Journal of Al-Qadisiyah for Computer Science and Mathematics Vol. 14(2) Vol. 14(2) 2022 , pp Math. 71–87

Available online at www.qu.edu.iq/journalcm

JOURNAL OF AL-QADISIYAH FOR COMPUTER SCIENCE AND MATHEMATICS

ISSN:2521-3504(online) ISSN:2074-0204(print)

Study the coupling agents of the common effect of adding high reactive mineral admixture meta-kaolin and super-plasticizer on the mechanical properties of lightweight concrete prepared by LECA aggregate

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ARTICLE INFO

Article history:
Received: 18 /05/2022
Rrevised form: 23/06/2022
Accepted : 30 /06/2022
Available online: 06/07/2022

Keywords:

Lightweight aggregate concrete, LECA concrete, high reactivity Meta kaolin, structural light weight concrete, coupling agent of light weight concrete.

ABSTRACT

The purpose of this paper is to look at how employing both super plasticizers and highly reactive meta-kaolin additives affects the compressive strength regarding LECAC lightweight expanded clay aggregate concrete in addition to various concrete parameters. The coarse-grained aggregate utilized was lightweight clay with maximum size of 10mm; the best percentages regarding chemical and mineral additives have been partial substitution of 10% cement for meta-kaolin mineral additives and 0.6 L / 100 kg cement for Super plasticizers. The percentages that have been gained from improved compressive strength (8.6, 20, and 17.6) % for processing ages have been 7, 28, and 56, respectively, in comparison with indicated level mix when meta-kaolin mineral admixture was only added to it, whereas the common effect of the two additives was evident in percentages (25.2, 29.4, 28) % for treatment ages 7, 28, and 56, in comparison with the mixture that has been indicated via the plane. For a concrete mix comprising additives, the equilibrium density attained was 1798 kg/m³ (ACI 213-R-03, < 1840 kg/m³ for structural purposes). Furthermore, the water absorption regarding LECA concrete was lowered through adding Meta kaolin (9.6 and 7.7) % at (28 and 56) days of curing, respectively, while addition of super plasticizer produces a rise in water absorption, and above-mentioned ratios that have been reduced to (5.8 and 2.1) % at such ages.

MSC. 41A25; 41A35; 41A36

DOI : 10.29304/jqcm.2022.14.2.971

1. Introduction

Lightweight Aggregate as Porous Medium LWA is a versatile and significant material utilized in lightweight aggregate concrete mixes (LWAC). Multi-story building frames, shell ceilings, curtain walls, floors, pre-cast elements,

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Communicated by: Alaa Hussein Hamadi

pre-stressed elements, and other applications are all possible with LWAC. [1]. The first is structural LWAC, which has a uniform density in the range (1400-1840) kg/m^3 in comparison with ordinary concrete, which has a density of roughly (2240-2400) kg/m^3, and is used in structural applications; concrete's strength must be more than (17 MPa) The 2nd type is lightweight insulating aggregate concrete that weighs between (1400 and 800) kg/m^3 and has a compressive strength of 7 MPa at most [2]. Recently, the scale was thorough and the requirement for it have witnessed an increase, the decrease in structure weight indicates that the foundations as well as other parts regarding the structure elements could be made smaller, and the costs of installation and handling of the components could be saved, allowing smaller lifting equipment to be utilized and larger units to be manufactured and handled [3]. LWAs have been utilized in antiquity, 3,000 years BC, and the majority of aggregates that have been utilized in the concrete are of igneous rock origin. As the demand for LWAC grew on a large scale, production technologies have been developed in order to start production lines in factories and materials that are utilized in aggregates productions. Natural minerals like slate, clay, and shale, along with industrial by-products like bed ash, fly ash, and blast furnace slag, have been used in order to make lightweights. [4] Because of its durable behavior and high strength, Structural Light-weight Aggregate Concrete (SLWAC) is now appealing to designers in various areas of constructions, including tall buildings, multi-story buildings, oil rigs, bridges, architectural purposes, and marine structures, as opposed to other LWC types, which often require higher costs and complex means throughout construction. [5].

2. Experimental work

2.1. Materials

2.1.1. Cement

Al-mas ordinary Portland cement has been utilized, and its physical and chemical parameters have been exhibited in Tables (1) & (2). The findings revealed that the cement complies with Iraqi Standard No. 5 from 1984. [6].

2.1.2. Fine aggregate

Al-Khider Sand is utilized as a fine aggregate in all types of concrete mixtures with a maximal size of 4.75 mm. The sieve analysis and the employed sand gradient curve are shown in Table 3. According to Iraqi standard No. 45/1984 requirements [7], the sand lies within the second region, as demonstrated by the degree curve in Table 3 and Figure 1. Table 4 shows the chemical parameters of natural sand.

