PRODUCTION OF HIGH PERFORMANCE CELLULAR CONCRETE USING WATER CRYSTAL BEADS +

انتاج خرسانة خفيفة خلوية عالية المقاومة باستخدام بلورات السليكا المائية

Nadia salim *   **Dhirar T . M.** **

Abstract

This paper outlines the method of producing high strength light weight cellular concrete using new simple method in production. An experimental program was conducted to determine the compressive strength, density, and absorption of this concrete. Cubes were tested in compression and other properties, and the results were compared with other types of cellular concrete produced by other methods. The results show that the use of water crystal beads with the addition of silica fume and superplasticizer with different percentage gave three types of cellular concrete : a – structural (20.87) MPa , b – moderate (15) MPa , and c - insulated (Less than 11 MPa) .

Key words: - crystal beads, silica fume, compressive strength, cellular concrete

المستخلص:

ان البحث يهدف الى انتاج خرسانة خفيفة خلوية عالية المقاومة باستخدام اسلوب بسيط ومبتكر. تم الاعتماد على الفحوصات المختبرية: مقاومة الانضغاط ، الكثافة ، والامتصاص للخرسانة المنتجة بأعمار مختلفة وتم مقارنة النتائج مع مواصفات الخرسانة الخفيفة المنتجة بأساليب اخرى . النتائج المحصلة اثبتت ان استخدام بلورات السليكا المائية بنسب حجمية مختلفة مع اضافة مسحوق السليكا والمضافات الملدنة بنسب معينة اعطت ثلاثة انواع من الخرسانة الخفيفة :

أ- خرسانة خفيفة إنشائية (20.87 MPa) ب – خرسانة خفيفة متوسطة التحمل (15 MPa) ج- خرسانة خفيفة عازلة للحرارة اقل من(11 MPa).

Introduction:

In concrete construction, self-weight represents a very large portion of the total load on the structure, so there are clearly considerable advantages in reducing the density of concrete. Light concrete gives better thermal insulation than ordinary concrete , the practical range of densities of lightweight concrete is between (300) to (1850) kg / m^3 [1,2] . Densities ranging from 1000 kg/m^3 to 1500 kg/m^3 (compared to traditional concrete of 2500kg/m^3) combined with

+ **Received on 22/5/2011 , Accepted on**

* **Ass. Prof /Technical college / Mosul**

** **Lecturer/ Technical college / Mosul**

compressive strengths of 10MPa to 25MPa ensures a suitable alternative to traditional concrete. Due to its weight advantages, transportation and erection costs are significantly reduced [3].

Cellular Concrete for Road Construction has the potential to provide economical solutions as part of road building program. Costing 25% to 30% less than regular concrete, and possible applications include 'Base Stabilization', enhanced the Design' and 'Bank Stabilization' [4] .

Cellular Concrete is a lightweight material that solves many heavy-duty construction problems, so it can be used beneath roadways, bridges, ramps, buildings and other structures, it reduces soil loading while adding compressive and shear strength ,when density of cellular concrete is 750 kg /m^3 the compressive strength 3 MPa and the bearing capacity (328) ton /m^2 [5].

Lightweight concrete has been used in American highway bridges for over 50 years , and has generally performed satisfactorily in service and there is increasing evidence that the durability is at least as good as normal weight concrete. Lightweight concrete appears particularly advantageous for pre-cast , pre-stressed components to reduce handling costs where access is limited or where ground conditions are difficult. This has potential application to the upgrading of existing bridges , local road improvements and urban renewal schemes where disruption to traffic flow must be kept to a minimum.[5]

Foamed Concrete is an extremely versatile material with a wide range of applications. It can be used for road sub-bases, bridge abutments , bridge strengthening and road widening . It is especially advantageous and cost effective when used for projects on soft ground [6]. Usually allows less excavation of the road bed, to achieve a proper road structure; because cellular concrete will provide high strength and insulation in one layer [7] .

