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The Physical and Mechanical Properties of Heavyweight Concretes Used in Radiation Shielding

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Abstract: The physical and mechanical properties of heavyweight concretes, have been prepared in 15 different types including ordinary, barytes included concrete and mixture of them in different rate, has been investigated. This would lead to find ideal w/c ratio and cement dosage in concrete. The concretes has also been investigated against γ-radiation both in theoretically and experimentally.

Key words: Heavy weight, concertes, w/c ratio, attenuation coefficents, radiation shielding

INTRODUCTION

Heavyweight concretes have been widely used in building construction especially for critical building as it contains a mixture of many light and heavy element and this is ideal materials to shield radiation. To choice of a shielding materials the linear attenuation coefficints (μ) which is defined as the probability of a radiation interacting with a material per unit path length, is important quantity and this has to be known. The magnitude of linear attenuation coefficients depends on the incident photon energy, the atomic number and the density (ρ) of the shielding materials (Woods, 1982). When density of shield concrete is increased, their thickness can be reduced. In order to increase density of shield concrete, the percent of aggregate in this concrete has to be increased. Concretes having specific gravities higher than 2600 kg m^{-3} are called heavyweight concrete and aggregates with specific gravities higher than 3000 kg m^{-3} are called heavyweight aggregate (TS EN 206-1, 2002). Barytes concrete is one of the most approximately heavy or intermediate concrete, shields for neutrons and gamma rays. The main object from the use of barytes aggregate in concrete for reactor shielding was to produce the workable concrete with a maximum density and adequate structural strength and to ascertain the physical, chemical, thermal and structural properties of the concrete. Barytes contains a large proportion of relatively soft barium sulphate particles. These particles main also contain open cracks, which are filled with powdery material consisting of barytes, iron oxide and clay particles. As the quantity of barytes ore reserve and its specific gravity are high in Turkey, it can be ideal choice to be used it as an aggregate in concrete. However the aggregates be used in concrete, have to satisfy some physical, mechanical and chemical properties. Heavyweight concrete is principally used for radiation shielding, counterweights and other applications where higher density is desired. Except for density, the physical properties of heavyweight concrete are similar to those of normal - or conventional- weight concrete.

To use concretes in building construction the physical and mechanical properties and the relation with the linear attenuation coefficient would be investigated. Topcu (2003) has performed a study on heavyweight concrete mixtures at different w/c ratios, prepared in order to determine the most favourable w/c ratio of heavyweight concrete produce with barytes. Several work have been performed on linear attenuation coefficients both theoretically (Hubbell, 1982; Bashter, 1997) and experimentally (Angelone *et al*., 2001; Akkurt *et al*., 2004; Abdo, 2002) on the variety of materials. A work has been performed by Bashter (1997) to calculate both linear (μ) and mass attenuation coefficients (μ/ρ) at photon energies of 10 keV to 1 GeV for concretes in different densities. An experimental study has been performed by Angelone *et al.* (2001) to evaluate mass attenuation coefficients of the materials ranged atomic numbers from 6 to 82 using X-ray of 13-50 keV energy. In this study 15 different characteristic concretes have been prepared to investigate their physical and mechanical properties and also attenuation coefficients for γ-rays shielding.

MATERIALS AND METHODS

The production of concrete: Production of 15 different concrete were made mixing in different ratio of cement, water, aggregate and barytes. The concretes have been produced in five different series each has three different classification. These are according to mixing value; if the

Table 1: The mixing ratio of 1 m^3 concrete (kg)

Concrete	w/c ratio	Water	Cement	Fine aggregate	Coarse aggregate	Fine barytes	Coarse barytes	Slump (cm)
A2				697	1092			7.5
B2						1113	1700	6.8
AB2	0.65	201	310	697			1700	6.9
BA2					1092	1113		7.0
K2				349	545	557	850	7.1
A3				697	1092			7.2
B3						1114	1701	6.5
AB3	0.51	184	362	697			1701	6.8
BA3					1092	1114		7.0
K3				349	547	558	850	6.9
A4				679	1061			4.5
B4						1083	1653	3.8
AB4	0.43	183	425	679			1653	4.0
BA4					1061	1083		4.1
K4				338	531	542	826	4.3

