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THE EFFECT OF CURING METHODS ON THE PROPERTIES OF HIGH PERFORMANCE LIGHTWEIGHT CONCRETE IN HOT DRY WEATHER CONDITIONS

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Abstract: This study is concerned with the effect of curing methods and early curing on the some properties of high performance lightweight concrete HPLWC that exposed to effects of hot dry weather conditions to improve the performance of concrete structures. The experimental work was carried out during Iraqi summer season at 12:00 pm. with average temperature 55°C and relative humidity RH 13% under actual atmospheric condition by used fixed mix proportions for preparing and casting specimens and applying different curing methods represented by water curing (WC) for 13 day, water based curing compound (WBC), and bitumen based curing compound (BBC), as well as curing specimens by burlap covering with sprinkling water 3 times a day(BWS) after (5:00, and 8:00,24:00)h. from casting for 13 day, and air curing(AC). The effect of selected curing methods on the properties of HPLWC was evaluated by measuring compressive and splitting tensile strength, modulus of rupture, static and dynamic modulus of elasticity and pulse velocity. The results show that the best performance with regard to the 28 day strength and later ages was in specimens cured by applying WBC followed WC, and then BWS, and less order BBC and in the decreasing order specimens of AC. The results display that early curing after (5:00, and 8:00) h. from casting does not improve concrete properties comparative to that cured after 24 h.

Keywords: *high performance lightweight concrete, hot dry weather, curing methods, curing compound*

تاثير طرق المعالجة على خواص الخرسانة الخفيفة الوزن عالية الاداء في ظروف الجو الحار والجاف

الخلاصة: يهتم هذه البحث بدراسة تاثير طرق المعالجة بالاضافة الى المعالجة المبكرة على خواص الخرسانة الخفيفة الوزن عالية الاداء والمعرضة لظروف الجو الحار والجاف وذلك لتحسين اداء المنشات الخرسانية .تم تنفيذ الجانب العملي خلال فصل الصيف في العراق في وقت 12 ظهراً بمعدل درجة حرارة 55 م° ورطوبة نسبية 13% تحت تأثير ظروف جوية واقعية باستخدام نسب خلط ثابتة لتهيئة وصب نماذج خرسانية باستخدام طرق معالجة مختلفة تمثلت بالاتي : المعالجة بالماء لمدة 13 يوم ، معالجة بالمركبات الكيمياوية ذات الاساس المائي ،واخرى ذات الاساس القيري ، معالجة بالتغطية بالجنفاص المرطب عن طريق الرش بالماء ثلاث مرات يومياً وذلك بعد 24 ساعة بالاضافة الى المعالجة المبكرة بعد (8,5) ساعات من وقت الصب لمدة 13 يوم، كما تم ترك النماذج بالهواء بدون معالــجة. تم تقييم طرق المعالجة على خواص اللخرســـانة من خلال قياس مقاومة الانضغاط ،الشد بالانفلاق ،معاير الكسر ، معامل المرونة الستاتيكي والديناميكي وسرعة الامواج فوق الصوتية . اظهرت النتائج ان افضل اداء لطرق المعالجة كان للنماذج المعالجة بطلائها بالمركبات الكيميائية ذات الاساس المائي تليها النماذج المعالجة بالماء ثم المعالجة بالجنفاص بعد 24 ساعة من الصب وبدرجة اقل النماذج المعالجة بالطلاء بالمركبات الكيميائية ذات الاساس القيري واقلها كان في النماذج المعالجة بالهواء.كما بينت النتائج ان المعالجة المبكرة بعد (8,5) ساعات من وقت الصب لم تؤدي الى تحسين خواص الخرسانة بالمقارنة مع تلك النماذج المعلجة بعد 24 ساعة .

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1. Introduction

The climatic conditions in the hot and arid areas of the world are considered to be very aggressive for concrete and create several problems for both fresh and hardened concrete [1].The climatic factors affecting concrete in hot weather are high air temperature and low relative humidity (RH), the effects of which may be considerably more pronounced with increases in wind velocity and intensive direct solar radiation [2].Increase rate of evaporation and mix concrete temperature led to excessive plastic shrinkage and cracking, reduction in strength and may give rise to discrepancy the durability of the concrete and ultimately endanger the safety of the structure [3, 4].

In such weather, the need for proper early moist curing and an interest in suitable curing methods and replacement cementitious materials is essential to improve concrete quality in hot countries [4]. There are two main types of curing; first, the continuous or frequent application of water through ponding, sprays, steam, or saturated cover materials such as burlap or cotton mats, sand, sawdust and straw; second, the prevention of excessive loss of water from the concrete by means of materials such as sheets of reinforced paper or plastic, or by the application of a membrane-forming curing compound to the freshly placed concrete [7]. Recently, lightweight aggregate (LWA) as well as to the other main benefits as reduced dead load of the structure and thermal conductivity, it have been used successfully in large construction projects for the purpose of internal curing (IC).It is a very promising technique that can provide additional moisture in concrete for a more effective hydration of the cement and reduced self-desiccation especially in low permeability concrete such as high performance concrete(HPC) which made of very low water /cement ratio mixes[8]. The use of internal curing, however, does not substitute recommended curing practices, as it is essential to keep the concrete surface always moist during the curing process in order to avoid surface cracking due to plastic or drying shrinkage in hot, dry or windy weather [8].

