Caucasian Journal of Science

Volume: 7, Issue: 2, Year : 2020 www.cjoscience.com e-ISSN: 2148-6840

Assessment of Mass Attenuation Coefficient, Effective Atomic Number and Electron Density of Some Aluminum Alloys

Gülçin BİLGİCİ CENGİZ[a,*], İlyas ÇAĞLAR[b]

[a] Kafkas University, Faculty of Science and Letters, Department of Physics, 36100, Kars, Turkey.
[b] Kafkas University, Vocational School of Technical Sciences, Department of Electricity and Energy, 36100, Kars, Turkey.

Araştırma Makalesi Research Article	Fizik Physics	Geliş Tarihi/Received 09.11.2020	Kabul Tarihi/Accepted 30.12.2020

Abstract

Aluminum alloys have numerous application fields in today's technology due to their excellent mechanical features, high electrical and thermal conductivity, magnificent corrosion resistance, good weldability, good formability and similar properties. In the present study, we investigated the mass attenuation coefficient (μ_m), effective atomic number (Z_{eff}) and effective electron density (N_e) of four different type commercially available aluminum alloys. For his purpose, μ_m, Z_{eff}, and N_e values of 5083, 5754, 6061 and 6082 coded aluminum alloys were determined by employing NaI(Tl) gamma ray spectrometry at 661.66,1173.23 and 1332.48 keV gamma ray energies obtained from ^{137}Cs and ^{60}Co radioactive sources. Also these parameters theoretically determined using PhyX-PSD computer program at the photon energies of 1 keV–1 GeV and compared with the experimental results. The variation of μ_m, Z_{eff}, and N_e with incident photon energy presented graphically. From the obtained results it might be concluded that the μ_m, Z_{eff}, and N_e values for studied alloy samples depend on the incident photon energy and elemental composition of alloys. In addition, it was observed from the theoretical and experimental results that aluminum alloys under study have almost the same gamma ray attenuation capacity.

Keywords: Gamma ray, Mass attenuation coefficient, Effective atomic number, Electron density

1. INTRODUCTION

Aluminum and its alloys have been charmed interest of many researchers, engineers and designers because of their high strength to weight ratio superior to steel and corrosion endurance. Aluminum alloys are created by adding copper, zinc, silicon, magnesium, manganese, iron, nickel, titanium and similar elements. The elements added to aluminum improve the properties of the material and make it superior to other metals. These alloys are widely used in many fields in today's technology such as automotive, aerospace, military and also nuclear reactors as the tank material for the TRIGA Mark Reactors as they are light and resistant to high temperatures and some chemical effects (Ozturk, Sisman, Toros, Kilic and Picu, 2016; Yıldırım, Tugrul, Buyuk and Demir, 2010;). Among the aluminum alloys, 6XXX and 5XXX series alloys are widely used in many application areas where good weldability and excellent corrosion resistance are needed. Magnesium is the major alloying element in the 5xxx

Gülçin BİLGİCİ CENGİZ : ORCID:https://orcid.org/ 0000-0002-6164-3232
İlyas ÇAĞLAR : ORCID:https://orcid.org/ 0000-0002-6958-8469
S Sorumlu Yazar/Corresponding Author E-mail: gulcincengiz@kafkas.edu.tr

series alloys and the use of magnesium creates a medium-to-high-strength workhardenable alloy. In the 6xxx series, magnesium and silicon are used together as basic alloying elements. These alloys become heat treatable alloys with the use of magnesium and silicon in the proportions required to form Mg_2Si. Due to the advantages like good extrudability, medium strength, formability, weldability, corrosion resistance and low cost, the application range of aluminum alloys is increasing day by day (Lee, Saito, Sakai and Utsunomiya, 2002). Various studies have been conducted to investigate the mechanical and physical properties of aluminum alloys for potential uses (Ozturk et al. 2010; Lee et al., 2002; Fuller, Krause and Dunand, 2002; El-Rayes and El-Danafa 2012).

Recently with the increase in the use of radiation in various applications in daily life, many researchers have focused on examining the gamma or X ray attenuation properties of many materials to reduce or retain X or gamma rays. In the literature, several experimental or computational studies have been extensively carried out to estimate X or gamma ray attenuation behaviors of diverse materials such as concrete (Akkurt, Basyigit, Kilincarslan and Mavi, 2005; Singh and Badiger 2014; Oto, Gur, Kavaz, Cakir and Yaltay, 2016), glass system (Mostafa, Issa and Sayyed, 2017; Kurudirek, Büyükyıldız and Özdemir, 2010; Sayyed, Kaky, Şakar, Akbaba, Taki and Agar, 2019a) stainless steel (Akkurt 2009; Singh, Medhat and Shirmardi, 2015; Alim, Şakar, Baltakesmez, Han, Sayyed and Demir, 2019) various ores (Oto, Yıldız, Akdemir and Kavaz, 2015) and like.

The mass attenuation coefficient (μ_m), effective atomic number (Z_{eff}) and effective electron density (N_e) are parameters of great importance to characterize the penetration of X or gamma rays in a material. The proper information of these radiation attenuation parameters in several materials is very helpful in medical, technological, agricultural, nuclear, space exploration and engineering applications (Sharma, Sharma, Kaur, Singh, Sharma and Singh, 2017). μ_m is defined as the probability of all interactions that occur between incident photons and the matter of the unit mass per unit area and depends on the incident photon energy and the chemical composition of the absorbing material. (Sharma, Sharma, Singh and Singh, 2012). Z_{eff} and N_e are parameters required to express the atomic and electron numbers of composite materials consisting of many elements such as alloys as a single number at a given energy value, and these parameters depend on the incident photon energy and the elemental diversity in the composite material (Şakar, Büyükyıldız, Alım, Şakar and Kurudirek, 2019).

