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^{60}Co γ-ray attenuation coefficient of barite concrete

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Background: Recently, the use of medium and high energy X-rays has increased in Iran, and radiotherapy centers along with a variety of accelerators have been installed in some provinces. Hence, there is not sufficient skill in designing and installing radiotherapy treatment rooms. This study was conducted to evaluate the efficacy of different mixtures of barite concrete for shielding the radiotherapy rooms. This way, we have emphasized on determining the size and amount of barite aggregations to achieve the maximum radiation attenuation which leads to minimizing wall thickness in treatment room. ***Materials and Methods:*** To increase concrete density, the barite aggregation was added to concrete. Different size variations of barite aggregates mixed with different water/cement ratio were examined. The dimension of cubic concrete specimens for compression strength test was 15×15×15 cm. The rectangular barite concrete blocks with different compressions as used for strength test with cross section of 10×10 cm, and thicknesses from 5 to 40 cm were used for radiation attenuation test. To do so, concrete specimens were irradiated by gamma beam of ^{60}Co (Phoenix Theratron). The transmission radiation through the blocks was measured by a Farmer ionization chamber (FC65P). ***Results:*** Our findings showed that in all specimens the highest mean compression strength was related to the specimens with equal ratio of fine to coarse barite aggregates, but the lowest HVL was obtained from mixtures with fine to coarse ratio of 35/65. The concrete sample with a 0.45 water/cement ratio, 350 kg/m^3 cement and equal amounts of fine and coarse barite sands had nearly minimum half value layer (HVL), and maximum compression strength, so the sample was considered as the best barite concrete sample. ***Conclusion:*** Since HVL of the barite concrete specimens with the same compression strength is markedly lower than the conventional concrete, and that there are quite a number of barite mines in our country, it is recommended to use barite concrete with the most suitable mixture condition based on our findings for shielding the radiotherapy rooms. **Iran. J. Radiat. Res., 2006; 4 (2): 71-75**

Keywords: *Barite concrete, ^{60}Co γ-rays, radiation protection, shielding, Half Value Layer.*

INTRODUCTION

To prevent population and employment staff exposure to ionization radiation, the exposure rate in working and public areas must be lower than the maximum permissible dose. The methods of radiation attenuation depend on the energy and the type of radiation. Selection of concrete or lead in γ-ray shielding usually depends on radiation energy and cost of shielding material [1]. Concrete wall thickness for 100kV$_p$ X-ray shielding is 80 fold, and its weight is 17 fold which is similar to lead shielding, but the concrete wall thickness for 1 MeV γ-ray shielding is only 6 fold and its weight is 25% which is more than lead wall; therefore the cost will be much lower with concrete than lead shielding [1]. In addition to making the structural base for building, the concrete has a good feasibility and could be made with different mixtures which will affect its compression strength, radiation attenuation and cost [1]. Using high density concrete in constructing the walls of cobalt and accelerator bunkers is more efficient than the conventional concrete [2]. The conventional concrete density is about 2.3 g/cm^3 which will increase by adding barite aggregates, iron stone bit, magnetite and still or lead [3]. Application of barite concrete in the nuclear reactor shielding was studied for the first time in 1950 in USA [4]. A barite concrete with density of 3.49 g/cm^3 was made by using barite stone with the density of 3.6 g/cm^3. Cameron *et al.* [5] were reported that the Half Value Layers (HVL) of the barite and conventional concrete for narrow beam of ^{60}Co gamma are 4.06 and 5.08 cm

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respectively. Researchers in British standard institution [6] reported the attenuation factors for radiation emitted from 11 different radioisotopes of barite concrete with density of 3.2 g/cm^3. In 1994 Abdul-majid *et al.* [7] studied the attenuation of ^{60}Co γ-ray and neutron of Am-Be for barite concrete with density of 3.2 g/cm^3. Sayed Abdo *et al.* [8], also, reported the neutron and γ-ray attenuation of barite concrete with density of 3.49 g/cm^3. And, recently, the physical characteristics of barite plaster in diagnostic X-ray shielding have been determined by Antonio *et al.* [9].

The above mentioned studies have emphasized the beneficial application of barite concrete due to its high density, but they have not provided a clear protocol to show the characteristics of concrete mixture. In addition to providing the radiation shielding, the compression strength of the concrete used in the construction of bunker walls is also an important factor, so in this study we evaluated the density, HVL and compression strength of different barite concrete specimens according to the ratio of fine to coarse barite aggregates, the amount of cement per volume (cement density), and the water/cement ratio (W/C).

