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Enhancement of Ilmenite-Serpentine Heavy Weight Concrete by Adding Rice Husk Ash as a Replacement for a Part of Cement

By

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Abstract:

Normal weight concrete of sufficient thickness is used for shielding and protecting buried structures. However, it is desirable to use heavy weight concrete to permit reduction of the size and thus to provide more working space. Such high-density concrete could be produced by the use of heavy weight aggregates. It could be made by adding a considerable proportion of based iron aggregates such as ilmenite. Analyzing and investigating the performance of heavy composite concrete media upgraded with adding rice husk ash (RHA) was the aim of this research. The coarse aggregate – ilmenite – was supplied in small sizes. An effort has made to overcome the disadvantage of small coarse ilmenite aggregate by adding gravel. The mix with ratio between Ilmenite: Serpentine: Gravel as 1:1:1 respectively gave better responses. It would be better than the other tested mixes to give the best mechanical properties with reasonable unit weight. The RHA is highly reactive pozzolanic material and can be used as a supplementary cementing material. The concrete containing 10% RHA - as a replacement for a part of the ordinary Portland cement - had higher compressive strengths at various ages up to 180 days compared with that of the mixes without RHA. Adding 10% RHA has a positive effect on mixes as they contained to gain strength concerning the values of compressive strength for a long period of time. It has no clear effect to enhance the tensile strength or the unit weight of mixes.

Keywords:

Ilmenite; Serpentine; Aggregates; Rice Husk Ash; Cement Replacement; Super-plasticizer.

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1. Introduction:

Establishing buried structure with protective layers above it can reduce, or better vanish, the effect of attacking weapons on the main structure. Normal weight concrete of sufficient thickness can be used, but it is desirable to use heavy weight concrete to permit reduction of size and provide more working space. Heavy weight concrete could be produced by using heavy weight aggregates. It could be made by adding a proportion of based iron aggregates such as ilmenite, and for economic reasons no special cement is used for this manner [1].

The use of residue in civil construction, especially in addition to concrete, has been the subject of many researches due to, besides reducing the environmental polluter's factors; it may lead several improvements of the concrete properties [2]. The objectives of the present research is to investigate the performance of heavy composite concrete media upgraded with adding rice husk ash (RHA) as highly reactive pozzolanic finer cementing material.

The local suitable materials used were Ilmenite as coarse aggregate, Serpentine as fine aggregate, ordinary Portland cement, tap water, super-plasticizer (Sikament-163) as water reducing agent, RHA as a supplementary of a part of cement, gravel, and sand. All concrete mixes were designed following The Absolute Volume Method recommended by the American concrete institute. A series of specimens was prepared and tested in the laboratory of the Construction Research Institute (CRI) at El-Kanater, Kalubia [3].

2. Contents of Concrete Mixes:

Contents of concrete mixes and its properties are shown in Table 1.

Table (1): *Contents of concrete mixes and its properties*

Content	Properties	
Ilmenite	Size 5 - 10 mm	Specific gravity = 4.11
Serpentine	Size < 5 mm	Specific gravity = 2.5
Ordinary Portland cement	Content = 400 Kg/m^3	Specific gravity = 2.84
Tap Water	W/c = 0.56	
SuperPlasticizer (Sikament-163)	1.5% cement weight= 6 Kg/m^3	Density = 1.2 Kg/lit
Rice Husk Ash (RHA)	10 % replace cement content	Specific gravity = 2.1
Gravel	Size 10 - 40 mm	Specific gravity = 2.65
Sand	Size < 2.5 mm	Specific gravity = 2.65

2.1. The Mineral Ilmenite:

Coarse aggregate was Ilmenite [Iron Titanium Oxides - $FeTiO_3$], supplied by El-Naser Phosphate Company. The size used ranging from 5 to 10 mm.

Ilmenite is an economically important and interesting mineral. It is the most important ore of titanium. Titanium alloys have found many applications in high tech airplanes, missiles, space vehicles, and even in surgical implants. Ilmenite color is black (Streak is brownish black). Its unit weight is 2.12 Kg/m^3, and specific gravity is 4.11 Kg/m^3 [3].

