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Durability performance of self-compacting concrete

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The methodological shift in the thinking about concrete from a strength-based concept to a durability-based design has led to the development of self-compacting concrete (SCC). This paper presents a systematic experimental programme on durability studies conducted, covering three grades of SCC from low strength (M20 grade) to high strength (M70 grade). The durability studies include acid attack, corrosion, sorptivity and thermal studies. The main objective of this investigation is to develop SCC mixes that are resistant to acid attack and suitable for Indian temperature conditions compared with vibrated normal concrete. Other durability factors such as capillary absorption and corrosion resistance of three such grades of SCC mixes have also been investigated. It was noted from the durability studies that in almost all cases the loss in durability is reduced with increase in grade of concrete. Furthermore, a comparison of SCC and normal concrete mixes has shown a good performance of SCC specimens as against normal concrete specimens.

Introduction

Self-compacting concrete (SCC) is defined as a concrete that can flow through and fill the gap between the reinforcement and corners of the moulds without any need for external vibration. SCC compacts itself due to its self-weight and de-aerates almost completely while flowing in the formwork. SCC can also be used in situations where it is difficult or impossible to use mechanical compaction for fresh concrete, such as underwater concreting, cast in-situ pile foundations, machine bases and columns or walls with congested reinforcement. The high flowability of SCC makes it possible to fill the formwork without vibration (Khayat *et al.*, 1999). Since its inception, it has been widely used in large construction works or projects in Japan (Okamura and Ouchi, 2003). Recently, this concrete has gained wide use for different applications and structural configurations (Bouzoubaa and Lachemi, 2001) across the world.

The functional requirements of a fresh SCC are different from those of a vibrated fresh normal concrete (NC). Filling of formwork with a liquid suspension requires workability performance such as filling ability, passing ability and resistance against segregation (EFNARC, 2005). SSC can be produced using standard cementing materials and additives (Dinakar *et al.*, 2008). It consists mainly of cement, coarse and fine aggregates, and filler, such as fly ash, ground granulated blast furnace slag and rice husk ash, water, super-plasticiser (SP) and viscosity-modifying agent.

Although SCC is a very promising cementitious material, the application of SCC in practice might be somewhat risky due to lack of knowledge concerning its actual durability (Safiuddin *et al.*, 2008). The degradation mechanisms of a cementitious material are greatly influenced by the permeability of the material for potentially aggressive media, and there is an important interaction between pore structure, transport mechanism and degradation. The permeability of concrete is strongly influenced by the pore structure of the material. Furthermore, the ongoing degradation process might have an influence on the pore structure of the material. As the pore structure might be different for SCC in comparison with the traditional concrete, due to difference in the composition, some changes in durability behaviour might occur. Acid attack, resistance to sulfate attack and resistance to chloride attack are some of the properties that determine the transport mechanism and chemical deterioration of the concrete (Al-Tamimi and Sonebi, 2003). Similarly, sorptivity is an indirect measure of permeability of concrete (Gopalan, 1996), while corrosion resistance is an important property for assessing the potential of a reinforcing material to adverse environmental conditions (Cioffi *et al.*, 2007).

From the literature available, it was noted that there are limited studies covering the durability issues on SCC although there is a lot of literature available on NC. Hence, it is felt that in the wake of SCC becoming an important material with numerous applications at present, there is a need to elucidate some of the durability-based parameters that govern the mix design of SCCs and influence strength and durability aspects of such SCCs. There is also a need to quantify the durability aspects of SCC.

Experimental programme

The experimental programme consisted of casting and testing SCC specimens. Although basically the Nan Su method of mix design (Su *et al.*, 2001) was adopted, several trials were made in producing SCC satisfying the EFNARC specifications (EFNARC, 2005). A total of three grades of concrete was investigated: M20, M30 and M70 grades, representing ordinary, standard and high-strength concrete, respectively, according to IS 456-2000 (BIS, 2000). A total of 108 standard cubes of SCC and 135 standard cubes of NC for acid attack study, nine standard cubes each for SCC and NC of size 50mm × 50mm for corrosion studies, 72 standard cubes each of SCC and NC for thermal studies; and nine specimens each for SCC and NC for sorptivity studies, was cast and tested.

The properties of the constituent materials used in the present investigation are given in Table 1. An appropriate dose of SP was used to improve the flowability, self-compacting ability and segregation resistance of fresh SCC for meeting the design requirements. The water content of the SP can be regarded as part of the mixing water. In the present work, SNF condensate (SP 430, a product of Fosroc Chemicals (India) Pvt. Ltd) was used as a water-reducing admixture (SP). The dosage of SP was obtained from trial and error to meet the requirements of EFNARC. LR (laboratory grade) hydrochloric acid 35–38% with specific gravity 1·18 kg/l and LR sulfuric acid 98% (Merk), 98·08 g/mol with specific gravity 1·84 kg/l were used in this study at different concentrations, namely 2% and 5%. Sodium chloride of 99% purity, molecular weight 58·44 g/mol, was used for corrosion tests.

