Behaviour of Self Cured Self Compacting Concrete with Fly Ash under Different Environmental Conditions

J. Shanmuga priya[1*], K. Chinnaraju[2] and [3]V.Jaganathan

[1*]*Research Scholar, Division of structural Engineering, Anna University, Chennai- Tamilnadu, India.*

[2]*Professor, Division of structural Engineering, Anna University, Chennai-Tamilnadu, India.*

[3]*Research Scholar, Division of structural Engineering, Anna University, Chennai-Tamilnadu, India.*
[1*]*priyasudhakar06@gmail.com,*[2]*kcraju64@gmail.com,*[3]*jagnthan@gmail.com*

Abstract

This paper focuses on the application of internal curing to self-cured self compacting concrete containing fly ash. Pre soaked super absorbent polymer (SAP) is used as an internal curing agent. Based on the chemical shrinkage of pastes and the absorption capacity of SAP, the internal curing water required to the concrete was determined. The Self Curing Self Compacting Concrete (SCSCC) specimens were allowed to cure in ambient conditions (moisture loss is allowed) whereas the conventional Self Compacting Concrete (SCC) specimens were allowed to cure in water till the date of testing. Compressive strength at 7, 28, 56, 90 and 180 days were determined. Rapid Chloride Penetration Test (RCPT) was conducted at the age of 28, 90 and 180 days and a strong correlation was found between compressive strength and RCPT values of Self Cured Self Compacting Concrete. It was found that, self cured self compacting concrete cured in ambient conditions had higher rate of strength gain than the conventionally cured self compacting concrete. Mix with 40% fly ash showed highest rate of strength gain at the age of 28 days. Compressive strength of SCC and SCSCC after exposure to chloride, sulphate and acid solutions were determined at 28, 56, 90 and 180 days. The difference in strength before and after exposure to chloride and sulphate solutions was lesser than the water cured self compacting concrete. Also loss of mass on acid exposure was determined. It was concluded that, self compacting concrete with SAP as an internal curing agent, in spite of exposure to drying conditions shows a constant increase in the compressive strength throughout 180 days. The gain in strength increased with increase in fly ash percentage.

Keywords: *self compacting concrete, Superabsorbent polymer, curing, chemical shrinkage, loss of mass, rate of strength gain*

1. Introduction

Concrete generally requires water for hydration and strength development. This water in concrete can be distinguished as physically bound water, chemically bound water and non evaporable water. In concrete with higher paste content such as self compacting concrete, initial curing is really essential to minimize shrinkage cracks due to moisture loss [1, 2]. Internal curing is done by providing additional water for curing to the concrete by means of internal reservoirs of water inside the concrete. Internal curing is generally

Corresponding author: J.Shamuga priya

done to increase the hydration and decrease the self desiccation in mixtures with low water-cement ratio. Hence it should not be mistaken as self curing which is an alternative to conventional curing procedures [3]. Though many materials are under research to be used as internal curing materials, the two most common materials are superabsorbent polymers and lightweight aggregate. [4-6].

Super absorbent polymers (SAP) can be used for different concrete applications such as shrinkage reduction, rheology modification, frost resistance, etc., [7-9]. Super absorbent polymers are materials which are capable of absorbing enormous quantity of water (5 to 500 times of its own weight) and release it to the surroundings at low relative humidity. The mechanism of absorption of fluids by super absorbent polymers is based on the principle of osmosis. Chemically stable covalently cross linked polymer acrylamides can be used in concrete applications. The suitability of super absorbent polymers to be used in concrete is decided upon its absorption capacity. Absorption capacity of super absorbent polymers can be found out using tea bag test. [10, 11].

Many research works have been carried out to utilize the beneficial properties of super absorbent polymers in concrete. The major factors which influence the concrete properties are the particle size, shape, cross linking density, absorption and desorption capacity of the super absorbent polymer. The dosage and method of incorporating internal curing water has significant effect on the workability. When the polymer was made to pre absorb the curing water, the slump value increases whereas the dry addition decreased the workability of concrete. The addition of SAP has no influence on the compressive strength at early ages and at later ages the compressive strength of concrete increases continuously. Also the particle size has a strong influence on the compressive strength gain [12, 13]. Inclusion of SAP decreases the internal relative humidity of concrete, whereas sealed concrete specimens give significant decrease in the internal relative humidity. The rate of decrease varies from 84% to 96% which helps in the reduction of shrinkage cracks [14, 15]. The effect of curing conditions also plays a major role in increasing the hydration and compressive strength. Curing of concrete by sealing performed better in all the cases in terms of compressive strength, chloride permeability and water absorption [16]. The water required for internal curing can be obtained by equating the water demand of the paste to the water supplied by the internal reservoirs on assumption that no water is lost to the surrounding due to evaporation [17]. The factors on which the water demand depends are the quantity of cementitious material used, chemical shrinkage of the hydrating paste and absorption capacity of the curing material [18]. Internal curing concept is applied to concrete mixtures which have a water- cement ratio less than 0.42. Lopez et.al investigated the effect of internal curing to traditional concrete having w/c greater than 0.42 and found that the internal curing when applied even under poor curing conditions would increase the degree of hydration, compressive strength and reduce the chloride permeability [19]. The effect of SAP on chloride permeability was significant for water–cement ratio of 0.33 but was minor for lower water cement ratios. The effect of micro fillers could improve the durability of internally cured concrete [20]. It was also reported that shrinkage in internally cured fly ash blended mortars was lesser when compared with the mortars with Ordinary Portland Cement. [21, 22]. Hence the effect of fly ash on internal curing of unsealed self compacting concrete specimens is particularly studied. Five mixes with percentage of fly ash replacement varying from 30 to 50% at 5% increments were considered for both self curing and water curing and properties like workability and compressive strength were studied. The internally cured concrete specimens were cured in ambient conditions in the laboratory and their compressive strength, resistance to chloride penetration and behaviour under various environmental conditions were studied.

