CSCE Annual Conference
Growing with youth – Croître avec les jeunes

Laval (Greater Montréal)
June 12 - 15, 2019

POTENTIAL USE OF HEAVY WEIGHT CONCRETE FOR RADIATION SHEILDING IN EGYPT

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Abstract:

This study attempts to produce adequate concrete with effective radiation shielding. In this study, a set of heavyweight aggregates were selected to be incorporated and to replace both coarse and fine aggregates aiming at reaching a sound concrete mix. These aggregates include granite, basalt and slag as coarse aggregates as well as iron powder, slag powder and direct reduced iron (DRI) as fine aggregates. The aggregates were subjected to rigorous testing including Energy-dispersive X-ray Spectroscopy test to determine the elemental analysis and ensure that materials used have a high metal content that can serve in blocking the radiation atoms and reducing their energy. The heavyweight concrete mixes were tested for fresh, hardened and durability tests. Most importantly, all mixes were evaluated for radiation shielding through the use of Gamma Ray Point source and a detector using various thicknesses to determine the attenuation coefficient of each mix. The attenuation coefficient gives an indication of the radiation shielding properties for each mix and hence classifying their potential protection. Concrete samples were also exposed for longer durations to a gamma source with high intensity to identify any loss in their mechanical properties; this test should further help show the effect of radiation exposure on the cubes' mechanical properties in comparison to the unexposed samples. The study concluded that using heavyweight aggregates especially iron by-products increases the radiation shielding properties of the concrete mixes, together with increasing the mechanical properties such as compressive strength.

1 INTRODUCTION

The world has been gradually shifting towards the use of nuclear power plants to produce conventional fossil energy. These power plants emit a spectrum of radiation, categorized as Ionizing radiation, such as alpha, beta and gamma which are caused by unstable atoms giving off energy to reach a more stable state. This ionizing radiation can cause, upon leakage, serious harm to humans as well as serious damage to the structures and the surroundings. Lead is well known for its powerful radiation shielding properties because of its high density that is caused by the combination of small size of bond lengths and high atomic mass and atomic radius (Midland Lead, 2017). Concrete is also used as a radiation shielding material but unlike lead, concrete is used in large thicknesses and sometimes with a layer of lead to make sure that there is no leakage. The main idea of using heavyweight concrete instead of the conventional concrete is to reach a higher density and to decrease the thickness of the concrete shielding walls thus, saving up on space as well as overall cost. Adding heavyweight aggregates to the concrete mix increases its unit weight thus producing a higher density that could help in radiation shielding. Hence, it is of vital importance to explore the effect of using different heavyweight aggregates in radiation shielding.

2 LITERATURE REVIEW

2.1 Investigation of gamma radiation attenuation in heavy concrete shields containing hematite and barite aggregates in multi-layered and mixed forms:

In this paper, barite and hematite were used as heavyweight aggregates for radiation shielding in separate and mixed forms. Concrete samples were subjected to a radiation source that emits gamma rays at 1173 and 1332 Kev energy levels, like the ones used in radiology centres. It was found that barite and hematite increase the gamma-ray attenuation coefficient of the concrete mix. The results also show that adding hematite and barite increased the compressive strength of the concrete by 23% and 21%, compared to the conventional concrete.

2.2 Evaluation of physical and mechanical characteristics of siderite concrete to be used as heavy-weight concrete:

This paper evaluates the physical and mechanical properties of heavyweight concrete rich in siderite. It also points out that there are other materials that could be used in heavyweight concrete such as limonite, barite, ilmenite, hematite and steel shots. Barite is the most widely used heavy-weight element in the heavy-weight concrete production. The specimens were tested by an ultrasonic measurement device and also tested for surface hardness. Radiation permeability was tested at different ratios and thicknesses (2,4,6 and 8 cm), and was measured by dosimetry devices. This test resulted in a high radiation permeability of concrete plates produced with siderite aggregate.

2.3 Gamma Radiation Absorption Characteristics of Concrete with Components of Different Type Materials:

This paper discusses the attenuation coefficient of heavyweight concrete mixes using barite as an aggregate and comparing it to the conventional concrete. The concrete samples were exposed with different thicknesses to a caesium radiation source with an intensity of 0.511 MeV and 0.622 MeV. The paper also evaluates the Monte Carlo simulation on the same mixes and with the same intensity source. The paper concludes that the mass attenuation coefficient of the Barite concrete mix was higher than that of the conventional concrete in the case of the 0.662 MeV source.

