Enhancement of Durability of self-compacting concrete with internal curing using super absorbent polymer

Kuruva Venkateswarlu*, Shirish.V.Deo, Meena Murmu
Department of civil engineering

National Institute of Technology Raipur

Raipur, India

*Email: venkateswar154@gmail.com

Abstract:

Self-compacting concrete contains higher cementitious materials in it. Therefore, it needs better curing for the complete hydration of total cementitious materials. External curing alone is insufficient to cure the concrete throughout the section of the concrete element. Internal curing is the solution to effectively cure the concrete and improve the microstructure. The super absorbent polymer in this investigation absorbs 170 g/g in normal water. The quantity of SAP has been decided with the Bentz equation. The effect of SAP has been studied in three curing regimes Water curing, Gunny bag curing and Air curing. Further, it resists aggressive ions and water penetration into the concrete. Electrical resistivity and ultrasonic pulse velocity tests measure the durability of concrete. Electrical resistivity test results give the risk of corrosion, and Ultrasonic pulse velocity gives denseness of structure by ultrasonic pulse velocity through the section of the concrete element. Super absorbent polymer is an adequate internal curing material and is economical. Enhancement of durability has been observed higher in the air curing regime.

Keywords: Internal curing; super absorbent polymer; Electrical resistivity; Ultrasonic pulse velocity; Self-compacting concrete.

1. INTRODUCTION

The self-compacting concrete (SCC) in the fresh state is flowable, and based on flow properties, it is considered as a Bingham fluid [1]–[4]. There is a higher need for curing to hydrate higher cementicious materials in the SCC. In practical conditions, external curing is impossible for all concrete elements. Insufficient curing leads to inadequate hydration resulting in porous microstructure. In this regard, internal curing is a suitable technique to achieve the total hydration of self-compacting concrete. An internally cured material called SAP is a macromolecular substance with solid water retention and super water absorption capabilities. It can effectively increase the volume stability of concrete and prevent issues like micro-cracks, autogenous shrinkage, and drying shrinkage. Due to its strong ability to retain water and chemically hydrophilic group structure, the concrete's volume stability and durability are also enhanced [5-7]. The internally cured technique has been proposed and shown to speed up the hydration of concrete significantly [7,8]. Scholars have researched using SAP materials in concrete engineering. D.Sarbapalli et al. discussed the effects of various fibre types, internal curing agents, and additional water equivalent on concrete [5]. Other researchers looked at how SAP affected concrete's mechanical properties, volume stability, and durability when the water-to-cement ratio was low [11–13]. In this work, three curing regimes have been considered for deriving the exact effect of SAP on SCC. In the case of internal curing concrete with SAP, when the effective w/c ratio decreases, the workability and compressive strength decrease in conventional water curing. The reduction of compressive strength is due to SAP hydrogel. The SAP hydrogel act as weak material and won't release the water due to relative humidity change is constant. But in Air curing, the compressive strength will increase due to SAP release the water and complete the hydration throughout concrete. Hence it is interesting to know the effect of adding super absorbent polymer on the durability properties of concrete in various curing regimes.

2.0 EXPERIMENTAL PROGRAM

2.1 Materials

The cement used in this investigation is Portland pozzolana cement (PPC) with a specific gravity of 2.90**,** confirming to Indian code (IS: 1489-1991) and manufactured by Ultratech Cement Company. Economic and sustainability point of view Pozzolanic cement has been chosen. The chemical compositions of the cement are given in Table 1. Poly carboxilic ether based super plasticizer including viscosity modifying agent (Master Glenium 8632) is used to achieve self-compactibility and contains a viscosity-modifying agent. A super plasticiser is confirming to Indian code IS: 9103-1999 [8] and has physical properties are Specific gravity of 1.08, pH of ≥6, and chloride ion percentage of <0.2% respectively. Sand and coarse aggregates with max size of 10mm used in this study confirm to Indian code (IS: 383-2016). Specific gravities of 10mm coarse aggregates and sand were 2.72 and 2.60. A super absorbent polymer is a water-absorbent hydrogel which is commercially available, and the chemical oxides of SAP have shown in table 1. Sodium-based Poly acrylate was used as SAP and has a bulk density of 0.65-0.80 g/cm^3 and particle size distribution of 18-50 mesh. Previous studies (Ding et al., 2017) also suggested for better internal curing results that, SAP particle size distribution should be 30-50mesh, and SAP dosage should be less than 0.2% of the mass of cement. The tea bag method has been used for water absorption capacity in water and cement solution. Water absorption of 170g/g in water and 36g/g in cement solution (water-cement ratio =5.0) (Schröfl et al., 2012). The internal curing water required to achieve complete hydration and the amount provided by SAP has been discussed in the previous publication(Venkateswarlu et al., 2021). Figure 1 shows how the SAP volume change after contact with water.