The lightweight concrete offers a cost-effective innovative solution to difficult and challenging road reconstruction in areas where there is weak soil, peat moss or where there is highly plastic clay. Traditional construction would have required considerable dewatering, extensive peat removal, the erection of sheet piling and then replacing the peat with granular material. About 950 cubic meters of the lightweight concrete was poured along a 120meter-long stretch, over a two-day period, the lightweight concrete was poured to a depth of 650 millimeters and then topped up with granular material and asphalt. Within about two weeks the road was reopened compared to the several weeks it would have taken with traditional construction [8].

Cellular concrete is more durable when compared to traditional insulating materials, especially when considering potential chemical / fire exposure such as in process facilities. Compressive strengths are typically four times greater than plastic foam insulations [9].

Applications of Lightweight Foamed Concrete; the cellular concrete can be used to produce, and construct the following:

Lightweight Foamed Concrete Blocks, Void Filling, Bridge Abutment,
Trench Reinstatement, Road Sub-Base, Wall Construction, Tunneling, Floor Construction, Lightweight Pre-cast Blocks, Ground Works, Fire Breaks, Sound Insulation [8, 9, 10].

There are three broad methods of producing lightweight concrete:

First, porous lightweight aggregates of low apparent specific gravity are used instead of ordinary aggregates whose specific gravity is approximately (2.6).

Second; aerated cellular, foamed or gas concrete by introducing large voids within the concrete or mortar mass.

Third; by omitting the fine aggregates from the mix so a large number of interstitial voids is present [11].

Cellular Concrete:

Cellular concrete is a cementitious paste of neat cement or cement and fine sand with a multitude of micro / microscopic discrete air cells uniformly distributed through out the mixes to create a lightweight concrete. It is commonly manufactured by three different methods:
Method A: consist of mixing a pre-formed foam or mix-foaming agents mixture into the cement and water slurry. As the concrete hardens, the bubbles disintegrate leaving air voids of similar size [4 , 11].
Method B: known as autoclaved aerated concrete (AAC) which consist of a lime, sand, cement, water and expansion agent. Expansion agent (aluminum powder or hydrogen peroxide) create a chemical reaction that generate gas, either as hydrogen or as oxygen to form a gas bubble structure within the concrete, the material is then formed into molds. After the initial setting it is then cured under high-pressure steam ($180^0 – 210\ ^0c$)" autoclaved "for specific period of time to produce the final micro / macro structure [2 ,6 ,11] .
Method C: Recently, a direction to concrete compositions prepared by using aqueous gels [aquagels] is being considered as all or part of the aggregate in a concrete mix. Aquagel spheres, particles, or pieces are formed from gelatinized starch and added to a matrix. Starch modified or unmodified such as wheat, corn, rice, potato or a combination of a modified or unmodified starches are examples of aqueous gels. A modified starch is a starch that has been modified by hydrolysis or dextrinizaton. Agar is another material that can create a pore or cell in concrete. During the curing process as an aquagel loses moisture, it shrinks and eventually dries up to form a dried bead or particle that is a fraction of the size of the original aquagel in the cell or pore in the concrete. This results in a cellular, lightweight concrete [12].

High- Performance Cellular Concrete :

High-Performance Cellular Concrete [**HPCC**] has all the properties of cellular concrete and can achieve (20- 50) MPa. Higher strengths can be produced with the addition of supplementary cementitious materials. Density and strengths can be controlled to meet specific structural and nonstructural design requirements. Where as in conventional cellular concrete these can not be achieved [13].

The advantages derived by the use of super plasticizers include production of concrete having high workability for easy placement and production of high strength concrete with normal workability but with lower water content [14].

Aim of research:

The research aim is to produce cellular concrete by using cement , sand , silica fume , super plasticizer and water crystal beads (magic crystal water jell). Water crystal beads used to make bubbles inside concrete paste. Silica fume and super plasticizer used to enhance compressive strength and workability.

Experimental work :

1 Material

1-1 Cement :

Ordinary Portland cement, Turkish cement (Adana) was used .Table (2.1) shows the physical properties of the cement used .

Table (1) Physical properties of cement used in the research.

