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Design of concrete mix to improve its properties against nuclear radiation (gamma rays)

Abstract:

This study was carried out for designing a concrete has ability to resist the effects of nuclear explosions, this leads to discuss theses effects (blast, thermal, radiation and so on).

The present study has been carried out with a view to establish the basic engineering data and information about the technology of heavy weight concrete from such local materials. It can be used as shielding materials against gamma rays because of its potential properties, radiation attenuation (gamma rays) mechanical characteristics, durability and economic structural use.
In this study Ilmenite is used as coarse aggregate, serpentine is used as fine aggregate mixed with normal Portland cement and water, also steel fibers were added with different percentages.

Different concrete mixes were designed, produced, cured, and tested for compressive, tensile, flexural, ultrasonic test and bulk density. Admixtures were employed to improve the mechanical properties. The results showed that the steel fiber Ilmenite-serpentine heavy weight concrete has good mechanical properties for construction of nuclear shelters.

Results show that Ilmenite-serpentine heavy weight concrete has a good mechanical property compared with the ordinary concrete in most of tests specially the tensile and flexural strengths. It has been found that the ISFHWC can be produced with a maximum density of the order 3.35 t/m3.

Also results show that the effect of Ilmenite-serpentine heavy weight concrete of suitable thickness provides adequate protection against nuclear radiation emitted during nuclear burst, specilly gamma rays, ordinary concrete can be used for shielding but excessive thickness may be required. The choice of suitable materials will improve the attenuation of radiation and reduce the required thickness. In this study gamma rays of different energies were used to study the attenuation properties of

Ilmenite-serpentine heavy weight concrete. Experimental measurements have been carried out to study the gamma rays attenuation of different types of Ilmenite-serpentine heavy weight concrete.

Keywords:

Design, Ilimonite, serpentine, steel fiber, nuclear, gamma rays, radiation.

1-Introduction:

The growth in the power and sophistication of explosives and firearms continued until World war I and defensive countermeasures merely increased the mass and strength of the structure in response to the more powerful attack, The conflict at this time was mainly confined to armed forces, who suffered twenty time more casualties than civilians. The next major shift in the balance of attack and defenses developed between 1918 and 1930 with the introduction of aerial warfare, widely used in World War II the use of aero planes to deliver explosives was new, but the means of combating it was known from front line experience now, however the general populace behind the front line could for the first time be directly involved in the conflict.

This led to improvements in defenses by the developments of public and private air-raid shelters, which could withstand a local explosion and in some cases, even a direct hit never the less, this did not prevent wholesale civilian carnage, in which civilians sustained as many casualties as the armed forces. The development of the atomic bomb and its 1st use on 6 August 1945at Hiroshima, when a 15 KT bomb known as thin Boy killed half the city's population, followed by a 20 KT bomb -Fat man- dropped three days later at Nagasaki, killing three quarters of its population, again radically. The following photo shows the great distortion in Nagasaki as shown in fig (1).

Fig. (1) The damage in Nagasaki after the nuclear explosions

Altered the nature of threat posed by the attacker, the increase in power afforded by the hydrogen Bomb was a quantum jump in men's continuing search for means to destroy each other, so that whole cities were vulnerable tracts of land downwind could be affected by a single bomb even, where military targets were selected, the whimsically named collateral damage (damage to civil centers of population by bombs aimed at other targets) would result in an effect little different from that if such purely civilian targets as cities were chosen[1].
This study illustrates the effect of nuclear weapon explosion and to be discussing the use of a new type of highly hydrated heavy weight concrete used as an effective nuclear shelter, moreover the effect of adding fibers to such concrete will be discussed.

2-Expermintal work

The scope of the work deals with an experimental investigation to study the properties of heavy weight fiber concrete, with a specified type of aggregate, as influenced by some important parameters such as aggregates gradation, ratio between fine aggregates and coarse aggregates, cement content, w/c, plasticizing admixture and fiber content by concrete volume .

In this study, heavy weight concrete was perepared from naturally occurring ilmenite and serpentine ores as coarse and fine aggregates respectively. The ilmenite ore was choosen in order to increase the unit weight of the concrete in addition to its strenght under static and dynamic loads, while the serpentine ore was choosen since it contains chemically bound water in its composition (about 11.6%). Thus it increases the hydrogen content in the final concrete mixture [2].

2-1 Scope of the Test Program

Concrete mixes with cement content 400 Kg/m^3 were investigated; four mixes were tested using various percentages of steel fiber contents. The consistency adopted for all mixes was the semi-dry concrete with a slump of 35-55 mm. The consistency of fresh concrete was determined by the slump test. The hardened concrete was tested for ultrasonic velocity, unit weight, compressive strength, indirect tensile strength, flexural strength and impact strength, also this work includes nuclear radiation tests to evaluate the attenuation coefficients of different gamma rays energies. The scheme of the concrete mixes is shown in Figure (2).

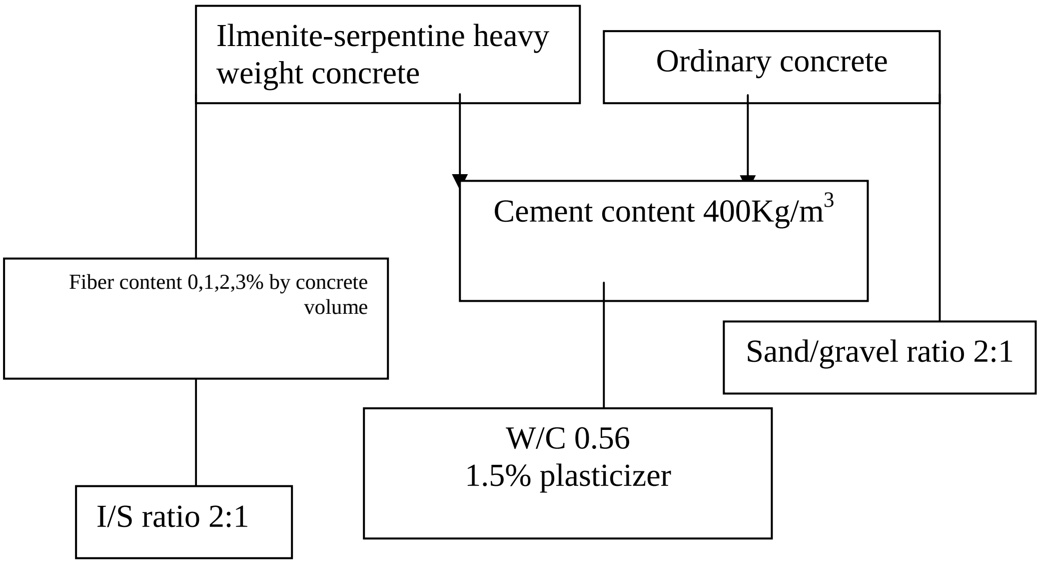


Fig.(2) Scheme of different concrete mixes of Ilmenite-serpentine heavy weight concrete
and ordinary concrete.

2.2 Mix Design

Concrete mixes were designed mainly by the empirical method based upon the absolute volume method recommended by the American Concrete Institute [3]

Table (1) Ingredients of 1m^3 of the control ordinary concrete mix number (1)

	Cement	gravel	Sand	Water	Fiber	S.P.
Material Quantity, kg	400	1328	664	224	0	6

Table (2) Ingredients of 1m^3 of I.S.F.H.W.C.

	Mix no.	Cement	Ilmunite	Serpentine	Water	Fiber	S.P.
Material Quantity, kg	2	400	1947	541	224	0	6
	3	400	1947	541	224	78	6
	4	400	1947	541	224	156	6
	5	400	1947	541	224	234	6

2-3 Preparation of Specimens for Test

In this study, series of specimens were prepared and tested in the laboratories of the Civil Engineering Department, Military Technical College in Cairo.

The factors that can affect the strength of concrete can be classified into four categories: constituent materials, methods of preparation, curing procedures, and test conditions. we will here be concerned primarily with the effects of the concrete constituents such as fiber content and type of aggregates [5,9].

The specimens used in the study take three shapes:

1-Standared cubes (15x15x15) cm

2-Standared cylinders (20x10) cm

3-Beams (70x10x10) cm

All samples were placed in the room temperature and were cured in water for 28 days, the curing water were changed every 7 days. 3-1 Properties of Fresh ISFHWC

Water cement ratios for different conditions are given in Table (3). The table contains the ratios for both ISFHWC with and without plasticizer, in addition to ordinary concrete. From this table the following results can be deduced.

- All concrete mixes have nearly the same slump values, which can be classified as a semi plastic consistency.

