Scholar **J** *Scholar J 2023, 1:4*

Research Article

Mass Attenuation Coefficient of Some Copper Alloys: A Computational Study

[1]Amanyi, I. M., [2]Ogwuche, E., [3]Onwoke, E.E. and [4]Onoja, E. D.

[1,3,4]Department of Medical Physics, Federal University of Health Sciences, Otukpo, Nigeria.

[2]Department of Science Laboratory Technology, Nigerian Army College of Environmental Sciences and Technology, Makurdi, Nigeria.

Received 3 January 2023; Acceptance 15 January 2023; Published 13 April 2023

Corresponding author: I. M. Amanyi (*matthew.amanyi@fuhso.edu.ng***)**

How to cite this article: Amanyi *et al.,* (2023). Mass Attenuation Coefficient of Some Copper Alloys: A Computational Study *Scholar J*, **1**:4 https://scholarj.com/ojs

Abstract

In this study, mass attenuation coefficient (MAC) of some copper alloys: a computational study was investigated. The study employed both XRF analyzer and XCOM software to determine MAC of a number of copper alloys, namely, brass, copper composite A, gun metal A, copper composite B, gun metal B were determined at 59.5, 356, 511, 661.5, 835, 1173.2, 1275 and 2580 keV. Results reveal that the highest values of MAC were 1.8964keV and 3.6271 keV obtained at 59.5keV for copper composite A and brass respectively. Finding also show the following values of 0.03904 keV and 0.03939 keV at 2589 keV for copper composite A and brass respectively. Based on agreement with experimental results, it was recommended that these results are applied to investigate other properties of materials for radiation analysis.

Keywords: Copper, Alloy, Mass, Attenuation, Coefficient

Introduction

Copper forms the basis for a large well established group of copper –base alloys which possess to a varying degrees property closely allied to those of the metal itself, in particular high corrosion resistance and good working characteristics by all the usual processes. In most commercial alloys, several elements are present in varying proportions to give specific properties. The alloying additions produce the following effects. Aluminium (up to 12 percent) forms the series of alloys known as aluminium bronzes, some of which are single phase and some duplex. These are used for castings and in wrought forms. They have high strength and, having a protective oxide film are resistant to corrosion. Other elements, in particular iron manganese, and nickel, are often added to improve mechanical properties.

The knowledge of mass attenuation coefficient is essential in determining the penetration of x-ray and photons in matter [1]. The measurement of attenuation coefficients of photons in biological and other materials is of significant interest in industrial, biological, agricultural and medical applications [1]. Accurate values of photon mass attenuation coefficients are also needed to establish the regions of validity of theory-based parameterization, in addition to providing essential data in such diverse field's tomography, x-ray fluorescence studies and radiation biophysics [2].

Tabulations of photon mass attenuation coefficients and interaction cross-sections have been published for several elements and composite materials that are of dosimetric and radiological interest [3]. The authors in [4] have also developed a computer program, XCOM, which calculates photon cross-sections and attenuation coefficients for pure elements and mixtures in energy range of 1 Kev to 100 Gev.

Gamma transmission measurements had been used for studying penetration of gamma rays in soil in order to evaluate different properties of soil and soil-water diffusion process [5]. For example, the size distribution of particles for the purpose of characterization of soil can be determined using gamma ray attenuation measurements.

Gamma ray transmission measurements has been used in solid phantoms to investigate the radiological equivalency of these phantoms and their water using transmission curves and compared with Monte Carlo calculations and standard published data [2]. The work resulted in an assessment of the dosimetric response of the solid phantoms as compared to water.

The input data required for determination of mass attenuation coefficient include name of element or compound, chemical symbol of element or compound, atomic number of element or compound and filename where the data is to be stored. Once appropriate input data is provided, the XCOM software automatically generates the value of mass attenuation coefficient at specific energies. In most cases, this may not include energies of interest. In such situations, the mass attenuation coefficient is determined by interpolation. This entails plotting a graph of mass attenuation coefficient versus energy using the data provided by XCOM and determining the mass attenuation coefficient from the slope and intercept of the resulting linear plot. The XCOM package was developed by [4] for calculation of mass attenuation coefficients or photon interaction cross-sections for any element, compound or mixture at energies from 1 keV to 100 GeV. Recently, this well-known and much used program was transformed to the Windows platform by [1].

Using these programs one can calculate the mass attenuation coefficient needed for any element, compound or mixture, at any energy between 1kev and 100Gev.

Owing to the various uses of Cu alloys in electronics, technology, jewelry, radiation protection and in the military, a computational study of mass attenuation coefficient of copper alloys is examined [6-8].

Computational Method

Sample Preparation

The copper alloys used in this research work was obtained at the Metallurgical Research Centre in Jos Nigeria of which Zn 40%, Cu 60% were alloyed to obtain Brass, Cu 70%, Fe 30% were alloyed to obtain Copper Composite A, 92%Cu, 8%Fe were alloyed to obtain Copper Composite B, 10% Cu, 25% Sn, 65% Zn were alloyed to obtain Gun Metal A, 60% Cu, 10%Sn, 30%Zn were alloyed to obtain Gun Metal B.

