Geosystem Engineering

ISSN: 1226-9328 (Print) 2166-3394 (Online) Journal homepage: http://www.tandfonline.com/loi/tges20

Assessing the physical, mechanical properties, and γ-ray attenuation of heavy density concrete for radiation shielding purposes

Ahmed S. Ouda & Hakim S. Abdelgader

To cite this article: Ahmed S. Ouda & Hakim S. Abdelgader (2018): Assessing the physical, mechanical properties, and γ-ray attenuation of heavy density concrete for radiation shielding purposes, Geosystem Engineering, DOI: 10.1080/12269328.2018.1469434

To link to this article: https://doi.org/10.1080/12269328.2018.1469434

Published online: 04 May 2018.

GEOSYSTEM ENGINEERING, 2018
https://doi.org/10.1080/12269328.2018.1469434

Taylor & Francis
Taylor & Francis Group

Assessing the physical, mechanical properties, and γ-ray attenuation of heavy density concrete for radiation shielding purposes

Ahmed S. Ouda[a,b] and Hakim S. Abdelgader[c]

[a]Housing and Building National Research Center, Giza, Egypt; [b]The University College of Taimaa, Tabuk University, Tabuk, Saudi Arabia; [c]Faculty of Engineering, Department of Civil Engineering, University of Tripoli, Tripoli, Libya

ABSTRACT

The main purpose of this research is to improve the shielding of gamma rays by developing special concrete with high physico-mechanical properties using local aggregates. Various concrete mixtures are designed using heavy fine aggregate as a substitute for normal fine aggregate at rates of 20, 40, 60, 80, and 100%, by weight. Other concrete mixtures have been designed by replacing coarse aggregate with 50 and 60% of heavy fine aggregate. The properties such as density, compressive strength, and tensile strength of hardened mixtures were studied. Gamma ray attenuation has been studied on concrete mixtures after exposure to utilized radiation source comprised ^{137}Cs radioactive element with photon energy of 0.662 MeV. From the results, we concluded that the density and compressive strength in addition to the linear attenuation coefficient of hardened mixtures increased with the ratio of replacing normal aggregate with heavy aggregate up to 60%. With an increase of the ratio more than 60%, compressive strength and tensile strength were reduced with the continued increase in density. On the other hand, density and the linear attenuation coefficient increased with the replacement of coarse aggregate by 50 and 60% of the heavy fine aggregate; while both compressive strength and tensile strength decreased.

ARTICLE HISTORY
Received 13 January 2018
Accepted 23 April 2018

KEYWORDS
Heavy density aggregate; heavy density concrete; gamma ray shielding; physico-mechanical properties of concrete; linear attenuation coefficient

1. Introduction

Nuclear reactors are one of the main sources of the radiation danger which generate during nuclear reactors operation such as X-rays, γ-rays, neutrons, and other rays that threaten human health and safety. Radiation shielding of such rays examination rooms is an important health safety in hospital clinics; therefore, it requires developing a protection system to be able to resist those radiations. Concrete is an ideal material for use in construction of radiation shields. Although there are other materials that could be employed for radiation shielding purposes. Concrete is not only economical, but also has the advantage of being a material that can be cast into any desired homogenous structural shape. Concrete is now commonly used for shielding of atomic research facilities, nuclear power plants and for radiation medical, and research units or equipment. Conventional concrete of sufficient thickness can be and is being used for such purposes. However, where usable space is a major consideration; the reduction in the thickness of the shield is accomplished by the use of high-density concrete. It is known that attenuation properties depend on the constituents, thickness, and density of concrete as well gamma ray energy.

Al-Humaiqani, Shuraim, and Hussain (2013) studied the linear and mass attenuation coefficients of gamma ray for different normal and heavyweight high-strength high-performance concretes (HPCs). They concluded that, the compressive strength of heavy HPCs plays a significant role in increasing the attenuation of gamma ray. Also, there is almost a linear relationship between the compressive strength and gamma ray attenuation of HPCs. Abadi, Salimi, Ghal-Eh, Etaati, and Asadi (2013) observed that nuclear radiation protection shields are fabricated using materials like lead, iron, graphite, water, polyethylene, and concrete, among which, concrete is one of the best and most widely used materials for gamma and neutron radiation shields. This is because, in addition to having the adequate strength and structural properties, concrete can be fabricated into any shape having different densities at relatively low cost. Kansouh (2012) studied the shielding properties of serpentine concrete, hematite–serpentine concrete, ilmenite–limonite concrete, and ordinary concrete. The results showed that ilmenite–limonite concrete is a better reactor biological shield than the other three concretes. While serpentine concrete was found to be a better reactor fast neutrons shield than ordinary and

CONTACT Ahmed S. Ouda aouda@ut.edu.sa

I II III

Figure 1. Three sizes of coarse aggregate termed as (I, II, III).

