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Effect of Internal Curing on StrengthDevelopment of High Performance Concrete by Using Crushed Lightweight Porcelinite

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ABSTRACT

High performance concrete, HPC, requires a low water-to-cementitious materials mass ratio *w/cm* and supplemental cementitious materials with silica fumes in the mixture, and use of a superplasticizer. Because of the low w/cm and rapid reaction at early ages, it becomes more difficult to provide curing water from the top surface and this water will be inadequate to satisfy the conventional curing. Therefore, there is a need to use internal curing that is supplied via internal materials, such as absorbent lightweight aggregate, which will be pre-saturated. The use of internal curing was investigated in this study by two ways. The first way was through the use of partial replacement of original coarse aggregate (gravel), meanwhile, the second was by replacing partiallythe original fine aggregate (sand)by crushed Porcelinite.The results showed that the fine Porcelinite replacement as internal curing material caused better enhancement instrengthof HPC than coarse Porcelinite. The replacement of original fine crushed Porcelinite caused an increase in compressive strength from 3.36 to 5.25percent, for splitting tensile strength from 5.48 to6.85 percent and for flexural strength from 11.76 to 12.74percent.

Keywords: High performance concrete (HPC), InternalCuring (IC)**,** Porcelinite**,**Strength.

تاثير الانضاج الداخلي على تطور المقاومة للخرسانة العالية الاداء وباستخدام البورسيلينايت المكسر الخفيف الوزن

الخلاصة

الخرسانة العالية الاداء تتطلب كمية مياه قليلة نسبة الى المواد الاسمنتية مع اضافة مواد اسمنتية مثل السليكا فيوم الى الخليط واضافة المواد الملدنة الفائقة . بسبب قلة الماء الى المواد الاسمنتية وسرعة التفاعل في الاوقات المبكرة يصبح من الصعوبة انضاج الخرسانه من السطح الخارجي بالطرق التقليدية . لذلك نستخدم الانضاج الداخلي الذي يتم تطبيقه عن طريق مواد داخلية مثل الركام الخفيف ذو الامتصاص العالي ويستعمل كركام مسبق التشبع بالماء عند الخلط .في هذا البحث جرى دراسة تأثير الانضاج الداخلي علىالخواص الميكانيكية مثل المقاومة .تم اعتماد اسلوبين في انجاز الانضاج الداخلي وهما : استبدال جزئي للركام الخشن وبأستخدام حجر البورسيلينايت المكسر. وتم في الاسلوب الثاني استبدال جزئي للركام الناعم وايضا بأستخدام حجرالبورسيلينايت

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المكسر.اظهر البحث ان استبدال الركام الناعم لحجر البورسيلينايت المكسر كمادة أنضاج داخلي كان الافضل في تعزيز الخواص الميكانيكية (المقاومة) من استبدال الركام الخشن لحجر البورسيلينايت المكسر. وكمثال على ذلك فقد كان استبدال الركام الناعم الاصلي بمواد الانضاج الداخلي سببا في زيادة مقاومة الانضغاط بعمر 28 يوم وبمقدار يتراوح ما بين 3.36 و 5.25 في المائة . بينما لمقاومة الشد كانت الزيادة من 5.48 الى 6.85في المائة ومقاومة الانحناء كانت الزيادة تتراوح بين 11.76 الى 12.74 في المائة .

