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Performance Studies on Potential Aspects of Self Compacting Concrete With Manufactured Sand and Fly Ash

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Abstract: Self compacting concrete (SCC) has been developed by using cement, fly ash and manufactured sand and coarse aggregate as main ingredients. Basics tests on SCC with various proportions of cement and fly ash have been performed and found that the values of slump flow, V-funnel, U-Box, L-box and J-ring are within the limits prescribed by EFNARC, Performance studies such as water absorption, sorptivity, sulphate resistance, shrinkage and Rapid chloride penetration resistance have been carried out for all the SCC mixes. Various physicochemical properties such as diffusion, permeability and absorption have been evaluated as per The French Association of Civil Engineering. It can be concluded that SCC with manufactured sand and fly ash will be a good candidate for all applications in the construction sector.

Keywords: Self compacting concrete; manufactured sand; fly ash; fresh properties; durability studies

I. Introduction

Concrete is the most common construction material used throughout the world for infrastructure, civil engineering and housing applications, followed by wood, steel and a number of miscellaneous materials. Concrete has been one of the most commonly used materials in the construction sector. One of the major problems is to preserve, maintain, and retrofit these structures. Concrete gives considerable freedom to mould the structural component into desired shape or form. Cement and concrete composites are presently the most economic materials for construction. A new trend in designing complex and heavily reinforced structures showed that compaction of concrete by vibrating may be difficult in some cases and strongly depend on a human factor. It is commonly noticed many times that after the formwork is removed; the fresh concrete had not spread to all the points, uniformly and perfectly. A homogenous property of the structure has thus been adulterated. These reasons prompted to the development of Self-Compacting Concretes (SCC). Such concrete was applied in practice for the first time in the mid-80s during underwater concreting in Japan. Ten years later, the SCC technology began to be used also for common concreting, especially for concreting of complex heavily reinforced structures. Development of a material without vibration for compaction i.e. Self Compacting Concrete (SCC) has successfully met the challenge and is now increasingly being used in routine practice. Self-compacting concrete (SCC) is considered as a concrete with high workability that is able to flow under its own weight and completely fill the formwork, even in the presence of dense reinforcement, without vibration, whilst maintaining homogeneity (Corinaldesi and Moriconi, 2004). It is known that SCC mixes usually contain superplasticizer, high content of fines and/or viscosity modifying additive (VMA). Whilst the use of superplasticizer maintains the fluidity, the fine content provides stability of the mix resulting in resistance against bleeding and segregation. The use of fly ash, blast furnace slag and silica fume in SCC reduces the dosage of superplasticizer needed to obtain similar slump flow compared to concrete mixes made with only Portland cement (Yahia et al., 1999; Holschemacher and Klug, 2002; Okamura, Ouchi, 2003; Heba, 2011; Mucteba Uysal, 2012).

In SCC, the aggregates generally contribute approximately 2/3 of the total volume. Proper choice of aggregates has significant effect on the fresh and hardened properties of SCC concrete. Aggregate characteristics such as shape, texture and grading influence workability, finishability, bleeding, pumpability, segregation of fresh concrete and strength, stiffness, shrinkage, creep, density, permeability, and durability of hardened concrete. In general it is observed that the effects of shape and texture of fine aggregate are much more important than the effects of coarse aggregate. It is in practice that river sand is being used as fine aggregate in concrete for many centuries. Most of the construction industries use river sand only as fine aggregate. Investigations are going on due to increase in demand and depletion of river sand, along with restrictions imposed on