hematite–serpentine concretes. Akkurt, Akyildirim, Mavi, Kilincarslan, and Basyigit (2010) investigated the radiation shielding properties of pumice concrete. They concluded that using pumice stone as aggregate in concrete does not give any better results in terms of gamma radiation shielding properties. Abo-El-Enein et al. (2014) concluded that the heavyweight HPC can be prepared with the use of ilmenite and hematite coarse aggregates when properties such as high strength and good radiation shielding are required. They found that, such concretes have high density than their counterparts made of the coarse aggregate of dolomite and air-cooled slag. On the other hand, they found that crushed air-cooled slag can be used to prepare high-strength concrete with better mechanical properties than concrete made with crushed hematite and ilmenite. High-density concrete made with fine portions of ilmenite and air-cooled slag were found to be suitable for shielding against gamma ray. Gencel 2011a) studied the gamma and neutron attenuation characteristics of concrete containing hematite aggregate. It was observed that, there was no effect of hematite inclusion in concrete with respect to the neutron absorption capability; however, the gamma ray attenuation capability and the mechanical strength of concrete increased with increasing the hematite content. Sharma et al. (2009) studied the mechanical and shielding properties of fiber-reinforced concrete containing steel fibers, lead fibers, and a combination of the two (hybrid fibers). Compressive strength, split tensile strength, and flexural strength as well as radiation shielding of gamma rays were investigated. The results revealed that, the concrete mix containing hybrid fibers showed a significant increase in both mechanical and radiation shielding properties.

The overall objective of this study is to reach the best concrete components using local fine aggregate to design high-density concrete that can be used to attenuate gamma rays after exposure to the utilized radiation source comprised ^{137}Cs radioactive element with photon energy of 0.662 MeV in thick shield of 15 cm. In the investigation, concrete mixtures were designed by replacing normal fine aggregate with 20, 40, 60, 80, and 100% of heavyweight fine aggregate, by weight. To achieve high gamma attenuation rate, other heavy density mixtures were also prepared upon replacing coarse aggregate by 50 and 60% of heavyweight fine aggregate.

Table 1. Chemical composition of heavyweight fine aggregate (wt. %).

	%
Fe_2O_3	46.66
SiO_2	22.58
Al_2O_3	20.73
CaO	0.43
LOI	9.6

2. Preparation of concrete mixtures

2.1. Materials

Ordinary Portland cement (42.5 N) in accordance with LSS-340 (2009) was used in the current study. Crushed limestone aggregate, locally known by 'Ras Gadeah' with three sizes (I, II, III) and maximum nominal size of 19 mm was used as coarse aggregate (CA). Figure 1 shows three sizes of coarse aggregate. Whereas, crushed limestone fine material with two sizes, obtained from 'Sedy- Alsayes and Gasr Akhyar' were used as normal fine aggregate (NFA). On the other side, a natural heavy fine material called red sand, collected from 'South of Libya near to Sabha' was used as heavy fine aggregate (HFA) and its chemical analysis was given in Table 1.

2.2. Physical properties of aggregates

2.2.1. Specific gravity

Specific gravity is defined as the ratio of the weight of a unit volume of aggregate to the weight of an equal volume of water. Relative density of coarse and fine aggregates were determined in accordance with ASTM C127 (2015) and ASTM C128 (2015), respectively. The bulk specific gravity test of the investigated aggregates whether coarse or fine was measured under two different conditions including dry (no water in sample), and saturated surface dry (water fills the aggregate's air voids) as shown in Table 2. It was found that the bulk-specific gravity of

Table 2. Specific gravity of coarse and fine aggregates.

	Aggregate type					
	CA			NFA		
Physical property	I	II	III	II	II	HFA
*S.G (Dry)	2.536	2.523	2.530	2.649	2.590	3.58
*S.G (SSD)	2.54	2.58	2.57	2.65	2.61	3.59

*S.G: Specific gravity, D: Dry, SSD: Saturated Surface Dry.

Table 3. Moisture content values of coarse and fine aggregates.

	Aggregate type					
	CA			NFA		
Physical property	I	II	III	I	II	HFA
Absorption (%)	1.75	1.5	1.06	1.5	2.5	3.3

dried HFA increased by 37.16% than dried NFA, while it was increased by 36.5% than NFA at saturated surface dry condition.

2.2.2. Moisture content

Moisture content is the quantity of water contained in a material. Since aggregates contain some porosity, water can be absorbed into the body of the particles or retained on the surface of the particles as a film of moisture and therefore both the water content and the water-to-cement ratio of concrete mixtures will be affected. Table 3 represents the moisture content values of coarse and fine aggregates according to ASTM C127 (2015) and ASTM C128 (2015). It has been observed that the water absorption of HFA increased by 54.54 and 24.24% than NFA-I and NFA-II, respectively.

2.2.3. Sieve analysis of aggregates

A sieve analysis is a procedure used to assess the particle size distribution of a granular material. The size of aggregate particles differs from aggregate to another, and for the same aggregate, the size is also different. The particle size distribution of fine and coarse aggregates has been assigned by sieving analysis. This method is used to determine the compliance of the aggregate gradation with specific requirements of ASTM C136 (2014). Sieve analyses of coarse and fine aggregates are given in Table 4.