Many studies have been extensively carried out in recent years for estimating radiation attenuation behaviors of various alloys using experimental techniques or computational methods. Han and Demir (2009) experimentally measured μ_m, Z_{eff} and N_e values for Ti, Ni alloys at 22.1, 25.0, 59.5 and 88.0 keV photon energies. They also investigated variations of these parameters with photon energy. Şakar et al., (2019) investigated radiation attenuation behaviors of some leaded brass alloys. They experimentally determined µm, Z_{eff}, N_{eff} and other shielding parameters of leaded brasses at 53, 276, 302, 356 and 383 keV photon energies and compared with the theoretical values. Akman et al. (2019) studied gamma ray attenuation performance of some ternary alloys consist of Cr, Fe and Ni elements in the energy range of 81 keV-1333 keV. Singh et al. (2018) reported some gamma ray attenuation parameters such as μ_m, Z_{eff} and N_e for some xPb-(1-x)Cu Binary alloys at 511, 662 and 835 keV photon energies. Kurudirek et al. (2010) carried out an extensive study to determine effective atomic numbers of diverse alloys in the energy range of 1keV to 100GeV using WinXCom program. Singh et al. (2015) computed μ_m, Z_{eff} values for steel alloys using Geant4 and MCNP codes in the energy range 279.1–1332keV.Then they compared simulated results with theoretical and experimental data.

The primary purpose of this research is to estimate variation of μ_m, Z_{eff}, and N_e values of four different type aluminum alloys with photon energies. For this purpose, μ_m, Z_{eff}, and N_{eff} values for 5083, 5754, 6061 and 6082 coded aluminum alloys experimentally measured at gamma ray energies of 661.66, 1173.23 and 1332.48 keV. These alloys were chosen because they have good weldability, corrosion resistance, machinability, anodizability and electrical conductivity. Furthermore, these attenuation parameters theoretically computed using PhyX-PSD program developed by Şakar et al. (2020) at the photon energies of 1 keV–1 GeV and compared with the experimental values.

2. MATERIAL AND METHOD

The μ_m, Z_{eff} and N_e values of four different types of aluminum alloys computed using the PhyX-PSD software that utilizes chemical parameters of a mixture materials in the 1 keV−100 GeV energy range. Photon Shielding and Dosimetry (PhyX-PSD) software newly developed by Şakar et al. (2020) is an effective online available software to calculate various shielding and dosimetric parameters such as µm, Z_{eff}, N_e and photon buildup factors for any selected material in the wide energy range of 1 keV–100 GeV (Şakar et al., 2020). The PhyX-PSD is an easy-to-use program that converts all protection and dosimetric parameters above previously introduced in a very understandable and practical method for analysis in MS Excel. The chemical compositions and some physical and mechanical properties of the investigated four types of aluminum alloys are listed in Table 1.

Table 1. The chemical composition and some physical properties for the present aluminum alloys.

Properties	Aluminum Alloys			
	5083	5754	6061	6082
Density (g.cm^{-3})	2.65	2.66	2.70	2.71
Thickness (cm)	0.20	0.25	0.30	0.25
Chemical Composition (Wt. %)	Fe; 0,4%	Fe; 0,4%	Fe; 0,5%	Fe; 0,5%
	Si; 0.4%	Si; 0.4%	Si; 0.6-1.0%	Si; 0.7-1.3%
	Cu; 0.1%	Cu; 0.1%	Cu; 0.6-1.1 %	Cu; 0.1%
	Mn; 0.4-1.0%	Mn; 0.5%	Mn; 0.2-0.8%	Mn; 0.4-0.1%
	Mg; 4.0-4.9%	Mg; 2.6-3.6%	Mg; 0.8-1.2%	Mg; 0.6-1.2%
	Zn; 0.25%	Zn; 0.2%	Zn; 0.25%	Zn; 0.2%
	Cr; 0.05-0.25%	Cr; 0.3%	Cr; 0.1%	Cr; 0.15%
	Ti; 0.15%	Ti; 0.15%	Ti; 0.1%	Al; rest
	Al; rest	Al; rest	Al; rest	
Temper	0/H111	0/H111	T6	T6
Yield strength (MPa)	125-145	80-100	240-270	260-310
Tensile strength (MPa)	275-300	190-215	260-310	310-340
Elongation (%50)	22	24	20	19
Hardness (Brinell)	70-75	50-55	95	95

The narrow beam transmission geometry was employed to measure mass attenuation coefficients of 5083, 5754, 6061 and 6082 coded aluminum alloys. The prepared samples were placed between gamma source and the detector with suitable geometrical arrangement as shown in figure 1. The samples were irradiated by 661.66, 1173.23 and 1332.48 keV gamma rays emitted by ^{137}Cs and ^{60}Co radioactive point sources. The incident and transmitted gamma-rays intensities were measured using a NaI(Tl) scintillation detector based on gamma spectrometry system (Cengiz and Caglar, 2016) The data were collected into 1024 channels of a multichannel analyzer and spectra were analyzed with Ortec Maestro software. Measurements were acquired for a period of 1800s with and without the sample and repeated four times for all samples. Figure 2 shows a typical attenuated and unattenuated γ-ray spectrum obtained from ^{137}Cs and ^{60}Co sources for 5083 coded alloy.