Acknowledgment of the important influence of the curing methods on decreasing the adverse effects of hot weather on the properties of the concrete has directed many of the experimental efforts towards trying different techniques of curing. Though, reported effects of these curing techniques on the properties of concrete are not always in agreement. The effect of curing period and initial water curing on compressive strength of SLWA concrete specimens which prepared outside the laboratory in summer season is well covered by literature [9,10]. In the field of effect of early curing on compressive strength of normal concrete, the results show that there is no clear effect on strength of concrete when curing started after 2,4 h from casting [11].While the effect of curing methods on strength of concrete was carried out by several investigators [10-14]. Information about effects of curing on strength development of high strength or high performance concrete is relatively less documented. The aim of this study is to investigate the influence of the different curing methods and efficiency of early curing on the several properties of HPLWAC in the actual hot dry weather conditions.

2. Experimental program

2.1. Materials

2.1.1. Cement

Ordinary Portland cement manufactured by Mass Bazian factory was used; its chemical composition and physical properties are shown in "Table 1" . They are conformed to Iraqi specifications (I.Q.S) No. 5/1984.

Table 1. Chemical composition and Physical properties of cement

Oxides composition	Content (%)	Physical properties	Test result	Limis of I.Q.S No.5/1984
CaO	65.85	Specific surface area Blaine methods (m^2/kg)	391	≥230
SiO_2	22.76			
Al_2O_3	5.59			
Fe_2O_3	3.28	Setting time (Vacats method)		
MgO	1.30	-Initial setting(h: min)	1:55	≥ 45 min
SO_3	2.75	-Final setting (h: min)	3:25	≤ 10 h
Na_2O	0.32			
MnO	0.10			
Loss on Ignition, (L.O.I)	1.05			
Insoluble residue	1.27	Compressive strength of mortar (MPa):		
		3-days	23.7	≥15
		7-days	31.4	≥23
Lim Saturation Factor, (L.S.F)	0.88	Soundness (Autoclave method),(%)	0.16	≤ 0.8

2.1.2. Silica fume

Silica fume was used known commercially as (Sika fume-HR). It was brought from Sika Company. The chemical composition and physical properties of the silica fume are given in "Table 2", respectively. The results show that the silica fume used satisfies the requirements of ASTM C 1240-06 .

Table 2. Physical properties and chemical composition of silica fume (SF)

Physical Properties	Test results	ASTM C1240 limitations
Unite weight (kg/m^3)	3.00	-
The amount of SF remaining on a sieve of 45 μm, (%)	4.20	≤ 10
Accelerated Pozzolanic Strength Activity Index with Portland cement at 7 days, % of control.	126	≥ 105

Chemical composition

Oxides composition	CaO	SiO_2	Al_2O_3	Fe_2O_3	MgO	SO_3	K_2O	Loss on ignition
content (%)	0.15	90.65	4.53	1.56	2.0	0.02	3.39	2.86

2.1.3. Fine Aggregate

Natural sand brought from Al-Ukhaider region was used as fine aggregate passing through sieve of 4.75 mm. The results indicate that the fine aggregate grading and the sulfate content conform to the Iraqi specification No.45/1984 Zone 2. Also, lightweight fine aggregate (Pumice) was used as partial replacement by volume of the natural sand ,this LWA was crushed by crusher machine. The gradation of pumice fine aggregate (PFA) was prepared as that of the natural sand.

2.1.4. Coarse lightweight aggregate

The lightweight coarse aggregate (pumice) was used as fully replacement of normal aggregate. Grading of pumice coarse aggregate (PCA) falls in the size designation of 12.5 to 2.36 mm in accordance to ASTM C 330-04[15]. Physical properties of pumice lightweight aggregate are shown in "Table 3".

Table 3. Physical properties of pumice lightweight aggregate

Property	Specification	Result	
		Fine	coarse
Specific gravity	ASTM C127-88 ASTM C128-88	1.32	0.93
Absorption at 24 hours, (%)	ASTM C127-88 ASTM C128-88	17.3	28.6
Dry loose-unit weight,(kg/m^3)	ASTM C29-89	968	672
Dry rodded- unit weight,(kg/m^3)	ASTM C29-89	1117	758

2.1.5. High Range Water Reducing Admixture: Superplasticizer

A high range water reducing agent was used (commercially known as Sika Visco Crete - 5930), and meets the requirements for superplasticizer (Sp)according to ASTM C -494 type G and F[16].

2.2. Mix proportion, mixing procedure, and preparation, casting of the specimens

Mix design is made in accordance with volumetric method ACI 211.2[17].The reference concrete mixture is designed to give at 28-day characteristic compressive strength of 40 MPa. The design was made to conform to the requirement of structural LWAC, according to ACI Committee 213 classification [18].Many trial mixes was carried out to select suitable mix, the final mix had the constituents listed in "Table 4".

