Engineering and Technology Journal *Vol. 37, Part C, No. 1, 2019*

DOI: http://dx.doi.org/10.30684/etj.37.1C.29

Fourth International Scientific Conference on Environment and Sustainable Development (4th ISCESD), Egypt, Cairo, 24-28 November 2018

Waleed A. Razaq
University of Technology, Baghdad, Iraq

Qais J.Freih
University of Technology, Baghdad, Iraq

Shubbar J. Al Obaidey
University of Technology, Baghdad, Iraq

Received on: 02/10/2018
Accepted on: 10/01/2019
Published online: 25/04/2019

The Effect of Using Multi Types of Mineral Admixtures on Some Properties of Lightweight Self-Compacting Concrete

Abstract *The main objective of this research was studying the effects of using multi types of mineral admixtures as high reactivity Attapulgite (HRA), high reactivity Metakaolin (HRM) and fly ash (FA) on some rheological and mechanical properties of lightweight self - Compacting concrete (LWSCC), when were used as a partially replacement by weight of cement. The results showed that using of (HRA) and (HRM) increased the superplasticizer (SP) dosage, while (FA) with spherical particles reduced the (SP) dosage relative to reference mix (Ref. mix) to get the same slump flow target value. The optimum content for (HRA) used in this study was 10 %, and the percentages of increment in compressive strength and splitting tensile strength relative to (Ref.mix) were (10.0%, 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. Using of (FA) reduced early age strength, but long term strength increased with (FA) content increases. LWSCC mix contained 10% (HRM) showed a better mechanical properties than both (HRA) and (FA) LWSCC mixes, and the percentages of increment when cement was replaced with 10 % (HRM) relative to (Ref.mix) were (15.0%, 17.6%, 13.9% and 15.7%) and (16.0%, 24.2%, 22.2% and 21.6%) at 7, 28, 56, and 90 days for compressive strength and splitting tensile strength respectively.*

Keywords: *Lightweight self-compacting concrete, High reactivity Attapulgite, High reactivity Metakaolin, Fly ash.*

How to cite this article: W.A. Razaq, Q.J.Freih and S.J. Al Obaidey, “The Effect of Using Multi Types of Mineral Admixtures on Some Properties of Lightweight Self-Compacting Concrete,” *Engineering and Technology Journal*, Vol. 37, Part C, No. 1, pp. 186-194, 2019.

1. Introduction

Lightweight self-Compacting concrete (LWSCC) is one of the latest building material which combines the advantages of lightweight concrete (LWC) and self-consolidating concrete (SCC). Using of LWC in SCC reduces the density of concrete and providing self-consolidating properties [1]. LWSCC provides high-quality structural members with reducing labor. Also, LWSCC can also impact the construction cost by reducing the total dead load of the structural members up to 25%, and needing less safekeeping than a similar steel structure [2]. LWSCC can fulfill better strength and durability with excellent workability [3], and its mechanical properties are in general either emulative or better than those in conventional lightweight concrete LWC and SCC [4]. The Aim of the Research is studying the effects of using multi types of mineral admixtures as (HRA), (FA) and (HRM) on some rheological and mechanical properties of LWSCC when were used as a partial replacement by weight of cement.

2. Experimental work

I. Materials

a. Cement

Tables 1 and 2 show the results of the chemical analysis and physical properties of the Ordinary Portland Cement used in this research respectively. Results declared that the used cement is compatible with the Iraqi Specification No.5/1984[5].

b. Fine Aggregate (Sand)

Sand falls within zone two according to the requirement of the Iraqi Specification No. 45/1984[6] was used as fine aggregate in all concrete mixes. Table 3 contained the sieve analysis and Table 4 contained the chemical and physical properties of natural sand used.

