Fresh and Hardened Properties of Lightweight Self Compacting Concrete Containing Attapulgite

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ABSTRACT

The main objectives of this study were investigating the possibility of producing lightweight self - Compacting concrete (LWSCC) by using artificial coarse lightweight aggregate manufactured by burning locally available Attapulgite clay, estimating the optimum dosage of high reactivity Attapulgite (HRA) and studying its effects on fresh and hardened properties of LWSCC when using it as a partial replacement by weight of cement. Tests results showed that, It is possible to produce (LWSCC) by using Attapulgite as artificial coarse (LWA) and (HRA). The optimum content for (HRA) used in this study was 10 %, the percentages of increment in compressive strength and splitting tensile strength with 10% (HRA) relative to reference mix were (10.0%, 12.1%, 11.1% and 12.4%) and (12.0%, 18.2%, 16.6% and 16.2%) for 7, 28, 56 and 90 days respectively. The values of the calculated equilibrium density ranged between (1788 and 1829) kg/m^3

Keywords: Lightweight self-compacting concrete, High reactivity Attapulgite

INTRODUCTION

Structural Lightweight aggregate concrete (SLWC) is a multipurpose and important material in modern construction. It has been used in many applications such as multi-story building frames and floors, bridges, off shore oil platforms, and pre stressed or precast structural elements of all types [1]. ASTM C 330-04[1] guide for SLWC specifies SLWC as those having a 28 day compressive strength and splitting tensile strength in excess of 17 MPa and 2.1MPa respectively and calculated equilibrium density not exceeding 1840 kg/m^3. In recent years the need to develop concrete performance in strength, durability and flow ability with low cost of casting and maintenance leads to innovate a revolutionary type of concrete called Self-Compacting Concrete SCC. SCC differs with conventional concrete in that it compacts under its self-weight without any internal or external compaction, so it can spread and fill every corner of the formwork, even with using very congested reinforcement in concrete members and flows without segregation [2]. (Ozawa et al.)[3] have defined SCC as a highly flow-able concrete that should meet the following demands:

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1-**Flow-ability**: SCC should flow under its own weight and fill all parts of formwork without any external vibration.

2- **Passing ability**: SCC should pass through congested reinforcing steel bars.

3-**Segregation resistance:** SCC should remain homogenous without any segregation or separation of its large ingredients (aggregates or/and fibers).

Although the mentioned advantages, use of SCC is in sometimes limited because it has high self-weight in comparison with other construction materials [4]. Accordingly, combined of SCC with lightweight aggregate to produce Lightweight Self-Compacting Concrete (LWSCC) can seriously increase the applications and advantages of SCC [5].

LWSCC needs no external vibration, and can spread into place, fill the formwork with sophisticated geometry and surrounding reinforcement without any segregation or bleeding. LWSCC efficiently reduces the dead loads of the structure and the in situ noise level and can be used for maintenance and repairs of damaged concrete structure [6].

The Aims of the Research

The main aims of this study are:

1- Investigating the possibility of producing lightweight self - Compacting concrete (LWSCC) by using artificial coarse lightweight aggregate manufactured by burning locally available Attapulgite clay.

2- Estimating the optimum dosage of high reactivity Attapulgite (HRA) and studying its effects on fresh and hardened properties of LWSCC when using it as a partial replacement by weight of cement.

Experimental work

Materials

Cement

Al Mass Ordinary Portland Cement (OPC) manufactured in Iraq was used in this research. Tables (1) and (2) show the results of the chemical analysis and physical properties of the cement used respectively. Results demonstrated that the used cement is identified with the Iraqi Specification No.5/1984[7].

Fine Aggregate (Sand)

Ekhaider sand as fine aggregate with maximum size 4.75 mm was used in all concrete mixes. Table (3) contained the sieve analysis for the sand used and it indicates that the sand falls within zone two according to the requirement of the Iraqi Specification No. 45/1984[8].The chemical and physical properties of natural sand are shown in Table (4).

Table (1) chemical composition and main compounds of cement *

Oxide composition	% by weight	Limits of Iraqi specification No.5 / 1984
SiO_2	19.6	------------------
Fe_2O_3	3.52	------------------
Al_2O_3	4.65	------------------
CaO	61.56	------------------
MgO	2.77	5.0(max)
SO_3	2.71	2.8(max)
Loss on ignition	1.65	4.0(max)
Insoluble residue	0.8	1.5(max)
Lime saturation factor	0.95	0.66-1.02
Main compounds(Bogue's equation)%by weight of cement		
C_3S	57.65	-------------------
C_2S	12.7	-------------------
C_3A	6.37	More than 5%
C_4AF	10.71	--------------------

***Chemical test was performed by the State Company of Geological Survey and Mining**

Table (2) Physical properties of cement

Physical properties	Test results	Limits of Iraqi Specification No.5/1984
Specific surface area (Blaine method), m^2/kg	240	230 (min)
Setting time (Vicate's method) Initial setting, hrs:min Final setting, hrs:min	 1:45 5:30	 00:45 (min) 10:00 (max)
Compressive strength, MPa 3 days 7 days	 19.6 28.6	 15.00 (min) 23.00 (min)
Soundness using Autoclave expansion, %	0.4	0.8 (max)

Coarse Aggregate

Attapulgite clays from Tar AL-Najaf (Injana) region in AL- Najaf governorate are the raw material for the production of artificial lightweight Attapulgite aggregate. The procedure of Production process was developed by (Kais et.al) [9] and can brief it as below:

1-Attapulgite rocks were crushed to give a maximum aggregate size of about 12.5mm.