Table 4.Selected mix design proportion

Concrete ingredients	Cement (kg/m^3)	Normal Sand +PFA (kg/m^3)	PCA (kg/m^3)	Water + SP (kg/m^3)	Sp (by wt. of cement) (%)	*SF (kg/m^3)*	w/cm (%)
Contents	572	763	482	188	1.5	57.2	0.32

Mixing process was conducted outside the laboratory under actual hot dry weather conditions in the summer season at 12:00 pm. with average temperature 55°C and relative humidity RH 13%. Before mixing, all concrete ingredients and mixer as well as molds keeping them under sun radiation, and the pumice aggregates was pre-soaked for 30 minutes in water and used after removal of excess surface water to produce the aggregate particles in state saturated surface dry (SSD) condition. A pan mixer of 0.1 m^3 capacity was used. PCA was added first to the drum followed sand and PFA. All these materials were first mixed for 1 minute to get homogenous materials. The required cement and SF were mixed manually until a homogenous mixture was obtained, then they were added to the rotary drum. Two thirds of mixing water was added to the dry mixture and mixed for 1 minute. Finally the superplasticizer and one third of the remained water were stirred and added. After that the mixture was mixed for 6 minutes.

A specially prepared timber molds were used they were tightened thoroughly .After mixing process the fresh concrete was casted in the molds with approximately equal layers of 50mm for all the specimens and consolidated by means of vibrating table for a sufficient period. Care should be taken to avoid segregation of the LWA. A number of standard test specimens of different sizes were casted for investigating the various parameters.

- A total of 120 cubes 100 mm were casted for testing compressive strength and ultrasonic pulse velocity.
- Splitting tensile strength test was conducted on 120 cylinders of 100*200 mm.
- A total of 154 prisms of 100*100*400 mm, 120 prisms were used for flexural strength test, and 54 prisms for testing dynamic modulus of elasticity.
- 24 Cylinders of 150*300 mm were used to determine static modulus of elasticity.

2.3. Curing of the test specimens

After 24 hours from casting, the specimens were demolded and cured by one of the following curing methods under actual weather conditions as shown in “Table 5”.after specified period of curing, the specimens left outside exposure to atmospheric conditions until time of casting.

To provide a sound basis for comparison anther mixture (reference mixture) referred to (M-Ref); mixing of materials, preparing, casting and curing of specimens carried out inside the laboratory where temperature 23± 2° C and RH about 65±5%.

Table 5.curing methods adopted throughout this investigation

Mix designation	Curing Conditions
M- Ref	water cuing for 13 days(cured under laboratory conditions), then left in laboratory conditions until time of casting.
M- WC	water cuing for 13 days.
M -BWS	burlap covering with sprinkling water 3 times a day for 13 days.

M- WBC	brushing by (water based)curing compound.
M-BBC	brushing by bitumen based curing compound.
M -AC	air curing.
M -EC-5:00	early curing , after (5:00) hours from casting, the specimens demolded and cured by covering with burlap and sprinkling water 3 times a day for 13 days
M- EC-8:00	early curing , after (8:00) hours from casting, the specimens demolded and cured by covering with burlap and sprinkling water 3 times a day for 13 days

3. Results and Discussion

3.1. Compressive strength

The effect of different curing methods on compressive strength of HPLWAC specimens can be seen in "Table 6”, and "Fig. 1", the results indicated that compressive strength up to 7 days of all concrete specimens which casted and cured by different methods under actual hot dry weather conditions approach from others, this may be due that the water existing in capillary pores at early ages assist to continuous hydration process and there is insignificant effects of curing methods [11]. The results also show that up to 7 days, the specimens without curing (air curing) does not seem to have a noticeable effect on the compressive strength, this may be attribute to the internal reservoir of water, which is stored in pores lightweight aggregate particles, this internal water keeps the hydration process going[10].

From "Fig. 1" it can be seen that all specimens cured under actual hot dry weather conditions have strength at early ages higher than that casted and cured in the laboratory (M-Ref).The percentage increase in strength of specimens M(WC, WBC, BBC,BWS and AC) at age (3, and 7) days compared to that (M-Ref) was (10.4,9.5,7.7,8.6,and7.2)% and (12.3,10.2,8.5,9.7,and6.8)% respectively. This may attributed to exposure specimens to severe conditions which air temperature about (55ºC) and relative humidity (13%) results in evaporation some of mixing water and reducing W/C ratio resulted in an increasing in compressive strength[19] . It can be also observed that there is enhanced in strength at 28 days for specimens (M-WC), and (M-WBC), the percentage increase was (5.3, and 6.6) % respectively, while a very slight decrease in the compressive strength of specimens (M-BBC) and (M-AC). Whereas strength of specimens (M-BWS) slightly increased by about (2.6) % compared to their (M-Ref).At later ages there is decrease in strength for all specimens cured by different curing methods except specimens (M-WBC) ,it is approach to the strength (M-Ref) , it is slightly increased by about 1.9 % at 90 day ,while it slightly decreased by about 1.6% at 180 day. The percentage decrease in strength of specimens (M-WC, M-BBC,M-AC, and M-BWS) at (90,and180)day compared with specimens(M-Ref) was(2,7.8,10.1,and 5.1)% and (3.8,8.2, 10.9,and 6.7) %respectively. However, at the age of 180 days, i.e., after prolonged exposure of specimens to hot-dry weather conditions, the effect of lack of curing has an effect on the strength development. These results are in agreement with the finding of Al-Khaiat and Haque [10].

