The influence of superabsorbent polymer beads used as internal curing agent on the compressive strength of mortar

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Abstract - *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. Super-absorbent polymers (SAP) prove to be good internal curing agent, 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. The scope of this research is to assess the potential use of superabsorbent polymer beads as an internal curing agent in improving the compressive strength of concrete. The objective of this research is to first establish the basic properties of Superabsorbent polymers used herein and then a comparative study in terms of compressive strength of mortar under the influence of SAP in mix against its control mix under four curing conditions: sealed, unsealed, pond and mist. Curing without using water is suitable for places where there is not enough water for the curing process. And sealing of the concrete surface after casting should be practiced in order to prevent any moisture loss which supports the internal curing in the presence of SAP beads.*

Key Words: Internal Curing, Superabsorbent polymers, Shrinkage, Mortar cubes, Curing conditions

1. INTRODUCTION

The introduction of SAP as a new additive for the production of concrete materials presents a number of new possibilities in respect of water control, i.e., the purposeful water absorption and/or water release in either fresh or hardened concrete. The most prominent use of these properties is the internal curing of high strength concrete, as initially suggested by Jensen and Hansen. Today, many concrete structures experience early-age shrinkage cracking. This approach was dealt with already as part of the work of the RILEM Technical Committee 196-ICC "Internal Curing of Concrete". It was shown there, that because of their very high water absorption capacity, SAP have great potential to mitigate autogenous shrinkage.

The increasing interest in the use of SAP as a concrete additive and the need for intensive scientific consultation among research groups led in 2007 to the initiation of the RILEM Technical Committee 225-SAP "Application of Superabsorbent Polymers in Concrete Construction". From different countries around the world this committee brings together researchers who are presently investigating the mechanisms of SAP action in concrete materials and the possibilities and limitations of using SAP as a potential solution to various problems encountered by practitioners in the field.

Proper curing of concrete structures is important to ensure they meet their intended performance and durability requirements. 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.

1.1 Internal curing

Internally cured concrete is not a new concept; some might even say it is ancient since it can be considered to date back to concrete constructed during the Roman Empire. Internal curing provides something that most concrete needs and conventional curing cannot provide: additional internal water that helps prevent early age shrinkage (reducing early age cracking) and increases hydration of cementitious materials throughout the concrete.

Once concrete sets, hydration creates partially-filled pores in the cement paste which causes stress that result in shrinkage. IC provides readily available additional water throughout the concrete, so hydration can continue while more of the pores in the cement paste remain saturated. This reduces shrinkage, cracking, early age curling/warping, increases strength and lowers the permeability of the concrete, making it more resistant to chloride penetration.

Internal curing does not replace conventional surface curing, but works with it to make concrete more robust. Internal curing can also help compensate for less than ideal weather conditions and poor conventional curing that is often seen in the real world. ACI defines internal curing (IC) as a process by which the hydration of cement continues because of the availability of internal water that is not part of the mixing water.

The even distribution of additional water sources within the concrete will lead to greater uniformity of moisture throughout the thickness of the section, and thus reduced internal stresses due to differential drying. While drying shrinkage may not be completely prevented in the long term, delaying it will allow the mixture to gain strength and be better able to resist the associated stresses.

1.2 Shrinkage in concrete

Concrete is subjected to changes in volume either autogenous or induced. Volume change is one of the most detrimental properties of concrete, which affects the long-term strength and durability. To the practical engineer, the aspect of volume change in concrete is important from the point of view that it causes unsightly cracks in concrete.

One of the most objectionable defects in concrete is the presence of cracks, particularly in floors and pavements. One of the important factors that contribute to the cracks in floors and pavements is that due to shrinkage. It is difficult to make concrete which does not shrink and crack. It is only a question of magnitude.

Now the question is how to reduce the shrinkage and shrinkage cracks in concrete structures. The term shrinkage is loosely used to describe the various aspects of volume changes in concrete due to loss of moisture at different stages due to different reasons. To understand this aspect more closely, shrinkage can be classified in the following way:

1) Plastic Shrinkage
2) Drying Shrinkage
3) Autogeneous Shrinkage
4) Carbonation Shrinkage

One of the most important factors that affect shrinkage is the drying condition or in other words, the relative humidity (RH) of the atmosphere at which the concrete specimen is kept. If the concrete is placed in 100 per cent relative humidity for any length of time, there will not be any shrinkage; instead there will be a slight swelling.

