Study of the shielding properties for some composite materials manufactured from polymer epoxy supported by cement, aluminum, iron and lead against gamma rays of the cobalt radioactive source (Co-60).

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ABSTRACT

In this research, we have study the shielding properties against gamma rays with energy (0.662MeV) emitted from the radioactive source of (Cs-137) for the shields of epoxy polymer supported by cement, aluminum and lead using a Geiger-Muller Counter tube detector. The numerical buildup factor and the linear attenuation coefficient were accounted as a function for the concentration of lead in shields in range of (5-50%), and as well as the numerical buildup factor and the linear attenuation coefficient as a function of the shield thickness of shields that supported by concentration of (50%) of iron powder in the range of (6 - 30)mm. The results showed a decrease in the buildup factor and increase in the linear attenuation with increase the concentration, while the observed increase in the buildup factor and in the linear attenuation coefficient with increase the thickness of shields in the certain concentration of (50%). Effect of adding other substances as Iron and adding more substance to strengthen the epoxy has also been study in this work with concentration rate of (50%) for each case. Study of the buildup factor and the attenuation coefficient for all shields samples with concentration (50%) Showed that the buildup factor value is greater as possible and that the value of the attenuation coefficient is little as possible in case pure epoxy (without any substance addition), and little as possible of the buildup factor value and greater as possible of the attenuation coefficient value in case of strengthening the epoxy with concentration (50%) of equal blocks mixture of lead, iron, aluminum and cement powders.

1.INTRODUCTION

Nuclear shields protective radiation play many functions most important to reduce radiation exposure to people in the whereabouts of radiation, they are working on the attenuation of radiation and reducing the intensity, so the theme of the protective shields of radiation which has become an important part in our daily lives is one of the important things, especially after the great scientific progress which began to concentrate on the subject of the use of radioactive materials and other sources of radiation in medical and agricultural fields as well as other scientific fields such as building of nuclear reactors, as well as researches reactors in the field of power generation.[1]

Polymers-supported mineral have been used to replace the metal lead in the shielding of medical devices, especially that are used in nuclear medicine after that possessed a small shielding properties when compared to the lead as well as they are characterized by being non-toxic and easy configuration and low-cost materials.

The high-density composite materials have similar behavior of heavy metals when increasing the proportion of material supported in composite material.

D.K. Trubey submitted in 1966 [2]. The report is an important reference to the present day, and included a survey of the most important empirical equations used to calculate the buildup factor, also included calculation of buildup factor of various types and by a large extent of energy using the point source and the symmetric level.

H.A.Y. AL-Ammar in 1996 [3] studied buildup factor and dispersion angular of source (Co-60) and the scintillation detector (NaI (Tl)) for single and multi layers shields and for seven materials (concrete, aluminum, iron, steel, copper, brass, and lead), and the results showed the single shields and thickness of approximately 4mfp that values increase with free path increasing and decrease with increasing atomic number of the shield.

It also K. Abdo in 1999 [4] measured buildup factor of gamma radiation using shields composed of a single layer and two layers for several formations of materials (aluminum, iron, lead) using (Co-60) and (Cs-137) sources and was found that buildup factor value decreased with increasing atomic number.

A study by N.J.D. Fatohi in 2006 [4] had been to calculate the numerical buildup factor of (Co-60) and (Cs-137) sources using the scintillation detector for powder of Iraqi black carbon and graphite substances after mixing them with epoxy substance at the energy (1.25MeV). The study showed that the buildup factor depends on the ratio of mixing, bulk density and type of material and decreasing of buildup factor with increasing of mixing ratio and bulk density were observed, and the buildup factor values for Black carbon higher than it is for graphite, either when energy (0.662MeV) there is little effect of the thickness of the mixing ratios, density and type of material and the buildup factor decreases with increasing energy radioactive source.

In 2007, S. Dasharatham [5] had studied the properties of shielding against gamma rays and neutrons for composite materials where use of lead and some of its compounds, boron and some of its compounds, lithium and some of its compounds and glass supported by lead in different proportions, and he use of several mixed materials in different proportions and classified them depending on the grain size. It was concluded that shielding gamma rays and neutrons techniques using of multiple compounds composite materials that be balanced between them gives results better than those using the mixtures of composite material that contains a compound one because the portion of the multiple compounds composite materials captivates gamma rays and the other weakens neutrons .

2.THEORETICAL CONSIDERATIONS

The study of the properties of a substance shielding against gamma rays are mainly dependent on calculation radiation attenuation coefficient values and buildup factor of radiation in the article. The processes that you get when gamma rays passing through the material is a complex process, the photon interacts in many ways, but the main important interactions that are high probability of occurrence can be classified into three reactions are:

2.1. Photoelectric Effect

It is the interaction between the photon gamma rays and electron associated with the atom and as a result of this process gives a photon all his energy to the electron orbital and then the electron spewing and to be free, and the proportion of this interaction to occur directly proportional to the fourth power of the atomic number of the material (z^4) and have prevalent at low-lying energies and for materials with large atomic numbers [6].

