

PHOTON INTERACTIONS AND RADIATION SHIELDING PROPERTIES OF ALUMINUM ALLOYS

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Abstract

The total mass attenuation coefficients, partial interactions, effective atomic number and effective electron density of aluminum alloys No 5052, No 5083, and No 6010 have been investigated by using WinXCom program in the energy range 1 keV to 108 keV. The results of total mass attenuation coefficients and partial interactions found to be the same trend because the aluminum is the major composition which concentration higher than 90% for aluminum alloys. The photoelectric absorption is the main interaction for energy lower than 102 keV. The result shows that the absorption edge found at 1.56 keV, corresponding to the K-absorption edge of aluminum. The incoherent scattering is the main interaction for energy range 102 keV to 104 keV. For energy higher than 105 keV found that the pair production is the main interaction. The effective atomic number and the effective electron density are also calculated. The result shows that the interaction probability is strongly depend on the effective atomic number and effective electron density.

Keywords: Aluminum alloys, mass attenuation coefficients, partial interaction, WinXCom program

Introduction

Aluminum alloy materials are widely used in many industries due to having high strength, high stiffness, high temperature strength, etc. Most aluminum alloys reaching the market place and have extensive application area (Rana *et al.*, 2012; Yildirim *et al.*, 2016).

Pure aluminum is relatively soft, ductile and corrosion resistant and has a high electrical

conductivity. Some elements are selected to adding into the aluminum alloys for improve some specific properties for some application. Silicon (Si) can reduce thermal expansion coefficient of aluminum alloys. Copper (Cu) increases alloy hardness. Magnesium (Mg) can impart good corrosion resistant. The combination of manganese (Mn) and chromium (Cr) can improve ductility property. Zinc

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(Zn) effects to tensile and electrochemical properties. Iron (Fe) effects ductility property (Gang *et al.*, 2009; Joshi *et al.*, 2009).

The knowledge of radiation shielding parameters such as mass attenuation coefficient, partial interactions (photoelectric absorption, coherent scattering, incoherent scattering and pair production), effective atomic number and electron density are the basic quantities required in determining the penetration of X-rays and gamma ray with matter. These parameters are depended on photon energy, density and chemical composition of materials (Aggrey-Smith *et al.*, 2016). The mass attenuation coefficient is a measure of probability of interaction that occurs between incident photons and matter per unit mass per unit area thickness of the material encountered (Gupta and Sidhu, 2014). Accurate values of mass attenuation coefficients are required to provide essential data in diverse fields such as nuclear diagnostics (computerized tomography), radiation protection, radiation dosimetry, gamma ray fluorescence studies, radiation physics, shielding, security screening and etc (Gounhalli *et al.*, 2012).

Theoretical values for the mass attenuation coefficient and partial interactions can be found in the tabulation by Hubbell (Hubbell, 1982). Then Berger and Hubbell developed XCOM for calculating mass attenuation coefficients or photon interaction cross-sections for any element on a personal computer (Berger and Hubbell, 1987). Recently, XCOM have been reengineering and transformed to the Windows platform by Gerward *et al.* and the Windows version is being WinXCom (Gerward *et al.*, 2001; 2004).

In composite materials, for photon interactions, a single number cannot represent the atomic number uniquely across the entire energy region, as in the case of pure elements. This number for composite materials is known as “effective atomic number” (Z_{eff}) and it varies with energy. The energy absorption in a given medium can be calculated if certain constants are known. These necessary constants are Z_{eff} and electron density N_{el} of the medium. As effective atomic numbers and electron densities are useful in many technological applications (Chaiphaksa *et al.*, 2016).

The aluminum alloys, studied in this work, are aluminum alloys No 5052, No 5083, and No 6061. These alloys are aluminum-based that have other elements, such as Cu, Cr, Zn, Mn, Mg, and Si, in alloy structure. The iron (Fe) is added to aluminum No 5083 and No 6061 for improve the ductility of aluminum alloys (Gang *et al.*, 2009; Joshi *et al.*, 2009; Sritharan and Chandel, 1997). The aluminum alloys can be used as tank material for nuclear reactors, so the knowledge of radiation shielding

properties of aluminum alloys are necessary for this application (Kaewkhao *et al.*, 2008; Limkitjaroenporn *et al.*, 2012; Singh and Badiger, 2013; Elmahroug *et al.*, 2015; Yildirim *et al.*, 2016). The photon interactions of these aluminum alloys have been investigated in energy range 1 keV to 10^8 keV using WinXcom program (Gerward *et al.*, 2001; 2004) in this work.