2.2. The Mineral Serpentine:

Fine aggregate was serpentine [Hydrous magnesium silicate - $MgSiO_2$ (OH)] in the form of small lumps. It is supplied by El-Naser Phosphate Company in small sizes less than 5 mm. Serpentine is a major rock-forming mineral and is found as a constituent in many metamorphic and weathered igneous rocks. Most rocks that have a green color probably have serpentine in some amount [3]. Its color is olive green, yellow or golden, brown, or black (Streak white). Its specific gravity is about 2.5, and unit weight is 1.38 Kg/m^3.

Serpentine ore contains chemically bound water in its composition (about 11.6%). Thus, it increases the hydrogen content in the produced concrete element. It still retains significant amount of water of crystallization up to 600°C. For these reasons, the specific gravity is approximate for serpentine [1].

2.3. Mixing Water:

Tap ordinary drinking water free from impurities was used throughout the tests. All the mixtures were mixed in dry state for 180 sec. to ensure the uniform distribution of solid particles before adding water [3].

2.4. Ordinary Portland cement:

Ordinary Portland Helwan cement was used. Its chemical and physical properties are shown in Table 2 and Table 3 respectively.

Table (2): *Chemical properties of the used Portland cement*

Constituent	% Percent by weight
Silicon dioxide Sio_2	22.025
Aluminum oxide Al_2O_3 and Iron oxide FeO	8.1
Calcium oxide CaO	63.8
Sulfur trioxide So_3	2.1
Ignition loss	3.3
Other oxides and impurities	0.7

Table (3): *Physical properties of the used Portland cement*

Parameter	Value
Specific gravity	2.84
Specific surface area	3320 (cm^2 / g)
% Passing opening sieve 0.3 mm	100%
Color	Dark gray

2.5.High Performance Water-Reducing Agent:

Increasing water content brings harmful effects to concrete if there were an extra amount of non-hydrated water. It increases the porosity of concrete and decreases its compressive strength. A concrete admixture named super plasticizer has been added into concrete mix to provide increasing the workability without increasing the water content.

The super-plasticizer used was sodium silicate supplied by Sika-Egypt Co. under the name (Sikament-163). It has Polymer type dispersion, brown color, 1.2 Kg/lit density, and its percentage ranges between 0.6 to 2.5 % of cement weight. It can achieve water reduction 5 to 10 % [1], Increase workability of concrete mix, improve the speed of hardening, increase the earlier and final strength, and also decrease shrinkage and creep.

2.6. Rice Husk Ash (RHA):

Recently, there has been considerable effort worldwide for utilizing waste materials in concrete. One such material is rice husk. Under controlled burning and if sufficiently grinded, the produced ash can be used as a cement replacement material in concrete. Rice husk is an agricultural waste produced in significant quantities in the world. It is already used as a fuel source in some regions, but in others, it is a waste causing pollution [4].

The utilization of RHA in concrete can obtain several benefits. It contributes to reduce of agricultural waste that is the main cause of environmental problems. On the other hand, it is an approach to improve the quality of concrete without using costly additives [5]. It is abundant and cheap material in Egypt and its use as a replacement part of the cement content leads to low cost of cementation, high strength, and more durability. This is better than burning rice husk irregularly that causes civilians and all kinds of life to suffer from pollution.

RHA consists essentially of silica in non-crystalline matter. The non-crystalline matter and high surface area form are responsible for the pozzolanic activity. The pozzolanic properties means that the non-crystalline matter under ambient condition hydrates slowly even in the presence of the alkaline solution formed by the dissolution of Portland cement mineral [6]. It should be noted that for mixes containing RHA, the required water content increases as RHA content increases. This can be overcome by the use of chemical admixture. The rate of strength development of the RHA mortar is slower in the early age if it is compared with the rate of the ordinary Portland cement mortar but vice versa after longer time [7].

The properties of fresh and hardened concrete (incorporating Rice Husk Ash as a supplementary cementing material for producing high-performance concrete) have been studied. Based on the test results a concrete mix with 10% RHA, as cement replacement by weight, was selected [8]. Also it has been approved that 10% RHA content in the sand-cement mix is the optimum for improved structural performance. It would be the optimum content to replace cement with in order to obtain a very compact block [9]. It has been found that using 10% RHA to replace for cement obtains substantial improvements in properties, especially, compressive strength, and chloride resistances [5]. According to the results of splitting tensile test achieved, there is no interference of adding RHA in the splitting tensile strength [2].