2.2. Compton Scattering

It is non-elastic scattering occurs between the incident photon and electron of the external orbits of atoms Where electrons are weak link nucleus and cause the loss of part of the incident photon energy of those electrons, causing the electron emission out of atom at angle of □ and with kinetic energy (***E***) so that the incident and collided photon and the electron keep the conservation of energy and momentum laws, and the occurrence of this interaction is directly proportional to the atomic number (z) of the material and it is common at medium energies (0.662 - 1.25MeV) and at low atomic numbers [7].

2.3. Pair Production

A phenomenon which annihilation of photon radiation falling on the material in the Coulomb's field of the nucleus to form a pair of electron-positron when the energy of photon is equal or greater than (1.022MeV) and equals to twice the rest mass of the electron, and this interaction common in the case that the fallen photons with high energy and high atomic number of the material. Occurrence of this interaction is directly proportional to the square of atomic number of the material (z^2).

The relationship for the probability of each interaction that derived using quantum mechanics, which represents the probability of the interaction of each of the three interactions, which can be expressed in absorption coefficient or cross-section of the interaction of [8].

The amount of attenuation occurring in falling radiation beam when penetrate the objective material depends on the cross-section of the interaction and on the intensity of falling radiation, as the (μ) represents probability of removing a photon from the beam per unit path through its interaction with atoms of material as a result of absorption and scattering interactions, where the total attenuation coefficient (μ) represents the sum of the coefficients of partial absorption of each of the photoelectric effect, the Compton scattering and the pair production as in the following equation[9]:

$$\mu\ (cm^{-1}) = \mu_{Ph} + \mu_{co} + \mu_{P.P} \qquad (1)$$

Where:

μ_{Ph} - represents probability of removing the photon and its absorption in the material as a result of Photoelectric effect.

μ_{co} - represents the probability of the photon Compton scattering include probability of scattering and the probability of absorption.

$\mu_{P.P}$ - represents probability of removing the photon and absorption it in the material as a result of production of the electron-positron pair.

The Lambert-Pierre equation used to study the attenuation of gamma radiation (absorption and scattering) inside the material, by measuring the change of well collimated radiation intensity with the change of material thickness, is given by the following relationship [10]:

$$I = I_o\, e^{-\mu x} \qquad (2)$$

Where:

I - radiation intensity rate passing through thickness x of the absorber material.

I_o - the intensity of radiation falling rate without an absorbent material.

μ - linear absorption coefficient.

This equation is valid only when the beam of photons is very narrow, parallel and single-energy and the thickness of absorber material is very little.

This exponential relationship shows a lack of a specific range of gamma radiation inside the material, so a concept of mean free path is appeared which represents the average distance between two successive photon interactions and is given by the following relation:

$$\lambda(cm) = \frac{\int_0^\infty x e^{-\mu x} dx}{\int_0^\infty e^{-\mu x} dx} = \frac{1}{\mu} \qquad (3)$$

And the material thickness in units (mfp) is given by the following relation:

$$x\,(mfp) = \frac{x\,(cm)}{\lambda\,(cm)} = \mu x \qquad (4)$$

In all cases where the photons beam is petition or asymmetric or thickness of the shield is a relatively large, equation (2) becomes non-viable due to what is known as a buildup factor which results from the accumulation of photons at a certain point.

Buildup factor is an important factor where it enters in the accounts relating to the right thickness that appropriate for shielding of radioactive sources of gamma radiation [11].

Attenuation exponential equation (Lambert-Pierre equation) applies only the unscattered beam, so equation (2) can be written in the following form:

$$I_g/I_{og} = e^{-\mu x} \qquad (5)$$

Where:

I_g - The intensity of the total beam with the shield and collimator existence (good geometric arrangement).

I_{og} - The intensity of the total beam with the only collimator existence (good geometric arrangement).

But for uncollimated (bad geometric arrangement) , so equation (2) can be written in the following form:

$$I_b/I_{ob} = e^{-\mu x} \qquad (6)$$

Where:

I_b - The intensity of the total beam with the shield existence (bad geometric arrangement).

I_{ob} - The intensity of the total beam without the shield existence (bad geometric arrangement).

B - Buildup factor

From equations (5) and (6) we can get the value of the buildup factor (***B***) from the following relation:

$$B = (I_b / I_{ob}) \;/\; (I_g / I_{og}) \qquad (7)$$

We can rewrite the equation (2) to calculate the absorbance ratio (R_A) for radiation inside the material shield by the following form [X-ray search]:

$$R_A = e^{\mu x} \qquad (8)$$

Where: R_A = (Io/I).