Theory

The theoretical mass attenuation coefficients of the mixture alloy and compound element have been calculated by WinXCoM, based on the mixture rule (Gerward *et al.*, 2001; 2004). Thus

$$\mu_m = \sum_i^n w_i (\mu_m)_i \quad (1)$$

where $(\mu_m)_i$ is the mass attenuation coefficient for the individual element of alloy, and w_i the fraction by weigh of the individual element of alloy.

The total atomic cross-section ($\sigma_{t,a}$), can be evaluated from the values of the total mass attenuation coefficients by the relation (Limkitjaroenporn *et al.*, 2012; Elmahroug *et al.*, 2015). Thus

$$\sigma_{t,a} = \frac{(\mu_m)_{alloy}}{N_A \sum_i^n (w_i/A_i)} \quad (2)$$

where N_A is Avogadro's number, A_i is atomic weight of composition element of alloy.

The total electronic cross-section ($\sigma_{t,el}$) for the element is expressed by relation (Limkitjaroenporn *et al.*, 2012; Elmahroug *et al.*, 2015)

$$\sigma_{t,el} = \frac{1}{N_A} \sum_i^n \frac{f_i A_i}{Z_i} (\mu_m)_i \quad (3)$$

Where f_i denotes the fraction abundance of the element i with the number of atoms, Z_i is the atomic number of the element i .

The effective atomic number (Z_{eff}) of the material can be defined as the ratio by relation (Limkitjaroenporn *et al.*, 2012; Elmahroug *et al.*, 2015):

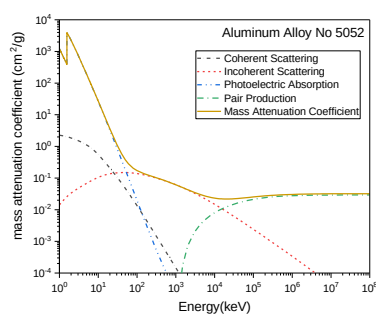
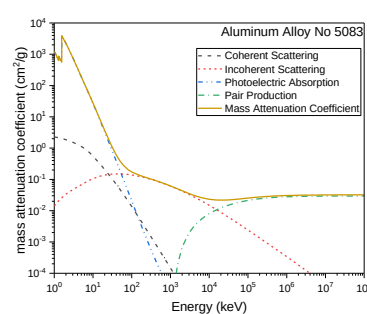
$$Z_{eff} = \frac{\sigma_{t,a}}{\sigma_{t,el}} \quad (4)$$

The effective electron number or electron density (N_{eff}) the number of electron per unit mass, can be calculated by relation (Limkitjaroenporn *et al.*, 2012):

$$N_{eff} = \frac{\mu_m}{\sigma_{t,el}} \quad (5)$$

Table 1. Chemical composition of aluminum alloys (weight fraction)

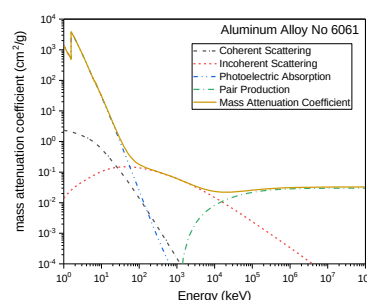
Alloy No	Al	Cu	Cr	Zn	Mn	Mg	Si	Fe
5052	0.9882	0.0010	0.0035	0.0010	0.0010	0.0028	0.0025	-
5083	0.9270	0.0010	0.0025	0.0025	0.0100	0.0490	0.0040	0.0040
6061	0.9615	0.0040	0.0035	0.0025	0.0015	0.0120	0.0080	0.0070

**Figure 1. The total mass attenuation and partial interactions of aluminum alloy No 5052 at the energy range 1 keV-10⁸ keV****Figure 2. The total mass attenuation and partial interactions of aluminum alloy No 5083 in the energy range 1 keV-10⁸ keV**

Results and Discussions

The aluminum alloys in this study are the aluminum alloys No 5052, No 5082, and No 6061 obtained from Sahamit Machinery Public Company Limited. The chemical compositions of these aluminum alloys are shown in Table 1 obtained by ISO standard of aluminum alloys from this company. The compositions show that aluminum (Al) is the major composition for aluminum alloy, Copper (Cu), Chromium (Cr), Zinc (Zr), Manganese (Mg), Magnesium (Mg) and Silicon (Si) are the minor compositions for aluminum alloys. The iron (Fe) found to be the minor composition of the aluminum alloy No 5083 and No 6061 but not added in the aluminum alloy No 5052