Table1: 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	--------------------

Table 2: Physical properties of cement

Physical properties	Test results	Limits of Iraqi Specification No.5/1984
Specific surface area (Blaine method), m²/kg	240	230 (min)
Setting time (Vicate's method)		
Initial setting, hrs:min	1:45	00:45 (min)
Final setting, hrs:min	5:30	10:00 (max)
Compressive strength, (MPa)		
3 days	19.6	15.00 (min)
7 days	28.6	23.00 (min)
Soundness using Autoclave expansion, %	0.4	0.8 (max)

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

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	---------------

c. Coarse Aggregate

Artificial lightweight Attapulgite aggregate manufactured according to the process was suggested by [7] by burning Attapulgite clays from Tar AL-Najaf (Injana) region in AL-Najaf governorate was used as a lightweight structural aggregate (SLWA). Table 5 and Table 6 show sieve analysis and some properties of Attapulgite lightweight aggregate respectively.

Table 5: Sieve Analysis of Coarse Lightweight Aggregate

Sieve size (mm)	Cumulative Passing (%) ASTM C330-04[8]	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

d. Water

Tap water was used to mix and cure the concrete samples.

e. Chemical Admixture

Glinume 51 complies with ASTM C494-05[9] types A and F was used as a high-performance concrete superplasticizer (SP).

f. Mineral Admixtures

1-High Reactivity Attapulgite (HRA)

HRA was produced by grinding and firing of Attapulgite clays according to the procedure developed by [11]. Table 7 shows chemical analysis and some physical properties of (HRA). Table 8 indicated that (HRA) conformed to both chemical and strength activity indexes (S.A.I) requirements of the ASTM C618–05[12] Class N pozzolana

2. High Reactivity Metakaolin (HRM)

Locally available kaolin is the raw material of (HRM). (HRM) was produced when kaolin was ground by storming to convert it to fine grain size, then it is burned at 700 C° for one hour as a soaking time, next left to cool down [13]. The chemical analysis and some Physical properties of (HRM) were shown in Table 7. Table) indicated that (HRA) conformed to both chemical and strength activity indexes (S.A.I) requirements of [12] Class N pozzolana

3. Fly Ash (FA)

Hard coal (FA) from the power station of Iskenderun in Turkey was used in this study. The chemical analysis and some Physical properties of (FA) were shown in Table 7.

Table 6: Some Properties of Attapulgite Aggregate

Propertiess	Specifications	Results	Limits
Absorption %	ASTM C127-04[10]	27.9	5-30
Bulk Density(dry loose),kg/m³	ASTM C330-04[8]	810	880(max)
Specific gravity(SSD)	ASTM C127-04[10]	1.92	--------
Specific gravity(OD)	ASTM C127-04[10]	1.46	2.6(max)

Table 7: Chemical and physical analysis of (HRA, HRM and FA)

Oxide composition	Oxide content 0f (HRA) %	Oxide content of (HRM) %	Oxide content of (FA) %
SiO_2	60.48	54.88	65.65
Al_2O_3	13. 95	36.29	17.69
Fe_2O_3	6.07	1.4	5.98
CaO	8.46	0.38	0.98
MgO	5.92	0.21	0.72
Na_2O	1.2	0.66	1.35
SO_3	0.45	0.21	0.19
K2O	2.47	--------------	2.99
L.O.I	0.1	2.47	3.1
Physical properties			
Specific Surface Area m²/kg	2010	1980	773
Specific Gravity	2.2	2.5	2.35
Density kg/m³	2193	2493	2343

Table 8: Requirements of mineral admixture according to [12]

Requirement of ASTM C618-05	HRA	HRM	FA
(SiO_2+Al_2O_3+ Fe_2O_3) (%)	80.5	92.57	89.32
SO_3 (%)	0.45	0.21	0.19
Loss on ignition (%)	0.10	2.47	3.1
S.A.I at 7 days (%)	101.4	108.0	78
S.A.I at 28 days (%)	108.8	120.5	89

The result contained in Table 8 shows that the (FA) used in this study was (Class F) because the summation of (SiO_2, Al_2O_3, and Fe_2O_3) is to be greater than 70%, and it identified with both chemical and strength activity indexes (S.A.I) requirements of the [12] Class F pozzolana

II. Design of Concrete Mixes

The mix design method of [14] was adopted to design SCC mixes with a target slump flow of 730 ± 20 mm. Multi trail mixes were carried out with modifying the proportions of materials to satisfy both requirements of SLWC and self-compatibility. Table 9 shows the details of mixes used by weight in this research.

