ASIAN JOURNAL OF CIVIL ENGINEERING (BHRC) VOL. 14, NO. 5 (2013)
PAGES 773-781

Technical Note

STUDY ON INTERNAL CURING OF HIGH PERFORMANCE CONCRETE USING SUPER ABSORBENT POLYMERS AND LIGHT WEIGHT AGGREGATES

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Received: 2 November 2012; **Accepted:** 14 February 2013

Abstract

High performance concrete (HPC) is popular for its low water-to-cementations materials ratio (w/cm). Because of this low w/c ratio and rapid hydration, proper curing is essential at the earliest time. This paper explores the use of Super Absorbent Polymers (SAP) and Light Weight fine Aggregates (LWA) as internal curing material. Mix M2 is achieved by adding SAP at 0.3% weight of cement and in mix M3 is obtained by replacing 25% weight of LWA to fine aggregates. Strength and durability of these HPC are studied experimentally and the results show greater strength with LWA mix. Load carrying capacity of the beams in flexure and shear also greater in LWA mix and the durability study results reveal that mix with SAP is better compared to the other two mixes.

Keywords: Internal curing; high performance concrete (HPC); super absorbent polymers (SAP); light weight fine aggregates (LWA)

1. Introduction

Over the last decades, HPC with a low w/c has become widely used and research works on this matter have been increased tremendously. The high strength and durability performance of HPC were considered as key issues for structural use under severe conditions [1].

However, from the practical point of view and laboratory investigations, it has been proven that HPC is very sensitive to the risk of early age cracking unless special precautions are taken. One of the specific requirements is the curing practice of concrete for the

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development of strentgh.Proper curing of concrete structures is important to ensure that they meet their intended performance and durability requirements [2, 7]. In conventional construction, this is achieved through external curing, applied after mixing, placing and finishing. Internal curing (IC) is a very promising technique that can provide additional moisture in concrete for a more effective hydration of the cement and reduced self-desiccation. Internal curing implies the introduction of a curing agent into concrete that will provide this additional moisture [3].

Currently there are two major methods available for internal curing of concrete. The first method uses saturated porous lightweight aggregate (LWA) in order to supply an internal source of water, which can replace the water consumed by chemical shrinkage during cement hydration [4]. This internal curing water is naturally drawn during cement hydration from the relatively large pores of the lightweight aggregate into the smaller pores of the cement paste [5]. The second method uses super-absorbent polymers (SAP), as these particles can absorb a very large quantity of water during concrete mixing and form large inclusions containing free water, thus preventing self-desiccation during cement hydration[3,6].The large absorption characteristics of SAP is shown in Figure 1.Internal Curing distributes extra curing water (uniformly) throughout the entire microstructure of the concrete so that it is more readily available to maintain saturation of the cement paste during hydration, For internal curing to do its job, the individual pores in the internal reservoirs should be much larger than the typical sizes of the capillary pores (micrometers) in hydrating cement paste and should also be well connected for proper percolation [7]. Internal curing is not a substitute for external curing. As a minimum, evaporative moisture loss, after set, should be prevented using conventional external measures like misting, fogging, curing membrane or compound [8].

Figure 1. Super absorbent polymers

2. Experimental Investigation

2.1. Materials

High performance concrete with water binder ratio of 0.32 was produced [9]. The cement used was ordinary Portland cement of 53 grade and the silica fume had a specific surface area of 19 m^2/g. The replacement ratio of silica fume was 10% by weight of cement. Sieved aggregate with a maximum size of 10mm and fine sand with a fineness modulus (FM) of 1.94 were used. The relative proportions of the coarse aggregate and the sand were determined for the reference normal weight concrete to obtain sufficient workability. Commercially available super absorbent polymer was used and the light weight fine aggregates were obtained from waste aerocon blocks by breaking and sieving them through 4.15mm size sieve. The results of water absorption tests are given in Table 1. For the concrete in which part of the normal-weight aggregate was replaced by lightweight aggregate, the replacement ratio of aggregate was 25% of the total volume of aggregates and for the concrete with SAP the percentage of SAP added was 0.3% weight of cement. The dosage of super plasticizer (naphthalene formaldehyde sulfonate type) for each mix was determined to obtain a slump of 100 ± 20 mm. Mix proportions of the concrete are given in Table 2.