2.1.3. Coarse Aggregate

The raw material for creation of light-weight expanded clay aggregate, LECA clay, was brought in from the Governorate of Al-Najaf. The procedures for the manufacturing process could be summarized as follows: The dried clay was crushed in a jaw crusher, then combined with water before being extruded into pellets (cylinders) with a diameter of 8 mm and varied lengths ranging from (10 - 15) mm. The bloating was after that placed in an oven that was set at temperature of 1050 °C to 1170 °C for a period of 10 mins. Blowing capacity tests have been performed at various temperature degrees of 20 °C till the samples' melting half temperature was attained. The hot samples were removed from the oven, cooled to the temperature of the room, then weighed, and placed in water bath for 24 h by overburdening. Soaked samples have been weighed and their volume has been measured by using a volume meter after being taken from the water and wiped with a damp cloth. Burning and drying are the following steps in the expanded clay pellet production process. Since the temperature is relatively low and the clay particles do not swell till complete extension, establishing the ideal firing temperature is critical in expanded clay manufacture. In the case when the clay particles are extremely high, they stick together for forming a homogeneous mass, which is undesirable. Samples have been fired at temperatures ranging from (1050 to 1170) °C to identify the best slurry firing temperature. [8] The grading and characteristics of LECA coarse lightweight aggregate have been listed in Table 5 and Table 6. Figure 2 indicates that the LECA was employed to meet the ASTMC330-04 standard. [19].

2.1.4. Water

For all concrete mixtures, tap water was utilized for mixing and curing the samples.

2.1.5. Super plasticizer

As a chemical admixture, a high-performance concrete super-plasticizer based upon the modified poly carboxylic ether Glenum 54 was utilized in this study; it meets ASTM C494-04 Types A and F. [9]. The properties of a superplasticizer are shown in Table 7.

2.1.6. High Reactivity Meta kaolin (HRM)

Kaolin is a soft white clay substance. It was traditionally used in the manufacture of ceramics. Kaolin is basically the mineral kaolinite, which is a hydrated aluminum silicate with the chemical formula ($Al_2O_3.2SiO_2.2H_2O$). Under normal environmental conditions, kaolin is quite stable, when kaolin is heated in the range from (650 to 850) °C, it is converted into meta kaolin ($Al_2O_3.2SiO_2$), losing 14% of its mass, since this heat treatment or calcination destroys kaolin structure, therefore, silica and alumina layers lose their long-range arrangement and the water is expelled, and meta-kaolin exhibits the properties of pozzolanic [10].

$$AL_2O_3.2SiO_2.2H_2O \xrightarrow{\text{Heating}} AL_2O_3.2SiO_2 + 2H_2O$$

According to ACI 232.1R-00, [11] the quantity of kaolin included in the original clay material determines the reaction of the meta-kaolin. Domestically available kaolin is a raw material for (HRM). In addition, HRM has been created by the grinding of the kaolin to a fine grain size, immersing it at 700 ^oC for 1 h, and after that cooling it [12]. Tables 8, 9 and 10 reveal that the (HRM) utilized in this work complies with the chemical standards of ASTM C618 - 05 Class N pozolana [13].

2.1.7. Trial Mixing

This stage seeks to find the best chemical admixture (super plasticizer) dose that is compatible with the mineral meta-kaolin admixture. The results of the experimental mixes are shown in Table 11, and the best dose of super plasticizer was 0.6 L / 100 kg of cement to partially replace 10% of the cement with the mineral meta-kaolin addition.

2.1.8. Mixture Proportions

For all mixtures that have been utilized in the present paper w/c ratio has been (0.40) and the target aggregate (110 ± 5) mm to the mixing ratio (1: 1.45: 0.85), with a 540 kg/m^3 cement content, the saturated surface Dry fine aggregate used was 780 kg/m^3, and 459 kg/m^3 for coarse aggregate (LECA) respectively the mixing ratio is compatible with ACI 213R-87 [2].

2.1.9. Mixing Method

A laboratory mixer with a capacity of 150 L is used for mixing concrete. For ensuring that no other materials were present to interfere with the mixture, the blender blades and frying pan were wiped with a damp cloth. The mixture of concrete and dry ingredients was placed in. For ensuring division and homogeneity of cement particles, mixing commenced for 2 min. The following were the steps in the mixing process: The mixer was loaded with coarse aggregates (LECA), sand, and half of the mixing water, and it was combined for one minute. The appropriate amount of dry cement is after that mixed with 45 of the remaining water in a blender for 2 min with the desired Meta kaolin admixture in its dry condition. The remaining 5% of water was combined with the super plasticizer to form a solution, which was after that added to the Mixer for a two-minute continuous mixing operation.

3. LECA concrete Fresh characteristics

3.1. Fresh Density

Fresh Density (LECA Concrete) has been prepared in accordance with the ASTM C-138-04 [14], with cylinder capacity of 0.003 m^3 utilized for sampling and an average of three samples derived from the results, as indicated in Table 12.

3.2. Slump

The slack (slump) test has been performed in accordance with the ASTM C-143-03 [15], and test results are shown in Table 13. The slack (slump) test was performed using (LECA & sand) in the case of SSD. This variation is related to the addition of additives and differences in aggregate saturation, which impacts the water content by the amount of water which is absorbed by the aggregate from fresh concrete mix.

