Calculation and Study of Gamma ray Attenuation Coefficients for Different Composites

K.H.Mahdi, Z.S.Ahmed*, A.F.Mkhaiber
Department of Physics , College of Education Ibn Al-Haithem, University of Baghdad
***Ministry of Science and Technology.**
Received in :18 Sptember 2011, Accepted in: 12 February 2012

Abstract

In this work, the total linear attenuation coefficients μ (cm^{-1}) were calculated and studied for particulate reinforced polymer-based composites. Unsaturated polyester (UP) resin was used as a matrix filled with different concentrations of Al, Fe, and Pb metal powders as reinforcements. The effect of the metal powders addition at different weight percentages in the range of (10,20,30,40,50)wt % and gamma energy on attenuation coefficients was studied. The results show, as the metallic particulates content increase, the attenuation coefficients will increase too, while it, were exhibited a decrease in their values when the gamma energy increase.The total linear attenuation coefficients of gamma ray for 15 composites have been calculated using the XCOM program (version 3.1) in the energy range of 0.1-20 MeV.

Key words: linear attenuation coefficients, composite materials, gamma ray.

Introduction

Shielding is one of the most effective radiation protection methods; others include time and distance. With shielding, radiation dose can be lowered to a desired level [1].Furthermore; different types of radiation can be shielded by different types of materials [2]. For shield designs, gamma ray was one of the main types of nuclear radiation, which have to be considered; since any shield attenuates the gamma rays will be more effective for attenuating other radiations [3]. Recently, there was a continuous demand for improved polymers for use as shielding materials [4]. Therefore, composite materials used for this purpose. Composites is a material brought about by combining materials differing in composition or form on a macroscale for the purpose of obtaining specific characteristics and properties. Composites consist from two components: matrix and reinforcement [5] . Reinforcement materials played the important role to improve the matrix properties. Since polymeric materials are on their own hydrocarbonic substances we would expect good neutron moderation then, with the good choice of metallic fillers, gamma rays and X-rays could be also shielded [6,7].Therefore, in this study, we attempted to prepare and characterize the polymer based composite radiation shields using unsaturated polyester resin as a matrix and Al, Fe, and Pb as filler with different concentrations (10,20,30,40,50)wt%. Then, the effect of gamma energy and filler concentrations on attenuation coefficients was studied.

Linear attenuation coefficient (μ) :

In the design shielding materials , the linear attenuation coefficient (μ) which is defined as the probability of a radiation interacting with a material per unit path length, is important quantity and its magnitude depends on the incident photon energy and on the atomic number of the material, as well as, on the density (ρ) of the shielding material [8].Also,the mass attenuation coefficient (μ / ρ) ($cm^2.g^{-1}$) directly measures the effectiveness of a shielding material based upon unit mass of material. Generally, calculations of the mass attenuation coefficient at high energies are widely needed and used as a radiation shielding design database for radiation sources, reactors and particle accelerators.[9].

Calculation of the total linear attenuation coefficients (μ):

In shielding calculations, materials made of homogeneous mixture of elements are frequently encountered. For a mixture of known composition, the total mass attenuation coefficient μ/ρ ($cm^2\ g^{-1}$) can be determined from basic data by relationships [10]:

$$\mu = \sum_i \mu_i = \sum_i N_i \sigma_i \qquad (1)$$

$$\mu/\rho = \sum_i w_i \left(\mu/\rho \right)_i \qquad (2)$$

Where μ : the total linear attenuation coefficient, cm^{-1}.

N_i: number of atoms, cm^{-3}.

σ_i : Microscopic cross section, cm^2.

ρ_i : Density of the i th constituent, g .cm^{-3}.

w_i : Proportion by weight of i th constituent.

The total linear attenuation coefficients (μ) were calculated for the 15 (unsaturated polyester / metal) composite samples using a computer program called XCOM (version 3.1). The used XCOM program and database cross sections for elements ranging from Z=1 to 100 have been recently modified to calculate the total mass attenuation coefficients (μ/ρ) for elements, compounds and mixtures from1 keV to 100 GeV [11], and provides total cross section as well as partial cross sections for various interaction processes. With a known density (ρ) of shield materials, the total linear attenuation coefficients (μ) were extracted from calculated results of XCOM.

The density of composite materials was calculated using the rule of mixtures formula given by the following equation [12]:

$$\rho_c = V_f \rho_f + (1 - V_f)\rho_m \quad (3)$$

Where ρ_c, ρ_f, ρ_m : Density of composite body, reinforcement and the matrix materials respectively.