3 OBJECTIVE AND SCOPE

In this research, the main objective was to explore the feasibility of using heavyweight aggregates concrete for radiation shielding. This objective was obtained through conducting experimental work and comparing the results reached for both heavyweight concrete and conventional concrete mixes.

4 EXPERIMENTAL PROGRAM

4.1 Material Properties

Cement: Type 1 Ordinary Portland Cement Concrete

Fine Aggregates:

- ***Sand:*** Natural Sand was used as a fine aggregate for Conventional concrete mixes***.***
- ***Slag Powder:*** Slag powder was used as fine aggregate for heavyweight mixes, obtained as a by-product from an Iron factory in Cairo, Egypt. The aggregate was well-graded.
- ***Iron Powder:*** Iron powder was used as fine aggregate for heavyweight mixes, obtained as a by-product from an Iron factory in Cairo, Egypt. The aggregate was well-graded.
- ***Direct Reduced Iron (DRI):*** DRI was used as fine aggregate for heavyweight mixes, obtained as a by-product from an Iron factory in Cairo, Egypt. The aggregate was well-graded.

Coarse Aggregates:

- ***Dolomite:*** Well-graded Crushed dolomite was used for Conventional concrete mixes with MNA of 38 mm. The aggregate was well-graded.
- ***Granite:*** Well-graded crushed Red Aswan granite was used for heavyweight mixes with MNA of 38 mm, from the area of Shaq Al Thu'ban, Cairo, Egypt. Aggregate had to be crushed to be well-graded.
- ***Basalt:*** Well-graded crushed basalt was used for heavyweight mixes with MNA of 38 mm, from the area of Shaq Al Thu'ban, Cairo, Egypt. Aggregate had to be crushed to be well-graded.
- ***Slag:*** Well-graded crushed slag was used for heavyweight mixes with MNA of 38 mm, obtained as a by-product form an iron factory. Aggregate had to be crushed to be well-graded.s

4.2 Concrete Mix Design

The characteristics of the concrete mixes that were used in this study has a cement content of 400 kg/m^3 and a water-to-cement ratio of both 0.40 and 0.50 for the conventional concrete mixes and for one heavy weight concrete mix (Slag and iron powder). As for the remaining mixes, the water-to-cement ratio was fixed to be 0.40. For the heavyweight concrete mixes, the whole percentages of dolomite and sand were replaced by heavyweight aggregates. The ratio of fine aggregates to coarse aggregates was fixed to be around 0.67 and this was determined after consulting the literature and initial mixing. Concrete mixing and casting of specimens were carried out according to ASTM standards.

Table 1: Concrete Mix Design

Mix ID	W/C ratio	Cement (kg/m^3)	Water (kg/m^3)	Dolomite (kg/m^3)	Slag (kg/m^3)	Granite (kg/m^3)	Basalt (kg/m^3)	Sand (kg/m^3)	Slag Powder (kg/m^3)	Iron Powder (kg/m^3)	DRI (kg/m^3)
CC4	0.40	400	160	954	-	-	-	636	-	-	-
CC5	0.50	400	200	899	-	-	-	599	-	-	-
S.IP4	0.40	400	160	-	1291	-	-	-	-	811	-
S.IP5	0.50	400	200	-	1216	-	-	-	-	741	-
S.SF	0.40	400	160	-	1111	-	-	-	741	-	-
S.DRI	0.40	400	160	-	1160	-	-	-	-	-	773
G.SF	0.40	400	160	-	-	1019	-	-	679	-	-
G.IP	0.40	400	160	-	-	1168	-	-	-	778	-
G.DRI	0.40	400	160	-	-	1060	-	-	-	-	706
B.SF	0.40	400	160	-	-	-	1125	-	750	-	-
B.IP	0.40	400	160	-	-	-	1310	-	-	873	-
B.DRI	0.40	400	160	-	-	-	1176	-	-	-	784

Mixes	Coarse aggregate	Fine aggregate
CC4	Dolomite	Sand
CC5	Dolomite	Sand
S.IP4	Slag	Iron Powder
S.IP5	Slag	Iron Powder
S.SF	Slag	Slag Fine
S.DRI	Slag	Direct Reduced Iron
G.SF	Granite	Slag Fine
G.IP	Granite	Iron Powder
G.DRI	Granite	Direct Reduced Iron