3.3. Hardened Concrete Properties

Testing of Hardened Concrete

The ASTM methods and criteria were followed to complete the hardened concrete test. Compressive strength, oven dry density, water absorption, and splitting tensile strength were all tested.

3.4. Oven Dry Density and Equilibrium Density

The estimated equilibrium density findings conform to the structural requirements (LWAC) based on the ACI 213-R - 03 [2], as can be seen in Table 14, and all of the mixes conform to RILEM [16] ratings because all Density results are less than 2000 kg/m^3. The equation below calculates the equilibrium density based on ASTM C 567-03 [17]:

$$Ec = Oc + 50\ kg/m^3$$

where:

Oc represents the oven dry density

Ec represents the calculated equilibrium density

Table 15 lists results of the density of (LECA Concrete) for each type of mixture; in another hand Figure 3 shows that the all types of densities are decreasing with the increasing of mineral admixture Meta kaolin because the last has a lower density compared to the density of cement.

3.5. LECA Concrete Water Absorption

Cylindrical samples for (LECAC) were evaluated according to ASTM C642-97 [18] at processing ages of 28 and 56 days, and the findings have been reported in Table 16 and Figure 4. With treatment ages of 28 and 56, respectively, the inclusion of a highly reactive meta-kaolin admixture reduced (LECAC) water absorption, mix B, by 9.6% and 7.75%, respectively, although when superplasticizer with the metal. At 28 and 56 days, the reduction ratios of Admixture, Mix C, were decreased to 5.8% and 2.1%, respectively.

3.6. Compressive Strength

For predicting the specific properties regarding the concrete mixes, the compressive strength of LWC is critical. All of the mixes' compressive strength findings at 28 days were found to be within ASTM C330-04 [19] acceptability standards, which are set for minimal compressive strength of sand light weight. With a calculated equilibrium density of 1680 kg /m^3 should be not less than 17 MPa in 28 days. The influence of mineral additives on concrete strength is determined by the qualities of both the concrete and the mineral additives. Mineral additives have two impacts on concrete strength. The first is a chemical (pozzolanic) reaction that occurs when it reacts with $Ca(OH)_2$ that had been produced throughout the process of cement hydration and converts it to C-S-H. This pozzolanic reaction reduces capillary voids in cement matrix and microcracks in interfacial transition zone ITZ. With regard to filling cement particles, the second effect is physical. Figure 5 and 6 and Table 17 demonstrate the compressive strength of (LECAC) values. To meet with ASTM criteria, the tested samples were cubic (100x100x100) mm and findings have been converted into cylindrical. Results have revealed that the association between treatment ages and compressive strength was nonlinear. The compressive findings of LECAC, for the most part, increased in strength between the ages of (28 and 56) days. Figure 5 and 6 and Table 17 show that mixture B (10% meta-kaolin highly reactive mineral admixture) had shown an increase in the values of the compressive strength (15.6, 20, 17.6) % in comparison with reference mixture A at (7 and 28 and 56) days of curing life. On the other hand, there has been another increase in compressive strength of the same mixture between (28 and 56) days of age by 4.3%, and such findings indicated that adding highly reactive meta-kaolin mineral admixture enhanced the LECAC's strength property. Furthermore, when put to comparison with mix (B) Super-plasticizer free, the chemical admixture (superplastisizer) increases the compressive strength of mixture C (10% metakaolin mineral admixture + 0.6 L/100 kg super plasticizer) by (8.4, 7.8, and 8.8) % at (7, 28, and 56) days of ages, respectively. The cumulative effects of the above additions had revealed in the results of mixture C was obvious in percentage increases of (25, 29, and 28) % for (7, 28, and 56) days of age, respectively, in comparison with reference combination A.

3.7. Splitting Tensile Strength

Since direct tensile strength testing is difficult, this test is utilized for estimating the concrete's tensile strength. Generally, the same factors which impact compressive strength also impact tensile strength, yet tensile strength is much lower in concrete compared with compressive strength since the already existing micro cracks in (interfacial transition zone) ITZ need much less energy to be continuous and spread quickly and join the cement voids matrix. The existence of $Ca(OH)_2$, which has an orientated structure with a low surface area, is the cause of the ITZ's weakness. [20] Table 18 displays the tensile strength values for all LECAC blends, demonstrating that all results are within the ASTM C330-04 [19] acceptability criteria, as specified by LWC with a predicted equilibrium density of 1680 kg/m^3. At 28 days, the tensile strength is at least 2.1 MPa. Table 18 also shows that the use of the mineral additives in LECAC has considerable impact upon tensile strength due to the mineral admixtures' high tendency for consuming high $Ca(OH)_2$ from ITZ and converting it into C-S-H, besides the high tendency of the mineral admixtures in consuming high $Ca(OH)_2$ from the ITZ and converting it into C-S-H. In terms of particle packing, the physical effects. Mineral additives, which have a lower density than Portland cement, might increase the paste's volume in the case when partially replaced by the weight of cement, increasing paste viscosity. As the paste viscosity rises, the amount of bleed water trapped beneath the coarse aggregate decreases, resulting in lower ITZ porosity. At (7 and 28 and 56) days of curing life, respectively, mixture B (10% meta-kaolin highly reactive mineral admixture) had shown an increase in splitting tensile strengths (11.8, 17.4 and 7.4) % compared to reference mixture A, as shown in Table 18 of the results and Figure 7, indicating that adding highly reactive meta-kaolin mineral admixture had resulted in the improvement of strength property of (LECAC). Furthermore, when compared to mix (B) Super-plasticizer free, the chemical admixture (super plasticizer) increases the tensile strength of mixture C (10% meta kaolin mineral admixture + 0.6 L/100 kg super plasticizer) by about (10.5, 14.8, and 13.8) % at (7, 28, and 56) days of age, respectively. cumulative effects of the above additions revealed in the results of mixture C have been visible in percentage increases of (23.5, 34.8, and 22) % for (7, 28, and 56) days of age, respectively, in comparison to reference combination A. As the compression strength value increases, the splitting tensile strength increases as well, as seen in Figure 8.