III- Mixing of Concrete

The method of [15] was used in the mixing of LWSCC. Aggregates had to be dried to SSD conditions after soaking it for about 48 hours. This method includes the following steps:

1-To pledge full dissolution of SP, it must be added to the water pail and mixed.

2-Before adding them to the mixer and to obtain high homogeneity, mineral admixtures and cement must be mixed well.

3- The coarse aggregate with two third of total water of the mixing were added to the mixer and mixed for a few revolutions.

4- Sand, cement and mineral admixtures mixture and the remaining water with SP were added respectively after discontinuing of the mixer.

5-The mixer was rotated for three minutes, rested covered for three minutes, and re-rotated again for two additional minutes.

IV- Testing of LWSCC Rheological Properties

The tests of (Slump flow, T500 mm slump flow, V-funnel, J-ring and L-box) were it is performed according to [16] on the fresh LWSCC to check its self-compatibility.

V. Testing of Hardened Concrete

a- Compressive Strength

This test was carried out on cubes of 100 mm according to [17]. The samples were tested at ages of 7, 28, 56 and 90 days and the average of three specimens testing results was depended on at each age.

b. Splitting Tensile Strength

This test was performed on cylindrical concrete specimens of (100×200) mm according to [18]. The samples were tested at the age of 7, 28, 56 and 90 days, the average of three specimens testing results was adopted at each age.

c. Oven-Dry Density

This test was conducted according to [19] on 100x200 cylinders.

d. *Calculated Equilibrium Density*

According to [19] calculated equilibrium density determined by addition 50 kg/m^3 to oven-dry density.

e. *Equilibrium (Air-Drying) Density at 90 days*

In this test cylindrical specimens of (100x200) mm was used. According to [20] and [19] equilibrium density for most structural members and ambient conditions can be supposed to be achieved at about 90 days of air drying.

Table 9: the mixes details by weight (kg/m3)

Mix designation	% Mineral admixture used	Cement kg/m^3	HRA kg/m^3	FA kg/m^3	HRM kg/m^3	Sand kg/m^3	Coarse Aggregate (Attapulgite) kg/m^3	water kg/m^3	S.p litre/m^3
Ref.mix	0	550	—	—	—	624	655	220	4.95
Mix2	5%(HRA)	522.5	27.5	—	—	624	655	220	5.5
Mix3	10%(HRA)	495	55	—	—	624	655	220	7.15
Mix4	15%(HRA)	467.5	82.5	—	—	624	655	220	8.25
Mix5	5%(FA)	522.5	—	27.5	—	624	655	220	4.4
Mix6	10%(FA)	495	—	55	—	624	655	220	3.85
Mix7	15%(FA)	467.5	—	82.5	—	624	655	220	3.3
Mix8	5%(HRM)	522.5	—	—	27.5	624	655	220	4.95
Mix9	10%(HRM)	495	—	—	55	624	655	220	5.5
Mix10	15%(HRM)	467.5	—	—	82.5	624	655	220	6.05

