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Shielding Properties of Heavyweight Concrete.

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HIELDING PROPERTIES OF HEAVYWEIGHT CONCRETE

خواص العزل الإشعاعي للخرسانة ثقيلة الوزن

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ملخص البحث:- يهدف هذا البحث الى الوصول لخلطات خرسانية ثقيلة الوزن ذات كفاءة عالية لامتصاص الاشعاعات الناتجة ع
اشعة X واشعة جاما. تم التخطيط لهذا البحث على اساس دراسه تأثير استخدام خام الالمنيت كركام كبير واستخدام الرمل كركام صغ
للوصول الى كثافه نوعية للخلطات تزيد عن مثيلتها فى حالة استخدام الركام العادى وتقترب من 3.3 طن /م^3 . تم تصميم 21 خلط
خرسانيه مختلفة تعطى هبوط 5 ±2 سم واجهادات فى حدود 40 ميجاباسكال عند عمر يعادل 56 يوم. تم استخدام ثلاث نسب مختل
للركام الناعم (0.48 ، 0.4 ، 0.25) كنسب من الركام الكلى ، كما تم استخدام ثلاث نسب مختلفه لمحتوى الاسمنت (350
400 ، 450 كجم/م^3) مع استخدام أربع نسب مختلفة من الالمنيت منسوبه الى الركام الكبير الكلى (زلط + المنيت) بنسب خلط للرك
الكبير (1.0 ، 0.75 ، 0.5 ، 0.25). وتم تسجيل نتائج الاختبار والمتمثله فى اجهاد الضغط للخرسانة ، ومعامل الامتصا
للأشعاعات لكل نسب الخلط الموضحة بتصميم الخلطات ودراسه تأثير تغير نسب الركام الناعم الى الركام الكلى ، ونسب محتو
الاسمنت ، ونسب خلط الالمنيت والزلط بمحتوى الركام الكبير حيث تم الوصول الى ان زيادة نسب الركام الناعم تعمل على تقليل ك
من مقاومة الضغط ومعامل الامتصاص الاشعاعى للخلطات . اثبتت النتائج ايضا انه بزيادة نسبة الالمنيت بمحتوى الركام الكبير يزدا
معامل الامتصاص الاشعاعى بنسبة 35% مع استخدام الالمنيت كركام كبير بنسبة 100% من محتوى الركام الكبير

ABSTRACT: Heavyweight concrete can be used when particular properties, such as combined high strength and good radiation shielding, are required. Such concrete, using Ilmenite aggregates, can have a density in the range 4.2 t/m^3, significantly higher than the density of concretes made with normal aggregate. The present paper deals with sand-Ilmenite heavy weight concrete. Ilmenite has been used as coarse aggregate because of high specific gravity compared with gravel.
In the present work, 21 mixes were selected to achieve a slump above 5± 2 cm and strength up to 40 MPa at 56 days. The investigation used three levels of fine aggregates to total aggregates ratio (0.25, 0.4, 0.48), three cement content (350, 400, 450 kg/m^3) and four levels of Ilmenite aggregate to total coarse aggregate (gravel + Ilmenite) ratio (0.25, 0.5, 0.75, 1) were used. The investigation provided information on compressive strength, shielding properties and indicated clear benefits from the use of Ilmenite as a coarse aggregate. For all type of coarse aggregate (gravel, Ilmenite), increasing the amount of fine aggregate leads to reduction in each of compressive strength and absorption co-efficient. Replacing the gravel with Ilmenite yields about 35% increase in absorption co-efficient.

Keywords: heavy weight concrete; Ilmenite concrete; heavyweight aggregate; compressive strength; shielding concrete, high density concrete.

