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Durability Performance of Self Compacting Concrete Incorporating Alccofine and Fly Ash

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ABSTRACT

The cost associated with the application of large volume of cement and synthetic admixtures was one of the major drawbacks of Self Compacting Concrete (SCC), which can be reduced by the use of supplementary cementitious materials (SCM). When the demand of cement reduces, the release of carbon dioxide (CO_2) from cement industries will come down, which has a positive impact on global warming. The present paper reports an attempt in this direction by experimental examination on the fresh properties and durability performance of SCC by replacing cement with SCM such as fly ash (FA) and ultra-fine Ground Granulated Blast Furnace Slag (GGBS) in varying ratios. SCC mix was obtained by fixing the water-binder ratio and superplasticizer (SP) dosage with respect to total cementitious content. Along with the Fresh properties, SCC mixes incorporating both alccofine and fly ash at 10 and 25%, respectively; which gave the best fresh properties were selected to assess the durability issues. Incorporating 10% alccofine and 25% fly ash gave the best result in both fresh and durability studies in comparison with other combinations.

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1. INTRODUCTION

Self compacting concrete (SCC) was developed in Japan due to the reduction of skilled labour force and the subsequent reduction of quality in construction industry. The first paper presentation in 1989 on SCC by Ozawa augmented its international attention. Positive aspects of SCC include reduction in labour, safety due to decrease in human risk, less construction time, refined filling capacity, better interfacial transitional zone (ITZ), decreased permeability, improved durability, more freedom in designing, superior quality production and good structural implementation [1]. One of the major drawbacks of SCC was its cost due to the utilization of high amounts of cement and chemical admixtures. The use of pozzolanic materials improves the durability of concrete which in turn reduces the usage of cement. This will result in strong structures which require fewer repairs during its life span. Addition of Supplementary Cementitious Materials (SCM) in SCC can upgrade the strength, durability, economic aspect and the effects due to inadequate compaction [2]. The durability of concrete with SCM was improved due to the pozzolanic reaction which occurs during the process of hydration in cement. The most commonly used SCMs were silica fume (SF), fly ash, ground granulated blast furnace slag (GGBS), metakaolin, rice husk ash etc. During cement hydration, calcium hydroxide (CH) and calcium silicate hydrate (C–S–H) gels were formed. CH which is the most soluble hydration product was a fragile linkage in cement [3]. When concrete was open to water, the CH will dissolve which increases the porosity and makes concrete more sensitive to further leaching and chemical intrusion. The pozzolanic materials added in SCC makes the pore refinement which blocks the passage of water and other chemicals [4].

Compared to ordinary concrete SCC has a lower viscosity and, therefore, a more significant flow rate when pumped. To achieve a high workability, SCC requires control on the nominal maximum size (NMS),

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amount and grading of the aggregate. So to maintain consistency of fresh mixture of SCC, and to reduce settlement effects, the practice was to utilize high range water reducers, to restrict the maximum size of coarse aggregate and content, and to utilize low water powder proportions or viscosity modifying agent (VMA) to modify the flow properties and rheology of SCC. The properties of fresh SCC were influenced by water to cement content (w/c) and water to powder content (w/p) ratios [5]. Flow ability and stability of SCC can be maintained either by increasing the paste content by, raising the cement content or some mineral admixtures, or by using a viscosity-modifying agent (VMA).

SCC has not yet improved all its widespread responses as a development material and its application stays constrained [6]. The improvement of a SCC with remarkable properties in the fresh and hardened state was essential for the response of such a concrete. Blend of high strength along with its self compacting property offers prospective advantages to construction world. The distinctive mix design along with the absence of vibration makes distinct changes in durability properties in SCC. The degradation of the cementitious material are extremely affected by the perviousness of the material. As the pore structure may be distinctive for SCC compared with normal concrete, a few changes in durability behaviour may be taken care. SCC was utilized without knowledge of the natural durability of the material itself and this could be the reason for the durability issues identified with the usage of SCC [7].

In the present paper an investigation was carried out on the practicality of developing a self-compacting concrete by replacing cement with SCM such as fly ash and ultra-fine slag [8–13]. It highlights the outcomes of the fresh properties and different durability studies of SCC mixtures. The paper moreover looks into the effects of using fly ash and alccofine on durability performance of SCC. Hence the paper addresses the improvement of SCC blended with SCM and examines its various properties like fresh and durability which will lead to a sustainable construction.

