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Influence of Phase Change Material in High-Performance Concrete

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ABSTRACT

Curing of concrete is maintaining moisture in the concrete during early ages specifically within 28 days of placing concrete, to develop desired properties. Curing concrete plays a major role in developing the concrete microstructure and pore structure. Good curing is not always practical in many cases. In case of High performance concrete (HPC) at low water cement ratio, the curing plays an important role in developing the strength of concrete. Improper or insufficient curing leads to a reduction in the strength of the concrete to a great extent. Concept of self curing is to reduce the water evaporation from concrete and hence increase the water retention capacity of the concrete compared to conventional concrete. Improper curing can easily cut the strength of concrete. Curing simply means keeping the water in the concrete where it can do its job of chemically combining with the cement to change the cement into tough glue that will help to develop strong durable concrete. Good curing means keeping concrete damp and at about 70 ^{o} F until the concrete is strong enough to do its job. The focus of this study is on the benefits of internal curing for pavement. Because concrete pavements have large surface to volume ratios and are exposed to the environment, it is particularly difficult to achieve proper curing. However, proper curing of pavements is important because it reduces early age cracking tendencies and improves concrete strength and performance. The aim of the study is to produce a properly cured and durable concrete and to study the mechanical properties of concrete. This paper shows how Super Absorbent Polymer (SAP) influences concrete properties, by comparing the results of concrete mixes with SAP and controlled concrete without SAP.

Keywords: Internal curing, super absorbent polymer, High Performance Concrete

I. INTRODUCTION

The concept of curing and recognition of its contribution to obtain desirable properties of concrete is not novel. This technique has been adopted to maintain moisture and temperature conditions in a freshly placed cementitious mixture to allow hydraulic cement hydration and (if applicable) pozzolanic reactions to occur so that the potential properties of the mixture may develop. In earlier stage though it has not received proper attention but nowadays it is found to be one of major concern in the study of concrete performance. However, the concept of internal curing has been developed and now been in practice to eliminate some problems occurred in case of traditional curing.

II. METHODS AND MATERIAL

1. Internal Curing

Internal curing refers to the process by which the hydration of cement occurs because of the availability of additional internal water that is not part of the mixing Water. Conventionally, curing concrete means creating conditions such that water is not lost from the surface i.e., curing is taken to happen 'from the outside to inside'. In contrast, 'internal curing' is allowing for curing 'from the inside to outside' through the internal reservoirs.

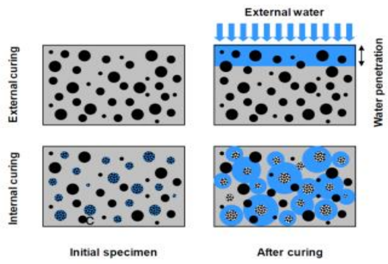

Figure 1. Difference between Internal and External Curing

1.1 Potential Material for Internal Curing

The following materials can provide internal water reservoirs:

1. Lightweight Aggregate (natural and synthetic, expanded shale),
2. LWS Sand (Water absorption =17 %)
3. LWA 19mm Coarse (Water absorption = 20%)
4. Super-absorbent Polymers (SAP) (60-300 micron size)
5. SRA (Shrinkage Reducing Admixture) (propylene glycol type i.e. polyethylene-glycol)
6. Wood powder.

1.2 Super Absorbent polymer

The common SAPs are added at rate of 0–0.6 wt % of cement. The SAPs are covalently cross-linked. They are Acryl amide/acrylic acid copolymers. One type of SAPs are suspension polymerized, spherical particles with an average particle size of approximately 200 microns. Another type of SAP is solution polymerized and then crushed and sieved to particle sizes in the range of 125–250 microns. The size of the swollen SAP particles in the cement pastes and mortars is about three times larger due to pore fluid absorption. The swelling time depends especially on the particle size distribution of the SAP. It is seen that more than 50% swelling occurs within the first 5 min after water addition. The water content in SAP at reduced RH is indicated by the sorption isotherm .SAPs are a group of polymeric materials that have the ability to absorb a significant amount of liquid from the surroundings and to retain the liquid within their structure without dissolving. SAPs are principally used for absorbing water and aqueous solutions; about 95% of the SAP world production is used as a urine absorber in disposable diapers. SAPs can be produced with water absorption of up to 5000 times their own weight. However, in dilute salt solutions, the absorbency of commercially produced SAPs is around 50 g/g. They can be produced by either solution or suspension polymerization, and the particles may be prepared in different sizes and shapes including spherical particles. The commercially important SAPs are covalently cross-linked polyacrylates and copolymerized polyacrylamides/ polyacrylates. Because of their ionic nature and interconnected structure, they can absorb large quantities of water without dissolving. From a chemical point of view, all the water inside a SAP can essentially be considered as bulk water. SAPs exist in two distinct phase states, collapsed and swollen. The phase transition is a result of a competitive balance between repulsive forces that act to expand the polymer network and attractive forces that act to shrink the network.