V_f : Fractional volume for reinforcement material which could be calculated from the equation:

$$V_f = 1 / \left[1 + \left(\frac{1-\psi}{\psi} \right) . \frac{\rho_f}{\rho_m} \right] \quad (4)$$

: Fractional weight for reinforcement materials: ψ Where

$$\psi = \frac{W_f}{W_c} \times 100\% \quad (5)$$

$$W_c = W_f + W_m \quad (6)$$

W_c, W_f, W_m : Weight of composite, reinforcement and matrix materials respectively [13].

Results and Discussion

In fig (1) , the linear attenuation coefficient (μ) was displayed as a function of the applied energy, it was clear that linear attenuation coefficient (μ) sharply decreased with the increase of the photon energy in the range (0.1-1) MeV for all composites .Such a behavior could be ascribed to the photoelectric and Compton scattering which were the main predominant interactions in this region. This sharp decrease was considered to be an indication that the (μ) was very sensitive to the photon energy.

In the range (1-5) MeV the total linear attenuation coefficients (μ) were noticed to decrease with the increase of the photon energy for all composites. In this region, the dominant interaction is pair production [14]. This slight decrease indicates that the (μ) is not very sensitive to the variations in the photon energy in this region.

In the region (E>5) MeV , there was no significant decrease in the values of total linear attenuation coefficient (μ) with increase of the photon energy for all composite samples and this could be attributed to the successive collisions, due to several Compton scatterings. There is an agreement with the results of [14,15].

In fig (2), the total linear attenuation coefficient (μ) displayed as a function of concentration of metal powders (Al, Fe and Pb) at the different energies. From this figure one may notice that the total linear attenuation coefficient (μ) increased with the increase of metal concentration, especially within low photon energy, but at higher energies there was no clear change in the (μ) .This could explain that as the concentration of metal powders increased, the absorption process will also increase and this mean an increase in the (μ) values. From table (1), the total linear attenuation coefficients (μ) calculated for the unsaturated polyester (UP) had the minimum values and reached a maximum values for composite samples containing 50% of different powder metals. The improved shielding capability of (UP) metal powder composites could be explained on the fact that, unsaturated polyester (UP) matrix is a bad shielding material, but when some filling metals powders add to it, it was modified and become a good shielding material. In other word, an increase in the probability of interaction between the incident gamma radiation and the shield atoms was happened. Thus, one may conclude that, the total linear attenuation coefficient of the composites was increased with increased filler content in the composites samples prepared.

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Table (1):Linear attenuation coefficient values at different energies for composite samples filled with(Al,Fe and Pb) powders at different weight percentages

Al					
ENERGY (Mev)	**μ (cm^{-1})**				
	Al 10% wt	**Al 20% wt**	**Al 30% wt**	**Al 40% wt**	**Al 50% wt**
0.1	0.198768	0.2128434	0.2287365	0.247079	0.268441
0.5	0.1121637	0.11839905	0.1254903	0.1336029	0.1430604
1	0.0818565	0.08638091	0.09152258	0.09741972	0.10427838
5	0.0351657	0.03739813	0.03992746	0.04283704	0.04621078
10	0.0258423	0.02781625	0.03006451	0.03263846	0.03563534
15	0.0226689	0.02463538	0.02687479	0.0294392	0.03242378
20	0.0212175	0.02322166	0.02550377	0.02813246	0.03117484

Fe					
ENERGY (Mev)	**μ (cm^{-1})**				
	Fe10% wt	**Fe20% wt**	**Fe30% wt**	**Fe40% wt**	**Fe50% wt**
0.1	0.2303956	0.2835144	0.3488362	0.431376	0.5382564
0.5	0.11559088	0.12635124	0.1395968	0.1563232	0.1780371
1	0.0841952	0.09182064	0.10122326	0.11308	0.12845766
5	0.0366452	0.04080762	0.04591426	0.0523776	0.06074088
10	0.02749024	0.0315948	0.03664416	0.0430144	0.0512577
15	0.02451044	0.02881278	0.0341202	0.0408144	0.04949856
20	0.02321708	0.0277503	0.0333412	0.040392	0.049539

Pb					
ENERGY (Mev)	**μ (cm^{-1})**				
	Pb 10% wt	**Pb 20% wt**	**Pb 30% wt**	**Pb 40% wt**	**Pb 50% wt**
0.1	0.8910356	1.749294	2.820099	4.19196	6.00692
0.5	0.12597312	0.1494954	0.1790136	0.216657	0.2663664
1	0.08600774	0.0959427	0.10837623	0.1243108	0.14532328
5	0.03825822	0.04442472	0.05213295	0.0620106	0.07504968
10	0.03014284	0.03752928	0.04673715	0.0585535	0.07414496
15	0.02788786	0.03637062	0.0469752	0.0605445	0.07850024
20	0.02712346	0.03648366	0.04816545	0.0631328	0.08291864