The rice husk used was obtained from rice covering removal factory in El-Baradia El-Kanater, Kalubia [3].

2.7. Physical Properties of the used RHA:

RHA can be obtained by burning the rice husk in an open furnace. After the burning process without using any additives the RHA was ground in the Los-Angeles apparatus. After a grinding time of about 7 hours, the particles of RHA can pass from a sieve with an opening size of 0.063 mm. The physical properties of RHA are shown in Table 4 [7].

Table (4): *Physical properties of the used RHA [7]*

Parameter	Value
Specific gravity	2.1
Specific surface area	8790 (cm^2 / g)
% Passing opening sieve 0.063 mm	100%
Color	Whitish gray

2.8. Chemical Properties of RHA:

In the chemical laboratory in the Construction Research Institute (CRI), the chemical composition of the RHA was determined. The chemical composition of RHA is shown in Table 5. The results in this table indicate that Silicon dioxide (SiO2) is the primary component of RHA. The particles of RHA are angular like those of cement [7].

Table (5): *Chemical properties of the used RHA [7]*

Constituent	% Percent by weight
Silicon dioxide Sio_2	78.025
Aluminum oxide Al_2O_3 and Iron oxide FeO	10.500
Calcium oxide CaO	0.086
Sulfur trioxide So_3	0.375
Ignition loss	6.201
Other oxides and impurities	4.813

2.9. Gravel and Sand:

Local natural gravel was supplied from El-Kanater, Kalubia. The gravel has a rounded shape. Its unit weight is 1.677 gm/cm^3, specific gravity is 2.65, and grain size ranges between 10mm and 40mm. Also local natural sand was supplied. Its grain size is less than 5mm and specific gravity is 2.65.

3. Mechanical Tests and Testing Machines:

The concrete was mixed by traditional methods. The mixer used for mixing all the specimens was the ordinary tilting mixer. The mechanical tests done to get the properties required of the specimens are the following.

3.1. Compressive Strength Test:

The recorded compression strength was taken as the average of the strength of three cubes of the tested mixes loaded till failure, at each tested date. The testing machine is shown in Figure 1. The cubes were 15 cm side length. They were filled in three layers; each layer is compacted by the mechanical vibrator shown in Figure 2. The compressive strength is calculated by dividing compressive force at failure by the surface area of the cube (225 cm^2).

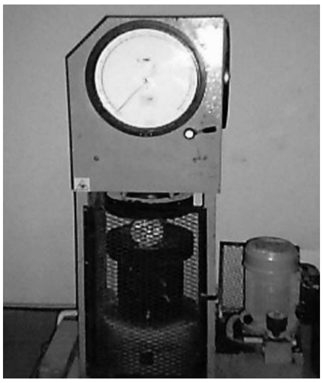


Figure (1):*Compressive strength testing machine*

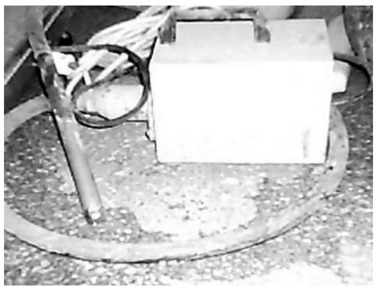
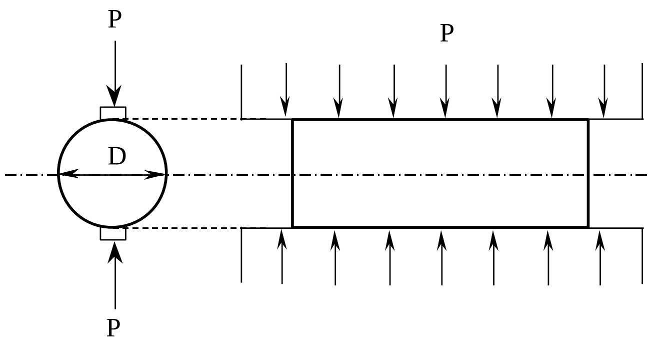


Figure (2): *Mechanical vibrator*

3.2. Tensile Strength Test:

The common method for estimating the tensile strength of concrete was the splitting tensile test using compression test machine. As specified in ASTMC496, the test is carried out on cylindrical specimens of dimensions 10 cm in diameter and 20 cm in height. The cylinders were filled in three layers; each layer is compacted by the mechanical vibrator. The recorded tensile strength was taken as the average of the strength of three cylinders of the tested specimens loaded axially till failure, at each tested date. The tensile strength is calculated by the equation ($2P/\pi DL$), where P is the applied compressive force, D is the cylinder diameter and L is the cylinder length. Figure 3 shows the indirect tensile strength test specimen.