Mix proportioning

The Nan Su mix design method was used (Su *et al.*, 2001). The details of the mix proportion are shown in Table 2, while the fresh properties of the three grades of concrete are shown in Table 3. The compressive strength of the three grades of concrete is also shown in Table 3.

Durability tests on SCC

Tests for acid attack, resistance to thermal cycles, resistance to corrosion and sorptivity were conducted.

Property/unit	Value
Cement – OPC 53 grade	
Specific gravity	3·10
Normal consistency	29·5%
Coarse aggregate	
Specific gravity	2·65
Bulk density: kg/m^3	1442
Fineness modulus	7·16
Super-plasticizer – Conplast SP 430	
Specific gravity	1·22
Chloride content	Nil
Fly ash	
Fineness: m^2/kg	335
Silicon dioxide (SiO_2): %	62·94
Lime reactivity: MPa	9·8
Fine aggregate	
Specific gravity	2·5 5
Bulk density: kg/m^3	1713
Fineness modulus	2·19

Table 1. Material properties of ingredients used for SSC and NC

Tests for acid attack on SCC

After 28 days of curing in water, each cube was tested for weight and compressive strength. The cured SCC and NC specimens of different grades viz. M20, M30 and M70 concrete specimens were kept exposed to 2% and 5% solutions of both sulfuric acid and hydrochloric acids. Cubes were continuously immersed in solution for up to 28 days. The response of the specimens to the solutions was evaluated through change in appearance, weight, compressive strength and dimensions of solid diagonals. Before testing, each specimen was removed from the bath and brushed with a soft nylon brush and rinsed in tap water. This process removes loose surface material from the specimens. For determining the resistance of concrete specimens to aggressive environment such as acid attack, durability factors such as acid strength loss factor (ASLF), acid attacking factor (AAF), acid weight loss

Type of mix	Mix proportion	w/b	Quantities: kg/m^3						
			Cement	Fly ash	Fine aggregate	Coarse aggregate	SP	VMA	Silica fume
SCC M20	1:1·4 2:4·49:3·80:0·043	0·455	210	300·0	944·00	800·00	9·12	—	—
NC M20	1:1·49:3·14	0·50	378	—	564·00	1188·00	—	—	—
SCC M30	1:1·08:3·47:2·83:0·016	0·435	285	308·7	991·13	807·30	4·708	—	—
NC M30	1:1·11:2·51	0·42	456	—	508·00	1146·00	—	—	—
SCC M70	1:0·450:1·250:1·170:0·03	0·269	680	305·5	850·30	795·65	15·85	1·75	34·0
NC M70	1:0·2:0·875:1·625:0·03	0·26	665	133·0	581·9	1080·7	19·95	—	39·9

Table 2. Mix proportions of SCC and NC

Sample no.	Grade of concrete	Slump flow value: mm	T_{50}: s	V-funnel: s	V-funnel at T_5: s	L-box H_2/H_1 (blocking ratio)	28-Day compressive strength: MPa	
							SCC	NC
1	M 20	660	2·0	4·0	5	1·00	27·67	28·25
2	M 30	695	4·2	4·0	7	0·98	49·75	41·00
3	M 70	720	4·0	6·0	6	1·00	79·30	79·20

Table 3. Fresh and hardened properties of M20, M30 and M70 grade SSC and NC

factor (AWLF) and acid durability loss factor (ADLF) (Venkateswara Rao, 2010) are proposed in this investigation, in keeping with the philosophy of ASTM C 666–1997 (ASTM, 1997).

ASLF is an indication of relative performance of concrete in strength, before and after immersion in a particular concentration of acid. This also depends on the period of immersion of the specimen. ASLF is mathematically calculated as

$$\text{Acid strength loss factor} = S_r \frac{N}{M} \tag{1}$$

where S_r is relative strength at N days (%), N is number of days at which the durability factor is required, M is number of days at which the exposure is to be terminated. A lower value of ASLF indicates greater stability towards acid attack.

AAF is meant to determine indirectly the disruption of concrete near the corners of the cube by way of measuring the change in the length of diagonal (referred to as diagonal loss) in a typical concrete cube after immersion in acid for a certain period of time. The extent of loss is determined as

$$\text{Acid attacking factor} = \frac{\text{Loss of acid diagonal after immersion}}{\text{Acid diagonal before immersion}} \times 100\% \tag{2}$$

A higher value of AAF indicates that the dimensional stability is lower.

AWLF is calculated as the percentage loss of weight of specimen immersing the cubes in various types and concentrations of acids for different immersion periods.

$$\text{Acid weight loss factor} = \frac{\text{Loss of weight of specimen after immersion}}{\text{Original weight of specimen before immersion}} \times 100\% \tag{3}$$

A higher value of the AWLF indicates that the weight loss is greater.