Figure 1: Super absorbent polymer before and after swelling with the addition of water.

2.2 Required amount of internal curing water

Previous research has provided the following equations to calculate the mass of SAP and the volume of water needed for internal curing to achieve the highest degree of hydration possible for concrete mixes [12].

$$M\text{SAP} = \frac{C \times CS \times \propto \text{max}}{S \times \emptyset SAP} \qquad \text{---Equation 1}$$

Where, C is the cement content in the mixture in kg/m^3;

CS is chemical shrinkage (ml/g);

$\propto$max is the expected maximum hydration degree of hydration;

S is the degree of saturation;

ϕ_{SAP} is water absorption of SAP.

2.3 Concrete mixes

Four concrete mixes were prepared: one standard SCC mix and three internal cured SCC mixes, with different dosages of SAP. The chemical composition of PPC and SAP are given in Table 1. The mix proportions of SCC are shown in Table 2, and the nomenclature of each mix: SAP-0, SAP-5, SAP-10, and SAP-15, indicates the doses of SAP 0%, 0.05%, 0.10%, and 0.15% of mass cement content. According to the Bentz formula, the SAP dosage needed to complete the hydration of cementitious materials is 0.194kg/m^3. However, divalent ions (Ca^{+2}) ions present in the cement reduce the absorption capacity of SAP. Hence SAP dosages started with 0.05% of cement, which is 0.27 kg/m^3, which is higher than the required quantity of 0.194kg/m^3.

Table 1: Chemical oxide compositions of cement and SAP.

Element	**PPC (%)**	**SAP (%)**
Silica (Si)	26.33	-
Calcium (Ca)	50.00	-
Aluminum (Al)	11.45	-
Iron (Fe)	1.75	-
Magnesium (Mg)	8.97	-
Potassium (K)	1.41	-
Sulphur (S)	-	-
Sodium (Na)	-	33.03
Oxygen (O)	-	55.78
Carbon (C)	-	11.19

Table 2: Mix proportions of SCC in kg/m^3

Mixes	**Cement**	**W/C ratio**	**Water**	**Sand**	**Coarse aggregate**	**SAP**	**SP**
SAP-0	533	0.3	160	863	821	0	8
SAP-5	533	0.3	160	863	821	0.27	8
SAP-10	533	0.3	160	863.33	821	0.53	8
SAP-15	533	0.3	160	863.33	821	0.80	8

3.0 RESULTS AND DISCUSSION

3.1 Electrical resistivity of hardened concrete

Concrete can be tested in a lab without being damaged using concrete electrical resistivity. Concrete was subjected to an electrical resistivity test to determine its quality regarding voids and internal cracks. Bulk Electrical Resistivity Testing adhered to ASTM C 1202 standards [16]. This test was run on a saturated cube, meaning that water had seeped into the pores of the concrete cube. As shown in Figure 2, the saturated, wet cubes were positioned between two parallel metal plates using a damp sponge and an electrical resistivity meter. Applying a small alternate current at the intended frequency allowed us to measure the voltage between the concrete specimen's two ends. The electrical resistivity meter's monitor showed the impedance 'z,' noted down.

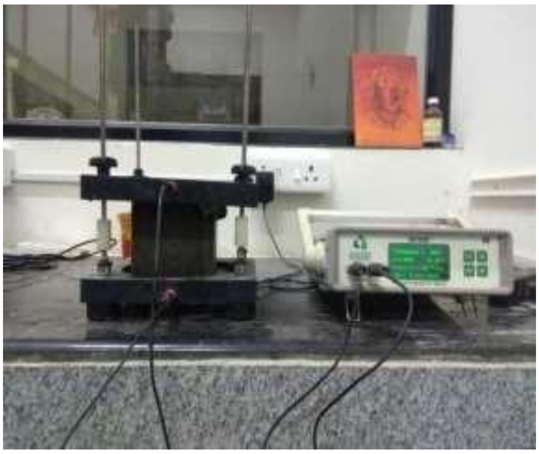

Figure.2 Setup for measuring electrical resistivity of hardened concrete

The average value of three samples is used for each test to calculate the concrete's electrical resistivity. The test was conducted on samples that had been curing for 7 days and 28 days. The impedance value from equation 2 was then used to calculate the concrete electrical resistivity. Table 3 lists the electrical resistivity of various concrete mixtures.

$$\rho = \frac{A}{Z} * l \text{----------------Equation 2}$$

Where, (ρ) denotes electrical resistivity (kΩ-cm), (A) the Sectional area of the specimen (cm^2), (L) represents the length of the specimen (cm) and (z) denotes the impedance (kΩ).