B.SF	Basalt	Slag Fine
B.IP	Basalt	Iron Powder
B.DRI	Basalt	Direct Reduced Iron

4.3 Tests

4.3.1 Aggregates Tests:

- *Sieve Analysis:* Sieve analysis was performed to determine the gradation of aggregates, in accordance with (ASTM C136).
- *Specific Gravity:* Specific gravity test was performed to determine specific gravity of aggregates, in accordance with (ASTM C127-15)
- *Water Absorption:* Water absorption percentages were performed to determine water absorption percentage for aggregates, in accordance with (ASTM D6473-15).
- *Energy Dispersive X-ray (EDX):* EDX test was performed to determine the elemental composition of the aggregates, in order to know the percentage of Fe in each material.

4.3.2 Fresh Concrete Tests:

- *Slump:* slump test was performed to test the workability of the fresh concrete mixes, in accordance with (ASTM C143).
- *Air Content:* This test was performed to determine the percentage of air in the fresh concrete mixes, in accordance with (ASTM C173).
- *Unit Weight:* This test was performed to determine the unit weight of the fresh concrete mixes, in accordance with (ASTM C138).
- *Temperature:* The temperature of the fresh concrete mixes was measured, in accordance with (ASTM C1064).

4.3.3 Hardened Concrete Tests:

- *Compressive Strength:* This test was performed to evaluate the strength of hardened concrete mixes, using cubes in accordance with (BS 1881). The test was performed on cubes of 15cm*15cm*15cm at 3 days, 7 days, and 28 days.
- *Flexural Strength:* This test was performed to measure the flexural strength of the mixes, in accordance with (ASTM C78). Three-point test was performed on beams of 15cm*15cm*75cm at 28 days.
- *Ultrasonic Pulse Velocity:* This test was performed to measure the amount of air voids in the hardened concrete mixes, in accordance with (ASTM C597), it was conducted on cubes of 15cm*15cm*15cm at 28 days.

4.3.4 Concrete Radiation Tests:

- *Degradation of Concrete from Radiation:* This test was conducted to obtain the differences in the mechanical properties before and after subjecting the concrete mixes to a continuous radiation source with intensity reaching 20 kGy per day. The test was conducted on cubes of 15cm*15cm*15cm in the Egyptian Atomic Energy Authority located in Cairo, Egypt.
- *Gamma Ray Attenuation:* This test was conducted to obtain the attenuation coefficient of concrete mixes, by measuring how easily the concrete can be penetrated by radiation. The test was performed on concrete layers of thicknesses 2cm,3cm,4cm,5cm,6cm,7cm and 7.5 cm. Dimensions of the cubes used were (7x7xT), were “T” is the thickness of each layer. layers were subjected to a cesium point source that emits gamma ray.

5 RESULTS AND DISCUSSION

5.1 Aggregates tests

5.1.1 Sieve Analysis

Figure 1: Basalt Gradation

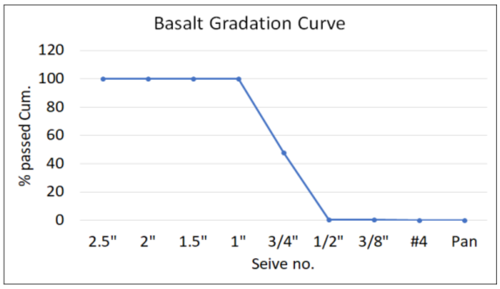
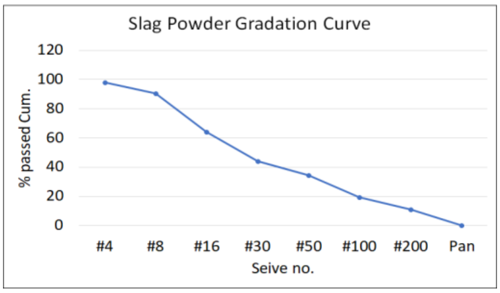