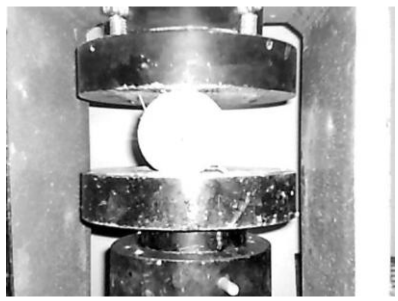


Figure (3): *Splitting tensile test by using compression test machine*

3.3. Average Unit Weight:

The weight of the tested specimens in each mix was used to calculate the average unit weight (the average weight of the specimens per unit volume).

4. Evaluation of Contents of tested Mixes:

Several mixes were tested to obtain the optimum mix with the best mechanical properties of workability, compressive strength, tensile strength, and unit weight. The mixes were upgraded by adding 10% of RHA as a replacement of cement and their properties after 3, 7, 28, 90 and 180 days were found. The following guidelines were considered in all the prepared mixes:

- Ilmenite and serpentine varied depending on the contents of every mix (calculated by the absolute volume equation).
- The cement content was kept constant at 400 kg/m^3, except when adding RHA as a replacement of cement percentage.
- The best ratio used for cement replacement by RHA in the mixes is 10% by cement weight [5], [8], [9].
- The water/cement ratio was kept constant at 0.56 for all mixes [1].
- 1.5% of High performance water-reducing agent (Super-plasticizer - Sikament 163) was added to improve the workability and to achieve water reduction [1].

4.1. Effect of Using Small Ilmenite, Gravel and Sand:

Table 6 shows the contents of the mixes tested to study the effects of using small coarse aggregate of ilmenite and using gravel and sand as a replacement for a part of ilmenite and serpentine respectively compared with the control mix CM and the concrete mix (OC).

Table (6): *Contents of concrete tested mixes and its ratio*

Mix No.	Ilm. (%)	Ser. (%)	Gravel (%)	Sand (%)	Cement Kg/m^3	RHA Kg/m^3	Water Kg/m^3	Sikament Kg/m^3
CM	66.7	33.3	----	----	400	----	224	6
A1	66.7	33.3	----	----	400	----	224	6
B1	44.5	22.2	22.2	11.1	400	----	224	6
C1	33.3	33.3	33.3	----	400	----	224	6
OC	----	----	66.7	33.3	400	----	224	----

- The control mix (mix CM) [the same mix contents proposed by Nadal-2001] was prepared using coarse aggregate of ilmenite size 5-40 mm, ilmenite and Serpentine ratio 2:1, cement content 400 Kg/m^3, water/cement ratio 0.56, and water reducing agent as 1.5% by cement weight [1].
- The mix A1 was prepared as mix CM with the same contents, but the ilmenite size is ranging from 5-10 mm.
- The contents of the mix B1 are the same like mix A1 but after replacing percentage of the ilmenite by gravel and percentage of the serpentine by sand. The final ratio between Ilmenite: Serpentine: Gravel: Sand was 4:2:2:1 respectively.
- In the mix C1, the ratio between Ilmenite: Serpentine: Gravel is 1:1:1 respectively. No sand is used in this mix.
- The ordinary concrete mix (mix OC) was prepared by using conventional gravel and sand with a ratio of 2:1, the same cement content and water/cement ratio was used without adding water-reducing agent.

4.2. Effect of Adding RHA:

The effect of adding RHA, as a replacement for a part of the ordinary Portland cement, was investigated up to age of 180 days. The mixes B2 and C2 are the same like mixes B1 and C1 but a percentage of 10% of the cement was replaced by RHA. Table 7 shows the contents of the mixes tested.