The above equation shows that the relationship absorbance ratio (R_A) to thickness of the material shield or absorbent matter is exponential, so this relationship can be converted to a linear relationship as in the following form:

$$\ln R_A = \mu x \qquad (9)$$

The recent equation can be used to calculate the linear attenuation coefficient, which represents the slope of straight line of the relationship between (**x**) and ($\ln R_A$), ie ***μ=slope.***

In addition to can be calculation standard of statistical deviation and fractional statistical deviation from follow[12] :

$$S.D = B[(1/I_g) + (1/I_{ob})]^{1/2} \qquad (10)$$

$$F.S.D = [(1/I_g) + (1/I_{ob})]^{1/2} \times 100\% \qquad (11)$$

Where:

S.D : Standard of statistical deviation.

F.S.D : Fractional statistical deviation.

3. EXPERIMENTAL PART

3.1. measurement system:

measurement system consist two main parts :

3.1.1. Geiger-Muller Counter tube detector

It was used the following specifications:

GAT: PA1885-020,030

TYPE ABG, hi-energy ALPHA/BETA/GAM

INDUSRIAL EQUIPMENT & CONTROL PTY. LTD. AUSTRALIA

3.1.2. Radioactive source

Radioactive source used in this study is to cobalt-60 (Co-60) with effective radiation (0.699μCi) and a half-life of (5.27y), which emits photons gamma with two energies values (1.333MeV) and (1.173MeV), i.e. it emits gamma rays at a rate of (1.253MeV).

3.2. Shields Preparation

We have been using epoxy material (in the form of a paste) negotiable hardening by adding hardener, a commercial product (Epoxy 696; Sweden production) for the purpose of producing Shields is intended to be used in shielding against gamma rays.

The choice of epoxy among many polymers is due to many reasons, the most important that it can be manufactured in the form and dimensions as needed, and the second reason it is important is that the epoxy polymer is characterized by highly resistant against gamma rays [13].

Since the recipes composite materials vary with variation their compounds have been used more than one type of powder such as powders of lead, aluminum, iron, cement and to determine the preference of these materials in use as a composite material with epoxy in shielding.

Number of shields that were used in this research are fifteen shields for random granular size powders with size no more than (0.5mm) and different mixing proportions with a thickness of (6mm) and diameter of (60mm), four of lead with epoxy shields by proportions mixing (5,20,35,50%), five iron with epoxy by proportion mixing (50%), five shields are epoxy with cement, aluminum with epoxy, iron and cement with epoxy, lead and aluminum with epoxy, lead, iron, aluminum and cement with epoxy by mixing (50%) for all and pure epoxy without any additions.

3.3. The geometric arrangement of the system

For the purpose of examining the buildup factor of manufactured shields , two collimators were used to obtain the good geometric arrangement that by lifting them(Collimators) we get the bad geometric arrangement . these two Collimators made of lead material and dimensions (50 x50x15)mm have centered circular hole with diameter (5mm) to get collimated beam, figure (1) represents the good and bad geometric arrangement.

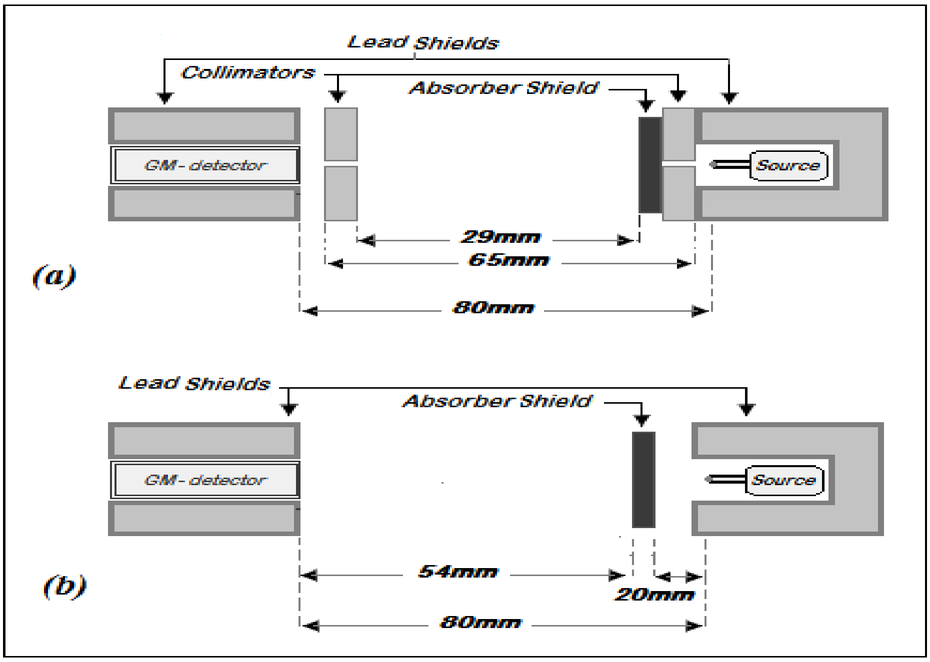

Figure (1) : (a)-The good geometric arrangement (with existence of collimator).
(b)- The bad geometric arrangement (without existence of collimator).

