Effect of Super Absorbent Polymer on Workability, Strength and Durability of Self Consolidating Concrete

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Abstract

This study presents the effect of super absorbent polymer (SAP) as internal curing agent on workability, durability and compressive strength of self-consolidating concrete (SCC). In order to estimate the internal curing efficiency of SAP in different curing conditions and curing ages, compressive strength and electrical resistivity tests have been performed. Homogenous and denser microstructure was formed by gradual release of water from SAP into pores created by SAP. Further pozzolanic reaction of fly ash has enhanced the strength and durability properties. High desorption rate of water from SAP in air curing condition resulted in an increased electrical resistivity and compressive strength. Compressive strength of internal cured SCC mixtures increased to 15-25% at 7 days and 10-19% at 28 days. Electrical resistivity values were increased 11-30% in water curing condition and 16-53% in air curing condition. The costs for 0.35w/b and 0.40 w/b at optimum internal cured SCC mixtures compared to control SCC mixtures were reduced to 9.39 and 9.70%, respectively.

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NOMENCLATURE

| Symbol | Description |
|--------|-------------|
| W/C | Water cement ratio |
| V_water | Volume of water (m³/m³) |
| C | Quantity of cement in the mixture (kg/m³) |
| CS | Chemical shrinkage of cement paste (ml/g) |
| a_max | The expected maximum hydration degree of hydration |
| ρ_w | Unit weight of water (kg/m³) |
| M_SAP | Mass of super absorbent polymer |

1. INTRODUCTION

Presently self-consolidating concrete (SCC) has become high performable concrete by introducing concrete additives. SCC is high flowable concrete which can flow through every corner of heavy reinforced concrete sections with its own weight without external vibration [1]. In recent years construction industry is using significant amount of SCC in pre-cast elements due to many advantages [2, 3]. Past studies states that mineral admixtures can be used as fines which are required to achieve self compactability of SCC. Especially fly ash can enhance workability, durability and mechanical properties of SCC [4]. Higher requirement of cementitious material in SCC needs sufficient curing to complete the hydration especially at high temperature climatic regions. External curing is not adequate to achieve 100% hydration in practical conditions of site. Authors reviewed that internal curing by super absorbent polymers (SAP) can achieve full hydration which further increase the durability and reduce the shrinkage [5]. SAPs are cross linking chain polymers which can absorb the moisture 100 to 1000 times of their own mass. At the time of mixing, dry SAPs will absorb the moisture and becomes stable during placing, consolidation of concrete [6]. SAP addition affects the SCC in different manner in different properties which has shown by the following studies. Snoeck et al. [7] investigated that shrinkage can be eliminated by internal curing with SAP. They also reported that workability decreases when the dry SAP is

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added to concrete without additional water. However, additional water reduces the compressive strength of concrete. But, Pourjavadi et al. [8] reported that air curing results increase in compressive strength of concrete than reference concrete. Whereas workability decreases due to initial water absorption. Other studies shown that electrical resistivity values can assess the resistance to corrosion [9, 10]. Most of the researchers focused on the reduction of shrinkage by using higher dosage of SAP [11, 12]. But lower amounts of SAP especially less than 0.2% of mass of cement can decrease the shrinkage and also enhance the mechanical and durability properties of concrete [13]. Hence in this study effect of SAP on self-consolidating concrete was assessed by testing workability, compressive strength, and electrical resistivity of concrete. Pinheiro [14] found the importance of green and sustainable buildings and less CO₂ materials should introduce instead of cement. Rubberized concrete with waste rubber would also lead to sustainable and environmental friendly concrete [15]. Rath et al. [16] have confirmed the use of fly ash to reduce the corrosion of concrete by electrical resistivity values. Even in the fly ash and rice husk ash combination mixes also fly ash removed the difficulties of workability and particle packing of binding materials [17] where rice husk ash act internal curing agent. Joel [18] suggested that 30% fly ash replacement gives optimum compressive strength results. But, Kanthe et al. [19] specially conducted strength and durability experiments on fly ash from Bhilai steel Plant, India and quoted that 15% fly ash can give optimum results than higher fly ash percentages. Hence in the present investigation the mixtures having 85% cement in binder remaining 15% is fly ash which is from Bhilai steel plant, India. From the literature it was concluded that to eliminate the shrinkage higher SAP dosage has been used and SAP effect on SCC less literature is available. Hence lower dosages of SAP (0.05% to 0.15%) could enhance the strength and durability with addition to shrinkage reduction. Hot weather concrete present in India leads to increase the water demand and permeability. However, internal curing can be the best possible way to resolve this problem.