Table 6. Compressive strength of HPLWAC specimens using different curing methods

Mix Designation	Compressive strength(MPa) at age (days) 3	7	28	90	180
M-Ref	33.7	35.1	45.3	52.4	55.2
M- WC	37.2	39.4	47.7	51.3	53.1
M -WBC	36.9	38.7	48.3	53.4	54.3
M- BBC	36.3	38.1	44.8	48.3	50.7
M- AC	36.1	37.5	44.2	47.1	49.2
M - BWS	36.6	38.5	46.5	49.7	51.5
M- EC 5:00	35.6	37.1	44.1	45.1	46.5
M- EC 8:00	36.1	37.8	45.2	47.7	49.6

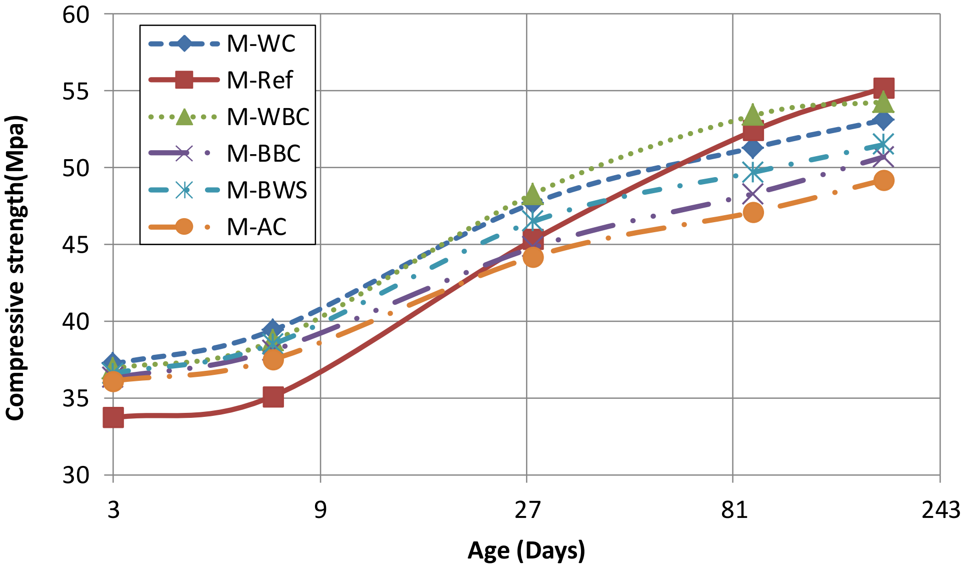

Figure1.Development compressive strength of HPLWAC specimens cured by using different curing methods

The results indicated in "Table 6" also show that the compressive strength of HPLWAC specimens cured by covering with wet burlap after 24 h. higher than that of specimens cured after (5:0, and 8:00) h. from casting at all ages ,however the difference in strength between these specimens at early ages is negligible; this behavior may be ascribed to the “inner water” stored in the porous lightweight aggregate (pumice) of HPLWAC , while the difference become a little more at 28 day and at later ages. The average percentage decrease of compressive strength at later ages was (10.5,and 4)% respectively, this may be attribute to fact that the initial concrete temperature for specimens cured after (5:00,and 8:00)h. from casting was high, approximately (50,54)°C respectively and water temperature about (36,33)°C respectively, this resulted in moisture gradient and probably causes cracking in concrete and reduction in compressive strength due to the wetted process by burlap followed by exposure specimens to prevailing wind result to extremely gradient in temperature between concrete surface and inside[11].

In general the results of compressive strength of HPLWAC specimens indicated that there is improvement in strength due to the physical and chemical effect of SF. Its acts as a filler of the spaces between the cement grains, and reduces the pore volume in the concrete by refined pore structure, also due to pozzolanic reaction the open channels are blocked by the high pozzolanic reaction products and therefore, the porosity is reduced [20]. On the other hand, the action of SP on the structure of hardened pastes of low water-binder ratio is also reflected on the result of compressive strength.

3.2. Splitting tensile strength

The splitting tensile strength values of HPLWAC specimens cured by different curing regimes under actual hot dry weather conditions are included in "Table 7", also the relationship between the splitting tensile strength of these specimens with age plotted in "Fig. 2", it can be seen that all specimens have higher splitting tensile strength at 3, and 7 days than that (M-Ref). The percentage of increase for specimens M(WC, WBC, and BWS) at 28 day comparatively with(M-Ref) was (5.1,6.2, and 3)% respectively, whereas the strength decrease slightly for specimens (M-BBC, and M-AC)by about (1.7,and 3.5)% .While at later ages (90, and 180) day specimens M(WC, BBC, BWS, and AC) had strength less than that for specimens(M-Ref) by about (3.1,7,5.2,and8.7)% and (5.3,8.9,7.4, and10.6)% respectively . The results also show that the strength of specimens (M-WBC) at 90 day is approximately similar to that (M-Ref), but it decrease slightly by about 2.6% at 180 day.