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1. INTRODUCTION

X-rays and gamma–rays are widely used in most fields of applied science. For example, there are used for obtaining information on solids and liquids and for inspecting materials for flaw or foreign materials. X-rays are also used in medical diagnosis , and gamma-rays are used in medical treatment (1, 2, 3).
The early workers in the field of radiation has a little knowledge of the dangers connected with exposure to radiation. In today's installations the operators are usually protected by absorbing shields around the radiation source. Concrete has useful properties as a radiation containment material. Normal concrete can be used for shielding but may require excessive thicknesses (4, 5). The choice of suitable materials to be used as aggregates (6) will improve the attenuation of radiation and reduce the required thicknesses. High density materials are good attenuators, and use of special high density aggregates is desirable. Moreover, attenuation of fast neutron also requires a high density materials, while the presence of hydrogen atoms will make moderate and slow neutrons to be absorbed. Consequently, it is more useful to use heavy weight concrete as shielding material to protect the workers from damaging effects of gamma rays produced by radiation sources.(7, 8)

1.1 Research significance

The fundamental objects of the present work is to present a new type of heavy weight concretes by using one of the local materials such as Ilmenite as a coarse aggregates for producing this type of concrete, which may be used as shielding against x-rays and Gamma-rays.

2. EXPERIMENTAL PROGRAMME

2.1 Materials

Detailed information about the materials used and their characteristics are given in this section.
Cement Portland cement has been found to be adequate for production of heavy weight concrete. Experience has indicated that PC is, in most cases, entirely satisfactory and adequate for constructing concrete shielding (2, 8).
Aggregate The types of coarse aggregates which were used for the different mixes of the present work were grave land Ilmenite. The physical properties of gravel (swiss desert) and Ilmenite (from red sea mines, Egypt), and ASTM limits are shown in Table 1. The absorption of gravel was small enough to be neglected in concrete mix design, while the absorption value of Ilmenite was not relatively high and was considered in concrete mix design. The results of chemical analysis of coarse aggregate are presented in Table 2. The grading used was chosen according to the ASTM C-33 requirements for gravel and ASTM C 637-84 and C 638-84 requirements for Ilmenite. The sieve analysis for aggregates are given in Table 3.The desert sand from El Tal El-kabir quarry used as a fine aggregate in preparing different concrete mixes. The main physical properties of the used sand as well as corresponding recommended limits of ASTM specification.

2.2 Mixed design

For designing concrete mixes, the mixes proportions are determined from making trial mixes which are based on the absolute volume method. From the results of trial mixes, 21 different mixes of concrete have been made and divided into two groups.
The first group contain nine mixes. These mixes involves a range of fine aggregate to coarse aggregate (0.25, 0.4, 0.48), type of coarse aggregate (Ilmenite, gravel, both with equal volume). The cement content for each mix was 350 kg/m^3 .The main purpose of this group is to study the effect of the change of fine aggregate to coarse aggregate ratio on the compressive strength and shielding properties.
The second group contain 12 mixes These mixes involved a range of Ilmenite aggregate to total coarse aggregate(gravel + Ilmenite) ratio (0.25, 0.5, 0.75, 1), cement content (350, 400, 450 kg/m^3). The effects of these parameters on compressive strength and shielding properties have been studies.

For all mixes, The water content has been assumed on condition that is should give a plastic concrete mix having a slump Of (5 ± 2) cm. Table 4, 5 gives the composition of selected mixes.

Table 1 Physical and mechanical properties of different coarse aggregates

Property	Gravel	Ilmenite	ASTM limits
Specific gravity	2.63	4.2	1.6 – 3.2
Unit weight t/m^3	1.72	2.69	1.2 – 1.76
Voids ratio %	37	41.6	< 50 %
Absorption %	0.7	2.21	0.2 – 4 %
Crushing value	15.1	33.3	< 40 %

Table 2 Chemical analysis of Ilmenite coarse aggregate

Chemical analysis	$Ti O_2$	Fe O	$Fe_2 O_2$	$Si O_2$	$Al_2 O_3$	Ca O
Ilmenite	39	27.92	29.15	3.12	0.59	0.15

Table 3 Sieve analysis of coarse aggregate

Sieve Size	37.5 mm	25 mm	19 mm	12.5 mm	9.5 mm	4.75 mm	2.36 mm
Passing % by weight	100	95	80	45	30	8	-

Table 4 Composition of mixes used in group A.