4. ACCOUNT, RESULTS AND DISCUSSION

Practically, the linear absorption coefficient had been measured follow the good geometric arrangement and results using equation (5) were obtained, as well as the numerical buildup factor was calculated using equation (7).
Linear attenuation coefficient and factor accumulation have been certified as main coefficients to judge the durability of shield and its ability in shielding with respect to gamma rays. On the basis of getting a light mass shields and at a lower cost and in any thickness and shape, an increase in the concentration of lead powder in epoxy polymer has been studied and a certain concentration of iron powder in epoxy polymer, the effect of increasing the thickness of the shield has been studied.
Comparing between several powders of different materials and different mixtures that added with a certain concentration (50%) to epoxy polymer are made so as to determining the preference of powders used.
Finally, We've compared the results of this study with similar results, as well as solid materials (Bulk Materials) such as lead alone or aluminum alone, and to highlight the suitability of composite materials manufactured in the limited manner of the current research using a detector Geiger's counter compared to those materials in a point of a view of radiation shielding against.

4.1. The effect of increasing lead powder concentration

Attenuation coefficient calculation as a function of lead powder concentration(figure (2)) shows increasing of attenuation coefficient with increasing of the powder concentration. This act is a natural behavior of attenuation coefficient. standard of statistical deviation and fractional statistical deviation can be calculated from equations (10) and (11) respectively as values shown in table (1).
As shown in the figure(3) that is sketched of the values of buildup factor as a function of the lead powder concentration increasing in polymer epoxy and the source of the radioactive Co-60 that in the case of concentration (0%) (Shield epoxy pure), the buildup factor value take the highest possible value then it is beginning to decline with a little and variable with concentration increasing and from the first concentration (5%) until the concentration (50%).
The high value of the buildup factor of epoxy alone represents the transparency of epoxy with respect to Gamma radiations, which can prevent (epoxy) is not suitable for use as a shield alone, and decreasing of buildup factor at the first concentration of the lead powder, which can be attributed to the change in the properties of epoxy and the manifestation of the composite material properties so the composite material becomes a good material for using as a shield against gamma rays.

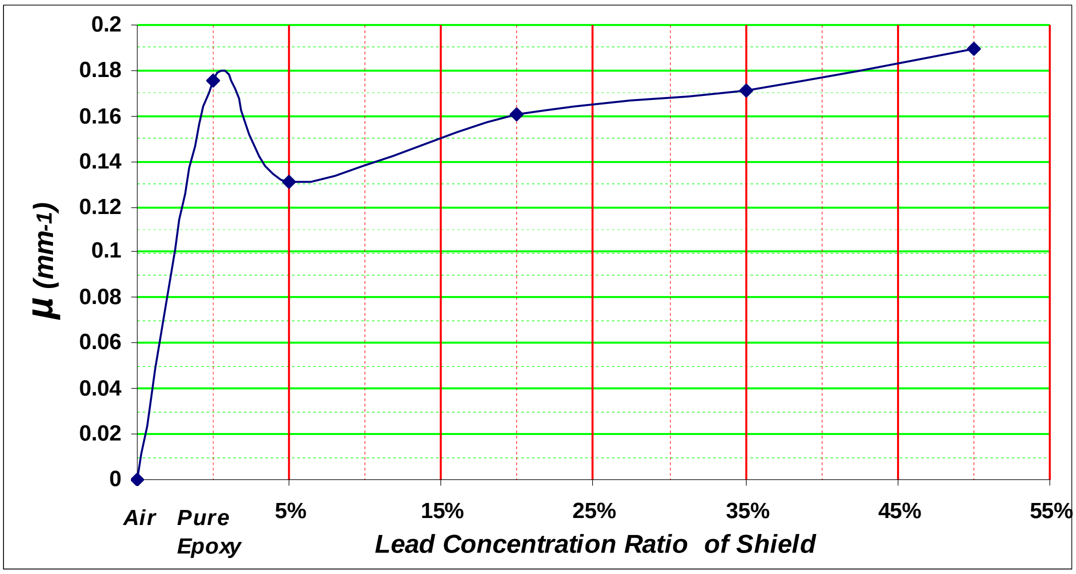

Figure (2) : Shows the attenuation coefficient as a function of the concentration of lead powder.

Table (1) : Linear attenuation coefficient (μ) , Buildup factor (B), Standard of statistical deviation (S.D) and Fractional statistical deviation (F.S.D) values for different concentrations of lead powder in epoxy shields.