Table 1: Water absorption

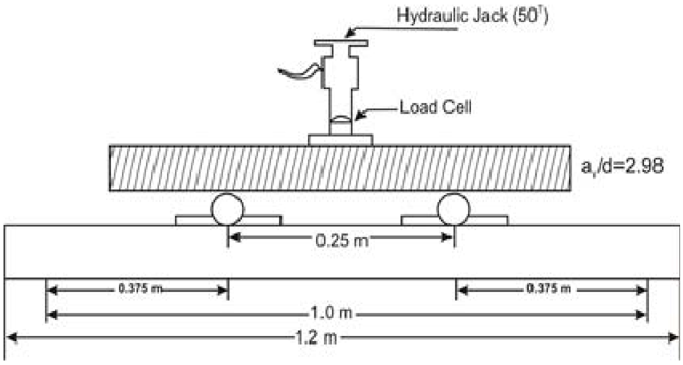
S. No	Material	Dry weight (gms)	Saturated weight (gms)	Water Absorption
1	Super Absorbent polymers	25	2640	105 times its weight
2	Light weight aggregates	1000	4050	4 times its weight

Table 2: Mix Proportion (kg/m^3) of concrete

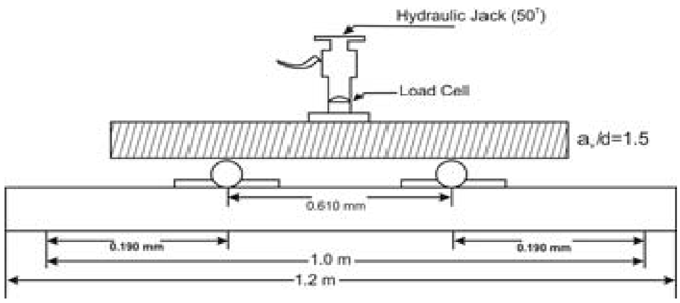
Mix	Cement	Fine Aggregate		Coarse Aggregate	Water	Super plasticizer (1.5% of Cement)	Super Absorbent polymers
		River sand	LWA				
M1	547	779.68	---	941.8	166.8	8.2	---
M2	547	779.68	---	941.8	166.8	8.2	1.64
M3	547	584.68	195	941.8	166.8	8.2	--

2.2. Strength tests

Strength tests are conducted to find out compressive strength, tensile strength, flexural and shear behaviour of test specimens. Cube specimens of size 150 x150 x 150 mm were cast for compressive strength, cylindrical specimens of size 150 mm x 300 mm were used for tensile test. Similarly the flexural and shear behaviour of beams size 1200 x 100 x 150 mm were studied in this experimental program. Compressive strength tests were carried out at the age of 3, 7, and 28 days. Tensile strength, flexural and shear behavior were calculated at 28 days after casting. The load setup for finding flexural and shear strength are shown in Figure 2.



(a) For flexure



(b) For shear

Figure 2. Schematic representations of load set up in beams

2.3. Durability tests

Durability tests that are done in this study are permeability test and rapid chloride penetration test. Cylindrical moulds of size 100 mm diameter and 150 mm height are cast for permeability test and specimens of size 100 mm diameter and 50 mm height is used for rapid chloride penetration test. Durability studies are done at the age of 28 days curing.

3. Results and Discussions

3.1 Compressive Strength

The compression test is carried out at 3, 7 and 28 days age of curing. The test results given in Figure 3 shows that the 3days compressive strength is greater in mix M1 and it implies that the hydration process has not fully started due to the internal curing of water within 3 days. But the 7and 28 days results proved that the internal cured mix has a greater compressive strength when compared to the control mix. Mix with SAP has attained 6.88% increase and LWA mix has shown 12.35% increases on 28 days compressive strength than the control concrete mix. This predicts that there is an increased hydration; leading to a strong microstructure of concrete gives greater compressive strength.

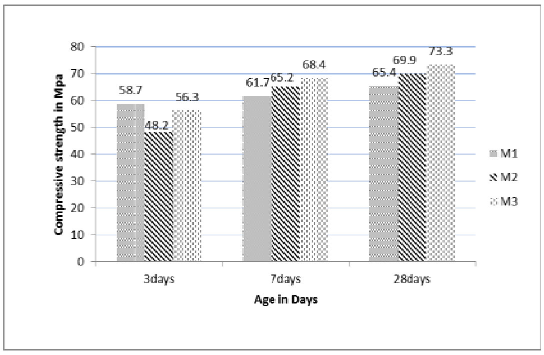
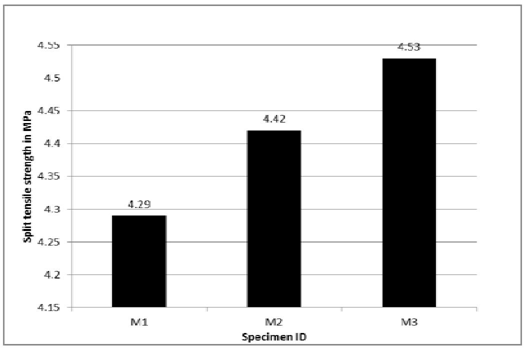


Figure 3. Compressive strength



Figuer 4. Tensile Strength

3.2 Split Tensile Strength

The Split tensile strength test is carried out at 28days and strength results are given in Figure.4 shows that mix M3 has better results compared to other two mixes. Mix M3 has 2.43% higher tensile strength than mix M2 and 5.3% greater than mix M1.

