Study on SAP with different absorption capacities and its effects on Self Curing HPC

Poornima V¹, Venkatasubramani R², Sreevidya V³, Vaishnau Vignesh⁴ and K Adithan⁵
¹Department of Civil Engineering, Amrita School of Engineering, Coimbatore, Amrita Vishwa Vidyapeetham, India.
²Department of Civil Engineering, Dr. Mahalingam College of Engineering and Technology, Coimbatore, Tamilnadu, India.
³Department of Civil Engineering, Sri Krishna College of Technology, Coimbatore, Tamilnadu, India.
⁴,⁵Department of Civil Engineering, Amrita School of Engineering, Coimbatore, Amrita Vishwa Vidyapeetham, India.

Email: ¹v.poornima@cb.amrita.edu

Abstract: Internal moist curing by Super Absorbent Polymer (SAP) plays an vital role in strength development and durability of High Performance Concrete (HPC). The aim of this study is to examine how the strength reduction happens by adding super absorbent polymer and rectification of strength reduction using micro fillers. The amount of SAP added to the concrete was calculated using the absorption capacity that was obtained as a result of tea bag test. The present study also involves the use of super absorbent polymer in gel and dry state to both mortar and concrete. First strength property was tested in mortar for both gel and dry state. It was found that SAP added in dry state to mortar has no adverse effect on compressive strength and tested. In the present work additional micro filler (silica fume) with different ratios: 0.0%, 10%, 15%, 20% of weight of cement is added to improve the mechanical properties of high strength concrete with SAP. The concrete samples are subjected to ambient curing and mechanical properties (compressive strength and modulus of rupture) were evaluated at different ages, up to 28 days. Durability property such as sorptivity, water absorption and carbonation was conducted on HPC. The effect of internally cured concrete was studied and compared with conventionally cured concrete.

Key words: Internal curing, Super Absorbent Polymer, High Performance concrete, Silica fume, Mechanical properties, Durability

1. INTRODUCTION

The American concrete institute (ACI) states Internal Curing (IC) as “A process which continues the hydration of cement because of the presence of internal water that is not part of mixing water”. Curing is valuable for concrete structures. In association with curing, when we compare plain concrete to IC concrete we can see that the plain concrete surface is penetrated only by few mm and is dependent on surface curing whereas the concrete with IC curing agent distributes water throughout the matrix internally[20]. IC water is hidden in the IC agent and begins to release water immediately at the time of set[6]. This investigation involves SAP as internal curing agent which absorbs water 500 times greater than its own weight[8,16]. An extensive experimental program was performed using SAP amount in proportion to the weight of cement. But it cannot be put in practice for SAP having different absorption capacities. It is very difficult to get SAP with same absorption capacity in construction industries. So addition of SAP amount can calculated using the absorption capacity which is obtained from tea bag test. If SAP’s absorption capacity is 100gm of water/gm of SAP then the
amount of SAP to be added is given by dividing the internal curing water amount by absorption capacity[13]. So that it absorbs only the internal curing water. In SAP the water can be stored either before adding to the concrete or while mixing the concrete. In other words SAP can be added in two forms. One in gel condition and another in dry condition. Before starting the mixing concrete, SAP and IC water are mixed together to become gel so that curing water cannot escape from polymer. This is one type mixing. In the other type SAP and IC water can be added separately while mixing concrete. Absorption of free water by SAP while mixing may affect the rheology and mechanical properties of concrete. So further research on addition at amount of SAP without affecting the rheology and durability properties of internally cured HPC with additional micro filler is required. Strength property can be improvised by extra cementitious material or micro fillers[2,7,]. The internal curing’s effect on the compressive strength of concrete decreases with time[15].

2. EXPERIMENTAL PROGRAM:

Many research attempts have been made to improve the RCA properties by various treatment methods. Each has its own advantages and disadvantages.

2.1 Materials used:
Ordinary Portland Cement with specific weight of 3.12 and powder form of silica fume with silica of 95%, river sand and gravel as fine and coarse aggregate of nominal size of 10mm were used[1]. On different curing conditions the results are more evident on early stages than with older stages[3]. Super absorbent polymer is spherical in shape with the particle size of 300 microns[9]. SAP’s absorption capacity was found by tea bag test method by immersing the SAP in solution of water and cement. In water it has maximum absorption capacity of 100g of water/g of SAP and in cement solution 30g of water/g of SAP. When it reaches the maximum absorption capacity after a while desorption of water or cement solution from SAP takes place which indicate that it will release water for concrete during hydration process[12]. Superplasticizer used CERAPLAST 400 which is of sulphonated melamine formaldehyde condensate type.