Lead Concentration	$I_{og} = 191$, $I_{ob} = 475$							
	I_b	I_g	I_b/I_{ob}	I_g/I_{og}	μ (cm^{-1})	Buildup Factor	S.D ±	F.S.D %
0%	436.0	160.3	0.9179	0.8393		1.0937	0.0999	9.1343
5%	445.5	167.6	0.9379	0.8775		1.0688	0.0960	8.9843

20%	429.2	162.6	0.9036	0.8513		1.0614	0.0964	9.0859
35%	420.3	160.9	0.8848	0.8424		1.0504	0.0958	9.1216
50%	412.0	158.0	0.8674	0.8272		1.0485	0.0963	9.1839

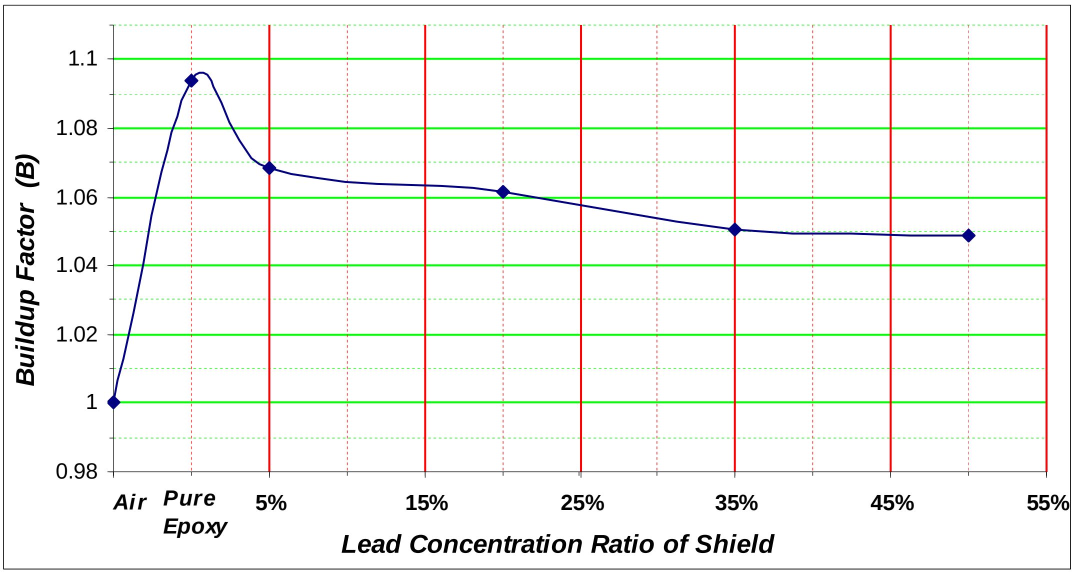

Figure (3) : Buildup factor as a function of lead mixing ratios with epoxy.

Simple and uneven decline of the buildup factor values after the first concentration and up to (50%) illustrates the important result for epoxy materials subsidized by the lead powder where using of a few particular concentration can be enough to be used as shields, which gives preference in manufacturing because of produced shield softness that has been sufficient to allow production of them in any geometric shape as we need.

4.2. The effect of increasing the thickness of the epoxy samples supported by iron powder

The attenuation coefficient of relationship as a function of the epoxy samples thicknesses supported by iron powder and with concentration (50%), as shown in the figure (4), showing an increase in attenuation coefficient values with samples thicknesses clearly.

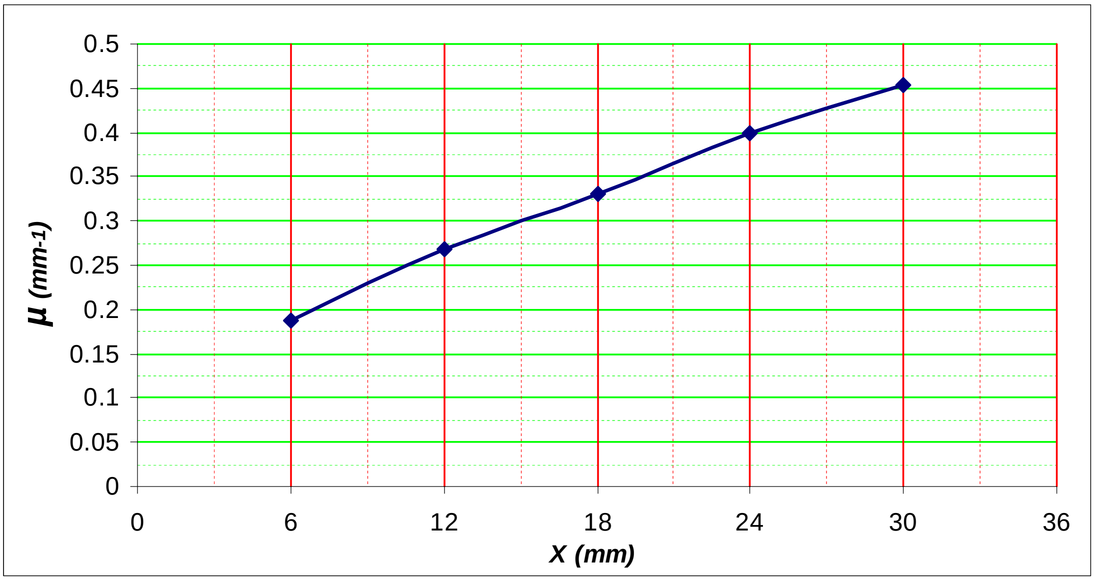

Figure (4) : Shows the attenuation coefficient as a function of thickness of the epoxy shields with 50% iron powder.

