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# Influence of Iron and Brass Filling Replacement on the Efficiency of Concrete as Radiation Shield

This study investigates the effect of replacing different substances with 50% of sand on the radiation shielding performance of concrete used in medical structures. Seven groups of three samples have been prepared and tested based on an ordinary concrete batch. The first group (Re) was the reference group without any replacement casted with 7 cm thickness. In the second, third, and fourth groups (Fe groups), a 50% of sand was replaced with iron filings and the samples were casted with 5, 7, and 10 cm thicknesses, respectively. In the fifth, sixth, and seventh groups (Br groups), a 50% of sand was replaced with brass filings and the samples were casted with 5, 7, and 10 cm thicknesses, respectively. The average size of iron filings was (0.35 mm), while the average size of brass filings was (1.172 mm). All specimens have been exposed to radiation beam from Bi-207 which was coupled with NaI(Tl) detector. The results show that replacing sand with iron or brass, can improve the radiation protection efficiency of concrete. However, the results show a superiority in radiation attenuation of iron-filing specimens ( $0.0931 \text{ cm}^{-1}$ ) to that of its counterpart brass-filing specimens ( $0.0893 \text{ cm}^{-1}$ ). Hence, the bigger particle size of brass might be behind the deficiency of brass samples compared to their counterpart, iron-filings samples.

**Keywords:** Concrete; Radiation shielding; Attenuation, Iron-filings; Brass-filings  
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## 1. Introduction

The exposure of staff and public to radiation can cause serious health issues. Radiation shielding design and materials has become a concern and investigated widely in the last few years. It is well known that concrete is the corner stone in the building of radiation facilities. The fresh concrete is a mixture of three basic materials (coarse aggregates, sand and cement) mixed together with different percentages with a specific amount of water according to the designated strength and purpose it used for [1]. The increasing usage of concrete in the nuclear and medical applications as a radiation shielding can be attributed to its advantages including its efficiency, cost effectiveness, and ease of construction. There are several studies in the literature have investigated the effect of replacing and adding different materials on the efficiency of concrete shielding against radiation such as lead [2], ulexite/colemanite [3], barium oxide [4], iron oxide [5], iron cuttings [6], iron filings [7] and brass and boron carbide [8].

Rezaei-Ochbelagh et al. [2] studied the effect of adding three forms of lead: powder, shots and plates with different percentages to the concrete mixture. The increase of the additives percentage resulted in increasing shielding properties. However, the increase of the addition percentage resulted in reducing the compressive strength. Hence, the optimum additive percentage was found to be 90% despite the

improvement in the radiation shielding properties at higher addition percentage.

Uçar et al. [3] showed experimentally that the replacement of traditional aggregates with ulexite or colemanite can improve the mechanical properties of concrete, however, the enhancement in the radiation attenuation was negligible. Ahmed et al. [4] presented a comparison between ordinary concrete and heavy weighted concrete (barite concrete) in terms of the efficiency in radiation shielding. The study showed that heavy concrete is more efficient for radiation shielding in bunkers than its counterpart ordinary concrete.

Minh et al. [5] investigated the radiation shielding features of iron oxide enhanced concrete. The study showed that the enhanced concrete presented better radiation shielding compared to the control sample (ordinary concrete). For all energies under study, Minh et al. showed that the radiation shielding properties of the mixture are better for lower gamma energies compared to the highest gamma energies.

Shahid et al. [6] studied the effect of sand replacement with iron cutting waste (ICW) at rates of 10, 15 and 20. Shahid et al. [6] showed that replacement rate of 15 presented the most significant improvement in radiation attenuation and mechanical properties of concrete.

Elamin et al. [7] studied the effect of iron filing on the radiation shielding properties. In the first mixture, 30% of cement was replaced with iron filing. In the

second mixture, 30% of sand was replaced with iron filing. In the third mixture, 30% of gravel was replaced with iron filing. It was found that the addition of iron filing in the second mixture presented the best radiation attenuation properties compared to the replacement samples in the same study.

Ercokuncu et al. [8] studied the radiation protection and mechanical properties of brass-reinforced concrete and boron carbide concrete. Samples were experimentally tested for gamma radiation. The higher gamma attenuation occurred at 50% brass-cement replacement. The replacement of cement could result in a reduction of the concrete strength as cement is used as an adhesion agent and it strengthens the concrete mixture. Therefore, the current study focuses on the replacement with sand rather than cement.

It can be clearly seen that there are few studies in the literature investigates the effect of replacing iron filings with sand, while there is no study has been performed on the effect of replacing sand with brass-filings yet.