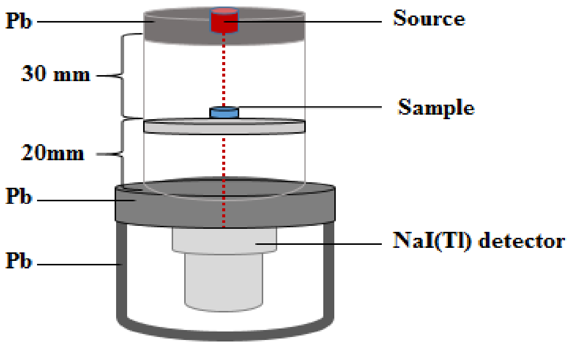

Figure 1. Experimental setup.

The experimental mass attenuation coefficients values of aluminum alloys at different energies were evaluated by the well-known Beer -Lambert law which is given by the equation 1 (Sayyed, 2016; Şakar et al., 2020):

$$I = I_0 e^{-(\frac{\mu}{\rho})x} \quad (1)$$

where, μ/ρ is the mass attenuation coefficient (cm^2g^{-1}), x is the sample thickness (gcm^{-2}), I_0 and I are the unattenuated and attenuated photon intensity, respectively.

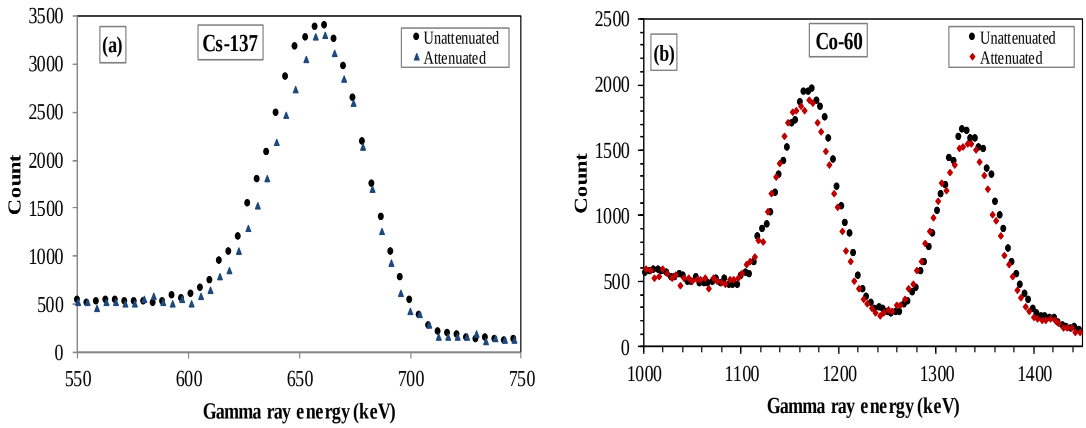

Figure 2. Attenuated and unattenuated gamma ray spectrum obtained from ^{137}Cs and ^{60}Co

2.1. Calculations

The theoretical μ_m values of present alloys were determined using PhyX-PSD program which uses mixture rule given in equation 2;

$$\mu_m = \frac{\mu}{\rho} = \sum_i w_i (\mu_m)_i \quad (2)$$

In this equation, wi and μ_m are the weight fraction and mass attenuation coefficient for individual element in the sample, respectively. The effective atomic number (Z_{eff}) represents the weighted average atomic number of the material consisting of different elements and directly related to total atomic and electronic cross-sections (σ_a and σ_e) through the following formula (Akkurt, 2009; Elmahroug, Tellili and Souga, 2015; Singh et al., 2018):

$$Z_{eff} = \frac{\sigma_a}{\sigma_e} \tag{3}$$

where

$$\sigma_a = \frac{\sum_i f_i A_i}{N_A} \mu_m \tag{4}$$

and

$$\sigma_e = \frac{1}{N_A} \sum\nolimits_i \frac{f_i A_i}{Z_i} (\mu_m)_i \tag{5}$$

where N_A is the Avogadro's number, μ_m mass attenuation coefficient of alloy, f_i, A_i, Z_i and $(\mu_m)_i$ denote fractional abundance, atomiweight, mass attenuation coefficient and atomic number of the of the *ith* element in alloy respectively. Also, the effective electron number is closely related to the Z_{eff} and can be computed using the following equation (Akkurt, 2009; Elmahroug et al., 2015; Sayyed et al., 2016):

$$N_e = \frac{\mu_m}{\sigma_e} = \frac{Z_{eff} N_A}{\sum_i \frac{w_i}{A_i}} \tag{6}$$

where N_A is the Avogadro's number, A_i and w_i is atomic weight and fractional weight of the ith element respectively.

3. RESULTS AND DISCUSSION

The μ_m values of 5083, 5754, 6061 and 6082 coded aluminum alloys were measured at 661.66, 1173.23 and 1332.48 keV gamma ray energies and given in Table 2. While the highest experimental μ_m values were seen in 661.66 keV gamma ray energy for all samples, the lowest values were observed in 1332 keV gamma ray energy.

Table 2. The mass attenuation coefficient (µm, cm^2g^{-1}) for the investigated aluminum alloys at 661.66, 1173.23 and 1332.48 keV gamma ray energies.

Aluminum Alloys	**Gamma ray Energies (keV)**		
	661.66,	**1173.23**	**1332.48**
5083	0.07400	0.05615	0.05419
5754	0.07308	0.05601	0.053903
6061	0.07288	0.05439	0.052966
6082	0.07231	0.05402	0.05242

In Figure 3, it is shown that the experimental µm values of all alloys decrease exponentially with increasing gamma energy.