Figure 2: Slag Powder Gradation



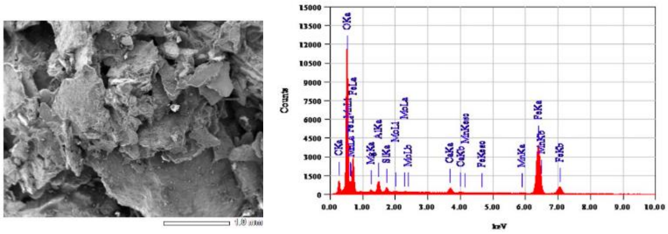
The sieve analysis was done for all the aggregates and showed that the fine aggregates were well-graded and did not need adjustments. The coarse aggregates were poor-graded and they had to be crushed in order to fill in the missing sieve sizes. The above graphs are a sample of one coarse aggregate, Basalt, and one fine aggregate, Slag Powder. The remaining coarse aggregates followed the same trend of the Basalt and the remaining fine aggregates followed that of Slag Powder.

5.1.2 Energy Dispersive X-ray (EDX)

Table 2: Aggregates Properties

Aggregates	Fe %
DRI	65.6%
Iron powder	62.2%
Slag Coarse	12.9%
Basalt	10.5%
Slag Fine	9.2%
Granite	0.0%

Figure 3: Iron powder EDX



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Element          (keV)    Mass%     Counts    Sigma    Atom%
 C  K            0.277     5.14    5601.57     0.04    12.80
 O  K   (Ref.)   0.525    25.55   71975.66     0.11    47.75
Mg  K            1.253     0.44    1654.86     0.02     0.54
Al  K            1.486     2.15    7675.64     0.04     2.39
Si  K            1.739     0.87    3030.28     0.03     0.93
Ca  K            3.690     2.27    4668.48     0.06     1.69
Mn  K            5.894     0.71     744.55     0.05     0.39
Fe  K            6.398    62.24   57056.68     0.39    33.32
Mo  L            2.293     0.63     488.86     0.08     0.20
Total                    100.00                        100.00
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The energy dispersive x-ray test showed the different iron percentages for each material used to give a preliminary indication to the tendency of each material to shield radiation. The research showed that high iron percentages were necessary to protect against radiation and the values obtained from the test further proved that the aggregates selected were capable of being used in the heavyweight concrete mixes.

5.1.3 Specific Gravity and Absorption

Table 3: Specific Gravity and Absorption

Aggregates	Specific Gravity	Specific Weight (kN/m^3)	Absorption (%)
Dolomite	2.6	25.5	1.3
Granite	2.6	25.5	0.4
Basalt	3.1	30.4	1.8
Slag	3.0	29.4	1.8
Sand	2.6	25.5	0.4
Iron powder	4.9	48.1	0.2
Slag (Fine)	3.0	29.4	0.3
DRI (Fine)	3.8	37.3	18.0

The specific gravity for all the heavyweight aggregates selected, were proven to be higher than that of the dolomite and sand that are normally used in the conventional concrete mixes. These results further proved that these aggregates are of heavyweight nature and are suitable for usage in the heavy weight concrete mixes. This was further proven in the specific weight and the values were in the expected range for heavyweight aggregates and much higher than the aggregates used for conventional mixes. The absorption was also calculated for the aggregates as to account for the absorbed water in the mix design. The highest absorption value was that of the DRI, at 18%, and that might be due to its porous nature. These percentages were then added to the water percentages in the mix design to ensure an acceptable workability.

5.2 Fresh Concrete tests

Mix	Slump (cm)	Air Content (%)	Concrete Temperature (℃)	Unit Weight (kg/m^3)
CC4	0.5	2.2	27.2	2376
CC5	6.0	3.7	27.5	2330
S.IP4	17.0	7.4	26.1	2884
S.IP5	6.0	3.4	23.1	2891
S.SF	8.0	2.5	22.9	2829
S.DRI	7.5	2.0	24.2	2790
G.SF	19.0	1.4	27.3	2547
G.IP	s18.0	5.7	24.1	2586
G.DRI	0.7	0.8	27.1	2538
B.SF	3.0	2.4	24.5	2586
B.IP	1.0	1.8	24.6	2547
B.DRI	5.0	1.5	24.8	2091

The slump of the heavy weight concrete mixes was relatively high in comparison to the conventional concrete; however that was expected due to the nature of the heavyweight aggregates as they pull the mix down due to their high unit weight and gravitational force. The air content for all the mixes was within the expected range, up to 7%, that was based on the literature review. The temperature values for all the mixes were within range, with the exception of the DRI mixes that had a slight increase in the temperature, which might be due to the nature of the DRI material, and should be further investigated. The unit weights for all the mixes, with the exception of the B.DRI mix, proved to be noticeably higher than the conventional concrete mixes and that shows that all mixes are considered to be of heavyweight nature and are suitable for our application.