2. Experimental procedure

2.1 Materials

OPC of grade 53 conforming to the requirements of IS 269 – 2015 [23] was used whose specific gravity and specific surface area were 3.15 and 300 m^2/kg respectively. The chemical composition of cement and fly ash is presented in Table 1. Class F Fly ash conforming to IS 3812 [24] obtained from Ennore thermal power station, Tamilnadu, India was used whose specific gravity is 2.2. Commercially available poly carboxylic ether based super plasticizer (AURAMIX 400) with a specific gravity of 1.09 and solid content not less than 30% was used as a chemical admixture. Natural river sand of specific gravity 2.5 and fineness modulus of 2.36 was used. The sieve analysis results are given in Table 2 and the aggregate grading belongs to zone II of IS 2386 [25]. Crushed granite was used as coarse aggregate whose nominal size is 12.5 mm and specific gravity is 2.8. Acrylic sodium salt polymer commercially called (SAP) was used as the internal curing material whose size fraction is 150 to 300 microns. The absorption capacity of the polymer was found using tea bag method and was found to be 125 g/g in potable water.

Table 1 Chemical composition of cement and fly ash

Component	Composition in cement (%)	Composition in Fly ash (%)
SiO_2	18.91	48
Al_2O_3	4.51	29
Fe_2O_3	4.94	12.7
CaO	66.67	1.76
MgO	0.87	0.89
Na_2O	0.12	0.39
K_2O	0.43	0.55
SO_3	2.5	0.5
loss on ignition	1.05	1.61

Table 2 Sieve analysis of river sand

Sieve size (mm)	Cumulative passing (%)
4.75	100
2.36	100
1.18	89
0.6	55.5
0.3	18
0.15	1.5

2.2 Mixture proportions and sample preparation

Mixture proportioning was done for self compacting concrete with 30 to 50% fly ash replacement considering the efficiency factor [26-29] of fly ash. EFNARC guidelines were followed for determining the water content, paste content and aggregate content. The criteria laid by EFNARC for satisfying the self compaction criteria were maintained. Super absorbent polymer was used for internal curing. The optimum dosage of internal curing water for each mix was determined based on the chemical shrinkage of cement paste containing fly ash. Chemical shrinkage was determined by gravimetric method of ASTM C1608[30,31].The chemical shrinkage of pastes per gram of cementitious material was determined for a period of seven days and the results are presented in Table 3.

Table 3 Chemical shrinkage of pastes

Percentage of fly ash replacement (%)	Cement content (kg)	Fly ash content (kg)	water-cementitious material	Chemical shrinkage (ml/g)
30	350	150	0.39	0.047
35	325	175	0.39	0.042
40	300	200	0.38	0.034
45	275	225	0.37	0.033
50	250	250	0.35	0.025

The super absorbent polymer was presoaked in total water content (which includes mixing water and internal curing water) for 24 hours prior to concrete production. While mixing the excess water was decanted and used for further mixing. Mixture proportions for Self Compacting Concrete (SCC) and Self Cured Self Compacting Concrete (SCSCC) specimens are presented in Table 4.

Table 4 Mix proportions

Mix designation	Cement (kg/m^3)	Fly ash (kg/m^3)	Coarse aggregate (kg/m^3)	Fine aggregate (kg/m^3)	w/c	SAP (% by wt of cement)
30 SCC	350	150	800	801.82	0.39	-
35 SCC	325	175	800	796.18	0.39	-
40 SCC	300	200	800	795.44	0.38	-
45 SCC	275	225	800	798.68	0.37	-
50 SCC	250	250	800	813.74	0.35	-
30 SCSCC	350	150	800	801.82	0.43	0.05
35 SCSCC	325	175	800	796.18	0.43	0.05
40 SCSCC	300	200	800	95.44	0.41	0.04
45 SCSCC	275	225	800	798.68	0.4	0.04
50 SCSCC	250	250	800	813.74	0.37	0.03
1% Superplasticizer by weight of binder was used for all mixes						

All the dry ingredients were introduced into the mixer and mixed to obtain a homogenous mixture after which water along with superplasticizer was introduced and mixed for around two minutes. After thorough mixing, presoaked SAP was added to the mixer and was mixed for additional two minutes. After mixing, fresh properties like slump flow, V funnel and L box were determined according to EFNARC guidelines. Sample preparation was done after determining the fresh properties. The samples consisted of 150 mm×150 mm cubes for compressive strength determination, 100 mm×100 mm cubes for durability studies and 100 mm diameter cylinders for rapid chloride penetration tests. The mixes without SAP were cured conventionally by immersing in water before testing. The mixes with SAP for internal curing were allowed to cure under ambient conditions inside the laboratory.