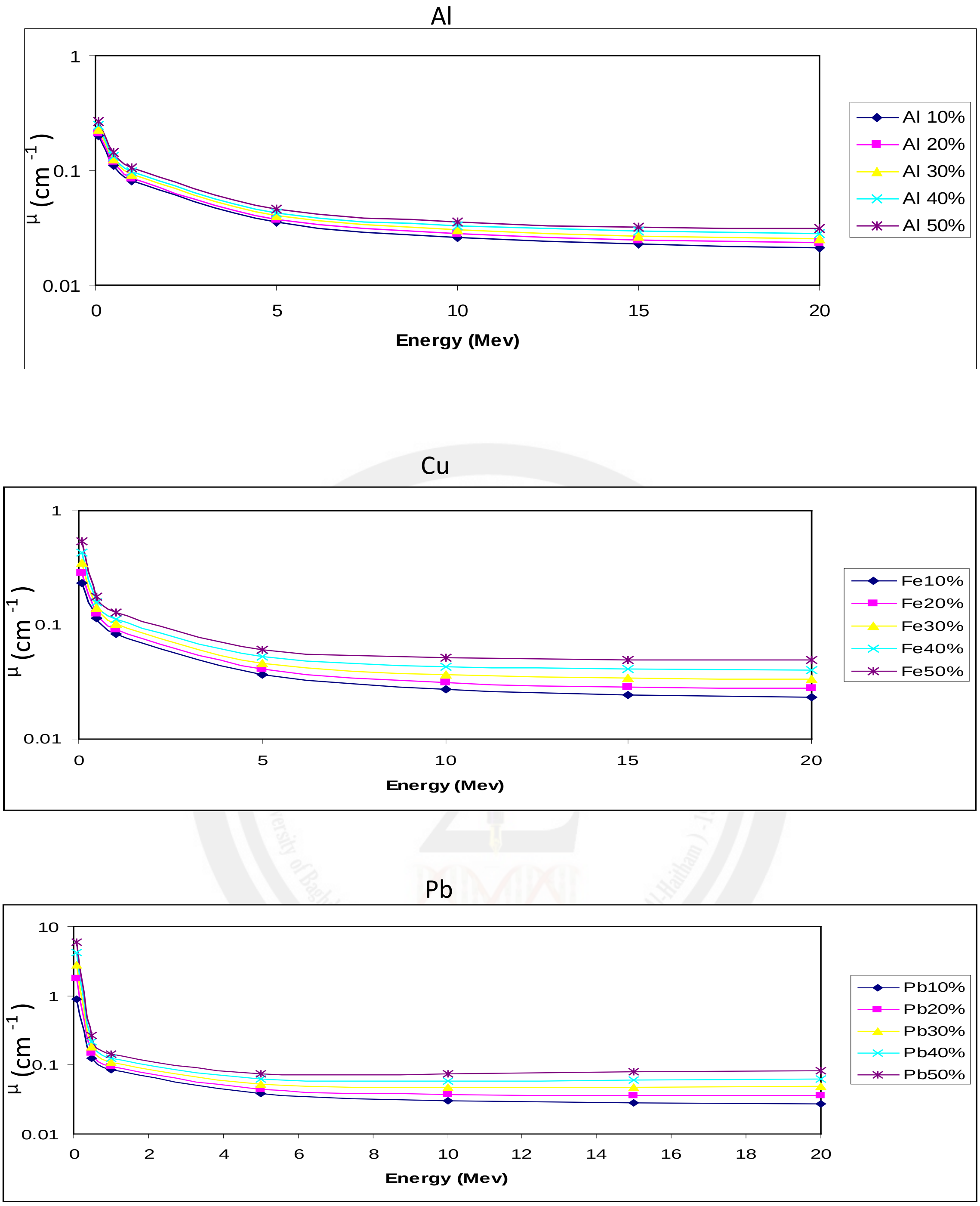

Fig .(1):Total linear attenuation coefficient (μ) as a function of energy (E) at different concentrations of (Al,Fe and Pb)