2.2 Mix proportion of mortar and concrete:
As per ACI211.4 mix proportion for HPC was calculated. The mix ratio for M75 concrete is 1: 1.03: 1.973: 0.269. The quantity of concrete batches is given in table1. In order to keep the required slump mini slump test was conducted on cement paste containing a w/c ratio of 0.26 and various SP dosages. The optimum dosage was found and used in every concrete mix. To reduce the trials on determining the strength of concrete it is checked using mortar initially. The mixture proportion for mortar is as same as the cement and fine aggregate content in concrete. To check the strength property ratio of 1:1.03 and with 0.26 w/c ratio were used.

| Mix notation | Cement in Kg/m³ | Mix water Kg/m³ | Silica fume Kg/m³ | IC water Kg/m³ | Fine aggregate Kg/m³ | Coarse aggregate Kg/m³ | SAP Kg/m³ | SAP Kg/m³ | Superplasticizer % wt of cement |
|---------------|-----------------|-----------------|-------------------|----------------|----------------------|------------------------|-----------|-----------|-------------------------------|
| C             | 583.41          | 151.686         | -                 | 57             | 602.55               | 1258                   | 0.57      | 1.9       | 1.2%                           |
| C'<sub>1</sub>| 583.41          | 151.686         | -                 | 57             | 602.55               | 1258                   | 0.57      | 1.9       | 1.2%                           |
| SF<sub>1</sub>| 525.069         | 151.686         | 58.341            | 57             | 602.55               | 1258                   | 0.57      | 1.9       | 1.3%                           |
| SF<sub>2</sub>| 495.898         | 151.686         | 87.512            | 57             | 602.55               | 1258                   | 0.57      | 1.9       | 1.4%                           |
| SF<sub>3</sub>| 466.728         | 151.686         | 116.682           | 57             | 602.55               | 1258                   | 0.57      | 1.9       | 1.4%                           |
3. METHODOLOGY:

A set of mortar cubes of size 70.6mm made of Portland cement for each mixture were cast to study the compressive strength on 7th and 28th day. To check the concrete’s mechanical and durability properties, cubes (100mm x 100mm x 100mm) and beams (100mm x 100mm x 500mm) were cast for both the absorption capacities from water (SAP pre soaked with extra curing water becomes gel and added to concrete while mixing) and cement solution(dry SAP directly added to concrete while mixing). The control specimens were cured for 28 days in water tank and for remaining cubes air-dried curing was done for 28 days in room temperature.

3.1 Tea bag test method for absorption capacity of SAP

The SAP’s absorption capacity was found by tea bag test method by immersing the SAP in solution of water and cement[1][10]. In water it has maximum absorption capacity of 100g of water /g of SAP and in cement solution 30g of water /g of SAP when it reaches the maximum absorption capacity after a while desorption of water or cement solution from SAP takes place which indicate that it will release water for concrete during hydration process[19]. Figure 1 and Figure 2 shows SAP added pre soaked with IC water and DrySAP. It is required to study the effect of SAP on the rheological properties of cement-based materials with ultra-low w/b, and their evolution with time[14]. Studies shows that low w/b ratio HPC has negative effects on mechanical properties due to the addition of curing water and SAP[5][11].

3.2 Slump test of fresh mortar and compressive strength of hardened mortar:

The fresh state property slump was checked immediately after mixing mortar. The mortar was hand mixed in pan with the proportion as mentioned above. Fill the slump cone, lift it immediately after pouring mortar and leave them to take 25 jolt. Then spread diameter of mortar was measured in mm for all the mixes. The mix and spread diameter for all mixes shown in table 2. Mortar cubes of size 70mm were cast and tested in CTM at loading rate of 140 kg/cm² as per IS 516(1959). Mortar cubes internally cured are tested for 7th and 28th day.