In order to have a unified factor describing durability, these factors are combined to derive a factor termed the ADLF: ADLF = ASLF × AAF × AWLF.

Tests for thermal cycling effect

A detailed experimental programme was conducted to investigate the thermal behaviour of concrete, both SCC and NC (Srinivasa Rao *et al.*, 2006). The parameters involved are the number of cycles (7, 14, 21 and 28), type of concrete (SCC and NC), grade of concrete (M20, M30 and M70) and exposed temperature (50°C and 100°C). In one thermal cycle according to the procedure the specimens were subjected to 50°C and 100°C as required for 8 h and for the remaining 16 h the specimens were kept at room temperature.

Tests for corrosion resistance

The corrosion resistance of concrete was measured using potential dynamic polarisation (Safiuddin *et al.*, 2008). The accelerated corrosion behaviour of steel bars embedded in concrete was found using these studies. The test specimen consisted of a concrete cube of size 50 × 50 × 50 mm and a steel bar was embedded at its centre. In order to accelerate the corrosion, the specimens were kept in 5% NaCl solution for a period of 1 week. The experiment was started by keeping the range of the potential resistance from −700 mV to +700 mV. The specimen was immersed in 500 ml of NaCl solution of the same concentration. The corrosion analysis was automated and Thales software was used. The current required to maintain the fixed potential against potential resistance was measured.

With the corrosion current from the graph of current against potential, the corrosion rate can be calculated using Equation 4

$$C_R = \frac{I_{corr} K E_W}{DA} \quad (4)$$

where C_R is the corrosion rate (units given by the choice of K); I_{corr} is the corrosion current (amperes); K is a constant that defines the units of corrosion rate = 3272 mm/(amp cm year); E_W is the equivalent weight in g/equivalent; D is density (kg/cm^3); A is the area of the sample (cm^2).

Tests for sorptivity

Sorptivity is an index of moisture transport into unsaturated concrete specimens. Sorptivity has been recognised as an important index of concrete durability because the test method used for the determination of sorptivity reflects the way water and other injurious agents will penetrate into the concrete and it represents an especially good measure.

Sorptivity tests for SCC and NC were conducted on cube specimens of size 150 × 150 × 150 mm on the basis of Hall's method (Hall, 1989). After 28 days of curing, the specimens were removed from the curing tank and were dried. After drying, the initial weights of the cubes were measured. Then, the specimens were kept so that the level of the water was 10 mm from the bottom of the cube as suggested in Hall's method. The cube absorbs water from the bottom and transmits it upwards by capillary action. After a predefined time (28 days of curing) the cubes were removed from the containers and the weights of the specimens were measured at times of 15 min, 30 min, 1 h, 2 h, 4 h, 6 h, 24 h, 48 h and 72 h after the end of curing. Hence, sorptivity studies were conducted continuously for 3 days after the required curing period.

The sorptivity coefficient (s) was obtained from the expression

$$s = \frac{i}{t^{1/2}}, \qquad i = \frac{\Delta W}{Ad} \quad (5)$$

where ΔW is the amount of water absorbed (kg); A is the cross-section of specimen that was in contact with water (m^2); d is the density of the medium in which the specimen was dipped ($d = 1$, as the medium used was water); t = time (min). The unit of s is kg/(m^2 min$^{1/2}$).

The variation of i against $t^{1/2}$ was plotted.

Test results and discussion

Experimental studies on fresh and hardened properties of SCC were carried out. It was noted that the fresh properties were satisfied for all three grades of concrete. In all the three grades the compressive strength was satisfied. From the detailed experimental studies on acid effect on SCC and NC specimens, it was noted that most of the SCC specimens performed well compared with NC specimens. To estimate the effects of acid on SCC and NC, certain factors are determined, as explained in the following paragraphs.

ADLF for SCC and NC

When the specimens were dipped in an acid environment, the net loss in strength, physical change in the dimensions of the cube and weight loss were noted. All of these can be considered to derive a unique factor typically depicting the various losses due to acid attack and termed the ADLF (Venkateswara Rao, 2010). The different losses are individually quantified in terms of different factors.

Acid strength loss factor

The ASLF highlights the variation in the compressive strength of SCC and NC when dipped in different acidic environments, namely HCl and H_2SO_4 at different concentrations. The ASLF is calculated according to Equation 1. Figure 1 shows the variation of ASLF in SCC and NC for 28 days of immersion in acids. The figure indicates that the SCC and NC showed more or less similar percentage loss in strength for the same grade of concrete. Furthermore, it is observed that as the strength grade increased there is a slight increase in percentage loss of strength in both SCC and NC. This trend justifies the notion that increase in strength may not bring increase in durability, as interpreted from the loss of strength. This fact also underpins the performance-based design rather than strength-based design of concrete. The ASLF is less for 2% HCl than for 5% HCl. A similar trend is observed for the sulfate effect; however, the rate of increase of ASLF is greater in sulfuric acid solution.