MATERIALS AND METHODS

To investigate the radiation attenuation of barite concrete the concrete samples were irradiated by ^{60}Co γ-ray (Theratron Phoenix, Canada, 5330 Ci) in a radiotherapy center in Yazd, Iran. To provide a narrow beam and to limit the beam scattering, a collimator consisting 20 lead square slabs with a center hole (4 cm in diameter) was used. A set of barite concrete samples with a variety of barite composition in block (10×10×5 cm for radiation attenuation test) and cubic (15×15×15cm for compression strength test) forms were made. The set up for the evaluation of radiation attenuation for each concrete sample is diagrammatically illustrated in figure 1. The distance between the source and the exposed surface of all samples was measured by SSD light indicator of machine which was 200 cm. The distance from the source to the detector was also constant for all detections (240 cm). Concrete samples were made by using the barite stone from Ardakan mines (Yazd, Iran) with mean density of 4.44 g/cm^3 and Portland type 1 cement from Kerman factory (Kerman, Iran). The barite aggregates with two different size ranges (>5 mm as coarse and <5 mm as fine) were produced in the concrete lab of Yazd university. In this study two different ratios of fine to coarse barite aggregate (35/65 and 50/50), four different cement densities (350, 400, 450 and 500 kg/m^3), and five different water to cement ratios (0.4, 0.45, 0.5, 0.6 and 0.7) were used for constructing the barite concrete specimens. For each specific barite concrete specimens the appropriate mixture of cement, barite aggregate and water were placed in a bunker to yield a proper homogenate to be used in construction of concrete samples. Homogenates were well vibrated to avoid any bubble trapping. To increase the compression strength of specimens, they were transported into a water pool after removing from their moulds. The specimens were divided into two groups which were kept in water pool for 28 and 42 days, respectively. After the end of the delay time relevant to each group of specimens, the concrete density for all specimens was measured by determining the weight to volume ratio. All cubic specimens (15×15×15

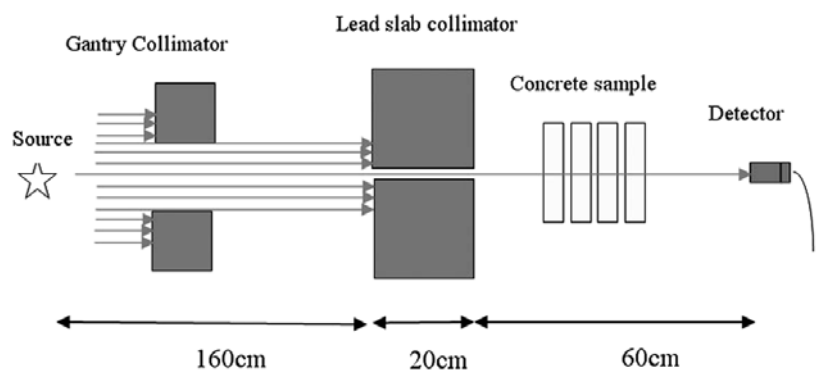

Figure 1. The set up illustration of concrete sample, detector, lead slab collimator and source arrangement for radiation attenuation measurements.

cm) were tested for measuring compression strength by hydraulic instrument (Wykehan, France). To measure the radiation transmission from the concrete blokes (10×10×5 cm) according to the design illustrated in figure 1, a Farmer ionization chamber (FC65P, PTW) and an electrometer (Dose 1, PTW, Germany) were used. The radiation measurements were achieved free in air by a build up cap detector.

RESULTS

Different samples according to cement density, water to cement ratio and the ratio of fine to coarse barite aggregate are nominated in tables 1 and 2. The data obtained from these samples were first divided into two categories according to the ratio of fine to coarse barite aggregates. The data related to the first category (35% fine to 65% coarse) consisting compression strength after 28 ($C.S_{28}$) and 42 ($C.S._{42}$) days of delay time, linear attenuation coefficient (μ), concrete density (ρ) and HVL are summarized in table 3. The same data related to the second category (50% fine to 50% coarse) are summarized in table 4. HVL for each concrete sample was calculated according to the formula:

$$HVL = \frac{x_1 \mathrm{Ln}\frac{2Y_2}{Y_o} - x_2 \mathrm{Ln}\frac{2Y_1}{Y_o}}{\mathrm{Ln}\frac{Y_2}{Y_1}}$$

Where the direct exposure reading is denoted as Y_0, Y_1 and Y_2, with the concrete thicknesses of X_1 and X_2, respectively.