3.3 Compressive strength and flexural strength of hardened concrete:

As per IS 516(1959) Compressive strength of specimen were tested by compression testing machine with the load capacity of 2000 KN after curing for 7th and 28th day. Load applied gradually at the rate of 140kg/cm² per minute till the specimen fails. Three specimens are tested at the selected age and the average compressive strength of three specimens were noted. For modulus of rupture of hardened concrete, the prism specimens were tested for two point loading to create pure bending as per IS 9399-1979.
3.4 Sorptivity:
It can be determined by the measurement of the rate of absorption of capillary rise on a reasonably homogeneous material. The concrete specimens were tested for sorptivity after 28 days. The sample were oven dried at 50°C for 24 hrs. After 24 hours the specimens were taken out of the oven and cooled for 2hrs at laboratory temperature and then the experiment is carried out. The specimens are weighed initially and noted as \( W_1 \). Then specimens were coated with epoxy at the surroundings leaving the top and bottom surface for the penetration of water. Impermeable base sticks are kept in tray to keep the specimen on top of the stick to allow water to penetrate from the bottom. Record the weight of each specimen at the time interval \((t) \) 3, 10, 15, 30, 60, 120, 180 min. Noted down the weight as \( W_2 \). Make sure the surface of the exposed specimen before weighing should be in surface saturated condition.

Then the absorption (\( I \)) was given by the formula,
\[
I = \frac{\Delta W}{A d}
\]
Absorption values were plotted against time to produce absorption curves. Sorptivity value in \( \text{mm/min}^{0.5} \) is given by \( I/\sqrt{t.u} \)

3.5 Water Absorption of concrete:
In concrete dry samples water absorption is the most prominent transport mechanism. As per ASTM C 642 at the age of 28 days curing Water absorption (SWA) tests were carried out on 100 mm cube specimen. At 110°C temperature the concrete specimens were oven dried for 24 hours. This weight was taken as the dry weight \( (W_1) \). After immersion of specimen in water for 24 hours the weight was taken as the wet weight \( (W_2) \).

\[
\% \text{ Water absorption} = \frac{(W_2-W_1)}{W_1} \times 100
\]
Where \( W_1 = \) Oven dry weight of cube in grams
\( W_2 = \) Wet weight of cube after 24 hours in grams.

3.6 Carbonation depth of concrete:
The effect of reduction of the pH value of the concrete by acidic compounds in atmosphere are known as carbonation[17].Sides of cracks and the surface of Concrete gets carbonated. Steel reinforcement does not get necessary protection from carbonated concrete. Concrete specimen cube of size 100mm can be split into length were used for testing. Based on CPC-18RILEM recommendation, curing samples and specimen making were performed. After carbonizing the split discs sections phenolphthalein was sprayed on it and Concrete carbonization depths were measured. Around the four sides of the section the carbonization depth was measured with scale. The depths of carbonation result for 90 days are graphically drawn.

4. RESULTS AND DISCUSSIONS:

4.1 Study on SAP:
Figure 3 shows Teabag test in cement solution and water. Figure 4 and Figure 5 shows that SAP added pre soaked with IC water(100gm AC) has more strength reduction when compared to directly added dry SAP(30gm AC). 30gm absorption capacity absorbs alkaline solution from the cement paste later decelerate for hydration process.
4.2 Slump test of fresh mortar and compressive strength of hardened mortar:
The main objective of this study in mortar was to check the workability and strength increment between SAP added pre soaked with IC water(100gm AC) and directly added dry SAP (30gm AC) with incorporation of silica fume[18]. The results are compared between the absorption capacities. The same procedure was followed on concrete to study the effect of IC.

The workability of mortar for both the absorption capacity was almost same. But the SAP’s addition [19] causes absorption of water from the mix and thus reduces the workability. The test results in table 2 shows the average spread diameter and compressive strength of mortar for both the absorption capacity. From Figure 6 and Figure 7 for 30gm absorption capacity 7th day compressive strength increases 15% and 28th day has no negative effects when compared with 100gm absorption capacity. The strength achievement of SF is 19% and 10% higher than conventional mortar with or without SAP.