3. Results of LWSCC Fresh Properties Testing

I. Slump flow

The slump flow of mixes in this research was a function of superplasticizer (SP) dosage to get a required slump flow target value of (730±20) mm. Results of testing of LWSCC fresh properties for all mixes are included in the Table 10. For LWSCC mixes with (HRA) the dosage of (SP) increased directly with increasing replacement percentage of (HRA) by weight of cement [21]. attributed that to a high surface area and plate-like particles of (HRA). While high surface area increases water requirement due to high water absorption, the morphology of (HRA) particles increases inter- particles friction, so they slide over each other very difficultly, and mixes contained it needed more SP dosage to get same slump flow of Ref. mix. Figure 1 shows the morphology of (HRA) particles. Table 10 also shows that the dosage of (SP) reduced with increasing the replacement percentage of (FA) by weight of cement. For 5% replacement percentage, the dosage of (SP) was 4.4 liters/m^3 to get slump flow of 740 mm, but it reduced to 3.3 liters/m^3 to obtain the same slump flow by using 15 % replacement percentage. The reason attributes to spherical particle shape of (FA) particles with lower surface area and water absorption which they need lower effort to slide over each other, so it needs lower (SP) dosage than (Ref. mix) to get same slump flow target values. Figure 2 shows the morphology of (FA) particles. As mixes containing (HRA), the dosage of (SP) increased with the increasing in replacement percentage by weight of cement for LWSCC mixes containing (HRM) when is compared with (Ref mix), because it has a plate-like particle with high surface area, but the rate of increasing was lower when compared with (HRA) mixes. The reasons attributed to higher specific surface area and lower density of (HRA), which increases water requirement to get same slump flow due to increment in paste volume. Figure 3 shows the morphology of (HRM) particles.

II. T500 mm

Table 10 contains the results of T500 mm and shows clearly that all results are within the acceptance criteria of [16]. Table 10 also shows that LWSCC mixes containing mineral admixtures had higher T500 value than (Ref.mix) because all these mineral admixtures have a lower density than cement, so adding them to concrete as partially replacement percentage by weight of cement increases paste volume, accordingly cohesiveness and viscosity of paste will increase [22]. The highest value is noticed when 15% of (HRA) was used (5sec), while for (FA) and (HRM) were 4 and 4.5 sec for the same replacement percentage by weight of cement respectively ,because of highly increment in paste volume of LWSCC when it contains (HRA) resulting from the lowest density of (HRA) when is compared with both (FA) and (HRM). The morphology of mineral admixture also effects on T500 mm results, so (FA) with its spherical particle shape consequently lower inter-particles friction makes this result low because it helps LWSCC to move easily, while (HRA) and (HRM) which it has plate-like particles are not.

III.J Ring

Table 10 shows that the results of J Ring test for all LWSCC mixes are within the acceptance criteria of [16]. Table (10)also shows that using of (HRA) increased J Ring values, and the highest value recorded with mix4 (10 mm) because it had the highest viscosity and the lowest flowability on account of paste volume increment. For mixes containing (FA) the results ranged between 8.4 to 7.6 for 5% to 15% replacement percentage by weight of cement respectively, while for mixes containing (HRM) the results ranged between 8.9 to 9.5 for 5% to 15% replacement percentage by weight of cement respectively, so mixes containing (FA) had the highest passing ability because they had the highest flowability

IV. L Box

Table 10 shows that the results of L Box test (H_2/H_1) for all LWSCC mixes are within the acceptance criteria of [16]. Table 10 shows that using of (HRA) reduced H_2/H_1 values; the lowest H_2/H_1 was 0.8 noticed with mix4, because it had the highest viscosity and the lowest flowability. The values of H_2/H_1 for mixes containing (FA) recorded the highest value when compared them with mixes containing (HRM) and (HRA) because they had the highest flowability due to the spherical shape of (FA) particles.

Table 10: Results of fresh LWSCC

Mix designation	Sp dosage L/100 kg of powder	Slump flow (mm)	T 500 (sec)	J Ring (mm)	L Box H_2/H_1
Ref.mix	0.9	745	3	8.7	0.9
Mix2	1	740	3.5	9.2	0.85
Mix3	1.3	735	4	9.7	0.84
Mix4	1.5	725	5	10	0.8
Mix5	0.8	740	3.5	8.4	0.92
Mix6	0.7	740	3.5	8.1	0.94
Mix7	0.6	740	4	7.6	0.95
Mix8	0.9	740	3.5	8.9	0.92
Mix9	1	745	4.5	9.3	0. 91
Mix10	1.1	740	4.5	9.5	0.88