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the exploitation of the river sand. It is observed from the literature (Gonçalves et al., 2007; Yüksel et al., 2011; Kou et al., 2009), that the alternative materials for river sand include manufactured sand, industrial by products (some forms of slag, bottom ash), recycled aggregates, etc. Among the above materials, manufactured sand (Msand) is relatively receiving significant attention as a replacement for river sand. The Msand is produced by impact crushing rock deposits to obtain a well graded fine aggregate (Alexander, 2005). It is known that for SCC, high powder (cement, cementitious materials and inert fillers) content is required for achieving the required fresh concrete properties (Nanthagopalan and Santhanam, 2006; Santhanam and Subramanian, 2004). Since, Msand contains large amount of fines, can be used as an alternative to river sand (Gonçalves et al., (2007). Due to high fines content in Msand, increases the yield stress of the mortar and contributes to the increase in plastic viscosity. On the other hand, the mechanical and durability properties of the concrete are reported to be considerably improved by using Msand (Gonçalves et al., 2007 and Donza et al., 2002). From the literature, it is observed that Msand is being used as fine aggregate in conventional aggregate and limited applications in SCC. Further, it is observed that the studies on durability aspects of SCC with fly ash, silica fume, GGBS, manufactured sand are scanty.

In this paper, an attempt has been made to use Msand and fly ash in SCC. Characterization of all ingredients of SCC has been performed. Various durability aspects have been examined for all SCC mixes in the present investigation.

II. Development Of Scc Mix And Evaluation Of Fresh Properties

Materials used

Ordinary Portland cement of 43 grade [IS: 12269-1987, Specifications for 43 Grade Ordinary Portland cement] has been used in the study. In the present investigation, manufactured sand (Msand) is used as fine aggregate. It is obtained by crushing of granite. The Msand is first sieved through 4.75mm sieve to remove any particles larger than 4.75mm and then is washed to remove the dust. Properties of the fine aggregate used in the experimental work are tabulated in Table 1. The aggregates were sieved through a set of sieves to obtain sieve analysis and the same is presented in Table 1. The fine aggregates belonged to grading zone III.

organic materials. Fly ash used in this investigation is procured from Thermal Power Station, Tamilnadu, India. It confirms with grade I of IS: 3812 – 1981 [Specifications for flyash or use as pozzolana and admixture]. The chemical composition and physical characteristics of fly ash used in the present investigation are given in Tables 2 and 3.

In the present work, water-reducing admixture, Conplast SP 430 conforming to IS 9103: 1999, ASTM C - 494 types F, G and BS 5075 part.3 is used and Viscosity Modifying Agent used in this investigation is Glenium.

III. Evaluation Of Fresh Properties

The proportioning of the quantity of cement, cementitious material like Fly ash, fine aggregate and coarse aggregate has been done by weight as per the mix design. Water, super plasticizer and VMA were measured by volume. All the measuring equipments are maintained in a clean serviceable condition with their accuracy periodically checked. The mixing process is carried out in electrically operated concrete mixer. The materials are laid in uniform layers, one on the other in the order - coarse aggregate, fine aggregate and cementitious material. Dry mixing is carried out to obtain a uniform colour. The fly ash is thoroughly blended with cement before mixing. Self Compacting characteristics of fresh concrete are carried out immediately after mixing of concrete using EFNARC specifications.

In order to study the effect on fresh concrete properties when fly ash is added into the concrete as cement replacement, the SCC containing different proportion of fly ash have been tested for Slump flow, V-funnel, U-Box, L-box and J-ring. The results of various fresh properties tested by slump flow test (slump flow diameter), J-ring test (flow diameter and difference in concrete height inside and outside J-ring (h2-h1)); L-box test (ratio of heights at the two edges of L-box (H2/H1)); V-funnel test (time taken by concrete to flow through V-funnel after 10 s T10s), U-box test (difference in height of concrete in two chambers (H2-H1)) for various mix compositions have been studied in detail (Tables 4 and 5). All the mixes in the present study conform to range given by EFNARC standards since the slump flow of SCC mixes is in the range of 610-698 mm. The J-ring diameter and difference in concrete height inside and outside J-ring are in the range of 585-640 mm and the difference in height is less than 40 mm. In addition to the slump flow test, V-funnel test is also performed to assess the flowability and stability of the SCC. V-funnel flow time is the elapsed time in seconds between the opening of the bottom outlet depending upon the time after which opened (T10s