To draw the buildup factor values to thickness of shield in units (m.f.p), one must find the linear attenuation coefficient (μ) in unit (mm^{-1}).

The linear attenuation coefficient (μ) can be determined from regression line of relationship between (lnR_A) and thickness of shield in units (mm) where (***μ=slope***) from equation (9)and we determined (X) in units (m.f.p) by using of equation (4), see figure (5).

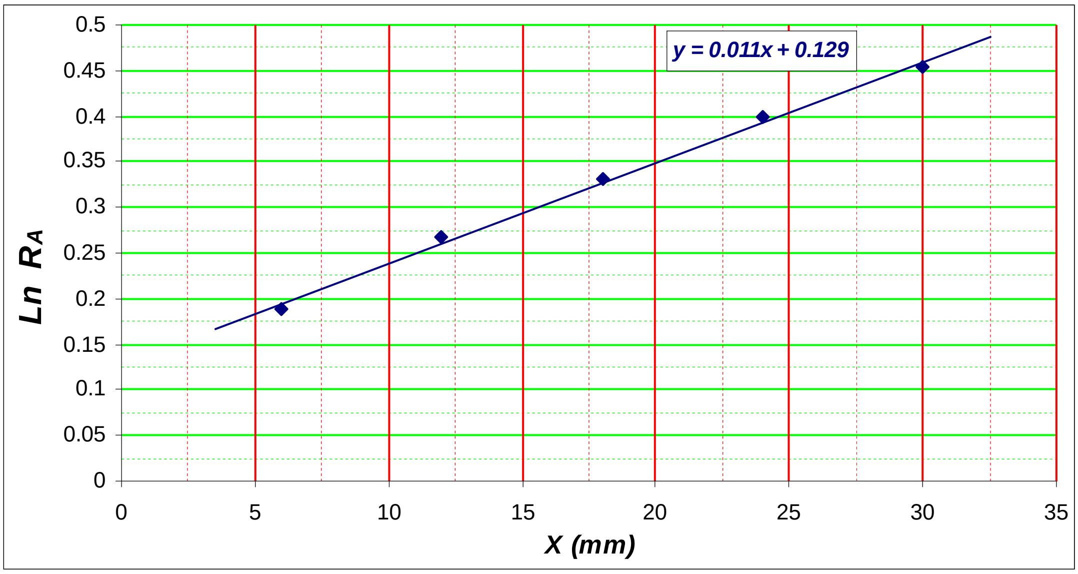

Figure (5) : Shows (ln R_A) as a function of thickness of the epoxy shields fortified with 50% iron powder.

Absorbance ratio (R_A), Buildup factor (B), Standard of statistical deviation (S.D) and Fractional statistical deviation (F.S.D) values for different concentrations of lead powder in epoxy shields are calculated by using equations (9),(7),(10) and (11) respectively, and arranged in table (2).

Also, the figure (6) represents the buildup factor values as a function of the epoxy samples thickness, in units (m.f.p), fortified with iron powder and with concentration of (50%).

4.3. The effect of changing the type and number of powder addition to the epoxy polymer

In addition to the use of lead and iron, other types of reinforcement materials such as aluminum and cement with a concentration of 50% are used, as well as the study of the use of add mixture of powders for more than one material to strengthen the epoxy such as mixture of iron and cement powders, mixture of lead and aluminum powders, as well as a mixture of lead, iron, aluminum and cement powders with concentrations 50% for each mixture.

Table (2) : Absorbance ratio (R_A), Buildup factor (B), Standard of statistical deviation (S.D) and Fractional statistical deviation (F.S.D) values for different concentrations of lead powder in epoxy shields.

