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INVESTIGATION OF THE IMPACT OF GLASS WASTE IN REACTIVE POWDER CONCRETE ON ATTENUATION PROPERTIES FOR BREMSSTRAHLUNG RAY[†]

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Reactive Powder Concrete (RPC) is one of the most advanced recent high compressive strength concretes. This work explored the effects of using glass waste as a fractional replacement for fine aggregate in reactive powder concrete at levels of 0%, 25%, 50%, and 100%. Linear and mass attenuation coefficients have been calculated as a function of the sample's thickness and bremsstrahlung energy. These coefficients were obtained using energy selective scintillation response to bremsstrahlung having an energy ranging from (0.1-1.1) MeV. In addition, the half-value thickness of the samples prepared has been investigated. It was found that there is a reversal association between the attenuation coefficient and the energy of the bremsstrahlung ray. The results showed that, with the exception of the specimen with a partial replacement of 25% glass waste, adding fine aggregate in part by glass waste had a negative impact on the reactive powder concrete's attenuation properties. That means the sample's density can be improved with the glass waste content ratio to 25%. Also, the bremsstrahlung radiation shielding capabilities of reactive powder concrete can be enhanced using glass waste of not more than 25%.
Keywords: *Attenuation properties; Bremsstrahlung ray; Reactive Powder Concrete (RPC); Glass waste; Sustainable material*
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1. INTRODUCTION

Bremsstrahlung ray one of the nuclear radiations which classify as a great harmful ray, it has an extensive series of applications. Shielding parameters for this ray is important in the field of radiation protection to prevent its effects. It is essential to know the bremsstrahlung ray spectrum distribution that yield from $^{90}Sr/^{90}Y$ beta source in lead. Beta sources are increasingly used in the medical applications. One of the troubles in the request of beta radiation shields regards to the bremsstrahlung ray and it requires shielding against beta particles reserves [1].

To reduce the effects of radiation on the human body, many safety materials were produced. In nuclear reactors, concrete and lead are frequently employed. Additionally, reactive powder concrete (RPC) is regarded as the most significant recent development in high compressive strength concrete. These concrete varieties were created using technologies to support microstructures. It is more durable and also has better mechanical properties than regular concrete [2, 3]. Wen L., et al [4] investigation focused on the mechanical and micro structural characteristics of RPC samples. In order to create RPC samples, coal gangue sand was substituted for natural river sand at various weight ratios ranging from 0 to 100% at intervals of 25%.

In order to selection appropriate type of material to sufficiently prevent various forms of radiations, the attenuation properties must be intentional [5]. The exact values of attenuation coefficients for bremsstrahlung ray in numerous materials are necessary for nuclear and radiation physics. The energy of radiation and the nature of the object determine the attenuation coefficient [6]. In nuclear and environmental physics, there are a lot of researches have been reported to study the relatives between energy, attenuation properties and material thickness as in refs. [7-13].

Through the use of cementations materials, some of these researches have been designed to improve the mechanical properties of concrete [14–16].

The concrete industry is aware of these materials' ability to enhance certain of the characteristics of regular concrete [17]. By testing linear and mass attenuation coefficients using several radiation sources with varying energies, Wasan et al. [18] investigate the potential of employing reactive powder concrete as a shielding material. Reactive powder concrete was shown to be capable of absorbing beta particles and gamma rays without significantly reducing the specimen's compressive strength.

The linear attenuation coefficient μ (cm^{-1}) is an important shielding parameter which describe the ability of the material to attenuate the incident radiation. In the present work, the μ was measured experimentally using bremsstrahlung ray transmission method according to lambert law:

$$I = I_0 \exp(-\mu x). \quad (1)$$

where x is the absorber thickness, I_0 and I were the incident and transmitted intensities respectively. Then, the mass attenuation coefficient μ_m (cm^2/g) was calculated through the linear attenuation coefficient using equation (2):

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$$\mu_m = \frac{\mu}{\rho}. \quad (2)$$

ρ is particle density of absorber in gm/cm^3. The half value layer ($X_{1/2}$) is given by:

$$X_{1/2} = \frac{0.693}{\mu}. \quad (3)$$

In this work, cube samples of RPC with glass waste as fractional replacement of fine aggregate by 0%, 25%, 50% and 100% have been prepared to estimate the performance of samples composite in attenuating bremsstrahlung ray.

