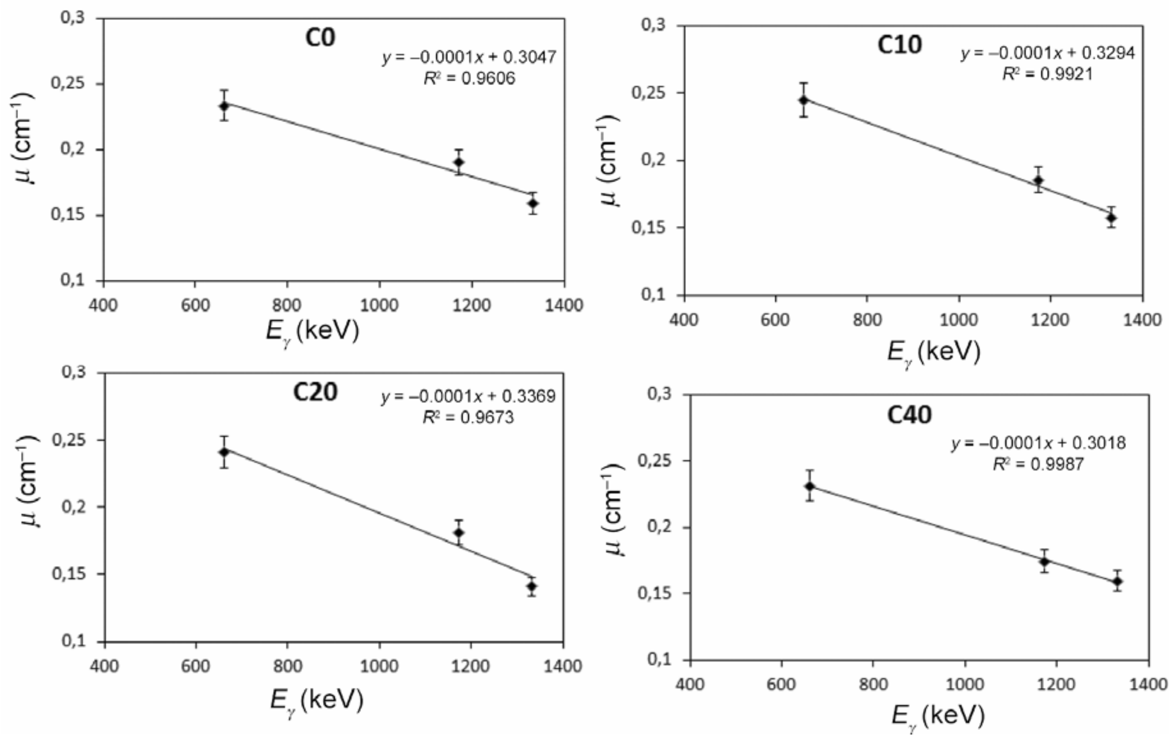

Figure 4. Measured linear attenuation coefficient vs photon energy for composites.

Table 1. The chemical compositions of composites.

Composition (%)	C0	C10	C20	C40
B_4C	0·00	9·09	18·37	37·51
Al	96·00	87·27	78·36	59·99
Cu	4·00	3·64	3·27	2·50
Density (g cm^{-3})	2·787	2·760	2·732	2·677

A γ-ray spectrum obtained from ^{60}Co source is displayed in figure 3, where attenuated (N) and unattenuated (N_0) γ-rays at 1173 and 1332 keV can be clearly seen.

The chemical compositions of composites are shown in table 1. The linear attenuation coefficients (μ) of composites were obtained via their mass attenuation coefficients (μ/ρ), which were calculated using the XCOM code. XCOM uses the chemical composition of the composites to provide total cross sections as well as partial cross sections for various interaction processes. XCOM is a database running on a PC and was prepared by combining pre-existing databases for interaction processes such as photoelectric absorption, scattering (both coherent and incoherent) and pair production at photon energies from 1 keV to 100 GeV (Berger and Hubbell 1987).