Table 2: Physical and mechanical properties of cement PC42.5

Fineness 90 (μ)	Blaine (cm^2 g)	Specific Gravity (g cm^{-3})	Flexural Strengh E28 (MFa)	Compressive Strength E28 (MFa)
0.1	2919	3.12	7.88	55.8

Table 3: Physical and mechanical properties of normal and barytes aggregate

				Barytes aggregate	Normal aggregate	Turkish standards
Physical properties	Specific gravity (g cm^{-3})	Oversize 4 mm		4	2.66	TS 707
		Undersize 4 mm		4	2.50	
	Unit weight (g cm^{-3})	Oversize 4 mm	Compact	2.85	1.47	TS 3529
			Loose	2.19	1.77	
		Undersize 4 mm	Compact	2.85	1.48	
			Loose	2.53	1.75	
	Fineness modulus (m)			6.23	3.89	TS 706 EN 12620
	Fine material content (%)			0.5	3.46	TS 3527
Mechanical properties	Pressure, MPa (Cube and Surface area 50 cm^2)			26.25		
	Los Angeles Abrasion Loss (100 cycles) (%)			58	26	TS 3694
	Soundness rate (%) (Chemical method – $NaSO_4$)			2.82	3.55	TS 3655

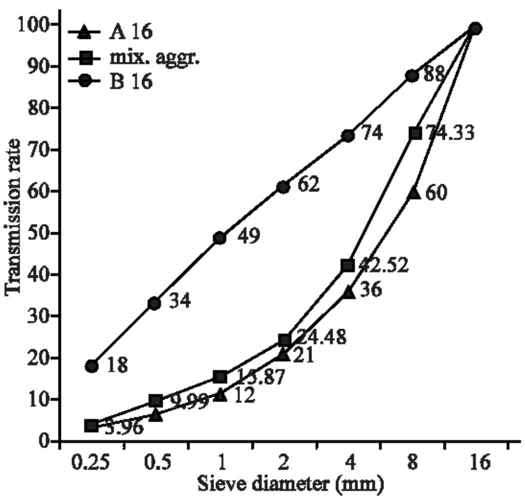

Fig. 1: Grading curve of barytes aggregate with reference curves (d_{max}=16 mm)

whole volume of aggregate is normal aggregate the concrete called A, if it is barytes called B, if the fine aggregate normal and coarse aggregate barytes called AB while course aggregate barytes and fine aggregate normal called BA, if the half of aggregate normal and half barytes called K. The indices of 2,3,4, represent the w/c ratio of 0.65, 0.51 and 0.43, respectively. The value of mixing rate of all types of concretes are given in Table 1. The cement of PC 42.5 obtained from Goltas cement factory were used in this study and barytes aggregate were obtained from Sarkikaragac-Isparta region at south of the Sultandaglari barytes region where the pureness of barytes ore is 90% $BaSO_4$ and barytes ore reserve is about 8.000.000 tonnes. Properties of PC 42.5 are listed in Table 2. Ordinary aggregate were used from Atabey aggregate mine. In Table 3 the physical and mechanical properties of normal and barytes aggregate are tabulated (Basyigit, 2003). Each quantity, shown in last column of Table 3, are measured according to method described related Turkish standard. Both barytes and aggregate were graded according to their sizes 0-0.200, 0.200-0.250, 0.250-0.500, 0.500-1, 1-2, 2-4, 4- 8, 8- 16 mm by sieving analyses. The grading of barytes ore which fits to Turkish standard TS 706 EN 12620 (2003), is shown in Fig. 1. Barytes and normal aggregate have to be kept from moisture and humidity. All samples cylindirical standard speciment with diameter of

15x30 cm were used in the experiment. These were installed in three steps during the filling of concrete specimens and at each step were vibrated on shaking tables. The specimens were then kept in a 20±2°C curing room having 95±5% relative humidity for 24 h after which they were preserved for 27 days which is the time when experiment is performed, in lime saturated water. The experimental study for physical and mechanical properties were carried out at the construction materials laboratory at the Suleyman Demirel University.