2. MATERIALS AND METHODS

2. 1. Materials

The constituent materials used for the preparation of the conductive SCC included Ordinary Portland cement 53 grade conforming to BIS: 12269-1987 [14], coarse aggregates of 10 mm maximum size and fine aggregate of zone III conforming to IS: 383 – 1970 [15]. High range water reducer (HRWR) based on modified sulfonated nathalene formaldehyde (SNF) – Conplast SP 430 [16] was used as a superplasticizer to mobilize the flow of the concrete to acquire self-compacting properties.

Alccofine (AL-1203) was obtained from Ambuja Cement Ltd, Goa having the specific gravity of 2.9 confirming to ASTM C989-1999 [17] was used in entire study. The properties (i.e. physical and chemical) of the cement used are tabulated in Tables 1 and 2, respectively. The physical properties and chemical properties of AL-1203 are given in Tables 3 and 4, respectively. Fly ash Class F was obtained from Rayalaseema Thermal power Plant (RTPP), Muddanur, Aandhra Pradesh, India and confirming to ASTM C 618. The physical properties and chemical composition are represented in Table 5. The Microstructural properties of the cement, fly ash and alccofine used are shown in Figures 1, 2 and 3, respectively.

TABLE 1. Physical properties of cement

Characteristics	Test Results	Requirements as per BIS code
Grade	53	53
Specific gravity	3.10	-
Standard consistency	30%	-
Initial setting time	94 min	>30 min
Final setting time	280 min	< 600 min
Specific surface area (m^2/kg)	340	-

TABLE 2. Chemical properties of cement

CaO	SiO_2	Al_2O_3	Fe_2O_3	SO_3	MgO
60.84%	16.34%	6.95%	5.38%	1.99%	2.32%

TABLE 3. Physical properties of AL-120

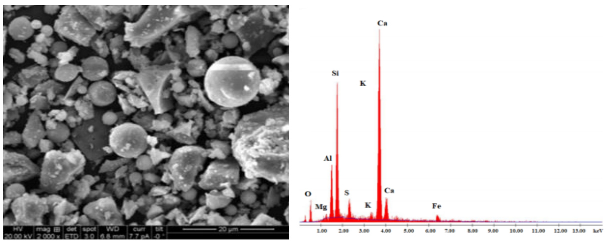
Characteristics	Test Results
Specific gravity	2.90
Specific surface area [m^2/kg]	1200
Bulk density [kg/m^3]	680
Particle Size in Micron	
D10	1.5
D50	5
D90	9

TABLE 4. Chemical Properties of AL form EDAX

Characteristics of Element	Results for EDAX	
	Weight %	Atomic %
C K	45.69	57.64
O K	35.26	33.39
Al K	4.01	2.25
Si K	6.38	3.44
Ca K	8.66	3.27

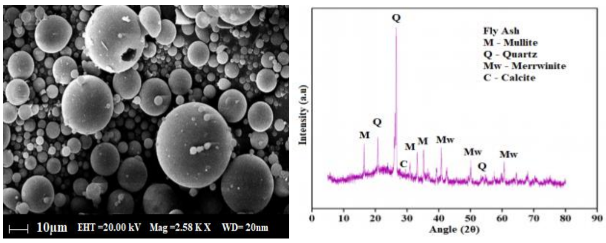
TABLE 5. Physical properties and chemical composition of class F Fly ash

Particulars	Class F Fly ash	ASTM C 618 Class F Fly ash
Physical properties		
Fineness (m^2/kg)	360	Min 225
Specific gravity	2.23	-
Chemical composition		
Silica	65.6	
Iron oxide	3.0	Silica + Alumina + Iron oxide >70
Alumina	28.0	
Magnesia	1.0	
Lime	1.0	
Sulphur trioxide	0.2	Max 5.0
Titanium oxide	0.5	
Loss on Ignition	0.29	Max 6.0



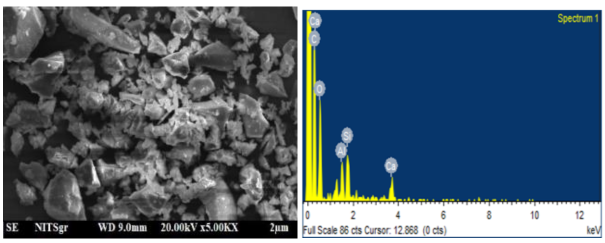
(a) (b)

Figure 1. Microstructural analysis of cement using (a) SEM (b) EDAX



(a) (b)

Figure 2. Microstructural analysis of fly ash using (a) SEM (b) XRD



(a) (b)

Figure 3. Microstructural analysis of alccofine using (a) EDAX (b) SEM

2. 2. Fabrication of Concrete In the present investigation, M25 grade normal concrete mix design carried out according to BIS: 10262-2009 [18]. Mix proportions: 1:1.66:2.97:0.52. Self-compact ability largely affected by the characteristics of materials and mix proportions. In this experimental study, three types of self-compacting concrete mixture proportions adopted. The mortar or the paste in the self-compacting concrete requires high viscosity and deformability, thereby the water-powder ratio has been adopted as 0.36 (as per EFNARC guidelines) constantly. The concrete is drenched into steel moulds and left to harden. After 24 hours, these cubes are exiled from the moulds for curing. A total of four altered mixes with constant dosage of fly ash and 1.2% of SNF and with varying dosages of alccofine have been prepared. The concrete mix proportion details are given in Table 6.