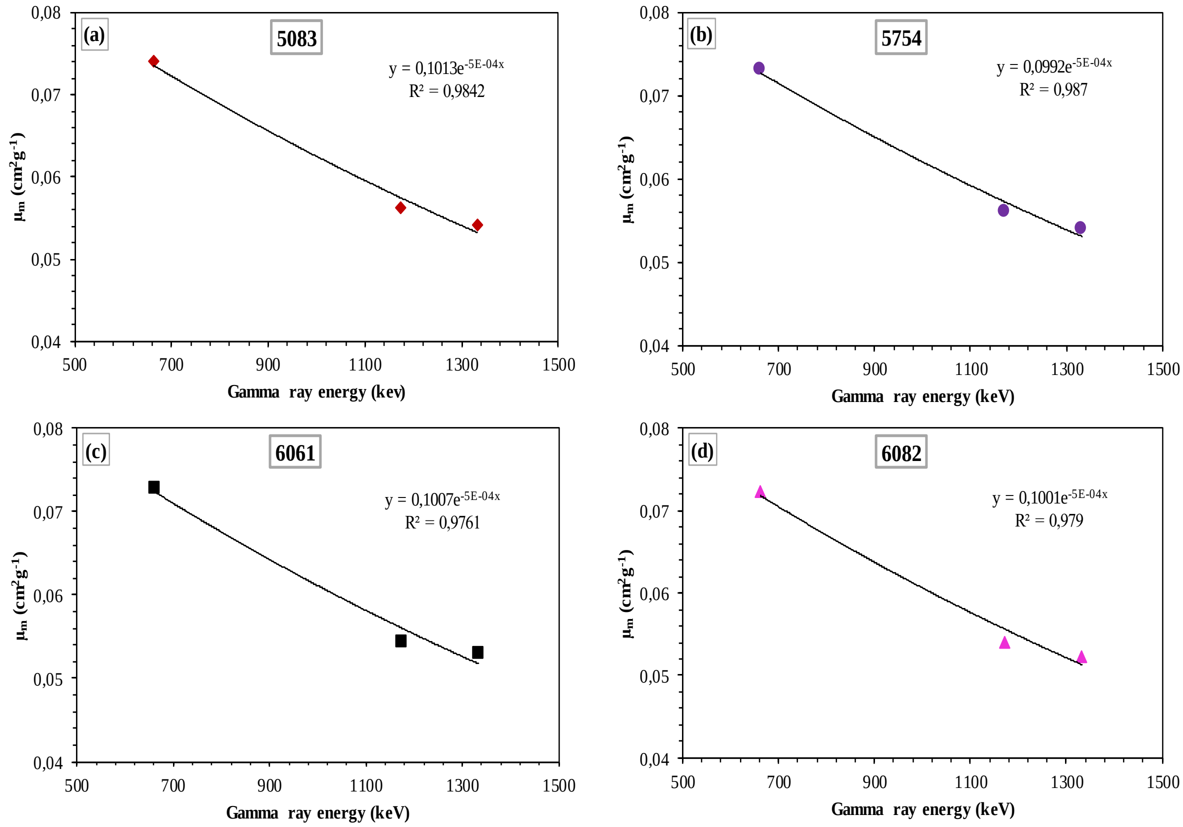

Figure 3. Measured mass attenuation coefficient for (a) 5083 (b) 5754 (c) 6061 (d) 6082 aluminum alloys.

The theoretical μ_m values for studied alloy samples were determined by using PhyX-PSD software in the region of 1keV to 1 GeV. The theoretical results were displayed in figure 4 and compared with the experimental values. As can be seen from the figure 4 (a-d), a good agreement was observed between PhyX-PSD and experimental values (diff. $\leq$ 4.82%). On the other hand, the variations of measured and computed μ_m values with incident photon energy could be seen in figure 4. It observed that the both measured and calculated μ_m values for selected alloys vary with increase in the photon energy.