Table 1. The nomenclature of barite concrete samples with 65% coarse to 35% fine barite aggregates.

W/C \ Cement	350 Kg/m³	400 Kg/m³	450 Kg/m³	500 Kg/m³
0.7	A11	A12	A13	A14
0.6	B11	B12	B13	B14
0.5	C11	C12	C13	C14
0.45	D11	D12	D13	D14
0.4	E11	E12	E13	E14

Table 2. The nomenclature of barite concrete samples with 50% coarse to 50% fine barite aggregates.

W/C \ Cement	350 Kg/m³	400 Kg/m³	450 Kg/m³	500 Kg/m³
0.7	A21	A22	A23	A24
0.6	B21	B22	B23	B24
0.5	C21	C22	C23	C24
0.45	D21	D22	D23	D24
0.4	E21	E22	E23	E24

W/C is the ratio of water to cement

Table 3. The compression strength after 28 ($C.S_{28}$) and 42 ($C.S._{42}$) days of delay time, linear attenuation coefficient (μ), concrete density (ρ) and half value layer (HVL) related to the samples containing 35% fine to 65% coarse barite aggregates.

No	Sample name	$C.S_{28}$ (MPa)	$C.S._{42}$ (MPa)	μ (cm^{-1})	ρ (g/cm^3)	HVL (cm)
1	A11	20	21.5	0.19	3.22	3.6
2	A12	14	14.5	0.189	3.49	3.7
3	A13	14.9	16.5	0.177	3.26	3.9
4	A14	16	17.5	0.1802	3.3	3.8
5	B11	23.4	23.4	0.1861	3.46	3.7
6	B12	22.8	26.6	0.1854	3.44	3.7
7	B13	23	23	0.1848	3.41	3.8
8	B14	23.9	24.5	0.1727	3.18	4
9	C11	31.2	34.2	0.1896	3.53	3.7
10	C12	30.1	33	0.1869	3.47	3.7
11	C13	29.8	33.2	0.1838	3.41	3.8
12	C14	28	29.8	0.181	3.35	3.8
13	D11	34	34	0.1878	3.51	3.7
14	D12	33.6	36.1	0.1911	3.55	3.6
15	D13	35.3	37.8	0.1862	3.46	3.7
16	D14	32.4	35.3	0.1851	3.43	3.7
17	E11	28.2	30.6	0.1807	3.37	3.8
18	E12	32.6	32.6	0.188	3.5	3.7
19	E13	35.6	37.6	0.1872	3.48	3.7
20	E14	30.2	34.8	0.1801	3.34	3.8

In an overall view, our findings showed that there is a negative relation between cement density and concrete density, and, also a negative relation between concrete density and HVL. In category 1 the highest HVL was obtained from B14 (4 cm) and the lowest one from A11 (3.6 cm). The maximum

Table 4. The compression strength after 28 ($C.S_{28}$) and 42 ($C.S._{42}$) days of delay time, linear attenuation coefficient (μ), concrete density (ρ) and half value layer (HVL) related to the samples containing 50% fine to 50% coarse barite aggregates.

No	Sample name	$C.S_{28}$ (MPa)	$C.S._{42}$ (MPa)	μ (cm^{-1})	ρ (g/cm^3)	HVL (cm)
1	A21	20.7	24	0.1779	3.3	3.9
2	A22	19.1	20.5	0.1774	3.29	3.9
3	A23	18.3	18.5	0.1732	3.17	4
4	A24	18.7	19.3	0.1738	3.19	3.98
5	B21	24.5	26.3	0.1817	3.37	3.8
6	B22	23.6	24.9	0.1805	3.34	3.8
7	B23	21.7	23.8	0.1847	3.9	3.8
8	B24	22.8	24	0.1733	3.2	4
9	C21	32.3	32.5	0.1888	3.52	3.7
10	C22	35.2	35.2	0.185	3.44	3.7
11	C23	31.9	33.6	0.1831	3.37	3.8
12	C24	30.1	33.5	0.1804	3.34	3.8
13	D21	37.4	39.4	0.1861	3.47	3.7
14	D22	37.4	38	0.1845	3.42	3.8
15	D23	37.6	39	0.1852	3.44	3.7
16	D24	34	38.2	0.1803	3.35	3.8
17	E21	31.8	31.8	0.1734	3.24	4
18	E22	36.4	39.1	0.1837	3.43	3.8
19	E23	35.1	37.5	0.1847	3.44	3.8
20	E24	32	32	0.1809	3.36	3.8

compression strength in these samples was achieved for E13 (35.6 Mpa after 28 days and 37/6 Mpa after 42 days of delay time). In category 2 the lowest HVL was 3.7 cm, and the maximum compression strength after 28 days of delay time was for D23 (37.6 Mpa), and after 42 days was for D21 (39/4 Mpa). The maximum compression strength in all specimens, as shown in figure 2 was for D21 sample (39.4 Mpa after 42 days of delay time). This sample also showed the lowest HVL (3.7 cm).