2. MATERIALS AND METHODS

The chemical compositions and physical characteristics of common Portland cement according to Iraqi specification No. 5/1984 are shown in Tables 1 and 2 [19]. Table 3 shows the grain size distribution of the fine aggregate, which was represented by river sand, and ranged from (150 to 600) µm. As shown in Table 4, all characteristics of the river sand complied with Iraqi specification No. 45/1984 [20]. In this investigation, there was a waste of window glass. The employed river sand had been crushed and ground in a laboratory using Los Angeles abrasion equipment before being sorted through sieves calibrated to acquire the same gradation as stated in Table 5.

Physical and chemical properties of silica fume are displayed in Tables 6, 7, and it complies with ASTM C1240-03 requirements [21]. Bulk density in Table 6 was obtained from the manufacture data sheet (MEYCO®MS610).

In order to conduct the research's experimental program, four collections of standard cubes (50×50×50) mm were cast utilizing the RPC's implemented mix, as shown in Table 8.

Table 1. Chemical composition and major compounds of cement

Oxides	Content %	Iraqi Specification Limits (I.Q.S 5/1984) % [19]
CaO	61.91	-
Fe_2O_3	3.28	-
Al_2O_3	5.04	-
SiO_2	21.38	-
MgO	2.09	Max, 5
SO_3	2.19	Max, 2.8
L.O. I	2.64	Max. 4
L.S. F	0.887	0.66-1.02
In. Residue	0.72	Max. 1.5
	Major compounds (Bogue's equations)	
C_3S	57.60	-
C_2S	29.844	-
C_3A	7.813	-
C_4AF	9.981	-

Table 2. Physical properties of cement

Property	Result	Iraqi Specifications Limits No. 5/1984 [19]
Fineness, Blaine Method (m^2/kg)	323	Min, 230
Setting time (hr: min)		
-Initial setting	2:15	Min. 45 min.
- Final setting	4:20	Max. 10 hrs.
Compressive strength (MPa)		
3 days	22.6	Not less than 15MPa
7 days	30.1	Not less than 23MPa

Table 3. Grading of the fine aggregate (river sand)

Sieve opening(mm)	Passing %	Iraqi Specification Limits (I.Q.S. 45/1993) % [20] (Zone 4)
10	100	100
4.75	100	95-100
2.36	100	95-100
1.18	100	90-100
0.6	85.1	80-100
0.3	22.4	15-50
0.15	9	0-15

Table 4. Properties of the fine aggregate.

Item	Result	Iraqi Specification Limits (I.Q.S. 45/1993) [20]
SO_3 content %	0.17	Max. 0.5
Bulk density(kg/m^3)	1687	-
Specific gravity	2.54	-
Water absorption %	0.8	-

Table 5. Grading of the waste glass.

Sieve opening(mm)	Passing %	Iraqi Specification Limits (I.Q.S. 45/1993) % [20] (Zone 4)
10	100	100
4.75	100	95-100
2.36	100	95-100
1.18	100	90-100
0.6	85.5	80-100
0.3	32.3	15-50
0.15	13.5	0-15

Table 6. Physical properties of silica fume.

Property	Test result	ASTM C 1240 Specification [21]
Specific surface area, m^2/kg	21060	Min. 15000
Retaining on sieve 45µ, %	4.8 %	Max. 10%
Pozzolanic Activity %	113	Min. 105
Bulk Density* kg/m^3	550-700	-

Table 7. Chemical analysis of silica fume.

Oxides	Content %	ASTM C1240 Specification % [21]
SiO_2	90.59	Min. 85%
Fe_2O_3	1.56	-
Al_2O_3	0.75	-
CaO	0.73	-
MgO	1.21	-
SO_3	0.59	-
L.O. I	2.60	Max. 6%
Moisture content	1.13	Max. 3%

Table 8. Mixing proportion of RPC.