Mix No.	Cement	water	Gravel	Ilmenite	Sand	Sand/ (Total agg.)
	kg/m^3	kg/m^3	kg/m^3	kg/m^3	kg/m^3	By volume
G1/A0	350	175	1392	-	464	0.25
G2/A0	350	192	1086	-	724	0.4
G3/A0	350	192	941	-	869	0.48
I1/A4	350	175	-	2248	464	0.25
I2/A4	350	210	-	1710	706	0.4
I3/A4	350	210	-	1482	847	0.48
M1/A2	350	175	696	1124	464	0.25
M2/A2	350	192	543	877	724	0.4
M3/A2	350	210	459	741	847	0.48

2.3 Test specimens and Instrumentation

Compressive strength Compression tests were carried out on 100×100×100 mm cubes. All the cubes have been tested by the use of a hydropower machine of a capacity of 200 ton. The load was applied continuously, and the loading rate was equal to about 2.45/kg/cm^2/sec. Load was applied until failure, and the maximum load carried by specimen was recorded.
Shielding test Radiation shielding tests were performed using Cobalt-60 as a source for gamma rays. Cobalt-60 has a half-life of 5.27 years, and its gamma rays have energies of 117.1 keV and 1332 keV. The tests were carried out at National Institute of Standards, Dokki, Cairo, Egypt. The used thicknesses of the tested specimens were ranging between 40 to 120 mm. Each specimen was placed between the gamma-rays source and the detector. The specimen, source and detector were all on-line with the specimen in contact with the source. Figure 2 show the arrangements required for carrying out the shielding test, and Figure 1 shows the specimens prepared for shielding test. Moreover, Figure 2 shows the ionization chamber and the farmer which are used for measuring the radiation dose.

Table 5 Composition of mixes used in group B

Mix No.	Cement	water	Gravel	Ilmenite	Sand	Ilmenite / (Total coarse agg.)
	kg/m^3	kg/m^3	kg/m^3	kg/m^3	kg/m^3	By volume
M1/A4	350	175	-	2248	464	1.00
M1/B4	400	200	-	2120	437	1.00
M1/C4	450	225	-	1991	411	1.00
M1/A3	350	175	348	1686	464	0.75
M1/B3	400	200	328	1590	437	0.75
M1/C3	450	225	308	1493	410	0.75
M1/A2	350	175	696	1124	464	0.5
M1/B2	400	200	656	1060	437	0.5
M1/C2	450	225	616	995	410	0.5
M1/A1	350	175	1044	562	464	0.25
M1/B1	400	200	984	530	437	0.25
M1/C1	450	225	924	497	410	0.25

Tests were carried out on 150 diameter and 300 mm length cylinders. Each specimen was cut by saw to different thickness, ranging from 40 to 120 mm. In a thickness dx of absorber material the fractional reduction In the photon intensity I is – dI/I which is related to the attenuation coefficients μ and the thickness dx thus $- dI / I = \mu\, dx$. If the initial photon intensity is I_o and the thickness of the absorber is x, then by further manipulation the following equation (2) can be derived:

$$I = I_o \times e^{-\mu x} \qquad (1)$$

This equation is called the exponential equation. It is more convenient to refer to the layer or thickness of shield required to reduce the original radiation intensity by a factor of 2 or by a factor of 10. These are called the "half value" "tenth value" thickness respectively. The attenuation coefficient for each type of concrete was determined graphically from the transmission curve of this concrete type.

From the test, it is possible to calculate the thickness required to reduce the dose by factor 2 from the equation estimated from the transmission curve as a function of distance.

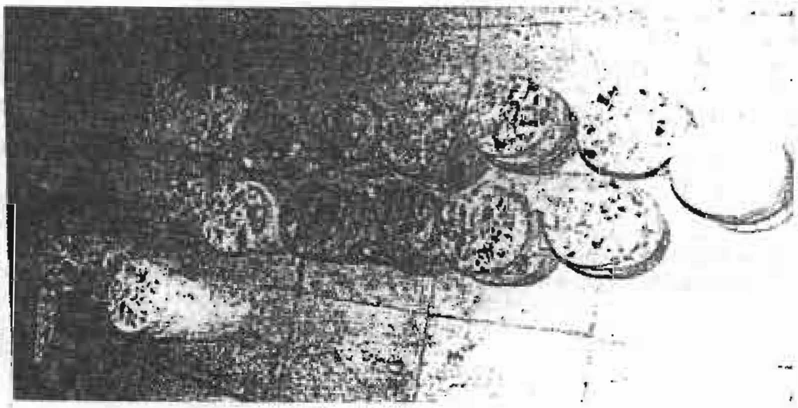

Figure 1 Test specimen prepared for shielding test.