It is also known that reinforced cement concrete exhibits higher corrosion resistance when the electrical resistivity of the concrete is more increased, broadening the range of its applicability. Figures 3 and 4 illustrate the electrical resistivity values of SCC mixtures graphically.

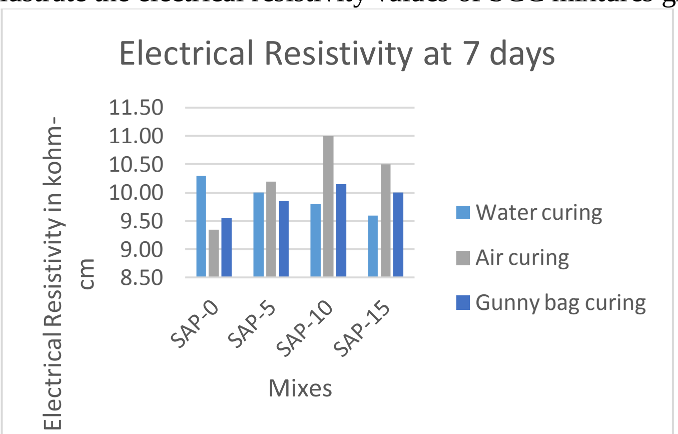

Figure 3. Electrical resistivity of SCC mixes at 7 days in different curing regimes

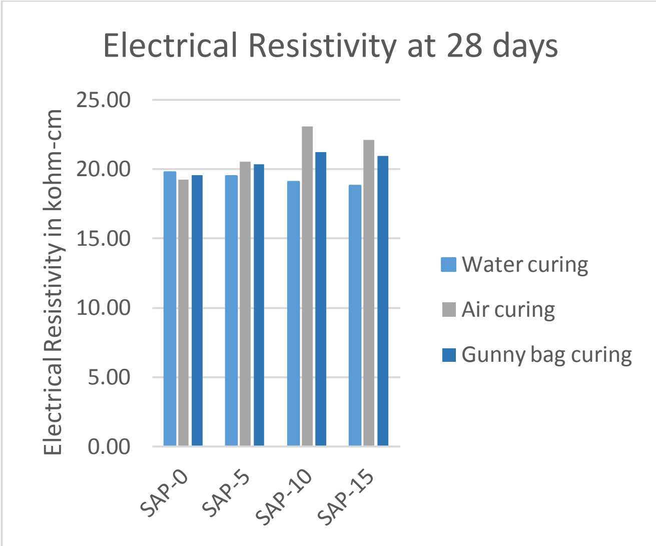

Figure 4. Electrical resistivity of SCC mixes at 28 days in different curing regimes

The potential rate of corrosion of reinforced steel in SCC can be determined by electrical resistivity [13]. Similar to the results for compressive strength, electrical resistivity values of SCC mixtures with SAP increased in air curing at 7 and 28 days. According to Figures 3 and 4, electrical resistivity values increased under air curing and gunny bag curing regimes, whereas those results decreased under conditions of water curing as SAP dosage increased. Electrical resistivity values increased to 0.1% SAP dosage before declining at 7 and 28 days under air curing gunny and bag curing regimes. In contrast, during water curing, electrical resistivity values decreased throughout 7 and 28 days as SAP dosage increased. With water curing and SAP concrete will have higher availability of water in concrete. Hence resistivity reduces. As a result of electrons being discharged from anodic to cathodic regions, an increase in electrical resistivity values reveals high corrosion resistance of reinforcement [14]. Additionally, M. Nematollahzade et al. [15] confirmed that mixtures with internal curing compounds that cure in the air increased electrical resistivity by about 12%.

Table 3: Corrosion range with electrical resistivity values [16]

Electrical Resistivity (kΩ -cm)	**Corrosion risk**
More than 20	Negligible
10 to 20	Low
5 to 10	High
Less than 5	Very high

Electrical resistivity values indicate the durability of concrete because the values correlate with the corrosion of structural reinforcement elements [17], as shown in Table 3. It can be observed that if electrical resistivity values are more than 20 kΩ-cm, corrosion risk in reinforcement is negligible [18]. The experimental results showed that the electrical resistivity values of SCC mixtures were more than 20 kΩ-cm at 28 days.