2.3 Testing

2.3.1 Fresh properties: The slump flow test and V funnel test were used to determine the filling ability of self compacting concrete. L box test was used to determine the passing ability of concrete. The tests were carried out as EFNARC guidelines. The tests were carried out for all the ten mixes. For slump flow test, the diameter of the spread concrete was measured in two perpendicular directions and the average diameter was reported. Also the time required for the concrete to reach 500 mm diameter was noted. The V funnel test was used to measure the ease of flow of the concrete and the test was also performed after allowing the concrete to stay in the funnel for 5 minutes. This was an indication of the resistance offered by concrete to segregation. The blocking ratio was calculated by determining the difference in heights of the L box. The values are reported in table 5.

Table 5 Fresh properties

Mix designation	Slump flow (mm)	T_{50} (s)	V funnel Time (s)	$T_{5\ min}$ (s)	Blocking ratio
30 SCC	678	3.7	8.4	10.9	0.94
35 SCC	680	3.5	8.1	10.6	0.94
40 SCC	684	3.4	7.9	11.2	0.95
45 SCC	686	3.2	7.7	11.0	0.96
50 SCC	688	3.0	7.6	10.8	0.97
30 SCSCC	730	3.3	8.0	10.7	0.97
35 SCSCC	743	3.1	7.8	11.3	0.97
40 SCSCC	77	2.8	7.3	11.6	0.97
45 SCSCC	782	2.8	7.1	11.8	0.98
50 SCSCC	784	2.6	7.1	12.3	0.98

2.3.2 Compressive strength: The compressive strength of concrete cubes was tested at 7, 28, 56, 90 and 180 days. The water cured SCC specimens were cured in water till the period of testing. On the day of testing, the specimens were taken out from water and allowed to surface dry before testing. The internally cured samples were allowed to cure at ambient conditions inside the laboratory without any external means of curing till the time of testing. Testing was carried out in a Compression Testing Machine of capacity 200 T. Gradual load was applied at the rate of 140 kg/cm^2/minute according to IS 516-1959 [32] and the maximum load applied to the specimen was noted. Three specimens were tested for each mix and the average compressive strength of three specimens was reported.

2.3.3 Rapid chloride penetration test (RCPT): RCPT provides an indication of the resistance of concrete against penetration of chloride. The test was carried out according to ASTM C 1202-97[33]. Three disc specimens of 100 mm diameter and 50 mm thickness were subjected to testing for each mix at 28, 90 and 180 days. The samples were conditioned before conducting the test. Lesser the charge passed, lower is the penetrability of chloride into the concrete. The relationship between the compressive strength and chloride resistance was also reported.

2.3.4 Exposure to chloride, sulphate and acid solutions: The resistance to chloride, sulphate and acid environments was studied to assess the real time behavior of self curing self compacting concrete specimens. The SCC specimens without SAP were cured in water for a period of 28 days before immersion. The specimens with SAP were cured in air for 28 days and then immersed in salt and acid solutions for various time spans such as 28, 56, 90 and 180 days.

The specimens after a curing period of 28 days were immersed in 5% chloride solution which consists of 4% of Sodium Chloride and 1% of Magnesium chloride for assessing the resistance to chloride attack. Similarly to determine the resistance to sulphate attack the specimens were immersed in 5% solution of Sodium sulphate. Also the specimens were immersed in Sulphuric acid solution of 5% concentration. The specimens were tested for change in compressive strength at 28, 56, 90 and 180 days and were reported. In addition, the change in mass for acid immersion was reported. The solutions were replaced with fresh solutions after every 30 days to maintain a constant pH throughout the test period. The change in mass and compressive strength was calculated according to ASTM C267 [34].

3. Results and discussions

3.1 Fresh properties

Tests for filling ability, passing ability and segregation resistance were carried out conforming to EFNARC guidelines. It was inferred that, inclusion of fly ash increases the workability of concrete. The filling ability and passing ability of 50SCC mix was better than 30SCC mix. But a slight segregation was seen for mixes with more than 40% fly ash. Inclusion of SAP in the form of presoaked gel enhanced the workability even better. The problem of segregation was also overcome with the inclusion of SAP.