The copper alloys sample which includes; Brass, Copper Composite A, Gun Metal A, Copper Composite B and Gun Metal B where all shaped into various diameters and were weighed in a Precision Electronic Digital Balance capable of weighing up to a fraction of a milligram. The weighing was repeated a number of times to obtain consistent values of the mass. The mean of this set of values was taken to be the mass of the sample.

The analyses of the material sample were carried out using Pan-analytical EPSILON 3 XRF analyzer. The prepared samples were cut into appropriate size that is easily accommodated by the sample holder of the equipment. The machine (Epsilon 3 XRF). The machine uses a direct excitation method to analyze elements in samples and has been configured with calibration standards and that cover a wide range of element between Na to U.

The analytical procedure involves an initial process of subjecting the machine to perform gain stabilization process in order to stabilize the equipment before commencement of sample analysis. Samples were then loaded on the sample tray which can handle 12 samples simultaneously and specific conditions for analysis including measurement time, X-ray filter, tube current etc set before actual measurement. Quantitative analysis was carried out using the dedicated OMINIAN software which converts the measured intensity to concentration of the various elements present in the samples.

Determination of Mass Attenuation Coefficient using XCOM

Each of the copper alloys obtained were subjected to the XRF analyzer to obtain the various elements present in the alloys with their respective percentages.

The elements with their data obtained were then imputed to the XCOM software from which the mass attenuation coefficient was obtained for the various energy of 59.5, 356, 511, 661.5, 835, 1173.2, 1275, and 2580KeV

The XCOM package was developed by [4] for calculation of mass attenuation coefficients or photon interaction cross-sections for any element, compound or mixture at energies from 1 keV to 100 GeV. Recently, this well-known and much used program was transformed to the Windows platform by [1].

Using the program, the mass attenuation coefficient needed for the copper mixture, at the specified energy level were calculated. WinXCOM has the additional advantage of making it possible to export the cross-sectional data to a predefined MS Excel template. The later feature greatly facilitates any subsequent graphical or numerical data treatment.

It has also been established that there is good agreement between theoretically based XCOM software and experiment, hence the extensive applications of XCOM software in scientific and engineering applications.

Determination of Mass Attenuation Coefficients of Cu-based Alloys

The mass attenuation coefficients of Cu-based Alloys at various photon energies were determined using the mixture rule which is based on the fact that the contribution of each element of the compound or mixture to total photon interaction is the sum of the appropriately weighted proportions of the individual atoms. Thus, the mass attenuation coefficient $(\mu_m)_c$ of compound or mixture is given by:

$$(\mu_m)_c = \sum_i W_i \left(\frac{\mu}{\rho}\right)_i \qquad (1)$$

Where $(\mu_m)_c$ is the photon mass attenuation coefficient for the compound, $(\mu/\rho)_i$ is the photon mass attenuation coefficient for the individual elements in the compound, and w_i is the fractional weight or concentrations of elements in the compound. Thus, in order to determine the mass attenuation coefficient of Cu-based alloys at various photon energies, the weight fractions of the constituent elements were first determined using x-ray fluorescence technique and subsequently used as input data in the mixture rule along with mass attenuation coefficient. Application of equation (1) for determination of mass attenuation coefficient of compounds and mixtures involves averaging over atoms of all the elements in the compound or mixture. This requires the values of mass attenuation coefficient of the individual constituent elements, their weight fractions, atomic number and Avogadro's number as input data.

Results and Discussion

Table 1 shows the theoretical values of the total mass attenuation coefficients of the various Cu-based alloys in the energy range 59.5–2580 keV using the mixture rule and WinXCOM program. It is readily observed that the mass attenuation coefficient for the various Cu-based alloys varies with photon energy and the concentration of elements in the alloys. From Table 1, it is clearly observed that the mass attenuation coefficient is different for different alloy samples. This is attributed to variation in the type and amount of constituent elements in the samples. The mass attenuation coefficient actually represents the average attenuating characteristics of individual elements contained in the alloy samples.

The calculated total atomic and electronic cross-sections (σ_a and σ_{el}) for the Cu based alloys were also presented in Tables 2 and 3 respectively. The changes of σ_a and σ_{el} show almost similar behavior to the mass attenuation coefficient μ/ρ as the values of both σ_a and σ_{el} decrease because the probability of absorption reduces with increasing incident photon energies.