The results also show that the behavior of specimens (M-WBC) in splitting tensile strength are the same as that observed in compressive strength. This may be attributed that (WBC) impedes the loss of moisture in a hot dry weather ,the resultant film retains sufficient moisture in the concrete to ensure enough hydration of the cement, while in the case of (AC) ,self–desiccation will occur, with accompanying autogenous shrinkage that causes internal microcracking since there is no external supply of water[14].

The data in "Table 7" show also that the splitting tensile strength of specimens cured after(5:00,and 8:00) h. from casting slightly less than that cured after 24 h. at all ages, the percentage decrease at (3,7,28,90,and 180)day was (3.8,3.7,5.3,5.8,and 5.6)% for specimens cured after 5:00h.,and about (2.7,2.7,3.6,3.9,and3.8)% for specimens cured after 8:00 h., respectively, this may be probably due to the fact (in addition to the reason mentioned previously) that in the case of specimens cured after 24 h., only one face of the sample is exposed to the environment during the first 24 h.(before demolding),while the other faces are insulated by the wooden mold. In other words, only one-six of the sample surface area was exposed to the environment. Such exposure condition delayed water retention inside the samples and minimized water loss [6]. The relationship between the compressive strength and the splitting tensile strength of specimens at age 28 and 180 days are presented in Table (11). These results show that the splitting/compressive strength ratios range between (9.84% to 10) % and (9.57% to 10%) respectively. These results to same extent are in agreement with findings by Sampebulu [21] where the tensile strength of high strength lightweight aggregate concrete about (8.3) % of its compressive strength when ambient temperature was 40°C.

Table 7. Splitting tensile strength of HPLWAC specimens using different curing methods

Mix Designation	splitting strength(MPa) at age (days) 3	7	28	90	180	Splitting tensile strength/compressive strength at age 28days	Splitting tensile strength/compressive strength at age 180 days
M-Ref	3.27	3.47	4.52	5.13	5.37	9.97	9.72
M-WC	3.8	4.12	4.75	4.97	5.08	9.95	9.57
M- WBC	3.74	4.05	4.8	5.18	5.23	9.93	9.63
M- BBC	3.69	3.98	4.44	4.77	4.89	9.91	9.64
M- AC	3.64	3.96	4.36	4.68	4.8	9.86	9.75
M- BWS	3.72	4.02	4.66	4.86	4.97	10.02	9.65
M- EC 5:00	3.54	3.83	4.34	4.53	4.65	9.84	10.0
M-EC 8:00	3.62	3.91	4.49	4.67	4.78	9.93	9.63

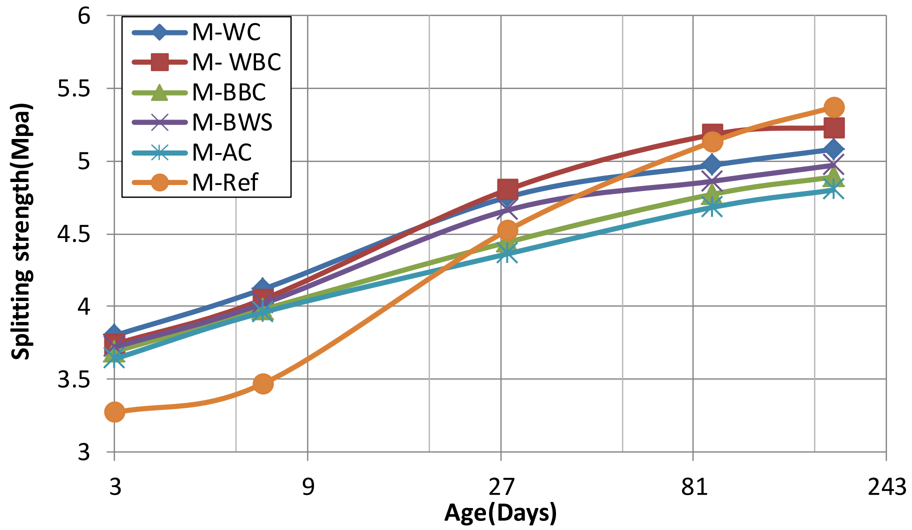

Figure 2. Development in the splitting tensile strength of HPLWAC specimens

3.3. Flexural strength (Modulus of Rupture)

The relationship between the modulus of rupture (ultimate flexural strength) of HPLWAC specimens and age are shown in "Table 8"and" Fig. 3".In general it can be seen that all specimens had higher modulus of rupture than that (M-Ref) at early ages (3, and 7) days ,the percentage increase for specimens(M-WC, M-BWS, M-WBC, M-BBC, and M-AC) was (10.1, 9.2, 7.6,5.9, and 3.5)% at 3 days and (11.4,10.8,9.2,6.5 and 3.4)% at 7 days respectively, while at 28 days, the percentage increase was (5.0,3.2,6.6, and 1.5)% respectively ,and for specimens (M-AC) approximately the same. The results also indicated that at later ages (90, and 180) days , the modulus of rupture of these specimens decreased by about (3.5,4.0,1.3,5.4,and 8.2)% and (4.2,6.1,2.2,8.4, and 11.1)% respectively, compared to their (M-Ref) .