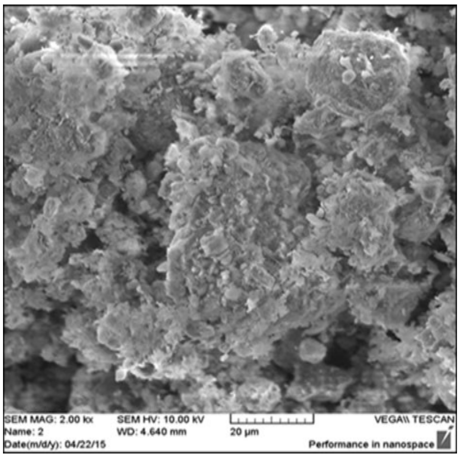

Figure 1: SEM of (HRA) particles at 2000X [23]

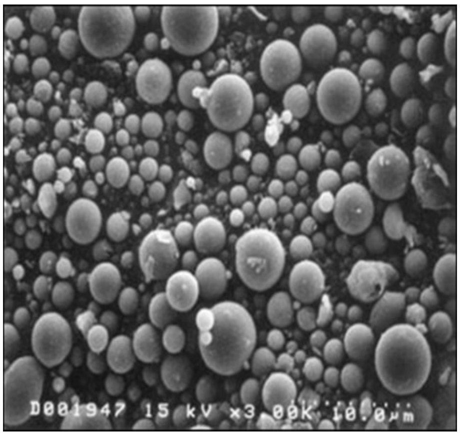

Figure 2: SEM of (FA) particles at 2000X [24]

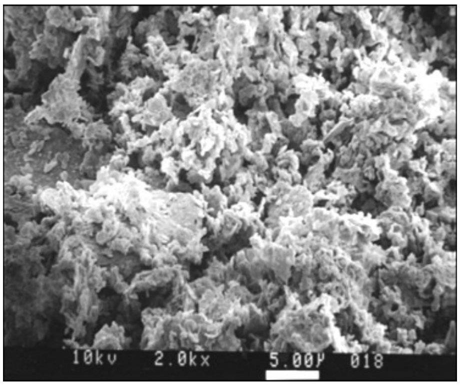

Figure 3: SEM of (HRM) particles at 2000X [25]

4. Hardened Properties of LWSCC

I. Equivalent Compressive Strength of Cylinder

Compressive strength of LWSCC in this study depended on [17] which is stipulated using of cubic specimen, while the acceptance limits of SLWC in [8] stipulated using of cylinder (150*300) mm according to [26] to measure compressive strength, so it is very important to convert strength of cube to equivalent strength of cylinder. The conversion factor of 0.9 suggested by [1] for SCC was adopted in this research. Tables 11 contained the equivalent cylinder specimen compressive strength and splitting tensile strength results for LWSCC mixes.

II. Compressive Strength

The compressive strength results for all mixes were listed in Table 11 which is showed clearly that the results of LWSCC mixes at 28 days are within acceptance limits of [8]. Table 11 shows clearly that the compressive strength increased by using 5% and 10% of (HRA) as a partial replacement percentage by weight of cement at all age relative to (Ref.mix) due to its high pozzolanic reactivity [23], while mix 4 which is contains 15% (HRA) exhibited a reduction in compressive strength with relative to Ref.mix due to the clinker dilution effect [27]. For all mixes contained (FA) the results showed that the early strength is reduced relative to Ref.mix, and the rate of reduction increases with (FA) content increasing. The reduction in compressive strength at early age can be attributed firstly to low CaO content for class F (FA)[28], which it was 0.98% for (FA) used in this study**,** secondly to low alkalinity of pore water due to low cement hydration products, whereas high alkalinity lead to break down the glass material of (FA) [29]. At late ages (beyond 28 days) the results showed that the compressive strength increases when (FA) content increases, and with highest (FA) content the highest long term strength can be obtained due to slow pozzolanic reactivity of (FA) which it can be begun only after increasing of cement hydration products specifically $Ca(OH)_2$, subsequently increasing the alkalinity of pore water due to increasing of $Ca(OH)_2$ amount. For LWSCC mixes containing (HRM), the results show that using of (HRM) as partial replacement by weight of cement led to increase compressive strength at all ages due to good particle packing of cement and the pozzolanic reaction with $Ca(OH)_2$ which it assists in refining the capillary porosity of binder and reduces microcracks in ITZ causing mechanical properties improvement especially at an early age [30].