2-The crushed aggregate was sieved on a standard sieve series compatible with ASTM C330-04[1] as shown in Table (5). The series was made up from, 19, 12.5, 9.5, 4.75 and 2.36 mm sieves. Table (5) and (6) shows the Attapulgite selected grading sample used for mixing and some properties of Attapulgite LWA respectively.

3-The crushed rocks burn by using oven with burning temperature at 1100ºC, the rate of temperature increasing is 5˚C/min. the sample stills for 1/2hour as soaking time in this temperature.

Table (3) Sieve analysis of sand

Sieve size (mm)	Cumulative passing%	Cumulative passing % Limits of Iraqi specification No. 45/1984, zone (2)
4.75	99.8	90-100
2.36	84.4	75-100
1.18	65.6	55-90
0.60	41.8	35-59
0.30	11	8-30
0.15	2.2	0-10

Water

For all concrete mixes tap water is used for mixing and curing of samples

Chemical Admixture

A high performance concrete superplasticizer (SP) based on modified polycarboxylic ether Glinume 51 is used in this research as chemical admixture, and it complies with ASTM C494-05[10] types A and F.

Mineral Admixtures

High Reactivity Attapulgite (HRA)

Attapulgite clays from Tar AL-Najaf (Injana) region in AL- Najaf governorate was used to produce high reactivity Attapulgite. The raw material of Attapulgite contains rocks so it needs to grind by storming to convert it to high fineness powder. The suitable calcinations temperature was investigated by (Kais et al.) [11] and they concluded that the optimum firing temperature was 750 ˚C and the rate of temperature rising was (4˚C/ min), and the sample stills for 1/2 hour as a soaking time when the oven temperature reaches to the required degree. Table (7) shows chemical analysis of (HRA). Table (8) indicated that (HRA) conformed to the chemical requirements of the ASTM C618–05[10] Class N pozzolana. The strength activity indexes (S.A.I) of (HRA) were 101.4 and 108.8 at 7 and 28 days respectively, and they conformed to requirements of ASTM C618–05[12]which is specified S.A.I for both 7 and 28 days to be not less than 75%.

Table (4) Chemical and Physical Properties of Sand

Property	Test results	Limit of Iraqi Specification No .45/1984
Specific gravity.	2.6	---------------
Absorption, %	2.97	---------------
Dry loose unit weight, kg/m³	1587	---------------
Sulphate content as SO_3,%	0.07	0.5(max)
Material finer than 75µm, %	2.6	5.0(max)
Fineness modulus	2.95	---------------

Table (5) Sieve Analysis of Coarse Lightweight Aggregate

Sieve size (mm)	Cumulative passing %ASTMC330-04	Cumulative passing%	Cumulative %Retained
19	100	100	0
12.5	90-100	95	5
9.5	40-80	55	40
4.75	0-20	10	45
2.36	0-10	0	10

Table (6) Some Properties of Attapulgite Aggregate

Properties	Specifications	Results	Limits
Absorption, %	ASTM C127-04[13]	27.9	5-30
Bulk Density(dry loose),kg/m³	ASTM C330-04	810	880(max)
Specific gravity(SSD)	ASTM C127-04	1.92	--------
Specific gravity(OD)	ASTM C127-04	1.46	2.6(max)

Table (7) Chemical and physical analysis of (HRA) *

Oxide composition	Oxide content %
SiO_2	60.48
Al_2O_3	13. 95
Fe_2O_3	6.07
CaO	8.46
MgO	5.92
Na_2O	1.2
SO_3	0.45
K_2O	2.47
L.O.I	0.1
Physical properties	

Specific Surface Area m^2/kg	2010
Specific Gravity	2.2
Density kg/m^3	2193

***Chemical test was performed by the State Company of Geological Survey and Mining**

Table (8) Chemical requirements of (HRA) according to ASTM C618-05[12]

Oxide Composition	Attapulgite %	Pozzolan Class N
$SiO_2 + Al_2O_3 + Fe_2O_3$	80.5	70% Min.
SO_3	0.45	4 % Max.
Loss on Ignition	0.1	10% Max

Design of Concrete Mixes

The mix design method of SCC used in this research is according to EFNARC 2005[14] to obtain target slump flow of 730 ± 20 mm, then the proportions of materials are modified to satisfy both self-compatibility and requirements of SLWC, so multi trail mixes were carried out for this purpose. Six mixes are used throughout this research. For all mixes, powder content, fine aggregate content, coarse aggregate content and water/powder ratio (w/p) (powder = cement + (HRA)) were 550 kg/m^3, 624 kg/m^3, 655 kg/m^3, and 0.4 respectively. The air volume assumed to be 2% from total mix volume [14]. The details of mixes used throughout this research are shown in Table (9).

