EXPERIMENTAL STUDY ON SELF COMPACTING CONCRETE WITH ADDITION OF SUPER ABSORBENT POLYMER

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Abstract. This experimental work focuses on the effect of superabsorbent polymer (SAP) in self-compacting concrete (SCC). The target strength to be achieved is M40. The superabsorbent polymer acts as an Internal curing agent (ICA) which is added at a percentage varying from 0.1 to 0.3 and superplasticizer to about 0.8% with respect to the mass of cementitious materials. SCC is super workable due to its low water-cement ratio, which gives rapid strength, more durability, and best quality. In this study the properties of fresh and hardened concrete were investigated. The workability properties like Slump flow, V Funnel and L Box tests were carried out. The mechanical behaviour and durability study such as Rapid Chloride Penetration Test (RCPT) were also conducted on SAP added SCC. SEM Analysis was carried out to identify the newly formed materials within the concrete system. The concrete added SAP behaves similarly and as like the conventional concrete in strength aspect but varies in case of durability properties.

Key words: superabsorbent polymer, RCPT, SCC, superplasticiser.

1. Introduction

Bountiful amount of wastes are generated from the ferrosilicon industries and thermal powerplant. Major environmental issues are caused by these waste products. Utilization of these products in concrete reduces this issue to some extent. Self-Compacting Concrete (SCC) is an exclusive building material which is identified by its distinctive characteristics. SCC is a highly flowable concrete that has a potentiality to integrate through its self-weight [1]. Gradation of the materials, appropriate dosage of admixtures and proper selection of materials contributes to the higher workability and strength of SCC [2]. The workability properties of SCC were examined by various mineral admixtures. The strength property can be achieved by the addition of mineral admixture along with dosages of chemical admixtures [3]. Cement, water, aggregate and chemical admixtures are the major constituents of the SCC. In order to reduce the cement content in SCC, mineral admixtures were added [4]. For the preparation of the SCC with chemical admixture, which is added to attain the workability of fresh concrete(SCC). To decrease the water content and to reduce the friction between the cementitious materials is achieved by addition of superplasticizer along with water (2). According to the guidelines by EFNARC the amount mineral admixtures is to be used, setting out a measure for the workability test for fresh SCC. Meanwhile there are some predominant properties which can appraise the fresh concrete tests they are filling capacity, passing capacity and...
resistance to segregation [5]. The investigations of fresh concrete inculcates the usage of chemical admixtures is diminished in contrast with mineral admixtures in SCC with the use of high volume of FA [6]. Hardened properties are intensified by the application of micro and NS has a better microstructural hardened concrete when examined. The compression and flexural strength are increased by the improved pozzolanic reactivity of silica particles [7,8].

The durability of SCC contains SAP material of 0.1%, 0.2%, 0.3% and 0.4% in M40 grade of SCC. The Rapid chloride penetration test, porosity and sorptivity test was carried out for 28 days [9]. The concrete used in all mixes satisfied the least standard flow diameter [10]. Superabsorbent polymers have high capacity to liquid uptake its cross-linked hydrophilic networks. The water molecules are diffused into the void space of the SAP, this leads to formation of polymer gel. The effect of SAP in workability is expected in mortars and concrete. The usage of SAP’s in concrete structures is very promising.

The main aim of the research was to determine the performance of SCC mixes containing SAP. The admixtures like SP and Micro silica are added to the SCC at preferred dosage. This is used to determine the flowability by determining the slump flow cone test, V funnel and L box test. The physical properties are found by compression strength at 28 days of the testing period. The durability nature of the SCC is determined by the Rapid chloride penetration test. The target of the study is to use SAP as an internal curing agent against conventional type of water curing

2. Materials and mix ratio
2.1. Materials
In the experimental study, the ordinary Portland cement grade 53 is used as per IS:12267-1987[11]. The fine aggregate was collected from the locally available river that has the fineness modulus of 2.91. The coarse aggregate used was 12.5 mm. The Superplasticizer (SP) of type polycarboxylate ether was used. The optimum percentage of SP to be used was determined using Marsh cone test method. Normal water or Potable water [12] was used for mixing. The Scanning Electron Microscope (SEM) test is carried out on the specimen and is shown in figure.7. Scanning Electron Microscope report represents the structural morphology of the concrete system. The chemical content of cement is listed in Table 1.

| S.No | Chemical Analysis | Cement |
|------|-------------------|--------|
| 1.   | SiO₂              | 21.6   |
| 2.   | Al₂O₃             | 3.83   |
| 3.   | Fe₂O₃             | 2.96   |
| 4.   | CaO               | 62.02  |
| 5.   | TiO₂              | 0.490  |
| 6.   | MgO               | 3.44   |
| 7.   | Na₂O              | 0.42   |
| 8.   | K₂O               | 0.71   |
| 9.   | SO₄               | 2.09   |
| 10.  | Others            | 3.17   |
2.2. Mix Proportions

As per EFNARC guidelines, several trials were carried out and the optimum mix that results in M40 grade of concrete was finalized. Out of several trials, trial18 achieved the target strength M40. Hence SAP was added in the mix and the strength was assessed. The mix details are shown in table 2.