Table (3) Variation of water-cement ratio for different concrete mixes

Mixes with plasticizer for all mixes

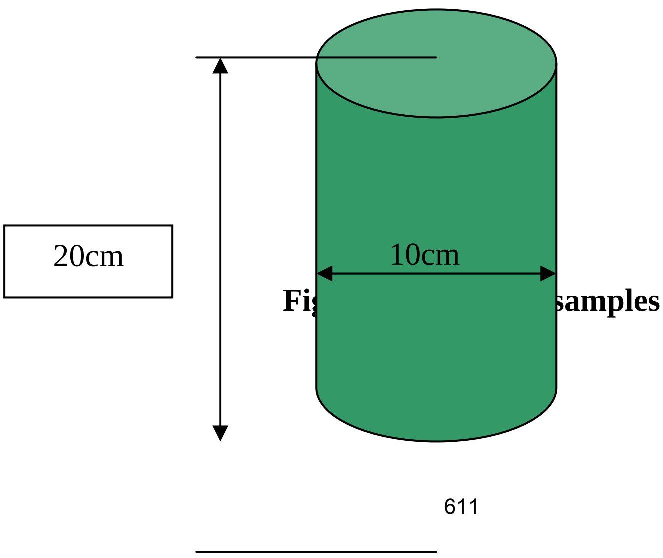
	O.C.	I.S.C.			
Cement content Kg/m^3	400	400	400	400	400
% of serpentine	33	33	33	33	33
W/C ratio	0.65	0.65	0.65	0.65	0.65
Fiber content,%vol.	0	0	1	2	3

Properties of Fresh ISFHWC

2.4 Nuclear Raiation Physics Experimental Work

2. 4.1 *Samples Under Investigation*

The samples under investigation were prepared in form of cylinders made from ilmenite-serpentine impregnated and different percentages of steel fibers in addition to the ordinary concrete as reference samples. The cylinders have 10cm diameter and a thickness varies from 2.5 up to 20cm.



Fi samples

4. 4.2 Sources of Gamma Rays

Three different radioactive materials were used individually as point sourses of gamma rays covering wide range of gamma ray energies. The sources were Na-22,Cs-137 and Co-60 ,such sources emit five different gamma photons of different energies . The first sources emits two gamma photons of energies 0.511 and 1.25 Mev., the second one emits single photon of energy 0.662 Mev., while the Co-60 emits two gamma photons of energies 1.17 and 1.33 Mev.

4. 4.3 Gamma Ray Scintillation Spectrometer

The measurements of the gamma-ray spectrum were performed by using NaI(Tl) scintillation detector. The detector is hermetically sealed assembly, which includes a high resolution (~ 6.7 %) 3\\×3\\ NaI(Tl) crystal and photomultiplier tube. The compact P.M. tube base contains a high-voltage divider network to supply all necessary voltages for the dynodes. The blocking capacitor is to couple the anode and dynode signal outputs to a spectroscopy amplifier then to discriminator. The spectroscopy amplifier, provides linear amplification and high resolution of the input pulses. The schematic diagram of a scintillation detector was shown in Figure (4). The pulse height spectrum of gamma rays emitted from gamma source was recorded and analyzed in the PCA.

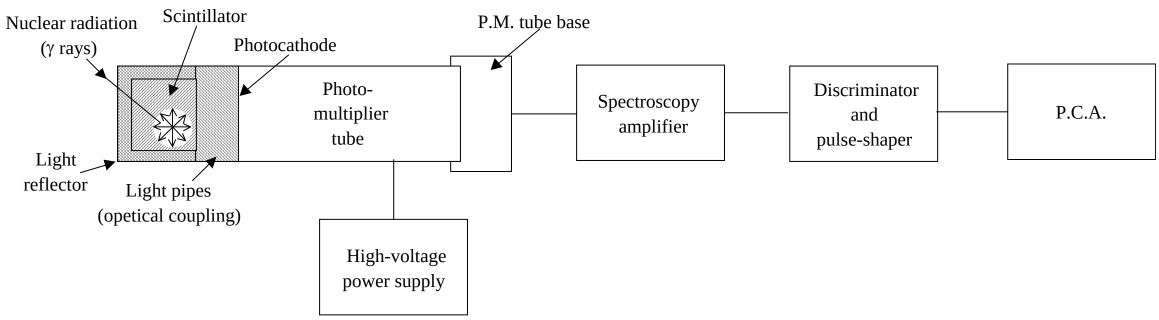


Fig.(4) Schematic diagram of the scintillation γ-ray spectrometer

4. 4.4 Experimental setup

The studies of absorption of gamma rays were made through measurements of its transmission through the prepared concrete samples. Figure (5) shows the experimental setup for the measurement of the transmitted intensity of the beam, which reaches the detector. The gamma sources were placed inside 15 mm lead holder (source collimator), while the scintillation detector had been surrounded by 5 mm lead (detector collimator), in order to prevent the scattered γ-rays from reaching the detector. The beam, the absorbers and the detector centers were placed in the same horizontal plane.[5]

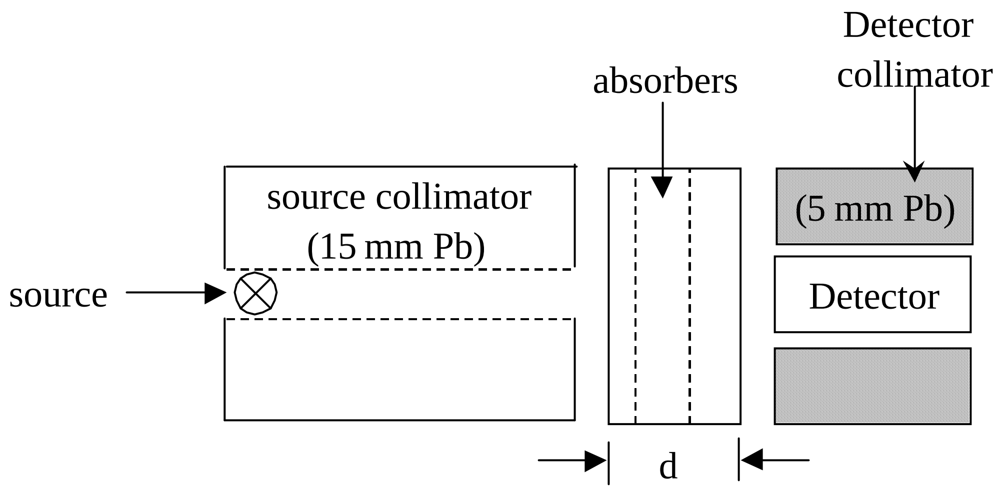


Fig.(5) Experimental arrangement for the measurement of the transmitted gamma rays.

3- Results

3-1 Bulk Density

Table (4) shows that bulck density is influenced by different parameters. Since the bulk denisty of concrete is the property of main concern, it is important to study the parameters which have the influence on the bulck denisty. In this study the ISFHWC was produced using ilmenite as coarse aggregate and serpentine as fine aggregate with bulk density ranges between 3 and 3.47 ton per cubic meter. This value is 25%-48% higher than that of O.C.

Table (4) Bulk density kg/m^3

		I.S.C.			
Fiber content % by volume of concrete	O.C	0	1	2	3
Compressive strength kg/cm^2	333	342	354	412	408
Bulk density kg/m^3	2194	3215	3321	3359	3286

3-2 Properties of hardned ISFHWC

1.Ultrasound Testing OF ISFHWC

Since the pulse velocity depends only on the elastic properties of the material, so the ultrasound test is very convenient technique for evaluating concrete quality. In this test we determined the pulse velocity through a known thickness of ISFHWC.Figure

(6) shows that the ultrasound velocity in ISFHWC is 6.25% greater than that in O.C.,while the study shows that the ultrasound velocity increases with increasing fiber content up to 2% while at higher percentages the ultrasound velocity decreases ,this behavior can be attributed to the cracks or honey comb formation inside the concrete samples when the fiber content exceeds 2%.