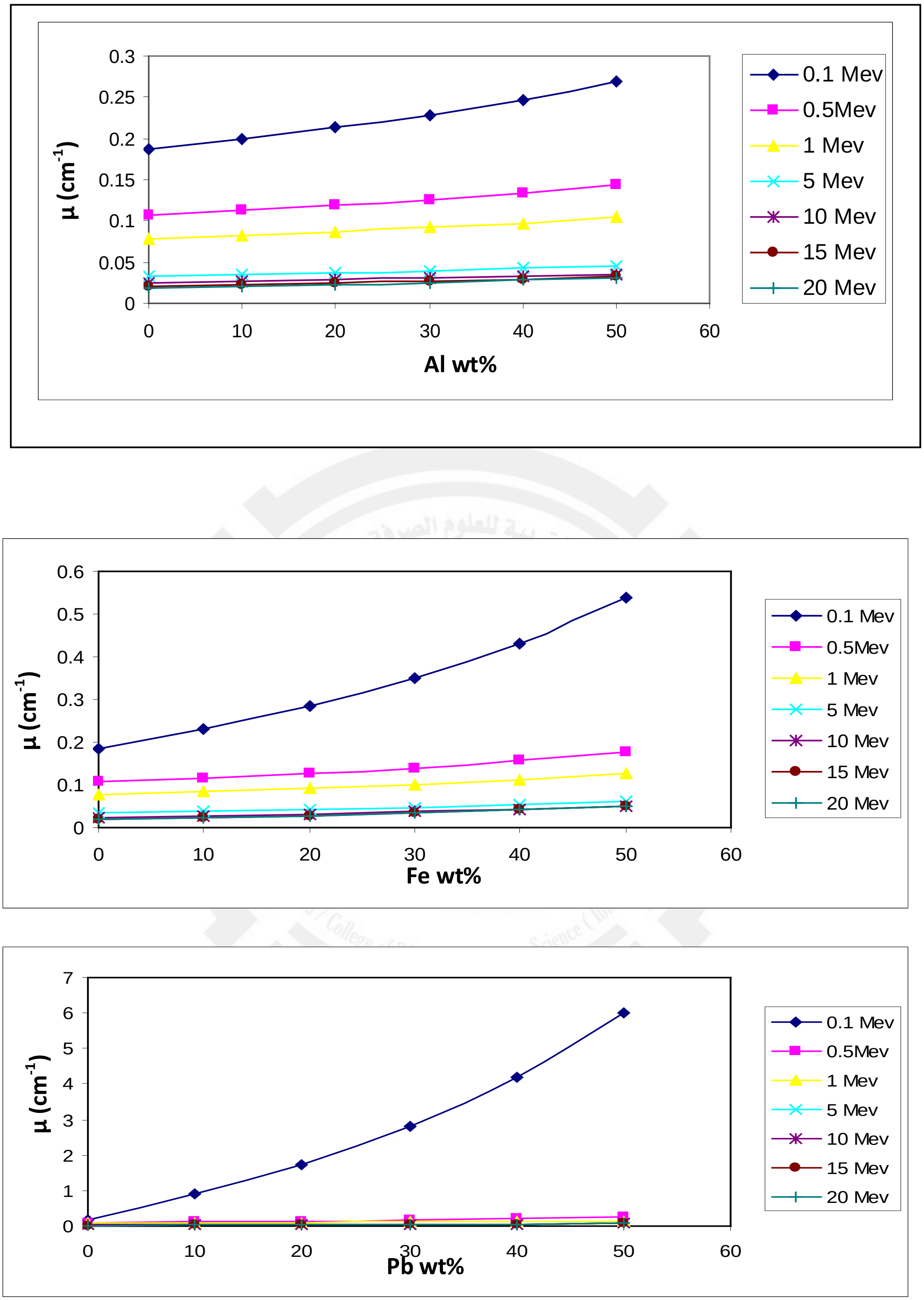

Fig .(2):Total linear attenuation coefficient (μ) as a function of concentration of (Al,Fe and Pb) at different energies

حساب ودراسة معامل توهين أشعة كاما لمتراكبات مختلفة

خالد هادي مهدي، زياد شهاب احمد*، احمد فاضل مخيبر
قسم الفيزياء، كلية التربية، جامعة بغداد
*** وزارة العلوم والتكنلوجيا**

استلم البحث في: 18 ايلول 2011 ، قبل البحث في: 12 شباط 2012

الخلاصة

في هذا البحث ، حُسب ودُرس معامل التوهين الخطي الكلي (μ) (cm^{-1}) لمتراكبات بوليميرية مدعمة بالدقائق مكونة من راتنج البولي استر غير المشبع (UP) (كمادة أساس) مدعم بتراكيز مختلفة من (الألمنيوم، والحديد، والرصاص) (مواد تدعيم). دُرس تأثير اضافة المساحيق المعدنية عند تراكيز (10،20،30،40،50)%، وكذلك طاقة أشعة كاما على معاملات التوهين. أظهرت النتائج انه عندما يزداد تركيز المعدن فان معامل التوهين سوف يزداد ايضا، بينما ظهر ان هناك نقصاناً في قيم معاملات التوهين عندما تزداد طاقة اشعة كاما. ان معاملات التوهين الخطية الكلية ولـ 15 متراكبة حسبت باستخدام البرنامج (XCOM) (version 3.1) ضمن المدى الطاقي (0.1–20) مليون إلكترون – فولت.

الكلمات المفتاحية: معامل التوهين الخطي ، المواد المتراكبة ،أشعة كاما.