Thickness of Shield		I_b	I_g	I_b/I_{ob}	I_g/I_{og}	LnR_A	Buildup Factor	S.D ±	F.S.D %
mm	m.f.p								
0	0.000	475.0	191.0	1	1	0	1	0.0037	0.3670
6	0.066	419.6	158.3	0.8834	0.8288	0.1878	1.0658	0.0045	0.4211
12	0.132	391.5	146.2	0.8242	0.7654	0.2674	1.0768	0.0048	0.4473
18	0.198	368.5	137.1	0.7758	0.7178	0.3316	1.0808	0.0051	0.4700
24	0.264	345.6	128.2	0.7276	0.6712	0.3987	1.0840	0.0054	0.4953
30	0.330	327.6	121.4	0.6897	0.6356	0.4532	1.0851	0.0056	0.5171

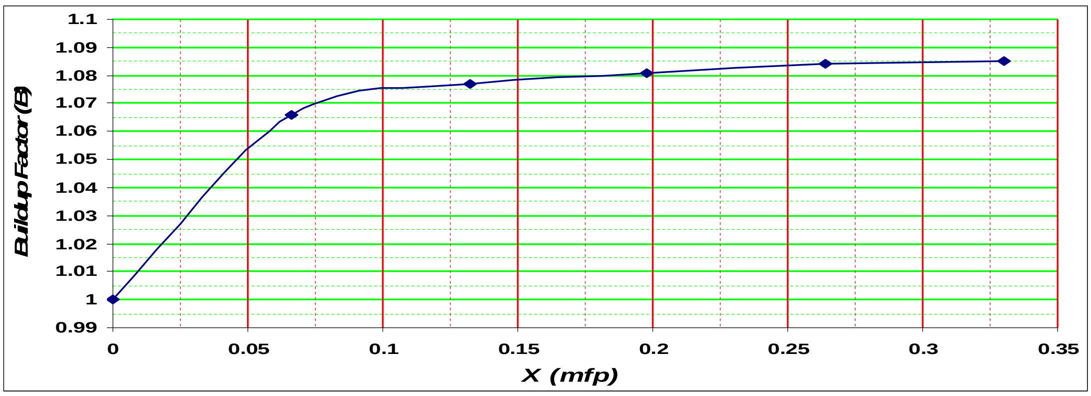

Figure (6) : Shows the buildup factor as a function of thickness of the epoxy shields (in units of (m.f.p)) with 50% iron powder.

Linear attenuation coefficient (μ), Buildup factor (B), Standard of statistical deviation (S.D) and Fractional statistical deviation (F.S.D) values are calculated by equations (5), (7), (10) and (11) respectively, and arranged in table (3).

Figures (7) and (8) show that the linear attenuation coefficient and buildup factor as a function of the type of single material powders and mixture material powders which are added to the epoxy polymer with concentration (50%) of shields and with thickness (6 mm) in addition to the pure epoxy (without any addition).

Table (3) : Linear attenuation coefficient (μ) , Buildup factor (B), Standard of statistical deviation (S.D) and Fractional statistical deviation (F.S.D) values for shields of different material powders and different mixture material powders with the same concentration.

Type of Shield		**I_{og} = 191 , I_{ob} = 475**						
	I_b	**I_g**	**I_b/I_{ob}**	**I_g/I_{og}**	**μ (cm^{-1})**	**Buildup factor**	**S.D ±**	**F.S.D %**
50%Pb.Fe.Al.Ce.	379.4	151.3	0.7987	0.7921	0.2104	1.0083	0.0941	9.3352
50% Pb.Al	382.9	152.0	0.8061	0.7958	0.2094	1.0129	0.0944	9.3189
50% Fe.Ce.	396.9	156.3	0.8356	0.8183	0.2037	1.0211	0.0942	9.2213
50% Pb	412.0	158.0	0.8674	0.8272	0.2015	1.0485	0.0963	9.1839
50% Fe	419.6	158.3	0.8834	0.8288	0.2011	1.0658	0.0978	9.1774
50% Al	424.0	159.2	0.8926	0.8335	0.1999	1.0709	0.0981	9.1579
50% Cement	428.8	159.7	0.9027	0.8361	0.1993	1.0797	0.0988	9.1471
Pure Epoxy	436.0	160.3	0.9179	0.8393	0.1986	1.0937	0.0999	9.1343