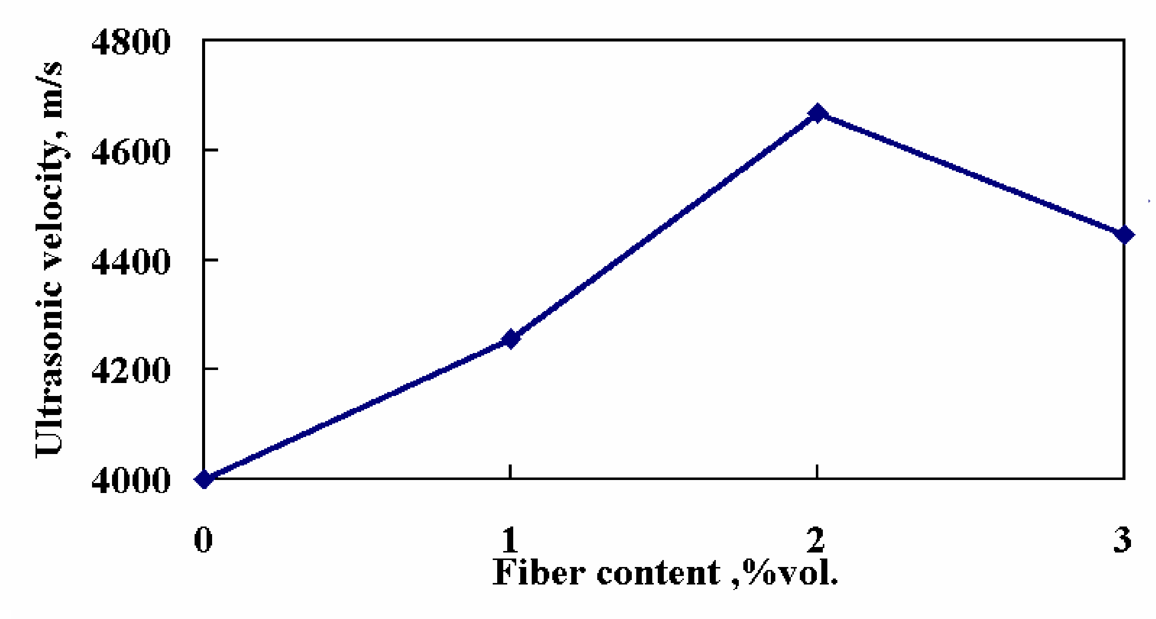


Fig. (6) Ultrasonic velocity values of I.S.C. impregnated with different percentage of steel fiber

2. Compressive Strength

In many codes the compressive strength is named a concrete rank because of its importance,the compressive strength test was carried out on samples containing steel fiber (Harks) with percentages 0,1,2,3% by concrete volume . Such results are illustrated in figure (7).

The specimens were tested at 7 and 28 days age for all mixes with and without fibers. From the curves the following conclusions can be found:

- Compressive strength increases as concrete age increases.
- Generally ISFHWC behaves in a manner similar to that of ordinary concrete.
- It is clear that increasing fiber content the compressive strength increases up to 2% vol., this increasing may be attributed to the increasing Young’s modulus and to the hindering effect of the fibers to the production and propagation of the cracks.
- The above phenomena occurred up to 2% fiber content, while at higher percentages the compressive strength went to decrease, this may be attributed to the production of voids which make weak points which leads to decreasing the compressive strength.

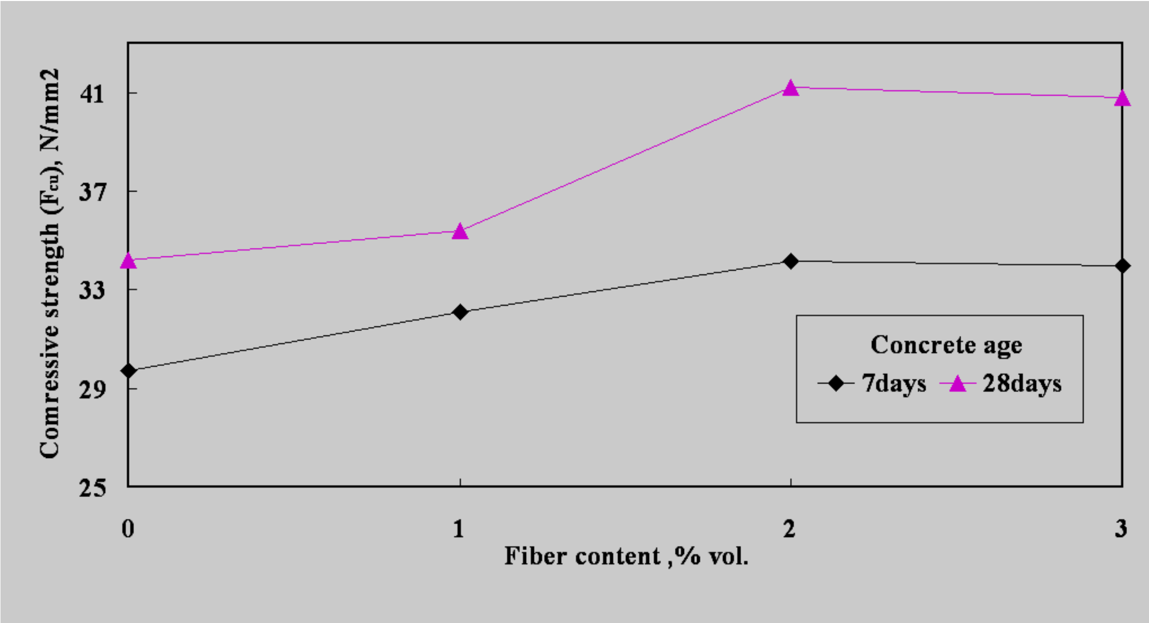


Fig. (7) Compressive strength of I.S.C impregnated with different percentages of steel fibers

3.Tensile Strength

Tensile strength is not an important property as well as the importance of compressive strength for concrete; there is relatively relationship between compressive strength and tensile strength. General important remarks can be summarized as follows:

1- The tensile strength increased as fiber content increased up to 2%.

2- The tensile strength of I.S.F.H.W.C. is 1.48 times than that of O.C.

3- The maximum tensile strength of I.S.F.H.W.C. reached 19.2 Kg/cm^2 at fiber content 2%.

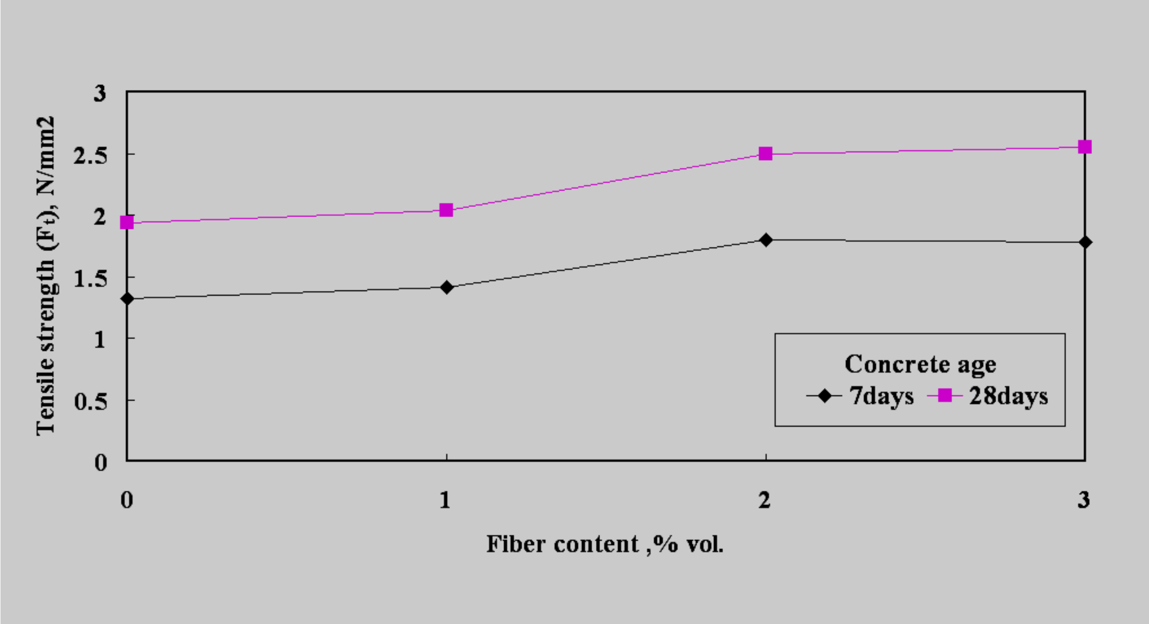


Fig. (8) Tensile strength of I.S.C impregnated with different percentage of steel fibers

3. Flexural Strength

Results of flexural strenght test show that introducing fiber into I.S.C causes improvement of the flexural strength with nearly 10%, the increasing of fiber content the increasing of flexural strength up to 3%, this may be due to the presence of fiber,which in turn cuase a big surface faces the bending . Such results were displayed in fig (9).