Table (7): Contents of tested mixes (RHA effect)

Mix No.	Ilm. (%)	Ser. (%)	Gravel (%)	Sand (%)	Cement Kg/m^3	RHA Kg/m^3	Water Kg/m^3	Sikament Kg/m^3
B2	44.5	22.2	22.2	11.1	360	40	224	6
C2	33.3	33.3	33.3	----	360	40	224	6

5. Results Discution:

5.1. Results of Using Small Ilmenite, Gravel and Sand:

Aggregates play a key role in high performance concrete. Increases in compressive strength due to small aggregate size have been attributed to reduction in average bond stress resulting from an increase in surface area per unit volume of aggregate. Optimum cement content increases with decreasing maximum nominal size of aggregate [10].

At present research, the available supplied ilmenite ranging from 5 to 10 mm. An effort has made to overcome the disadvantage of small coarse ilmenite aggregate by adding gravel ranging from 10 to 40 mm. Table 8 shows the results obtained for the five mixes tested in compression, tension, and unit weight tests.

Table (8): *Results of tested mixes*

Test / Mix	Compressive str. (Kg/cm^2)			Tensile str. (Kg/cm^2)			Unit weight (gm/cm^3)
	3 days	7 days	28 days	3 days	7 days	28 days	
CM	235	297	342	22.4	26.4	30.8	3.12
A1	112.44	206.89	300.22	13.48	21.48	29.92	2.73
B1	103.33	160	241.11	13.52	19.58	24.28	2.92
C1	175	271.11	332.78	20.76	28.64	32.28	2.79
OC	230	280	333	17.8	24	26	2.19

In compression test, after three days of curing mix CM and mix OC gave approximately the same response but both mix A1 and mix B1 have a compression values close to half percent of them. Mix C1 gave an almost acceptable value between them. After 28 days of curing, mix C1 shows continuous enhancement to be nearly closed to the value of the two mixes OC and CM. The mixes A1 and B1 show also continuous enhancement but still away from the other mixes. Figure 4 shows the compression test results.

In tension test, after three days of curing both the mix A1 and the mix B1 start from a lower value than the other mixes. They contain in the same way but mix A1 gives reasonable values close to mix CM with long period of time testing. The mix B1 stills the lowest value after 28 days of curing. The mix C1 starts from a value nearly close to the value of mix CM. It shows an increase in tension value to be the best quantity after 28 days of curing. Figure 5 shows the tension test results.

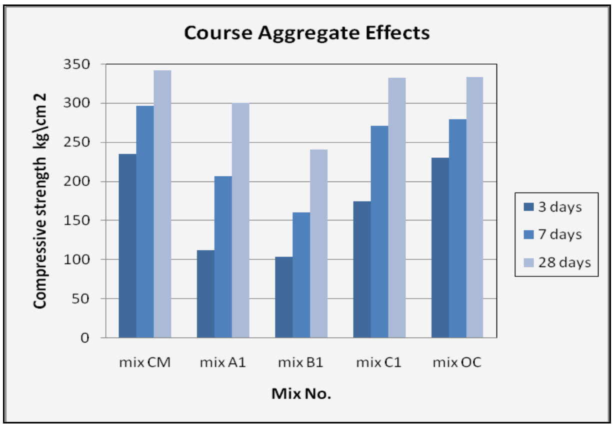


Figure (4): *Results of tested mixes in compression*

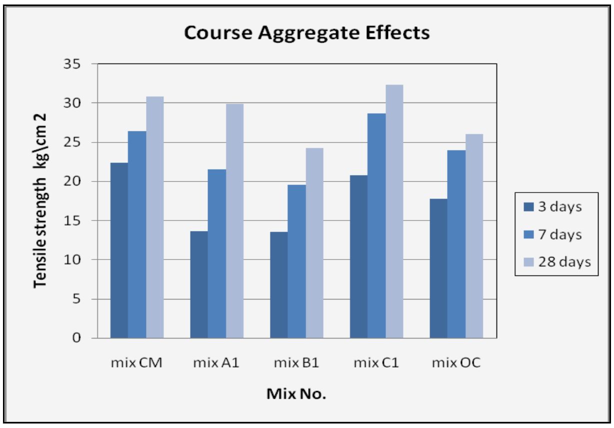


Figure (5): *Results of tested mixes in tension*

During testing of compression and tension, the specimens of mix A1 have almost broken to small pieces (that did not happen in testing of mix CM), because the small ilmenite supplied cause the specimens to give low response and bad workability as observed. Big size of gravel was added to improve the workability, to withstand effect of the small size of ilmenite supplied, and the bond between contents would be more efficient to minimize the disintegration of specimens. That response appears in testing of mix B1 and mix C1 as discussed.