2. 3. Methods

2. 3. 1. Frsh Properties To decide the fresh stage properties of SCC blends, individual workability test like Slump Flow, T50 Slump Flow, V-Funnel and L-box etc. were completed according to EFNARC specifications [19].

2. 3. 2. Water Absorption Test Measurement of water absorption test on cube sample of size 150 mm was carried out under ASTM C642-06 at 28 days. Initially, the cube specimens had been placed in an oven at a temperature of 105ºC for 24 hours. Later, the specimens were taken out from the oven, cooled and were weighted (B). The specimens were immersed in water for two days and weighted (A). The water absorption value of the cube specimen was determined as per Equation 1 below.

$$\text{Water absorption (\%)} = \frac{A-B}{B} \quad (1)$$

where, A is saturated surface dry weight of specimens (g) and B is oven dry weight of specimens (g).

2. 3. 3. Electrical Resistivity of Concrete Electrical resistivity (ρ) of a material is characterized as its ability to withstand the exchange of ions exposed to an electrical field. It is reliant on the concrete microstructure properties such as pore size and state of the interconnections; by this the durability of concrete can be judged. Leader RCON™ Concrete Electrical Resistivity Meter has been used to measure the electrical resistance of concrete as per standards guidelines in ASTM C1202-19. The test was done for 150 mm size cubical specimens at one predetermined position on each specimen for normal concrete with and without addition of fly ash and alccofine at a curing period of 28 days. The electrical resistivity of concrete cubes is expressed as follows:

$$\rho = \frac{RA}{l} \quad (2)$$

where, ρ is electrical resistivity (unit: Ω-m), R is electrical resistance (unit: Ω), l is electrical path length in the specimen (unit: m), and A is the cross-sectional area of the specimen (unit: m^2).

2. 3. 4. Rapid Chloride Penetration Test As per ASTM C1202 test, the water statured concrete specimens having a thickness of 50 mm and a diameter of 100 mm are placed in a vacuum desiccator to eliminate air particles and these specimens were exposed to 60 V DC voltage supply for 6 hours with the RCPT apparatus and having three cell arrangement as illustrated in Figure 4. The specimens were placed among the cells without a bit of air gap and the boundaries were coated with silicon glue to prevent the escape of chemical solution. There is a 0.3M NaOH solution in one reservoir and a 3% NaCl solution in another reservoir. The total charge carried out in coulombs at an interval of 30 minutes for 360 minutes was used to measure the concrete resistance against chloride ion penetration. The total charge passed is assessed and used to measure the concrete quality as per the criteria set out in Table 7.

3. ESULTS AND DISCUSSION

3. 1. Fresh Properties The fresh mixes of SCC with inclusion of 25% fly ash and varying dosage of alccofine (0%, 5%, 10% and 15%) were tested to check its rheological properties. As discussed earlier the SCC should have four main characteristics, namely flowability, viscosity, passing ability and smooth surface after de- moulding. Tests described in Table 8 were performed on freshly prepared concrete: as per the procedure as explained in EFNARC and ACI 237R code.

Fresh mix prepared was tested for slump flow to check its flow-ability. Test results are shown in Table 9. From obtained results, it can be seen that the measured diameter of flow is within the prescribed limits of EFNARC for all the mixes. It was observed that as alccofine volume increases flow of SCC slightly increases (Upto 10%). The required time for flowing concrete for a diameter of 500mm i.e. T500 was also found and is tabulated in Table 9. It was observed that all the results fall within the limits prescribed by EFNARC.

Table 10 gives the test results of L-box test. This test was conducted to check the flowing and passing ability of SCC through reinforcement. Results obtained for all the mixes fall within the prescribed limits of EFNARC. In L-box test results H1 represent horizontal distance on L-box filled with concrete and H2 represents vertical distance on L-box filled with concrete.