3.2. Compressive strength development over time

The compressive strength of water cured SCC and ambient cured SCSCC samples at 7, 28, 56, 90 and 180 days are given in figure. It was found that, the compressive strength of concrete decreased with the inclusion of fly ash. The strength gradually increased over time. The inclusion of SAP decreased the compressive strength. SAP incorporated samples, though cured at ambient conditions, developed compressive strength throughout the period of 180 days. Air cured specimens with 30% fly ash behaved similar to water cured specimens with 45% fly ash. Though the SCSCC specimens showed lesser compressive strength, the percentage strength gain from 7 to 28 days was higher than that of water cured SCC specimens. The rate of increase was higher till the addition of fly ash was 40% and further increase in fly ash decreased the strength gain. At 180 days, the rate of strength gain was similar to water cured SCC specimens till the addition of fly ash was 35% and then showed a gradual increase of strength gain for all the mixes. This may be due to the fact that at early ages, fly ash hinders the hydration reaction and the voids due to the presence of SAP increases the porosity and thus the reduction in strength. At later ages, the water in excess contributes to pozzolanic reaction and increase in strength was observed for mixes with fly ash. The compressive strength development over the period of 180 days is shown in Figure 1.

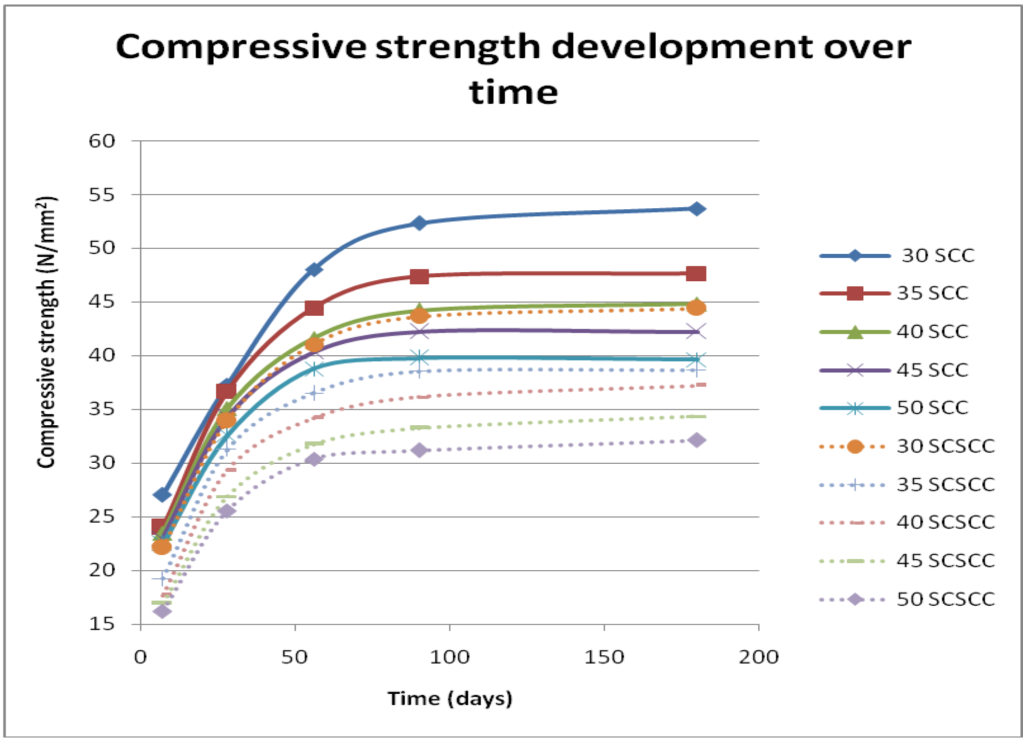

Figure 1 Compressive Strength Development over Time

3.3. Rapid chloride penetration test

The results show that, chloride ingress in self cured SCSCC specimens at 28 days was much higher than water cured SCC specimens. Also the resistance to chloride has decreased with increase in fly ash. At 90 and 180 days, the resistance of SCSCC specimens has been gradually increased and was better than water cured SCC. Concrete mix with 30% fly ash showed highest resistance among all the mixes. Though the RCPT values have increased with increase in fly ash content, specimens with 40% fly ash showed a reduction in the charge passed at 90 and 180 days. Also a strong correlation between compressive strength and charge passed was observed with an R^2 value of 0.819 and depicted in figure 2.