Physical properties	Test result	Limit of Iraqi specification No.5 /1984
Specific surface area (Blaine method , m^2 /kg)	261	230 (minute)
Setting time (Vicat apparatus) : Initial setting (hr) : Final setting (hr) :	 2 : 05 3:15	 45 (minute) 10 hrs (max)
Compressive strength : 3 days , N /mm^2 7 days , N/mm^2	 23 29	 15 (minute) 23 (minute)

Test result indicated that the adopted cement conformed to the Iraqi specification [15].

1-2 Fine aggregates :

River natural sand with 9 % silica contain and grading limit B.S 882 /1992 was used throughout this work . Table (2.2) show the grading used .

Table (2) Grading of fine Aggregates

Sieve size (mm)	Cumulative passing %	Limits of BS (882 /1992)%
4.75	98.3	89-100
2.36	82.6	60-100
1.18	65.9	30-100
0.6	37.2	15-100
0.3	16	5-70
0.15	9.1	0-15

1-3 Silica Fume :

Silica fume is an extremely fine, spherical powder , that is used as an additive for improving concrete performance . The normal addition rates of silica fume range between (6 – 10) % by weight of the cementation content of the mix, this percentage can be increased to 15 %. Grey – colored un-defined silica fume was used percentage of Sio_2 is 98.5 %.

1-4 Super plasticizer :

High range water reducing admixture type sulphonated melamine formaldehyde condensate which is known commercially as (melment 10) was used . The material was prepared as a solution.

1-5 Water crystals beads :

Water crystal is kind of super water absorption polymer . It can absorb water up to several hundred times ,its weight in a short time and turns into jel form , the slowly release the water . One small packet of (10) gm will produce about 500gm of beads , see fig 2.1 and fig 2.2

2- Mixing , Casting and Curing:

First, the water crystal beads are socked in water ,for 24 hrs , in order to swell to reach their volumes .The beads then were mixed with dry cement to coat them and to increase the friction between the particles and concrete mixtures during the casting process. Super plasticizer mixed with water and added to the mixture .

The concrete mixture was mixed manually. Water added to the mix calculated depending on workability requirements as a percentage of binding materials
(cement + silica fume) .

Molds (100 x 100 x 100) mm were used to prepare (32) samples and the surface of each tamped by the rod in order to distribute the beads uniformly throughout the mixture , the surface of the mold then was covered by plate (100 x 100) mm with light load to keep the beads from floating up to the mold surface .

After one day the samples were removed from molds and divided into two groups , first group was soaked in water of a (23 c^0) temperature , the second was cured without water was covered with polythene sheets , and kept to the time of test.

2-1 Testing program:

Samples were used to test :
Compressive strength test for 3 , 7 , 28 , 56 days according to ASTM [16].
Absorption test, at age 28 days according to ASTM [17] .
Dry density test, at age 28 day according to ASTM [17] .

<u>Results and Discussion:</u>

Tables (3.1 to 3.6) show mixture properties and the results of testing specimens. Figure (3.1) show section across one of the tested specimens. Figures (3.2 to 3.4) indicate the relationships between the parameters measured for the research mixes.

1- Compressive strength:

In general lightweight concrete (LWC) is not as strong as normal weight concrete , and thus the concrete strength will depend on a number of considerations :type , quality , amount of aggregate used , size of fraction used , type and quality of binder used , and the type of admixture. The results of compressive strength for 3 , 7 , 28 , 56 day shown in tables (3.2 , 3.3) and figs (3.2 , 3.3) show strength increasing with age .

For mix (1) ; the percentage of strength increasing between 7 and 56 day is about 24 % and 21.5 % for mix (2) and so on , this increasing is less than percentage of increasing at early ages , because the *absence* of silica fume help the concrete to gain strength at early ages . Figs (3.2, 3.3) indicate that the compressive strength was affected by the type of curing. Compressive strength for the specimens cured with water at 23 c^0 gave higher results than self-curing specimens , due to enough curing water existing when using traditional curing method .For mix (4) the compressive strength for specimens cured with water was less than specimens cured without water at early ages due to mix proportion properties and curing condition that delayed the period of bond creation between the particles for specimens cured with water , and for this reason the specimens which contain high percentage of beads are preferable to be cured in water after 48 hours from date of casting.