INTRODUCTION

The term high performance would describe mixtures that possess the following three properties: high workability, high-strength, and high durability. The definition and commentary that were approved by the American Concrete Institute in 1998 are as follows: HPC is defined as a concrete meeting special combination of performance and uniformity requirements that cannot always be achieved routinely using conventional constituents and normal mixing, placing, and curing practices [1].Conventional curing procedures of water ponding, as used for drying shrinkage, are not effective in the case of autogenous shrinkage. They may eliminate the autogenous shrinkage in small cross-sections only, because the penetration of water from the external surface is limited. Moreover, external curing might be difficult to apply to some surfaces. In view of this limitation, different strategies have been developed in recent years, based on the use of internal water reservoirs.The term “curing” is frequently used to describe the process by which hydrauliccement concrete matures and develops hardened properties over time as a result of the continued hydration of the cement in the presence of sufficient water and heat.The objectives of curing are to prevent the loss of moisture from concrete and, when needed, supply additional moisture and maintain a favorable concrete temperature for a sufficient period of time. Proper curing allows the cementitious material within the concrete to properly hydrate. Hydration refers to the chemical and physical changes that take place when Portland cement reacts with water or participates in a Pozzolanic reaction. Both at depth and near the surface, curing has a significant influence on the properties of hardened concrete, such as strength, permeability, abrasion resistance, volume stability, and resistance to freezing and thawing, and deicing chemicals [2].In Dallas, Texas, concrete with internal curing has been used for residential paving. Intermediate sized lightweight aggregate with particle size of 9.5 to 2.36 mm (3/8 inch to number 4) was used as a substitution for about 120 kg/m^3(200 lb/yd^3) of fine aggregate and 180 kg/m^3(300 lb/yd^3) of coarse aggregate. Intermediate sized particles provide internal curing and improve the overall aggregate gradation. Over two years, about 420,000 m^3 (550,000 yd^3) of this concrete has been placed, nearly half on a single large project. Strength was improved, and the projects have exhibited very little cracking. A typical increase in compressive strength is about 7 MPa(1,000 psi) [3].The principal contribution of internal curing results in the reduction of permeability that develops from a significant extension in the time of curing. Powers*et.al.* [4] showed that extending the time of curingincreased the volume of cementitious products formed whichcaused the capillaries to become segmented and discontinuous

Experimental Work

Materials:

Iraqi ordinary Portland cement - Type I,conforming to IQS 5-1984 [5]. The chemicaland physical properties of the used cement are given in Tables 1and 2 respectively.Silica-fume was used as a supplementary cementitious material with replacement content of 10% by weight of cement.A high-range water reducing admixture, Sika® ViscoCrete®-PC 20 is a third generation superplasticizer for concrete and mortar [6], was used throughout this work. It is based on modified polycarboxylates based polymer.

Table (1): Chemical composition and main compounds of ordinary Portlandcement

Properties		%-by weight	Limits of IQS No.5/1984
Oxide composition	Abbreviation		
Lime	CaO	61.89	-
Silica	SiO_2	21.77	-
Alumina	Al_2O_3	4.61	-
Iron oxide	Fe_2O_3	3.35	-
Sulphate	SO_3	2.4	≤ 2.8%
Magnesia	MgO	3.05	≤ 5%
Loss on Ignition	L.O.I.	2.16	≤ 4%
Lime saturation factor	L.S.F.	0.87	0.66-1.02
Insoluble residue	I.R.	0.6	≤ 1.5
Maincompounds(Bouge eq.)		% by weight of cement	
Tricalcium silicate (C_3S)		53.1	
Diacalcium silicate (C_2S)		20.4	
Tricalcium aluminate (C_3A)		6.55	
Tetracalcium aluminoferrite (C_4AF)		12.2	

These tests were carried out in the Central Organization for Standardization and Quality Control.

Table (2): Physical properties of ordinary Portland cement

Physical properties	Test result	Limits of IQS No.5/1984
Specific surface area BlaineMethod, (m2/kg).	391	>230
Setting time (Vicat,s method) -Initial setting(hr:min) -Final setting (hr:min)	 1:55 2:24	 ≥ 45 min ≤ 10 hrs
Compressive strength of Mortar (MPa): 3-days 7-days	 33 37	 ≥ 15 ≥ 23
Soundness(Autoclave),%	0.05	≤ 0.8

These tests were carried out in the Central Organization for Standardization and Quality Control.

Al-Ukhaider natural sand Zone 2 and naturalcrushed gravel with grading (5-20mm),were used in mixes, and conforming to the Iraqi specification No.45/1984[7], as shown in Tables 3 and 4.Crushednatural Porcelinite rocks from Western Region of Iraq with a gradation of (5-20 mm) as coarse aggregate, (**PG**) and as a fine aggregate, (**PS**) with the same gradation zone as the original aggregate were used.