III. Splitting Tensile Strength

Table 11 shows the results of splitting tensile strength for all LWSCC mixes, and it shows that all the results had to split tensile strength more than 2.3 MPa at 28 days, so they are within the acceptance limits of [8] for SLWC with calculated equilibrium density of 1840 kg/m³. Table 11 shows also that using of mineral admixtures in LWSCC has a significant effect on splitting tensile strength because of the high tendency of mineral admixtures to consume high amount of $Ca(OH)_2$ from ITZ and convert it to CSH , in addition to physical effects of them in term of packing of particles. Due to their lower density relative to Portland cement, mineral admixtures can increase paste volume when they are partially replaced by cement weight. Consequently, the viscosity of paste will increase. This increment in paste viscosity causes a reduction in ITZ porosity due to the reduction in bleeding water entrapped beneath coarse aggregate [31]. For mixes contained (HRA) at replacement percentages of 5% and 10% by weight of cement the results showed that an increment in early and late age splitting tensile strength relative to (Ref. mix), while mix4 showed a reduction in splitting tensile relative to (Ref.mix) due to a clinker dilution effect. The results of mixes contained (FA) showed, as in compressive strength that using of (FA) leads to reduce early age splitting tensile strength, and the percentage of reduction is proportioned directly with (FA) content. At a later age, the splitting tensile strength was increased by using (FA) due to slow pozzolanic reactivity which it improves the splitting tensile strength at later age, and the highest (FA) content leads to obtain the highest splitting tensile strength for the same reasons mentioned in section **II**. The results of LWSCC mixes containing (HRM) showed that using (HRM) as a partial replacement by cement weight led to increasing both early and late splitting tensile strength due to its high pozzolanic reactivity, and the highest increment was noticed with mix9, which contained a replacement percentage of 10% by weight of cement, and the increments were (16.0%, 24.2%, 22.2% and 21.6%) for 7, 28, 56 and 90 days respectively.

IV. Unit Weight

Equilibrium density occasionally referred to as air drying density is used to specialize and design of SLWC. According to [19] Equilibrium density is defined as LWC density after it incurrences of the relative humidity of 50 ± 5 % at a temperature of (23 ± 2)°C for adequate time to get lower loss of weight, because of long period to evaluate it, [19] suggested instead of that a method to calculate equilibrium density approximately by employing of oven dry density. According to [20] equilibrium density ranged between 1680 to 1920 kg/m^3 for most lightweight concrete. LWC can be reached to equilibrium with its ambient for most structural members and ambient condition at about 90 days of air drying [19].

Table 11: Equivalent compressive and splitting tensile strength results

Mix designation	Compressive strength (MPa)				Splitting tensile strength (MPa)			
	7 days	28 days	56 days	90 days	7 days	28 days	56 days	90 days
Ref. mix	34.0	41.3	46.0	47.5	2.5	3.3	3.6	3.7
Mix2	35.2	42.0	47.6	48.4	2.5	3.5	3.7	3.8
Mix3	37.4	46.3	51.1	53.4	2.8	3.9	4.2	4.3
Mix4	32.9	40.7	45.1	47.2	2.1	3.15	3.3	3.5
Mix5	33.4	41.6	46.6	48.2	2.5	3.3	3.6	3.8
Mix6	33.2	40.3	48.5	49.3	2.4	3.2	3.7	3.9
Mix7	31.8	38.8	47.3	50.3	2.3	3.2	3.6	4.1
Mix8	37.6	46.2	49.6	52.8	2.8	3.8	4.1	4.2
Mix9	39.1	48.6	52.4	55.0	2.9	4.1	4.4	4.5
Mix10	35.2	42.2	47.2	51.1	2.65	3.6	3.9	4.2