Iron and brass are used widely in the essentials of people lives; therefore, factories and workshops are spread all over the cities. The re-form of materials causes waste, which results in environmental pollution. Hence, the usage of iron and brass which are available, reachable and cost-effective materials can reduce pollution.

This study investigates the Influence of replacing 50% of sand with iron-filings on the efficiency of concrete radiation shielding compared to its counterpart brass-filings.

## 2. Theoretical Aspect

The attenuation represents blocking intensity of radiation during its propagation in the medium due to the interaction of photon processes represented by scatter and absorption [9]. The simplest representation of attenuation of monoenergetic gamma ray beam is Beer Lambert, as expressed in Eq. (1):

$$I = I_0 e^{-\mu(h\nu, z)x} \quad (1)$$

where  $I_0$  is the original intensity of the unattenuated beam, and  $\mu(h\nu, z)$  is the linear attenuation coefficient, as  $\mu(h\nu, z)$  is a function of photon energy ( $h\nu$ ) and the attenuator atomic number ( $Z$ ) [9]

A linear relation is the logarithm of Eq. (1) as in Eq. (2):

$$\mu = \ln\left(\frac{I_0}{I}\right)/x \quad (2)$$

The measure of the material effectiveness in absorbing or scattering radiation is known as the mass attenuation coefficient ( $\mu_m$ ), and is calculated using Eq. (3):

$$\mu_m = \mu/\rho \quad (3)$$

where  $\rho$  is the density of the substance measured in  $\text{g}\cdot\text{cm}^{-3}$ .

The mean free path (MFP) represents the path that a photon travels before interacting with the target atoms

or molecules, deflecting its direction or changes its energy. MFP is calculated using Eq. (4):

$$\text{MFP} = 1/\mu \quad (4)$$

The thickness of attenuator required to reduce the beam intensity to half its original value (HVL), and the thickness required to attenuate the beam to the tenth of its original value (TVL), are calculated in equations (5) and (6), respectively:

$$\text{HVL} = \ln 2 / \mu \quad (5)$$

$$\text{TVL} = \ln(10) / \mu \quad (6)$$

## 3. Materials and Method

The concrete mixture used in this study is the ordinary concrete which consists of cement, sand and gravel mixed at the ratios 1:2:3 (cement:sand:gravel) for structural elements. Three samples were prepared. The first sample was the reference sample without any replacement. The second sample mixture was prepared with iron-filings replacing 50% of sand. The third sample mixture Brass-filings replacing 50% of sand. Both iron and brass were ground using a lathe machine then a food grinder machine. The ground particles were sieved and measured using 500 X USB digital microscope. The particle size ranged as: 0.016 to 0.75 mm for sand, 0.055 to 2.124 mm for iron filings, 0.91 to 2.129 mm for brass filings, and 6.86 to 7.26 mm for gravel. The brass used in this study consists mainly of about 70.9% copper, 19.3% zinc, and 5.3% of lead, in addition to other minerals, hence its effective atomic number ( $Z_{\text{eff}}$ ) is 32.18 with  $8.6 \text{ g}/\text{cm}^3$  density. The iron was pure with atomic number 26 and the density  $7.86 \text{ g}/\text{cm}^3$ .

The workability, strength and durability of the concrete is affected by the water-to-cement ratio (w/c), which is inversely related to concrete strength. This ratio also affects the photon attenuation in the radiation shield [10]. The water remaining in the pore system of the cement-water paste acts as a source of reaction water during the hydration period [11]. Hence, w/c for this mixture was chosen to be 57% as the best ratio for the mixture under study. The fresh concrete was mixed carefully to avoid the segregation of Br and Fe filings due to the high density with respect to concrete mixture compositions.

The mixture was prepared and poured manually using hand-made equipment in open molds made of wood with  $7 \times 7 \text{ cm}^2$  surface area, and three different molds with thicknesses of 5 cm, 7 cm, and 10 cm. For each group sample, three specimens were prepared to reduce the casting error. The thickness of the reference samples was 7 cm. The specimens were cured with water for 28 days, then air dried and weighted. Samples were coded according to table (4). The letters of the samples are either Re, Fe, or Br, referring to reference specimen, iron-filings specimen, and brass-filing specimen, respectively. The first number represents the

specimen thickness, and the second number to the number of sample within the same sample group.

The density  $\rho$  of the samples with the reference thickness were calculated as in Eq. (6):

$$\rho = m/V \quad (7)$$

where  $m$  is the mass of the sample, and  $V$  is the volume.