3.8. Static Modulus of Elasticity

The static elasticity modulus has been determined using ASTM C-469-03 [25] at a point of 40% final load and a static load rating of (0.24+0.03) MPa/sec. The elastic modulus values for all mixtures increased with processing time, as indicated in Table 19 and Figure 9. Mineral admixtures also have a substantial impact on the modulus of elasticity because they have a tendency to increase the elasticity modulus of the cement paste matrix by lowering porosity, capillary voids, micro cracks, and calcium hydroxide crystals oriented in the ITZ. The combined action of the super plasticizer additive and the highly effective mineral admixture of meta kaolin resulted in a (0.65 and 1.4) % increase in elasticity modulus at (7 and 28) days, respectively, which might be associated with improved matrix characteristics of (LECAC) caused by adding the mineral admixture. Figure 9 shows that a typical reference mixture has fewer cracks and defects and has a higher compressive strength. Figure 10 shows that when compressive strength values increased, elastic modulus values increased as well.

4. Conclusion

1. There is a possibility to prepare a light-weight concrete containing local Iraqi light weight coarse aggregate (LECA) to produce a LECA concrete compatible with the ACI 213R-03 requirement.

2. There is a possibility to utilize the local Meta Kaolin high reactive mineral admixture with local LECA to improve LWC compressive strength as well as other associated characteristics.

3. The use of local Iraqi LECA produces a LECA concrete with compressive strength equal to 23.5 MPa, equilibrium density equal to 1815 kg/m^3 and a splitting tensile strength equal to 2.3 MPa at 28 days, which made this LWC compatible with the ACI 213R-03 requirement.

4. Using high reactivity Meta kaolin mineral admixture improves coupling agents of LECAC, hence; improves the compressive strength with percentage of (15.6, 20 and 17.6) % at (7, 28 and 56) days respectively.

5. Using high reactivity Meta kaolin mineral admixture improves the coupling agents of LWC, hence; improves the splitting tensile strength with percentage of (11.8, 17.4 and 7.4) % at (7, 28 and 56) days respectively.

6. The common action of a highly reactive mineral admixture of Meta kaolin with super plasticizer additive have given LECAC compressive strength improvement (25, 29 and 28) % for ages of (7, 28 and 56) days, respectively.

7. The common action of a highly reactive mineral admixture of Meta kaolin with super plasticizer additive gave the LECAC splitting tensile strength an improvement of (23.5, 34.8 and 22) % for (7, 28 and 56) days of age, respectively.

8. The common action of a highly reactive mineral admixture of Meta kaolin with super plasticizer additive reduced the water absorption of LECAC by percentages (5.8 and 2.1) % at (28 and 56) days of treatment respectively.

9. Using a highly reactive Meta kaolin mineral admixture reduced water absorption of LECAC by (9.6 and 7.75) % percentages at (28 and 56) days of treatment.

10. Addition of a highly reactive Meta kaolin mineral admixture as a partial cement replacement had reduced all types of densities of LECAC.

Table 1. Physical requirement of the cement.

Physical characteristics		units	Test results	IQ.S. no5/1984 [6]
Specific surface area (Blaine Approach)		m²/kg	310	≥ 230m²/kg
Setting time (Vicate's method)	Initial setting time	hr:min	1:45	≥ 45min
	Final setting time	hr:min	3:30	≤ 10hrs
Compressive strength N/mm^2	3 days	MPa	17.7	≥ 15MPa
	7 days	MPa	25.3	≥ 23MPa

Table 2. Chemical Analyses of the cement compounds.

Oxide compositions	% by wt.	specification of Irai Limits No5 / 1984 [6]
SiO_2	19.50	---------------
Al_2O_3	4.64	---------------
Fe_2O_3	3.5	---------------
SO_3	2.690	2.80(max)
CaO	61.53	---------------
MgO	2.790	5(max)
Loss on ignition	1.640	4(max)
Insoluble residue	0.820	1.50(max)
Lime saturation factor	0.940	0.66-1.02
Main compounds (Bogue's equation) % by weight of cement		
C_3S	57.65	---------------
C_3A	6.35	---------------
C_2S	12.7	---------------
C_4AF	10.73	---------------

Table 3. Sieve analyses of fine aggregate.