Figure 3. Teabag test in cement solution and water

Figure 4. SAP’s Absorption capacity in cement solution

Figure 5. SAP’s Absorption capacity in water solution
Table 2. Slump test and compressive strength result for mortar

| Mix notation | Average spread Diameter in mm | Average compressive strength on 28th day in N/mm² |
|--------------|-------------------------------|-----------------------------------------------|
|              | 100gm | 30gm | 100gm | 30gm |
| C            | 303.33 | 300.00 | 48.97 | 48.97 |
| C₁           | 293.66 | 287.34 | 39.7  | 53.06 |
| SF₁          | 288.67 | 275.5  | 48    | 58.16 |
| SF₂          | 287.33 | 276.36 | 48    | 55.103 |
| SF₃          | 288.33 | 278.5  | 53.06 | 57.147 |

Mortar cubes internally cured are tested for 7th and 28th day with different absorption capacities and the values has been represented in Figure 6 and 7.

Figure 6. Compressive strength of internally cured mortar on 7th day with different absorption capacities (AC)

Figure 7. Compressive strength of internally cured mortar on 28th day with different absorption capacities (AC)

4.3 Compressive strength and flexural strength of hardened concrete:
The concrete specimen’s mechanical properties were reported in table 3. Compressive strength of internally cured concrete on 7th and 28th day with different absorption capacities (AC) are given in Figure 8 and Figure 9. And also internally cured specimen has higher modulus of rupture than the conventionally cured concrete. Figure 10 shows that 30gm AC has higher modulus of rupture 8.5N/mm² where conventionally cured concrete was 8N/mm².
Table 3. SAP’s effect on mechanical properties of concrete specimen

| Mix notation | Compressive strength of concrete in MPa | Modulus of rupture in N/mm² |
|--------------|----------------------------------------|-----------------------------|
|              | 100gm Absorption capacity | 30gm Absorption capacity | 100gm Absorption capacity | 30gm Absorption capacity |
| Day          | 7    | 28    | 7    | 28    | 28   | 28 |
| C            | 48   | 77    | 50   | 77    | 8    | 8  |
| C₁           | 43   | 68.75 | 46.875 | 63    | 6.5  | 7.75 |
| SF₁          | 41   | 62.5  | 48.75 | 71.5  | 7    | 8.5 |
| SF₂          | 40   | 65.62 | 42    | 65.5  | 6.25 | 6.75 |
| SF₃          | 43.5 | 70    | 40    | 67.75 | 6.25 | 6.25 |

Figure 8. Compressive strength of internally cured concrete on 7th day with different absorption capacities (AC)

Figure 9. Compressive strength of internally cured concrete on 28th day with different absorption capacities (AC)
Figure 10. Modulus of rupture of concrete on 28th day with different absorption capacities (AC)

The SAP pre-soaked with internally curing water swells and becomes gel. Their size and shape will be more than the dry SAP. This releases water in very slow rate and fails to achieve early strength. This also leaves large size of pores inside concrete which weakens them. So more strength reduction was observed in concrete with 100gm AC. Dry SAP added directly to the concrete uptake the alkaline solution and releases them before the initial set of the concrete for hydration process. The deceleration of water also takes place throughout the curing period which was observed from tea bag test with cement pore solution. Thus effective internal curing takes place in 30gm AC with silica fume[4].

4.4 Sorptivity, Water Absorption and Carbonation

Durability test (sorptivity and water absorption) in 30gm absorption capacity shows mix with high replacement of silica fume is less porous and permeable. Figure 11 shows that increase in compressive strength is associated with a decrease in water absorption percentage. Figure 12 shows no carbonation effect was shown conventionally cured concrete while in internally cured concrete almost the same effect were produced by all mixes. Figure 13 shows the sorptivity and values for all the mixes.

Figure 11. Water Absorption vs Compressive Strength of internally cured concrete with 30gm absorption capacities (AC)
5. CONCLUSION:

This investigation shows an effective approach of reducing the strength reduction of HPC specimens which was internally cured. In reviewing literature internally cured HPC concrete has strength reduction up to 10%. Additions of Dry SAP directly to the concrete with incorporation of silica fume (SF₁) result in decrease of strength reduction up to 4% and modulus of rigidity was higher than conventionally cured concrete. Reduced porosity is good for durability due to silica fume’s high replacement of cement. Further microstructure study can be done on SAP with concrete to find reason for strength reduction.

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