2.3. Mix proportions

In the present investigation, six concrete mixtures designated as M0, M1, M2, M3, M4, and M5 were prepared by partial replacement of NFA with HFA at different percentages of 0, 20, 40, 60, 80, and 100%, respectively. Also, two concrete mixtures designated as M6 (50:50) and M7 (40:60) were manufactured upon replacing CA with 50 and 60% of HFA, respectively. The mix proportions of different concrete mixtures were designed according to ACI 211.1 (1991), and outlined in Table 5.

2.4. Mixing, casting, and curing procedures

Initially, a part of the mixing water was added to the coarse aggregate, and then starts the mixer rotation. After that, the normal fine aggregate, heavyweight fine aggregate, cement, and the amount of water remaining were added to the mixture. All the concrete ingredients were mixed together for 3 min, followed by other 3-min rest. Finally, all batches were mixed for a total time of 5 min before casting. To avoid segregation of fresh concrete, the mixing duration was kept as low as possible. Slump test was conducted to assess the workability of fresh concrete containing normal fine aggregate and those containing heavy fine aggregate. The slump test was carried out according to ASTM C143 (2015). For each mix in the test program, a sample of freshly mixed concrete is placed and compacted by rod in a frustum of cone mold as shown in Figure 2. The slump value is equal to vertical distance between the original and displaced position of the center of the top surface of the concrete after raising a mold.

After the mixing process is completed, fresh mixtures were casted into 150 × 150 × 150 mm^3 cubic steel molds for

Table 4. Sieve analysis results of fine and coarse aggregates.

	Passing percentage (%)				
Sieve size (mm)	Coarse aggregate (I)	Coarse aggregate (II)	Coarse aggregate (III)	Mixed normal fine aggregate (I and II)	Heavyweight fine aggregate (HFA)
37.5					
25.0					
19.0	100				
12.5	65.7	100			
9.5	15.1	95.9	100		
4.75	1.40	20.0	94.3	100	100
2.36	0.00	0.00	0.51	100	81.4
1.18		0.00	0.00	99.9	69.5
0.600				97.8	49.4
0.300				58.4	19.7
0.150				25.9	7.00
0.075				1.90	0.30

Table 5. Mix proportions of different concrete mixtures.

	Concrete mix ingredients (kg/m^3)							
			CA			NFA		HFA
Mixes	OPC	Water	I	II	III	I	II	
M0	436.0	205.0	495.0	247.5	232	494.5	164.8	0
M1	436.0	205.0	495.0	247.5	232	411.6	145.34	139.3
M2	436.0	205.0	495.0	247.5	232	327.4	115.56	295.3
M3	436.0	205.0	495.0	247.5	232	232.2	81.97	471.3
M4	436.0	205.0	495.0	247.5	232	124.1	43.79	671.4
M5	436.0	205.0	495.0	247.5	232	0	0	900.8
M6	436.0	205.0	375	187.5	175.875	0	0	1306.4
M7	436.0	205.0	300	150	140.7	0	0	1515.2

Figure 2. Slump test of fresh concrete mixtures containing different proportion of heavyweight fine aggregate using cone mold.

conducting compressive strength and gamma ray shielding tests. Other mixtures were casted into 150 × 300 mm^2 cylinders for tensile strength test. After demolding, concrete specimens were transferred into water tank until 28 days. Curing of specimens was performed according to ASTM C511 (2013).

2.5. *Methods of investigation*

The density of hardened concrete specimens was determined according to BS EN12390-7 (2009). The compressive strength test was conducted on four samples. The splitting tensile strength test was carried out according to ASTM C496 (2011).

The linear gamma ray attenuation coefficients of concrete mixtures were measured by exposing the samples to photons emitted from ^{137}Cs source (5 μCi) with energy of 0.662 MeV. ^{137}Cs is a radioisotope commonly used as a gamma emitter in many applications. Its advantages include a half-life of roughly 30 years, its availability from the nuclear fuel cycle, and having

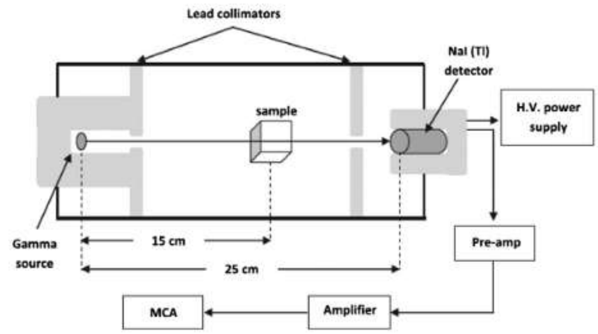

Figure 3. Schematic representation for gamma ray attenuation measurement.