Size of the Sieve (mm)	**Cumulative passing%**	**Cumulative passing % Limits of IQ.S. No45/1984**, [21] **zone (2)**
10.0	**100**	**100**
4.75	**99.9**	**90-100**
2.36	**84.3**	**75-100**
1.18	**65.5**	**55-90**
0.60	**41.7**	**35-55**
0.30	**12**	**8-30**
0.15	**2.3**	**0-10**

Table 4. Chemical characteristics of fine aggregate.

Characteristics	**Test results**	**Specifications**	**IQ.S. No45/1984** [21]
Specific gravity.	2.6	ASTM C-128-03 [7]	---------------
Dry loose unit weight, kg/m³	1585	ASTM C-29-03 [7]	---------------
Absorption %	2.97	ASTM C-128-03 [7]	---------------
Material finer than 75μm, %	1.95	IQS 45/1984 [21]	≤ 5
Sulphate content %	0.35	IQS 45/1984 [21]	≤ 0.5
Fineness modulus	3.75	IQS 45/1984 [21]	---------------

Table 5. LECA Coarse aggregate (LWA) Sieve Analysis.

Size of the Sieve (mm)	Cumulative passing % ASTM C330-04 [19]	Cumulative %Retained	Cumulative passing%
19	100	0	100
12.50	90-100	7	93
9.50	40-80	41	54
4.750	0-20	45	10
2.360	0-10	10	0

Table 6. LWA Characteristics.

Characteristics	Specification	Results	Permitted limits
Absorption, %	ASTM C 127-04 [22]	17	5-30
Specific gravity(SSD)	ASTM C 127-04 [22]	1.45	--------
Bulk Density(dry loose), kg/m^3	ASTM C 330-04 [19]	436	880(max)
Specific gravity(OD)	ASTM C 127-04 [22]	1.23	2.6(max)

Table 7. Typical Properties of super plasticizer Glinume 51.

Forms	Viscous liquids
Color	Dark brown
pH	6.60
Relative density	1.07 at 20ºC
Alkali content as (Na_2O) equivalent	0.26%
Viscosity	128+/- 30cps at 20ºC
Transport	Not categorized as dangerous
Normal dosage	0.50-1.60 liters/100 kg of the cement

Table 8. Chemical and physical analyses of the Meta-Kaolin HR Admixture.

Oxide compositions	`Oxide content %
SiO_2	54.9
Al_2O_3	36.27
Fe_2O_3	1.39
MgO	0.22
CaO	0.39
SO_3	0.20
L.O.I	2.48

Na_2O	**0.65**
Physical Characteristics	
Specific Surface Area m²/kg	**1980**
Density kg/m³	**2492**
Specific Gravity	**2.5**

Table 9. Chemical Requirements of (HRM) based on ASTM C-618-05 [13].

Composition of the Oxide	HRM%	Pozzolan class N
Loss on ignition	**2.45**	**10% max**
$SiO_2 + Al_2O_3 + Fe_2O_3$	**92.55**	**70 % min.**
SO_3	**0.25**	**4% max.**

Table 10. Strength Activity Index results for meta-kaolin mineral admixture [13], [23].

Mixes	Cement content gm	Standard sand gm	Meta-kaolin admixture gm	Water content ml	w/c ratio	7 days compressive strength MPa
Control mix	**500**	**1375**	**-----**	**242**	**0.484**	**27.6**
20% replac	**400**	**1375**	**100**	**254**	**0.509**	**29.7**

Table 11. Trial mixing results.

Mix no.		Meta-kaolin mineral admixture	Super plasticizer L/100 kg cement	Slump mm	Dry density	7 days Compressive strength MPa	28 days Compressive strength MPa
A	Reference	0	0	97	1825	18.6	23.5
	Mix 1	5%	0	97	1820	18.8	23.9
	Mix 2	8%	0	94	1817	19.5	24.6
	Mix 3	9%	0	92	1830	20.3	27.3
B	Mix 4	10%	0	90	1819	21.5	28.2
	Mix 5	11%	0	87	1824	19.9	25.2
	Mix 6	12%	0	84	1810	19.4	26.1
C	Mix 7	10%	0.5	98	1805	22.9	29.7

			0.6	110	1819	23.3	30.4
			0.75	200	1840	23	29.2
	Mix 8	11%	0.5	155	1863	20.7	28.5
			0.6	180	1924	21	29.9
			0.75	flow	-----	------	-------
	Mix 9	12%	0.5	210	1837	19.7	26.4
			0.6	Flow	------	--------	-------
			0.75	flow	------	-------	-------

Cement=540 kg Sand=780 kg LECA=459 kg W/C=0.4

Table 12. Fresh density results.

Mixture design	A	B	C
Fresh density kg/m^3	2110	2075	2095

Table 13. Results of slump test.