2. EXPERIMENTAL PROGRAM

2.1. Materials In the present investigation chemical oxide compositions of OPC-43 grade cement and fly are given in Table 1. The specific gravities of cement and fly were 3.05 and 2.20, respectively. Super plasticiser from BASF Company which is poly carboxylate ether based water reducing admixture used to achieve self-compactability. Specific gravity, pH, and chloride ion percentage of super plasticiser are 1.08, ≥6, <0.2%, respectively. Aggregates used in this project are confirming to IS: 383-2016. Zone-II locally available river sand and 10mm coarse aggregates with 2.6 and 2.7 specific gravities, respectively [20] was used. Commercially available sodium based poly acrylate was used as super absorbent polymer. Water absorption capacities of SAP is 36g/g in cement solution (solution prepared with W/C=5.0) and 170g/g in water calculated by Tea bag method which was given by Schröfl et al. [21]. Higher ionic concentration of Ca<sup>2+</sup>, Na<sup>+</sup> present in cement solution may decrease the water absorption of SAP. Even significant percentage of SiO₂ present in cement and fly ash but most of SiO₂ are immobile [22]. Hence SiO₂ ions cannot affect the water absorption of SAP.

2.2. Required Amount of IC Water To achieve maximum degree of hydration of concrete mixes, previous studies has given following equations to calculate the volume of water required for internal curing and to calculate the mass of SAP [23, 24].

\[ V_{\text{water}} \times \rho_{\text{water}} = C \times CS \times \alpha \times \text{max} \]  
\[ M_{\text{SAP}} = \frac{C \times CS \times \alpha \times \text{max}}{S \times \delta \text{SAP}} \]  

Volume of water required to get maximum degree of hydration is 32 kg/m<sup>3</sup> as per equation (2). However water supplied by SAP to SCC mixtures are 0, 38.86, 77.71, and 116.60 kg/m<sup>3</sup> for SAP0, SAP0.05, SAP0.10, and SAP0.15 respectively. But, these quantities were decreased to 0, 8.23, 16.44, 24.68 kg/m<sup>3</sup> in cement solution. Generally in practice W/C ratios would be in the range of 0.1-0.7. Hence SAP dosages has fixed according to absorption of SAP in pure water as shown in Table 2.

3. RESULTS AND DISCUSSIONS

3.1. Workability As shown in Figures 1 and 2 the flowability of SCC was decreased with increasing

| Chemical Oxides | Cement (%) | Fly ash (%) |
|-----------------|------------|-------------|
| CaO             | 68.5       | 1.23        |
| SiO₂            | 16.5       | 64.5        |
| Al₂O₃           | 4.5        | 24.5        |
| Fe₂O₃           | 3.7        | 5.01        |
| MgO             | 1.68       | 0.55        |
| SO₃             | -          | -           |
| K₂O             | 2.36       | 2.51        |
| Na₂O            | 0.4        | 0.10        |
TABLE 2. Mixture proportion of SCC in kg/m³

| Mix   | Cement | Fly ash | W/B ratio | Water | Sand | Coarse aggregate | SAP | SP |
|-------|--------|---------|-----------|-------|------|------------------|-----|----|
| 35S0  | 389    | 69      | 0.35      | 160   | 928  | 840              | 0   | 6.9 |
| 35S5  | 389    | 69      | 0.35      | 160   | 928  | 840              | 0.23| 6.9 |
| 35S10 | 389    | 69      | 0.35      | 160   | 928  | 840              | 0.46| 6.9 |
| 35S15 | 389    | 69      | 0.35      | 160   | 928  | 840              | 0.69| 6.9 |
| 40S0  | 372    | 66      | 0.4       | 175   | 912  | 821              | 0   | 6.6 |
| 40S5  | 372    | 66      | 0.4       | 175   | 912  | 821              | 0.22| 6.6 |
| 40S10 | 372    | 66      | 0.4       | 175   | 912  | 821              | 0.44| 6.6 |
| 40S15 | 372    | 66      | 0.4       | 175   | 912  | 821              | 0.66| 6.6 |

SAP dosage but it is in limits. As compared to control SCC mix internal cured SCC mixes were reduced the slump flow diameters 1-2% from Figure 2. It may be because of dry SAPs absorb the water initially from the SCC mix. These results are compatible with other researchers with the same fly ash additions [25, 26]. In this experimentation super plasticiser was restricted to 1.5% of binder beyond these dose it could shows bleeding and reduction of strength. These super plasticiser dose leads to 610 to 640mm slump flow diameter. This range of slump flow classified SCC as SF1 as per IS 10262:2019 [27].

With increase in dosage of SAP from 0 to 0.15% both V-Funnel and T500 values were increased with increasing w/b ratio independent of SAP dose, as shown in Figure 3. The workability of SCC was decreased with increasing SAP dose from 0 to 0.15% as slump flow diameters decreased.

From flowability tests the relationship between viscosity and yield stress has been introduced based on T500 and V-Funnel time. As shown in Figure 4 T500 and V-Funnel times had R² value of 0.955 which shows strong correlation as other researchers observed [28].