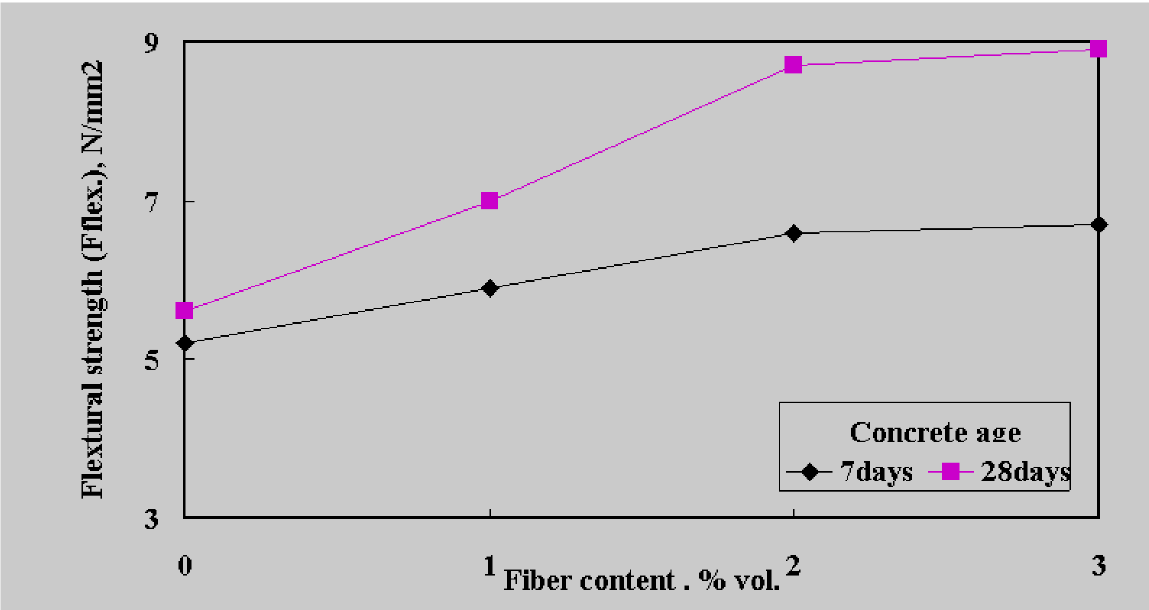


Fig. (9) Flexural strength of I.S.C impregnated with different percentages of steel fibers

5. Gamma-Ray Attenuation in ISFHWC

The transmitted intensities of gamma rays were measured as a function of barrier thickness for barriers of ISFHWC and O.C. It can be noticed that the gamma ray intensity decreases exponentially with increasing the barrier thickness. The slope of these curves were used to deduce the average values of gamma ray attenuation coefficients (μ_γ) at different incident gamma ray energies (E_γ) These figures show that the values of μ_γ decrease slowly as (E_γ) increases, At higher energies up to 1330 Kev the values of μ_γ began to increase this behavior appears for all values of fiber impregnation. These results indicate that the concrete as a whole and the ISFHWC in particular is an effective shield against gamma-rays emitted after the nuclear explosion (prompt or delayed).

Regarding the magnitudes of (μ_γ) for the ISFHWC and O.C., one can deduce that the sample with 2% of fiber content is the most effective one among the other samples for all values of incident gamma ray energy and the average values of μ_γ for the ISFHWC is not much less than that of O.C. up to gamma ray energy 1.17 Mev, while at higher energies O.C. provable to be more effective.

6. Evaluation of Half Reduction Thickness (X1/2)

The half reduction thickness $x_{1/2}$ is very important value for civil engineers, since it gives the minimum thickness of concrete required to attenuate the fifty percent of gamma ray intensity. Fig (10-16) show the values of $x_{1/2}$ for both concrete types at different incident gamma ray energies as well as their values for different percentages of fiber impregnation.

The half reduction thickness can be calculated from the following equation:

$$X_{1/2}= \ln 2/ (\mu_\gamma)$$

Where

(μ_γ) is attenuation coefficient of gamma rays.

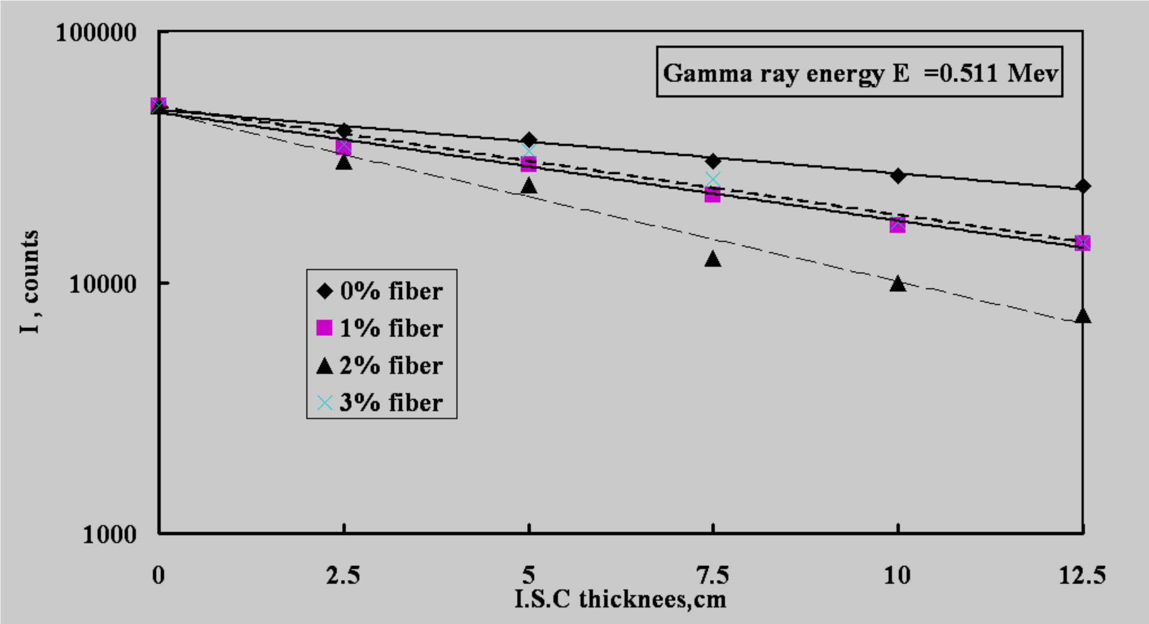


Fig. (10) Attenuation of gamma ray of energy 0.511 Mev in I.S.C impregnated with different percentage of steel fibers

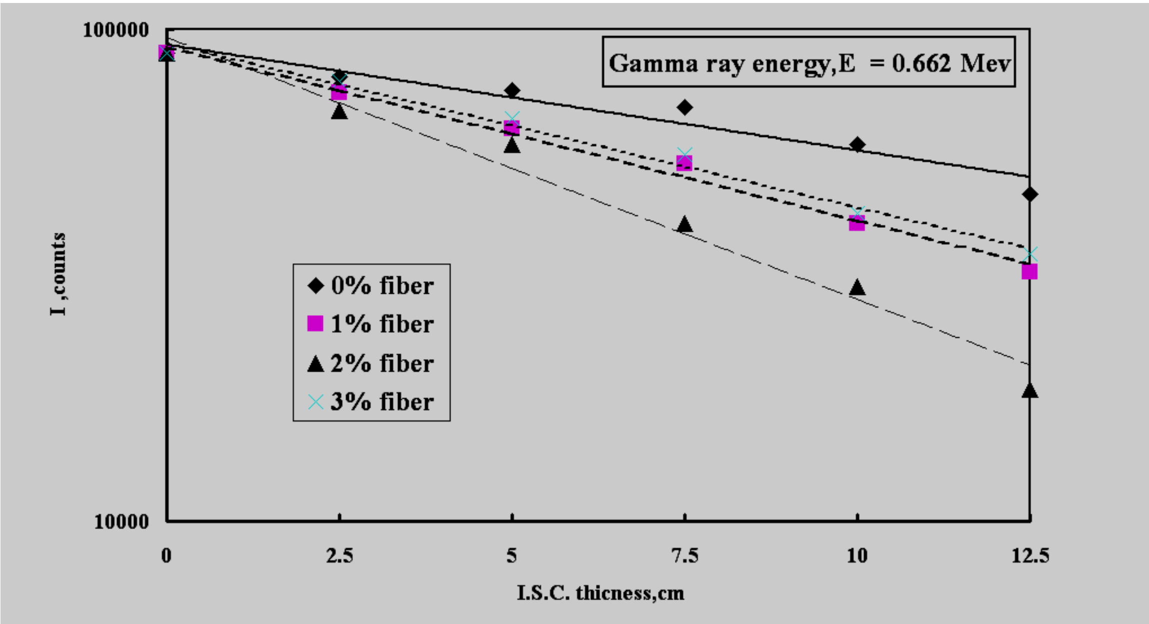


Fig. (11) Attenuation of gamma ray of energy 0.662 Mev in I.S.C impregnated with different percentage of steel fibers