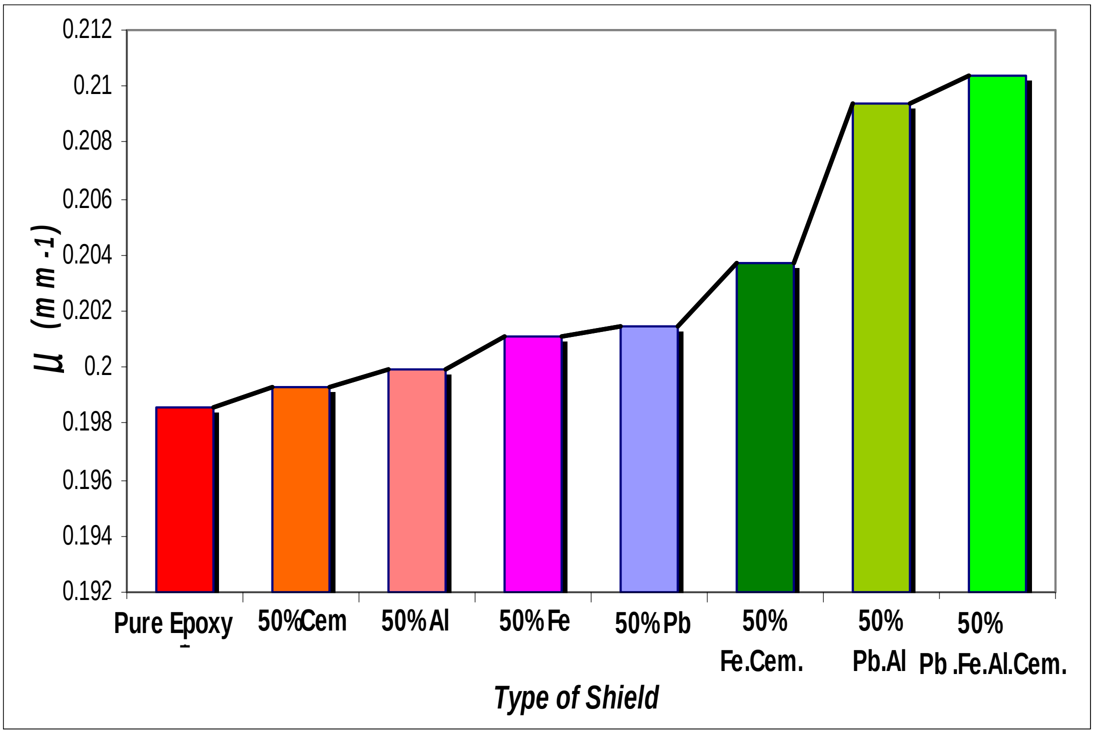

Figure (7) : Linear attenuation coefficient as a function of the epoxy supported by the different materials.

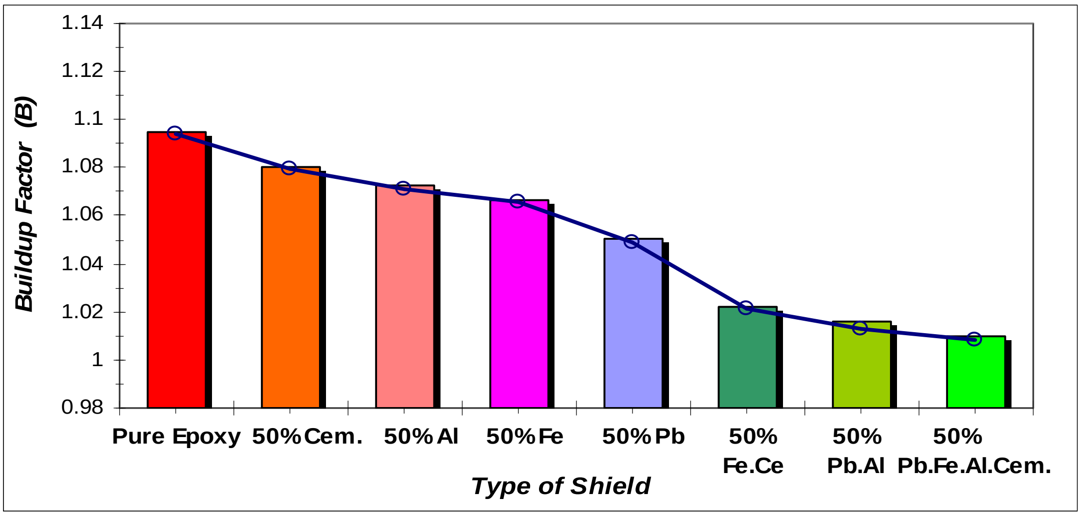

Figure (8): Buildup factor as a function of the epoxy supported by the different materials.

From the last two figures, one can conclude that mixture powders of lead, iron, aluminum and cement is the better to use as a composite material with epoxy in shielding.

one can observe that with an increase of the effective atomic number the linear attenuation coefficient will increases and buildup factor decreases, and again this is an obvious act of the linear attenuation coefficient and buildup factor with effective atomic number [14,12,11], as well as clear that the addition of more than one material to strengthen the epoxy used for shielding gives the best results and the best suited to get the shields with high shielding specifications.

5. THE CONCLUSIONS

From the above we can give some important conclusions that extracted from this study:

5.1. Increasing of the attenuation coefficient and decreasing of buildup factor with increasing of the concentration of reinforcement materials in a sample that used for the manufacture of shields.

5.2. Each of the linear attenuation coefficient and buildup factor started to grow with increasing of used samples thickness as it is an evident from the increasing buildup factor values with regard to increasing of the epoxy samples thickness fortified by iron powder.

5.3. Attenuation coefficient increases and buildup factor decreases with outward density of reinforcement material and this behavior is so an evident in case increasing the number of added powders for used types.

The most important conclusion we have reached is that the composite materials that supported multiple powders give satisfactory and good results compared to rigid materials and composite materials enhanced by powders with one type.

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