Table (9) the details of the mixes by weight (kg/m^3)

Mix designation	Ref. mix	Mix2	Mix3	Mix4	Mix5	Mix6
%Mineral admixture used	0%	5% (HRA)	7.5% (HRA)	10% (HRA)	12.5% (HRA)	15% (HRA)
Cement kg/m^3	550	522.5	508.75	495	481.25	467.5
H.R.A kg/m3	—	27.5	41.25	55	68.75	82.5
Sand kg/m^3	624	624	624	624	624	624
Coarse Aggregate (Attapulgite) kg/m^3	655	655	655	655	655	655
water litre/m^3 w/p=0.4	220	220	220	220	220	220
SP litre /100 kg of powder	0.9	1	1.1	1.3	1.4	1.5

Mixing of Concrete

The aggregates had to be soaked for about 48 hours and then dried to SSD conditions. In this study the method of [15] was used in the mixing LWSCC. This method includes the following steps:

1-To ensure full dissolution all SP was added to the water pail and mixed.

2-Cement and mineral admixtures must to be mixed well to guarantee high homogeneity before adding them to the mixer.

3-Next the coarse aggregate with 2/3 of the mixing water were added to the mixer and mixed for a few revolutions.

4-The mixer was then stopped to add sand, cement and mineral admixtures mixture, and the remaining water with SP were added respectively.

5-The mixer was rotated for 3 minutes, rested covered for 3 minutes, and then spun covered for 2 more minutes.

Testing of LWSCC Rheological Properties

The tests of self-compatibility (Slump flow, T500 mm slump flow, V-funnel, J-ring and L-box) were performed on the fresh LWSCC for each mix. Test methods for workability of SCC were carried out according to [16]

Testing of Hardened Concrete

Compressive Strength

The compressive strength test is carried out on 100 mm cubes according to BS 1881, Part 116, 1989 [17]. The specimens are tested at ages of 7, 28, 56 and 90 days and at each age the average of three specimens were adopted.

Splitting Tensile Strength

The splitting tensile strength test is performed according to ASTM C 496/C - 04 [18], 100×200 mm cylindrical concrete specimens are used. The specimens are tested at age of 7, 28, 56 and 90 days and in each age the average of three specimens has been adopted.

Oven-Dry Density

This test was conducted according to ASTM C 567-05[19] on 100x200 cylinders.

Calculated Equilibrium Density

This test was carried out according to ASTM C 567-05[19], to calculate the equilibrium density by using the oven-dry density determined in accordance with **3-5-3** and formula below:
Calculated equilibrium density (kg/m^3) = Oven dry density + 50 kg/m^3

Equilibrium (Air-Drying) Density at 90 days

This test was conducted according to ASTM C 567-05 [19]. Cylindrical specimens of (100x200) mm were used in this test. According to ACI 213-03 [20] and [19] equilibrium density for most structural members and ambient conditions can be supposed to be achieved at about 90 days air drying.

Results of LWSCC Fresh Properties

Slump flow

The slump flow of mixes in this study was a function of superplastisizer (SP) dosage, because using of constant dosage of (SP) not easy. A constant dosage of SP making one mixture not spread while leading to segregate another mixture. Instead of that LWSCC mixes were designed to get constant slump flow as a target value which it was 730±20 mm. [12] allows ±80mm as a deviation value from target slump flow value. The SP dosages and result of slump flow test for all mixes are included in Figure (1) and (2) respectively. For LWSCC mixes with (HRA) the dosage of (SP) increased directly with increasing replacement percentage of (HRA) by weight of cement .The reason of that is the (HRA) has a plate- like particle with high surface area, so it slides over each other very difficultly because of high inter-particles friction, while high surface area increases water requirement because of high water absorption, Figure (3) shows morphology of (HRA) particles, so it needs more SP dosage to get same slump flow of Ref. mix (by using cement only).

T500 mm

Figure (4) contains the results of T500 mm and shows clearly that all results are within the acceptance criteria of [14]. Figure (4) shows also that LWSCC mixes contained (HRA) had higher T500 value than Ref. mix, and T500 value increased directly with increasing replacement percentage of (HRA) by weight of cement because (HRA) have lower density than cement, so adding them to concrete as partially replacement percentage by weight of cement led to increase paste volume accordingly cohesiveness and viscosity of paste will increase [21].