The linear attenuation coefficients: The linear attenuation coefficients (μ) were calculated using a computer program called XCOM (version 3.1). The XCOM prepared by uses chemical parameters of a mixture materials and calculates the mass attenuation coefficients (μ/ρ) at photon energies of 1 keV to 100 GeV and provides total cross sections as well as partial cross sections for various interaction process. With a known density (ρ) of materials, the linear attenuation coeffficients (μ) were extracted from calculated results of XCOM. As the chemical properties of shielding materials are important input for XCOM code these were obtained by X-ray diffraction. The linear attenuation coefficients (μ) were measured using Geiger-Muller counter and ^{60}Co γ-ray sources. If N and N_0 are the measured count rates in G-M respectively with and without the absorber of thickness *x* (cm) of the absorber the linear attenuation coefficients (μ) can be extracted by the standard equation:

$$N = N_0 e^{-\mu x}$$

Plotting In(N_0/N) versus χ would give straight line and μ was obtained using the value of the slope.

RESULTS AND DISCUSSION

The physical and mechanical properties of 15 different heavyweight concrete and the linear attenuation coefficients were investigated. In Table 4 the results of

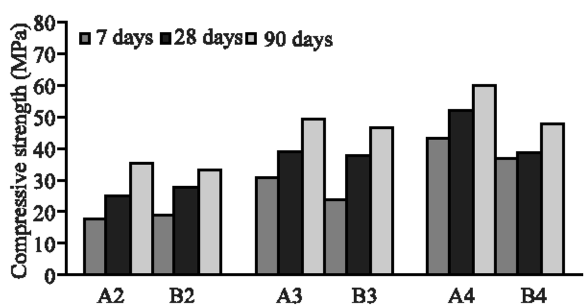

Fig. 2: Variation of compressive strength for ordinary and barytes concretes

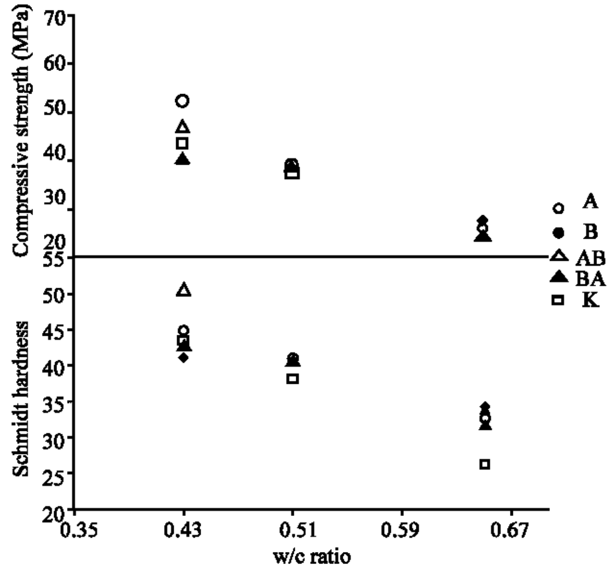

Fig. 3: Variation of compressive strength (upper, obtained at 28 days) and schmidt hardness (lower) as a function of w/c ratio