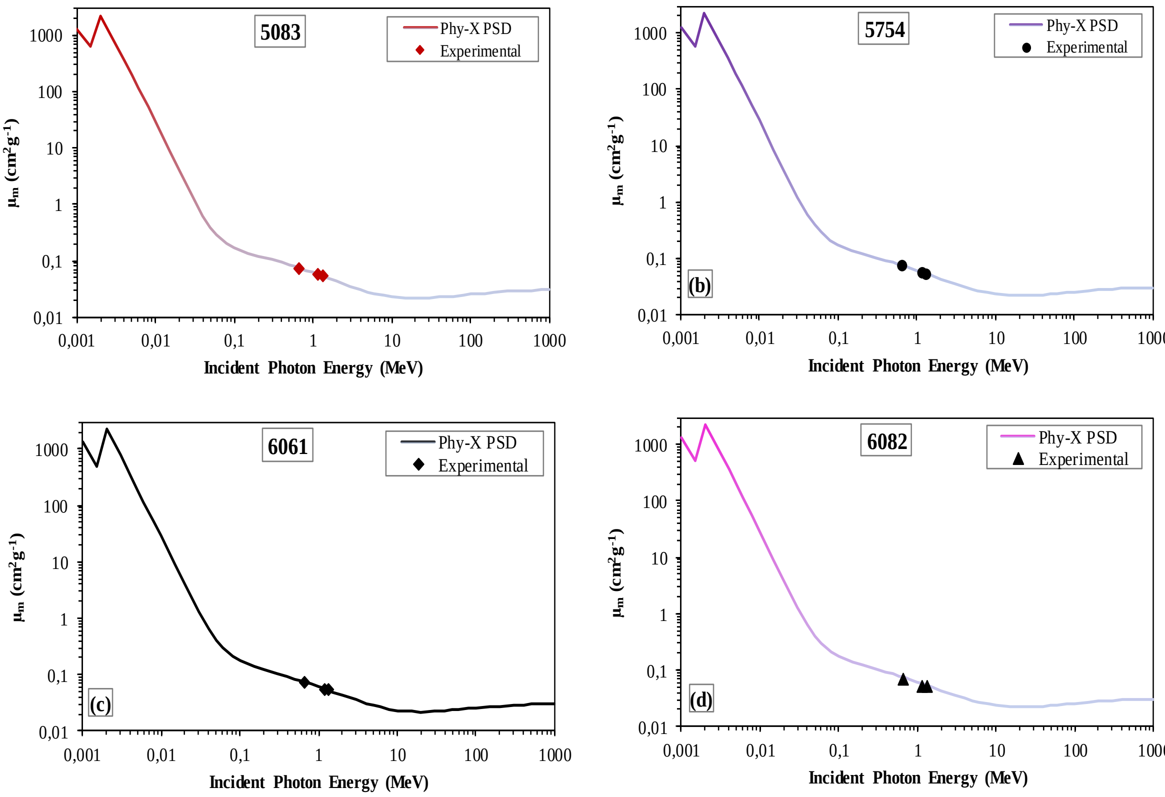

Figure 4. Theoretical and experimental μ_m values of (a) 5083 (b) 5754 (c) 6061 (d) 6082 alloys as a function of photon energies.

According to our findings, it was seen that the μ_m values of four different type aluminum alloys decrease very sharply in the E ≤ 0.1 MeV region, decrease slowly at 0.1 MeV < E < 6 MeV region and slowly increase at E> 6 MeV region. As early discussed by different researchers, these observed variations may be expressed by the fact that different interaction processes occur between photons and materials in different energies. Because photoelectric absorption is the dominant interaction mechanism in the low energy region (0.1 MeV ≤ photon energy for studied samples) and the photoelectric cross section is inversely proportional to the photon energy ($E^{3.5}$). In the moderate energy region (0.1 MeV < incident photon energy < 6 MeV for investigated samples), Compton scattering gradually becomes the dominant interaction process, and the Compton scattering cross-section changes directly with the atomic number Z of the atom in the absorber material and inversely depend on the photon energy (E^{-1}). In the high energy zone (incident photon energy > 6 MeV for investigated samples), the dominant interaction mechanism between the photon and the material is the pair production and the cross section of this event is proportional to Z^2 (Yorgun and Kavaz, 2018; Sayyed, Kaky, Gaikwad, Agar, Gawai and Baki, 2019b; Şakar et al., 2020). In addition, it observed that the μ_m

values of our investigated alloys are consistent with the consequence acquired by Yıldırım et al. (2016) who are investigated radiation attenuation behavior of some aluminum alloys. For example, they measured μ_m values of 6063 coded aluminum alloys as 0.07351cmg^{-1} for 662 keV gamma ray energy and this value is very close to our values. On the other hand, our results consistent with the result by Narender et al. (2013) who determined experimental mass attenuation coefficient values of 5070 aluminum alloys as 0.0751, 0.05742 and 0.05352 cmg-1 for 661.16, 1173 and 1332 keV energies.

Figure 5 (a-d) show the variation of the Z_{eff} values of the investigated aluminum alloy measured for 661.66, 1173.23 and 1332.48 keV energies and theoretically computed for the energy range of 1kev to 1GeV with photon energy. It can be seen from figure 5 that the experimental Z_{eff} values are compatible with the values obtained from PhyX-PSD. At 661.66, 1173.23 and 1332.48 keV gamma ray energies Z_{eff} values were measured as 12.91, 12.90 and 13.28 for 5083 alloy, 12.77, 12.89 and 13.23 for 5754 alloy 12.86, 12.64 and 13.13 for 6061 alloy and 12.66, 12.45 and 12.88 for 6082 alloy, respectively. PhyX-PSD results of Z_{eff} values at the same gamma ray energies were also determined as 13.046, 13,045 and 13.045 for 5083 alloy 13.66, 13.65 and 13.65 for 5754 alloy 13.11 13.10 and 13.10 for 6061 alloy and 13.13, 13.12 and 13,12 for 6082 alloy, respectively. The maximum difference between theoretical and experimental Z_{eff} values was found to be 4.05 percent for 6082 coded sample at 661.66 keV gamma ray energy. Since the main component of alloys is aluminum, effective atomic number values range from 12 to 14 (ie $12<Z_{eff}<14$). In addition, Z_{eff} values for all alloys are quite high in the low energy region where photoelectric absorption is the strong interaction process and reduces with growing photon energy in moderate energies where Compton scattering is the strong interaction process, and increases gradually at higher energies where pair production is the stronginteraction procedure.