Mix Sample	Cement(kg/m^3)	Silica Fume 87 (kg/m^3)	Fine Aggregate (kg/m^3)	Glass Waste (kg/m^3)	Water (kg/m^3)
NG (0%)	800	200	1000	0	200
NG1 (25%)	800	200	750	250	200
NG2 (50%)	800	200	500	500	200
NG3 (100%)	800	200	0	1000	200

Bremsstrahlung ray was formed in suitably thickness of lead using $^{90}Sr/^{90}Y$ pure beta source with end-point energies of 0.546 and 2.274 MeV. The bremsstrahlung ray absorption characteristics of reactive powder concrete at various thicknesses have been investigated and tested. For the measurements, which were authorized, two collimators with a combined diameter of 5 mm and energies ranging from 0.1 to 1.1 MeV were used. The distance between source and detector was about 35 cm.

The bremsstrahlung ray intensities have been carried out with NaI(Tl) scintillation detector of dimension 2″×2″. Equations (1), where is the absorption coefficient, can be used to evaluate the intensities, which were determined for a set duration of 1000 sec.

3. RESULTS AND DISCUSSIONS

To investigate the shielding parameters in reactive powder concrete, it is essential to know bremsstrahlung ray distribution or spectra. The absorption spectra for bremsstrahlung ray without and with glass waste replacement (0%, 25%, 50% and 100%), respectively has been shown in Fig. 1. It is apparent that the intensity of bremsstrahlung ray decreases as the energy increased.

Fig.2. shows the variation of intensity I of bremsstrahlung ray with glass waste replacement 0%, 25%, 50%, and 100% compared with the original intensity as a function of energy. It is obvious that the intensity decreasing for reactive powder concrete containing 25% glass waste is more than other specimens of glass waste partial replacement.

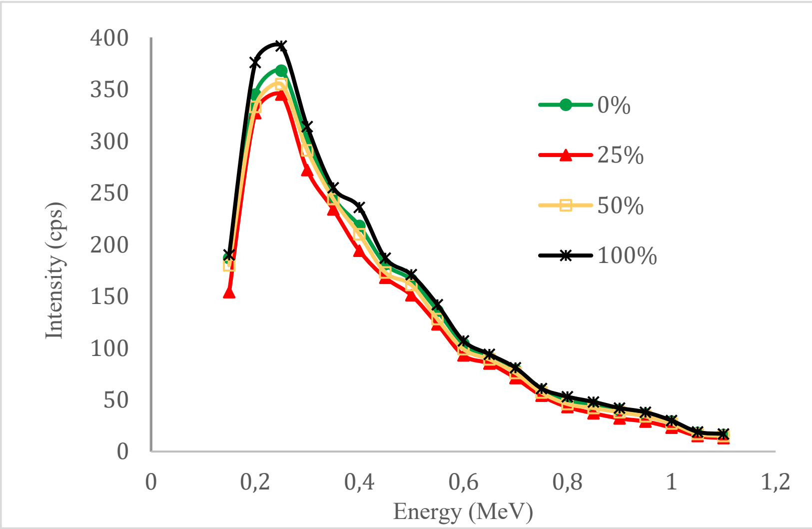

Figure 1. Absorption spectra with different glass waste replacement for bremsstrahlung ray as a function of energy