Considering the specifications , ACI manual [1] and from the results shown , we can conclude that ; specimens have compressive strength between (15.22 – 20.87) MPa will be considered as structural concrete, specimens have strength between (11- 18) MPa as moderate concrete and below (11) MPa will be considered as insulation concrete .

Table (3.8) show a comparison between concrete block , cellular concrete (thermistone) product in Iraq [18] and cellular concrete produced in this research . From the information shown in table, compressive strength for cellular concrete mixes gave higher compressive strength.

2- Absorption :

Results for the different concrete mixes are shown in table (3.5). The absorption of the mixes is between 11.9 % to 14 %. Compared with concrete block, it is clear that the absorption are in agreement with the specification , although the mixes have more less densities than concrete block . Table (4-8) shows also the specification of concrete block and cellular concrete (thermistone) according to Iraqi specifications (No. 1077/1987) (1441 / 2000) respectively .From the table ,and when compared with thermistone the results of the research mixes are very good.

3- Air dry density :

The 28 – Air dry density of all mixes are shown in table (3.5). Results of the different concrete mixes show that using water crystal beads and getting the air bubbles inside the concrete reduce the density. Mix 1 gave (1600) kg / m^3 when the proportion of the crystal beads to ordinary sand was (1 : 0.5) , but when this proportion increased the density was reduced to (1200) kg / m^3 .

ACI manual [1] indicates the relation between compressive strength and densities. Concrete of density less than (350) kg / m^3 will have a strength between (1-3) MPa . Densities between (900 – 1850) kg / m ^{3} will give strength more than (20) MPa . The results in this research are within accommodation with the manual. See fig (3.4)

4- Thermal conductivity :

The important reason for producing cellular concrete is thermal insulation . According to ACI [1], thermal conductivity factor (k) is calculated from the equation:

$K = 0.072\ e^{(0.00125\rho)}$

K : thermal conductivity factor w / m . kcal

ρ= dry density kg / m^3

Compared with ordinary concrete (k = 1.45 w / m. kcal) , the results show good properties of thermal insulation table (3.4) .

5- Self curing :

The essential way to achieve the designed properties of concrete is proper curing, this mean avoiding water evaporation at the surface of the concrete member and supplying water from the exterior .If enough water is available to cement paste for hydration to proceed, the concrete will achieve excellent properties. The concrete with w /c lower than (0.4) in combination with the high cement content and with the addition of silica fume , show a high rate of hydration and a well-known relatively high compressive strength of early age . So creating a source of water supply inside the concrete mix (self-curing) enough for hydration process is a good idea [19, 20]. The water bubbles (water crystal beads) used in this research contain an amount of water, which will supply the concrete with the desired amount of water for hydration.

Conclusions:

From the results the research conclude the following:

1- Cellular concrete can be produced using the water crystal beads with dry densities between 1200 to 1600 kg / m^3.

2- At 28 days, the compressive strength for samples cured with water are between (8.8 to 19.7) still more than the results for samples cured without water (8.28 to 15.67) but both are of acceptable range .

3- The research mixes can be classified according to the results as:

a - mix 1 (compressive strength at 28 days age > 15 MPa) and mix 2 (compressive strength at 28 day age >11 MPa) can be used to produce structural concrete.

b- Mixes 3 and 4 can be used to produce isolative concrete (compressive strength at 28 day age < 11 MPa) .

4- Absorption for mixes are less than 14 % and this value can be considered good when compared with Iraqi cellular concrete (thermistone) blocks (45 %) .

5- Adding silica fume increase the compressive strength and using the super plasticizer increase the workability at the same w/ c ratio.

6- The calculated cost for the suggested cellular concrete is approximately the same as for traditional concrete but less than Iraqi cellular concrete (thermistone) cost.

7- Curing without using water is proper for places where there is not enough water for the curing process.