Acid attacking factor

The AAF gives an idea of the disruption in the geometry of the specimen due to an acidic environment. This is quantified by measuring the loss in the diagonals of standard test specimens.

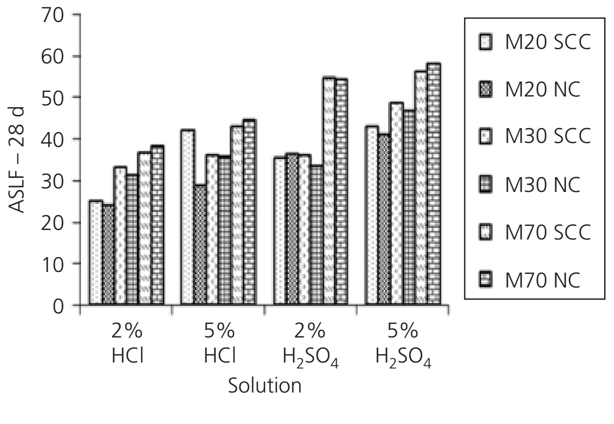

Figure 1. Acid strength loss factors (ASLF) of SCC and NC at 28 days of immersion

The average loss in the diagonals was measured for all the specimens immersed in acid at the end of 3, 7 and 28 days. Again a comparison for all the grades of concrete between SCC and NC revealed that SCC specimens performed better than NC specimens. Figure 2 shows the variation of AAF in SCC and NC for 28 days of immersion in acids. This indicates that there is less loss of diagonal (i.e. greater dimensional stability) in SCC mixes than in NC mixes. A similar trend was found when specimens were subjected to H_2SO_4. However, there was a greater loss of dimensional stability with H_2SO_4 than with HCl.

Acid weight loss factor

Because of the acidic environment, the pH of the concrete decreases; at the same time the cement and the mortar part in the interstices will be completely eaten away by the acid. This results in decrease in the weight of the specimen. It can be noted in general that the loss is greater with 5% H_2SO_4 than with HCl. Figure 3 shows the variation of AWLF in SCC and NC for 28 days of immersion in acids.

Acid durability loss factor

The above losses in strength, weight and geometry are combined to obtain a durability factor termed ADLF. Figure 4 shows the variation of ADLF in SCC and NC for 28 days of immersion in acids. It can be noted that the losses are greater in NC specimens than in SCC specimens. Hence, it can be said at this stage that the SCC specimens are more durable compared to NC.

In the present study, three grades of concrete and two types of acids (HCl and H_2SO_4) with different concentrations (2% and 5%) were considered. The ADLF values were calculated from the loss factors of ASLF, AAF and AWLF. The average ADLF values are given in Table 4. Figure 5 shows the variation in average ADLF with acid concentration levels for both SCC and NC. The figure reveals that for low acid concentration the SCC and NC behaved similarly, but as the concentrations increase the NC showed higher damage levels than SCC. This indicates that the performance of SCC is better than that of NC under acidic environmental conditions. It also supports the use of SCC in acidic environments. As long as concentrations are less than 0·5, one can use either SCC or NC; for higher concentrations (greater than 0·5) use of SCC is preferred.