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Figure 2. SAP in dry state

Figure 3. SAP after adding water

The use of internal curing is a highly effective means of mitigating autogenous shrinkage in cement mortars (w/c = 0.35, 8% silica fume) was studied. Two different sources of internal water supply are compared. Replacement of a portion of sand by partially saturated lightweight fine aggregates and the addition of super absorbent polymer particles (SAP).At equal water addition rates, the sap system is seen to be more efficient in reducing autogenous shrinkage at later ages, most likely due to a more homogeneous distribution of the extra curing water with in the three dimensional mortar microstructure. A comparison of the water distribution in the different systems, based on computer modeling and direct observation of two dimensional cross section. It showed an improvement in concrete durability and strength. [1]

Internal curing refers to the time-dependent improvement of concrete strength due to the gradual release of water from aggregate, in which it was absorbed before mixing, to the cement particle to allow continued hydration. High performance with low water cement ratio experiences the considerable chemical shrinkage and self desiccation during its hydration process, leading to a high autogenous shrinkage deformation. So a study had been done by adding super absorbent polymer into the HPC as an internal curing agent and by adding additional curing water to the concrete mixture the above problems are reduced. Unfortunately this process curing also has some disadvantages effects on the mechanical properties. It slightly reduces the 28 day compressive strength when compared to the ordinary concrete. In case 70 kg/m^3 of internal curing water is provided with the SAP, an optimal reduction of the cracking risk is noticed, mainly caused by the autogenous shrinkage reduction and the appearing expansive deformation peak directly after setting takes place.[2]

In another study the super absorbent polymer is used by prewetted with water before mixing into the cement. The water release process of prewetted super absorbent polymer (SAP) particles in cement paste is illustrated by a cracking viewer and it is found out that water entrained by SAP is almost exhausted after 7 days, producing many pores in the paste structure. Meanwhile the effect of SAP dosage and entrained water on internal relative humidity, autogenous shrinkage and compressive strength of concrete are discussed. Results indicated that incorporation of SAP obviously delays the IRH decline and mitigates AS at early age. However it negatively influences the pore structure of cement paste. Thus, compressive strength of concrete decreases with a higher content of SAP or entrained water. [3]

The next study is focused on Freeze and Thaw effect of concrete. The results of freeze thaw resistance tests performed on a reference mixture and a mixture with super absorbent polymer addition. The SAP mixture showed results of freeze thaw resistance tests performed 40% less scaling than the reference mixture and a slight increase of the compressive strength. [4]

2. Required Water for Internal Curing

From Literature, the following methods are available to calculate the required amount of internal water.

1) $(w/c)ic = 0.18\ (w/c)$
2) $W_{ic} = C \cdot \alpha_{max} \cdot CS$
   where,
   c – cement content in the mix
   α_{max} - maximum degree of hydration
   cs – chemical shrinkage at full hydration
3) Maximum 10% of the total water added in concrete mix (from literature got from Previous Results)

3. Behaviour of Sap in Cement Mortar

TRIAL 1:

To identify the behavior of SAP in cement, cement mortar cubes were prepared in the following proportions.

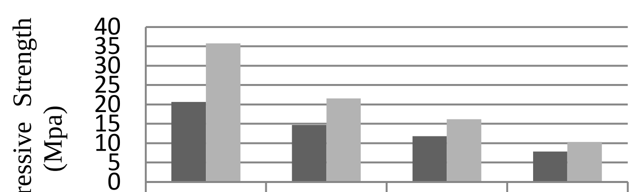
1) Cement mortar with 1g of SAP

2) Cement mortar with 2g of SAP

3) Cement mortar with 3g of SAP

Additional water added as 45ml per gram. The additional water is added in accordance with the absorption capacity of the SAP.