Unit weight of mix B1 (2.92 gm/cm^3) has the closest value to mix CM. But, this mix gave the lowest results in the other responses. Both mix A1 and mix C1 gave almost the same value of unit weight; in between of both unit weight of mix CM (3.12 gm/cm^3) and unit weight of mix OC (2.19 gm/cm^3). So, these mixes with small coarse ilmenite aggregate give a semi-heavy weight concrete mix. Figure 6 shows the unit weight quantities obtained.

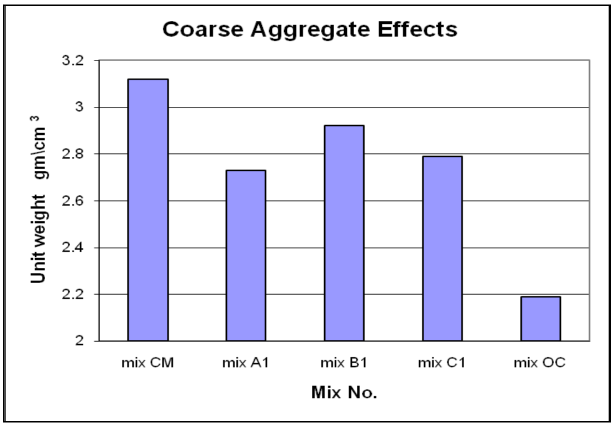


Figure (6): *Unit weight of tested mixes*

It was deduced that mix C1 with ratio between Ilmenite: Serpentine: Gravel as 1:1:1 respectively; showed better responses and would be better than the other mixes to give the best mechanical properties with reasonable unit weight value.

5.2. Results of Adding RHA:

Results of adding 10% RHA as a replacement for a part of cement have discussed. The same two mixes B1 and C1 were prepared with the same contents but a percentage 10% of the cement was replaced by RHA. The new two mixes named B2 and C2; they compared with the mix C1 obtained previously. The rate of strength development of the RHA mortar is slow in early age if it compared with the rate of the ordinary Portland cement mortar but vice versa after long time [7]. So, a long term laboratory-testing program was carried out up to 180 days to investigate and to compare the behavior of the modified mixes. Table 9 shows the results of long time test obtained.

Table (9): *Results of tested mixes (RHA effect)*

Test / Mix	Compressive str. (Kg/cm^2)					Tensile str. (Kg/cm^2)				
	3 days	7 days	28 days	90 days	180 days	3 days	7 days	28 days	90 days	180 days
C1	175	271.11	332.78	333.55	337.78	20.76	28.64	32.28	32.22	33
B2	165	252.22	321.11	324.63	341.63	19.1	25.46	31.84	31.84	32.62
C2	165.78	244.44	332.22	337.3	346.22	18.3	25.46	31.2	31.24	31.84

Test / Mix	Unit weight (gm/cm^3)
C1	2.79
B2	2.89
C2	2.76

In compression test, mix B2 and mix C2; have approximately the same value of compression after three days of curing and lower than mix C1. Test results in 28 days of curing gave a value of compression for both the mix C1 and the mix C2 the same and higher than that of mix B2. The mix C1 with no RHA shows a little change in values from 28 days of curing testing up to 180 days of curing testing. But the two mixes B2 and C2 contained to increase up to 180 days of curing to be higher than mix C1 values. The mix C2 was still higher than mix B2 in compression value. Figure 7 shows the compression test results.

In tension test as shown in Figure 8, the two mixes; mix B2 and mix C2; have nearly the same response. A very small difference indicated in three days of curing testing. When reaching 28 days of curing, the tension value for mix B2 exceeded that of mix C2, but they were lower in values than that of mix C1. When reaching 180 days of curing the three mixes have contained the increase of tension values with almost the same manner and still mix C1 higher than the others along the tension test. The difference between mixes in tension is marginal.