Table 12 contains the densities results for LWSCC mixes, and it shows that all results are within the requirement of [8] and [20]. The results showed a reduction in oven dry density relative to Ref.mix for all mixes when mineral admixtures were used, and this reduction increased directly with increasing of mineral admixtures content, because this test was executed after de-moulded directly according to [19], at that time no significant cement hydration occurred, so the oven dry density of LWSCC depended on the density of its ingredients, when all mineral admixtures used in this research have a lower density than cement, so the reduction increase with increasing of replacement percentage of mineral admixtures by weight of cement. Mixes containing (HRA) showed the lowest oven dry density because (HRA) has a lower density (specific gravity) than both (FA) and (HRM). The lowest oven dry density was noticed with mix4 when cement was replaced by 15% (HRA). in contrast with oven dry density, the equilibrium (air drying) density showed an increment when mineral admixtures were used and the increment depended on the replacement percentage which it gave the best pozzolanic reactivity with $Ca(OH)_2$, because the pozzolanic reaction leads to an increment in the cementation compounds, it also leads to condensation of the transition zone and the concrete matrix through the processes of pore- size and grain-size refinement [31]. The highest increment in equilibrium (air dry) density is noticed when cement was replaced by 10% (HRM) 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.

Table 12: Results of Oven Dry, Calculated and (Air Dry) Equilibrium Densities

Mix designation	Oven Dry Density at 24 hour (kg/m³)	Calculated Equilibrium Density (kg/m³)	Equilibrium (Air Dry) Density at 90 days (kg/m³)
Ref.mix	1785	1835	1870
Mix2	1779	1829	1874
Mix3	1769	1819	1888
Mix4	1738	1788	1868
Mix5	1783	1833	1873
Mix6	1780	1830	1876
Mix7	1778	1828	1880
Mix8	1783	1833	1886
Mix9	1782	1832	1889
Mix10	1780	1830	1883

5. Conclusions

Based on the results of this study, the following conclusions can be drawn:

1-Using of (HRA) and (HRM) in LWSCC mixes increased the (SP) dosage relative to (Ref. mix) to get a same slump flow target value, and the (SP) dosage was increased directly with the increment of replacement percentage by weight of cement due to lower density and plate- like particles of them, but the rate of increments for mixes containing (HRA) was higher due to its lower density with compared to (HRM), while (FA) with spherical particles reduced the (SP) dosage relative to (Ref.mix) directly with replacement percentage increment due to reducing inter-particles friction.

2-Using of mineral admixtures increased T500, J ring, but reduced H_2/H_1 ratio of L box.

3- Using of (HRA) as a replacement percentage by weight of cement of 5%, and 10% increase the compressive strength and splitting tensile strength 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 (10.0%, 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.

4- Using of (FA) reduced early age strength, the percentages of reduction and the time was taken to neutralize strength of Ref. mix proportioned directly with (FA) content, but long term strength increased with (FA) content increasing, the percentages of increment at 90 days were (1.5%, 3.8% and 5.9%) and (2.7%, 5.4% and 10.8%) for compressive strength and splitting tensile strength for 5%, 10% and 15% (FA) content respectively.

5- Using of (HRM) as a replacement percentage of 5%, 10% and 15% by weight of cement increased compressive strength and splitting tensile strength at all ages. The highest percentage of increment was noticed when cement was replaced with 10 % (HRM), and the percentages of increment relative to (Ref.mix) were (15.0%, 17.6%, 13.9% and 15.7%) and (16.0%, 24.2%, 22.2% and 21.6%) at 7, 28, 56, and 90 days for compressive strength and splitting tensile strength respectively.

6- The values of the calculated equilibrium density ranged between (1788 and 1829) kg/m^3, (1828 and

1833) kg/m^3 and (1830 and 1833) kg/m^3 for mixes contained (HRA), (FA) and (HRM) respectively.

7- The values of the equilibrium (air dry) density ranged between (1868 and 1888) kg/m^3, (1873 and 1880) kg/m^3 and (1883 and 1889) kg/m^3 for mixes contained (HRA), (FA) and (HRM) respectively.

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