Tables 5 and 6 show the chemical composition and physical properties of used Porcelinite. The PG and PS were putin water forsoakinguntil fullsaturation, (constant mass). Water absorption value for PG was 19% and for PS was 35%. Trial mixes, to obtain the average required compressive strength of cylindersequals to75 MPa, were done.

Thereplacement for coarse material (crushed Porcelinite)was done with two percentages 7.5% and 15% (mixes **PG7.5** and **PG15)**, and forfine (crushed Porcelinite) with two percentages 5% and 10% (mixes **PS5** and **PS10)**.The replacement materials wereseparatedby sievingand then were put in plastic containers.The volumetric basis was adopted to replace the normal aggregate by Porcelinite as shown in Table 7. After that the two types of aggregate (normal and lightweight) were mixed together to obtaine the original gradatio. For more details see Al-Saad [8].

Table (3): Grading and physical properties of fine aggregate

Sieve size (mm)	Percentage passing	Limits of IQS No.45-1984/Zone 2
10	100	100
4.75	97	90-100
2.36	76	75-100
1.18	55	55-90
0.6	37	35-59
0.3	16	8-30
0.15	0	0-10
Sulphate content = 0.1%		max.= 0.5%
Fine materials passing from sive (75μm) = 4.2%		max. = 5%
Specific gravity: 2.65		
Fineness modulus:3.19		

Table (4): Grading and physical properties of coarse aggregate

Sieve size (mm)	Percentage passing	Limits of IQS No.45/1984
37.5	100	100
20	99	95-100
14	---	---
10	30	30-60
5	0	0-5
Sulphate content: 0.072%	max.:0.1%	
Specific gravity: 2.7		
Dry rodded density: 1635 kg/m^3		

Table (5): Chemical composition of Porcelinite rock

Component	% by weight
SiO_2	71.48
Fe_2O_3	2.09
AI_2O_3	4.71
TiO_2	0.03
CaO	7.85
MgO	2.25
SO_3	0.39
Na_2O	0.50
K_2O	0.20
CI	0.67
P_2O_5	1.10
L.O.I	7.51

Table (6): Physical properties of Porcelinite rock

Property	Result
Specific gravity	1.49
Absorption %	35 (fine) 19 (coarse)
Dry rodded unit weight, kg/m^3	830
Aggregate crushing value,%	16
Sulfate Content (as SO_3), %	0.39

Table (7):Wet of dry and saturated replacement material equivalent to (10) kg of normal aggregate by volume

Replacement material	Weight of dry replacement material equivalent to (10) kg of normal aggregate by volume, kg	Weightof saturated equivalent replacement material, kg	Absorption %
(PG)	7.418	8.828	19
(PS)	7.830	10.565	35

In this work, the conducted tests were the compressive, splitting and flexural strength test.For compressive strength two cylinders specimens with dimensions (d= 100 mm, h= 200mm) were test, cured in water and without water (sealed specimens by plastics bags). Cylinders of (d=100 mm, h=200 mm) were used in the splitting tensile strength and(100*100*500) mm concrete prisms were used for flexural strength test.

Results and discussion
Compressive strength
Water-curried specimens:

From the Figures (1) and (2), it could be observed that at early age (7 days), the reference mix has ahigher strength than other mixes that contained the internal curing material. The decrease in strength observed with the incorporation of internal curing materials is due primarily to mechanical considerations: the LWA is simply not as strong as normal weight aggregate. Other effects, such as differences in paste/aggregate bonding when LWA is used in place of NA or the effect ofage on paste/aggregate bonding cannot be discounted, and may also have an effect [9].