**Table 2. Mix Proportions for trial mixes**

| S. No | MIX   | Cement (kg/m³) | FA (kg/m³) | CA (kg/m³) | Water (kg/m³) | SP % |
|-------|-------|----------------|------------|------------|---------------|------|
| 1     | SCC 1 | 400            | 888        | 942        | 172           | 0.5  |
| 2     | SCC 2 | 404            | 897        | 930        | 173           | 0.5  |
| 3     | SCC 3 | 408            | 906        | 916        | 175           | 0.5  |
| 4     | SCC 4 | 412            | 915        | 903        | 177           | 0.5  |
| 5     | SCC 5 | 414            | 920        | 896        | 178           | 0.5  |
| 6     | SCC 6 | 416            | 923        | 891        | 179           | 0.6  |
| 7     | SCC 7 | 418            | 927        | 885        | 180           | 0.6  |
| 8     | SCC 8 | 420            | 933        | 877        | 181           | 0.6  |
| 9     | SCC 9 | 424            | 942        | 864        | 183           | 0.6  |
| 10    | SCC 10| 428            | 950        | 852        | 184           | 0.6  |
| 11    | SCC 11| 434            | 963        | 833        | 187           | 0.7  |
| 12    | SCC 12| 436            | 968        | 826        | 189           | 0.7  |
| 13    | SCC 13| 440            | 975        | 815        | 190           | 0.7  |
| 14    | SCC 14| 442            | 982        | 806        | 191           | 0.7  |
| 15    | SCC 15| 444            | 985        | 801        | 191           | 0.7  |
| 16    | SCC 16| 446            | 990        | 794        | 192           | 0.8  |
| 17    | SCC 17| 448            | 995        | 788        | 193           | 0.8  |
| 18    | SCC 18| 450            | 1000       | 780        | 194           | 0.8  |
| 19    | SCC 19| 454            | 1010       | 770        | 195           | 0.8  |
| 20    | SCC 20| 460            | 1022       | 750        | 197           | 0.8  |

The best mix from the trials has been selected and superabsorbent polymers were added. The number of mix chosen is shown in table 3.
Table 3. Mix proportion for SAP added SCC

| S.No | MIX    | Cement (kg/m³) | FA (kg/m³) | CA (kg/m³) | Water (kg/m³) | SP % | SAP % |
|------|--------|----------------|------------|------------|---------------|------|-------|
| 1    | SAP 0.0 | 450            | 1000       | 780        | 194           | 0.8  | 0     |
| 2    | SAP 0.1 | 450            | 1000       | 780        | 194           | 0.8  | 0.1   |
| 3    | SAP 0.2 | 450            | 1000       | 780        | 194           | 0.8  | 0.2   |
| 4    | SAP 0.3 | 450            | 1000       | 780        | 194           | 0.8  | 0.3   |

2.3. Workability tests

It is a kind of capability of the concrete which is in a fresh state from which the mix has to be filled in the form that is properly with proper work that is a vibration which does not reduce the property of the concrete. It depends on the following properties such as water content, aggregate (its shape and size distribution), cementitious content, mix design ratio and use of admixtures (like superplasticizer). In some cases, the porosity of aggregate is also included. In this experiment, some of the workability tests like 1) Slump flow test 2) V Funnel test 3) L box tests were conducted.

2.3.1. Slump Flow

The slump flow test is usually done to evaluate the horizontal free flow of self-compacting concrete with the absence of any obstructions. It is also conducted to assess the workability of SCC which is shown in figure 1. The ability of filling was set on by the Abrams cone (slump cone) as per EFNARC guidelines (2005). The stopwatch is started and the time is taken for concrete to reach the 00mm spread circle (T50 times). It is a secondary induction of flow. The EFNARC Code suggested that the time of 3-7 seconds is acceptable for civil engineering works whereas 2-5 seconds for housing applications.

2.3.2. V Funnel Test

This test is done to assess the unconfined flowability of the concrete with a maximum aggregate size of 20mm. The equipment used for this experiment is shown in figure 2. Start the stopwatch once the trap door is opened and the time is recorded for complete discharge (i.e. Flow time). This is to be noted once all the apparatus gets emptied.
2.3.3. L Box Test
This test is done to examine the flow of concrete and also the extent to which the concrete is subjected to the reinforcement blocking. This test apparatus consists of L shape rectangular section boxes with sections over horizontal and vertical. These sections were divided by the movable gate, the vertical length of reinforcement bars is fixed in the front. The concrete is poured in the vertical section then the gate is grabbed to make the concrete to come in contact with the horizontal section. The difference in the concrete level at the beginning and end was noted. The L-Box ratio is examined by the height ratio (H2/H1).