Mix design	A	B	C
Slump mm	97	90	110

Table 14. ACI 213 R – 03 Structural LWAC Requirements.

Calculated Equilibrium Density max, kg/m^3 (lb/ft^3)	Average 28-day Splitting Tensile Strength, min, MPa (psi)	Average 28-day Compressive Strength, min, MPa (psi)
	All Lightweight Aggregate	
1760 (110)	2.2 (320)	28 (4000)
1680 (105)	2.1 (300)	21 (3000)
1600 (100)	2.0 (290)	17 (2500)
	Sand/Lightweight Aggregate	
1840 (115)	2.3 (330)	28 (4000)
1760 (110)	2.1 (310)	21 (3000)
1680 (105)	2.1 (300)	17 (2500)

Table 15. Oven dry density and equilibrium density of (LECA Concrete).

Mixture design	A	B	C
Oven Dry Density kg/m^3	1765	1740	1748.4
Equilibrium Density kg/m^3	1815	1790	1798.4

Table 16. Results of water absorption of LECAC.

Mix design	Meta kaolin mineral admixture %	Super plasticizer L/100 kg cement	water absorption %	
			28 day	56 day
A	0	0	15.6	14.2
B	10%	0	14.1	13.1
C	10%	0.6	14.7	13.9

Table 17. Results of compressive strength test.

Mix design	Meta kaolin mineral admixture %	Super plasticizer L/100 kg cement	Compressive strength MPa		
			7 days	28 day	56 day
A	0	0	18.6	23.5	25
B	10%	0	21.5	28.2	29.4
C	10%	0.6	23.3	30.4	32

Table 18. Results of splitting tensile strength test.

Mix design	Meta kaolin mineral admixture %	Super plasticizer L/100 kg cement	Splitting tensile strength MPa		
			7 days	28 day	56 day
A	0	0	1.7	2.3	2.7
B	10%	0	1.9	2.7	2.9
C	10%	0.6	2.1	3.1	3.3

Table 19. Results of modulus of elasticity test.

Mix design	Meta kaolin mineral admixture %	Super plasticizer L/100 kg cement	Elasticity Modulus GPa	
			7 days	28 day
A	0	0	15.3	21.5
B	10%	0	15.4	21.6
C	10%	0.6	15.4	21.8

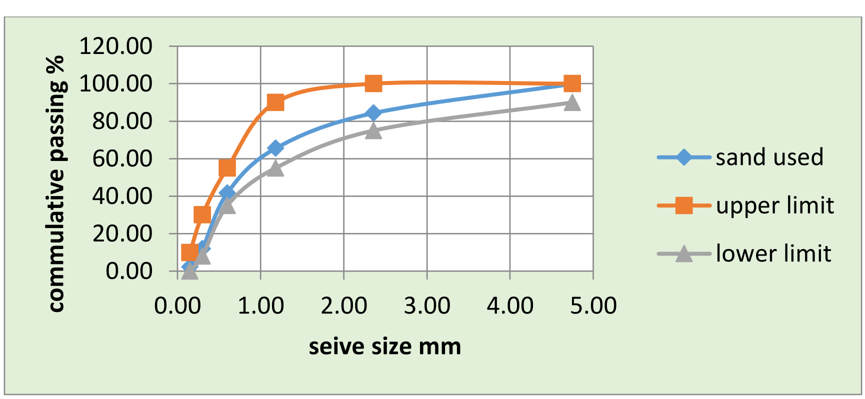

Fig. 1. Seive analysis of fine aggregate showing theat the sand confirm to the requirements of Iraqi standard No. 45/1984 [7].

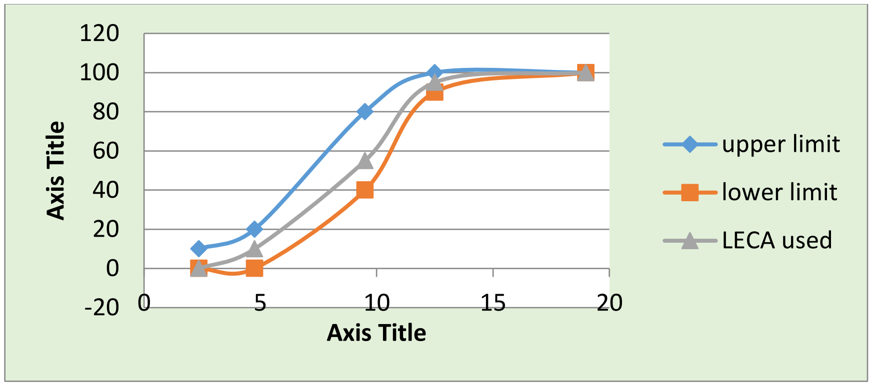

Fig. 2. Seive analysis of coarse aggregate (LECA) showing theat the LECA confirm to the requirement of ASTMC330-04 [19].