Crushed granit

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and T5min) and the time when the light becomes visible from the bottom, when observed from the top. V-funnel time, which is less than 6 s, is recommended for concrete to qualify as a SCC. As per EFNARC, time ranging from 6 to 12 s is considered adequate for a SCC. In the present study, V-funnel flow times are in the range of 8-11 s. Test results of this investigation indicated that all SCC mixes meet the requirements of allowable flow time. Maximum size of coarse aggregate is kept as 16 mm in order to avoid blocking effect in the L-box. The gap between rebars in L-box test is 35 mm. The L-box ratio H2/H1 for the mixes is above 0.8 which is as per EFNARC standards (2002). U-box difference in height of concrete in two compartments is in the range of 5-40 mm. As a whole, it is observed that all the fresh properties of concrete values are found to be in good agreement to that of the values provided by European guidelines. Figure 1 shows typical pictures while evaluating fresh properties of various SCC mixes.

where,
CM = Control Mix, w/p= Water/ Powder (cement+SCM)
SCC1 = Self-compacting Concrete with 15 % FA as cement replacement.
SCC2 = Self-compacting Concrete with 25 % FA as cement replacement.
SCC3 = Self-compacting Concrete with 35 % FA as cement replacement.
SCC4 = Self-compacting Concrete with 45 % FA as cement replacement

3.0 Durability studies

Various durability aspects such as water absorption, sorptivity, sulphate resistance, shrinkage and Rapid chloride penetration resistance have been performed for all the SCC mixes. The details are presented below.

3.1 Water Absorption

Water absorption studies have been carried out on cubes made up of SCC with fly ash. The cube containing different proportion of fly ash have been prepared and kept for initial curing for 28 days. After the initial curing the water absorption is carried out at the age of 28 days and 56 days. Table 6 presents the results of water absorption for various SCC mixes at 28 days and 56 days. From Table 6, it can be observed that water absorption increases because of the inert behaviour of fly ash and the more pore percentage as compared to control mix at the initial ages, after that when fly ash reaction mechanism takes place there is no significant rise in percentage of water absorbed at 28 days and at 56 days. This may be attributed to continuous hydration of cement with concrete, and also when the fly ash is added in concrete, the calcium hydroxide liberated during hydration of cement reacts with the amorphous aluminosilicates (the pozzolanic compound available in fly ash) and produce a binding gel which fills the pores in concrete.

3.2 Shrinkage

Figure 2 shows the values of shrinkage for various ages for different SCC mixes. From Figure 2, it can be noted that increasing the amount of fly ash results in a systematic reduction in shrinkage. At low FA content i.e. 15 % (SCC1) the shrinkage is more or less same as Control Mix, but there is significant change in high FA content 45 % (SCC4) and in Control Mix as shown in Figure 2. Further, it can be noted that the final (20 days) shrinkage is approximately 2 times less than the control mix. This happens because amount of fly ash gets hydrated with the age and fills the vacant pores, hence increase the shrinkage resistance of concrete.

It is observed from the literature that shrinkage capacity is increased with the increase of the ash (Khatib, 2008). It was mentioned that at high fly ash content (60%), at 56days, shrinkage is reduced to half and with very high fly ash content (80%) the shrinkage is observed to be about 1/3rd compared with that of control. Safiuddin et al., (2008) showed that the reduced coarse aggregate content and increased amount of cementing material are expected to cause more shrinkage in SCC. The shrinkage tends to decrease in SCC since a very small amount of free water is available in the system.

3.3 Sorptivity

Sorptivity coefficient is estimated by means of simple test allowing one face of concrete specimen in contact with water and the mass of water absorbed by capillary suction is measured at predefined intervals. For this, cubical specimens of size 150 mm have been cast and cured for 28 days. After curing period cubes are kept in natural air to get dry for 4 hours. Then 4 sides of concrete specimen are sealed by a water proof seal. To avoid evaporative effect as well to maintain uniaxial water flow during the test and opposite faces are left open. After a predefined period of time, the samples are removed from the recipient to proceed to weight calculation. Before the weight, the sample‘s superficial water is removed with a wet cloth. Immediately after the weight, the samples are replaced in solution till reach the following time. The procedure is repeated, consecutively, until the last reading. The weight observed is shown in Table 7.