The density of the reference specimen (i.e. 2.309 g.cm<sup>-3</sup>) was compared to the standard value (i.e. 2.3 g.cm<sup>-3</sup>) published by the National Institution of Standards and Technology (NIST) [12]. The samples were weighted using a digital scale with 1g graduation, and 5 kg as a capacity. The average density of Br and Fe specimens were 2.44 g.cm<sup>-3</sup> and 2.48 g.cm<sup>-3</sup>, respectively.

The radiation attenuation for the specimens was tested in in the Nuclear Laboratory of the Department of Physics/ College of Science at University of Baghdad- Iraq, using NaI(Tl) scintillator detector equipped with ORTEC NIM rack and electronic module. This detector gives the accumulated number of counts of the source. The selected radioactive source was Bi-207 with the specifications tabulated in table (5).

Figure (1) illustrates the experimental setup. A narrow gamma beam was obtained using two collimator blocks made of lead (Pb) placed in parallel with 11.3±0.1 cm gap. Both collimators have a 15 mm hole in the centre of each block. The source was placed on the hole of the first collimator and a Pb block was placed behind the source to reduce the back scatter. The other collimator block was placed in front of the detector. Both holes were adjusted to be in line with the centre of the detector.

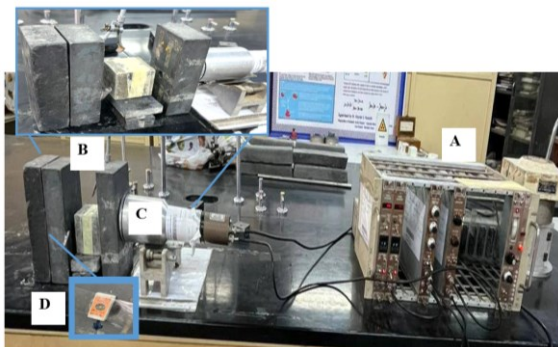


Fig. (1) The experimental setup with a sample between the two parallel collimators, A (ORTEC NIM instrument), B (collimator blocks), C (NaI(Tl) detector), and D (magnified: Bi-207 source)

The voltage of the ORTEC NIM was adjusted to 1150 volts to obtain good electron amplification in the photomultiplier tube (PMT) of the NaI(Tl) detector. The counting time was selected to be 100 seconds to allow for higher event registration and reduce the dead-time losses. The initial counts were determined by registering the number of counts before placing the

specimens ( $x=0$  cm). The attenuation was determined using equation (1) and (2) and the measurements were repeated three times to reduce the statistical errors.

#### 4. Results and Discussion

Figure (2) illustrates the effect of thickness on the registered counts passing through the depth of the samples. Each point represents the average counts value against thickness (three readings were for each three samples) passing through the nominated mixture as a function of thickness.

It is clear from Fig. (2) that the attenuation of the photon is comparative or slightly higher for Fe samples compared to its counterparts Br samples and is manifested when the thickness is 7 cm. The ‘average number of counts’ passing through the Fe and Br specimens are 4% and 1.37%, respectively, less compared to Re specimen.

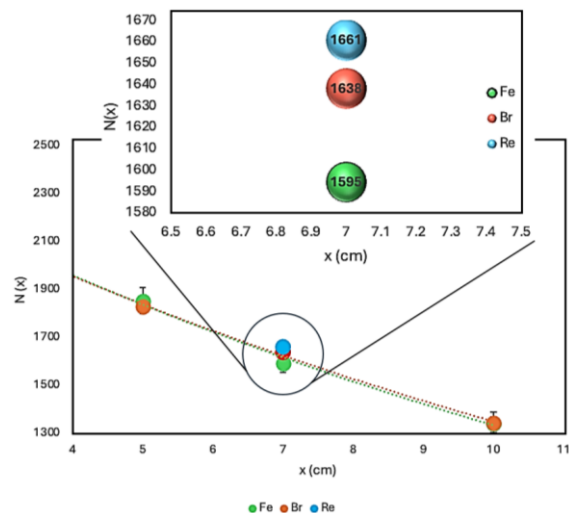


Fig. (2) A comparison of counts vs sample thickness amongst the three specimens, Fe, Br and Re. Note that the reference sample (Re) is 7 cm thickness only

Figures (3) and (4) show the linear attenuation coefficient ( $\mu$ ) of Fe specimen and Br specimen, respectively. The linear attenuation coefficient for Fe specimen (tabulated in table 1) is 1.043% and 1.09% higher than Br and Re specimens, respectively. The mass attenuation coefficients ( $\mu_m$ ) and mean free path (MFP) are calculated according to equations (3) and (4), respectively. Table (1) presents a comparison of  $\mu$  and MFP for the three samples, Re, Fe and Br.