Table 3.1Composition of mixes

Materials	Mix 1	Mix 2	Mix 3	Mix 4
Cement kg /m^3	565	565	565	565
Sand kg/ m^3	1060	1060	1060	1060
Sand / water crystals (by volume)	1: 0.5	1 : 1	1 : 1.5	1 : 2
Sand m^3	0.631	0.631	0.631	0.631
Water crystal beads m^3	0.315	0.631	0.947	1.262
Silica fume kg/ m^3	85	85	85	85
Super plasticizer kg/ m^3	7	7	7	7
W /c (calculated)	0.18	0.17	0.12	0.08

Table 3.2 compressive strength curing with water at 23 C^0

Mix no.	At 3 days MPa	At 7 days MPa	At 28 days MPa	At 56 days MPa
Mix 1	13.38	15.9	19.7	20.87
Mix 2	8.26	14	15.54	17.84
Mix 3	6.75	12.47	14.9	16.3
Mix 4	2.4	5.3	8.8	10.87

Table 3.3 compressive strength curing without water

Mix no.	At 3 days MPa	At 7 days MPa	At 28 days MPa	At 56 days MPa
Mix 1	12.4	14.1	15.67	17
Mix 2	6.49	8.16	14.84	15.22
Mix 3	5.9	7.82	10.1	11.68
Mix 4	4.5	7.03	8.28	8.9

Table 3.4 properties of mixes

Mix no	Dry Density kg/m^3 At 28 days	Compressive strength at 28 days MPa curing with water	Compressive strength at 28 days MPa curing without water	Absorption % at 28 days	Thermal conductivity (k)*
Mix 1	1600	19.7	15.67	11.9	0.532
Mix 2	1550	15.54	14.84	12.12	0.499
Mix 3	1400	14.9	10.1	13.5	0.414
Mix 4	1200	8.8	8.28	14	0.322

* $k = 0.072 (e^{0.00125\rho})$ ρ = dry density

Table 3-5 Comparison between concrete block, and Iraqi cellular concrete (thermistone) specifications and research mixes.

Item	Allowable absorption%	Density kg / m^3	Thermal conductivity (k)	Compressive strength at 28 days age (MPa)
Concrete block type (A)	10	2400	1.45	> 13
Concrete block type (B)	15	2400	1.45	> 9
Thermistone	45	350 - 850	0.25	1 - 6
Mix 1	11.9	1600	0.532	19.7
Mix 2	12.12	1550	0.499	15.54
Mix 3	13.5	1400	0.414	14.9
Mix 4	14	1200	0.322	8.8

Fig (2.1) Crystal water beads before soaking in water

Fig (2.2) Crystal water beads after soaking in water

Fig (3.1) View in specimen after testing .