2.4 Mixing, casting and curing

Mixing concrete components has been done by using horizontal mixer with capacity of 0.125 m^3 and speed of 15 revolution per minute. The fine and coarse aggregates have been placed into the mixer and have been mixed for 2 minutes. Then, the cement has been added to the aggregate and mixing operation has been carried out for other 2 minutes. Next, water has been added and the mixing operation has been performed for about 10 minutes to obtain a uniform and homogeneous mix. The fresh concrete has been placed in the molds at three equal layers, and each layer has been compacted by placing the mold on mechanical vibrator table. After filling the molds with concrete, they were kept with their surfaces covered with plastic sheets in air for 24 hours. Then, specimens were extracted from the molds and were immersed in fresh water until tested

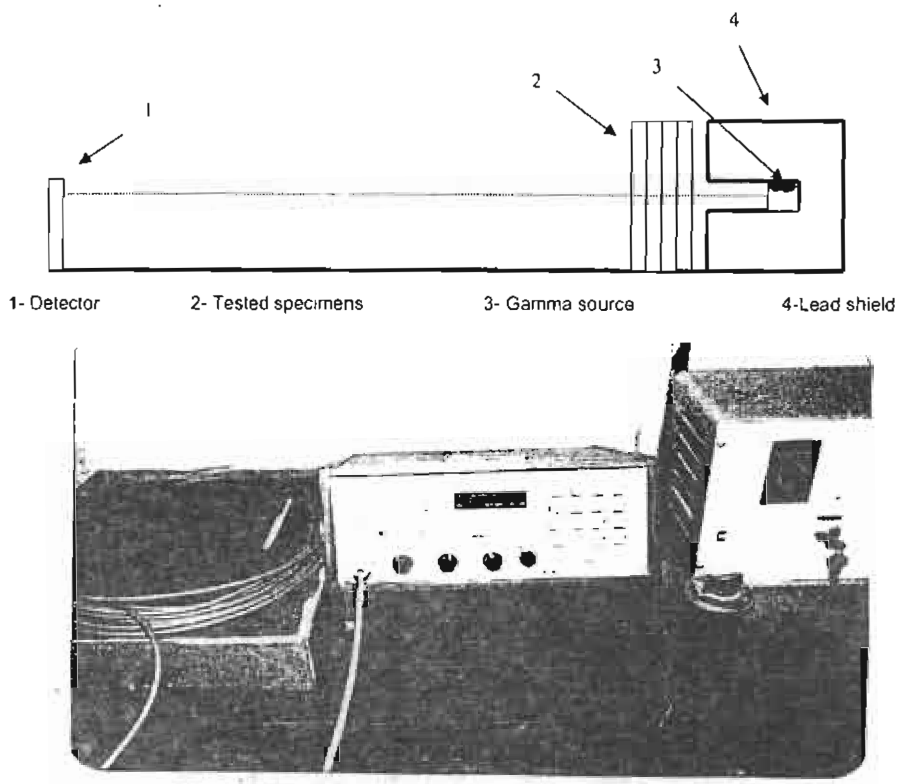

Figure 2. Arrangement required for carrying out the shielding test

3. EXPERMENTAL RESULTS

3.1 Results and discussion of compressive strength

Figure 3 shows the values of the compressive strength at different ages for the mixes of group A. Increasing the ratio of fine aggregate from 0.25 to 0.4 leads to about 22% reduction in compressive strength, and increasing the same ratio from 0.25 to 0.48 yields a 25% reduction in compressive strength. Comparing gravel mixes with those of Ilmenite mixes, it can be noticed that that replacing gravel with Ilmenite yields a (3 – 24 %) reduction in compressive strength, as shown in Figure 5. Comparing the Gravel Ilmenite mixes with those of the Ilmenite mixes, It can be remarked that replacing a half of the gravel with Ilmenite leads to a (3 -8 %) reduction in compressive strength.