Figures 1-3 show the results of total mass attenuation coefficient and partial interaction, calculated by WinXCoM program in energy range 1 keV to 10⁸ keV, of the aluminum alloys No 5052, No 5083 and No 6061, respectively. The results of the coherent scattering show the decreasing trend in energy range 1 keV to 6×10² keV. The photoelectric absorptions show the decreasing trend in energy range 1 keV to 10³ keV and it's found to be the main interaction for energy lower than 10² keV. The absorption edge found at 1.56 keV which corresponding to the K-absorption edge of aluminum alloys No 5052, No 5083, and No 6061. The absorption edge at energy 1.31 keV which corresponding to the K-absorption edge of magnesium occurred for aluminum alloy No 5083. The energy of the K-absorption edge, the aluminum alloys strongly absorb energy at level immediately above their

**Figure 3. The total mass attenuation and partial interactions of aluminum alloy No 6061 in the energy range 1keV-10⁸ keV**

respective edges. The magnitude of mass attenuation coefficient abruptly rises at each K-absorption edge, then gradually decrease above the edges. The incoherent scatterings show the increasing trend in energy range 1 keV to 10² keV but show the decreasing trend in energy range 10² keV to 4×10⁶ keV. The incoherent scattering is the main interaction in energy range 10² keV to 10⁴ keV. The pair productions (occurred at 1022 keV), which corresponding to the rest mass energy of electron and positron, show the rapidly increasing to energy 10⁵ keV and show a little increasing at energy higher than 10⁵ keV. The pair production is the main interaction at energy higher than 10⁴ keV. The total mass attenuation and partial interactions which strongly depended on the energy and chemical composition show the same trend and similar value for aluminum alloys in this work because the aluminum is the major composition which concentration higher than 90% for aluminum alloys.

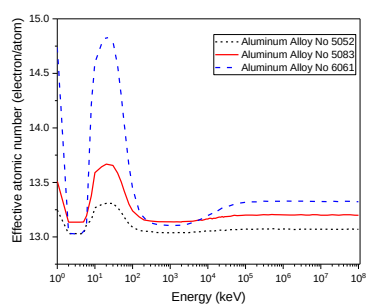


Figure 4. The effective atomic number of aluminum alloys No 5052, No 5083, and No 6061 in energy 1 keV to 10^8 keV

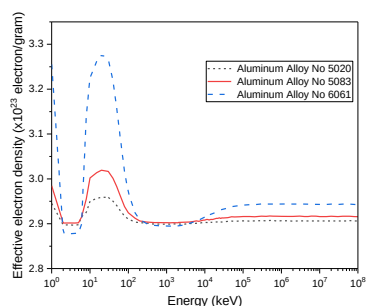


Figure 5. The effective electron density of aluminum alloys No 5052, No 5083, and No 6061 in energy 1 keV to 10^8 keV

Figures 4 and 5 show the effective atomic number and the effective electron density results of aluminum alloys which determined using equation (4) and (5), respectively. For both graph, the peaks are corresponding to the K-absorption edge of aluminum. The strongest peak donated for aluminum alloy No 6061 due to the minor compositions which heavy atomic number have the highest concentration in aluminum alloy. The electron density refer to the electron that interacted when photon passing through and closely related to effective atomic number, so these results are in the same trend and show the interaction probability are strongly depend on effective atomic number and effective electron density.

Conclusions

The photon interactions of aluminum alloys No 5052, No 5083, and No 6061 have been studied in this work. The total mass attenuation coefficients and partial interactions were calculated by WinXCoM program in energy range 1 keV to 10^8 keV. The photoelectric absorption is the main interaction at energy lower than 10^2 keV. The absorption edge found at the energy 1.56 keV which corresponding to the K-absorption edge of

aluminum for aluminum alloys No 5052, No 5083, and No 6061. The absorption edge at energy 1.31 keV which corresponding to the K-absorption edge of magnesium occurred for aluminum alloy No 5083. The incoherent scattering is the main interaction in energy range 10^2 keV to 10^4 keV and the pair production is the main interaction at energy higher than 10^4 keV. The total mass attenuation and partial interactions which strongly depended on the energy and chemical composition show the same trend and similar value for all aluminum alloys in this work due to the aluminum is the major composition which concentration higher than 90%. The effective atomic number and effective electron densities found to be the same trend and show the peak which corresponding to the K-absorption edge of aluminum and show the strongest peak for aluminum alloy No. 6061 due to the minor compositions which heavy atomic number have the highest concentration in aluminum alloy.

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