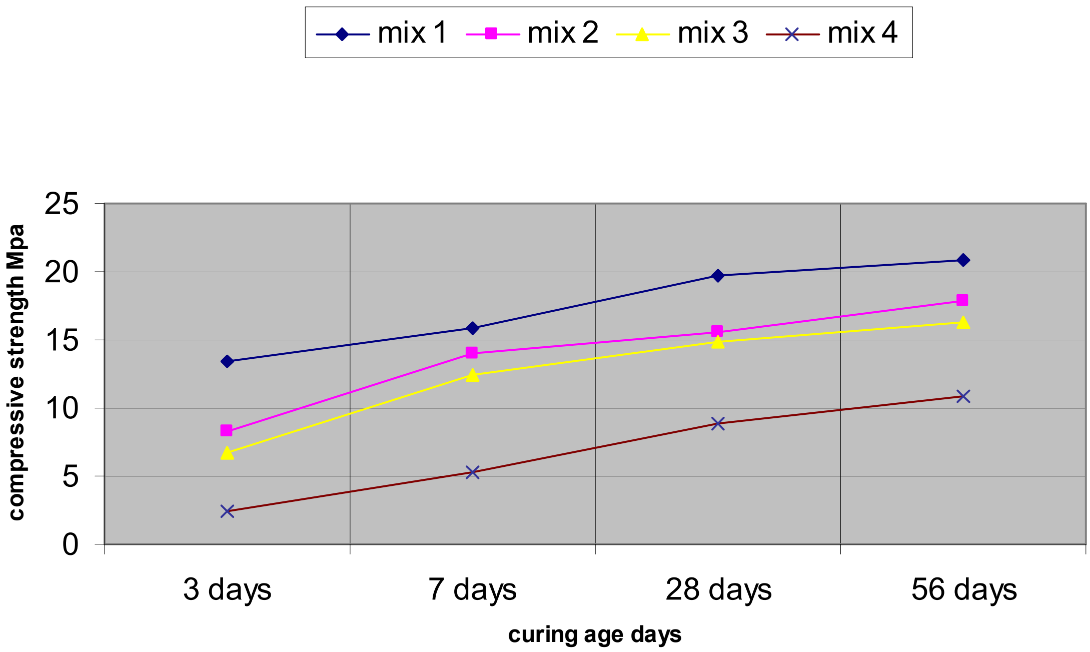

Fig (3.2) Relation between compressive strength and age with water

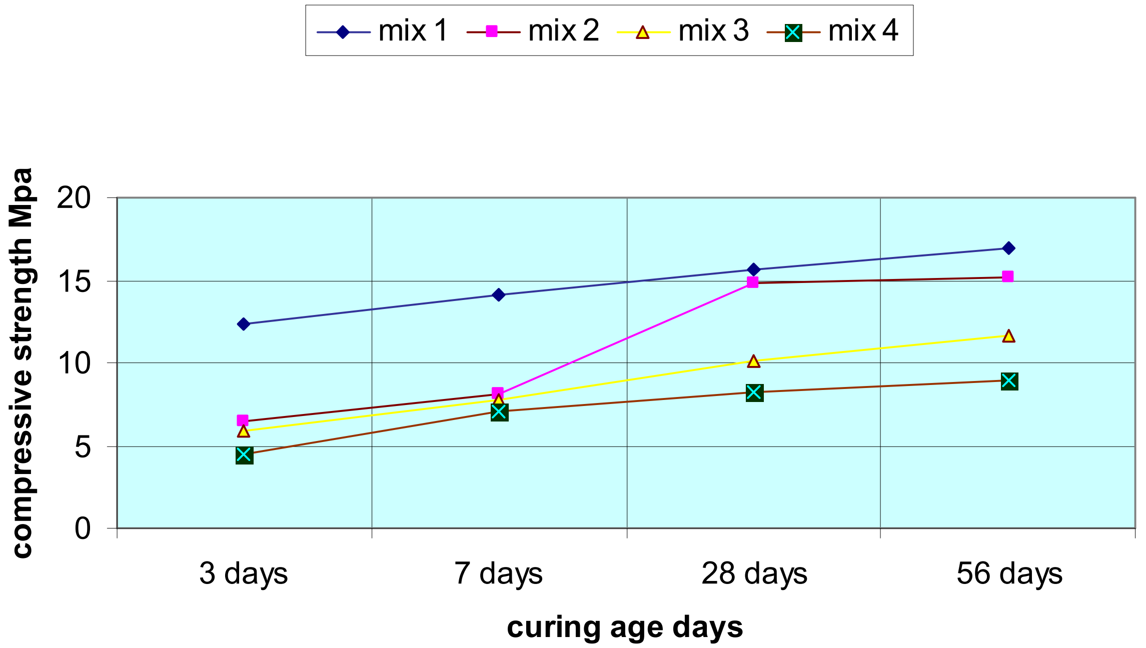

Fig (3.3) Relation between compressive strength and age without water

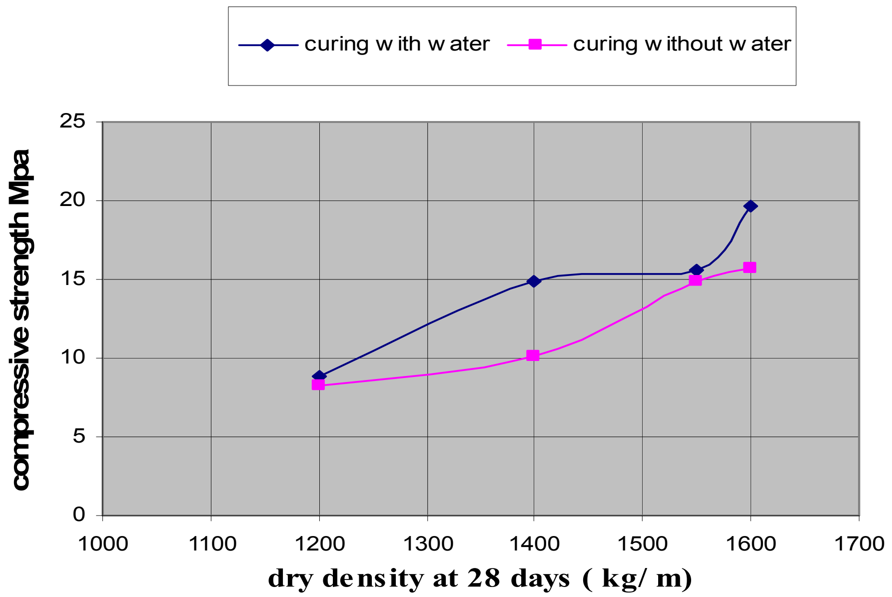

fig (3.4)Relation between density and compressive strength

References :

1- ACI manual of concrete practice . part 1 . Guide for use of admixtures in concrete . American institute . USA 1985.
2- Nadia S . , Daad M . " Foamed concrete masonry blocks using local raw materials " Raffiden jurnal / Mosul university vol 10 ,No.2 2002 p.1-6.
3- High strength lightweight concrete / Nova Nomination 23 / 2008.
4- Legatski , A. , " structural consideration of cellular concrete ,material and member behavior " proceeding of sessions at structures congress , ASCE ,NY , USA /1987.
5- K . Draithby and F.D Lydon " Lightweight concrete in highway bridges " Dept . of transport crowthome , UK 2003 .
6- Roald , A. ," Plastic foam in road embankment s " Ground Engineering , Jan. V. 19 . 1986 .
7- Sprinkel , M . , " Polymer concrete bridge overlays " Transportation Research Record , No . 1392 , USA.
8- Journal of commerce (western Canada's construction newspaper) " Lightweight Cellular concrete debuts in Ontario road project " September 6 / 2010 .
9- B. Dolton and C. Hannah " Cellular concrete : Engineering and Technological Advancement for Construction in Cold Climates " annual conference of the Canadian society for civil engineering , 2006.