The rate of shrinkage decreases rapidly with time. It is observed that 14 to 34 per cent of the 20 year shrinkage occurs in 2 weeks, 40 to 80 per cent of the 20 year shrinkage occurs in 3 months and 66 to 85 per cent of the 20 year shrinkage occurs in one year. Another important factor which influences the magnitude of shrinkage is water/cement ratio of the concrete. The richness of the concrete also has a significant influence on shrinkage. Aggregate plays an important role in the shrinkage properties of concrete. The quantum of an aggregate, its size, and its modulus of elasticity influence the magnitude of drying shrinkage. Harder aggregate with higher modulus of elasticity like quartz shrinks less than softer aggregates such as sandstone.

1.3 Superabsorbent polymers

All polymer materials that are able to absorb large quantities of water belong to the group of superabsorbent polymers (SAP). These materials were especially used so far in the hygiene industry. In civil engineering they are used as binder for joint poetries, paintings and coating. Different researchers showed that in concrete technology, their work will be discussed in greater detail in the following subsections, the SAPs can be used for internal curing preventing autogenous shrinkage. But the polymers can theoretically fulfil more functions:

1. They could counteract or postpone drying shrinkage.

2. They could function as air pore entraining agents, increasing the freeze-thaw resistance, the durability and the density of a concrete.

3. They could extract water of the fresh concrete mixture causing the stiffening of the paste which is accompanied by a reduction of the capillary porosity.

2. LITERATURE REVIEW

In the literature, information about the influence of SAP on concrete strength is not extensive and the reported results may seem contradictory. With regard to the 28-days compressive strength, some publications report reduction of compressive strength of mixes containing SAP, in comparison with reference mixes without SAP, whereas other publications demonstrate almost unchanged or even higher strength:

Piérard et al.: The strength of concrete made at w/c = 0.35 without SAP and with SAP contents of 0.3% and 0.6% (and extra water equivalent to 2% and 4% of cement mass, respectively), was measured on cubes cured at 20 ± 2 °C and minimum air relative humidity of 95% at ages of 2–28 days. Results showed that the early strength development (2–7 days) was slowed down with SAP, but the reduction in strength decreased at later ages. After 28 days, the reductions in strength were 7% and 13% for concrete mixes with SAP contents of 0.3% and 0.6%, respectively.

Lura et al. : For w/c = 0.30, internal curing by means of 0.4% SAP (extra water equivalent to 5% of cement mass) had almost no influence on the compressive strength of mortars, while the strength of cement pastes was reduced by 20% at early ages (up to 7 days) and by 10% at later ages (28 and 56 days).

Esteves et al.: In this work mortars with w/c at 0.25, 0.30, and 0.35 were tested. For each w/c, mixes were made without SAP and 0.2% SAP (extra water equivalent to 5% of cement mass), and specimens were cured at 30%, 50%, and

95% relative humidity. Results after 28 days of curing at 95% relative humidity showed a 15–20% reduction of compressive strength for mortar with SAP. But where the strength dropped at lower relative humidity for mortar without SAP, mortar with SAP had almost constant compressive strength no matter the curing conditions. At 30% relative humidity, the strength reduction for mortar with SAP was only 5%.

Mechtcherine et al.: Compressive strength was reported for ultra high performance SAP-containing mortars (w/c = 0.22, SAP content 0% (reference mix), 0.3%, and 0.6% relative to cement mass). Extra water was added to SAP-containing mixes to compensate the loss of workability. Noticeable decrease in compressive strength was observed at early ages, e.g. at 7 days, where the strength reductions were 12% and 30% for 0.3% and 0.6% mixes, respectively. At 28 days measurements exhibited only a minor decrease in strength for the 0.3% mixes: 4% (not significant). At 28 days, the strength reduction for the 0.6% mix was 20%.

Gao et al.: An increase in compressive strength was observed, when SAP was added to the aluminate cement paste made at w/c = 0.40, but without adding extra water: from 36.1 MPa (0% SAP) up to 40.5 MPa (0.2% SAP) and 44.4 MPa (0.6% SAP).