The effectiveness of γ-ray shielding is described in terms of the half value layer (HVL) or the tenth value layer (TVL) of a material. The HVL is the thickness of an absorber that will reduce the radiation to half, and the TVL is the thickness of an absorber that will reduce the γ-radiation to one-tenth of its original intensity. These are obtained as

$$\mathrm{HVL} = \frac{\ln 2}{\mu}, \quad \mathrm{TVL} = \frac{\ln 10}{\mu}. \tag{2}$$

3. Results and discussion

The linear attenuation coefficients (μ) for the different types of composites containing different rates of B_4C were measured at photon energies of 662, 1173 and 1332 keV and calculated at photon energies of 1 keV–100 GeV. The measured linear attenuation coefficients have been displayed in figure 4, where it can be seen that the linear attenuation coefficients decrease linearly with increasing photon energy for all types of composites.

The measured results were also compared with the calculated results obtained by XCOM and displayed in figure 5. It can be seen from this figure that both the results are in good agreement. It can also be seen from this figure that the linear attenuation coefficients decrease sharply at low energies ($E_g < 0{\cdot}1$ MeV), decreases slowly in the middle range ($0{\cdot}1$ MeV $< E_g < 10$ MeV) and increase at high energies ($E_g > 10$ MeV). This is due to the different photon absorption mechanism for different photon energies (Bashter 1997; Akkurt *et al* 2005b). The calculated and measured linear attenuation coefficients for all composite samples are tabulated in table 2. It is clearly seen in this table that both the calculated and the measured results are in good agreement.

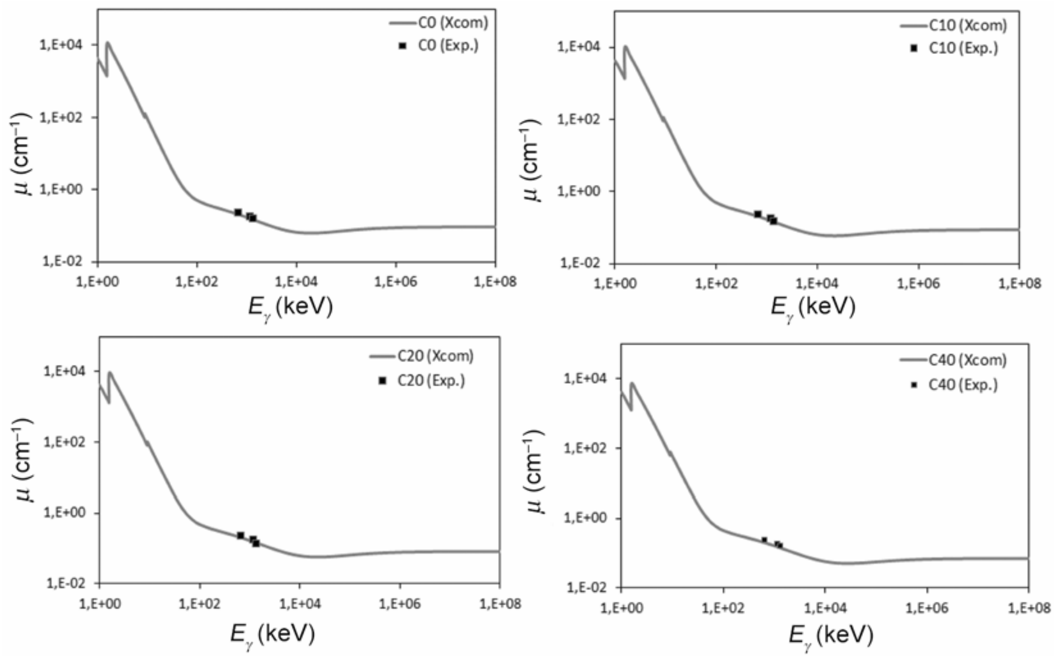

Figure 5. The linear attenuation coefficient of all composite samples as a function of photon energies.