^{137}Ba as a stable end product; in addition, a large number of previous literatures that studied the attenuation of gamma rays were used ^{137}Cs as a gamma ray emitter, of which Hassan, Badrana, Aydarous, and Sharshar (2015), Ochbelagh and Azimkhani (2012), Demir et al. (2011), and many others. The gamma ray attenuation measurements were performed using a 5 cm × 5 cm NaI (Tl) detector with a Multi-Channel Analyzer, supplied by Phywe Company, Germany. The schematic representation of the experimental setup is shown in Figure 3. The attenuation was examined by measuring the ratio of the penetrating radiation through the three axes for each cube. For each mixture, the measurements were conducted for 15-min counting time. The average values and the standard deviations were calculated to acquire the accuracy of the measurements and to assure the homogeneity of the cubes for each sample. The linear attenuation coefficients for these samples were experimentally determined using narrow collimated mono-energetic beam of gamma rays.

The linear attenuation coefficient, μ, has been obtained from the solution of the exponential Beer–Lambert's law:

$$\mu = \frac{1}{x}\ln\frac{\mathrm{I0}}{\mathrm{I}}$$

where I and I0 are the background subtracted number of counts recorded in detector with and without material

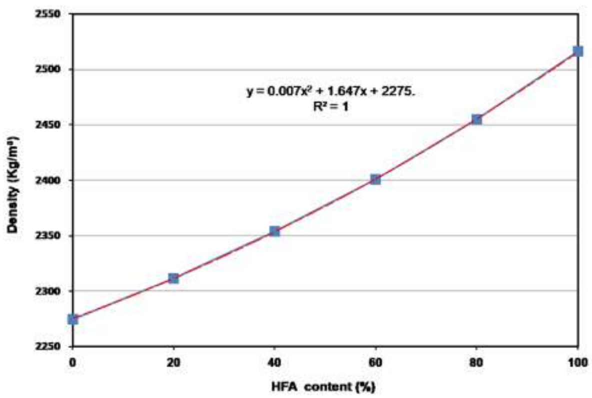

Figure 4. Workability of concrete mixtures (M0, M1, M2, M3, M4, M5) containing different ratios of HFA.

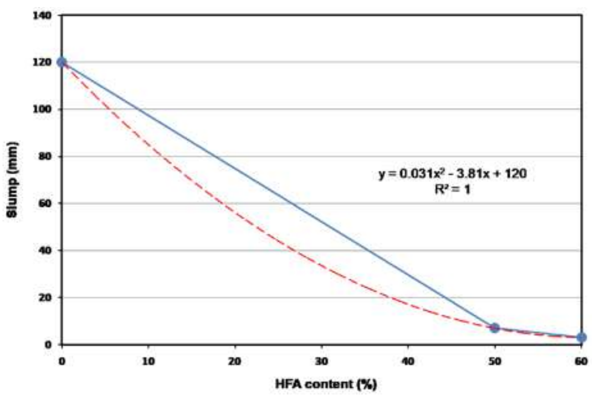

Figure 5. Workability of concrete mixtures (M0, M6, M7) containing different ratios of HFA.

between detector and source, respectively, and x is the material thickness (15 cm).

3. Results and discussions

3.1. Workability of fresh mixtures

The slump value was used as an indication of mix workability. The slump values of concrete mixtures containing 0, 20, 40, 60, 80, and 100% different ratios of heavyweight fine aggregate as well as mixtures prepared by replacing the coarse aggregate with 50 and 60% heavyweight fine aggregate after 28 days of hydration are graphically represented in Figures 4 and 5. It was found that the slump values decrease as the rate of HFA substituted with NFA increases to 100% relative to control mix as shown in (Figure 4). The figure represents nearly constant relation between slump and the percentage of HFA substituted. This decrease ranged from 120 to 11 mm. On the other hand, the slump values decreased by 94.16 and 97.5% when replacing the coarse aggregate with 50 and 60% of heavyweight fine aggregate, respectively, as shown in (Figure 5). The decrease in slump values with the increase

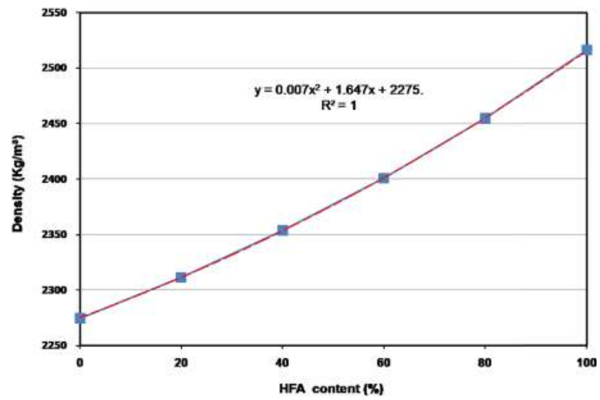

Figure 6. Density of hardened concrete mixtures (M0, M1, M2, M3, M4, M5) containing different proportions of heavyweight fine aggregates.