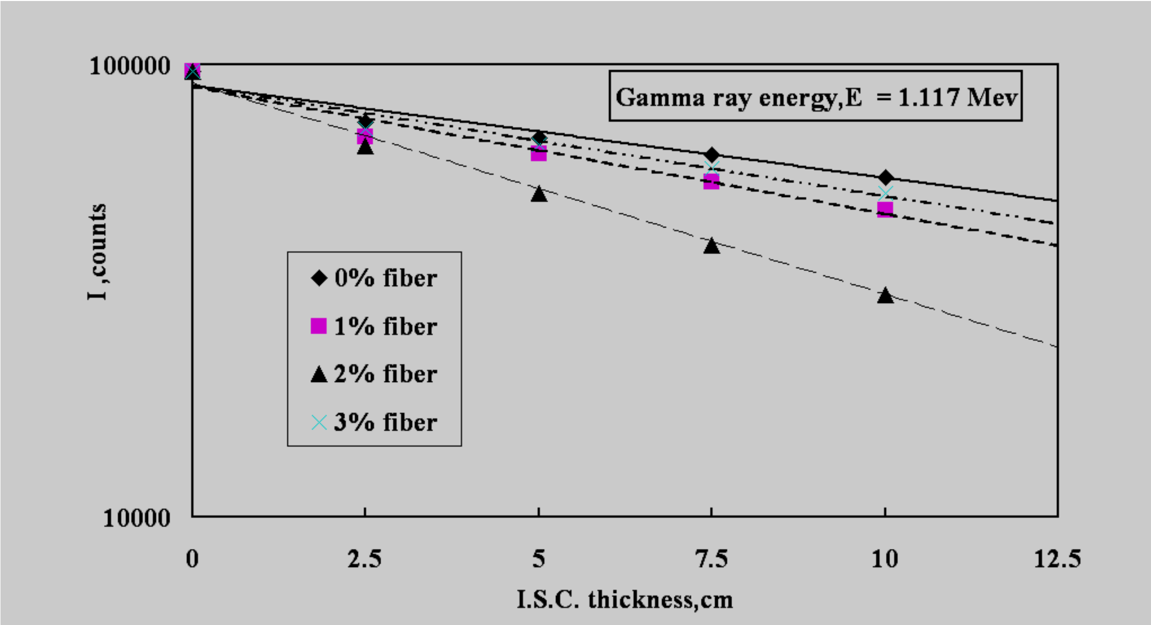


Fig. .(12) Attenuation of gamma ray of energy 1.117 Mev in I.S.C impregnated with different percentage of steel fibers

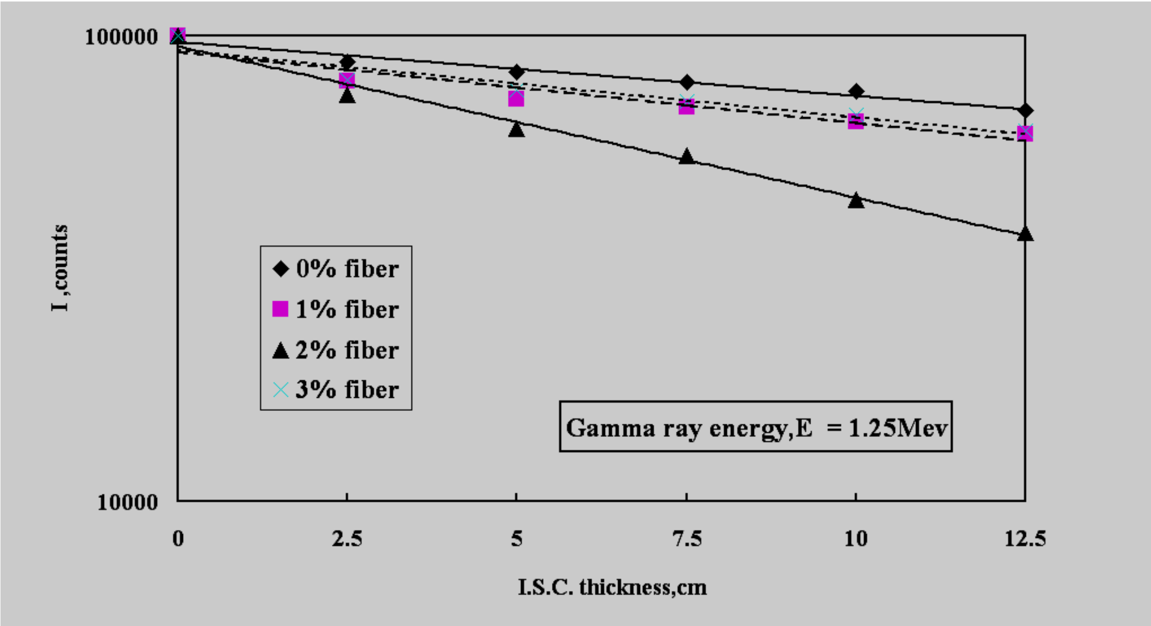


Fig. (13) Attenuation of gamma ray of energy 1.25 Mev in I.S.C impregnated with different percentage of steel fibers

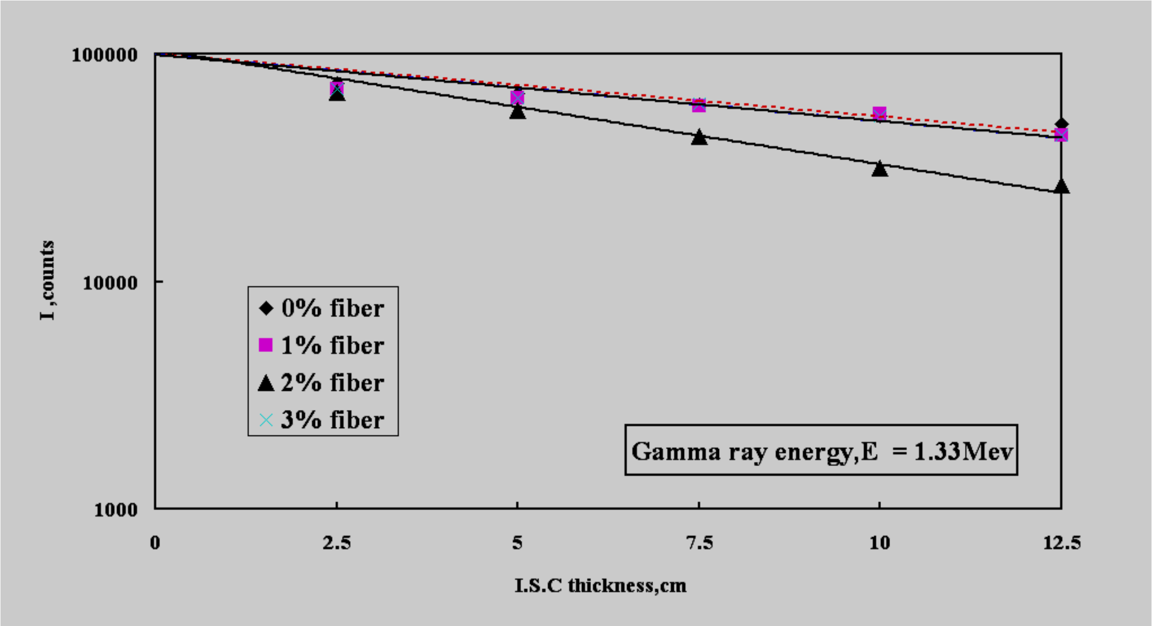


Fig. (14) Attenuation of gamma ray of energy 1.33 Mev in I.S.C impregnated with different percentage of steel fibers