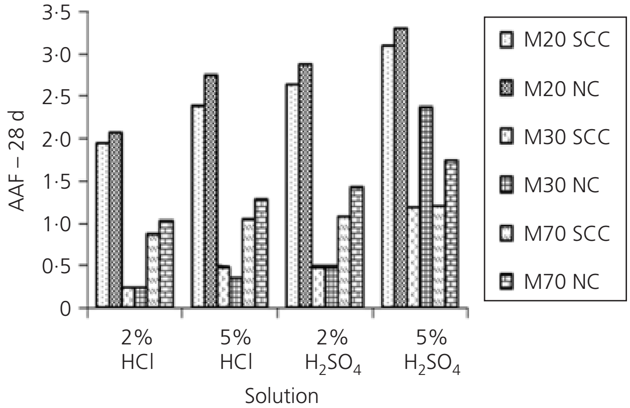

Figure 2. Acid attacking factors (AAF) for SCC and NC at 28 days of immersion

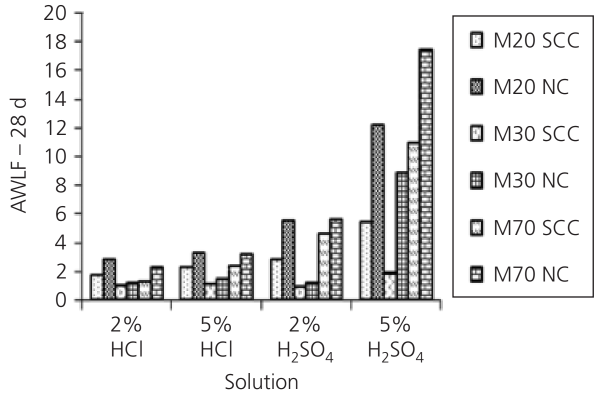

Figure 3. Acid weight loss factors (AWLF) for SCC and NC at 28 days of immersion

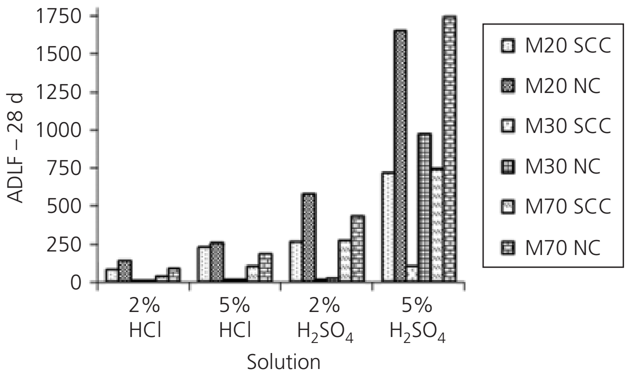

Figure 4. Acid durability loss factors (ADLF) for SCC and NC at 28 days of immersion

Thermal studies on SCC and NC

Thermal studies on SCC and NC are important because of the diurnal and seasonal changes in a tropical country like India (Srinivasa Rao *et al.*, 2006). The compressive strength of SCC and NC specimens subjected to different thermal cycles ranging from 7 to 28 days, at 50°C and 100°C temperature are shown in Figures 6 and 7. In the lower grades of concrete, the thermal cycling effect was greater than NC. The SCC mixes almost retained the strength and in some cases there was an increase in the compressive strength. This is in fact an advantageous factor for SCC mixes. In the case of higher grade concretes, both SCC and NC mixes behaved similarly. This may be due to the presence of higher quantities of binder in both SCC and NC mixes.

Solution	Average ADLF – 28 days								
	Normality	M20		M30		M70		Average ADLF	
		SCC	NC	SCC	NC	SCC	NC	SCC	NC
2% HCl	0·23	80·80	138·52	7·44	8·81	39·84	87·44	42·69	78·25
5% HCl	0·56	224·7	252·81	17·93	18·04	103·76	179·83	115·47	150·2
2% H_2SO_4	0·72	260·4	572·95	15·13	18·80	268·25	429·31	181·25	340·35
5% H_2SO_4	1·75	713·5	1646·8	100·72	971·45	734·76	1745·1	516·33	1454·5

Table 4. Average acid durability loss factor of SSC

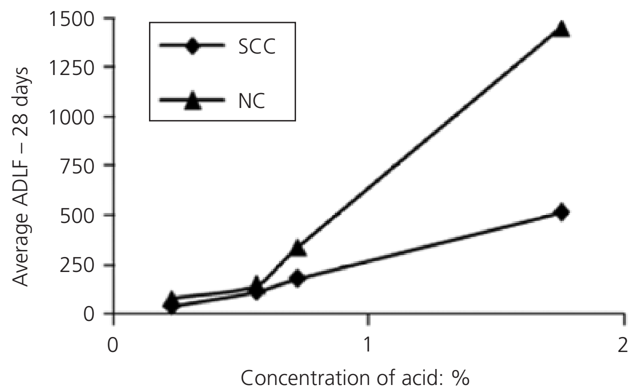

Figure 5. Plot of concentration of acid and average ADLF

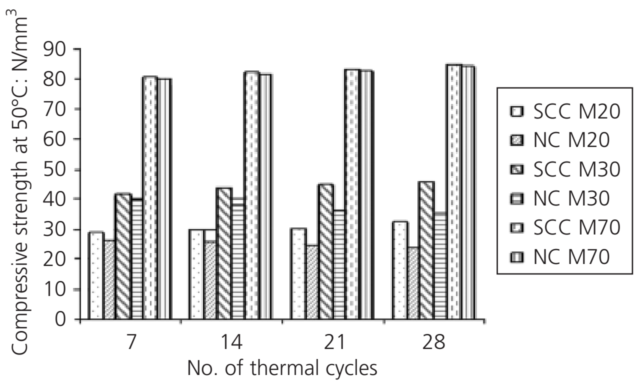

Figure 6. Compressive strength against number of thermal cycles at 50°C

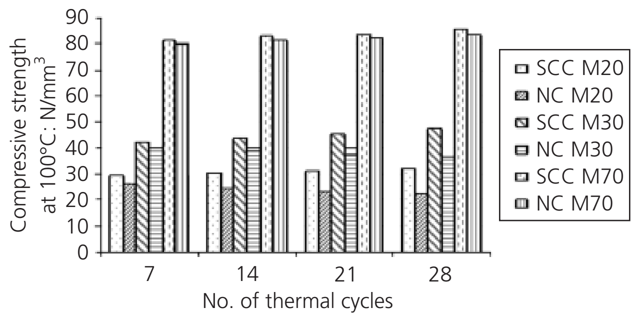

Figure 7. Compressive strength against number of thermal cycles at 100°C

It can be noted that with both the above exposure conditions for all grades of concrete, SCC behaved better than NC. It can be concluded that with the increase in grade of concrete and number of thermal cycles there is a decrease in the compressive strength in both SCC and NC at 50°C and 100°C. NC specimens always had lower compressive strength than SCC ones.