From the results, it is observed that increasing the amount of fly ash results in a gradual reduction in Sorptivity. At low FA content i.e. 15 % (SCC1) the water absorbed by capillary action is observed to be nearly same as control mix, but there is a significant difference in the capacity of SCC4 (45%) and control mix, the control mix has

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approximately 70 % high sorption capacity than SCC4 (45%). However by using high amount of FA, it is observed that the Sorptivity decreases as shown in Table 4. In general, it can be observed that water absorption by capillary increases with increase of time.

3.4 Sulphate Resistance

Sulphate resistance studies have been carried out after 28 days of curing at 3, 7, 14 and 21 days. It is observed that there is significant loss in weight of control mix compared to SCC1, SCC2,SCC3 and SCC4 (Figure3). The general observation is sulphate resistance of SCC increases with increase of FA content and percentage of weight loss decreases with increase of age. It can be observed from Figure 3 that there is significant loss in weight of control mix compared to SCC1, SCC2, SCC3 and SCC4. The general observation is sulphate resistance of SCC increases with increase of FA content and similar results were observed by many researchers in their investigations (Safiuddin et al., 2008; Najimi et al., 2011; Dinakar et al., 2008). The general observation is percentage of weight loss decreases with age.

3.4 Rapid chloride penetration resistance

The ability of concrete to resist the penetration of chloride ions is a critical parameter in determining the service life of RC structures exposed to deicing salts or marine environments. The measurement concerns the chloride ions that come into concrete and also those flowing through the samples. It was mentioned in the literature that the use of fly ash decreased the rapid chloride penetration coulomb value of concrete and the presence of fly ash (Patel et al., 2004) could improve the permeability of concrete due to its capability of transforming large pores of concrete into small pores and reducing micro cracking in the transition zone. The reduction of chloride penetration can be attributed to the fact that spherical particles of fly ash may improve the particle density the matrix and the interface zone between aggregates and paste.

Rapid chloride permeability test has been conducted for all the SCC mixes at 90 days and 365 days. It is observed from the studies that the coulomb charge of SCC4 (45 % fly ash) is 303 coulomb at 365 days, indicating high chloride penetration resistance. The general trend observed is chloride penetration resistance increased with the increase of % replacement of cement. The reduction in chloride ion penetration may be due to incorporation of fly ash whose spherical particles could improve particle packing density in the matrix. Figure 4 shows the results of RCPT for all SCC mixes.

From Figure 4, it can be observed that the coulomb charge of SCC4 (45 % fly ash) is 303 coulomb at 365 days, indicating high chloride penetration resistance. The general trend observed is chloride penetration resistance increased with the increase of % replacement of cement. In the literature, it is reported that the presency of fly ash reduced the chloride penetration (Patel et al., 2004; Nehdi et al., 2004). The reduction in chloride ion penetration may be due to incorporation of fly ash whose spherical particles could improve particle packing density in the matrix.

IV. EVALUATION OF PHYSICOCHEMICAL PROPERTIES

Diffusion, permeability and absorption are accepted to be the main physical processes which transport aggressive substances into concrete. It is known that The French Association of Civil Engineering (AFGC, 2004) considers some of the durability properties such as water porosity, chloride diffusion and oxygen permeability as general indicators of the potential durability of concrete (performance based evaluation, independent of the future site of exposure of concrete). The above mentioned tests have been performed after 28 days of water curing as per AFGC recommendations (AFPC-AFREM, 1997). In the present study, water porosity, mercury porosity, chloride diffusion and oxygen permeability has been studied.