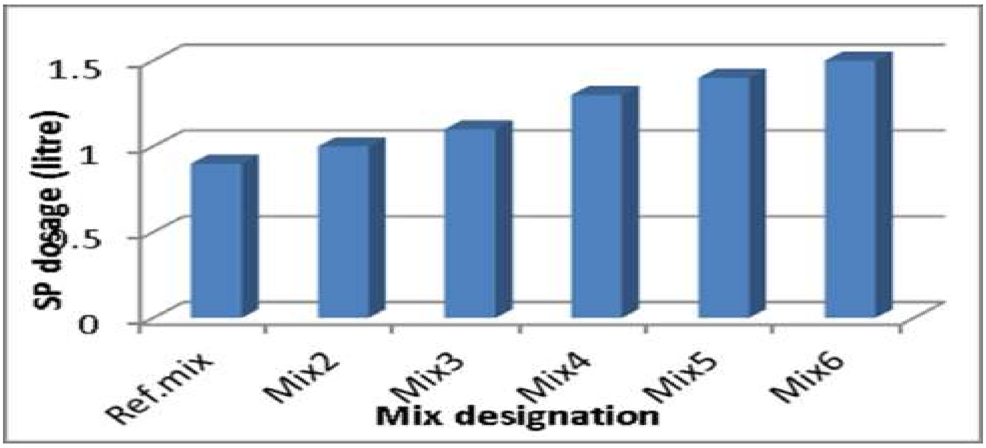


Figure (1) Superplastisizer dosage used for LWSCC mix

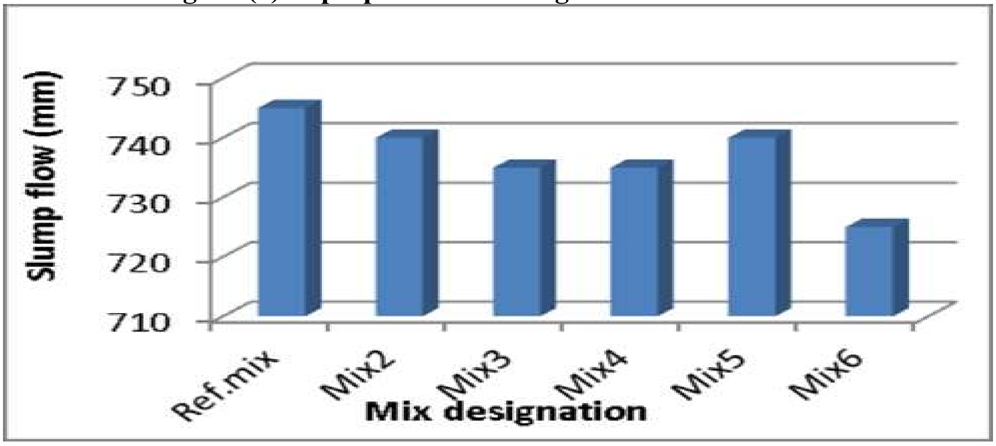


Figure (2) Slump flow results for LWSCC mixes

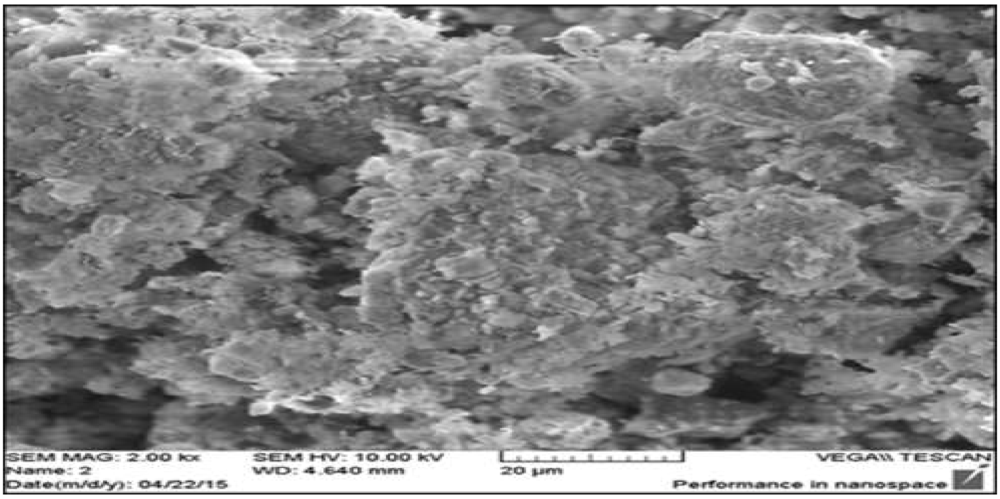


Figure (3) Scanning electron microscope micrograph of (HRA) particles at 2000X captured in Nano Technology Centre in University of Technology, Baghdad.

V Funnel

Figure (5) shows that all results of V funnel time are within the acceptance criteria of [16]. Figure (5) shows also that using of (HRA) increased V Funnel time, because LWSCC containing (HRA) had higher viscosity than (Ref. mix) for the same reason mentioned in previous section.