Bentz et al.: Measurements of compressive strength development were carried out for mortar mixes with w/b = 0.35, with and without SAP (0.4% relative to binder mass). After 7 days, the compressive strength of mortar with SAP was lower than the strength of a reference mortar without SAP, 53 MPa vs. 57 MPa. After 28 days of curing, the picture had changed; mortar with SAP showed higher compressive strength than the reference mortar, 73 MPa vs. 61 MPa (values for compressive strength are approximates, as mixes have been tested at slightly different age, and test results have been interpolated afterwards).

2. SCOPE AND OBJECTIVE

The scope of this research is to assess the potential use of superabsorbent polymer beads as an internal curing agent in improving the compressive strength of concrete.

The objective of this research is to first establish the basic properties of Superabsorbent polymers used herein and then a comparative study in terms of compressive strength of mortar under the influence of SAP in mix against its control mix under four curing conditions: sealed, unsealed, pond and mist.

2.1 Experimental investigation

2.1.1 Materials used

1. CEMENT: Ordinary Portland cement, 53 Grade conforming to IS 12269 – 1987. The specific gravity of cement is 3.15
2. SUPER ABSORBENT POLYMER: The super absorbent polymers constituting of Sodium Polyacrylate in the form of round beads are used. They are labelled as non-toxic and eco-friendly.
3. FINE AGGREGATE: The fine aggregate used was obtained from a near source: Adyar river. The fine aggregate is conforming to zone II according to IS: 383-1970. It is passed through 2.36 mm sieve.
4. WATER: Potable water was used in the experimental work for both mixing and curing purposes.

2.1.2 Laboratory condition

The laboratory work including preparation of mortar mix and casting of mortar cubes are conducted under controlled temperature of 23.5°C and relative humidity (RH) value of 65%.

2.1.3 Properties of superabsorbent polymer beads

Absorption rate

To conduct the absorption test of SAP, 1 gram of dry beads is weighed on weighing balance and soaked in distilled water. After the certain interval of time the beads are weighed and diameter is noted by using vernier caliper.

Table -1: Absorption rate

Absorption rate			
Time elapsed (Minutes)	Weight of SAP beads (Grams)	Time elapsed (Minutes)	Weight of SAP beads (Grams)
0	1	15	7.5
1	1.5	16	8
2	2.5	17	8
3	2.5	18	8.5
4	3.0	20	9
5	3.5	21	9
6	3.5	22	10
7	4.0	23	10
8	4.5	24	10.5
9	5.0	25	11

10	5.5	26	11.5
11	6	27	11.5
12	6	28	11.5
13	6.5	29	12
14	7	30	12.5
35	16	80	26.5
40	17.5	85	28
45	19	90	28.5
50	20	95	29.5
55	21	100	30.5
60	22.5	105	31.5
65	23	110	32.5
70	24	115	33.5
75	25.5	120	34.5

The dry beads have initial diameter of 3.58 mm. Upon being placed in distilled water for 2 hours, it swells to the diameter range of 16.9 - 19.8 mm and its water absorption capacity is found to be 33.5 gram of water absorbed per gram of beads during 2 hours of duration.

Fig -1: Scale showing the size of swollen SAP bead

Specific gravity

Specific gravity of SAP beads is calculated by dividing the mass density of each dry bead by that of water.

Mass of each bead = 0.05 g or 0.05 x 10-3 kg

Diameter of each bead = 3.58 mm

Volume = 24.02 x 10^{-9} m^3

Hence Specific Gravity = 2.08

2.1.4 Preparation of mortar mix

The quantity of SAP beads to be added to the mortar is determined based on the quantity of water required for internal curing which is taken to be equivalent to 5% and 10% of cement mass. Hence the beads are pre-soaked for certain duration of time and then weighed to ensure that the water required for internal curing is absorbed by them. The factor of safety of 1.5 is assumed with respect to mass of beads added. One set of control mix (containing no SAP beads) is also prepared for drawing comparison with the SAP mix.