3.2 Ultrasonic pulse velocity of hardened concrete

The ultrasonic pulse velocity method involves timing how long an ultrasonic pulse takes to travel through the concrete being tested. A relatively higher velocity is obtained when concrete quality is good in density, uniformity, homogeneity, etc.

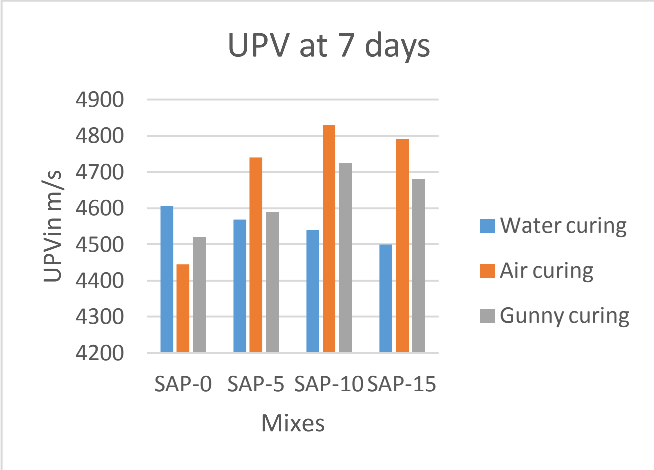

Figure 5. Ultrasonic pulse velocity of SCC mixes at 7 days in different curing regimes

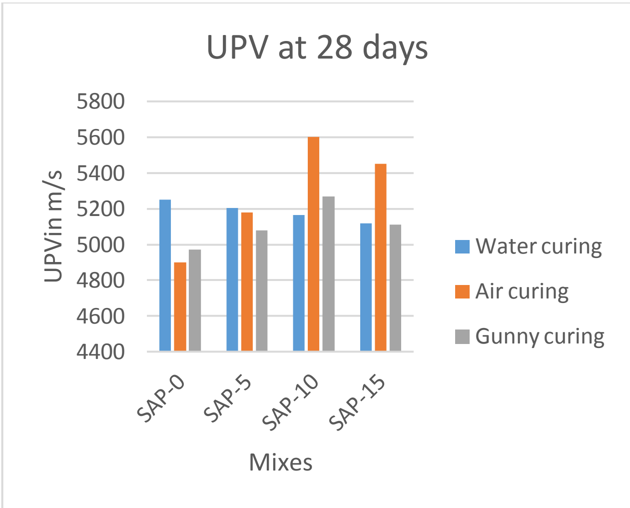

Figure 6. Ultrasonic pulse velocity of SCC mixes at 28 days in different curing regimes

The higher UPV indicates that uniformity, occurrence or absence of internal flaws, cracks, and segregation in concrete quality. Based on pulse velocity values, the quality of concrete can be assessed and concrete is characterised in terms of quality.

As shown in Figures 5 and 6, the ultrasonic pulse velocity values increased with 0.1% SAP dosage after declining air-curing gunny bag curing regimes at 7 and 28 days. On the contrary, in water curing, the ultrasonic pulse velocity values decreased with increasing SAP dosage at 7 and 28 days. The percentage of increment of air curing regimes 0.1% SAP dosage values was 9% and 14.3% compared to the control specimen at 28 days. Improvement in ultrasonic pulse velocity values was due to the improved microstructure due to enhanced hydration. Further, it leads to tedious entering aggressive ions into the concrete.

Table 3: Quality of concrete with electrical resistivity values as per IS 516(Part 5) [19]

Ultrasonic pulse velocity (m/s)	**Quality of concrete (Grading)**
More than 4400	Excellent
3750 to 4400	Good
3000 to 3750	Doubtful
Less than 3000	Poor

4. CONCLUSIONS

1. Self-compacting concrete requires internal curing with a super absorbent polymer to fully hydrate the higher cementitious material to reduce the shrinkage.

2. When SAP dosage was increased, electrical resistivity values greater than 20 k-cm were seen at 28 days in air-cured specimens. Air-cured specimens improved electrical resistivity better than water-cured and gunny bag specimens due to SAP hydrogel present in water cured and gunny bag cured specimens and act as week material. Therefore, the internal SAP curing in air-cured specimens dramatically impacts the strength and durability of self-compacting concrete.

3. Ultrasonic pulse velocity values of more than 4.4 km/s were seen at 28 days in air, gunny bag and water curing. Still, air curing produced better results than water-cured, gunny bag cured specimens. In light of this, internal curing with SAP in air-cured specimens significantly impacts self-compacting concrete's strength and durability properties.