2.4. SEM Analysis
The SEM analysis was carried out to study the microstructural changes that took place within the concrete medium. This study validates the outcome of the results.

2.5. Compressive strength test
The compressive strength at 7 and 28 days were carried out on the cube size of 150 × 150 × 150 mm. This test was performed as per IS:516-1959 (2004). The compressive strength was obtained by the ratio of crushing load by resisting area of a cross-section of the specimen. The test image was shown in Figure 3.
2.6. Rapid Chloride Penetration Test
The RCPT (Rapid Chloride Penetration Test) is done to examine the chloride penetration in concrete. This test was conducted based on ASTM C1202–2019 [13]. The concrete is cast in a cylinder of size 100 mm × 200 mm and cured in water for 28 days. The cube was sliced to the size of 100 mm × 50 mm. Then Epoxy coating was done over the sides of discs and allowed to dry. Then the specimen was placed in the vacuum chamber. The test setup, has two terminals which contain 0.3 N of NaOH solution in the positive node and 3% of NaCl in the negative node. The time taken to complete the entire test is 6hrs. Nearly 60V power supply is passed through the test specimen. Current passing which is in coulomb is noted and calculated for every half an hour. The experimental setup is as shown in figure 9 and the test values are as shown in table 4.

![Figure 9. RCPT Test](image)

| S.No | Mix ID | Charges Passed (Coulombs) |
|------|--------|---------------------------|
| 1    | SAP 0.0 | 3200                      |
| 2    | SAP 0.1 | 3500                      |
| 3    | SAP 0.2 | 3760                      |
| 4    | SAP 0.3 | 3805                      |

3. Results and discussions
3.1 Workability tests
3.1.1. Slump Flow:
As per European standards, the fresh concrete properties have been examined. The percentage of slump flow is mentioned in Table1. The slump flow of SCC was tested with a different proportion of SAP. Figure 4 shows the slump flow of SAP added SCC.
The slump flow of SCC with no SAP reached to 670 mm. The slump flow of SCC with the subsequent addition of 0.1%, 0.2%, 0.3%, 0.4% of SAP increases further as 688mm, 692mm, 705mm, 716mm. This increase in slump flow value is due to the availability of water content which the SAP provides. Thus, the cohesion between the particles was smooth without the friction that leads to an easy flow of SCC. The SCC with greater slump flow will take less time to fill 50cm as per experimentation.

3.1.2. V Funnel Test:
SCC with 0.4% of Super Absorbent Polymer took less time to get pass through the V- funnel this shows that it has more workability characteristics as segregation and blockage. SCC with 0% of SAP took 10 seconds in passing through V funnel which represents comparatively low viscous type concrete. SCC with 0.1% of SAP took 8 seconds in passing through V funnel which represents the low viscous type concrete. SCC with 0.2% of SAP took 7 seconds in passing through a V funnel which represents the moderate viscous type concrete. SCC with 0.3% of SAP took 6 seconds in passing through V funnel which represents the moderate viscous type concrete. SCC with 0.4% of SAP took 6 seconds in passing through V funnel which represents that its good in flow ability flaws as segregation, viscosity, high yield value and blockage was observed.

3.1.3. L Box Test
The examined values of all the workability properties of the concrete are listed in table 5

| S.No | Mix ID | Slump flow in mm | V Funnel in sec | L. Box |
|------|--------|------------------|----------------|--------|
| 1    | SAP 0.0| 670              | 10             | 0.82   |
| 2    | SAP 0.1| 688              | 8              | 0.86   |
| 3    | SAP 0.2| 692              | 7              | 0.9    |
| 4    | SAP 0.3| 705              | 6              | 0.92   |
| 5    | SAP 0.4| 716              | 6              | 0.98   |

Figure 4. Slump Flow test
The addition of SAP from 0% to 0.4% increase in time of L box value due to the increase in SAP. There shows the addition of superplastiser and the SAP shows that increase in L-box ratio. This represents that 0% of SAP has less passing ability than the other mixes. About 0.4% of SAP has the maximum filling passing ability and is represented respectively in figure 5 and 6.