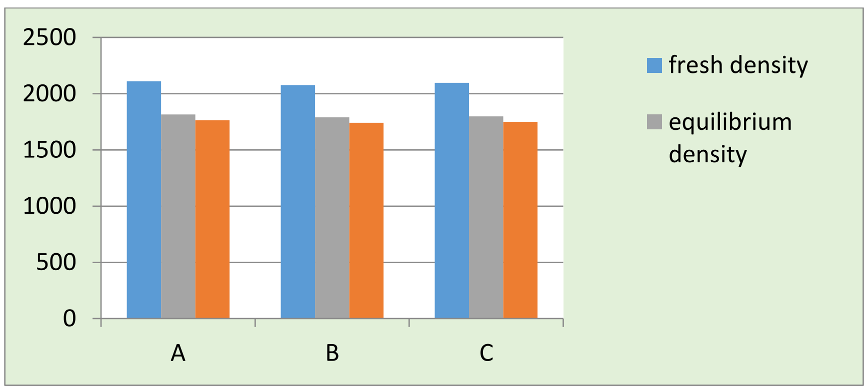

Fig. 3. All types of densities for deferent mixes decreasing with the increasing of meta kaolin content.

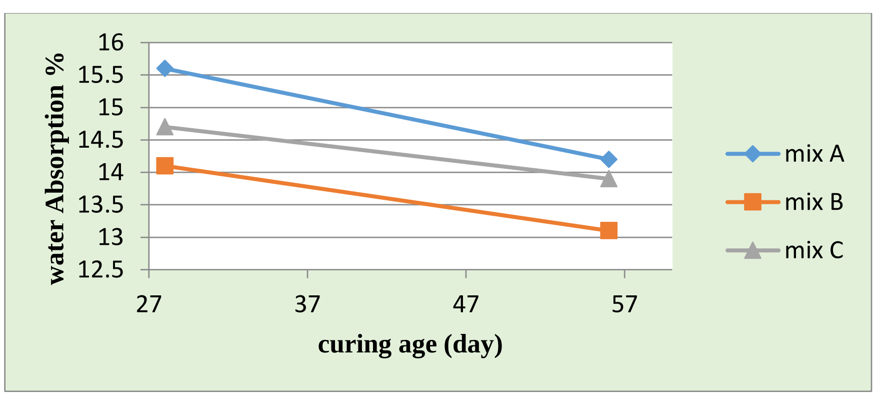

Fig. 4. decreasing in water absorbtion related to curing age for all mixes.

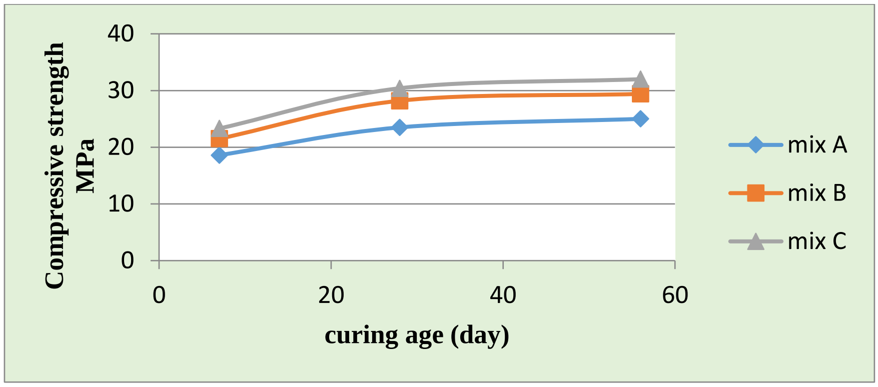

Fig. 5. Correlation between compressive strength and the curing age.

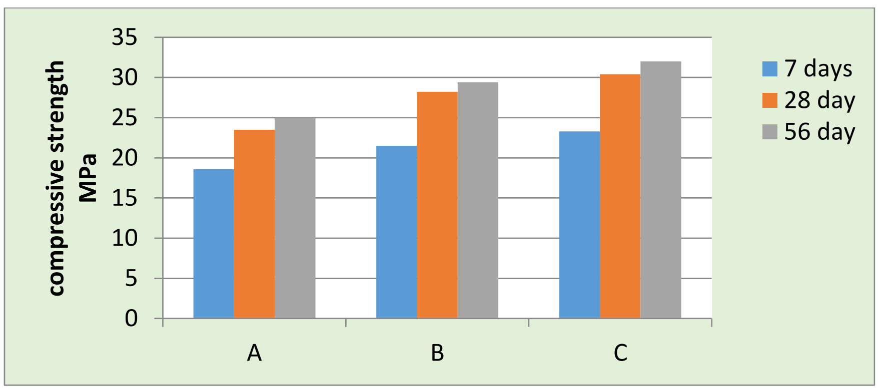

Fig. 6. The change in compressive strength with various types of mixes.