On the other hand, the results show also that covering the specimens by burlap and sprinkling water 3 times a day for 13 day improve its modulus of rupture and there is little difference relative to that for (WC, and WBC) specimens, however care should be taken by remaining the burlap as possible as wetting ,because when hot-dry weather conditions prevail, the rate of water evaporation from the surface of the concrete was so high that shortly after stopping the sprinkling of water the burlap gets dry and relatively hot and it may slightly increase the temperature of the concrete.

Table 8. Modulus of rupture of HPLWC using different curing methods

Mix Designation	Modulus of rupture (MPa) at age (days)				
	3	7	28	90	180
M-Ref	5.43	5.65	7.25	8.37	8.61
M -WC	5.98	6.38	7.61	8.08	8.25
M -WBC	5.84	6.17	7.73	8.26	8.42
M - BBC	5.75	6.02	7.36	7.91	7.88
M -AC	5.62	5.84	7.13	7.68	7.65
M- BWS	5.93	6.26	7.48	8.00	8.08
M-EC 5:00	5.66	5.93	6.88	7.32	7.54
M -EC 8:00	5.81	6.07	7.18	7.67	7.86

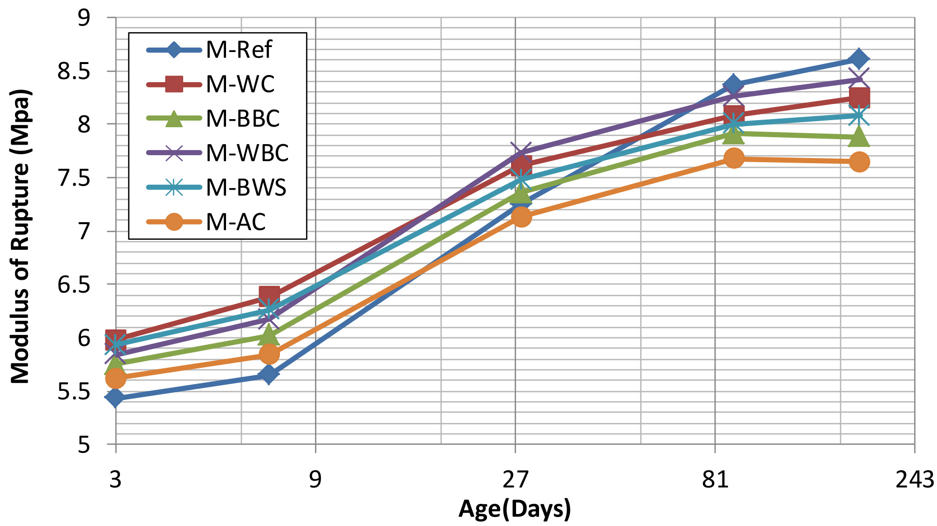

Figure 3. Development modulus of rupture of HPLWAC specimens using different curing methods

The data in the “Table 8” demonstrate also as compressive and splitting tensile strength that modulus of rupture of specimens cured after 24 h. higher than that for specimens cured after (5:00, and 8:00) h. at all ages .The percentage of decrease of modulus of rupture of specimens cured after 5:00 h. was (4.6,5.3,8,8.5 and 6.7)% at (3,7,28,90,and 180) respectively. While specimens cured after 8:00 h. exhibited modulus of rupture higher than that of specimens cured after 5:00 h. and show marginal decrease compared to that cured after 24 h. the percentage of decrease was (2,3,4,4.1, and 2.7)% at (3,7,28,90,and 180) respectively.

3.4. Static Modulus of Elasticity (Es)

“Table 9” and "Fig. 4" show the effect of curing methods after 24 h from casting on the Es of HPLWAC specimens casted under actual hot-dry weather conditions. It can be seen that Es ranged from (24.35-20.63) GPa, possibly the presence of inner reservoir of water in the porous LWA particles and the resultant ongoing hydration, irrespective of the exposure conditions, has not caused any degrading effect on the Es value. Normally for a given compression resistance, the modulus of elasticity for LWC is lower than that of conventional concrete. Elastic modulus of normal weight aggregate it varies from 21 to 49 GPa , the elastic modulus of a lightweight aggregate may be as low as 7 GPa or as high as 28 GPa. Generally, the elastic modulus of LWC ranges from 14 to 21 GPa, which is between 50 and 75 % of the modulus for NWC of the same strength [22]. This is due to the lightweight aggregates greater deformability with respect to the heavier ones [23]. However, an increasing in modulus of elasticity of HPLWC may be due to improvement in the interfacial transition zone, enhanced the hydration process because of internal curing and absence of shrinkage-induced microcracking.