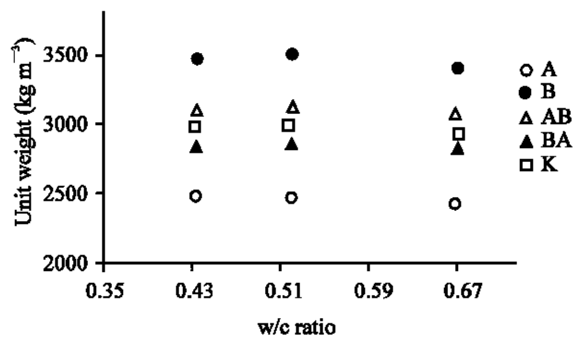

Fig. 4: Variation of unit weigth as a function of w/c

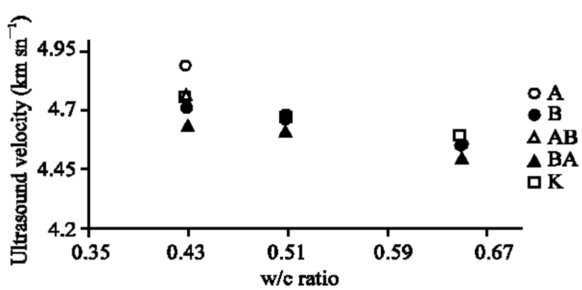

Fig. 5: Variation of ultrasound velocity as a function of w/c

physical and mechanical properties such as ultrasound velocity, unit weight, schmidt hardness, compressive strength are given. The variation of compressive strengths measured by axial tests on 7th, 28th and 90th days is displayed in Fig. 2 for A and B types concretes. As can be seen from this Fig. 2 that although there is no big differences between concrete types of A and B the

Table 4: Physical and mechanical test results of concretes

Concrete	w/c	Unit Weight ($kg\ m^{-3}$)	Ultrasound duration (km/s)	Schmidt hardness	Compressive Strength (7 days)	Compressive Strength (28 days)	Compressive Strength (90 days)
A2	0.65	2406	4.56	32.3	17.4	24.7	35.1
B2		3414	4.56	34.1	18.6	27.4	33.1
AB2		3061	4.52	34.0	18.2	27.0	36.9
BA2		2821	4.52	31.9	17.8	25.0	37.1
K2		2911	4.6	32.4	18.1	26.2	38.1
A3	0.51	2464	4.66	41.2	30.5	38.6	49.5
B3		3507	4.69	40.4	23.9	37.3	46.4
AB3		3124	4.62	40.9	28.0	38.4	48.1
BA3		2856	4.61	40.7	27.4	37.8	48.9
K3		2988	4.68	40.9	27.8	38.0	47.4
A4	0.43	2482	4.89	47.1	43.1	51.9	59.8
B4		3452	4.71	41.1	36.9	38.8	47.4
AB4		3083	4.76	45.8	38.1	47.1	54.5
BA4		2830	4.63	41.2	35.0	40.0	52.3
K4		2986	4.75	42.7	37.6	43.3	57.5

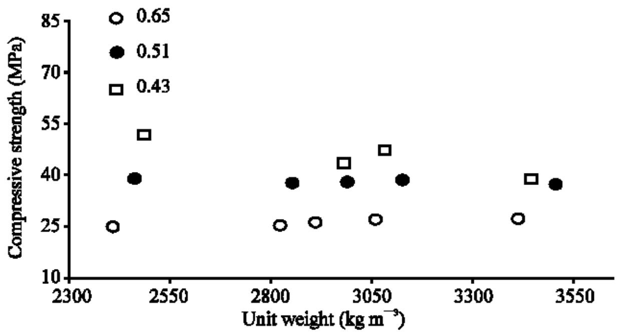

Fig. 6: Variation of compressive strength (obtained at 28 days) as a function unit weigth

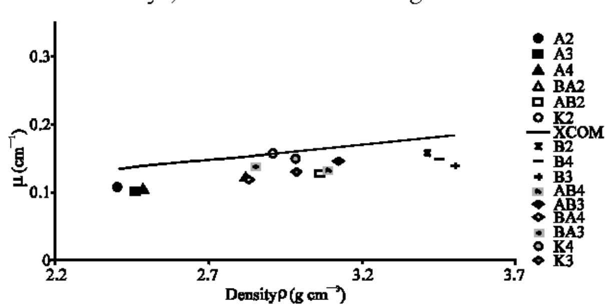

Fig. 7: The linear attenuation coefficients (obtained at 1.25 MeV) for all types of concretes as a function concrete's density