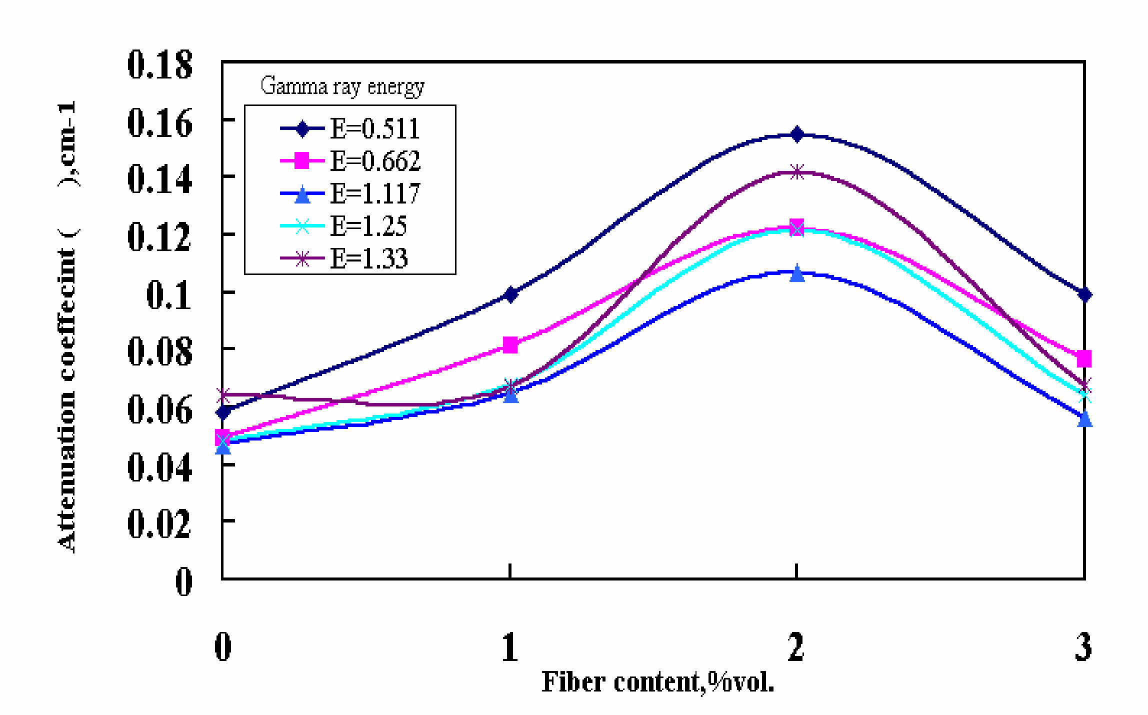


Fig. (15) Attenuation coefficients of gamma rays in I.S.C impregnated with different percentages of steel fibers

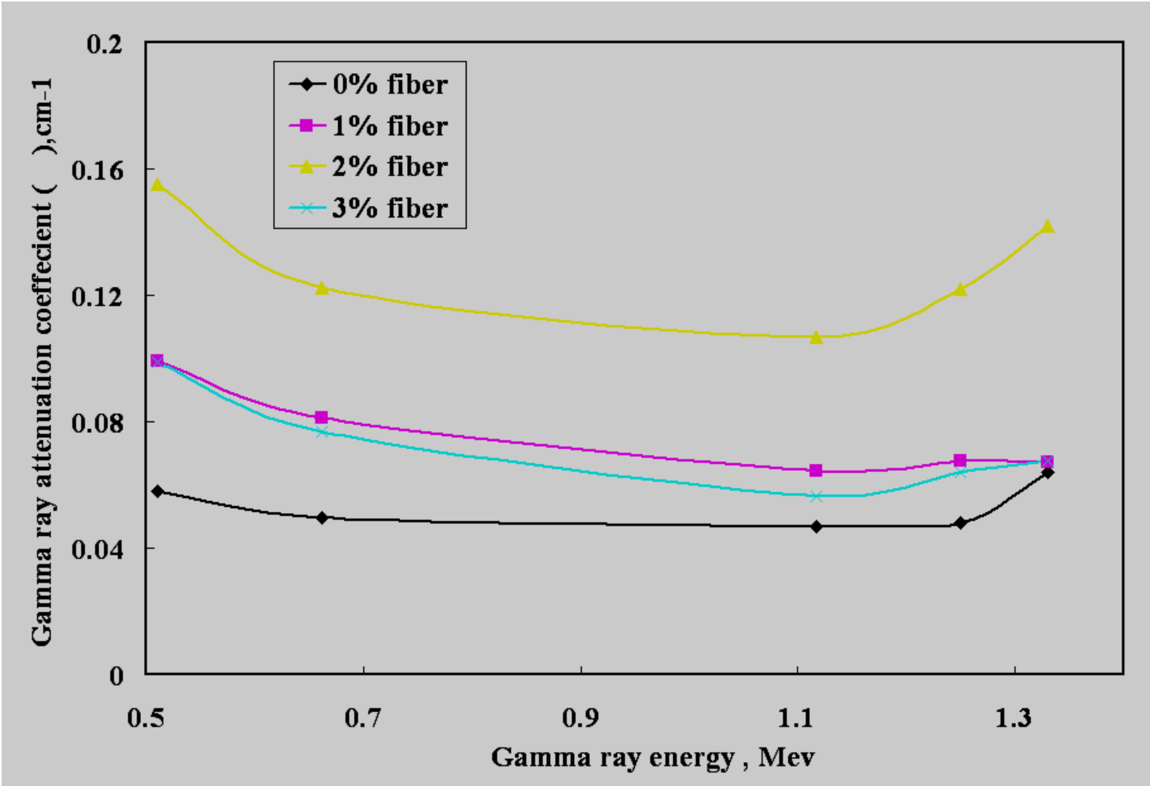


Fig. (16) Attenuation coefficient of gamma rays (at different energies) in I.S.C impregnated with different percentage of steel fibers