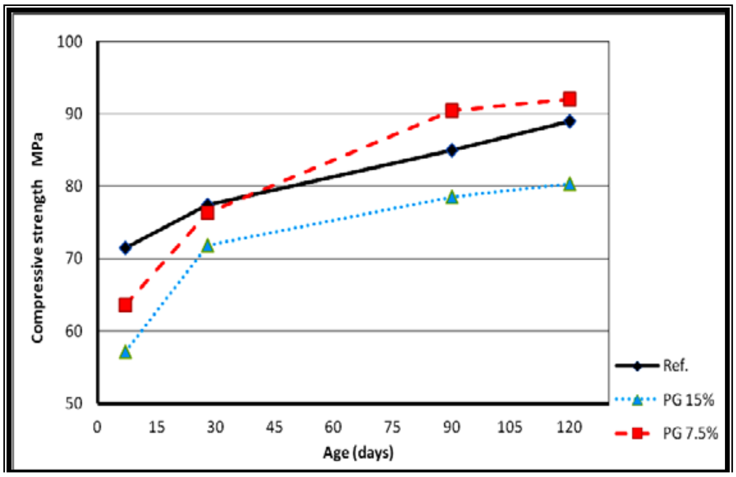


Figure (1): Compressive strength development for water cured mixes PG7.5 and PG15.

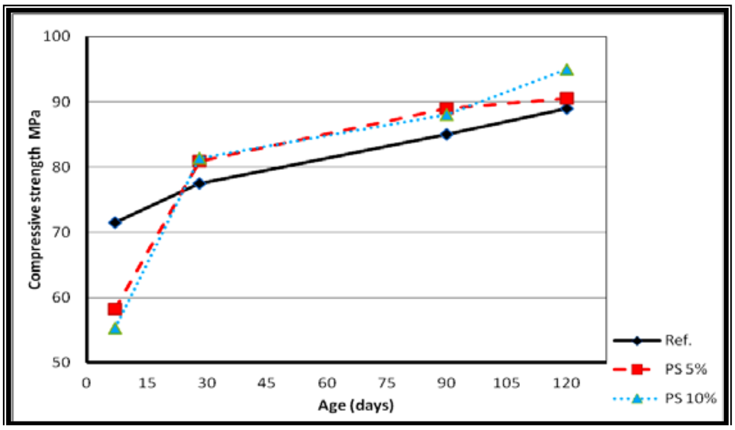


Figure (2) Compressive strength development for water cured mixes PS5 and PS10

The compressive strength at 28 days of PG7.5 and PG15 mixes were slightly lower in strength than referencemix, this could be explained by that the LWA aggregateshaslower stuffiness than the normal aggregate that is substituted, the compressive strength of HPC containing saturated LWA is expected to produce higher strength than HPC mixtures with NWA [10]. It has been known for a long time that both the density and the strength of LWA concrete are heavily dependent on the density and the strength of the lightweight aggregate particles [11].

The compressive strength for PS5 and PS10 mixes were 80.9 MPa and 81.4 MPa, respectively, these results at 28 days were higher than that of referencemix 77.5 MPa, by 4.4 and 5 percentage, respectively. The continuous hydration of the mixture at later ages promoted by the extra water stored in the LWA could be the cause of that increase.the compressive strength at the later ages 90-120 days is increasing always, due to both external and internal curing with existing silica fume.

The difference between PGmixes and the PSmixes resulted from the vesicular surface produced by crushing operation which allows paste penetration and provides more contact area between aggregate and paste. It is believed that the transition zone associated with a crushed aggregate has advantages over a more smooth and sealed surface.

Sealed specimens:

Figures (3) and (4) show that at early age (7 days), there was a decrease in compressive strength for all mixes relative to the reference mix. This is primarily due to mechanical considerations as explained for water-cured specimens, and some of the attributes that may have caused the decrease in compressive strength may be due to the increase in voids content.At later ages, the results have indicated a significant increase in the compressive strength for all mix except for the replacement of coarse aggregate with Porcelinite coarse aggregate. These are due to that the LWA have lower stiffness than the normal aggregate.In the absence of water from outside, the fine aggregate was more effective as an internal curing agent with respect to strength development. The higher percentage of replacement caused better development of strength.