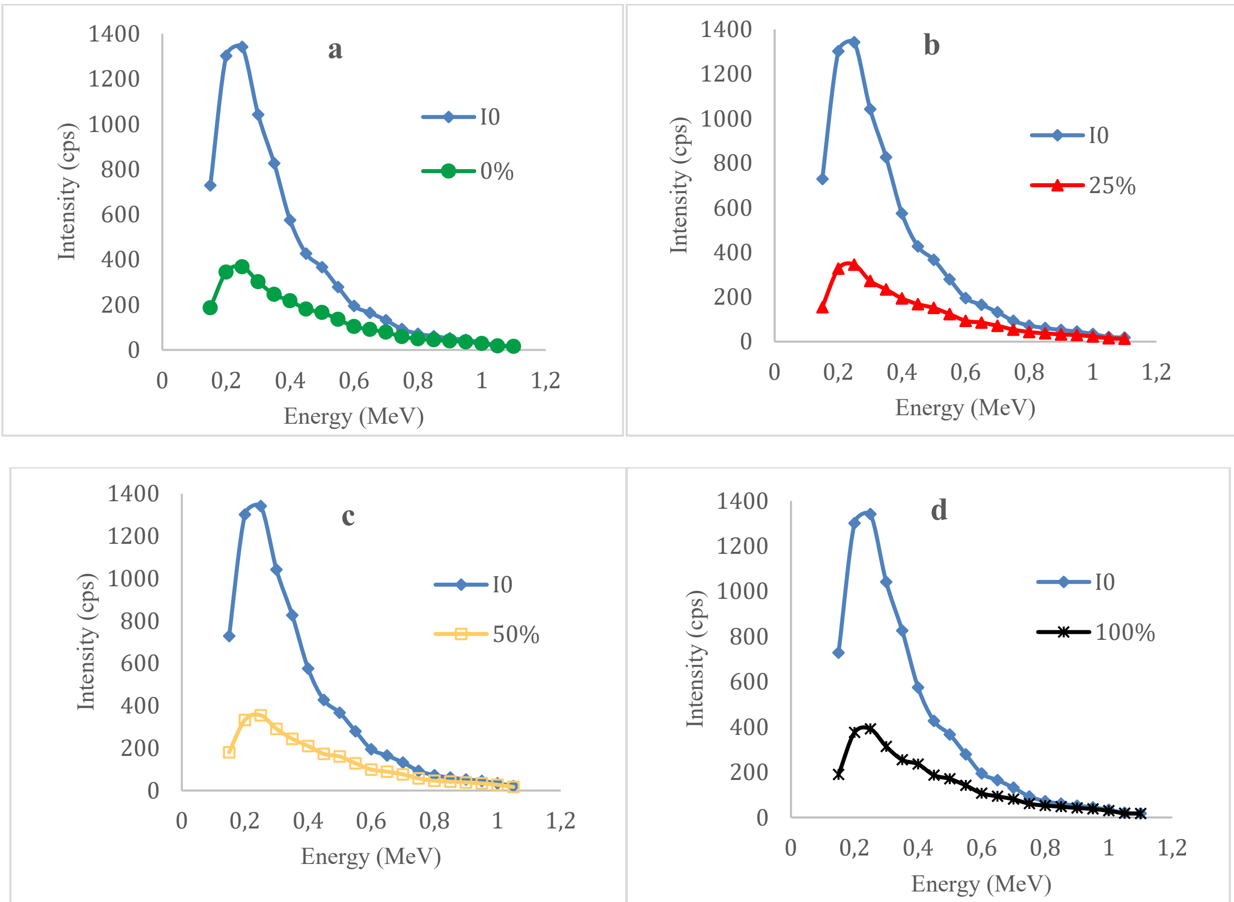

Figure 2. Original and absorption spectrum for bremsstrahlung ray with glass waste:

a) original I_0, 0% replacement. b) original I_0, 25% replacement.
c)original I_0, 50% replacement. d) original I_0, 100% replacement.

The effect of the bremsstrahlung ray energies on μ for all the tested specimens are presented in Fig 3. It is found that the inversely proportion with bremsstrahlung energies for the same thickness of reactive powder concrete.

The fitted curve of measured logarithmic transmissions intensity for reactive powder concrete containing 0%,25%, 50%, 100%, glass waste versus absorber thickness were plotted as in Fig. 4 to obtain linear attenuation coefficient.