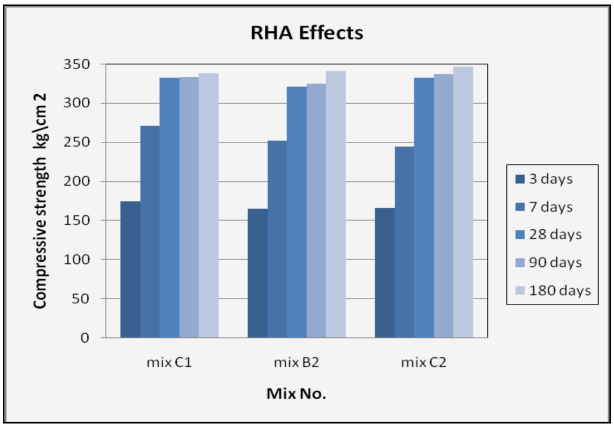


Figure (7): *Results of tested mixes in compression (RHA effect)*

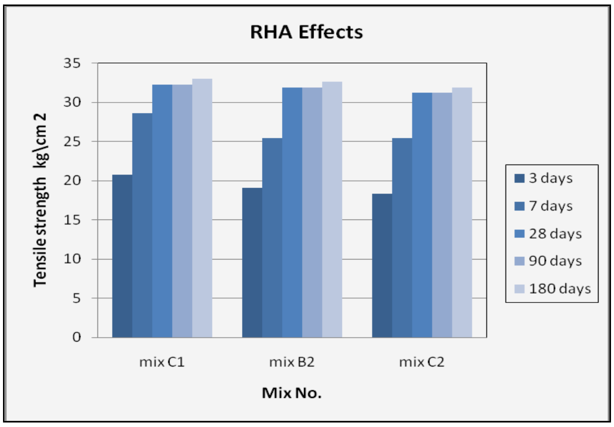


Figure (8): *Results of tested mixes in tension (RHA effect)*

Unit weight of mix C2 (2.76 gm/cm^3) as indicated in Table 9, has a value lower than that of mix B2 (2.89 gm/cm^3) and almost the same as that of mix C1 (2.79 gm/cm^3). Figure 9 shows the Unit weight of tested mixes.

From previous results, it was clear that adding 10% RHA has a positive effect on mixes B2 and C2, as they contained to gain strength concerning the values of compressive strength, especially after 28 days of curing. Mix C2 marginally was better in compressive strength after 180 days. The 10% RHA has no clear effect to enhance the tensile strength or the unit weight of these mixes.

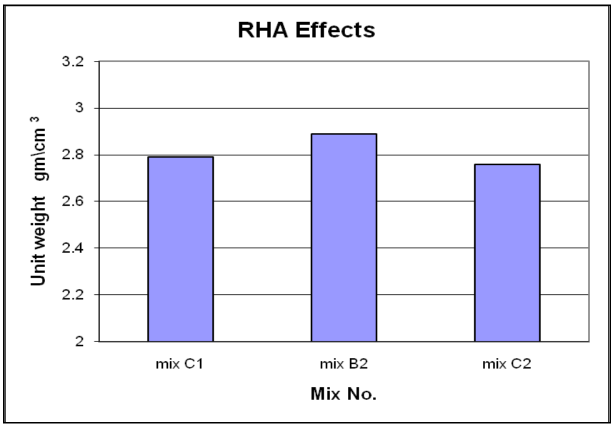


Figure (9): *Unit weight of tested mixes (RHA effect)*

6. Conclusions:

The following general conclusions could be derived from the experimental results previously obtained and discussed:

- The small ilmenite aggregate (5-10 mm) in addition to gravel (10-40 mm), serpentine aggregate (less than 5 mm), and without using sand can be used for the production of semi-heavy weight concrete with acceptable mechanical properties and reasonable unit weight value.

- The preparation of this mix by adding 10% RHA as a replacement for a part of the ordinary Portland cement gave the best result of compressive strength test for a long period of time up to 180 days of curing.
- The addition of 10% RHA has no clear effects to enhance the tensile strength or the unit weight of the tested mixes.

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