3.2 Compressive Strength

Internal curing affects compressive strength results in different curing conditions. As shown in Figure 5 as increase in SAP dose, almost similar compressive strength values have been observe in water curing condition. This lower compressive strength results due to early absorption of water by dry SAP from the specimen. It leads to permeable and porous structure in the concrete specimen [29]. However, internal curing with recycled aggregates lost their compressive strength by 7-19% compared to control concrete [30]. While in this research, an increase
in the SAP dose increases the compressive strength of SCC in air curing condition. This increment was high at high w/b ratio at 7 days in air curing condition. From Figure 5 in air curing at 7 days, the compressive strength has increased by 21-26% and 15-25% for 0.4w/b, 0.35 w/b ratios, respectively. But at 28 days this enhancement of compressive strength higher in low w/b ratio in air curing. The compressive strength with respect control mixture at 28 days of air curing has increased by 6.75-13.5% and 10-19% for 0.4w/b and 0.35w/b ratios, respectively. This is due to increased hydration of binder material due to higher availability of moisture from SAP at 28 days as compared to 7 days curing. It leads to better hydration denser interfacial transition zone (ITZ) and concrete matrix. Hence further it gives higher compressive strength. Other researchers also stated that when relative humidity of concrete drops SAP can supply the water in air curing effectively [8]. Other studies shown that LWA could increase the compressive strength with 2-5% only while SAP has increased compressive strength 10-25% in air curing condition [31]. In case of water curing condition reduction in compressive strength observed compared to control SCC at 7 days but it was slightly improved at 28 days as shown in Figure 5. At 0.35w/b and 0.40 w/b ratio concretes at 28 days a slight improvement in compressive strength with 2-4% was observed while at 7 days slight reduction of compressive strength with 1-6% was observed. This is due to initially SAP pores at early age causes the reduction of compressive strength after that improvement of hydration has filled the pores which are created by SAP [32, 33].

3. 3. Electrical Resistivity Possible rate of corrosion of reinforcement can be interpret by electrical resistivity test of concrete [34]. In both curing conditions electrical resistivity values at 7 and 28 days were similar increasing rate with compressive strength values. From Figure 6, at 28 days in water curing, the electrical resistivity was increased by 11 to 30% and 19 to 53% for 0.35w/b and 0.4w/b ratio, respectively. By increasing SAP dose from 0 to 0.15%, this increment higher in air curing specimens as 16-53% and 25-70% for 0.35 w/b and 0.40 w/b ratio concretes, respectively. Ramazanianpour et al. [35] showed higher the electrical resistivity concretes would show the higher resistance of corrosion of resistance due to discharging of electrons from anodic region to cathodic region. For 0.4W/C ratio the electrical resistivity values of SAP and fly ash combination given 16% higher than the rice husk ash and fly ash combination [17] and other researchers also confirmed that electrical resistivity in air curing increased by nearly 12% in 0.35 to 0.4w/b internal curing mixtures. Hence, the SAP can perform better than the other internal curing agents. As shown in Figure 6 electrical values were more than 20 kΩ-cm for 0.1% and 0.15% SAP dose which are in corrosion free zone.

Table 3 shows that risk of corrosion is having correlation with electrical resistivity values [9]. At 28 days for the above 0.1% of SAP dose electrical resistivity values were more than 20 kΩ-cm for 0.35w/b ratio concretes and for 0.15% of SAP dose electrical resistivity values were more than 20 kΩ-cm.

4. COST ANALYSIS OF CONCRETE

The cost analysis of control Self-consolidating concrete and internal cured self-consolidating concrete were worked out as per current market rate. Initially cost of control and internal cured concrete were the same. In curing stage cost would decreased for internal cured concrete due to spray curing or pond curing in the site. The cost was reduced to 9.39% and 9.70%, respectively for 0.35w/b and 0.40 w/b internal cured SCC mixtures.
compared to control SCC mixtures. Above internal curing SCC mixtures (SAP=0.1% of mass of binder) were given optimum results of compressive strength and electrical resistivity.

5. CONCLUSIONS

1. Workability of SCC mixtures were decreased to 1-2% due to initial absorption of water from mix by dry SAP particles. However, these values were in permissible limits. Slump flow time and V-funnel time shows the same pattern and both have perfect correlation with R² of 0.95.

2. Compressive strength values were increased under air curing condition by 15-25% at 7 days and 10-19% at 28 days with internal effect by SAP while small decreasing of compressive strength results 1-2% was observed in water curing condition. In both the curing conditions 0.1% SAP dosage has given higher strength than other conditions.

3. Electrical resistivity values were increased 11-30% in water curing condition and 16-53% in air curing condition. For 0.1% SAP dosage and above the electrical resistivity values were observed more than 20 kΩ-cm at 28 days in air curing and water curing. Hence SCC mixtures above 0.1% SAP dose could not subject to corrosion.

4. Based on test results of workability, compressive strength and electrical resistivity 0.10% dose of SAP is optimum for both w/b ratios.

5. The costs for 0.35w/b and 0.40 w/b for optimum internal cured SCC mixtures compared to control SCC mixtures were reduced to 9.39 and 9.70%, respectively.

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