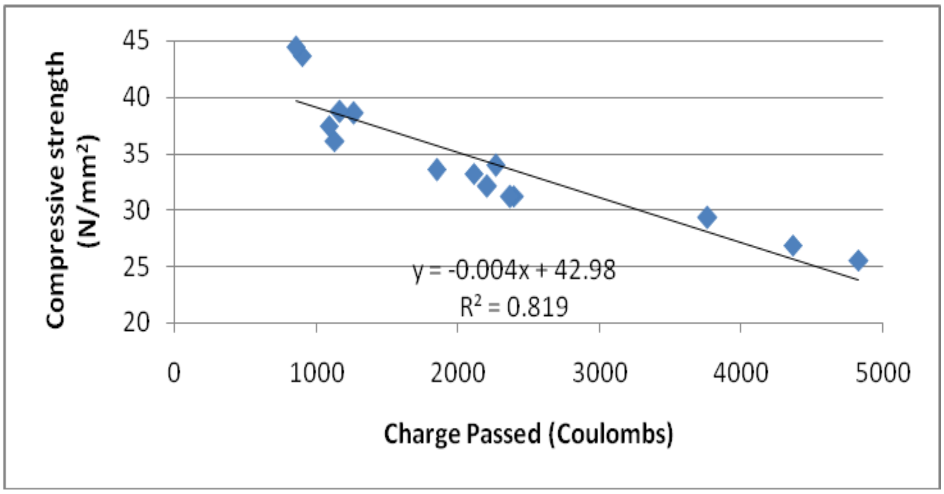

Figure 2 Relationship between compressive strength and charge passed

3.4. Change in compressive strength on exposure to chloride solution

On exposure to chloride solution, the change in strength was significantly different from that of normal concrete. A little degradation in strength was observed at all ages but no changes in appearance were observed even at 180 days. Considering the strength gain over time, there was decrease in percentage of strength gain after 28 days for water cured and air cured specimens. An interesting phenomenon was observed for SCSCC mixes with fly ash more than 40%. The specimens showed a tendency to increase in strength after 28 days, whereas water cured specimens with same dosage of fly ash showed a steep decrease in percentage strength gain. This is attributed to lesser number of available chloride binding sites in the densified concrete matrix due to improved pozzolanic reaction resulting from higher percentage of fly ash and the optimum quantity of provided internal curing water. The compressive strength at 28 days and the percentage of strength gain from 7 to 28 days is given in figure 3. Also the compressive strength of samples at 180 days and the percentage of strength gain from 7 to 180 days is given in figure 4.

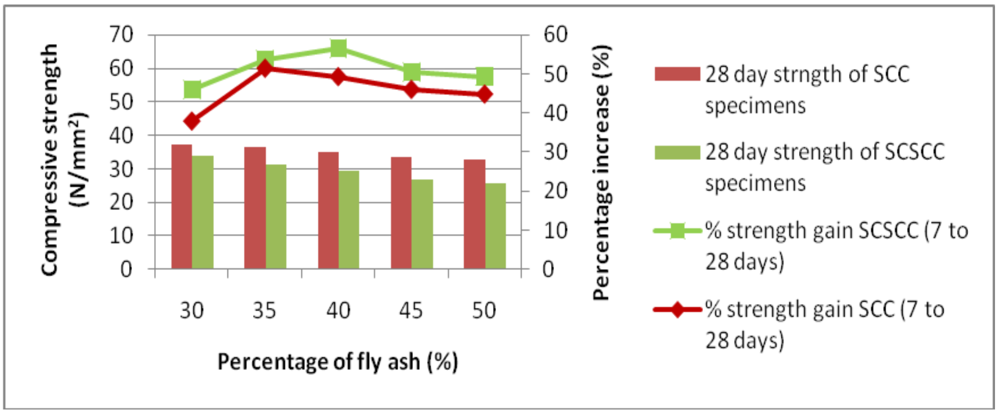

Figure 3 Compressive strength at 28 days & percentage increase from 7 to 28 days

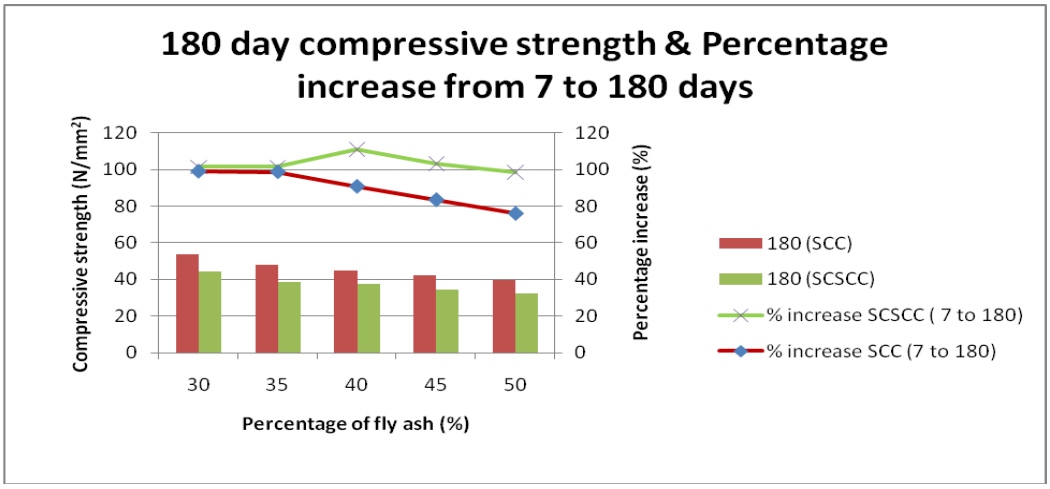

Figure 4. Compressive strength at 180 days & percentage increase from 7 to 180 days