3.3 Flexural Behavior

The flexural behaviour of the beam specimens are carried out at 28 days curing and the results are tabulated in Table 3. The initial crack for beam M1 originated when the load was about 7.5 kN and for beam M2 and M3 was 10 kN. The crack was mainly occurred between the points of loading and initiated from the tension side of the beam and moved towards the neutral axis layer. The stiffness was initially higher and started to decrease for all the beams gradually. The initial stiffness was greater for M3 specimens comparing with the other two specimens. The value of stiffness for M2 was 10 kN/m, which is greater than M1 and it is found to be less than beam M3. The ultimate load carrying capacity of the beams M1 and M2 were more or less equal but M3 had better load carrying capacity of 19.4% greater than M1 and 13.15% greater than M2. The pattern of failure cracks under flexure is shown in Figure 5. The experimental results of mid span deflection for all the three mixes are plotted in Figure 6.

Table 3: Ultimate load and stiffness in flexure

S.No	Beam Specimen	Initial Crack Load (kN)	Ultimate Load (kN)	Ultimate Moment (kN/m)	Maximum Stiffness (kN/m)
1	M1	7.5	21.6	4.05	8.33
2	M2	10	22.8	4.28	10
3	M3	10	25.8	4.84	13.89

Table 4: Ultimate load and stiffness in shear

S.No	Mix details	Initial Crack Load (kN)	Ultimate Load (kN)	Ultimate Moment (kN/m)	Maximum Stiffness (kN/m)
1	M_1	1.5	49.8	24.9	10.41

2	M_2	17.5	51.6	25.8	13.89
3	M_3	17.5	52.7	26.35	16.67

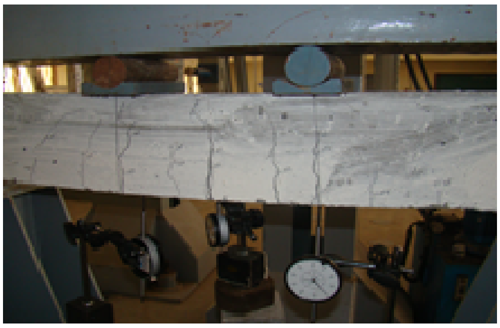


Figure 5. Pattern of flexural cracks

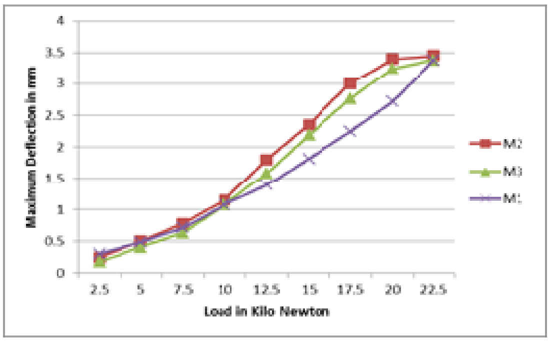


Figure 6. Load deflection curve in flexure

3.4 Shear Behavior

The shear behavior of the beams is studied at the age of 28days casting. The initial crack for beam M1 originated when the load was about 15 kN and for M2 and M3 specimens it was 17.5kN. Figure 7 shows the pattern of shear cracks. The shear cracks also mainly formed between the points of loading and started from the tension side of the beam and moved towards the neutral axis. The stiffness behavior was also similar to the flexural beams and it started to decrease for all the beams gradually. The initial stiffness was greater for beam M3.The value of stiffness for M2 was13.89 kN/m, which is greater than M1 and less than mix M3.The ultimate load carrying capacity of the beam M3 had is better it was 5.8% greater than M1 and 2.13% more than M2. The results of the beam under shear are given in Table 4 and same results are plotted graphically in Figure. 8.

Figure 7. Pattern of shear cracks

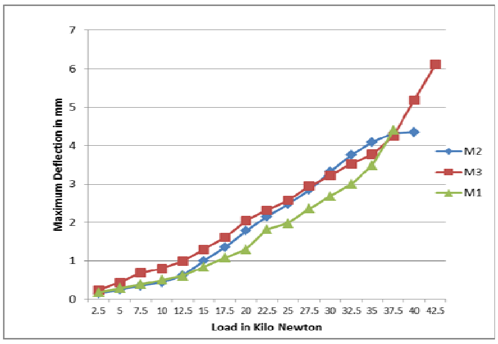


Figure 8. Load deflection curve in shear

3.5 Analytical Investigations

Finite element method of analysis is carried out in ANSYS. Finite element models are generated in ANSYS using Graphical User Interface (GUI). The Solid65 element was used to model the concrete. The material property of concrete and steel such as young's modulus and poison ratio was given in the elastic properties. The beams were modeled as volumes and hexagonal meshing was done. Boundary conditions and the load magnitudes are given in the analyses. The model was analyzed under transverse loading and the static type analysis is utilized. The model is solved using the current Limit State method. The experimental deflection of the beams was compared with the results obtained analytically using ANSYS.The deflection results are almost similar in both analytical and experimental investigation. Table 5 gives the better comparison of deflection results.