The water to cement ratio is determined by conducting flow table test by adding different quantity of water and hence the most suitable workability is taken into account for further experiment. Therefore the water to cement ratio is adjudged to be 0.45

Table -2: The design mix of mortar prepared to cast samples

S. No.	Cement: Sand	SAP Beads	Water / cement ratio
1.	1:3	5% of Cement mass	0.45
2.	1:3	10% of Cement mass	0.45
3.	1:3	NIL	0.45

The quantities of Cement and sand to be used in design mix are measured in relation to the proportion mentioned in above table. They are mixed rapidly in dry condition for 2 minutes with the help of electric blender. Later the calculated amount of water and SAP beads are added to the dry mix and allowed to mix for another 5 minutes to obtain a homogenous mix. The mixing, compacting and curing of concrete are done according to IS 516: 1959.

Fig -2: Mortar mixer and beaker filled with water and SAP beads

2.1.5 Casting of mortar cubes

Before casting the cubes, the suitable mould size is to be decided. Since there is no course aggregates being used, so the Acrylic made moulds of dimension 70 x 70 x 70 mm is used. First of all the moulds are applied evenly with oil or grease on the inner surfaces using a fine brush. This is done in order to make the de-moulding process easy. The mortar is now ready to be transferred into these moulds using trowel. It should be made sure that proper compaction of mortar is done externally by using tamping rod while laying it in three layers into the moulds. This is purposed to the uniform distribution of mortar along the corners and edges of the mould. The top surface of the moulds should be made plane so that proper adjustment could be achieved while keeping these cubes on compression testing machine. Now these moulds are left in isolation for letting the mortar mix to dry and get hardened. The drying process will generally take 12 to 15 hours.

Fig -3: Moulds of dimension 70 x70 x 70 mm filled with mortar using tamping rod

After almost 15 hours of drying, is was verified by placing finger on the surface. It is hard in touch which means that the mortar cube has attained hardened state to an extent allowing it to be de-moulded. The de-moulding should be carried out with the utmost care to prevent any breakage from the corners and edges of cube. Casting of the specimens were done as per IS:10086-1982

2.1.6 Curing of mortar cubes

After the removal from the moulds, the cubes are immediately promoted for curing process. This is to further carry out compression testing on the specimens to compute its 7-days and 28-days strength. The curing takes place under following four different laboratory conditions.

OPEN ATMOSPHERE
The temperature and RH value are same as atmospheric condition.

SEALED BAG
The mortar moisture content is preserved within the Polythene bag itself intended for self-curing. Hence this moisture is utilized for internal curing.

WATER CONTAINER
The RH level is 100% and temperature change is subjected to atmospheric condition.

MIST ROOM
The RH level is 95% to 100% and the temperature remains at 27 to 30°C

Fig -4: Different curing conditions

The following table enlists the details of mortar cubes being cast under different curing condition in order to test them for their compression strength after 7 and 28 days respectively.

Table -3: Summary of cubes cast

MIX No.	DESCRIPTION	CURING CONDITION	CURING DURATION	NO. OF SAMPLES
1	w/c = 0.45	Seal	7 & 28 days	3 + 3 = 6
2	w/c = 0.45	Open	7 & 28 days	3 + 3 = 6
3	w/c = 0.45	Pond	7 & 28 days	3 + 3 = 6
4	w/c = 0.45	Mist	7 & 28 days	3 + 3 = 6
5	w/c = 0.45; 5% beads	Seal	7 & 28 days	3 + 3 = 6
6	w/c = 0.45; 5% beads	Open	7 & 28 days	3 + 3 = 6
7	w/c = 0.45; 5% beads	Pond	7 & 28 days	3 + 3 = 6
8	w/c = 0.45; 5% beads	Mist	7 & 28 days	3 + 3 = 6
9	w/c = 0.45; 10% beads	Seal	7 & 28 days	3 + 3 = 6
10	w/c = 0.45; 10% beads	Open	7 & 28 days	3 + 3 = 6
11	w/c = 0.45; 10% beads	Pond	7 & 28 days	3 + 3 = 6
12	w/c = 0.45; 10% beads	Mist	7 & 28 days	3 + 3 = 6

2.1.6 Compression test on mortar samples

The compressive strength of 70 mm cubes was measured according to IS 516:1959. The cube specimens are tested on compression testing machine of capacity 250 kN. The bearing surface of machine is wiped off clean and sand or other material removed from the surface of the specimen. The weight of the specimen is noted down. The specimen is placed in machine in such a manner that the load is applied to opposite sides of the cubes as casted that is, not top and bottom. The axis of the specimen is carefully aligned at the centre of loading frame. The load applied is increased continuously at a constant rate until the resistance of the specimen to the increasing load breaks down and no longer can be sustained. The maximum load applied on specimen is recorded in kN and at the same time maximum stress developed is also noted in MPa or kN/mm².