Table (1) Linear attenuation coefficient ( $\mu$ ), mass attenuation coefficient ( $\mu_m$ ) and mean free path (MFP) for the sand-replaced specimens compared to the reference specimen ( $x=7$ cm, and the initial number of counts  $N_0=3060$  counts)

Composition	$N_{ave}$	STD <sub>Relative</sub> (%)	$\mu$ (cm <sup>-1</sup> )	$\mu_m$ (cm <sup>2</sup> .g <sup>-1</sup> )	MFP (cm)
Re	1661	1.24	0.0854	0.037	11.71
Fe	1595	1.29	0.0931	0.0375	10.74
Br	1638	1.48	0.0893	0.0366	11.20

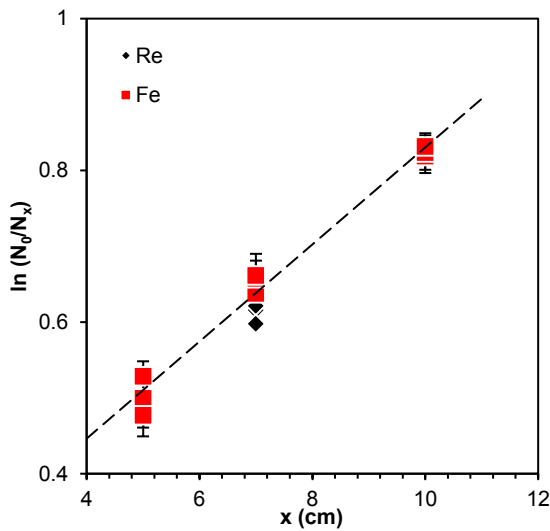


Fig. (3) Linear attenuation coefficient for Fe sample

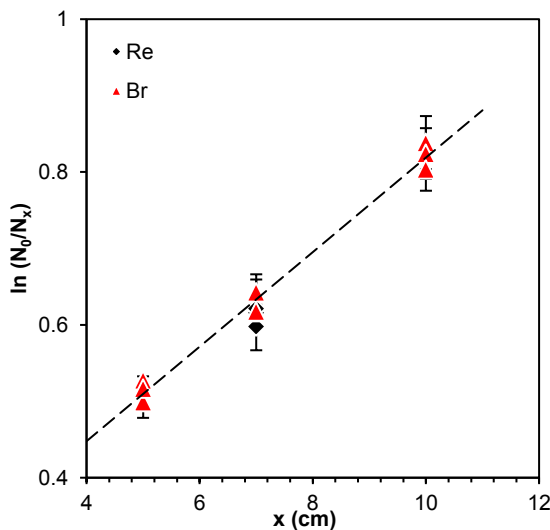


Fig. (4) Linear attenuation coefficient ( $\mu$ ) for Br sample

The linear attenuation coefficient ( $\mu$ ) depends on the type and density of the mixture of the specimen for the same photon energy. The higher density of the sand-replacing substance should result in a better linear attenuation. Brass has higher  $Z_{eff}$  compared to iron (i.e. 32.18 vs 26, respectively). The higher  $Z_{eff}$  should result in denser Br specimens compared to iron specimens. However, figures (3) and (4) show a superiority in linear attenuation of Fe specimen in comparison to Br and, definitely Re samples.

Those results are supported by the findings of Azeez et al. [14], and Husain et al. [15] where the decisive factor in this case is not only the density; the linear attenuation coefficient is inversely proportional to the size of filings (iron and brass). The brass filings are bigger in size compared to iron, as mentioned previously. Hence, this could lead to poorer distribution of the filings in the mixture, which makes the current results reasonable.

The density of brass-filing samples was 98.4% to the density of iron-filing samples, which might be due to the bigger average size of brass-filings (1.172 mm) compared to iron-filings (0.35 mm). The shape of the brass-filings as longitudinal fibres with high aspect ratio might result in random and uncontrolled arrangement in different directions. Additionally, the bigger size of particles reduces the number of particles per unit size of the material which could result in the decrease of materials spread to cover more surface area of the sand. This might lead to a smaller cross-section of interactions, which results in a reduction in beam attenuation.

To save space in healthcare and nuclear facilities, concrete treated with metal filings (such as iron or brass) has shown greater radiation shielding efficiency than regular concrete [7,16-18] This allows a reduced wall thickness whilst maintaining the same level of protection, saving valuable space within the facility.