Table 1. Photon Mass attenuation coefficient of some Copper Alloys in cm^2/g

Copper Alloys	Mass attenuation coefficients (cm^2/g) of Cu-based Alloys at various Gamma Ray Energy							
	59.5	**356**	**511**	**661.5**	**835**	**1173.2**	**1275**	**2580**
Brass	3.6271	0.10959	0.08604	0.07503	0.0654	0.05509	0.05103	0.03939
Cu-Composite A	1.89364	0.10284	0.08233	0.07312	0.06460	0.05488	0.05104	0.03904
Gun Metal A	2.04109	0.10395	0.08263	0.07324	0.06464	0.05486	0.05098	0.03900
Cu-Composite B	1.89943	0.10294	0.08237	0.07315	0.06462	0.05489	0.05105	0.03904
Gun Metal B	1.94282	0.10337	0.0826	0.07331	0.06476	0.05499	0.05112	0.03909

Table 2. Effective atomic Cross Section (b/atom) of Copper Alloys

Copper Alloys	Gamma ray energy (KeV)							
	59.5	**356**	**511**	**661.5**	**835**	**1173.2**	**1275**	**2580**
Brass	439.2515	13.2722	10.4200	9.0868	7.9201	6.6720	6.1803	4.7710
Copper Composite A	199.9961	10.8620	8.6959	7.7230	6.8234	5.7964	5.3907	4.1942
Gun Metal A	219.4682	11.1781	8.8850	7.8754	6.9509	5.8988	5.4823	4.1942
Copper Composite B	200.4474	10.8633	8.6931	7.7197	6.8200	5.7932	5.3873	4.1206
Gun Metal B	206.4596	10.9857	8.7777	7.7906	6.8824	5.8443	5.4331	4.15480

Table 3. Effective Electronic Cross Section (b/atom) of copper alloys

	Gamma Ray Energy (KeV)							
Copper Alloys	**59.5**	**356**	**511**	**661.5**	**835**	**1173.2**	**1275**	**2580**
Brass	15.2889	0.4432	0.3623	0.3042	0.2570	0.2119	0.1948	0.1503
Cu Composite A	14.1908	0.4306	0.3187	0.2776	0.2415	0.2035	0.1883	0.1452
Gun Metal A	18.4643	0.5524	0.3637	0.3057	0.2585	0.2135	0.1962	0.1524
Cu Composite B	24.9586	0.5675	0.3675	0.3073	0.2587	0.2129	0.1956	0.1514
Gun Metal B	14.8331	0.5379	0.3574	0.3012	0.2552	0.2110	0.1940	0.1502

Conclusion

Mass attenuation coefficient (MAC) of some copper alloys: a computational study is presented. Photon mass attenuation coefficient of some copper alloys such as brass, copper composite A, gun metal A, copper composite B, gun metal B were determined at 59.5, 356, 511, 661.5, 835, 1173.2, 1275 and 2580 keV using XCOM software and X-ray fluorescence analyzer. The attenuation coefficients were then used to compute the effective atomic number and electron density of copper alloys in photon energy range 59.5- 2580 keV. Results reveal that the highest values of MAC were 1.8964keV and 3.6271 keV obtained at 59.5keV for copper composite A and brass respectively. Finding also show the following values of 0.03904 keV and 0.03939 keV at 2589 keV for copper composite A and brass respectively. Based on these variations with photon energy which agree with result of experimental works [5,9,10], results of the present study can be applied to investigate other properties of materials for radiation analysis which is recommended.

References

[1]. Gerward L, Guilbert N, Jensen K.B and Levring H;(2001) Radiat. Phys. Chem. P.60

[2]. Hill–Sachs L, Workman T.L, and Goff W.B (1992) Comparison of detection with MR imaging, radiography and arthroscopy. Journal of the Korean society of magnetic resonance in medicine 17. P.26.

[3]. Hubbel J.H and Seltzer S.M (1995) Tables of X-ray mass attenuation coefficients and mass energy absorption coefficients and mass energy absorption coefficients 1KeV – 20MeV for elements Z=1 to 92 and 48 additional substances of dosimetric interest. NISTIR.

[4]. Berger M.J, Hubble J.H, (1999). XCOM: photon cross section database. Web Version 1.2 available at http://physics.nist.gov/xcom Originally published as NBSIR 87-3597 XCOM: Photon Cross Sections on a Personal Computer. Washington DC.

[5]. Baytas, A.F and Kabal S. (2002) Determination of soil parameters Gamma-ray Transmission. Radiation measurements. Nigeria Journal of Physics 35p17–21

[6]. Jackson D.F and Hawkes D.J (1985) Tissue analysis by dual energy computed tomography. British journal of cancer Vol 110(1) p64-69.

[7]. Shivaramu, Vijayakumar R, Namamurthy N and Rajasekaran L (2001) Effective atomic numbers for photon energy absorption of some low Z substances of dosimetric interest. Radiation Physics and Chemistry. 62(5) p.371-377.

[8]. Tursucu A, Onder P, Demir D and Oznuluer T (2013) Studies on mass attenuation coefficient, effective atomic number and electron density of some amino acids. International Journal of Physics vol 8 (4). P147-156.

[9]. Okunade, I. O., Adebe G. I., Jonah S. A. and A. O. Oladipo. (2008). Measurement of Mass Attenuation Coefficient of Zaria soil using Gamma Ray Transmission Method. *Nigeria Journal of Physics* 20(1): 23-28.

[10]. Gowda T.K. Yashoda.T, Krishnavenis .S and Umesh T.K (2003) X-ray production cross-sections and fluorescence yields in some low Z elements excited by 14.4KeV Photons P.78,323.