![V Funnel Test](image1)

**Figure 5. V Funnel Test**

![L Box](image2)

**Figure 6. L Box**

### 3.2. Microstructure Analysis
The SEM Analysis is used to analyze the microstructure of SCC specimens taken at 90 days. The visible voids are seen in dark color and white crystal structures represent the C-S-H gels that are shown in figure 7. In SCC, the formation of C-S-H gels is very minimal. The C-S-H gels improved the bond between the interfacial zone and enhanced the greater volume of reaction product near the inter-facial zone (ITZ). This accelerates the formation of more C-S-H gels as a layer and fills the pores formed during the hydration process.
3.3. Mechanical properties

3.3.1. Compression test

The compression test was done at the ages of 7 and 28 days and is shown in figure 8. There are many factors which affect the compressive strength of concrete which contains many supplementary cementitious materials like filling capacity of the material, pozzolanic reactivity of the material and the diluting effect of the materials used. However, the compression strength of the concrete hangs on various parameters like water bind ratio, the loading conditions, the method of curing and the ages of the concrete. This experiment is done for SCC and it is terminated that compression strength entirely depends on the constitution of the binder material used and the water-binder ratio. The mix proportions of SAP added SCC mixture is given in Table 3. Testing is done on the 7th day and 28th day. The control mix M1 showed 24 Mpa on the 7th day and 38 Mpa on the 28th day with SP of 0.8% and SAP of 0%. By increasing the percentage of SP and SAP by 0.8% and 0.1% shows that the compression strength has increased to 21 and 39 on the 7th day and 28th day. The incorporation of SAP in SCC shows that it plays an important role to make the SCC densely packed with refined microstructure. The addition of SAP to 0.2% and 0.3% shows the result as 18.5 Mpa, 16 Mpa on the 7th day and 37 Mpa, 42 Mpa on 28th day. The pozzolanic reactivity intensifies the concrete’s strength.
Figure 8. Compressive strength of SCC

3.4. Rapid Chloride Penetration Test
The chloride penetration of M40 grade SCC mixes. When compared to control concrete of 748 and 189 coulombs M3 mix showed 424 and 78 coulombs at 28 and 90 days respectively. The permeability of chloride was reduced with the addition of SAP at 28 days as the voids were filled in the cementitious system with the very good packaging of particles. The chloride ion penetration was reduced by the addition of concrete mixture as per ASTM C1202–2019. The concrete mix M8 represents 98 coulombs, retards the chloride ion penetration at the end of 28 days. Therefore, penetration of chloride seems very difficult in this scenario.

4. Conclusion
The following conclusions are made based on the investigations that are carried out in SCC

- Self-compacting concrete for M40 grade concrete has been developed successfully. The optimum percentage of SAP to be added to achieve the target strength was determined as 0.2% with constant SP as 0.8% to the weight of cementitious materials.
- All the workability tests confirm the EFNARC code provisions. Even though their occurs variations in the mix, it all satisfies the limits given by the code.
- The strength of the SAP added concrete has low strength than the concrete without SAP at 7 days. This is due to a higher moisture content which tends to reduce as the age of concrete increases.
- The strength of concrete that has SAP of 0.2% shows higher strength at 28 days and upon further addition decreases the strength of the concrete. This is due to the formation of voids that occurred during the hydration process.
- The microstructural studies confirm the presence of newly formed cementitious products that fill the gap formed due to desorption of water. This process of formation of new products contributes more to the mechanical properties of concrete.
- The chloride penetration is higher in SAP added concrete than the conventional concrete. This is due to voids that are formed by SAP during the hydration process. This may also be overcome by the addition of mineral admixtures.
5. Reference

[1] Jeevetha T, Krishnamoorthi S, Rampradheep GS 2014 *International Journal of Innovative Research Science, Engineering and Technology* 3 pp 11239–11244
[2] Dang J, Zhao J and Du Z 2017 *Polymers* 9 pp 672
[3] Fujiwara H, Nagataki S, Otsuki N and Endo H 1996 *Concrete Library JSCE* 28 pp 117–128
[4] Jalal M, Pouladkhah A, Harandi OF and Jafari D 2015 *Constr., Build Mater* 94 pp 90–104
[5] EFNARC 2005 Specification and guidelines for self-compacting concrete, *EFNARC Association* UK
[6] Naik T R, Kumar R, Ramme B W and Canpolat F 2011 Report no. CBU-2011-01
[7] Nandhini K, Ponmalar V 2018 *Micro & Nano Letters* 13 pp 1213–18
[8] Niwiadomski P, Stefaniuk D and Hola J 2017 *Procedia Engineering* 172 pp 776–783
[9] Nandhini K and Ponmalar V 2018 *Revista Romania de Materials* 48 pp 362–368
[10] Vivek S S and Dhinakaran G 2017 *Engineering Science and Technology- An International Journal* 20 pp 1173–79
[11] IS 12269:2013 Indian standard ordinary Portland cement, 53 grade specification bureau of Indian standards New Delhi, India
[12] IS 456:2016 Plain and reinforced concrete code for practice. Bureau of Indian Standards New Delhi, India
[13] ASTM C1202:2019 standard test method for electrical indication of concrete’s ability to resist chloride ion penetration, ASTM International