Figure 4 contains the values of compressive strength at different ages for mixes of group B. For mixes Ilmenile ratio 1, increasing the cement content from 350 to 400 kg/m^3 yields a 30% increase in compressive strength and increasing the cement content from 350 to 450 results in a 40% increase in compressive strength, as shown in Figure 6. Reduction of Ilmenite ratio from 1 to 0.75, it can be noticed that this reduction leads to about (10 – 38 %) increase in compressive strength. Decreasing the ratio of Ilmenite to total coarse aggregate from 0.75 to 0.5 leads to a (7 -13 %) reduction in compressive strength. For all mixes, compressive strength increases as cement content increases. But it can be noticed that the cement content has a great effect on compressive strength for the mixes containing limenite alone as coarse aggregate.

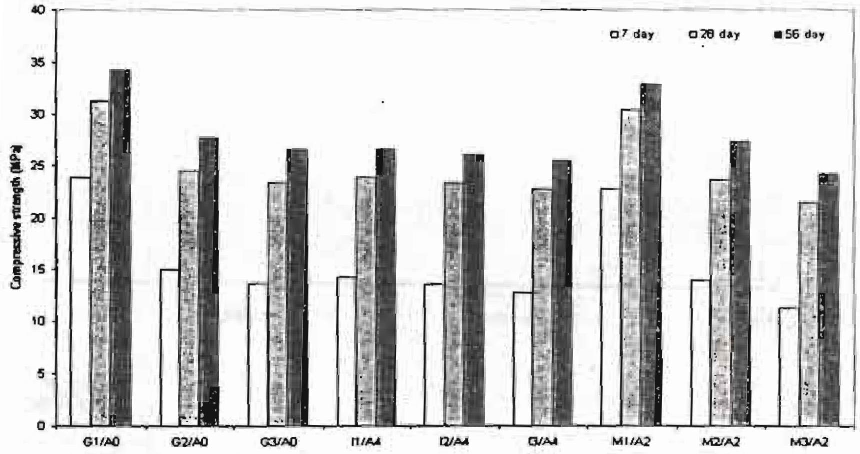

Figure 3 Compressive strength of group A at various aggregates

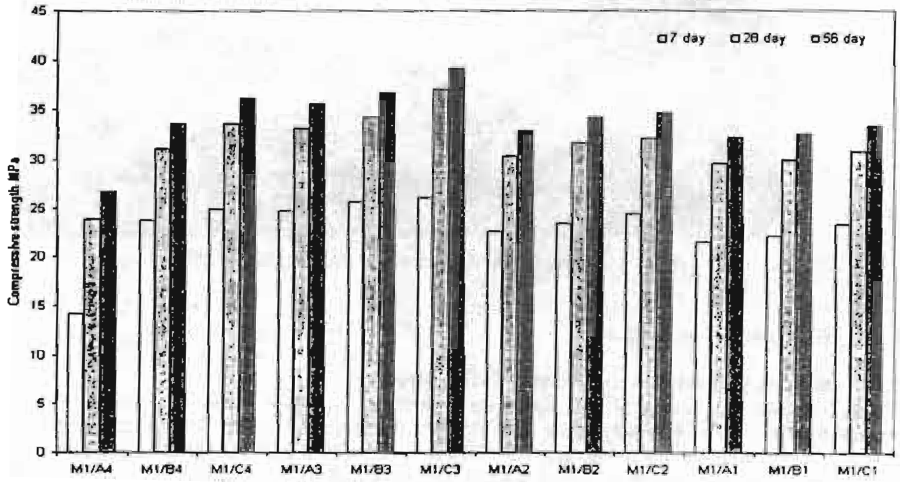

Figure 4 Compressive strength for group B at various ages

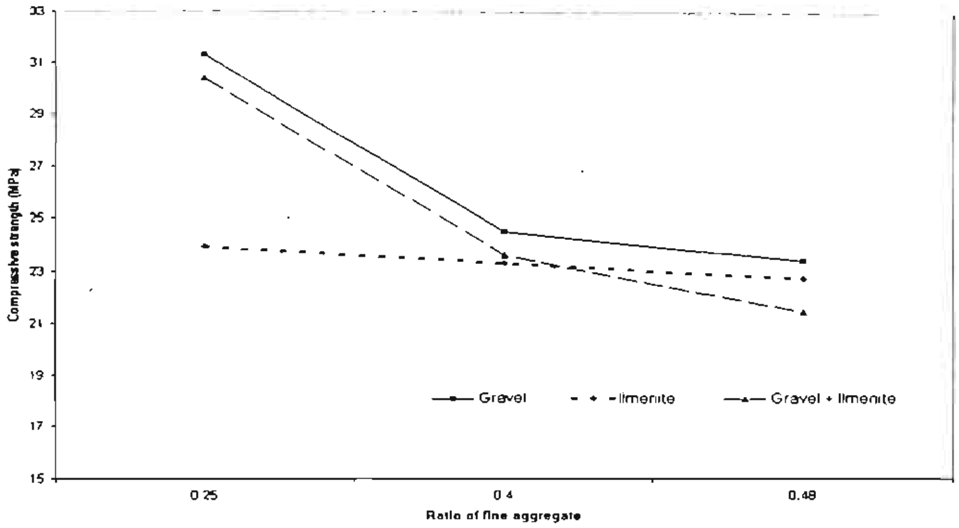

Figure 5 Effect of the ratio of fine aggregate on compressive strength for group A

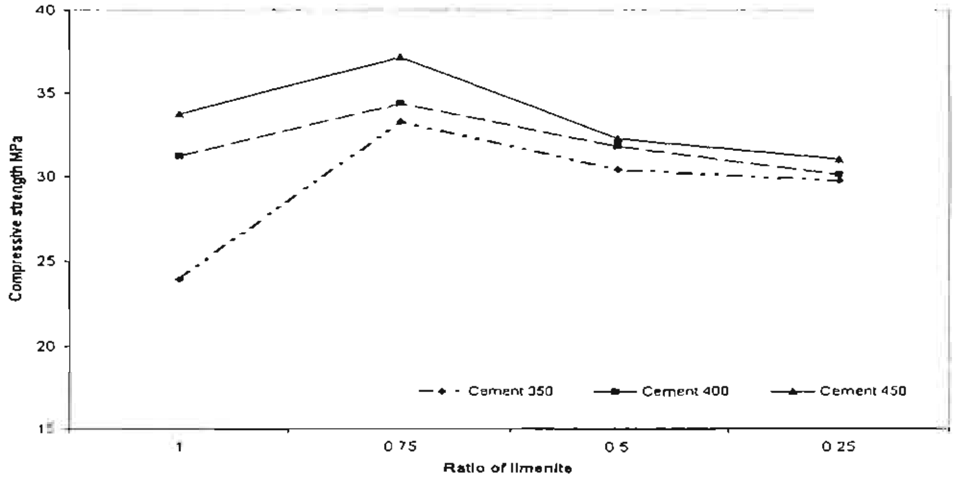

Figure 6 Effect of the ratio of Ilmenite to total Coarse aggregate on Compressive strength for group B

3.2 Results and discussion of shielding test