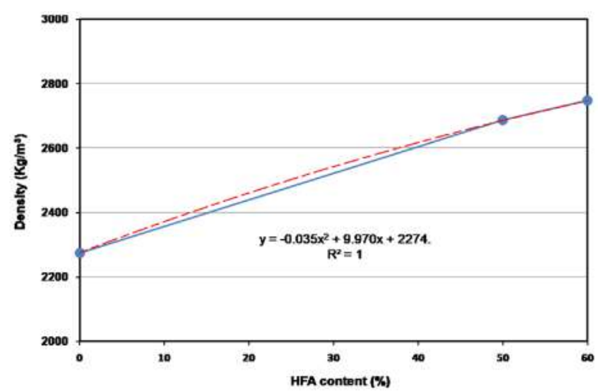

Figure 7. Density of hardened concrete mixtures (M0, M6, M7) containing different proportions of heavyweight fine aggregates.

of HFA content in mixtures is due to the difference in the rate of water absorption between CA, NFA, and HFA; where the latter absorbs more water than its former counterparts (Ouda, 2015).

3.2. Density of hardened mixtures

The average density values of hardened concrete specimens containing 0, 20, 40, 60, 80, and 100% different ratios of heavyweight fine aggregate after 28 days of curing are graphically shown in Figure 6. As the ratio of heavyweight fine aggregate in mixtures is increased, the density will gradually increase. Based on the results obtained, the samples achieved an increase in density of 1.62, 3.47, 5.54, 7.91, and 10.61% when the heavyweight fine aggregate replacement rate was 20, 40, 60, 80, and 100%, respectively compared to the reference samples.

In the same context, we noticed an increase in concrete density by 18.06 and 20.75% when replacing the normal fine aggregate with 50 and 60% of heavyweight fine aggregate, respectively (Figure 7). This increase in density is due to high specific gravity of heavyweight fine aggregate as

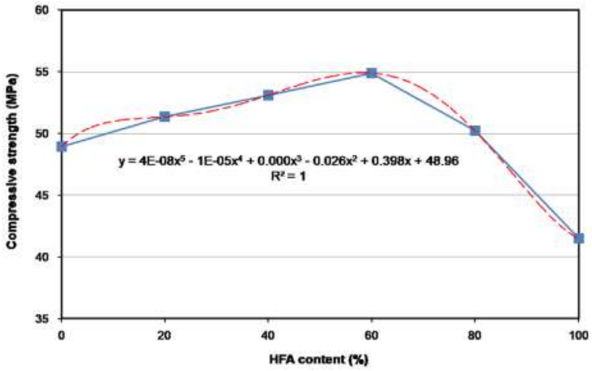

Figure 8. Compressive strength of hardened mixtures (M0, M1, M2, M3, M4, M5) containing different proportions of heavyweight fine aggregate.

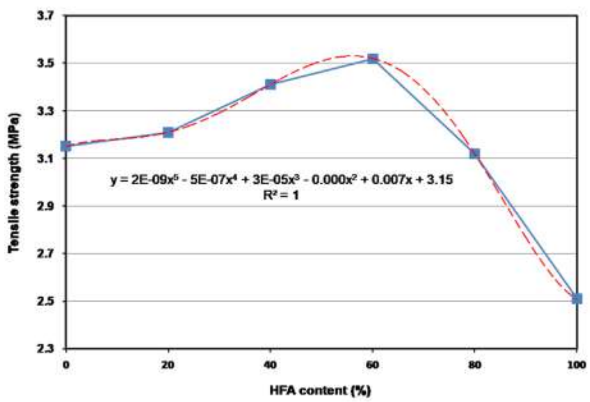

Figure 9. Compressive strength of hardened mixtures (M0, M6, M7) containing different proportions of heavyweight fine aggregate.

compared to normal fine aggregate and coarse aggregate (Table 2).

3.3. Compressive strength

Figures 8 and 9 show the compressive strength results of concrete mixtures made of 0, 20, 40, 60, 80, and 100% different ratios of heavyweight fine aggregate as well as mixtures prepared by replacing the coarse aggregate with 50 and 60% heavyweight fine aggregate after 28 days of hydration. It was noticed that, the compressive strength increased by about 5, 8.5, 12.15, and 2.55% when replacement levels of HFA were 20, 40, 60, and 80%, respectively, compared to the reference mixture. It decreased by 15.23% when the replacement rate increased to 100%. The results indicated that the mix containing 60% of HFA exhibited the highest compressive strength among all mixtures; therefore, it is the optimum proportion that can be replaced by NFA in concrete mixtures (Figure 8). On the other hand, compressive strength decreased by 24.22 and 35.66%, respectively, when replacing the coarse aggregate

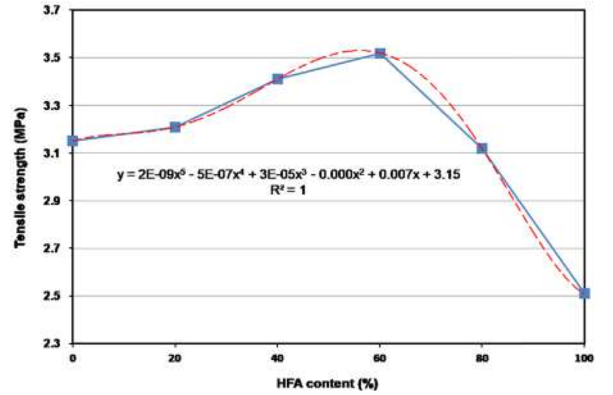

Figure 10. Tensile strength of hardened concrete mixtures (M0, M1, M2, M3, M4, M5) containing different proportions of heavyweight fine aggregate.