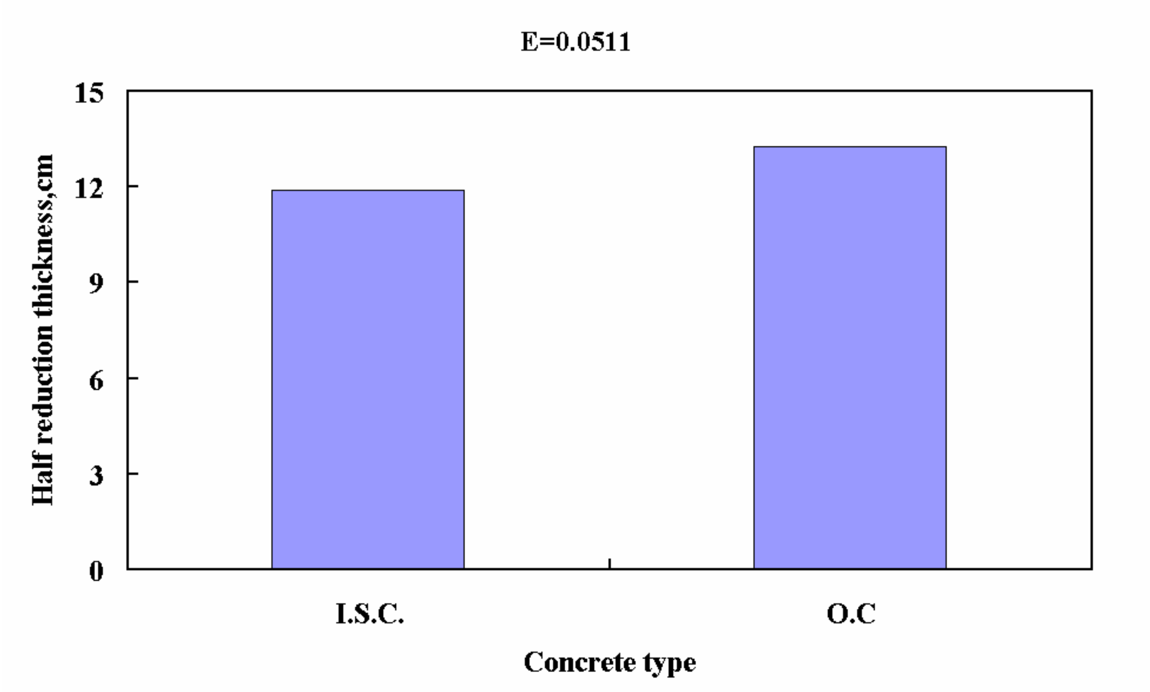


Fig (17) half reduction thickness of both O.C.and I.S.C. at 0.511Mev.energy

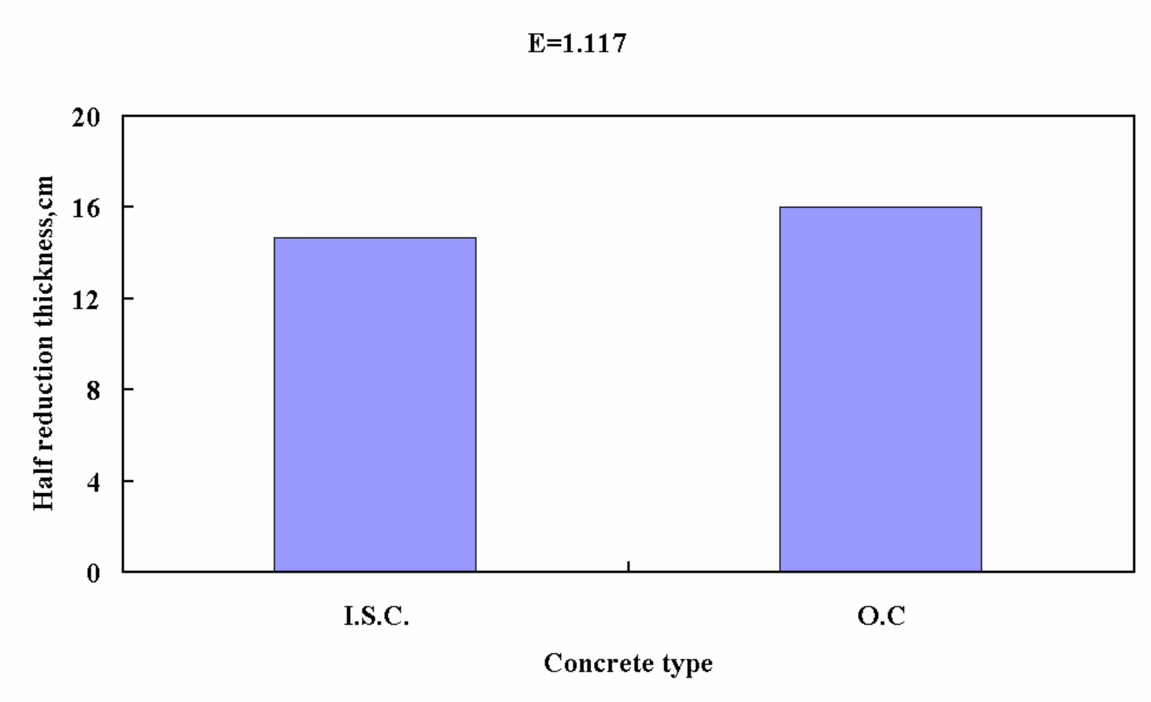
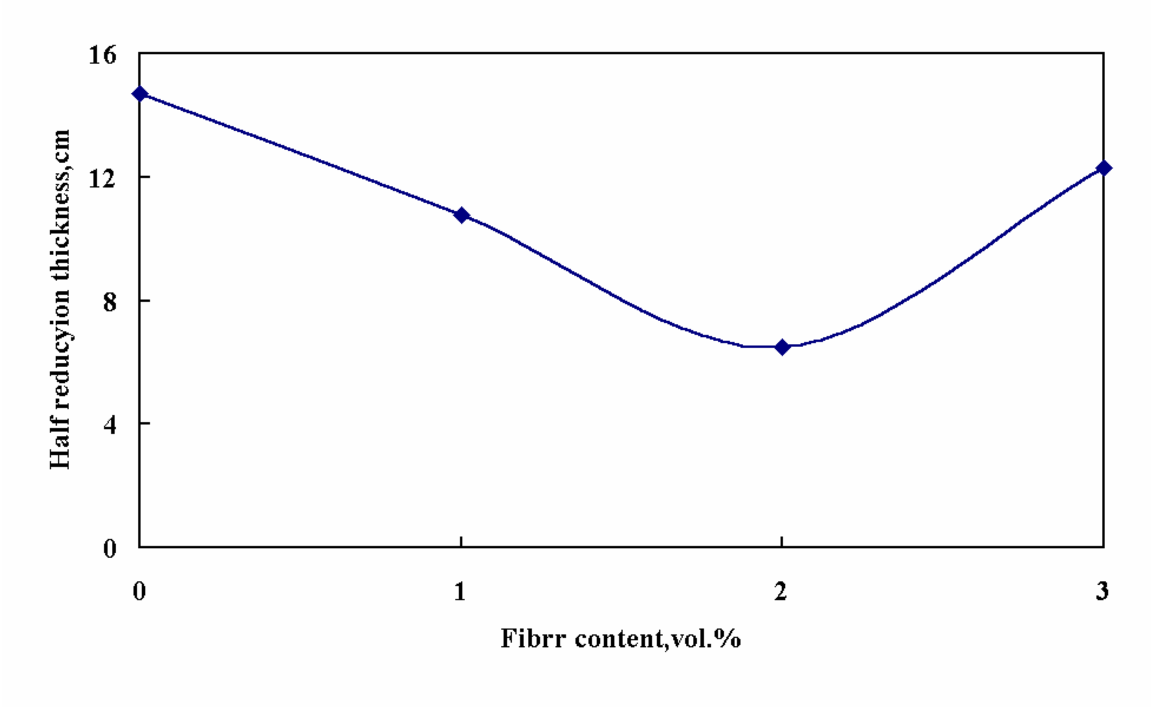


Fig (18) half reduction thickness of both O.C.and I.S.C. at 1.117Mev.energy



Fig(19) half reduction thickness for I.S.F.H.W.C. impregnated with different percentages of steel fibers at 1.117Mev.energy

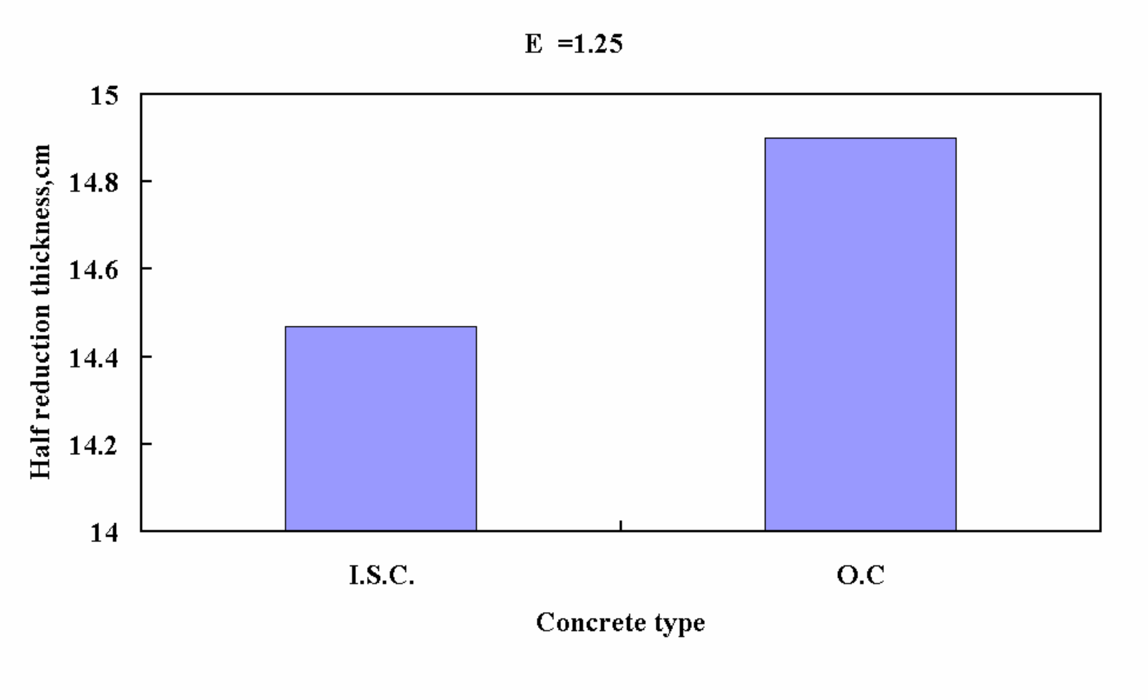
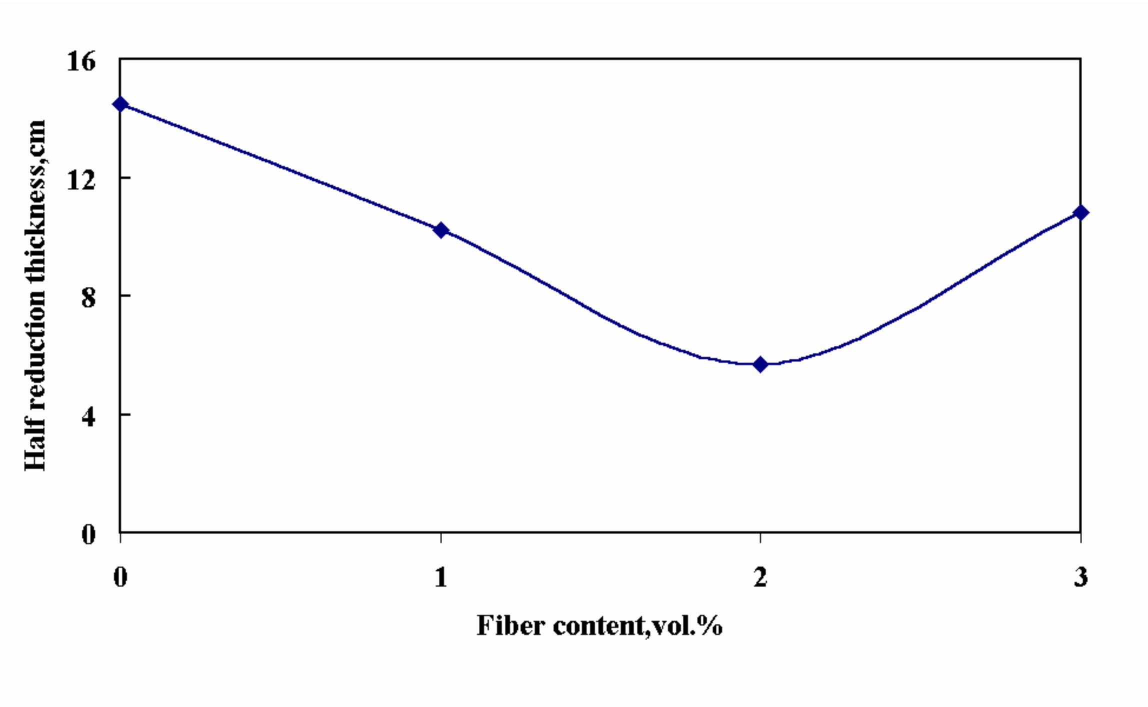