Fig -5: Compressive testing machine of 250kN capacity

Table -4: Compressive strength results

MIX NO.	Description	Curing Condition	Wt. @ 7-days (kg)	Wt. @ 28-days (kg)	DRY DENSITY @ 28-Days (kg/m3)	Compressive strength @ 7-days (MPa)	Compressive strength @ 28-days (MPa)
1	w/c = 0.45	seal	0.75	0.762	2221.57	23.41	28.31
2	w/c = 0.45	open	0.72	0.772	2250.73	17.74	17.93
3	w/c = 0.45	pond	0.765	0.795	2317.78	35.3	40.89
4	w/c = 0.45	mist	0.76	0.791	2306.12	30.1	32.4
5	w/c = 0.45 ; 5 % beads	seal	0.739	0.772	2250.73	25.4	26.84
6	w/c = 0.45 ; 5 % beads	open	0.723	0.742	2163.27	22.76	16.12
7	w/c = 0.45 ; 5 % beads	pond	0.769	0.79	2303.21	26.67	38.95
8	w/c = 0.45 ; 5 % beads	mist	0.766	0.761	2218.66	29.24	27.61
9	w/c = 0.45 ;10% beads	seal	0.763	0.754	2198.25	31.34	32.55
10	w/c = 0.45 ; 10% beads	open	0.743	0.725	2113.70	15.63	18.87
11	w/c = 0.45 ; 10% beads	pond	0.761	0.797	2323.62	32.48	39.17
12	w/c = 0.45 ; 10% beads	mist	0.755	0.767	2236.15	32.42	36.02

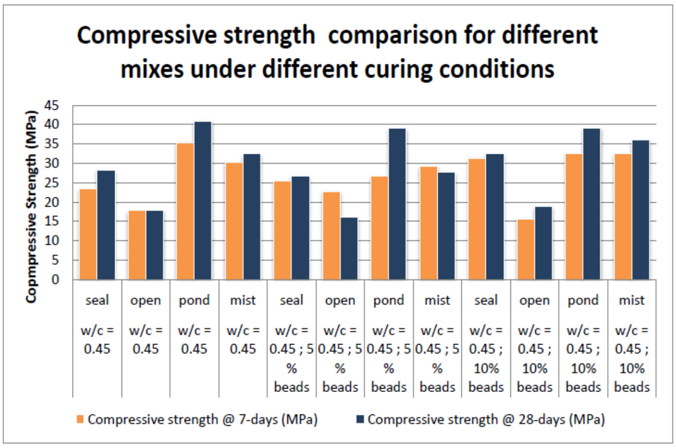

Chart -1: Compressive strength comparison

3. CONCLUSIONS

1) The superabsorbent polymer beads retain the moisture all throughout the mortar cubes for minimum 7 days which tend to promote internal curing.

2) Upon being placed in distilled water for 2 hours, it swells to the diameter range of 16.9 - 19.8 mm and its water absorption capacity is found to be 33.5 gram of water absorbed per gram of beads during 2 hours of duration.

3) The specific gravity of SAP beads is found to be 2.08

4) When the cubes with an inclusion of 10% beads are cured under sealed condition wherein the loss of moisture is controlled, there is an increase in 28-days compressive strength by 14.97% compared to the controlled mix whereas in case of 5% inclusion of beads, there is drop in strength by 5.19%.

5) When the cubes with an inclusion of 10% and 5% beads are cured under pond condition, there is drop in 28-days compressive strength by 4.74% compared to the controlled mix.

6) When the cubes with an inclusion of 10% beads are cured under mist room condition, there is an increase in 28-days compressive strength by 11.17% compared to the controlled mix.

7) Curing without using water is proper for places where there is not enough water for the curing process. And sealing of the concrete surface after casting should be practised in order to prevent any moisture loss which supports the internal curing in the presence of SAP beads.

8) A further research should be encouraged to investigate the mechanical behaviour under different tests. The quantity and quality of beads can also be altered to find the future scope of its usage on real site.

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