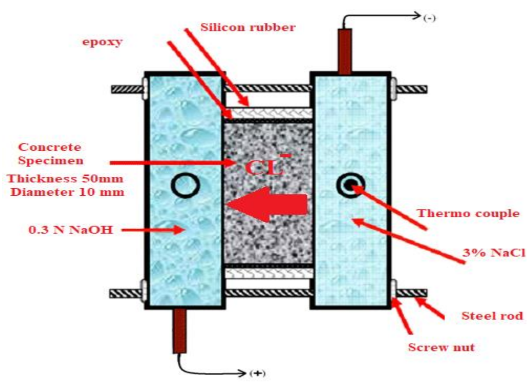


Figure 4. Schematic picture of the RCPT apparatus

TABLE 7. Chloride ion penetration of concrete according to ASTM C1202

Charge passed	Chloride ion penetration
<100	Negligible
100-1000	Very low
1000-2000	Low
2000-4000	Moderate
>4000	High

TABLE 8. Tests and purpose

Test Name	Purpose
Slump flow	To check the flowability of the freshly prepared mix
V – funnel	For knowing Viscosity property of fresh SCC
L-box	To check Passing ability and filling of SCC in between the bars

TABLE 9. Slump flow test results

Specimen Mix designation	Flow Dia (mm) Obtained in 30 seconds	Permissible range as per EFNARC	Time for 500mm Dia (T_{500}) (s)	Permissible range for T_{500} as per EFNARC
SCC0	655	650-800	4.1	2-5 s
SCC 1	671		3.7	
SCC 2	682		3.4	
SCC 3	631		4.5	

V-funnel test was also conducted to check the filling ability and viscosity of freshly prepared SCC. In this test, V-funnel was filled with freshly mixed concrete and concrete was left to fall freely under the force of gravity noting the time for emptying the funnel. All the results obtained were within prescribed limits of EFNARC and are shown in Table 11.

3. 2. Water Absorption Test Water absorption test is one of the most important parameters for finding the durability of concrete. The perforation of gases, water and ions depend on the microstructure and porosity of concrete. From Figure 5, it can be observed that normal concrete had high water absorption values than alccofine added concrete. The mixes with constant fly ash quantity and varying dosage of alccofine i.e. SCC0, SCC1, SCC2 and SCC3 showed the reduction in water absorption percentage values of 0.58%, 0.247%, 0.225% and 0.214%, respectively, with respect to NM (i.e. 1.02%) at 28th day. From the results, alccofine added concrete mixture showed low water absorption values because of high surface area of alccofine particles which settled in micro spaces in concrete [8–13]. The low water absorption percentage results in fly ash-alccofine based self compacting concrete mixes is due to occurrence of higher pozzolanic effect by alccofine and fly ash due to their micro and nano particle size which made the concrete more denser, more compacted and also improved the pore structure of the concrete which helped to reduces the water absorption percentage.

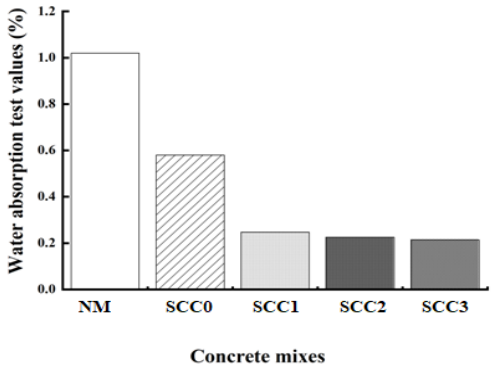


Figure 5. Graphical representation of water absorption test of fly ash-alccofine based self compacting concrete

3. 3. Electrical Resistivity of Concrete The electrical resistivity of concrete is the resistance offered by concrete against the flow of electrical current and is its material property [20]. This material property is used in condition surveying of concrete structures. Figure 6 shows electrical resistivity results of concrete with constant dosage of fly ash and varying dosages of alccofine. The mixes with constant fly ash quantity and varying dosage of alccofine i.e. SCC0, SCC1, SCC2 and SCC3 showed enhancement in electrical resistivity values of 2.04%, 11.26%, 8.14% and 2.97%, respectively with respect to NM at 28th day [20]. It is noticed that concrete cubes with adding of fly ash (25% by mass) and 5% of AL had high electrical resistivity. It was also noticed that the resistivity of concrete increases with increasing dosage of alccofine up to 5%. This improvement is due to the filling of pores with alccofine and formation of ettringite was followed by the combination of alccofine and fly ash. The reduction in electrical resistivity of concrete at higher dosages of alccofine is because of over precipitation of calcite at the surface region.