5.3 Hardened Concrete tests

5.3.1 Compressive Strength

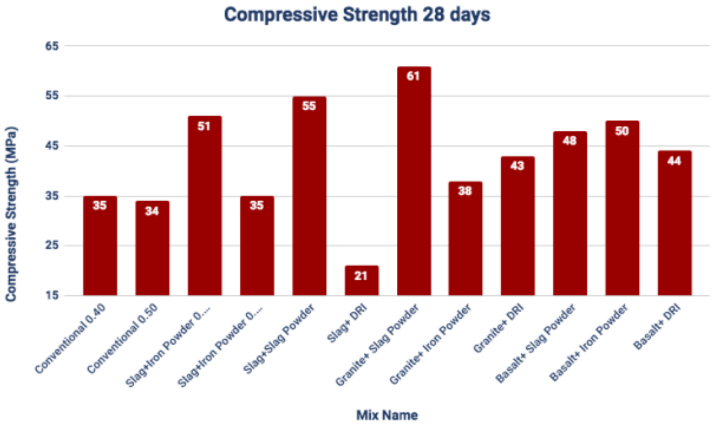
Table 4: Compressive Strength

Mix	3 days (MPa)	Standard Deviation	7 days (MPa)	Standard Deviation	28 days (MPa)	Standard Deviation
CC4	30.5	3.8	32.2	4.5	34.6	1.7
CC5	27.8	2.1	31.6	3.3	34.3	4.2
S.IP4	30.2	5.0	40.0	0.5	50.7	6.9
S.IP5	27.7	1.2	32.0	2.2	34.5	8.2
S.SF	37.7	15.6	47.7	0.4	54.4	5.6
S.DRI	17.0	2.8	16.8	2.9	21.0	1.6

G.SF	36.8	2.2	39.8	4.4	60.5	7.3
G.IP	19.9	3.3	28.2	4.0	38.5	6.0
G.DRI	30.3	4.9	35.1	1.2	43.3	1.4
B.SF	25.9	5.8	29.1	6.0	47.7	8.1
B.IP	30.2	8.3	36.6	2.5	49.5	5.8
B.DRI	35.1	9.0	37.4	3.1	44.0	8.1

The compressive strength was measured for 3 cubes from each mixture at 3, 7 and 28 days. The average values were then taken and recorded and compared to conventional concrete. The standard deviation was also calculated from the 3 values obtained to determine accuracy of results. The strength for the majority of the mixes was higher than the strength of the conventional concrete, especially at 28 days. Mix 3 had a lower strength than conventional concrete and this was mainly due to honeycombing as the amount of water was not carefully adjusted for absorption in the DRI. This was adjusted in the remaining mixtures involving DRI and therefore they gave suitable values. The absorption for the DRI was very high at 18% and had a major effect.

Figure 4: Compressive Strength



5.3.2 Flexural Strength

Table 5: Flexural Strength

Mix	CC4	CC5	S.IP4	S.IP5	S.SF	S.DRI	G.SF	G.IP	G.DRI	B.SF	B.IP	B.DRI
Flexural Strength (MPa)	2.70	2.70	2.25	2.20	3.10	1.60	2.45	2.30	2.70	2.00	1.70	1.40
Standard Deviation	0.1	0.3	0.2	0.5	0.3	0.4	0.4	0.3	0.3	0.5	0.3	0.3

Beams tested for flexural were PC (plain concrete) beams. Two of the DRI mixes showed the least results, while S.SF mix showed the highest flexural strength of 3.10 MPa. The standard deviation was very low, as expected due to them not being reinforced.