The results also show that Es at 28 days of specimens (M-Ref)was higher than other specimens cured by different curing methods. The percentage increase compared to (M-BWS, M-BBC, and M-AC) is (8.5,11.3, and 13.1)% respectively, this behavior may be due to elevated curing temperature hinders the hydration of cement at later ages and forms an open pore structure of cement paste and therefore affects the properties of hardened concrete. While Es for specimens (M-WBC, and M-WC) are approximately similar to reference specimens, due to its have high compressive strength. The modulus of elasticity of concrete is a function of compressive strength and normally Es increases with the increase of compressive strength. On the other hand, the results show that Es of specimens (M-WBC) higher than other specimens cured by other curing methods. The percentage increase of specimens (M-WBC) compared to specimens (M-WC, M-BWS,M-BBC, and M-AC) is (1.8,8.2,11.1, and 13.4)% respectively.

Most of the international standards take into account that modulus of elasticity of lightweight concrete depends on the compressive strength and the density. The tests conducted so far with different aggregates confirm both influences. Various building codes have provided empirical equations relating Es and compressive strength. The test results of Es are comparable to the values calculated according to "(1)" suggested in ACI -213 [18] expression of:

$$Es = 0.043\,\rho^{1.5}\sqrt{f_c} \qquad (1)$$

Where:
Es: static modulus of elasticity (GPa)
ρ: concrete density(Kg/m^3)
f_c : cylinder compressive strength (MPa)
and the values calculated according to "(2)" suggested in BS [24] , expression of:

$$Es = 1.7\,\rho^{2}\,f_{cu}^{\;0.3} \qquad (2)$$

Where:

f_{cu} : cub compressive strength(MPa)

Table 9. static modulus of elasticity (E_s) of HPLWC using different curing methods at age 28 days

mix designation	f_{cub} MPa	Es(Gpa) Experimental	Es (ACI)Formula	Es (BS) Formula
M-Ref	45.3	24.35	21.88	19.51
M- WC	47.7	23.87	21.65	19.86
M-WBC	49.9	24.30	21.60	19.92
M-BBC	45.3	21.87	21.17	19.44
M- AC	43.1	21.43	19.67	19.28
M-BWS	46.6	22.45	21.34	19.63
M- EC 5:00	44.5	20.63	20.30	19.36
M- EC 8:00	42.3	21.08	21.58	19.51

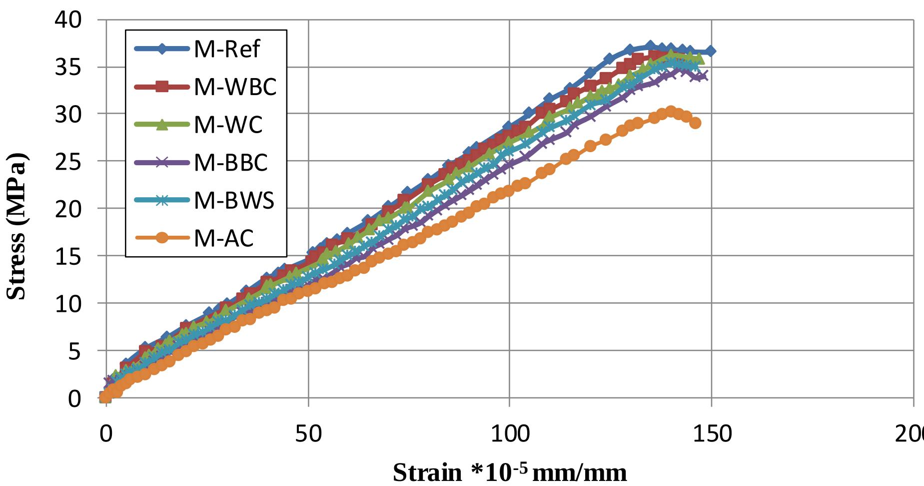

Figure 4. Static modulus of elasticity of HPLWC specimens cured by using different curing methods

It can be seen that the better estimate of the Es value against measured value has been obtained using ACI formula, while BS formula give underestimated values of elastic modulus for all values of concrete strength. The observed difference between measured values and calculated value using ACI formula is ranged from(2 to11) %, while the difference ranged from (6.5 to 25)% when using BS formula. This is because of these formulas applied with specimens casted and cured under laboratory conditions, while measured specimens exposed to actual hot dry weather conditions, also modulus of elasticity for lightweight aggregate concrete is significantly affected by moisture.

3.5. Ultrasonic Pulse Velocity (UPV)

The effect of using different curing methods on pulse velocity of the HPLWAC specimens is indicated in "Table 10" which shows that UPV of all specimens cured under actual hot dry weather conditions at early ages higher than that (Ref) specimen.