3.5.1 Water porosity

Water porosity has been computed from three masses (weighed hydrostatically or in air): apparent mass of saturated concrete samples (5 cylinders ∅15× H5 cm) after immersion (liquid saturation under vacuum) (Mwater), mass in the air while they were still soaked (M_{air}) and mass of dry samples (drying at 80 ± 5°C until they reached a constant mass) (M_{dry}).Water porosity (ε) can be calculated by using the following equation (Ste´phan et al., 2007)

$$\varepsilon = \frac{M_{air}-M_{dry}}{V} = \frac{M_{air}-M_{dry}}{M_{air}-M_{water}} \times \rho_{water,\theta} \times 100 \quad (1)$$

where, $\rho_{water,\theta}$ denotes, the density of water at testing temperature $(\theta\ K)$

3.5.2 Mercury porosity

Mercury porosity was obtained from a specific test: mercury was introduced into the porous medium under very high pressure (200 MPa) using a porosimeter. By modeling the pores as cylindrical channels, the test pressure (p) can be connected to the radius of these cylinders by the Washburn–Laplace law:

$$p = \frac{2\sigma cos\theta}{r} \quad (2)$$

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where p defines the mercury injection pressure (Pa), σ the surface stress applied to the liquid (N/m), θ the contact angle (rad) and r the radius of the cylinder (m).

Table 8 shows the water and mercury porosity for control mix and for various SCC mixes. From Table 8, it can be noted that mercury porosity is less compared to water porosity for all mixes. Further, it can be noted that porosity reduces with the increase in replacement of cement by fly ash.

3.5.2 Chloride diffusion

Chloride diffusion in terms of effective coefficient of diffusion has been estimated by conducting a migration test (Truc et al., 2000). This test has been performed in saturated material and at steady state by subjecting the samples (3 cylinders $\varnothing$15 11 $\times$ H4 cm) to an external potential of 12 volts. The effective coefficient of chloride diffusion (D_{eff}) has been estimated by determining the chloride loss as given below:

$$D_{eff(t)}=\frac{RTJ(t)}{CFE} \quad (3)$$

where R is the perfect gas constant (8.32 J/mol K), T the temperature (Kelvin), $J(t)$ the chloride flow migrating into the concrete (mol/m^{2}s), C the average chloride concentration during the test (mol/m^3), F the Faraday constant (96,487 C/mol) and E the potential difference applied (V/m).The chloride diffusion test was performed using an aggressive solution composed of deionized water and various ion species: sodium chloride ([NaCl] = 12 g/l), sodium hydroxide ([NaOH] = 1 g/l) and potassium hydroxide ([KOH] = 4.65 g/l).Table 9 presents the values of diffusion coefficient for various mixes. From Table 9, it can be noted that the values of diffusion coefficient are decreasing with increase of percentage replacement of cement by fly ash.

3.5.3 Oxygen permeability

The oxygen permeability test has been performed by using a CEMBUREAU experimental device (Kollek, 1989). The flow of oxygen through concrete samples (5 cylinders $\varnothing$15 $\times$ H5 cm) has been measured at steady state against the test pressure and the material saturation rate. The apparent coefficient of permeability (k_A) has been computed for laminar flow of a compressible viscous fluid through a porous material from the Hagen–Poiseuille relationship:

$$k_A=\frac{2Q\mu P_{atm}}{A(P_i^2-P_{atm}^2)} \quad (4)$$

where, Q is the measured oxygen flow(m^3/s), lthe dynamic viscosity of oxygen (N s/m^2),L the thickness of the sample (m), P_{atm} atmospheric pressure (Pa), A the cross-sectional area of the sample (m^2) and P_i the absolute pressure applied (Pa).

Table 10 presents the values of Oxygen permeability for various mixes. From Table 10, it can be noted that the values of Oxygen permeability are decreasing with increase of percentage replacement of cement by fly ash.

Table 10. Diffusion coefficient for various mixes

Mix	Oxygen permeability (10^{-18} m^2)
CM	283.4
SCC1	169.3
SCC2	143.9
SCC3	115.3
SCC4	92.5

V. SUMMARY AND CONCLUDING REMARKS

In the present study, self compacting concrete mix has been developed by using fly ash and manufactured sand. Characterization studies of all the ingredients of SCC have been carried out. SCC containing different proportion of fly ash have been tested for Slump flow, V-funnel, U-Box, L-box and J-ring and found that the values are within the limits prescribed by EFNARC.

Various durability aspects such as water absorption, sorptivity, sulphate resistance, shrinkage and Rapid chloride penetration resistance have been studied for all the SCC mixes. It is observed that water absorption increases because of the inert behaviour of fly ash and the more pore percentage as compared to control mix at the initial ages, after that when fly ash reaction mechanism takes place there is no significant rise in percentage of water absorbed at 28 days and at 56 days.