The compressive strength results are shown below,



	RM	CM WITH Ig OF SAP	CM WITH 2g OF SAP	CM WITH3 g OF SAP
3 days	20.63	14.71	11.77	7.85
7 days	35.78	21.59	16.19	10.32

Figure 4. Compressive strength results for trial mixes

RM-Reference mortar

CM-Cement mortar

TRIAL 2:

Due to the strength reduction in the cement mortar cubes when compared to reference mortar cubes in trial 1, trial 2 mix is prepared in which the percentage of SAP in the mix is kept constant and the additional water is varied.

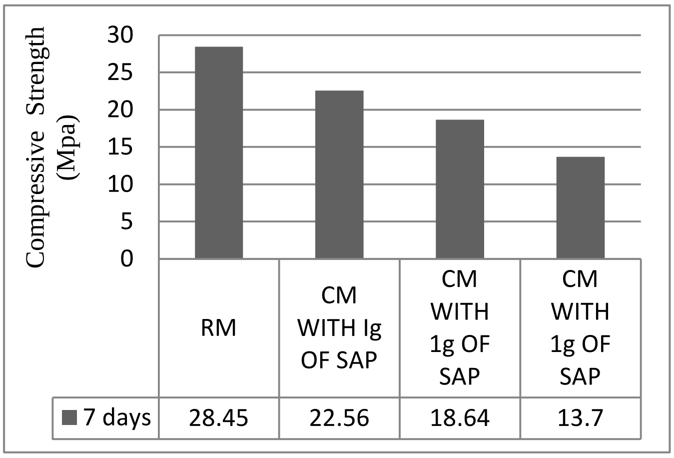


Figure 5. Compressive strength results for trial mixes

The additional water is added as 40ml, 60ml, and 80ml for the three SAP mixes respectively.

Since in trial 2 also there was a significant strength reduction in the mortar cubes is noticed. So, the project is continued by doing trial mixes in concrete cubes and the optimum amount of internal curing water is obtained. It is shown below in [5]

4. Materials And Mix Proportions

Ordinary Portland cement of 53 Grade corresponding to IS1489 (Part1)-1991.The coarse aggregate used are crushed stones of size passing through 20 mm and retaining on 12.5 mm IS Sieve with the specific gravity of 2.67.The steel slag with a specific gravity of 2.63.The fine aggregate (river sand) with a specific gravity of 2.6 is used. The concrete mix was designed for M-40 with w/c ratio of 0.35. Super absorbent polymer at 0.5% of weight of cement was added.

Table: 1 Mix proportion for 1 m^3 in kg

TYPE	CEMENT	FA	CA	WATER	SLAG
CC	445	658	1148	155	-
SAC	445	658	1148	202	-
SSAC	445	658	574	202	574

SAP is added as 0.5% of mass of cement to SAC and SSAC mix.

CC - Controlled concrete

SAC - Concrete with 0.5% of SAP with respect to mass of cement

SSAC - Concrete with 0.5% of SAP and 50% replacement of coarse aggregate with steel slag.

5. Optimum Amount for Internal Curing

To find the optimum amount of water for internal curing, concrete cubes of four trial mix were casted, by adding 20%, 30%, 40%, and 50% of additional water with respect to the original water content. Based on the compressive strength results of the trial mix the optimum amount of additional water required was estimated.

Trial 1 - 20% of additional water
Trial 2 - 30% of additional water
Trial 3 - 40% of additional water
Trial 4 - 50% of additional water
The results are shown below,

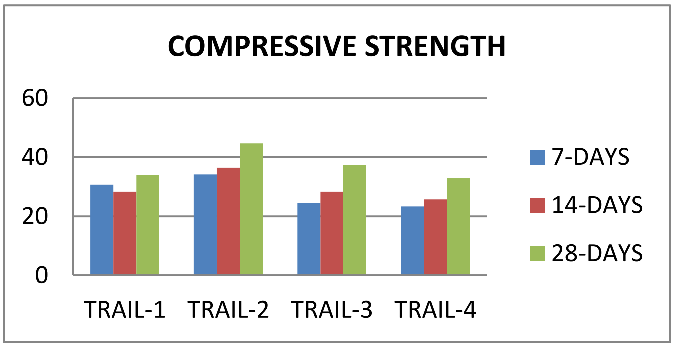


Figure 6. Compressive strength results for trial mixes

At the age of 28 days the 30% of additional water mix shows a higher strength than other trial mixes. So the optimum amount of internal curing water is taken as the 30% of the total water added in the mix.