3.3 Change in strength on exposure to chloride solution

Specimens immersed in chloride solution for 28 days showed an increase in strength. The strength decreased as the percentage of fly ash replacement was increased in conventionally cured SCC specimens. SCSCC specimens showed a similar trend but had a decrease in strength for mixes with 45% and 50% fly ash. At 90 days, there was a decrease in strength for both the cases but the difference was higher for SCC specimens than SCSCC specimens. Also the SCSCC specimens with 40 to 50% fly ash showed increase in strength. At 180 days, SCC specimens had a decreasing trend whereas SCSCC specimens with 40 to 50% fly ash showed increase in strength. The change in strength is shown in Figure 5 (a) and 5 (b)

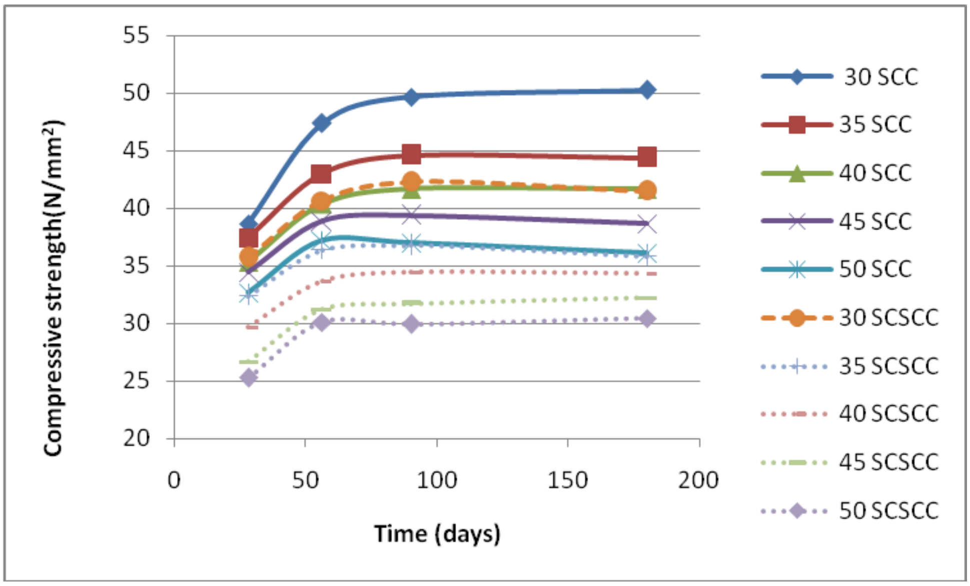

Figure 5 (a) Compressive strength after immersion in chloride solution

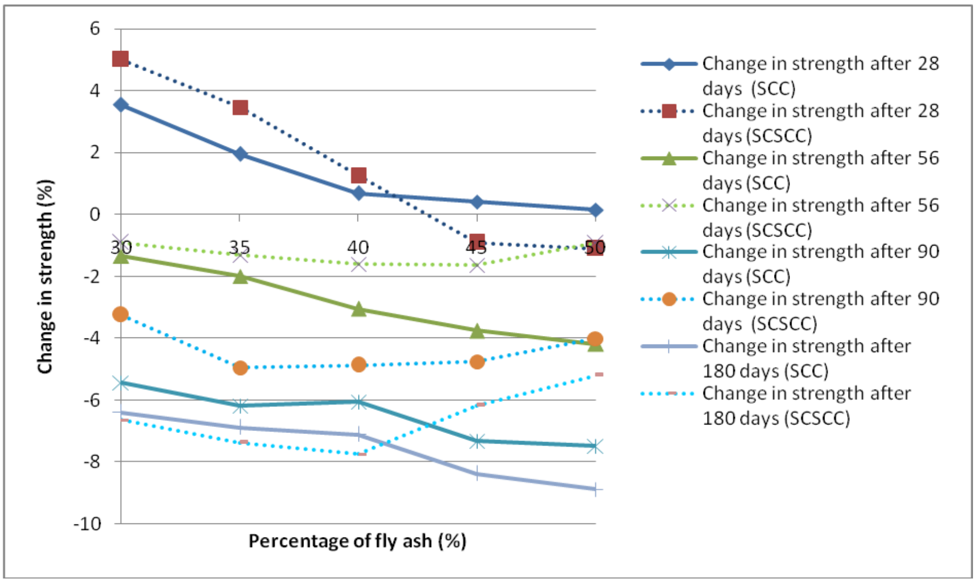

Figure 5(b) Change in strength after chloride exposure over time

3.4 Change in strength on exposure to sulphate solution

The compressive strength of concrete samples immersed in sodium sulphate solution was almost similar to that of normal concrete. The compressive strength of air cured SCSCC specimens was lesser at the age of 28 and 56 days and then increased thereafter. At 180 days, the strength of concrete with more than 40% fly ash increased tremendously. The rate of strength gain of SCSCC specimens cured in ambient conditions was also far better than water cured SCC specimens. The change in strength percentage is shown in Figure 6(a) and (b)