Fig (20) half reduction thickness of both O.C.and I.S.C. at 1.25Mev.energy



Fig(21) half reduction thickness for I.S.F.H.W.C. impregnated with different percentages of steel fibers at 1.25Mev.energy

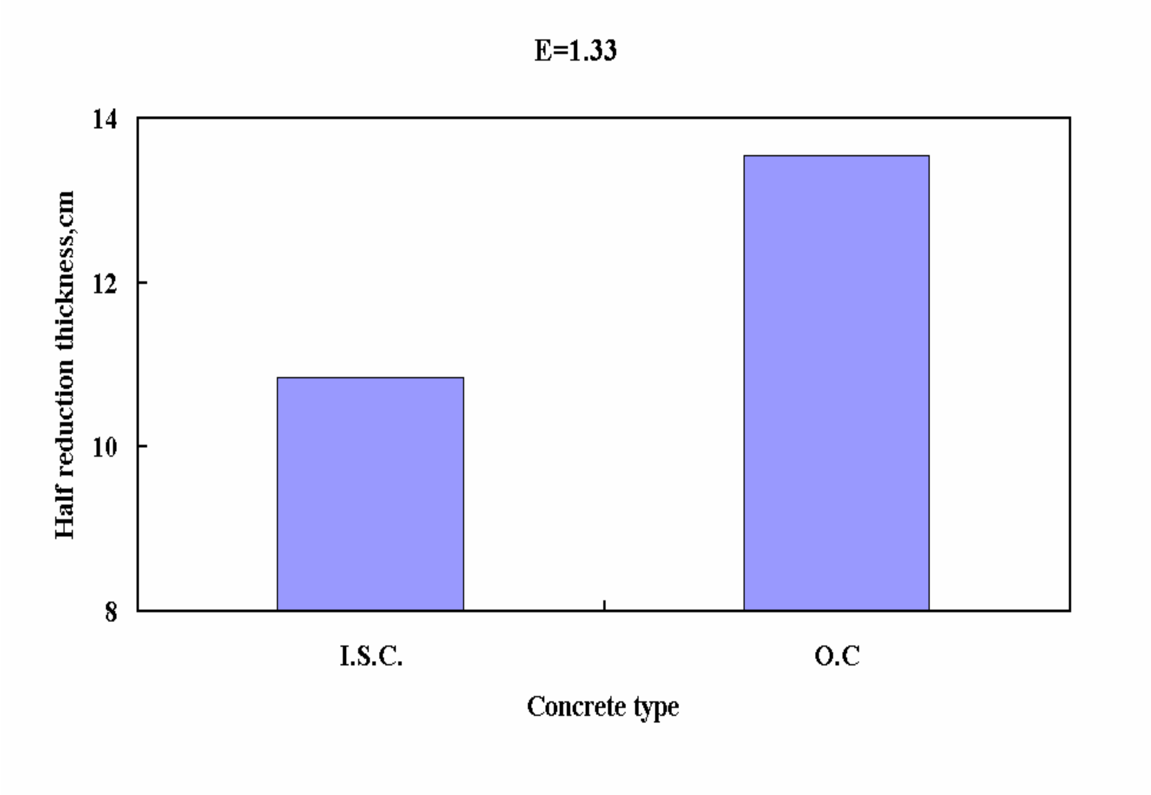
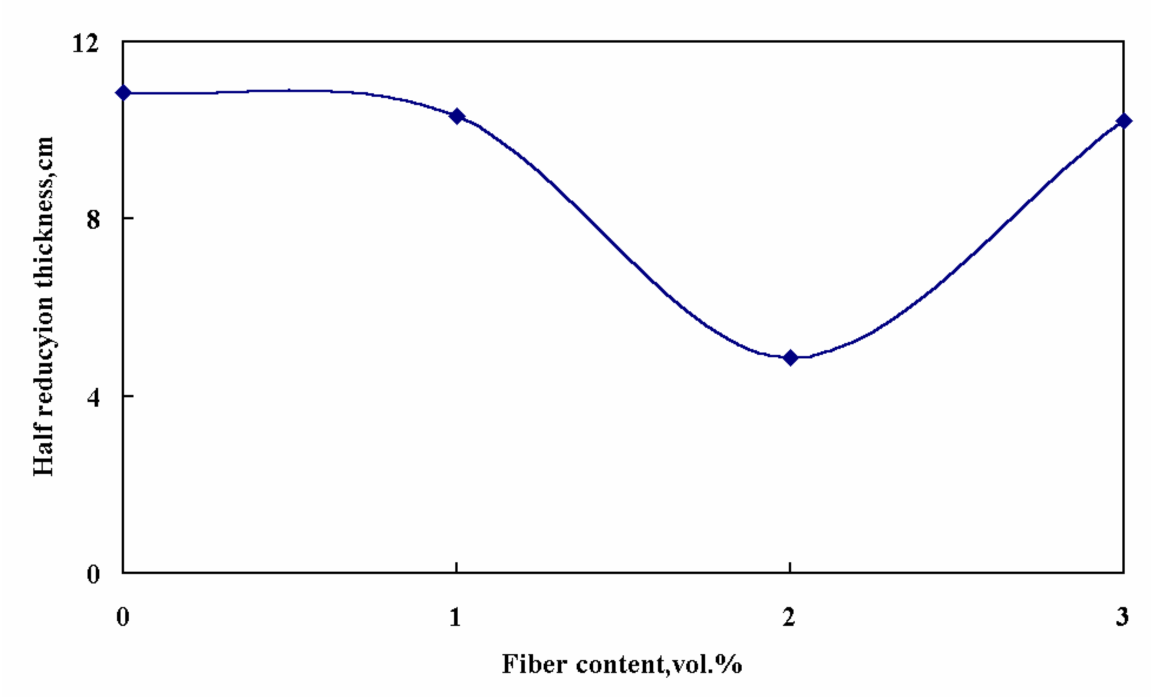


Fig (22) half reduction thickness of both O.C.and I.S.C. at 1.33Mev.energy



Fig(23) half reduction thickness for I.S.F.H.W.C. impregnated with different percentages of steel fibers at 1.33Mev.energy

4. Conclusions and Recommendations

4.1Conclusions

The following general conclusions could be derived from the experimental results previously obtained.

1- The ilmenite and serpentine ores in addition to steel fibers can be selected for the production of heavy weight concrete used for design nuclear shelters.

2- The ilmenite and serpentine ores and steel fibers can be used to produce a concrete of 3359 kg/m3 unit weight, and 410 Kg/cm2 compressive strength.

3- The addition of steel fibers to I.S.C. can lead to increase 100% the tensile strength compared to that of O.C.

4- The I.S.F.H.W.C. can be used to design all bending members because of its highly flexural strength.

5- The failure of the new concrete has no fragments, which ensure a high degree of protection for any thing inside the structures.

6- The new type of concrete shield has attenuation coefficients greater than the ordinary concrete (for different gamma ray energies).

7- The half reduction values of I.S.F.H.W.C.can be reduced by nearly 50% less than that of O.C.

8- The structure elements of the shelter can be designed by nearly a half dimensions when using I.S.F.H.W.C instead of O.C.

4.2 Recommendations

The following recommendations for future work can be displayed as follow:

a) Using another types and shapes of steel fibers in I.S.H.W.C.

b) Applying blast tests on I.S.F.H.W.C. for ensuring its resistance for blast loads using different amounts of explosive materials.

c) Taking the other effects of nuclear explosion into consideration in the following testing programs (i.e. neutron attenuation at different energies).

d) A theoretical modeling must be designed to adopt the design rules and equations applied in case of O.C. design and perform the necessary corrections.

e) Effect of I.S.F.H.W.C. on the reinforcement.

f) Construction of concrete elements and testing them under different cases of loading (beams, columns, slabs) under static and dynamic loads.

g) Prototype (model) for an actual structure and test it.

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