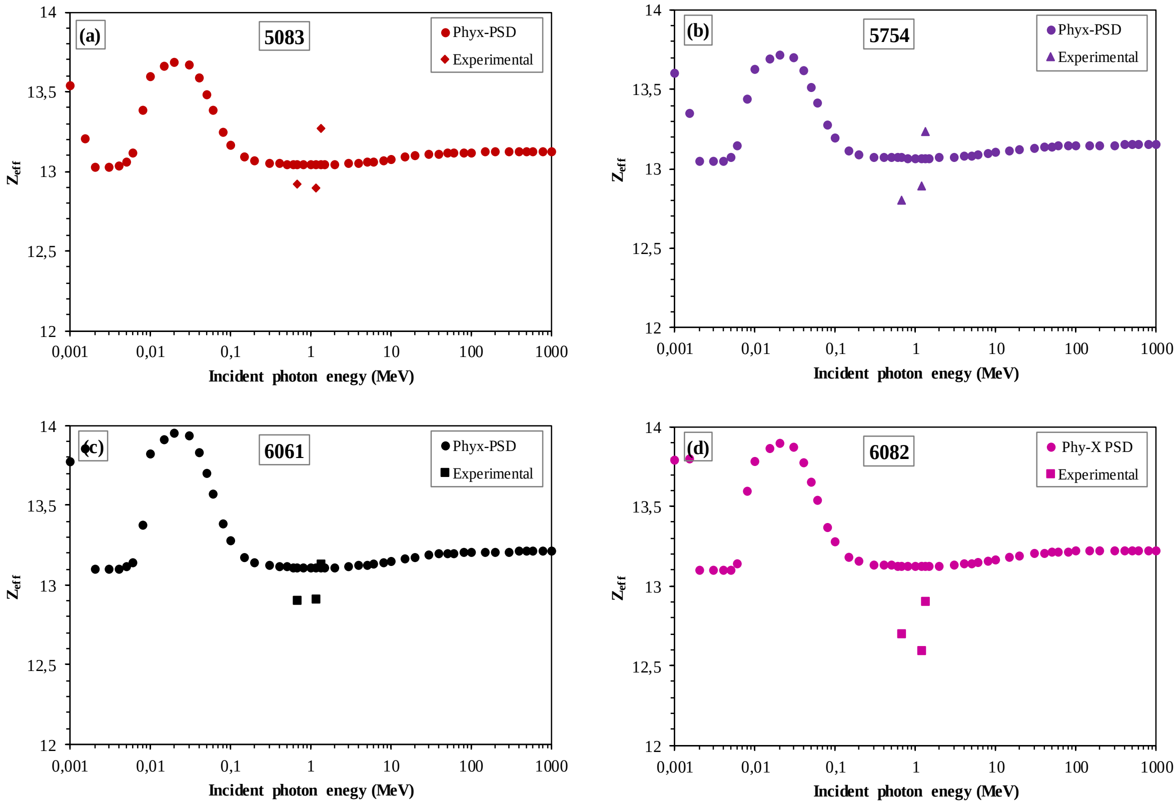

Figure 5. The variations of Z_{eff} for **(a)** 5082, **(b)** 5754, **(c)** 6061 and **(d)** 6082 coded alloys against incident photon energy

The variations of N_e for 5082, 5754, 6061 and 6082 coded samples with energy are given in figure 6 (a-d), respectively. As with the effective atomic number, the theoretical and experimental results of the N_e were found to be compatible with each other. At 661.66, 1173.23 and 1332.48 keV gamma ray energies N_e values were measured as 2.874, 2.870 and 2.55 (×1023electrong-1) for 5083 alloy, 2.838, 2.864 and 2.940 ($\times 10^{23}$electrong^{-1}) for 5754 alloy 2.830, 2.781 and 2.890 ($\times 10^{23}$electrong^{-1}) for 6061 alloy and 2.810, 2.762 and 2.860 ($\times 10^{23}$electrong^{-1}) for 6082 alloy, respectively. PhyX-PSD results of Ne values at the same gamma ray energies were also determined as 2.904, 2.903 and 2.903 ($\times 10^{23}$electrong^{-1}) for 5083 alloy 2.903, 2.902 and 2.902 ($\times 10^{23}$electrong^{-1}) for 5754 alloy 2.901, 2.900 and 2.900 ($\times 10^{23}$electrong^{-1}) for 6061 alloy and 2.902, 2.901 and 2.901 ($\times 10^{23}$electrong^{-1}) for 6082 alloy, respectively. The maximum difference between theoretical and experimental N_e values was found to be 4.15% for 6061 coded sample at 661.66 keV energy. Narender et al. (2013) determined the Z_{eff} values of the 5070 coded aluminum alloy as 13.134 for 661.16, 1173 and 1332 keV gamma ray energies. It was observed that our calculated and measured Z_{eff} values are consistent with the results of Narender et al. (2013). Similarly, the N_e values of the 5070 coded aluminum alloy for the same energies were reported as 2.904×10^{23} electronsg^{-1} by Narender et al. (2013). It was seen that our obtained theoretical and experimental N_e values were also consistent with their results.