Table 5: Deflection results

S.No	Specimen	Load (kN)	Maximum deflection Experimentally (mm)	Maximum deflection analytically (mm)
1	M_1	20	3.45	3.049
2	M_2	20	3.25	3.020
3	M_3	20	3.18	2.980

3.6 Rapid Chloride Penetration

In durability point of view some of the tests were conducted in all the three mixes. Chloride penetration properties are evaluated as shown in the Figure. 9 on the test specimens M1, M2 and M3 respectively and the test results were compared with the control mix. Chloride ion permeability test was conducted on cylinder at 28 days curing. The test results of chloride permeability are expressed in coulombs for different mixes and it is given in Table 6. The results showed that all the three mixes had low chloride permeability rating. The RCPT value of mix M2 was 470 Coulombs and it is better than M1 and M3 mixes, whereas RCPT value of mix M1 was 783 Coulombs and for mix M3 was 514 Coulombs. Greater the RCPT value implies the greater penetration.

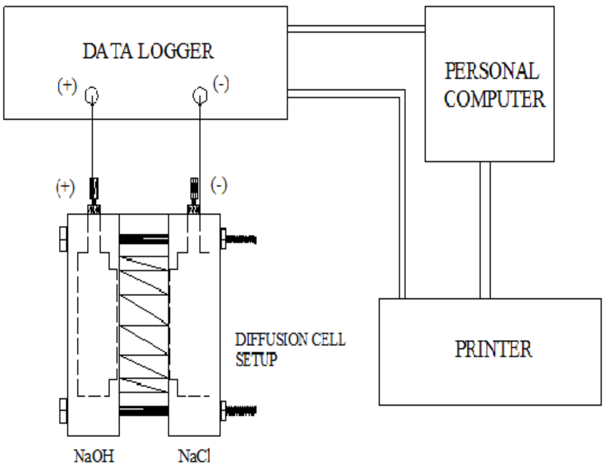


Figure 9. Schematic representation of rapid chloride penetration test

3.7 Permeability

The permeability test was carried out for all the mixes at 28days age. The test was carried out for 24 hours. The water passed through the specimen after 24 hours was measured form which the coefficient of permeability was calculated. The coefficient of permeability of mix M2 was 13.68 x10^{-12} m/sec which was lesser than all the other two mixes. Lesser the coefficient of permeability betters the results. The coefficient of permeability of mix M1 and M3 was 92.32% and 53.87% greater than Mix M2.

Table 6: Permeability test

S. No	Mix details	Amount of water collected	Time during which water collected	Co-efficient of permeability
1	M_1	783	Low	26.31
2	M_2	470	Low	13.68
3	M_3	514	Low	21.05

4. Conclusions

Based on the results of these investigations the following conclusions can be drawn.

(i) The internal cured specimens are proved to better than conventional cured specimens in all means.

(ii) The addition of internal curing agent increases the degree of hydration, producing a denser microstructure leading to better results.

(iii) Compressive strength results reveals that compressive strength of internal cured specimens at 7days and 28 days are greater but at the age of 3 days the strength is lower than conventionally cured specimens. SAP specimens shows a significant improvement of about 6.88 % increase in compressive strength and LWA specimens are found to be 12.35% on 28 days compressive strength than the control concrete mix. Hence ,the incorporation of Internal Curing components in high performance concrete by means of LWA has proven to be effective than internal cured HPC using SAP with respect to strength.

(vi) The durability studies have showed that internal curing by means of SAP has less chloride penetration than internal cured specimens using LWA.

(vii) The RCPT value for the control mix was 783 coulombs which was greater than both the internal cured specimens, while the mix using SAP had lower RCPT value of 483 coulombs which proved to be the best.

(viii) The coefficient of permeability of mix M2 was 13.68 x10-12 m/sec which was lesser than all the other mixes. Lesser the coefficient of permeability betters the results.

Acknowledgements: The authors wish to express their gratitude and sincere appreciation to the authority of Mepco Schlenk Engineering College, Sivakasi, Tamilnadu, India for financing this research work and also several on-going research projects related to the study on concrete structures.

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