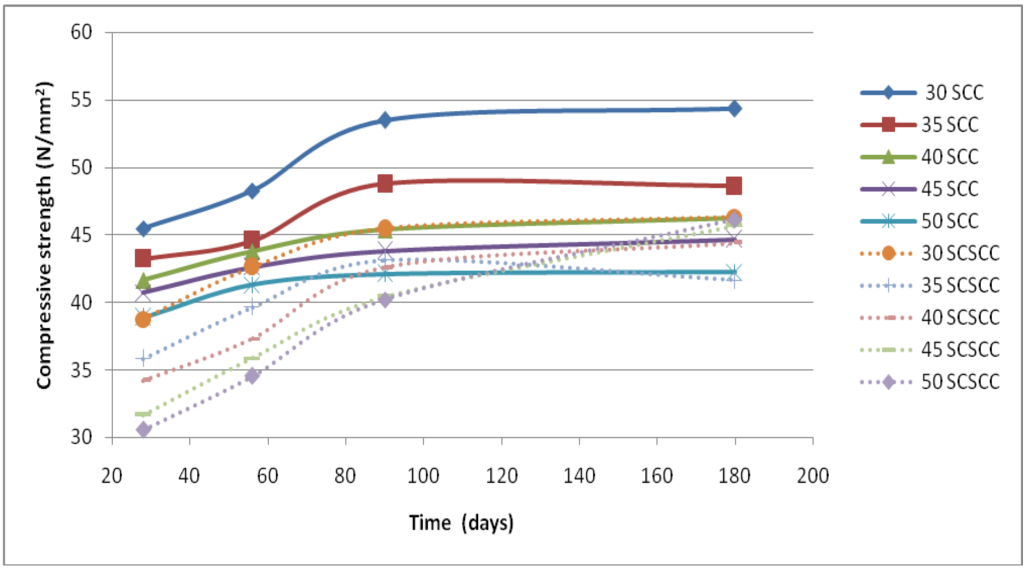

Figure 6(a).Compressive strength after immersion in sulphate solution

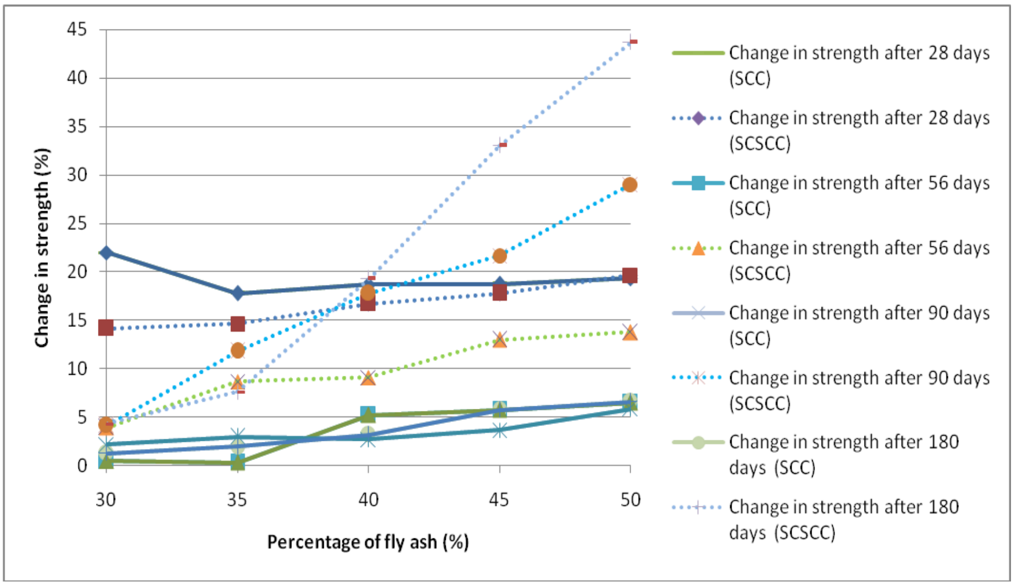

Figure 6(b) Change in strength on exposure to sulphate solution

3.5 Change in strength on exposure to acid solution

At 28 days, the SCSCC specimens showed a much higher decrease in strength for mixes with 45 and 50% fly ash replacement. However at 90 and 180 days the change in strength was lesser than that of SCC specimens. The strength decreased as the percentage of fly ash increased in both the cases. The change in strength is shown in Figure 7a and 7b.