5.4 Concrete Radiation tests

5.4.1 Degradation of Concrete from Radiation

5.4.1.1 Ultrasonic Pulse Velocity

Table 6: Ultrasonic results before and after Degradation from Radiation

	CC4	CC5	S.IP4	S.IP5	S.SF	S.DRI	G.SF	G.IP	G.DRI	B.SF	B.IP	B.DRI
Before Radiation	34	26	29	30	28	36	26	29	30	27	27	35
After Radiation	25	26	29	28	27	34	26	31	33	28	27	33

The ultrasonic test was conducted to show the effect of radiation on the mixes' quality and continuity. This test was conducted also to observe for any cracks in the cubes. The values from this test were used to compare between the cubes before and after subjecting to radiation, not to reach conclusions on the mixes. The ultrasonic pulse velocity test, which is non-destructive, was used to measure any differences in the concrete quality and compared to reference value before radiation to see effect of radiation on the mixes. The creation of micro cracks in the cube would have caused a reduction in the value obtained from the ultrasonic test. In the majority of the mixes, there was minimal decrease in the values, which could be attributed to errors in the machine's calibration or due to not fixing the tested face of the cube while conducting the test before and after subjecting it to radiation. Mix CC4 had a significant decrease in the value which should be repeated to further verify whether the conventional mix did degrade after being subjected to radiation due its un-heavy nature, or whether that was due to the above-mentioned errors. These values were only used to indicate a difference in the quality between the conventional mixes and the heavyweight mixes and how each mix will be affected by the radiation. The results were inconclusive due to the cubes being subjected to radiation for only 7 days and human errors.

5.4.1.2 Weights

Table 7: Weights Before and after Degradation from Radiation

Mix	Weight Before Radiation	Weight After 3 days in Radiation	Weight After 7 days in Radiation
	(kg)	(kg)	(kg)
CC4	8.40	8.38	8.38
CC5	7.72	7.70	7.70
S.IP4	9.89	9.83	9.82
S.IP5	10.70	10.64	10.63
S.SF	9.73	9.72	9.72
S.DRI	9.52	9.43	9.41
G.SF	8.48	8.48	8.48
G.IP	8.91	8.90	8.90
G.DRI	8.66	8.64	8.64
B.SF	8.78	8.75	8.75
B.IP	10.00	9.98	9.97
B.DRI	8.66	8.62	8.61

The trend shows that there were minimal to none decrease in weight values, averaging at around 20 grams, with the exception of mix S.DRI which showed a reduction of 90 grams. These minor reductions in weights could be due to several errors including: inaccuracy in the balance, handling and transporting the cubes, which might have caused some loss in the weight of the cubes.

5.4.1.3 Schmidt Hammer

Table 8: Schmidt Hammer before and after Degradation from Radiation

Compressive strength (MPa)	CC4	CC5	S.IP4	S.IP5	S.SF	S.DRI	G.SF	G.IP	G.DRI	B.SF	B.IP	B.DRI
Before Radiation	32.3	29.3	31.0	26.7	27.7	22.0	38.0	30.0	34.7	27.3	30.3	25.0

After Half Radiation period	38.0	30.0	30.0	27.0	32.0	21.0	40.0	30.0	32.0	28.0	36.0	27.0
After Full Radiation period	34.3	28.7	30.0	25.7	29.7	23.0	40.0	30.6	33.3	29.0	34.0	25.3

The Schmidt hammer test was conducted to show the effect of the radiation on the strength of the concrete mix. A non-destructive test was needed so as to not subject the cube to conventional compressive strength using the UTM “universal testing machine”, to be able to compare the same cube before and after being subjected to radiation. The values showed some fluctuations due to the low reliability of the Schmidt hammer test. Also, some factors may have contributed in the results, such as: human error in handling and performing the test, not ensuring the exact verticality of the Schmidt hammer, and not fixing the same face while conducting the test before and after subjecting the cube to radiation.