References:

[1] R. J. Flatt, “Towards a prediction of superplasticized concrete rheology,” *Mater. Struct.*, vol. 37, pp. 289–300, 2004.

[2] R. Saleh, T. Kemal, and K. Ramyar, “Thixotropy and structural breakdown properties of self compacting concrete containing various supplementary cementitious materials,” *Cem. Concr. Compos.*, vol. 59, pp. 26–37, 2015.

[3] N. Roussel, A. Lemaître, R. J. Flatt, and P. Coussot, “Steady state fl ow of cement suspensions : A micromechanical state of the art,” *Cem. Concr. Res.*, vol. 40, pp. 77–84, 2010.

[4] C. Hu and F. De Larrard, “THE RHEOLOGY OF FRESH HIGH-PERFORMANCE CONCRETE,” *Cem. Concr. Res.*, vol. 26, no. 2, pp. 283–294, 1996.

[5] D. Sarbapalli, Y. Dhabalia, and K. Sarkar, “Application of SAP and PEG as curing agents for ordinary cement-based systems : impact on the early age properties of paste and mortar with water-to-cement ratio of 0 . 4 and above,” *Eur. J. Environ. Civ. Eng.*, vol. 21, no. 10, pp. 1237–1252, 2017.

[6] A. Danish, “Robust evaluation of superabsorbent polymers as an internal curing agent in cementitious composites,” *J. Mater. Sci.*, vol. 56, no. 1, pp. 136–172, 2021.

[7] K. Venkateswarlu, S. V Deo, and M. Murmu, “Overview of effects of internal curing agents on low water to binder concretes,” *Mater. Today Proc.*, vol. 32, pp. 752–759, 2020.

[8] IS9103:1999, “Concrete Admixtures-Specification,” *Bur. Indian Stand.*, vol. 1, pp. 1–14, 1999.

[9] H. Ding, L. Zhang, and P. Zhang, “Factors Influencing Strength of Super Absorbent Polymer (SAP) Concrete,” *Trans. Tianjin Univ.*, vol. 23, pp. 245–257, 2017.

[10] C. Schröfl, V. Mechtcherine, and M. Gorges, "Relation between the molecular structure and the efficiency of superabsorbent polymers (SAP) as concrete admixture to mitigate autogenous shrinkage," *Cem. Concr. Res.*, vol. 42, pp. 865–873, 2012.

[11] K. Venkateswarlu, S. V. Deo, and M. Murmu, “Effect of Super absorbent polymer on workability, strength and durability of self compacting concrete,” *IJE Trans. B Appl.*, vol. 05, no. May 2021, pp. 1118–1123, 2021.

[12] D. P. Bentz, P. Lura, and J. W. Roberts, “Mixture Proportioning for Internal Curing,” *Concr. Int.*, pp. 1–6, 2005.

[13] A. A. Ramezanianpour, A. Kazemian, M. A. Moghaddam, F. Moodi, and A. M.

Ramezanianpour, “Studying effects of low-reactivity GGBFS on chloride resistance of conventional and high strength concretes Studying effects of low-reactivity GGBFS on chloride resistance of conventional and high strength concretes,” *Mater. Struct.*, vol. 49, pp. 2597–2609, 2015.

[14] A. A. Ramezanianpour, A. Kazemian, M. Sarvari, and B. Ahmadi, “Use of Natural Zeolite to Produce Self-Consolidating Concrete with Low Portland Cement Content and High Durability,” *J. Mater. Civ. Eng.*, vol. 25, pp. 589–596, 2013.

[15] M. Nematollahzade, A. Tajadini, I. Afshoon, and F. Aslani, “Influence of different curing conditions and water to cement ratio on properties of self-compacting concretes,” *Constr. Build. Mater.*, vol. 237, p. 117570, 2020.

[16] N. Singh and S. P. Singh, “Electrical resistivity of self compacting concretes prepared with reused concrete aggregates and blended cements,” *J. Build. Eng.*, vol. 25, no. April, p. 100780, 2019.

[17] O. Sengul and O. E. Gjørv, “Electrical Resistivity Measurements for Quality Control During Concrete Construction,” *ACI Mater. J.*, vol. 105, pp. 541–547, Nov. 2008.

[18] N. R. Buenfeld, J. S. Newman, and C. L. Page, “The Resistivity of mortars immersed in sea-water,” *Cem. Concr. Res.*, vol. 16, pp. 511–524, 1986.

[19] IS516(Part 5):2018, “NON-DESTRUCTIVE TESTING OF CONCRETE -METHODS OF TEST,” *Bur. Indian Stand.*, pp. 1–7.