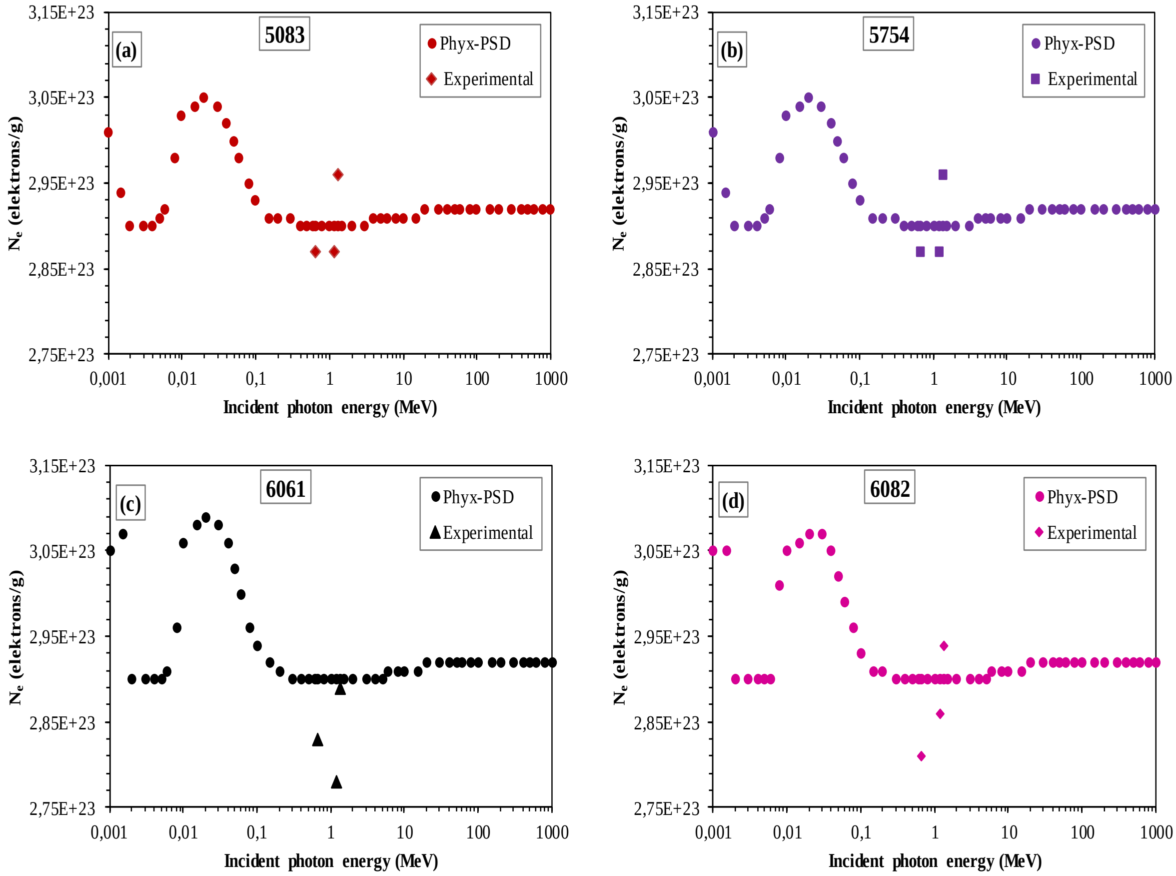

Figure 6. The variations of N_e for **(a)** 5082, **(b)** 5754, **(c)** 6061 and **(d)** 6082 coded alloys with the incident photon energy.

Furthermore, it is seen from figure 6 (a and b) that the Ne values of the aluminum alloys within the scope of the study decrease with increasing photon energy at low energies and the maximum values for N_e are below 100 keV. In the intermediate energies (100 keV – 6 MeV) N_e have minimum values and started to slowly increase above about 6 MeV. This trend observed in N_e values is the same as the trend in Z_{eff} values, because the effective electron density is pretty interrelated to the effective atomic number as it can be seen in equation 5. Hence, obtained trends in this investigation for Z_{eff} and N_e are consistent with the results obtained by Büyükyıldız (2017) who investigated radiological properties of 6061 aluminum alloy and some other shielding materials. On the other hand, it was observed from figures 4, 5 and 6 that there was a sudden jump in the curves of μ_m, Z_{eff} and N_e in the low energy region. This instantaneous splash can be elucidated by the K absorption edge of silicon at 1.839 keV.

4. CONCLUSION

The μ_m, Z_{eff}, and N_e values of 5082, 5754, 6061 and 6082 coded aluminum alloys were experimentally determined at 661.66, 1173.23 and 1332.48 keV gamma ray energies. Also, these parameters theoretically calculated using PhyX-PSD program in the energy region of 1 keV to 1GeV. A decent concurrence was observed among experimental and PhyX-PSD results. It can be concluded that the μ_m, Z_{eff} and N_e values of the aluminum alloys under study depend on the incident photon energy and are influenced by distinct dominant interaction processes (i.e. photoelectric effect, Compton scattering, pair production and etc.) in different energy regions. From the theoretical and experimental results, it was observed that there was no considerable difference among the gamma ray attenuation parameters of the studied aluminum alloys. The results of this work are anticipated to be beneficial in areas like nuclear, aerospace and engineering applications where these aluminum alloys are widely used.

REFERENCES

Akkurt, I., Basyigit, C., Kilincarslan, S., and Mavi B. (2005). The shielding of γ-rays by concretes produced with barite. *Progress in Nuclear Energy,* 46 (1), 1-11.

Akkurt, I. (2009). Effective atomic and electron numbers of some steels at different energies. *Annals of Nuclear Energy,* 36, 1702–1705.

Akman, F., Kaçal, M.R., Sayyed, M.I., and Karataş, H.A. (2019). Study of gamma radiation attenuation properties of some selected ternary alloys. *Journal of Alloys and Compounds,* 782, 315–322.

Alim, B., Şakar, E., Baltakesmez, A., Han, İ., Sayyed, M.I., and Demir L. (2019). Experimental investigation of radiation shielding performances of some important AISI-coded stainless steels: Part I. *Radiation Physics and Chemistry,*160, 108455.

Bilgici-Cengiz, G., and Çağlar, İ. (2016). Determination of the Health Hazards and Life Time Cancer Risk Due to Natural Radioactivity in Soil of Akyaka, Arpaçay and Susuz Areas of Kars, Turkey. *International Journal of Scientific &Engineering Research,* Volume 7(3),619-626.

Büyükyıldız, M. (2017). Investigation of radiological properties of some shielding materials on charged and uncharged radiation interaction for neutron generator. *Radiation Effects and Deffects in Solids,* 172, 216-234.