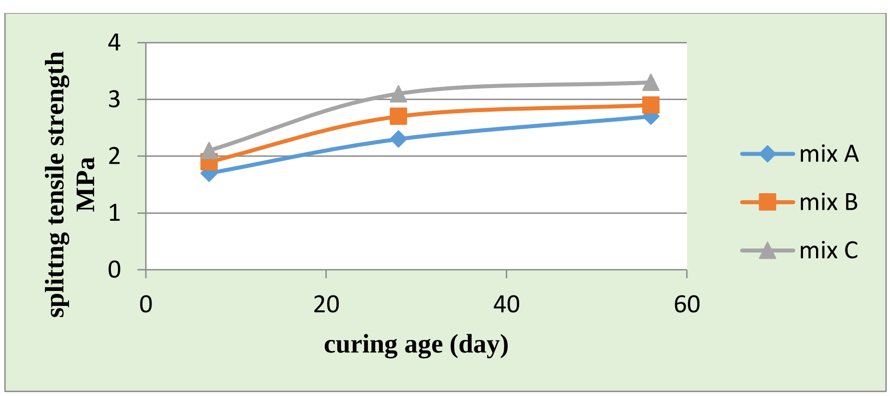

Fig. 7. The change in splitting tensile strength with different types of mixes.

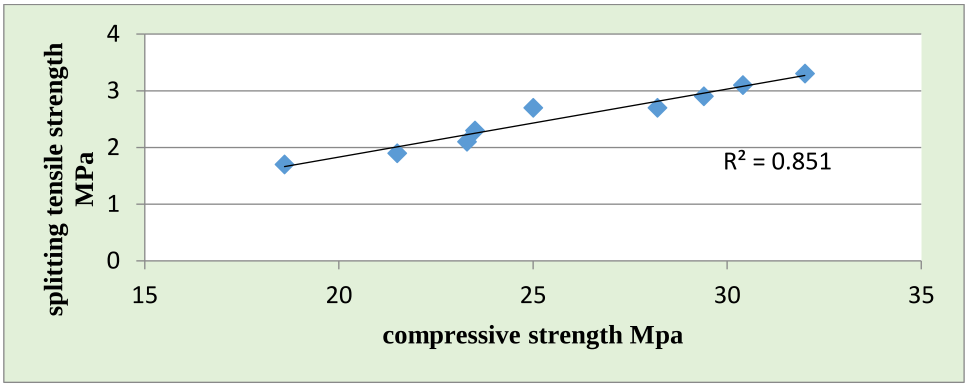

Fig. 8. The splitting tensile strength increases with the increase of the compressive strength.

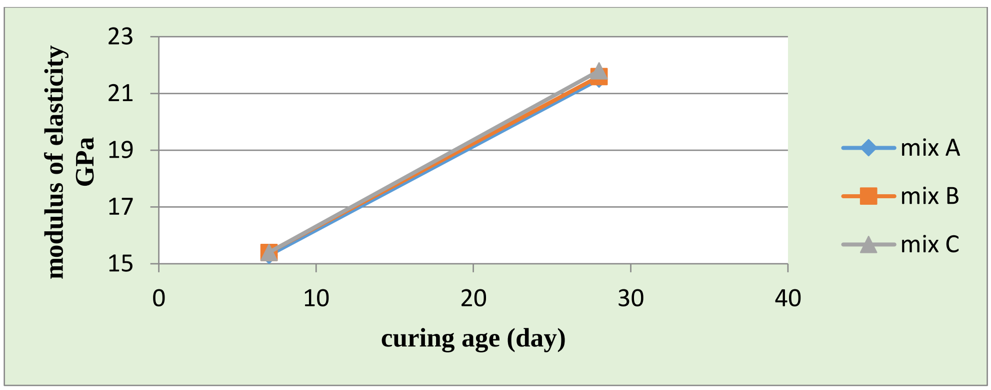

Fig. 9. Correlation between the elasticity modulus and the age of curing.

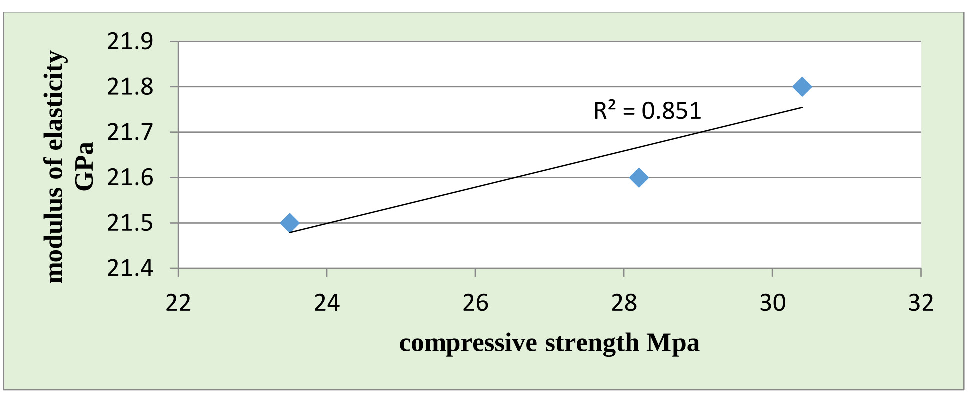

Fig. 10. Correlation between elasticity modulus and the age of curing.

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