From shrinkage studies, it is observed that at low fly ash content i.e. 15 % (SCC1) the shrinkage is more or less same as Control Mix, but there is significant change in the case of high fly ash content (SCC4). It is observed from sorptivity studies that increasing the amount of fly ash results in a gradual reduction in Sorptivity. At low fly ash content i.e. 15 % (SCC1) the water absorbed by capillary action is observed to be nearly same as control mix, but there is a significant difference in the capillary action of SCC4 (45%).

The general observation is sulphate resistance of SCC increases with increase of FA content and percentage of weight loss decreases with increase of age.

The chloride penetration resistance increased with the increase of % replacement of cement. The reduction in chloride ion penetration may be due to incorporation of fly ash whose

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spherical particles could improve particle packing density in the matrix.

Various physicochemical properties such as diffusion, permeability and absorption have been evaluated as per The French Association of Civil Engineering. These parameters will generally be considered as potential indicators for evaluation of durability. From overall study, it can be concluded that SCC with manufactured sand and fly ash can be used for all applications in the construction sector.

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(a) Slump flow test

(b) L-Box test

c) V - funnel test

(d) J-ring test

Figure 1 Evaluation of SCC fresh properties

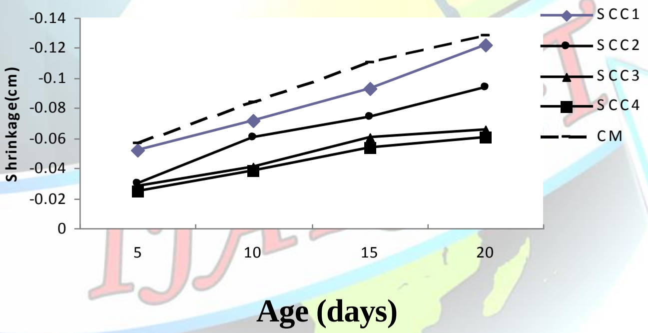

Figure 2 Shrinkage value at various ages

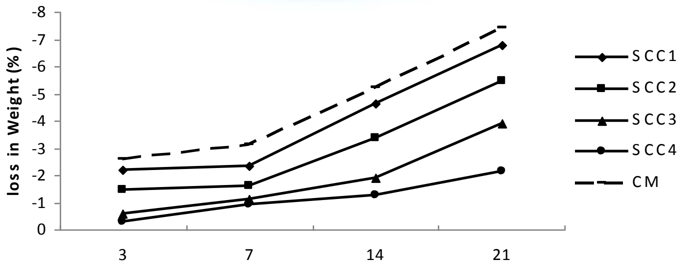

Figure 3 Percentage of weight loss with ages

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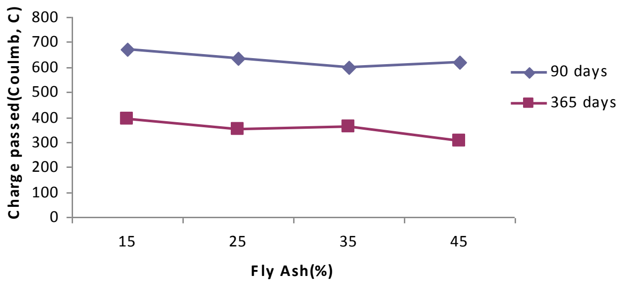

Figure 4 RCPT results at 90 and 365 days

Table 1 Physical Properties of fine aggregates

S.No.	Characteristics	Value
1	Specific gravity	2.56
2	Bulk density	1792 kg/m^3
3	Fineness modulus	2.57
4	Water absorption	0.87 %
5	Grading Zone (Based on percentage passing 0.60 mm)	Zone III