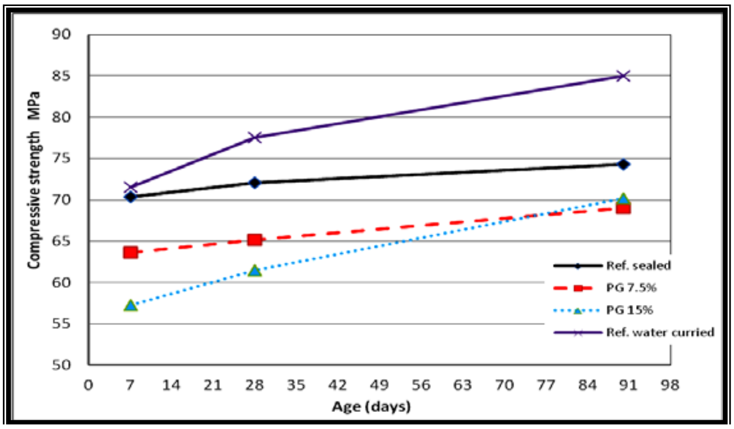


Figure (3) Compressive strength development for Mixes PG7.5 and PG15 made with sealed specimens.

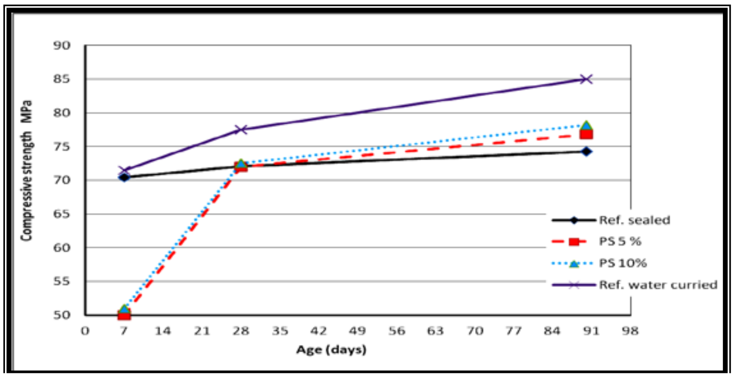


Figure (4) Compressive strength development for mixes PS5 and PS10 made with sealed specimens.

The increase of compressive strength of mixes PS5 and PS10were 3.36 and 5.25percentrespectively. Always water cured referencemix was the upper limit, where the sealed referencemix represented the lower limit at 28 days age and above. When comparing the compressive strength value of sealed to water cured specimens, the differences are not significant. This could lead to the conclusion that the internal curing is reliably effective.

Splitting Tensile Strength

The splitting tensile strength of all the tested specimens were cured in water.Figures (5) and (6) summarize the splitting tensile strength values for all HPC mixes at various ages of immersion in tap water.

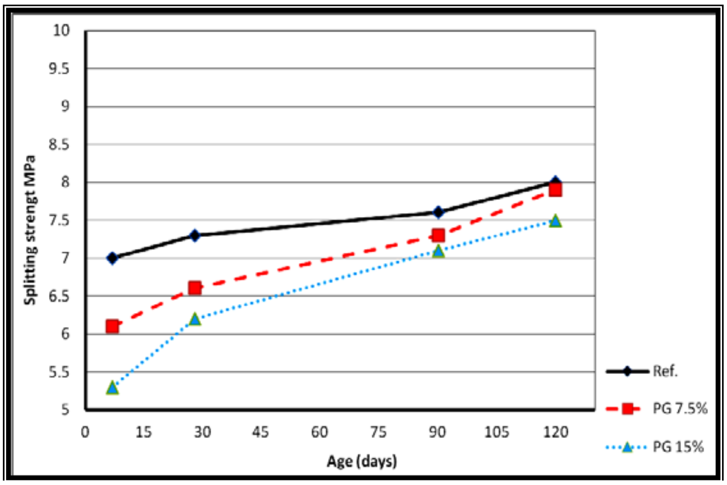


Figure (5): Splitting tensile strength development for water cured mixes PG7.5 and PG15.