Figure 7 show the transmission curves for the different mixes. Each of these curves show the relationship between the transmission factor and required thickness. Each of these curves is also the best fitting curve for the points representing the test records. For each mix the absorption Co-efficient has been determined from its curve, but the half –value layer has been determined from the equation 1. According to Figure 8, it is clear that the absorption co-efficient decreases as the ratio of fine aggregate to total aggregate increases.

For group A, it can be noticed that replacing gravel with Ilmenite leads to about (27 – 35) % increase in the value of absorption co-efficient. Also , It can be remarked that replacing a half of the gravel with Ilmenite leads to about (8 – 15) % increase in the value of the absorption Co-efficient. From Table 6, it can be remarked that the absorption Co-efficient increases as the unit weight increases.
Figure 9 shows the effect of the ratio of Ilmenite to total coarse aggregate on absorption Co-efficient for mixes of group B. It can be showed that the absorption co-efficient increases as the ratio of Ilmenite to total coarse aggregate increases. The effect of the cement on absorption co-efficient for the mixes of group B is shown in Figure 9. It can be remarked that the absorption co-efficient corresponding to 400 kg/m^3 cement content is less than that corresponding to 350 kg/m^3 cement content but the absorption co-efficient to 450 kg/m^3 cement content is greater than both. From Table 7, it can be noticed that reducing the ratio of Ilmenite to total coarse aggregate from 1.0 to 0.25 results in about 20% reduction in the absorption co-efficient.