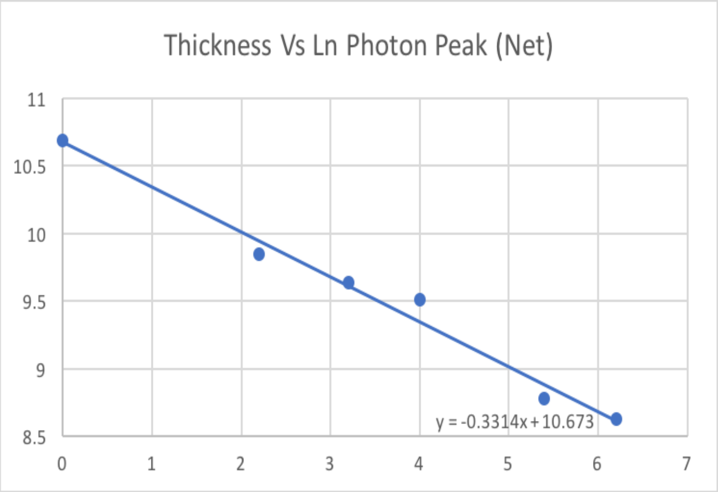
5.4.2 Gamma Ray Point Source

5.4.2.1 Gamma Ray Attenuation

Table 9: Gamma ray Attenuation

Mix ID	μ_l (cm^{-1})	ρ (gm/cm^3)	μ_m (cm^2/gm)	HVL (cm)
CC4	0.1904	2.376	0.0801	3.64
CC5	0.1737	2.330	0.0745	3.99
S.IP4	0.2863	2.884	0.0993	2.42
S.IP5	0.3314	2.891	0.1150	2.09
S.SF	0.2997	2.829	0.1059	2.31
S.DRI	0.2762	2.790	0.0990	2.51
G.SF	0.2036	2.547	0.0799	3.40
G.IP	0.2000	2.586	0.0773	3.47
G.DRI	0.1938	2.538	0.0764	3.58
B.SF	0.2105	2.586	0.0814	3.29
B.IP	0.2156	2.457	0.0880	3.21
B.DRI	0.2150	2.091	0.1028	3.22
Lead	1.8449	11.34	0.1627	0.38

Figure 5: Thickness vs. Ln net area of photon peak



The linear attenuation, mass attenuation and HVL (half value layer) were measured and compared to both the control mixes, together with Lead. Results showed that all mixes yielded better linear attenuation coefficients than the control mixes, which accordingly provided lower HVL values. Mix S.IP5 was found to have the highest linear attenuation and consequently having the lowest HVL (2.09cm), which reached almost half the HVL value of the control mix CC5 (3.99cm). As for the mass attenuation coefficients, 7 out of 10 mixes were found to have higher values of mass attenuation coefficients, compared to the ordinary control mixes. One of the unusual observations was finding mix S.IP5 with the higher w/c ratio (0.5), yield better results than mix S.IP4 with w/c ratio (0.4), in terms of both linear and mass attenuation coefficients, resulting in much lower HVL. This was quite different from the normal behaviour of the control mixes, where mix CC4, having the lower w/c ratio (0.4), was found to have better attenuation coefficients than mix CC5 with higher w/c ratio (0.5).

Accordingly, the concrete mixes with the highest densities (S.IP4, S.IP5, S.SF, and S.DRI) were found to be remarkably effective for gamma ray shielding. The effectiveness of shielding gamma radiation is further described in terms of the HVL of a material. HVL stands for the thickness at which the sample reduces the radiation source to half of its original intensity (Akkurt et al., 2010). Fig (5) shows a sample of mix S.IP5 results, where Ln (photon peak net area) was plotted against the different tested thicknesses of the mix, this helped calculate the slope of the curve, which represents the linear attenuation coefficient (µl) of the sample, applying two simple equations of ($\frac{\mathrm{Ln}(2)}{\mu\mathrm{L}}$) and ($\frac{\mu\mathrm{L}}{\rho}$) will result in calculating both the HVL value and the mass attenuation coefficient respectively.

6 CONCLUSIONS

1. All the mixes produced had higher mechanical properties than conventional concrete mix, such as compressive strength and unit weight.
2. The radiation tests showed that all heavyweight concrete mixes yielded better shielding properties than normal concrete mixes.
3. The heavyweight concrete mixes reached smaller HVL than normal concrete mixes, reaching up to almost half the HVL of the conventional CC5 control mix.
4. There were minor effects shown on the mechanical properties of the concrete mixes after subjecting them to radiation for 3 and 7 days, as shown by the results from the Ultrasonic Pulse Velocity test, Schmidt Hammer Test, Weight as well as Compressive Strength test.

7 RECOMMENDATIONS

1. To expand this work on much larger specimen sizes and concrete mixes for longer durations to validate the findings of this type
2. Provide access to different aggregates that were not covered in this study.
3. Subject the cubes to a much longer time under gamma radiation to notice any effects on mechanical properties and visual inspections.
4. All precautions covered by this study, such as higher slump and heavier weight, need to be communicated and dissipated to the applicators

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