Corrosion resistance studies on SCC and NC

The corrosion rate was evaluated for all the grades of concrete for both SCC and NC as explained earlier. Figure 8 shows the details of corrosion potential against corrosion current for M20, M30 and M70 grades of NC and SCC. The details of the potential resistance and current are shown in Table 5, while Table 6 shows the details of the rate of corrosion.

It can be observed that the corrosion rate was less in case of SCC, suggesting good durability of SCC compared with NC. This was true for all grades of concrete. The values in Table 6 indicate a decreased corrosion rate in SCC mixes. This may be attributed to a better uniformity of mixes in SCC than in NC.

Sorptivity study of SCC and NC

Sorptivity is the absorption and transmission of water by capillary action (Pereira de Oliveira *et al.*, 2006). Table 7 shows the details of the water absorbed due to capillary action and sorptivity coefficient for SCC and NC. Figures 9 and 10 show the variation of absorbed water per unit area, i against $t^{1/2}$. The cumulative water absorption was less for SCC than for NC with increasing time. This is true for all grades of concrete. For the sorptivity coefficient, asymptotic behaviour was observed for both SCC and NC mixes.

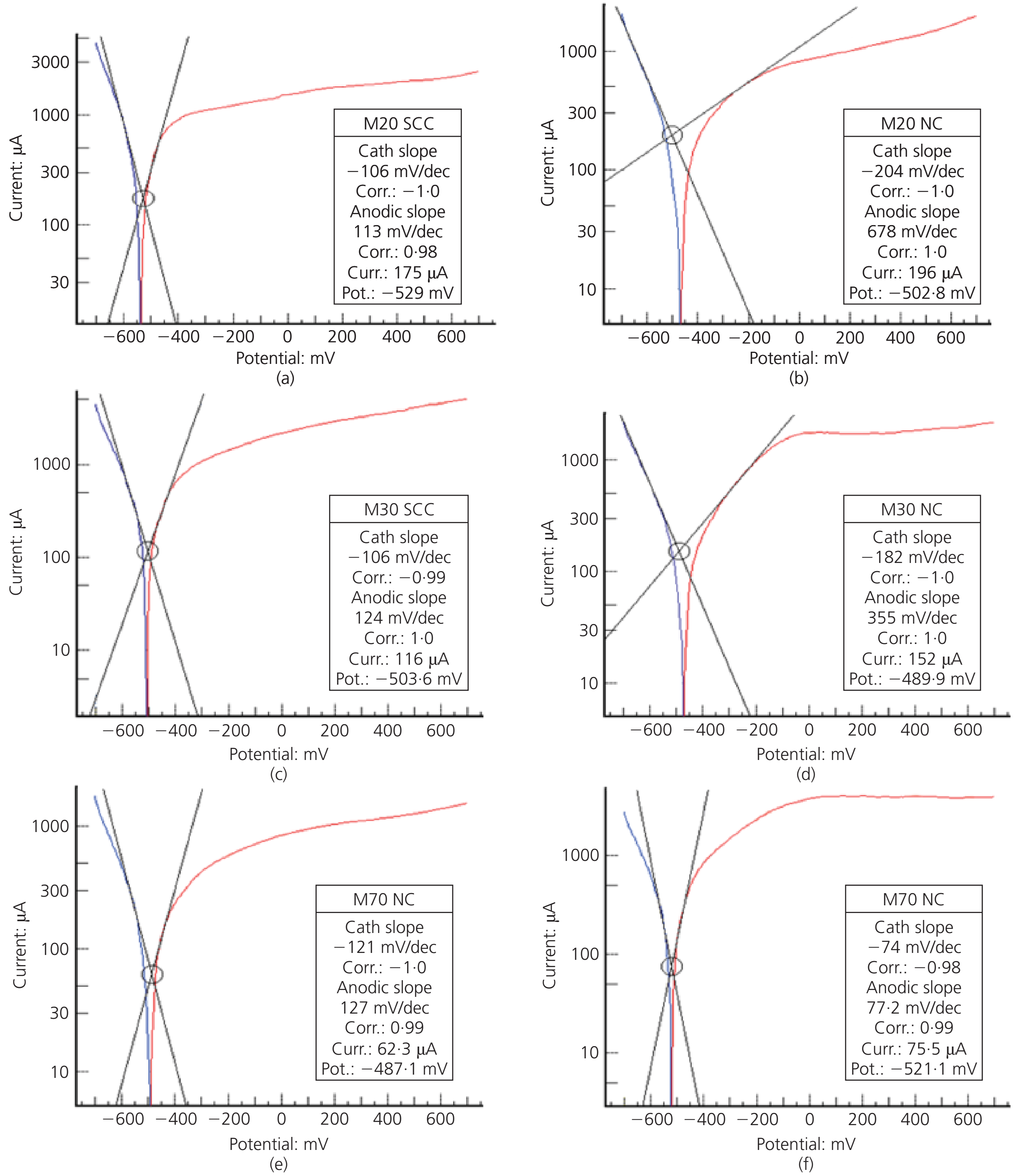

Figure 8. Corrosion potential against corrosion current of SCC and NC mixes

It can be noted from the above tables and figures that as the grade of concrete increases the water absorption decreases. Also, the values of water absorption in SCC are much lower than in NC.

Conclusions

The present study highlighted the durability aspects of NC and SSC covering different grades of concrete ranging from low to high strength. Different factors influencing the durability behav-

Grade of concrete	Potential resistance: mV		Corrosion current: μA	
	SSC	NC	SSC	NC
M20	−529·0	−502·8	175	196
M30	−503·6	−489·9	116	155