Table 2 Chemical requirements of fly ash

Characteristics	Requirements (% by weight)	Fly Ash used (% by weight)
Silicon dioxide (SiO_2) plus aluminium oxide (Al_2O_3) plus iron oxide (Fe_2O_3)	70 (minimum)	95.36
Silicon dioxide (SiO_2)	35 (minimum)	58.55
Magnesium Oxide (MgO)	5 (max.)	0.32
Total sulphur as sulphur trioxide (SO_3)	2.75 (max.)	0.23
Available alkalies as sodium oxide (Na_2O)	1.5 (max.)	0.05
Loss on ignition	12 (max.)	0.29
Chlorides		0.009

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Table 3 Physical requirements of fly ash

S No	Characteristics	Requirements for grade of flyash (IS:3812-1981)		Experimental Results
		Grade – I	Grade – II	
1	Fineness by Blain's apparatus in m^2/kg	320	250	325
2	Lime reactivity (Mpa)	4.0	3.0	9.1%
3	Compressive strength at 28 days as percentage of strength of corresponding plain cement mortar cubes	Not less than 80%		83%
4	Soundness by Autoclave expansion			Nil

Table 4 Mix proportions of SCC

Mixture ID	Cement (kg/m^3)	FA (kg/m^3)	Sand (Kg/m^3)	C.A (Kg/m^3)	Water (Kg/m^3)	w/p	SP (Kg/m^3)
CM	540	-	900	580	250	0.46	9.0
SCC1	459	81	900	580	228	0.42	10.71
SCC2	405	135	900	580	233	0.43	9.91
SCC3	351	189	900	580	240	0.44	9.91
SCC4	297	243	900	580	246	0.46	9.9

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Table 5 Fresh concrete properties

Mixture ID	Slump (mm)	V-funnel (seconds)	L-Box (H2/H1)	U-box (H1-H2)	J-Ring Dia.(mm)	J-Ring h2-h1 (mm)
SCC1(15% FA)	680	9	0.9	30	598	10
SCC1(15% FA)	613	10	0.85	25	640	12
SCC1 (15% FA)	648	8	0.9	20	620	14
SCC2(25% FA)	698	11	0.85	35	610	8
SCC2(25% FA)	628	10	0.9	35	625	10
SCC2(25% FA)	614	9	1.0	38	618	9
SCC3(35% FA)	642	10	0.85	40	623	12
SCC3(35% FA)	676	9	0.9	35	598	10
SCC3(35% FA)	653	11	0.8	30	631	9
SCC4(45% FA)	690	10	0.9	35	591	8
SCC4(45% FA)	610	9	0.8	30	585	10
SCC4(45% FA)	630	8	1.0	35	605	9

Table 6 Percentage of water absorbed at various ages

Mix	Percentage of Water absorbed in 28 days	Percentage of Water absorbed in 56 days
CM	0.210	0.398
SCC1 (15% FA)	0.412	0.681
SCC2 (25% FA)	0.682	1.198
SCC3 (35% FA)	2.63	3.63
SCC(45%FA)	3.87	4.934

Table 7 Evolution of water absorption by capillarity carried out with ages

	Water absorbed by capillarity (kg/cm^2)					
Mix	**15 min**	**30 min**	**1 hour**	**24 hours**	**48 hours**	**72 hours**
CM	0.0001	0.0002	0.00024	0.00036	0.00046	0.00056
SCC1 (15% FA)	0.00008	0.00014	0.0002	0.00030	0.00040	0.00050

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SCC2 (25% FA)	0.00006	0.00010	0.00017	0.00021	0.00030	0.00035
SCC3 (35% FA)	0.00005	0.00008	0.00015	0.00017	0.00020	0.00032
SCC4 (45% FA)	0.00004	0.00007	0.00013	0.00015	0.00017	0.00028

Table 8 Porosity of water and mercury

Mix	**Porosity (%)**	
	Water	**Mercury**
CM	13.6	11.2
SCC1	12.4	10.6
SCC2	11.8	10.1
SCC3	10.9	9.5
SCC4	10.1	9.2

Table 9 Diffusion coefficient for various mixes

Mix	**Diffusion Coefficient (10^{-12} m²/S)**
CM	32.3
SCC1	28.2
SCC2	16.8
SCC3	14.9
SCC4	12.1