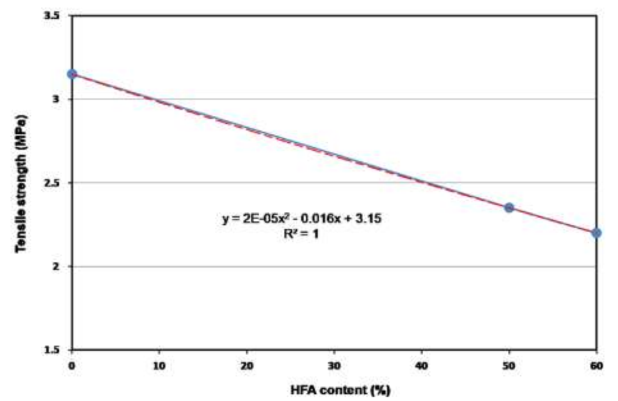

Figure 11. Tensile strength of hardened concrete mixtures (M0, M6, M7) containing different proportions of heavyweight fine aggregate.

with 50 and 60% of heavyweight fine aggregate (Figure 9). The increase of compressive strength is attributed to the mixtures containing HFA have large surface area, thus forming a large adhesion force between aggregate particles and the cement matrix (Ouda, 2015). This increase may also due to the HFA aggregate contains high percentage of hematite (α-Fe_2O_3) of 46.66% (Table 1), which had an effect in increasing the density of mixtures containing HFA; in addition to the rough surface of hematite aggregate, which guaranteed strong bonding with cement paste. Increasing the hematite ratio in mixtures to 60% had a negative effect on the reduction of compressive strength values.

3.4. Tensile Strength

The tensile strength of concrete mixtures made of 0, 20, 40, 60, 80, and 100% different ratios of heavyweight fine aggregate in addition to the mixtures designed by replacing coarse aggregate with 50 and 60% heavyweight fine

Table 6. The average values of linear attenuation coefficient of concrete mixtures containing different ratios of HFA.

Mixes	Destiny (kg/m^3)	Thickness (cm)	μ (cm^{-1})
M0	2274.80	15	0.030655 ± 0.001
M1	2311.74	15	0.047997 ± 0.0104
M2	2353.81	15	0.054327 ± 0.002
M3	2401.05	15	0.069137 ± 0.008
M4	2454.75	15	0.075757 ± 0.02
M5	2516.33	15	0.089094 ± 0.004
M6	2685.74	15	0.101878 ± 0.008
M7	2746.91	15	0.113065 ± 0.005

aggregate after 28 days of hydration is graphically plotted in Figures 10 and 11. It was observed that tensile strength was increased when the heavyweight fine aggregates were increased in the mixture. The results showed that the tensile strength increased when NFA aggregate was replaced with HFA aggregate at ratios of 20, 40, and 60% by 1.90, 8.25, and 11.74%, respectively, in comparison to the reference mixture; while it decreased when the replacement rate increased from 80 to 100% to become 0.96 and 25.49%, respectively. The aforesaid results showed that the mix containing 60% HFA exhibited the highest tensile strength among all the mixtures and therefore it can be considered an optimal ratio for substitution by NFA (Figure 10). On the other hand, it was observed that the tensile strength values decreased by 34 and 43.18%, respectively, when the coarse aggregate was replaced by 50 and 60% heavyweight fine aggregate (Figure 11). After studying the mechanical properties of concrete mixtures, we found a strong correlation between the results of compressive strength and tensile strength as the optimum mix that can be used in the design of heavyweight concrete is that contains 60% of HFA substituted NFA.

3.5. Gamma ray attenuation properties

The average values of linear attenuation coefficient and their standard deviation for all concrete mixtures containing 0, 20, 40, 60, 80, and 100% different ratios of HFA as well as the mixtures manufactured by replacing coarse aggregate with 50 and 60% heavyweight fine aggregate at 28 days of curing and after exposure to ^{137}Cs gamma ray source with photon energy of 0.662 MeV are given in Table 6 and graphically represented in Figures 12 and 13. It was noted that the values of the standard deviation are extremely small that varied from 0.001 to 0.02, this gives good indication that the prepared samples have good homogeneity and of even distributions of the dense components within the concrete cohesive mixture. The results observed that, linear attenuation coefficient values increased linearly with the increase of HFA content in mixtures up to 100%. The increase in the attenuation coefficient was estimated by 56.57, 77.22, 125.53, 147.12, and 190.53% when replacement levels of HFA were 20, 40,

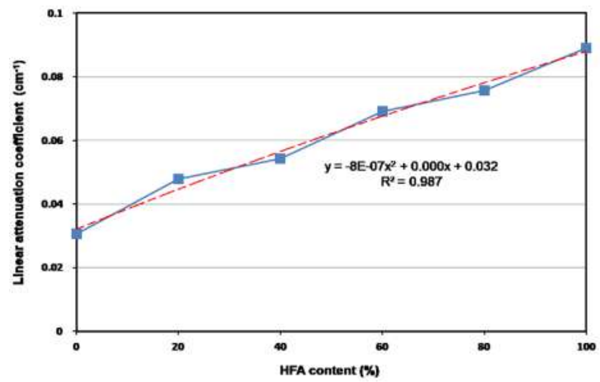

Figure 12. The average values of linear attenuation coefficient of concrete mixtures (M0, M1, M2, M3, M4, M5) containing different ratios of HFA.