Table 6. Results of shielding test group A

Mix No.	Sand/(Total agg.)	Density t/m^3	μ cm^{-1}	Half-value layer (cm.)
G1/A0	0.25	2.381	0.13	5.33
G2/A0	0.4	2.353	0.129	5.37
G3/A0	0.48	2.353	0.129	5.37
I1/A4	0.25	3.278	0.175	3.96
I2/A4	0.4	2.976	0.168	4.12
I3/A4	0.48	2.889	0.164	4.22
M1/A2	0.25	2.809	0.149	4.65
M2/A2	0.4	2.687	0.144	4.81
M3/A2	0.48	2.607	0.139	4.96

Table 7. Results of shielding test group B

Mix No.	*Cement content kg/m^3*	Density t/m^3	μ cm^{-1}	Half-value layer (cm)
M1/A4	350	3.278	0.175	3.96
M1/B4	400	3.175	0.17	4.07
M1/C4	450	3.077	0.175	3.96
M1/A3	350	3.023	0.161	4.31
M1/B3	400	2.955	0.154	4.50
M1/C3	450	2.887	0.167	4.15
M1/A2	350	2.889	0.149	4.65
M1/B2	400	2.753	0.147	4.70
M1/C2	450	2.697	0.165	4.20
M1/A1	350	2.595	0.139	4.98
M1/B1	400	2.551	0.135	5.10
M1/C1	450	2.508	0.142	4.88

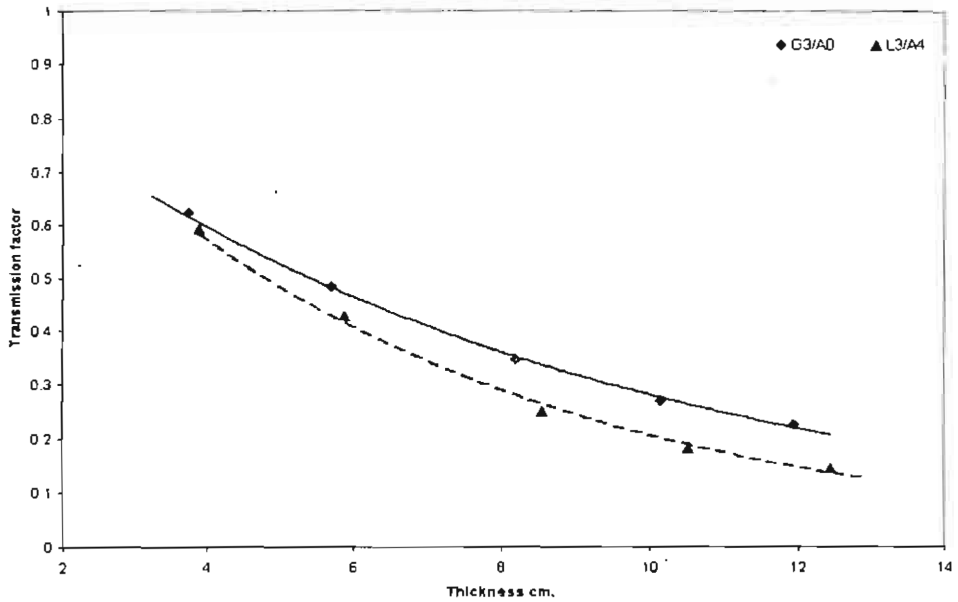

Figure 7 Transmission curve for G3/A0 and L3/A4 mixes.