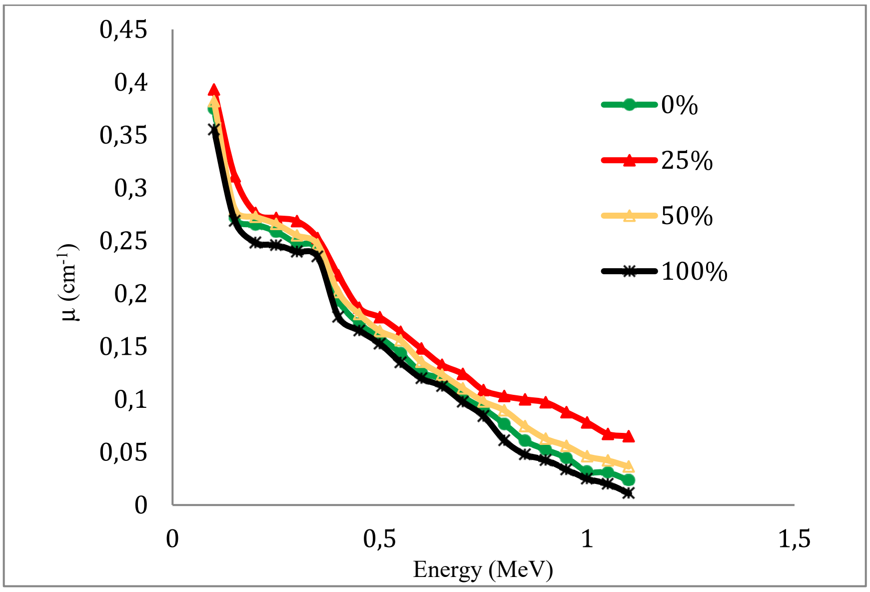

Figure 3. Attenuation coefficient as a function of energy.