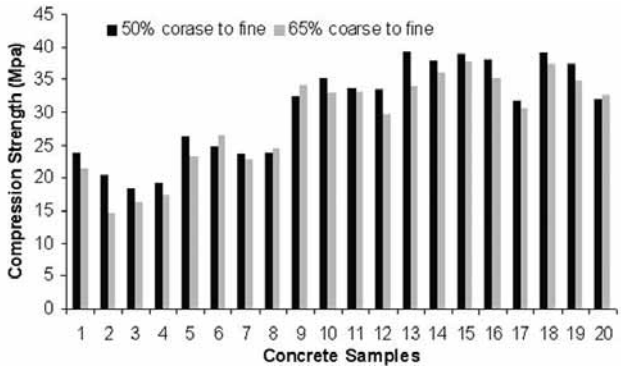

Figure 2. The compression strength for 40 different concrete samples after 42 days of delay time.

DISCUSSION

The choice of lead or concrete for radiation shielding usually depends on the amount, type and energy of radiation, as well as the cost of shielding materials [1]. The radiation attenuation of a barite concrete depends on its thickness, density and composition [11, 12]. The optimum concrete barrier thickness for radiation rooms depends on user factor, occupational factor, radiation work load and maximum permissible radiation dose [13]. These factors are especially important in building the radiotherapy rooms due to high radiation energy and high exposure rate [1]. In the radiotherapy rooms the concrete walls which are exposed to the primary beam need to have the greatest thickness, or the highest density to provide the optimum radiation attenuation [13]. To save the space in the radiotherapy room selection of high density materials in making concrete walls is the best choice also. Materials used to increase concrete density are barite, magnetite, uranium, steel, and lead [11, 12]. Among these materials barite aggregates seem to be more efficient due to their high density and low cost [8]. Tripak *et al.* showed that radiation attenuation of barite concrete for high energy γ-ray is related to the density of barite aggregates which is higher than conventional sand [3].

Akkurt *et al.* also reported that the linear attenuation coefficient is higher for barite loaded concrete than for ordinary concrete [11]. Akkurat *et al.* compared the efficacy of barite, marble and limra on attenuation coefficient of photons with the energies in the range of 1 keV to 300 MeV. They found that the barite stone had the best attenuation coefficient for different photon energies [12].

Beside the radiation attenuation, the compression strength of concrete wall in a

radiotherapy room is a critical factor. In our study, we examined the radiation attenuation, as well as the compression strength for 40 different barite loaded concrete composition. Also, the measured HVL for all specimens in our study were lower than the reported values for ordinary concrete [11]. Yet, the range of variations for HVL was much shorter than the compression strength (3.7 to 4 cm Vs 14 to 39.4 Mpa).

In line with the fact that, W/C ratio and the ratio of fine to coarse aggregate in barite loaded concrete affect the compression strength, we have achieved the best composition with the highest compression strength and lowest HVL in this study. Sample D21 with 39.4 Mpa compression strength and 3.7 cm HVL has been the best selection among all concrete samples. This sample was composed of 350 kg/m3 cement, 0.45 W/C ratio and 50% coarse to 50% fine barite aggregates. The lowest HVL (3.7 cm) in our specimens was in agreement with the findings of Sayed Abdo *et al.* [8] (3.8 cm), but it was lower than those reported by Akkurt *et al.* (4.4 cm) [11]. HVL and compression strength of conventional concrete with the density of 2.3 g/cm^3 are 5.25 cm and 35 Mpa respectively [10], and according to the 49th NCRP report [1], conventional concrete HVL for ^{60}Co γ-ray is 6.2 cm; where as HVL for sample D21 (3.7 cm) was lower and its compression strength (39.4 Mpa) is more than the conventional concrete.

CONCLUSION

Our findings as well as most of the related literatures support the use of barite aggregates for constructing radiotherapy rooms. Since the composition and barite aggregation of concrete are important factors, using the best sample according to this study will reduce the construction cost due to lowering the wall thickness which is needed to achieve the highest compression strength and lowest HVL.

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