10-R.N. Swamy " Lightweight aggregate concrete , the flagship of sustainable construction " Sixth CANMET / ACI International Conference on Durability of concrete , Jun , 2003.
11- AM Neville . " properties of concrete " 2003
12-" High- Strength structural lightweight concrete " /A new direction towards advanced construction , Light Concrete LLC 2003.
13-Malhtra , N.M . " properties of high- strength lightweight concrete incorporating fly ash and silica fume " ACI sp- 121 , 1990 , pp 645-666.
14-Concrete admixtures handbook properties , Science and technology V.S Ramachandren / 1984.
15- Iraqi standard specifications " Portland cement " NO .5 , 1984.
16-ASTM c 39 " Standard test method for compressive strength of lightweight concrete cube " .Annual book of ASTM , standards, vol . 04.02,1989.
17-ASTM 642 " Standard method for specific gravity , absorption and voids in hardened concrete " Annual book of ASTM , standards , vol. 04.02 , 1989.
18- Iraqi standard specifications " Cellular concrete " No . 1441, 2000 .
19-S. Weber and H.W Reihardt " modeling the internal curing of high strength concrete using light weight aggregates " Sixth (ANMET/ ACI International conference on durability of concrete , June 2003 pp 45-65 .
20-Arafah , A.M., " Effect of Dry – Curing on the compressive strength of semi Lightweight Concrete " Proceedings , Third international concrete under severe conditions , CONSEC 01 , university of British Columbia , Vancouver, Canada , 18-20 June 2001 , vol 2 , pp1217-1221.