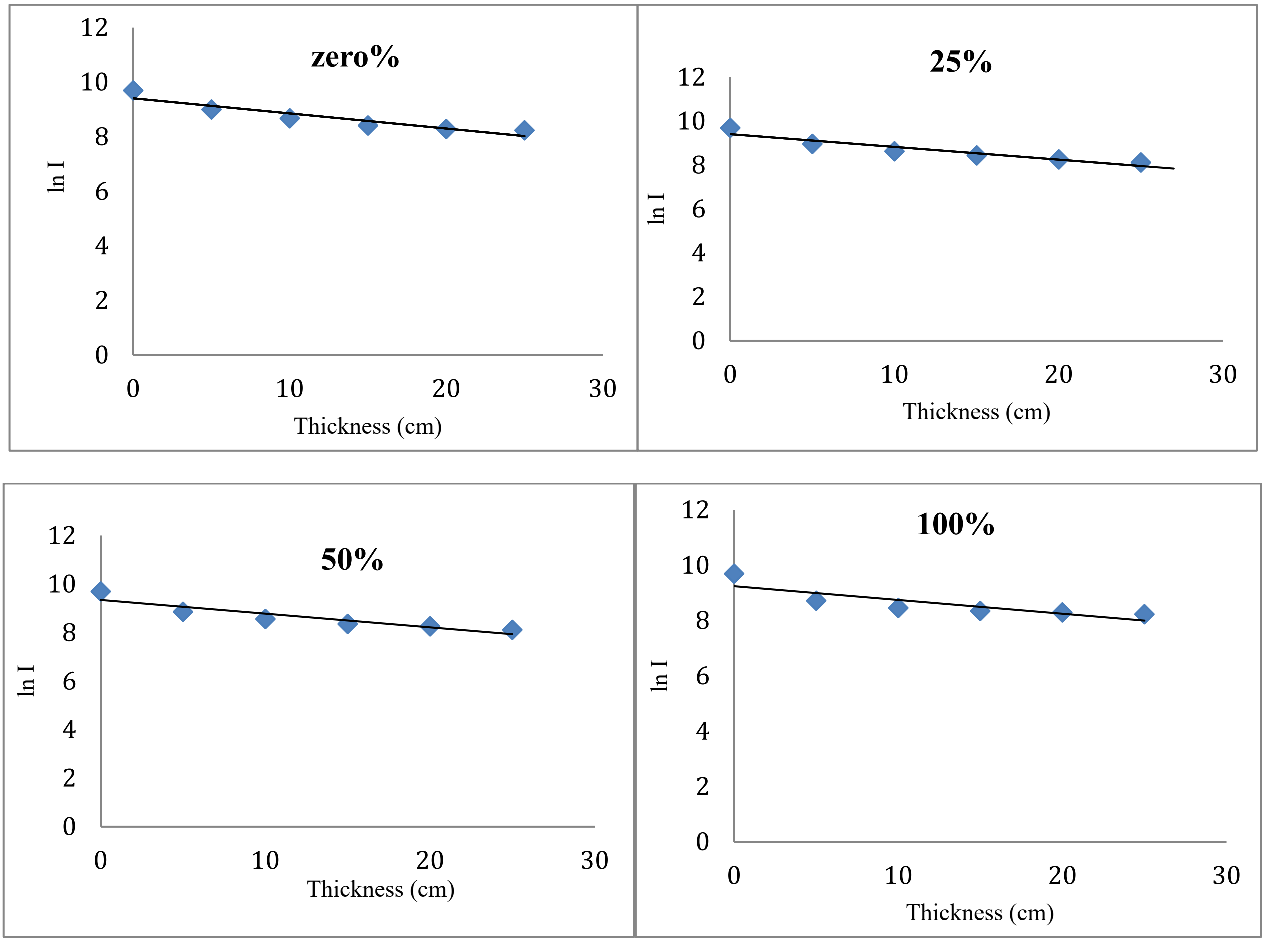

Figure 4. logarithmic transmissions intensity (ln I) for reactive powder concrete containing 0%,25%, 50%, 100%, glass waste versus absorber thickness in cm.

The experimental results of linear and mass attenuation coefficients for reactive powder concrete as a function of glass waste replacement had presented in Fig. 5a and 5b, respectively. It is obvious from this figure that the experimental values of linear and mass attenuation coefficients for reactive powder concrete containing 25% glass waste were higher than those which obtained from the specimen of (0%) glass waste replacement but the lowest values were found at 100% replacement of glass waste. It can be detected from this Figure that the attenuation coefficients decrease as the replacement of glass waste increases over 25%.

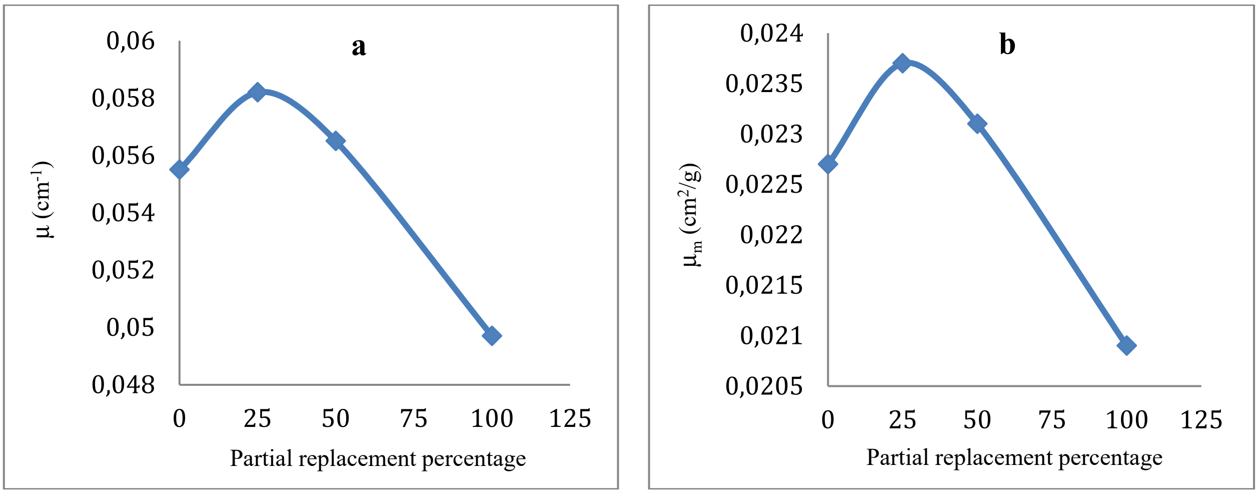

Figure 5. Attenuation coefficient of reactive powder concrete as a function of partial replacement percentage
a. Linear attenuation coefficient, **b**. Mass attenuation coefficient

According to Fig. 6, the behavior of the μ curve is the exact opposite of that of the $X_{1/2}$ curve. This shows that the qualities of the RPC attenuations improved and offered superior shielding when the RPC contained 25% of glass waste.