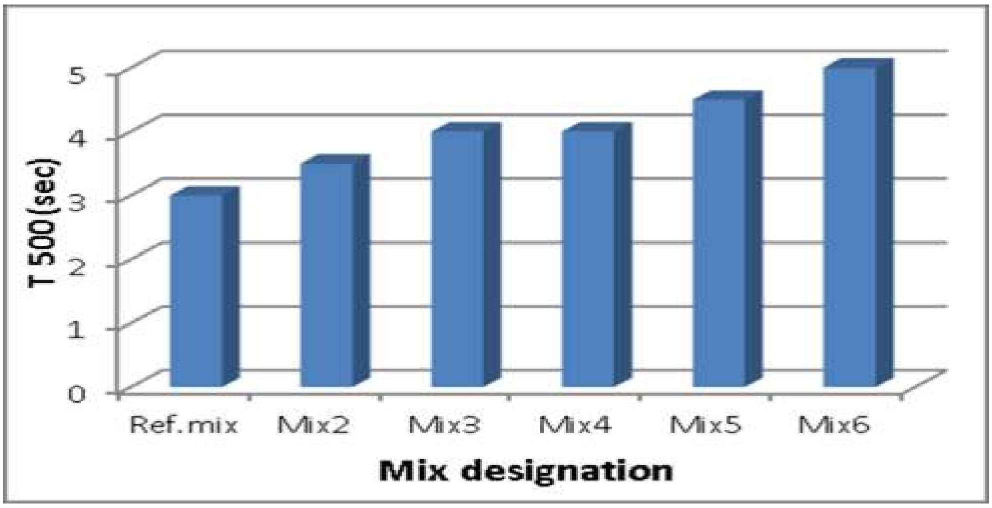


Figure (4) T500 results for LWSCC mixes

J Ring

Figure (6) shows that, all the results of J Ring are within the acceptance range of ref. [16]. So, they have good passing ability. Figure (6) shows also that using of (HRA) increased J Ring values, and the highest J Ring value was 10 mm recorded with mix 6 (15%HRA) replacement percentage by weight of cement, because it had the highest viscosity and lowest flow ability due to increasing paste volume.

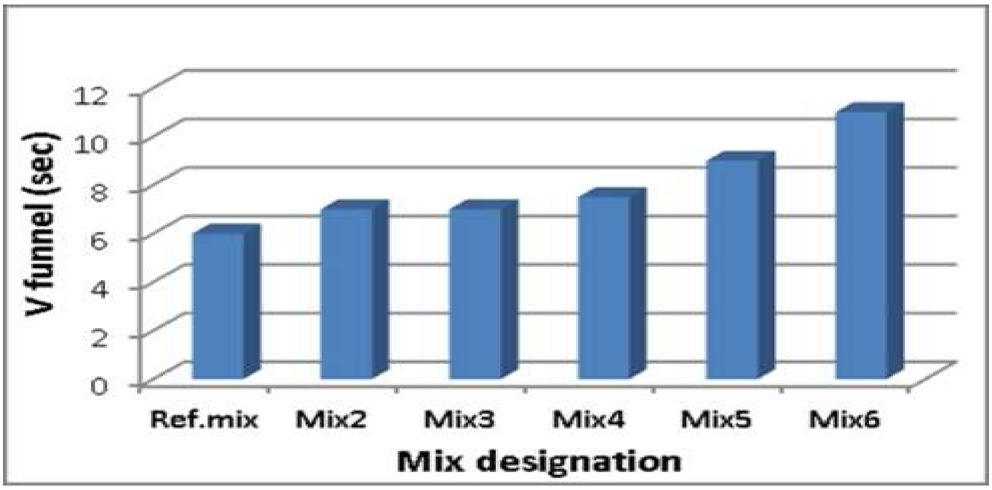


Figure (5) V Funnel results for all LWSCC mix

L Box

Figure (7) shows that, all results of L Box are within the acceptance criteria of [16]. Figure (7) shows that using of (HRA) reduced H_2/H_1 values, the lowest H_2/H_1 was 0.8 noticed with using 15% of (HRA), because it had the lowest flow ability and the highest viscosity

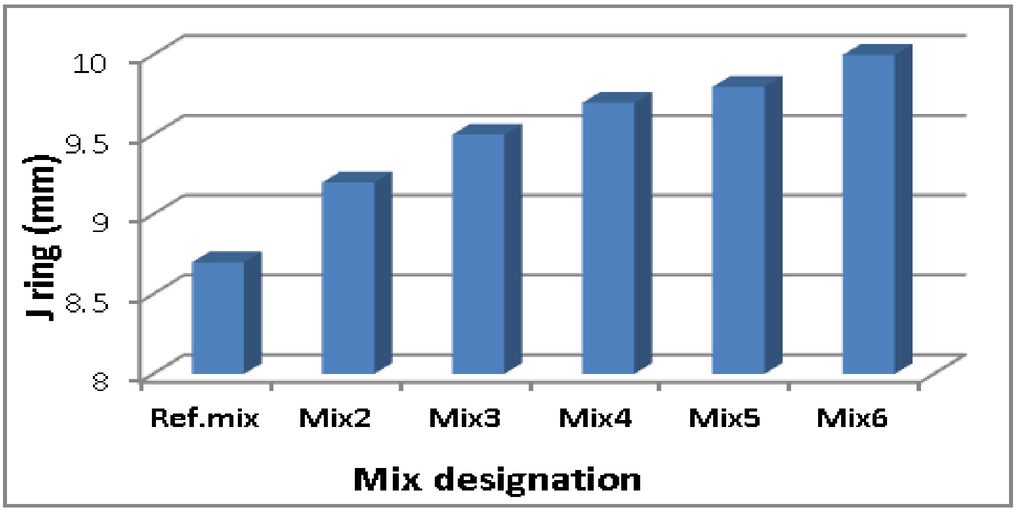


Figure (6) J Ring results for all LWSCC mix.