TABLE 10. L Box test results

Specimen Mix	H2/H1	Permissible limits of H2/H1
SCC0	0.75	0.8-1
SCC 1	0.83	
SCC 2	0.86	
SCC 3	1.0	

TABLE 11. V-funnel test results

Specimen Mix designation	V-funnel flow time (s)	Permissible range as per EFNARC (s)
SCC 0	9.62	6–12
SCC 1	8.91	
SCC 2	8.75	
SCC 3	11.5	

3. 4. Rapid Chloride Penetration Test From Table 12, it can observe that replacement of cement with constant fly ash and varying alccofine dosages decreases the chloride ion penetration. NM showed the RCPT value of 2468 coulombs and shows medium chloride

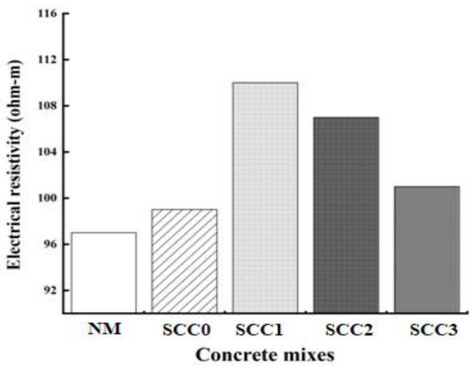


Figure 6. Graphical representation of electrical resistivity of fly ash-alccofine based self compacting concrete

TABLE 12. RCPT values of concrete with constant fly ash quantity and varying dosage of alccofine

Mix No	Mix Name	RCPT value in coulombs	Chloride penetration as per ASTM C1202
Mix 1	NM	2468	Medium
Mix 2	SCC0	1235	Low
Mix 3	SCC 1	232	Very Low
Mix 4	SCC 2	112	Very Low
Mix 5	SCC 3	104	Very Low

permeability as per ASTM C1202. With increasing the dosage of alccofine (i.e., 0%, 5%, 10% and 15%) into fly ash based concrete (i.e. Constant dosage of cement replaced with 25% fly ash by mass) showed from 1235 to 104 RCPT values and shows a low to very low permeability class in ASTM code. The reason behind that with adding of alccofine and fly ash showed better homogeneity in concrete, its help to improved pore microstructure and also reduce the RCPT values [21].

4. CONCLUSION

We investigated five different combinations of mixtures for Fresh properties, water absorption test, electrical resistivity and rapid chloride penetration test. With the constant dosage of fly ash and 10% alccofine showed better improvement in water absorption test, electrical resistivity, rapid chloride penetration test and fresh properties. SCC can be easily achieved with incorporation of SCM to the concrete. All the mixes showed good workability properties, which satisfied the EFNARC guidelines. From the water absorption test results, the concrete with adding of alccofine and fly ash showed a reduction of water absorption values compared to normal and fly ash based concrete due to filling of pores by alccofine particles. Resistivity of concrete has increased with adding of alccofine and fly ash because of homogeneity mixture up to 5% of alccofine and it decreased the further increment of alccofine dosage because of over precipitation of calcite at the surface region. Concrete with adding of constant fly ash quantity and 10% alccofine showed less RCPT value compared to other mixtures and showed chloride ion penetration changes from 1235 to 104 RCPT values with increasing alccofine dosages.

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Persian Abstract

چکیده

هزینه مرتبط با استفاده از حجم زیادی از سیمان و مواد افزودنی مصنوعی یکی از مهمترین ایرادات بتن خود متراکم (SCC) است که با استفاده از مواد اضافی سیمانی (SCM) قابل کاهش است. وقتی تقاضای سیمان کاهش یابد، میزان دی اکسید کربن (CO_2) آزاد شده از صنایع سیمان کم می‌شود که این امر تأثیر مثبتی در مسئله گرمایش کره زمین دارد. مقاله حاضر با استفاده از یک بررسی آزمایشگاهی در خصوص خواص تازه و عملکرد دوام SCC با جایگزینی سیمان با SCM مانند خاکستر حاصل از احتراق (FA) و سرباره کوره گرانول فوق العاده ریز (GGBS) در نسبت‌های مختلف، سعی در این راستا دارد. مخلوط SCC با تثبیت نسبت چسب–آب و دوز سوپر پلاستیسته با توجه به محتوای سیمان کل به دست آمد. همراه با خواص تازه، مخلوط‌های SCC که شامل دو گروه آلکوفیین و خاکستر حاصل از احتراق به ترتیب ۱۰٪ و ۲۵٪ به ترتیب که بهترین خواص تازه را به دست می‌آورند، برای ارزیابی مسائل مربوط به دوام انتخاب شدند. ترکیب ۱۰٪ آلکوکسین و ۲۵٪ خاکستر حاصل از احتراق در مقایسه با سایر ترکیبات بهترین نتیجه را در مطالعات تازه و دوام داشته است.