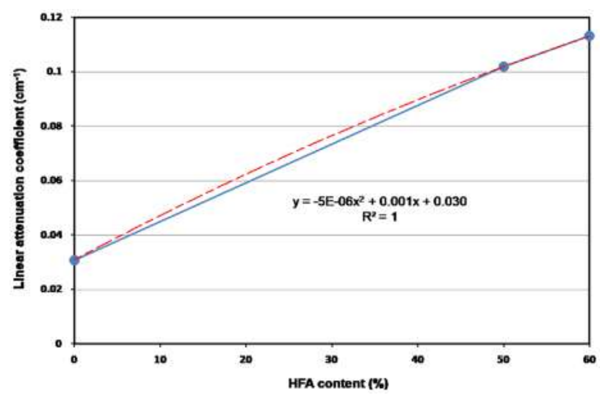

Figure 13. The average values of linear attenuation coefficient of concrete mixtures (M0, M6, M7) containing different ratios of HFA.

60, 80, and 100%, respectively compared to the reference mixture without HFA (Figure 12). On the other side, the values of linear attenuation coefficient were also increased for concrete mixtures designed upon replacing coarse aggregate with 50 and 60% heavyweight fine aggregate; these values were 232.33 and 268.83%, respectively (Figure 13). With regard to the improvement of concrete properties in terms of absorbing gamma ray, reasons behind this improvement might be the increase of concrete density as a result of heavy components. Also, this improvement might be due to the chemical composition of heavy red sand which mainly consists of iron oxide (Table 1), which had a positive impact in terms of making the concrete more attenuated for gamma rays. Many of previous literatures showed that the incorporation of iron oxides within concrete matrix are suitable for using as a barrier to emitted gamma rays, of which Delnavaz, Salavatiha, and Kalhor (2017) found that an increase in participation of the iron oxide aggregates caused increasing density and thereby intensification of the attenuation coefficient in concrete mixtures. In the same context, Mirmazhari, Entezari, and Azadi (2017) concluded that the addition of hematite ((Fe_2O_3) has a positive impact towards obtaining a heavyweight concrete and by increasing concrete density, the value of γ-ray attenuation coefficient increases.

4. Conclusions

Based on experimental observation, the following conclusions can be summarized:

(1) The density of concrete mixtures increased with the increase of heavyweight fine aggregate content, of which the mix M5 exhibited the highest value approximately 10.61% folds over that of the control M0. When replacing coarse aggregate with 50 and 60% heavyweight fine aggregate, the density increased by 18.06 and 20.75%, respectively. The significant difference in density is due to the high specific gravity possessed by HFA aggregate compared to NFA and CA aggregates.

(2) The compressive strength of concrete mixtures increased by about 5, 8.5, 12.15, and 2.55% when replacement levels of HFA were 20, 40, 60, and 80%, respectively, compared to the reference mixture; while it decreased by 15.23% when the replacement rate increased to 100%. The results indicated that the mix containing 60% of HFA exhibited the highest compressive strength among all mixtures. On the other hand, compressive strength has decreased upon replacing the coarse aggregate with 50 and 60% of heavyweight fine aggregate by 24.22 and 35.66, respectively.

(3) The tensile strength of concrete mixtures increased when NFA aggregate was replaced with HFA aggregate at ratios of 20, 40, and 60% by 1.90, 8.25, and 11.74%, respectively, in comparison to the reference mixture; while it decreased when the replacement rate increased from 80 to 100% to become 0.96 and 25.49%, respectively. The results showed that the mix containing 60% HFA exhibited the highest tensile strength among all mixtures.

(4) The values of linear attenuation coefficient increased linearly with the increase of HFA content in mixtures up to 100%. The increase in the attenuation coefficient was estimated by 56.57, 77.22, 125.53, 147.12, and 190.53% when replacement levels of HFA were 20, 40, 60, 80, and 100%, respectively, compared to the reference mixture without HFA. The values of linear attenuation coefficient were also increased for concrete mixtures designed upon replacing coarse aggregate with 50 and 60% heavyweight fine aggregate; these values were estimated by 232.33 and 268.83%, respectively.

(5) Finally, it is recommended to replace NFA aggregate with 60% HFA aggregate collected from South Libya, as it had achieved the best mechanical characteristics among all prepared mixtures; in addition, it also achieved a satisfactory attenuation of gamma rays in thick shield of 15 cm at photon energy of 0.662 MeV.