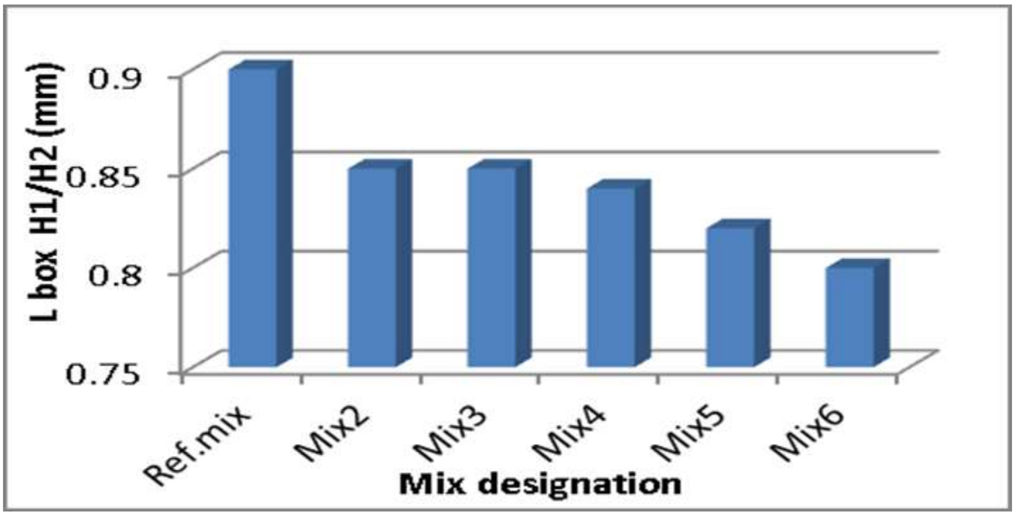


Figure (7) L box H_1/H_2 for all LWSCC mix.

Results of LWSCC Hardened Properties

Equivalent Compressive Strength of Cylinder

Khayat and Schutter [22] suggested with depending on studying the results of many research about SCC that conversion factor of cubic specimen compressive strength to equivalent compressive strength of cylinder to be 0.9 with standard deviation of 0.07. This factor is higher than that of normal vibrated concrete. Khayat and Schutter attributed that to denser microstructure of SCC, improved aggregate bonding which is leads to distribute stress uniformly during compression and lower aggregate content in SCC compared with normal concrete leads to make wall effect less significant in SCC. Depending on that the conversion factor for multi shapes and sizes specimen will be [22]:

$$f_{ccub,100} \approx f_{ccub,120} \approx f_{ccub,150}$$

$$f_{ccyl,100} \approx f_{ccyl,110} \approx f_{ccyl,150}(h/d = 2)$$

$$f_{ccyl,150,eq} \approx 0.9 \times f_{ccub,150}$$

Where: $f_{ccyl,eq}$ and f_{ccub} are strength of equivalent cylinder and strength of cube respectively.
Figure (8) shows the compressive strength results for equivalent cylinder specimen.

Compressive Strength

Compressive strength of SLWC is important to predict the specified properties of concrete mixes. The compressive strength results for all mixes are included in Figure (8) which is showed clearly that the results of all mixes at 28 days are within acceptance limits of ASTM C 330 [1], which is specified the minimum compressive strength for sand/lightweight aggregate with calculated equilibrium density of 1840 kg/m³ to be at least 28 MPa at 28 days. From Figure (8) it is clearly to conclude that the compressive strength increases by using (HRA) as a partial replacement percentage by weight of cement for all mixes at relative to (Ref.mix) except mix 6 which is contains 15% (HRA) whereas the compressive strength becomes lower than Ref. mix. The reason beyond that is the clinker dilution effect, which is resulting from replacing a part of cement by the comparable quantity of mineral admixture. Dilution effect reacts contrary with physical and chemical effects of mineral admixtures [23]. The results shows that (HRA) improved strength at all ages due to its high pozzolanic reactivity, and this agrees with (Caldarone et,al.) [24] who reported that using of high chemical activity calcined pozzolana can increase early age strengths, even when used as a replacement for cement, either by an equal volume or by mass. Figure (8) shows also that the highest increment in compressive strength, was obtained when: the replacement percentage of (HRA) was 10% by weight of cement. The percentages of increment were (10.05%, 12.2%, 11.15% and 12.3%) for 7, 28, 56 and 90 days relative to Ref.mix respectively.