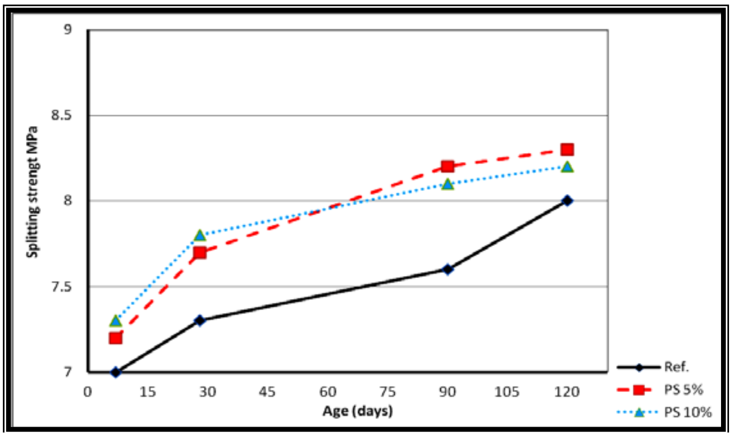


Figure (6): Splitting tensile strength development for water cured mixes PS5and PS10.

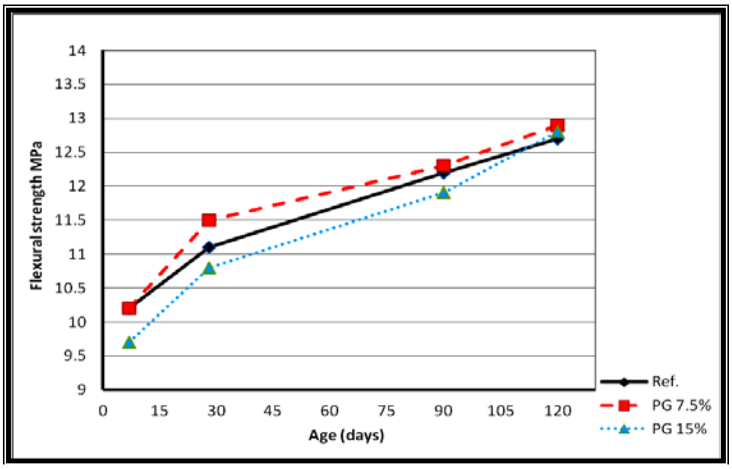
At early age (7days),there was a decrease in tensile strength for all mixes relative to referencemix.Mixes PS5 and PS10 were only the exceptions for that.Some of the attributes that may have caused the decrease in tensile strength are primarily due to mechanical considerations: the LWA is simply not as strong an aggregate as normal weight sand. Other effects, bonding in interfacial transition zone between paste and aggregate or may be due to the increase in voids system that linked to moisture within the concrete, there exists a large moisture gradient from the center of the cylinder to the surface, thus affecting the tensile strength of concrete.At 28days, the tensile strengths of PG7.5 and PG15 were lower than that of the referencemix, this conformsto the compressive strength reduction at same age, because the LWA aggregates has lower stiffness than the NWA. It has been known for a long time that both the density and the strength of LWA concrete are heavily dependent on the density and the strength of the lightweight aggregate particles [11].The mixes PS5 and PS10 had high strength than reference mix by 5.48 and 6.85 percentages respectively. The increase in tensile strength could be due to improvement of the interfacial transition zone, enhanced hydration because of internal curing, and absence of shrinkage-induced microcracking.At later age at (90-120) days, the mixes PG7.5 and GP15 have slightly lower or equal strength than referencemix, and that shows thatthe internal curing is significantly effective through continuous hydration. The mixes PS5 and PS10 showed significant increase in tensile strength,and this is may be due to improvement of the interfacial transition zone, enhanced hydration because of internal curing and absence of shrinkage-induced microcracking. The increasing in splitting tensile strength after 28 days of test is most probably attributed to filling up of pores by reaction products and crystallization of salts [12].Table (8) represented the ratio of splitting to compressive strength. According to this table, it could be concluded that for the present work, the splitting tensile strength has ranged from 8 to 13 percent from compressive strength.