M70	−487·1	−521·1	62·3	75·5

Table 5. Potential resistance and current of SSC and NC

Grade of concrete	Corrosion rate: mm/year	
	SSC	NC
M20	0·081	0·091
M30	0·054	0·072
M70	0·029	0·035

Table 6. Corrosion rates of SSC and NC

iour of SCC and NC were quantified in terms of ASLF (for strength loss), AAF (for disruption of geometry), AWLF (for loss of weight) and a composite general factor termed ADLF covering all these aspects was proposed. The effect of thermal cycling and corrosion studies on different types of concrete (SCC and NC) and different grades of concrete was studied. It can be concluded from this exhaustive study that with the increase in the grade of concrete, the performance of both the types of concrete was improved. It was also noted that the behaviour of SCC mixes was superior to that of NC mixes.

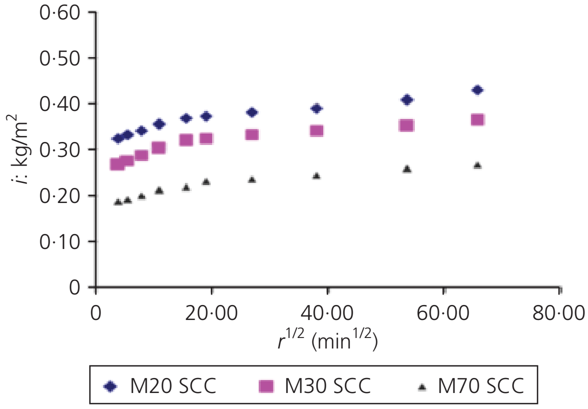

Figure 9. Absorbed water per unit area (i) against $t^{1/2}$ for SCC

The following specific conclusions may be drawn from this study:

- With the increase in duration of exposure to the acidic environment the ASLF increased. This was true for both SCC and NC.

Sample no.	Time: min	Cumulative water absorption (ΔW): kg						Sorptivity coefficient ($s = i/t^{1/2}$): kg/(m^2 $min^{1/2}$)					
		M20		M30		M70		M20		M30		M70	
		SCC	NC	SCC	NC	SCC	NC	SCC	NC	SCC	NC	SCC	NC
1	15	7·3	7·8	6	7	4·2	5·1	0·08	0·09	0·07	0·08	0·05	0·06
2	30	7·5	8·2	6·2	7·3	4·3	5·5	0·06	0·07	0·05	0·06	0·03	0·04
3	60	7·7	8·5	6·5	7·8	4·5	6	0·04	0·05	0·04	0·05	0·03	0·03
4	120	8	8·8	6·8	8·4	4·75	6·4	0·03	0·04	0·03	0·03	0·02	0·03
5	240	8·3	9·1	7·2	8·7	4·9	6·6	0·02	0·03	0·02	0·03	0·01	0·02
6	360	8·4	9·4	7·3	8·9	5·2	6·9	0·02	0·02	0·02	0·02	0·01	0·02
7	720	8·6	9·5	7·5	9·1	5·3	7	0·01	0·02	0·01	0·01	0·01	0·01
8	1440	8·8	9·7	7·7	9·2	5·5	7·2	0·01	0·01	0·01	0·01	0·01	0·01
9	2880	9·2	10·2	7·9	9·4	5·8	7·4	0·01	0·01	0·01	0·01	0·00	0·01
10	4320	9·7	10·6	8·2	9·6	6	7·7	0·01	0·01	0·01	0·01	0·00	0·01