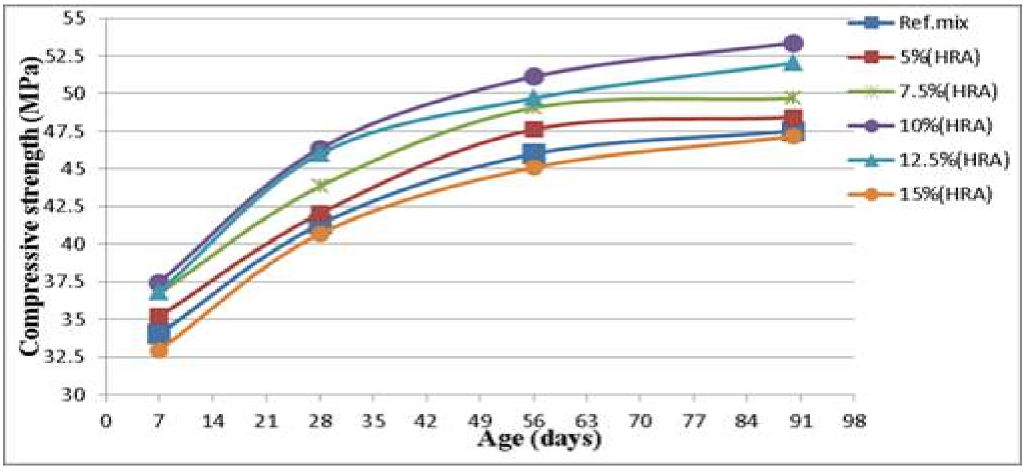
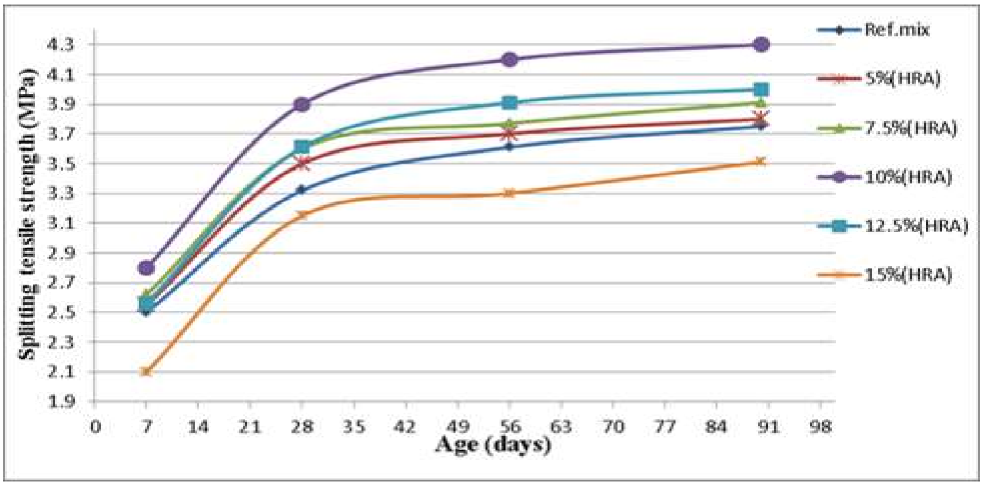


Figure (8) Compressive strength results for equivalent cylinder specimen.

Splitting Tensile Strength

Figure (9) shows the results of splitting tensile strength for all LWSCC mixes, and it shows that all results are within the acceptance limits of [1], which it stipulated for SLWC with calculated equilibrium density of 1840 kg/m³ the splitting tensile strength to be not less than 2.3 MPa at 28 days.

Figure (9) shows that the (mix2) to (mix5) which they contained 5% to 12.5% (HRA) as a partially replacement by cement weight have higher early and late age splitting tensile strength relative to (Ref.mix), because of its high pozzolanic reactivity and good particles packing. Figure (9) shows also that (mix 4) which it contained 10% (HRA) had the highest increment in splitting tensile strength relative to (Ref.mix) and the percentages of increment were (8.8%, 17.46%, 16.34% and 14.66%) at 7, 28, 56 and 90 days relative to (Ref.mix) respectively, while (mix 6) shows lower splitting tensile strength than (Ref.mix) due to a clinker dilution effect.



Figure(9) Splitting tensile strength results.