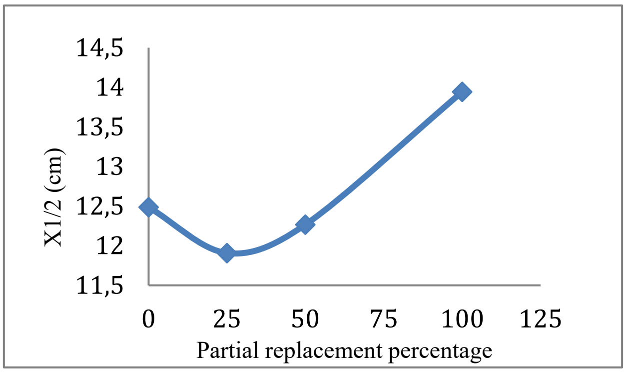

Figure 6. Half-value thickness as a function of glass waste replacement

4. CONCLUSION

In this study, linear attenuation properties such as linear attenuation coefficient, mass attenuation coefficient and half value thickness of reactive powder concrete without and with glass waste were calculated. Also, the effects of using glass waste as a fractional replacement for fine aggregate in reactive powder concrete at levels of 0%, 25%, 50%, and 100% was investigated.

From the obtained results, it can be concluded that the glass waste replacement gave a significant improvement in attenuation property. Also, tested samples in this work are a good absorbers of bremsstrahlung radiation. In addition, the density of the sample can be enhanced with the glass waste content ratio to 25 %. The bremsstrahlung radiation shielding capabilities of reactive powder concrete can be enhanced using glass waste not more than 25 %. By increasing the glass waste ratio in the reactive powder concrete up to 25 %; the density (ρ), the value of linear attenuation coefficients as well as mass attenuation coefficients are decreased and the half values thickness increases.

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ДОСЛІДЖЕННЯ ВПЛИВУ СКЛЯНИХ ВІДХОДІВ У РЕАКТИВНОМУ ПОРОШКОВОМУ БЕТОНІ НА ВЛАСТИВОСТІ ОСЛАБЛЕННЯ ГАЛЬМІВНОГО ВИПРОМІНЮВАННЯ

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Реактивний порошковий бетон (RPC) є одним із найдосконаліших сучасних бетонів високої міцності на стиск. У цій роботі досліджено вплив використання скляних відходів як фракційної заміни дрібного заповнювача в реактивному порошковому бетоні на рівнях 0%, 25%, 50% і 100%. Лінійні та масові коефіцієнти ослаблення були розраховані як функція товщини зразка та енергії гальмівного випромінювання. Ці коефіцієнти були отримані з використанням енергоселективної сцинтиляційної реакції на гальмівне випромінювання з енергією в діапазоні від (0,1 до 1,1) МеВ. Крім того, досліджено половинну товщину виготовлених зразків. Встановлено, що між коефіцієнтом ослаблення та енергією гальмівного випромінювання існує зворотний зв'язок. Результати показали, що, за винятком зразка з частковою заміною 25% відходів скла, додавання дрібного заповнювача частково відходами скла мало негативний вплив на властивості ослаблення реактивного порошкового бетону. Це означає, що щільність зразка може бути покращена за допомогою співвідношення вмісту скляних відходів до 25%. Крім того, здібності реактивного порошкового бетону до захисту від гальмівного випромінювання можна підвищити, використовуючи відходи скла не більше ніж на 25%.

Ключові слова: *властивості ослаблення; гальмівне випромінювання; реактивний порошковий бетон (RPC); скляні відходи; стійкий матеріал*