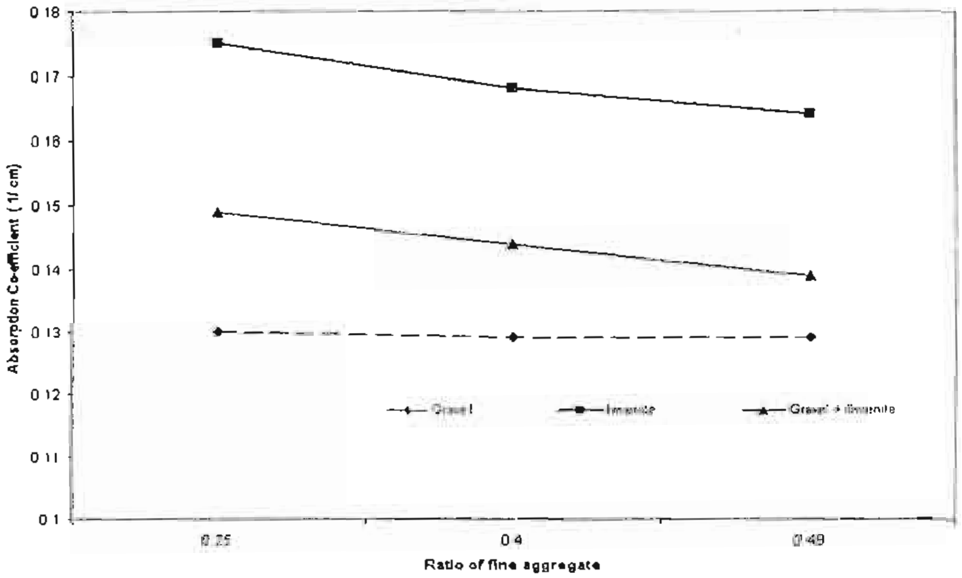

Figure 8 Effect of the ratio of fine aggregate to total aggregate on absorption Co-efficient for mixes of group A

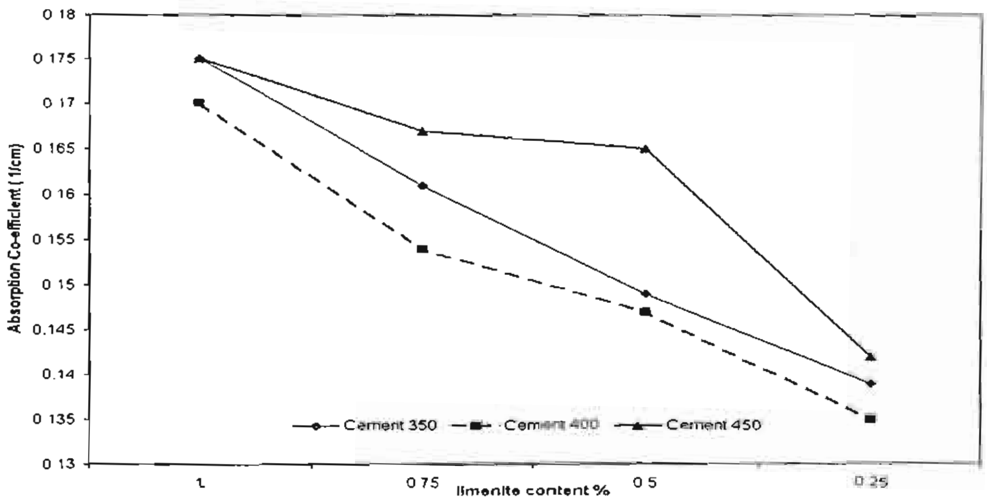

Figure 9 Effect of Ilmenite content on absorption Co-efficient for the mixes of Group B

4. CONCLUSIONS

Based on the test results obtained by presented study in this paper some conclusions concerning the effects the main mix parameters on compressive strength and shielding properties of heavy weight concrete (using Ilmenite as a coarse aggregate) can be recommended:

1. For all kinds of coarse aggregate, increasing the ratio of fine aggregate to total coarse aggregate leads to reduction in each compressive strength and absorption co-efficient.
2. Using Ilmenite 100% as a coarse aggregate increasing the absorption co-efficient by (27-35%) comparing with its value when the gravel is used as a coarse aggregate with ratio 100%.
3. Using the mixture from gravel and Ilmenite each with a ratio 50% from the coarse aggregate lead to about 15% increase in the value of absorption co-efficient as well as the unit weight increases.
4. The absorption co-efficient increases as the ratio of Ilmenite to total coarse aggregate increases, reducing the ratio of Ilmenite to total coarse aggregate from 100% to 25% leads to about 20% reduction in absorption co-efficient.
5. Cement content of 350 kg/m^3 and 450 kg/m^3 lead to increase in absorption co-efficient, While cement content of 400 kg/m^3 leads to decrease in absorption co-efficient, but the increase in cement content yields on increase in cube compressive strength.

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