The percentage increase in UPV of specimens(M-WC, M-WBC, M- BBC,M-BWS and M-AC) at age (3, and 7) days compared to that (M-Ref) was (7.3,6.2,4.1,5.4,and 2.6)% and (6.8,6.0,4.5,5.3, and 2.8)% respectively. This may attribute that exposure specimen to severe conditions that lead to rapid hydration reaction consequently hydration products occupied available space in the capillary pores resulted in an increasing in density, also strength and in turn an increase in UPV. At 28 days specimens (M-WBC) have UPV more than other specimens followed (M-WC),as well as they are slightly higher than (Ref) specimens, whereas pulse velocity of specimens M (BWS, BBC, and AC) very slightly decreased. On the other hand, the pulse velocity at later ages of specimens M (BWS, BBC, and AC) lower than that of (Ref) specimens, the percentage decrease is (3.2,4.5,and 6.4))% at 90 days ,and (4.2,5.5, and7.6)% at 180 days respectively .While specimens M (WBC,WC) have pulse velocity very closer to that (Ref) specimens. Also it can be noted from “Table 10” that the pulse velocity of specimens cured by covering with burlap after 24 h. higher than that cured after (5:00, 8:00) h. from casting at all ages . The percentage decrease in UPV of specimens cured after 5:00 h.is (3.4, 3.6,4.3,4.2, and 4.4)% at (3,7,28,90, and 180) days, respectively compared to that cured after 24 h., while pulse velocity of specimens cured after 8:00 h was close to that of specimens cured after 24h the percentage decrease was (1.2,1.7,2.7,1.8, and 2)% respectively.

Table 10. Ultrasonic pulse velocity of HPLWAC by applying different curing methods

Mix Designation	Ultrasonic pulse velocity (Km/sec) at age (days)				
	3	7	28	90	180
M-Ref	3.86	3.95	4.37	4.64	4.75
M- WC	4.14	4.22	4.47	4.58	4.63
M- WBC	4.10	4.19	4.51	4.61	4.67
M- BBC	4.02	4.13	4.32	4.43	4.49
M- AC	3.96	4.06	4.26	4.34	4.39
M- BWS	4.07	4.16	4.42	4.49	4.55
M -EC 5:00	3.93	4.01	4.23	4.3	4.35
M- EC 8:00	4.02	4.09	4.3	4.41	4.46

3.6. Dynamic modulus of elasticity(Ed)

The dynamic modulus of elasticity (Ed) results of HPLWAC of specimens using different methods of curing are illustrated in “Table 11”. In general it can be seen that the Ed of all specimens casted and cured under actual hot weather conditions decrease with increasing ages. These results also show that Ed less than that (M-Ref) at all ages. The percentage decrease in Ed of specimens M (WC, BWS, WBC, BBC, and AC) at age (28,90,and180) days is (4.4,7.3,3.6,8.4,and14) %,(7.8,10.5,7.3,10.7,and11.4) % ,and(10,12.7,9.7,13,and13.4)% respectively. Dropped of Ed may be related to the moisture loss from the specimens since moisture moves out with increasing age and the concrete specimens begin to dry up with increasing temperature and length of exposure[25] .This results are in agreement with finding obtained by Zain, and

Matsufuji[26].On the other hand ,it can be seen that Ed of (M-AC) specimens less than other specimens, it might be due to the insufficiency of water for full hydration, as well as the hydration of cement can take place only when the vapor pressure in the capillaries is sufficiently high, about 80% of saturation pressure [27].The data in "Table 12" indicated that Ed of specimens (M- BWS) that cured after 24 h. from casting little more than those specimens cured after (5:00, and 8:00) h. from casting .

Table 11. Dynamic modulus of elasticity (E_d) of HPLWC using different curing methods

Mix designation	Measured Ed(Gpa) at age (days)		
	28	90	180
M-Ref	34.55	35.45	36.14
M- WC	33.02	32.69	32.48
M-WBC	33.32	32.86	32.62
M-BBC	31.93	31.65	31.48
M- AC	31.73	31.41	31.28
M-BWS	32.03	31.72	31.55
M- EC 5:00	31.66	31.31	31.14
M- EC 8:00	31.77	31.47	31.30

4. Conclusions

The following conclusions can be drawn from the results and discussion presented from this investigation:

1.The results show that the compressive, splitting tensile strength and modulus of rupture at later ages of specimens, water based curing compound was the best performance followed water curing, and then burlap water sprinkling .The percentage increase in compressive strength of specimens water based curing compound compared to that of (water curing ,bitumen based curing ,burlap water sprinkling , and air curing) was (3.2,9.1,6.4,and 11.9) respectively.

2. The early curing by covering specimens by burlap and sprinkling water 3-times a day after (5:00 and 8:00) hours. from casting does not improve concrete properties comparative to that cured after 24 hours.

3. The modulus of elasticity of HPLWAC specimens that cured by using curing compound is higher than other methods. The average increase

4. There is insignificant effect of curing method in hot dry weather conditions on ultrasonic pulse velocity of HPLWAC at early age .In general pulse velocity of reference specimens at later ages slightly higher than other specimens casted and cured under actual hot weather conditions.

5. Dynamic modulus of elasticity of HPLWAC specimens casted and cured by different curing methods under actual hot dry weather conditions show slightly decrease after age 28 days to age 180 days, the results also show that there are a little decrease in dynamic modulus of of all curing methods compared with reference specimens.

Abbreviations

ACI American Concrete Institute
RH Relative Humidity
W/C water cement ratio
Es static modulus of elasticity
ρ concrete density
f_c cylinder compressive strength
E_d dynamic modulus of elasticity

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