In table (2), HVL and TVL are calculated practically according to equations (4) and (5), respectively. The experimental value of  $\mu$  for the ordinary concrete is compared with the standard value on NIST website [19].

The half value layer for iron-filing specimen in Elamin et al. [7] was 4.013 cm, in which a 30% of the iron-filings with sand was replaced and tested with energy of 662 keV. The HVL of Elamin et al. was 0.56 less than that in current study due to the difference in replacement percentage and the selected energy for the radiation test. The extrapolated data for the linear attenuation and HVL at the higher energy emission of Bi-207 (i.e. 1770 keV) were  $0.0893 \text{ cm}^{-1}$  and 7.76 cm, respectively, which shows better shielding properties compared to  $0.0858 \text{ cm}^{-1}$  and 8.08 cm, respectively in Erkoyuncu et al. [8] study.

Table (2) HVL & TVL of the specimens

Specimen	$\mu$ ( $\text{cm}^{-1}$ )	HVL (cm)	TVL (cm)	$\mu$ from NIST [10] ( $\text{cm}^{-1}$ )	HVL (cm)	TVL (cm)
Re	0.0854	8.12	27	0.089	7.8	25.9
Fe	0.0931	7.45	24.7	-----	-----	-----
Br	0.0893	7.76	25.8	-----	-----	-----

Table (3) shows the costs for the materials used to prepare the specimens. The production cost for each  $7 \times 7 \times 7 \text{ cm}^3$  sample was calculated. The results of HVL and TVL shown in table (2) indicate that the equivalent thickness to 100 cm of ordinary concrete is 91.5 cm for Fe sample, and 95.6 cm for Br. In other words, using Fe as filing material can reduce 8.5 cm for each meter of wall thickness to achieve the same efficiency in radiation shielding as Re walls, resulting in price reduction for Fe specimens compared to Br and Re concrete.

**Table (3) Quantities of materials used to prepare the samples with their cost**

No	Type of material	Total Material Cost (ID)	Price per kg (ID/kg)
1	cement	514	159.975
2	Sand	3500	957.85
3	Gravel	2,550	198.4
4	Iron filings	560	404
5	Brass filings	14,430	10,411.255

### 5. Conclusion

This study investigates the gamma radiation shielding characteristics for two concrete samples reinforced with brass- filings and iron- filings. The sand in the concrete samples was replaced at the percentage of 50% with the filings of brass and iron. The investigated parameters were  $\mu$ ,  $\mu_m$ , MFP, HVL and TVL for the reinforced samples were compared with the reference sample of ordinary concrete with no replacement. The experimental results showed better radiation properties of the new samples in general, with superiority of iron-filing samples in radiation attenuation capacity. This indicates that the size of the filings together with the density, play a critical role in the determination of the radiation shielding effectiveness of the manufactured concrete. The findings are promising and open new avenues for the design improvement of space saving and cost-effective designs of medical radiation facilities. It is recommended to study the mechanical properties of the new mixture, and the effect of replacing sand with different filings on radiation and mechanical efficiency. The sustainability and the environmental impact of the new specimens are also recommended for evaluation.

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**Table (4) Sample coding**

x (cm)	Reference (Re)			50% Iron (Fe)			50% Brass (Br)		
5	-----	-----	-----	Fe5,1	Fe5,2	Fe5,3	Br5,1	Br5,2	Br5,3
7	Re7,1	Re7,2	Re7,3	Fe7,1	Fe7,2	Fe7,3	Br7,1	Br7,2	Br7,3
10	-----	-----	-----	Fe10,1	Fe10,2	Fe10,3	Br10,1	Br10,2	Br10,3

**Table (5) Source specifications of Bi-207 with serial # 1A 132**

Energy (% I) (MeV)	Decay constant ( $\gamma^{-1}$ )	Date of calibration	$A_0$ ** ( $\mu\text{Ci}$ )	Test date	$A(t)$ *** ( $\mu\text{Ci}$ )
0.569 (97.76%)	0.022	01-Dec-87	11.37	05-Nov-24	5.0484
1.063 (74.58%)					
1.770 (6.87%)					

\* I is the intensity of the emitted gamma energy, \*\*  $A_0$ : Initial Activity, \*\*\*  $A(t)$ : Activity at time (t)

**Table (6) Cost of sample production for the three samples; Re, Fe and Br**

No	Sample	Production cost for 7cm <sup>3</sup> (ID)	Equivalent thickness to 100 cm of Ordinary concrete (cm)	Production cost equivalent to 100 cm <sup>3</sup> (ID)
1	Re	421	100	6014
2	Fe	340	91.5	4444
3	Br	1811	95.6	24733