Table (8): Ratio of splitting strength to compressive strength (f_t/f_c)

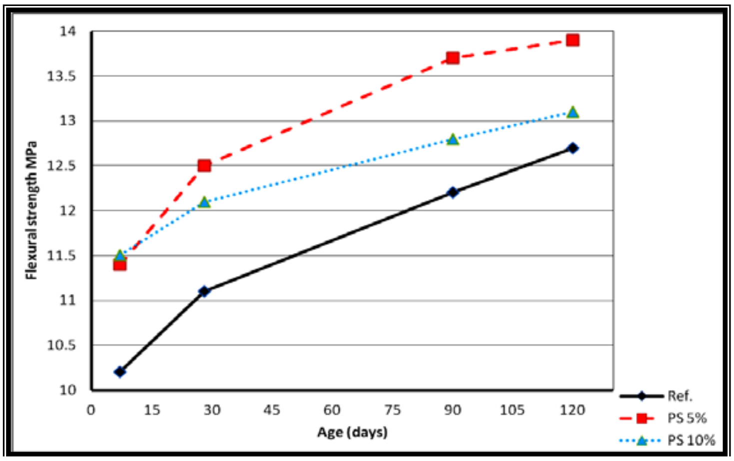
Mix Designation	Percentage of strength(splitting /compressive)			
	7 days	28 days	90 days	120 days
Ref.	9.8	9.4	8.9	9.0
PG7.5	9.6	8.7	8.1	8.6
PG15	9.3	8.6	9.0	9.3
PS5	12.3	9.5	9.2	9.2
PS10	13.2	9.6	9.2	8.6

Flexural Strength:

The flexuralstrength of all the tested specimens were cured in water,Figures (3-7) and (3-8) summarize the splitting tensile strength values for all HPC mixes at various ages of immersion in tap water .



Figure(7): Flexural strength development for water curried mixes PG7.5 and PG15.



Figure(8): Flexural strength development for water cured mixes PS5and PS10.

At early age(7days) the PG7.5 andPG15 have slightly lower (or equal)strength than reference mix. That conformsto lowering of compressive strength and splitting tensile strength at same age than reference mix.This reduction could be attributed to that the LWA is simply not as strong an aggregate as normal weight aggregate. Other effects, such as differences in paste/aggregate bonding when LWA is used in place of sand or the effect of age on paste/aggregate bonding cannot be discounted, and may also have an effect [9].The mixes PS5 and PS10 showed higher flexural strength than reference mix by 11.76 and 12.74 percentages respectively.This could be due to improvement of the interfacial transition zone, enhanced hydration process because of internal curing and absence of shrinkage-induced microcracking.

At later age (28-120days), all mixes havehigher strength(or equal)to that of reference mix and that showed that the internal curing is significantly effective in making hydration continuous. The increase in flexural strength is due to improvement of the interfacial transition zone, enhanced hydration because of internal curing and absence of shrinkage-induced microcracking.

CONCLUSIONS

1. The improvements caused by internal curing are much obvious for conducted tension tests(splitting and flexural)than for compression test, and this could be due to the enhancement of bond in microstructure of concrete (continuous hydration and less porous microstructure).
2. Fine aggregate replacement as internal curing material caused better enhancement in strength of HPC than coarse aggregate replacement.This could be explained by the increase in surface area and absorption which promote higher continuous hydration. For example the replacement of original fine aggregate with different materials caused an increments in strength, at 28 days for instance, due to internal curing ranged: for compressive strength from 3.36 to 5.25percent, for splitting tensile strength from 5.48 to 6.85 percent and for flexural strength from 11.76 to 12.74percent. Meanwhile, the replacement for coarse aggregate caused a decrease in compressive strength for the same aggregate and same trends were recorded for other type of strength.
3. In sealed specimens, the use of larger percentage of fine aggregate replacement gives insignificant increase in values of compressive strength from 28 days and above. Mix PS10 showed (0.7 and 1.8) percent higher strength than PS5 at 28 and 90 days respectively.

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