Table 7. Sorptivity coefficients of SSC and NC

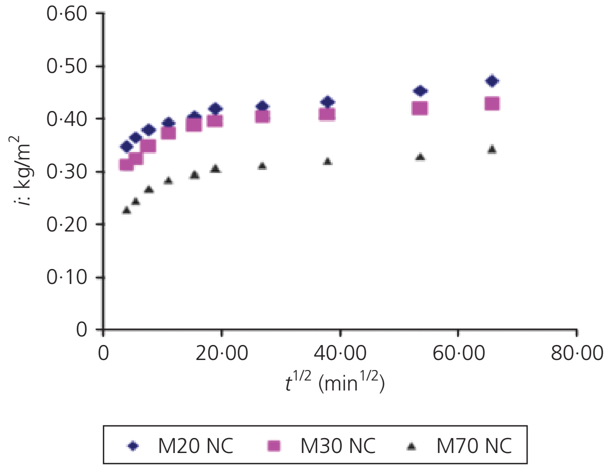

Figure 10. Absorbed water per unit area (*i*) against $t^{1/2}$ for NC

- SCC and NC showed more or less similar percentage loss in strength for the same grade of concrete.
- With increase in period of immersion of the concrete in various types (HCl and H_2SO_4) and concentrations of acid, there was a considerable disruption of concrete near the corners of the standard cube and such disruption in SCC was less than in NC, indicating superior durability of SCC.
- The weight loss was greater in NC than in SCC.
- The average ADLF is greater in NC for all grades than in SCC mixes. Hence, the SCC mixes were better than NC in all grades.
- Average ADLF may be considered a unified parameter to quantify durability because it considers both strength aspects and performance aspects simultaneously.
- Thermal studies indicated that the fly ash-based SCC mixes of higher grades performed better than NC of identical grade.
- The corrosion performance was better in SCC for all the three grades of concrete. Furthermore, the performance improved with increase in grade of concrete.
- SCC mixes performed better than NC and the higher grades showed lower absorption values than lower grades.

REFERENCES

Al-Tamimi AK and Sonebi M (2003) Assessment of self-compacting concrete immersed in acidic solutions. *ASCE Journal of Materials in Civil Engineering* **15(4)**: 354–357.

ASTM (1997) Historical Standard: ASTM C666–97: Standard test method for resistance of concrete to rapid freezing and thawing (superseded). ASTM International, West Conshohocken, PA, USA.

BIS (Bureau of Indian Standards) (2000) IS 456–2000: Code of practice for plain and reinforced concrete (4th revision). BIS, New Delhi, India.

Bouzoubaa N and Lachemi M (2001) Self-compacting concrete incorporating high volumes of class F fly ash: preliminary results. *Cement and Concrete Research* **31(3)**: 413–420.

Cioffi R, Colangelo F and Marroccoli M (2007) *Durability of Self Compacting Concrete*, RILEM TC 205 DSC, State of the art report. RILEM, Bagneux, France, pp. 208–212.

Dinakar P, Babu KG and Manu Santhanam (2008) Durability properties of high volume fly ash self compacting concretes. *Cement and Concrete Composites* **30(10)**: 880–886.

EFNARC (European Federation of Producers and Applicators of Specialist Products for Structures) (2005) *Specification and Guidelines for Self-Compacting Concrete*. EFNARC, Farnham, UK.

Gopalan MK (1996) Sorptivity of fly ash concretes. *Cement and Concrete Research* **26(8)**: 1189–1197.

Hall C (1989) Water sorptivity of mortars and concretes: a review. *Magazine of Concrete Research* **41(147)**: 51–61.

Khayat KH, Ghezal A and Hadriche MS (1999) Factorial design models for proportioning self consolidating concrete. *Materials and Structures/Matériaux et Constructions*, **32(Nov)**: 679–686.

Okamura H and Ouchi M (2003) Self-compacting concrete. *Journal of Advanced Concrete Technology* **1(1)**: 5–15.

Pereira de Oliveira LZ, de Castro Gomes JP and Pereira CNG (2006) Study of sorptivity of self compacting concrete with mineral additives. *Journal of Civil Engineering and Management* **XII(3)**: 215–220.

Safiuddin Md, West JS and Soudki KA (2008) Durability performance of self-consolidating concrete. *Journal of Applied Sciences Research* **4(12)**: 1834–1840.

Srinivasa Rao P, Sravana P and Seshagiri Rao MV (2006) Effect of thermal cycles on the strength properties of OPC and fly ash concretes. *Indian Concrete Journal*, **2006(March)**: 49–52.

Su N, Hsub KC and Chai HS (2001) A simple mix design method for self-compacting concrete. *Cement and Concrete Research* **31(12)**: 1799–1807.

Venkateswara Rao S (2010) *Experimental Studies on the Effect of Size of Aggregate and Fines on the Strength and Durability Properties of Self Compacting Concrete*. PhD thesis, Jawaharlal Nehru Technological University, Hyderabad, India.

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