Elmahroug, Y., Tellili, B., and Souga, C. (2015). Determination of total mass attenuation coefficients, effective atomic numbers and electron densities for different shielding materials. *Annals of Nuclear Energy,* 75, 268-274.

El-Rayes, M.M., and El-Danaf, E. (2012). The influences of multi-pass friction stir processing on the microstructural and mechanical properties of Aluminum Alloy 6082. *Journal of Materials Processing Technology,* 212; 1157–1168.

Fuller, C.B., Krause, A.R., Dunand, C.D., and Seidman D.N. (2002). Microstructure and mechanical properties of a 5754 aluminum alloy modified by Sc and Zr additions. *Materials Science and Engineering A,*338; 8-16.

Han, I., Demir, L., 2009. Mass attenuation coefficients, effective atomic and electron numbers of Ti and Ni alloys. *Radiat. Meas.* 44, 289-294.

Kurudirek, M. (2017). Heavy metal borate glasses: potential use for radiation shielding. *Journal of Alloys and Compounds*, 727, 1227-1236.

Kurudirek, M., Büyükyıldız, M., Özdemir, Y. (2010) Effective atomic number study of various alloys for total photon interaction in the energy region of 1 keV–100 GeV," *Nuclear Instruments and Methods in Physics Research A.* 613, 251–256.

Lee, SH., Saito, Y., Sakai, T., and Utsunomiya H. (2002). Microstructures and mechanical properties of 6061 aluminum alloy processed by accumulative roll-bonding. *Materials Science and Engineering A*, 325:228–35.

Mostafa, A.M.A., Issa, S.A., and Sayyed, M.I. (2017). Gamma ray shielding properties of PbO-B2O3-P 2O5 doped with WO_3. *Journal of Alloys and Compounds*, 708, 294-300.

Narender, K., Madhusudhan, R.A.S., Gopal, K.R.K., Gopi, K.N., and Ashok, R.K. (2013). Determination of effective atomic number and mass attenuation coefficient of 5070 wrought aluminum alloy with multi energetic photons. *Res. J. Phys. Sci.* 1,1-5.

Oto, B., Gur, A., Kavaz, E., Cakir T., Yaltay, N. (2016). Determination of gamma and fast neutron shielding parameters of magnetite concretes. *Progress in Nuclear Energy*. 92, 71- 80.

Oto, B., Yıldız, N., Akdemir, F., and Kavaz E. (2015). Investigation of gamma radiation shielding properties of various ores. *Progress in Nuclear Energy,* 85, 391-403.

Ozturk, F, Sisman, A, Toros, S, Kilic, S, and Picu, R. C. (2010). Influence of aging treatment on mechanical properties of 6061 aluminium alloy. *Materials and Design* 31; 972–975.

Sayyed, M.I., Kaky, K.M., Şakar, E., Akbaba, U., Taki, M.M., and Agar, O. (2019a). Gamma radiation shielding investigations for selected germanate glasses. *Journal of Non-Crystalline Solids,* 512, 33–40.

Sayyed, M.I., Kaky, K.M., Gaikwad, D.K., Agar, O., Gawai, U.P., and Baki, S.O. (2019 b). Physical, structural, optical and gamma radiation shielding properties of borate glasses containing heavy metals (Bi2O3/MoO3). *Journal of Non-Crystalline Solid,* 507, 30–37.

Sayyed, M.I. (2016). Bismuth modified shielding properties of zinc boro-tellurite glasses. *Journal of Alloys and Compounds,* 688, 111–117.

Sharma, R., Sharma, J.K., Kaur, T., Singh, T., Sharma, J., and Singh, P.S. (2017). Experimental investigation of effective atomic numbers for some binary alloys. *Nuclear Engineering and Technology,* 49, 1571–1574.

Sharma, R., Sharma, V., Singh, P.S., and Singh, T., (2012). Effective atomic numbers for somecalcium–strontium-borate glasses. *Annals of Nuclear Energy,* 45, 144–149.

Singh, T., Kaur, A., Sharma, J., Singh, P.S. (2018). Gamma rays' shielding parameters for some Pb-Cu binary alloys. *Engineering Science and Technology, an International Journal,* 21, 1078-1085.

Singh, V.P., Badiger, N.M. (2014). Investigation on radiation shielding parameters of ordinary, heavy and super heavy concretes. *Nuclear Technology Radiation &Protection*. 29 (2), 149-156.

Singh, V.P., Medhat, M.E., and Shirmardi, S.P. (2015). Comparative studies on shielding properties of some steel alloys using Geant4, MCNP, WinXCOM and experimental results. *Radiation Physics and Chemistry,* 106,255-260.

Şakar, E., Büyükyıldız, M., Alım, B., Şakar, B.C., and Kurudirek, M. (2019). Leaded brass alloys for gamma-ray shielding applications. *Radiation Physics and Chemistry*, 159, 64–69.

Şakar, E., Özpolat, Ö.F., Alım, B., Sayyed, M., and Kurudirek M. (2020). Phy-X/PSD: Development of a user friendly online software for calculation of parameters relevant to radiation shielding and dosimetry. *Radiation Physics and Chemistry*, 108496, 1-12.

Yıldırım, S., Tugrul ,A.B., Buyuk, B., and Demir, E. (2016). Gamma Attenuation Properties of Some Aluminum Alloys. *Acta Physica Polonica A*, 129; 813-815.

Yorgun, N.Y., and Kavaz E. (2019). Gamma photon protection properties of some cancer drugs for medical applications. *Results in Physics*, 13 (102150), 1-6.