Disclosure statement

No potential conflict of interest was reported by the authors.

References

Abadi, A. E. A., Salimi, M., Ghal-Eh, N., Etaati, G. R., & Asadi, H. (2013). Study of neutron and gamma radiation protective shield. *International Journal of Innovation Studies, 3*(4), 1079–1085.

Abo-El-Enein, S. A., El-Sayed, H. A., Ali, A. H., Mohammed, Y. T., Khater, H. M., & Ouda, A. S. (2014). Physico-mechanical properties of high performance concrete using different aggregates in presence of silica fume. *HBRC Journal, 10*, 43–48.

ACI 211.1. (1991). *Standard practice for selecting proportions for normal, heavyweight and mass concrete*, Reported by ACI Committee 211, 1–38.

Akkurt, I., Akyildirim, H., Mavi, B., Kilincarslan, S., & Basyigit, C. (2010). Radiation shielding of concrete containing zeolite. *Radiation Measurements, 45*(7), 827–830.

Al-Humaiqani, M. M., Shuraim, A. B., & Hussain, R. R. (2013). Effect of Compressive Strength on γ-Radiation Attenuation Coefficients for High Performance Concrete. *International Journal of Engineering and Technology, 5*(5), 566–572.

ASTM C127. (2015). *Standard test method for density, relative density (specific gravity), and absorption of coarse aggregate*, ASTM International, West Conshohocken, PA, DOI:10.1520/C0127-15, 1–6.

ASTM C128. (2015). *Standard test method for relative density (specific gravity) and absorption of fine aggregate*, ASTM International, West Conshohocken, PA, DOI:10.1520/C0128-15.

ASTM C136. (2014). *Standard test method for sieve analysis of fine and coarse aggregates*, ASTM International, West Conshohocken, PA, DOI:10.1520/C0136-14, 1–5.

ASTM C143 (2015), *Standard test method for slump of hydraulic-cement concrete*, ASTM International, West Conshohocken, PA, DOI:10.1520/C0143-15, 1–4.

ASTM C496 (2011), *Standard test method for splitting tensile strength of cylindrical concrete specimens*, ASTM International, West Conshohocken, PA, DOI:10.1520/C1144-89R11, 1–5.

ASTM C511. (2013). *Standard specification for mixing rooms, moist cabinets, moist rooms, and water storage tanks used in the testing of hydraulic cements and concretes*, ASTM

International, West Conshohocken, PA, DOI:10.1520/C0511, 1–3.

BS EN12390-7. (2009). *Testing hardened concrete. Density of hardened concrete*, British Standard, B/517/1[91.100.30].

Delnavaz, A., Salavatiha, A., & Kalhor, A. (2017). Effective parameters in gamma radiation transmission rate from heavy concrete with iron oxide and barite aggregates. *Journal of Materials in Civil Engineering,29* (9), 04017140 (1–7).

Demir, F., Budak, G., Sahin, R., Karabulut, A., Oltulu, M., & Un, A. (2011). Determination of radiation attenuation coefficients of heavyweight- and normal-weight concretes containing colemanite and barite for 0.663 MeV γ-rays. *Annals of Nuclear Energy, 38*(6), 1274–1278.

Gencel, O. (2011a). Physical and mechanical properties of concrete containing hematite as aggregates. *Science and Engineering of Composite Materials, 18*(3), 191–199.

Hassan, H. E., Badrana, H. M., Aydarous, A., & Sharshar, T. (2015). Studying the effect of nano lead compounds additives on the concrete shielding properties for γ-rays. *Nuclear Instruments and Methods in Physics Research Section B: Beam Interactions with Materials and Atoms, 360*(1), 81–89.

Kansouh, W. A. (2012). Radiation distribution through serpentine concrete using local materials and its application as a reactor biological shield. *Annals of Nuclear Energy, 47*, 258–263.

LSS-340. (2009). *Libyan Standard Specifications in Portland cement*. Libyan National Center for Standardization and Metrology, Tripoli.

Mirmazhari, S. S., Entezari, A., & Azadi, M. R. E. (2017). Determination of mechanical characteristics and radiation attenuation coefficients of heavyweight and normal-weight concretes containing hematite for 70 keV and 570 keV γ-rays. *International Journal of Civil Engineering, Construction and Estate Management, 5*(2), 13–23.

Ochbelagh, D. R., & Azimkhani, S. (2012). Investigation of gamma-ray shielding properties of concrete containing different percentages of lead. *Applied Radiation and Isotopes, 70*(10), 2282–2286.

Ouda, A. S. (2015). Development of high-performance heavy density concrete using different aggregates for gamma-ray shielding. *Progress in Nuclear Energy, 79*, 48–55.

Sharma, A., Reddy, G. R., Varshney, L., Bharath Kumar, H., Vaze, K. K., Ghosh, A. K., … Krishn amoorthy, T. S. (2009). Experimental investigations on mechanical and radiation shielding properties of hybrid lead-steel fiber reinforced concrete. *Nuclear Engineering and Design, 239*(7), 1180–1185.