6. Experimental Program

In order to access the strength of self curing concrete, study has been made by comparing the strength of conventional concrete and self curing concrete by conducting compressive and split tensile strength and Flexural Strength by adding SAP at 0.5% of mass of cement for one mix with 30% of additional water for one mix and by replacing 50% of coarse aggregate with steel slag and with 0.5% of SAP (including additional water) for another mix. Casting has done in the laboratory and table vibrator will be used for compacting the specimens.

6.1 Compressive strength:

Compression test is the most common test conducted on hardened concrete, partly because it is an easy test to perform, because most of the desirable characteristic properties of concrete are qualitatively related to its compressive strength.

6.2 Split Tensile strength:

Concrete is strong in compression but weak in tension. Tension stresses are likely to develop in concrete due to drying shrinkage, rusting of reinforcement, temperature gradient etc...In concrete load slab this tensile stresses are developed due to wheel loaded and volume changes in concrete will induce the tensile stress. Split test is one of the indirect methods to find out the tensile strength.

6.3 Flexural strength:

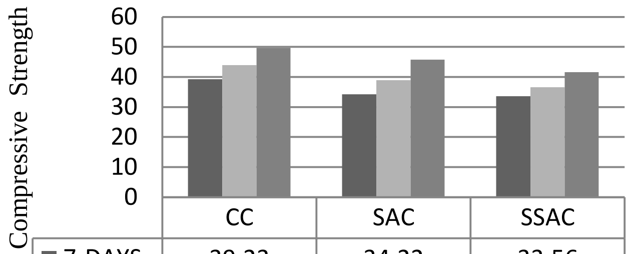
The stresses induced in concrete pavements are mainly flexural. Therefore flexural strength is more often specified than compressive strength in the design of concrete pavement construction. It is the ability of a beam or slab to resist failure in bending. So it is necessary to test the flexural strength of the concrete used for pavements.

III. RESULTS AND DISCUSSION

7.1 Compressive Strength

Compressive strength of the concrete cubes for various types of mixes (controlled concrete (CC), SAP-0.5% (SAC) and SAP + Steel Slag (SSAC)) for 7, 14 and 28 days was found.

The obtained results are shown in Fig.7.

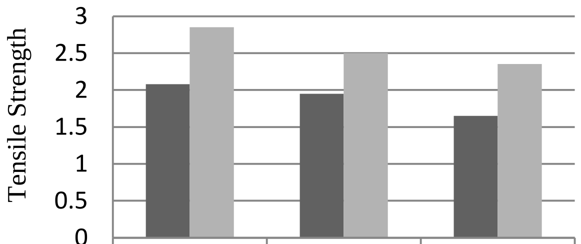


	CC	SAC	SSAC
7-DAYS	39.23	34.22	33.56
14-DAYS	43.96	38.88	36.63
28-DAYS	49.69	45.77	41.63

Figure 7. Compressive strength results of cubes

7.2 Tensile Strength

Tensile strength of the concrete cylinders for CC, SAC and SSAC at 7 and 14 days was found. The obtained results are shown in Fig.6.

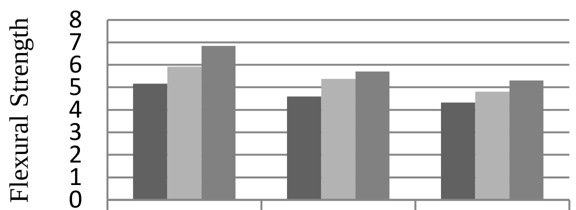


	CC	SAC	SSAC
7-DAYS	2.08	1.95	1.65
14-DAYS	2.85	2.5	2.35

Figure 8. Tensile strength results of cylinders

7.3 Flexural Strength

Flexural strength of the concrete prisms for mixes CC, SAC and SSAC at 7, 14 and 28 days was found. The obtained results are shown in Fig.6.



	CC	SAC	SSAC
7-DAYS	5.16	4.6	4.32
14-DAYS	5.92	5.38	4.8
28-DAYS	6.84	5.7	5.31

Figure 9. Flexural strength results of prisms

IV. CONCLUSION

Of the above tests conducted, the strength property for the concrete with addition of SAP curing is identified. Hence the strength of internally cured concrete with SAP shows a slight reduction in the mechanical properties when compared with the controlled concrete. When the replacement is made for the coarse aggregate with steel slag more strength reduction is observed.

But as per IS 456, Table 2, the required strength had been achieved for the M40 grade of concrete. (Eventhough the target mean strength is not achieved)

From the results it is proved that the self curing concrete can be used for the practical applications in a good manner.

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