compressive strength is about 30% lower for B4 than for A4 and also the compressive strength increase with the time and decreasing w/c ratio. Relation between barite ratio and Schmidt hardness can also be seen from Fig. 3. As can be seen from Fig. 3. that, w/c for 0.65 while the barite ratio increases, Schmidt hardness increases, w/c for 0.53 while the barite ratio increases, Schmidt hardness nearly constant, w/c for 0.43 while the barite ratio increases, Schmidt hardness decraeses. The similar results of compressive strength for the w/c of 0.65 and 0.51 have been obtained for the different types of concrete and this similarity is at 0.51 for Schimdt hardness. The variation of unit weight with the w/c ratio is shown in Fig. 4 where there is no big variations observed for different w/c ratio. As can also be seen from this figure that the unit weight increased with the increasing barytes rates in concrete and the maximum value of unit weight is 3507 $kg\ m^{-3}$ for B types concretes at 0.51 of w/c ratio. The relation between ultrasound velocity and w/c is plotted in Fig. 5. When w/c ratio decreased ultrasound velocity increased as it was seen relation between compressive strength and w/c. The maximum ultrasound velocity is for the value of 0.43 w/c for A series concrete and at the w/c ratio of 0.51 for B series and at the ratio of 0.65 for K series. The variation of compressive strength with the unit weight for different w/c ratio is displayed in Fig. 6. A linear relation between compressive strength and unit weight can be seen for the w/c ratio of 0.51 and this is fluctable for the 0.65. In Fig. 7 the linear attenuation coefficients (μ) is displayed as a function of materials density for a particular photon energy of 1.25 MeV. As can be seen from this figure that both calculated and measured data for the linear attenuation coefficients (μ) increase with the increasing concretes' density. It can be concluded from this reserch that

- w/c ratio of 0.51 is favorable for heavyweight concrete
- Although concrete at w/c ratio of 0.43 gives the highest compressive strength, the favourable compressive strength were obtained at w/c ratio of 0.51.
- Attenuation coefficients depends on photon energy
- Attenuation coefficients depends on concretes' density
- As the barite reserve are high in Turkey it can be used as an aggregate in concrete for radiation shielding.

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REFERENCES

Angelone, M., T. Bubba and A. Esposito, 2001. Measurement of the mass attenuation coefficient for elemental materials in the range 6Z82 using X-rays from 13 up to 50 kev, Applied Radiation and Isotopes, 55: 505-511.

Abdo, A.E., 2002. Calculation of the cross-sections for fast neutrons and gamma-rays in concrete shields, Ann. Nuclear Energy, 29: 1977-1988.

Akkurt, I., S. Kilincarslan and C. Basyigit 2004. The photon attenuation coefficients of barite, marble and limra, Ann. Nuclear Energy, 31: 577-582.

Bashter, I.I., 1997. Calculation of radiation attenuation coefficients for shielding concretes, Annals of Nuclear Energy, 24: 1389-1401.

Basyigit, C. *et al*., 2003. Research about usage of barite ore as aggregate in shield concrete for absorption of radioactive rays. Intl. Conference on Industrial Materials Building Stone (IMBS), Istanbul-Turkey.

Hubbell, J.H., 1982. Photon mass attenuation and energy-absorption coefficients The International Journal of Applied Radiation and Isotopes, 33: 1269-1290.

Topcu, I.B., 2003. Properties of heavyweight concrete produced with barite, Cement and Concrete Research, 33: 815-822.

TS 707, 1980. Method for sampling of aggregates for concrete reducing samples to testing size, TSE, Ankara, Turkey.

TS EN 206-1, 2002. Concrete- Part 1: Specification, performance, production and conformity TSE, Ankara, Turkey

TS 706 EN 12620, 2003. Aggregates for concrete, TSE, Ankara, Turkey.

Woods, J., 1982. Computational Methods in Reactor Shielding, Pergamon Press, New York.