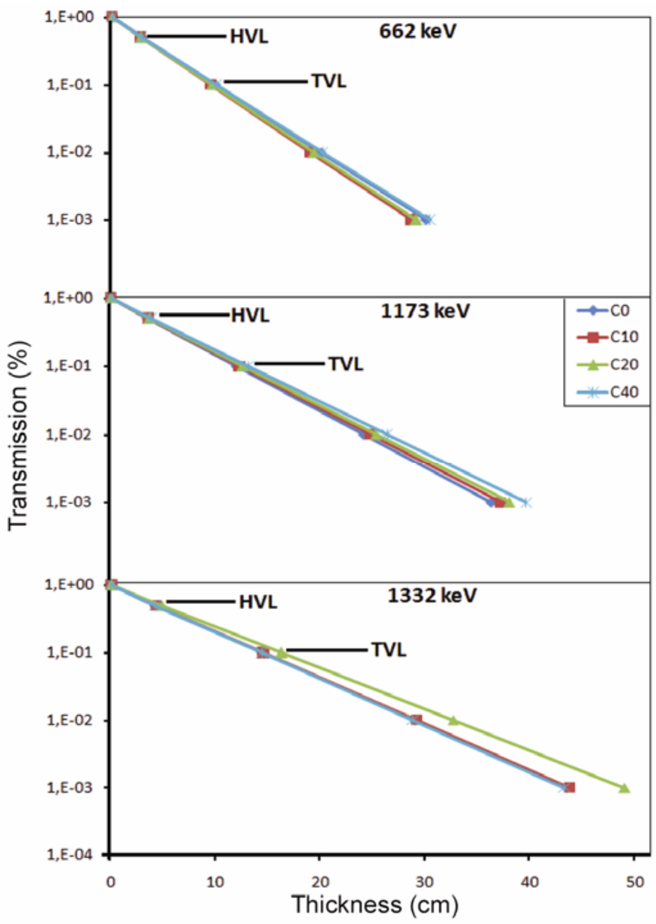

Figure 6. The transmission rate for all composite samples as a function of thickness at different photon energies.

Table 2. The numerical values of the linear attenuation coefficient for all composite samples.

	662 keV		1173 keV		1332 keV	
Composite	Calculation	Experiment	Calculation	Experiment	Calculation	Experiment
C0	0·208	0·233	0·158	0·189	0·148	0·158
C10	0·205	0·244	0·156	0·185	0·146	0·157
C20	0·203	0·240	0·154	0·181	0·144	0·140
C40	0·198	0·230	0·150	0·173	0·141	0·159

The transmission rate of gamma rays obtained for all types of concrete have been displayed in figure 6. It can be seen from this figure that stopping gamma rays property of an MMC decreased by using boron carbide (B_4C).

4. Conclusions

The comparison of measured and calculated linear attenuation coefficients shows good results. It can be concluded from this work that the gamma rays attenuation properties of MMCs can be reduced by adding boron carbide (B_4C) and that the linear attenuation coefficients decreased with the increasing photon energy.

References

Akkurt I, Basyigit C and Kilincarslan S 2004 *Ann. Nucl. Energy* **31** 577

Akkurt I, Basyigit C, Kilincarslan S and Mavi B 2005a *Prog. Nucl. Energy* **46** 1

Akkurt I, Mavi B, Akkurt A, Basyigit C, Kilincarslan S and Yalim H A 2005b *J. Quant. Spectrosc. Radiat. Transfer* **94** 379

Akkurt I, Basyigit C, Kilincarslan S, Mavi B and Akkurt A 2006 *Cem. Concr. Compos.* **28** 153

Akkurt I 2009 *Ann. Nucl. Energy* **36** 1702

Akkurt I, Çalik A and Akyıldırım H 2011 *Nucl. Eng. and Des.* **241** 55

Akkurt I, Altindag R, Günoğlu K and Sarıkaya H 2012 *Ann. Nucl. Energy* **43** 56

Baltaş H, Çevik U, Tıraşoğlu E, Ertuğral B, Apaydın G and Kobya A I 2005 *Radiat. Meas.* **39** 33

Bashter I I 1997 *Ann. Nucl. Energy* **24** 1389

Çevik U, Baltaş H, Çelik A and Bacaksız E 2006 *Nucl. Instrum. Meth. Phys. Res.* **B247** 173

Günoğlu K and Akkurt I 2011 *AIP Conf. Proc.* **1400** 502

Han I and Demir L 2009 *Radiat. Measu.* **44** 289

Kane P P *et al* 1977 *Nucl. Instrum. Meth.* **147** 507

Midgley S 2006 *Radiat. Phys. Chem.* **75** 945

Singh M *et al* 2006 *Appl. Radiat. Isotop.* **64** 373

Singh K, Gagandeep K, Sandhu G K and Lark B S 2001 *Radiat. Phys. Chem.* **61** 537

Turkmen I, Ozdemir Y, Kurudirek M, Demir F, Simsek O and Demirboga R 2008 *Ann. Nucl. Energy* **35** 1937