Unit Weight

Equilibrium density sometimes referred to as air dry density is used to specify and design of structural LWC. According to [19] Equilibrium density is defined as LWC density after it exposure to relative humidity of 50 ± 5 % at temperature of 23 ± 2 °C for sufficient time to obtain lower weight loss ,because of long time to measure it [19] suggest a method to calculate approximate equilibrium by using oven dry density. ACI 213R-03 [20] limits equilibrium density between 1680 to 1920 kg/m^3 for most lightweight concrete. LWC density decreases when it dries until it reach to equilibrium with its ambient, and can be approached it at about 90 days air drying for most members and ambient condition, but it takes about 180 days for high strength LWC [19]. Figure (10) below includes the results of LWSCC mixes densities, and it shows that all results are within the requirement of [1] and [20]. Figure (10) shows for oven dry density that the density reduces with using of (HRA) and this reduction proportioned directly with their content, because the test carried out at 24 hours (directly after demolded) according to [19], and at this time no significant cement hydration is occurred, so the oven dry density of LWSCC depended on the density of its ingredients, when (HRA) used in this research have a lower density than cement, so the reduction increase with increasing of replacement percentage of (HRA) by weight of cement. The lowest oven dry density was noticed when cement was replaced with 15% (HRA) (mix 6). On the contrary, the equilibrium (air dry) density showed an increment when (HRA) was used and the increment depended on the replacement percentage which it gave the best pozzolanic reactivity with $Ca(OH)_2$ resulting from cement hydration, because the pozzolanic reaction leads to an increase in cement gel (the cementation compounds), it also leads to condensation of transition zone and the concrete matrix through the processes of pore-size and grain-size refinement [25]. The highest increment in equilibrium (air dry) density is noticed when cement was replaced by 10% (HRA) because at this replacement percentage the highest pozzolanic activity occurred, so it consumed more $Ca(OH)_2$ to produce more cement gel ,thereby the voids between discrete cement and ITZ microcracks was reduced.

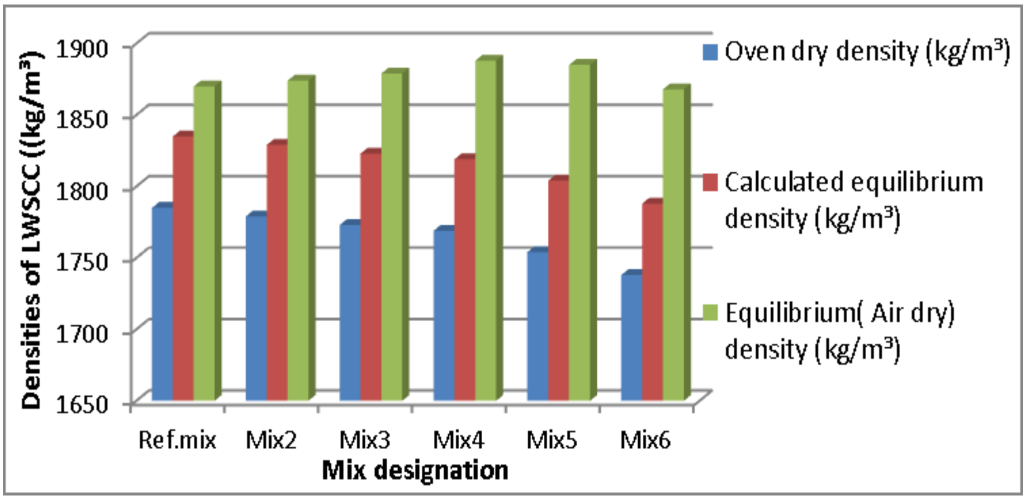


Figure (10) Oven Dry, Calculated and (Air Dry) Equilibrium Densities Results of LWSCC.

CONCLUSIONS

1- It is possible to produce lightweight self- compacting concrete (LWSCC) by using locally available Attapulgite as artificial coarse lightweight aggregate and mineral admixtures (HRA) within the acceptance criteria of EFNARC 2002 for SCC workability and within the requirements of ASTM C 330-04 for structural LWAC.

2- For LWSCC mixes contained (HRA) the dosage of (SP) increased directly with increasing replacement percentage of (HRA) by weight of cement to get same slump flow target value. The percentages of increment were (11.1%, 22.2%, 44.44%, 55.55% and 66.6%) for 5%, 7.5%, 10%, 12.5 and 15% replacement percentage of (HRA) by weight of cement relative to (Ref.mix) respectively

3-Using of (HRA) increased T500, J ring, V funnel time and segregation resistance, but reduce H_2/H_1 ratio of L box. T500 mm values ranged between (3.5 sec and 5 sec), the time of the concrete to pass through the V funnel ranged between (7 sec and 11sec) J ring values ranged between (9.2 and 10) and H_2/H_1 ratio of L box ranged between (0.85 and 0.8).

4- Using of (HRA) as a replacement percentage by weight of cement of 5%, 7.5%, 10% and 12.5% increased compressive strength and splitting tensile strength elasticity at all ages. The optimum content for (HRA) used in this study was 10 %, the percentages of increment in compressive strength and splitting tensile strength when cement was replaced with 10% (HRA) relative to (Ref.mix) were (10.05%, 12.2%, 11.15% and 12.3%) and (8.8%, 17.46%, 16.34% and 14.66%) for 7, 28, 56 and 90 days respectively.

5- The values of the calculated equilibrium density ranged between (1788 and 1829) kg/m^3. The values of the equilibrium (air dry) density ranged between (1868 and 1888) kg/m^3.

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