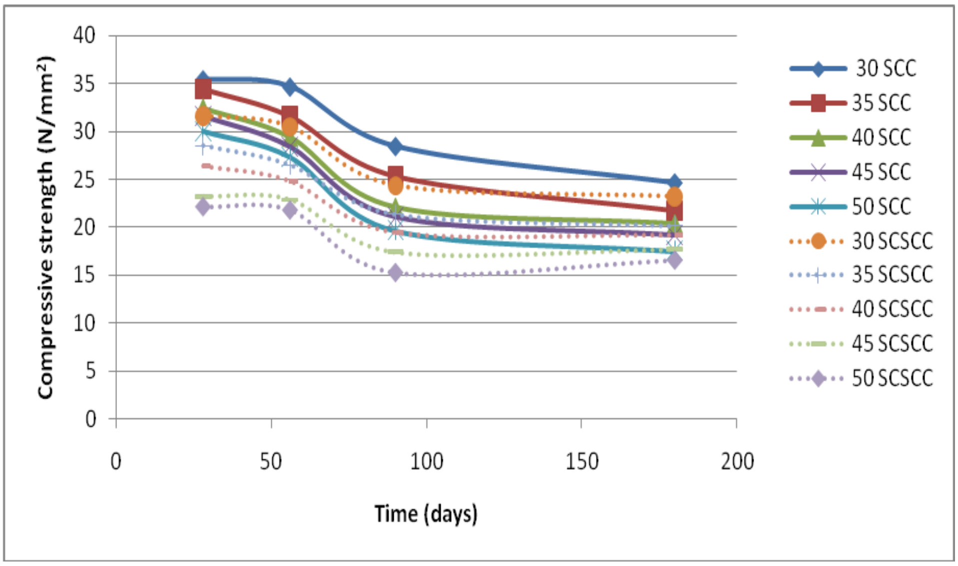

Figure 7(a) Compressive strength after immersion in acid solution

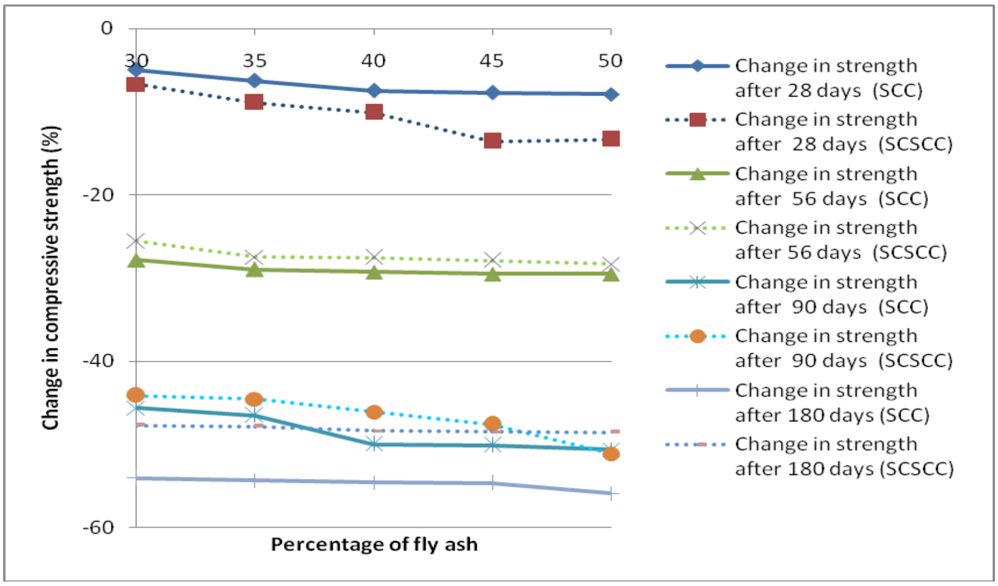

Figure 7 (b) Change in strength on exposure to acid solution over time

3.6 Change in mass after acid immersion

Decrease in mass was observed for all the water cured SCC specimens when immersed in acid solution. An interesting phenomenon was observed in SCSCC specimens at 28 days where there was an increase in mass for all the mixes invariably. The gain in mass was higher for the mix containing 50% fly ash replacement. At 90 and 180 days there was a decrease in mass however not greater than that of SCC specimens. Change in mass after acid immersion is shown in Figure 8.

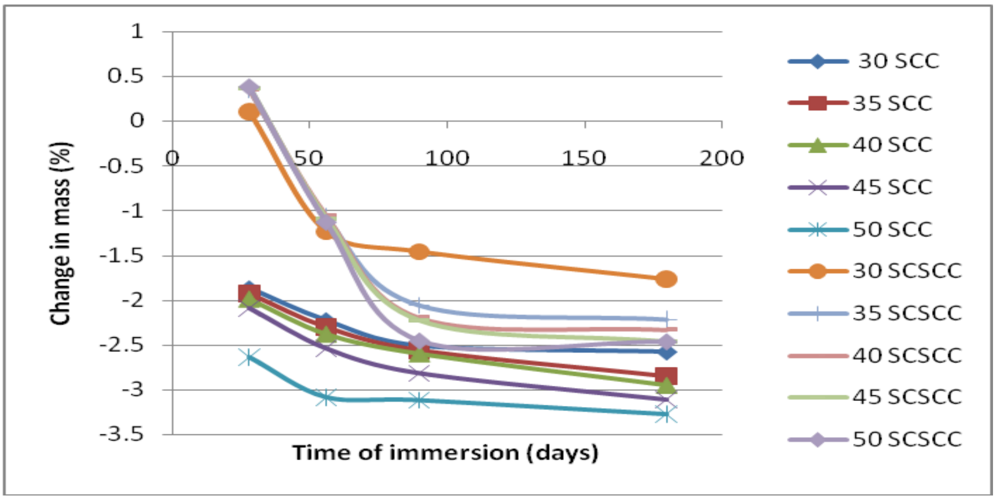

Figure 8 Change in mass after acid immersion

4. Conclusion

The following conclusions were arrived from the above experimental study:

- The benefits of internal curing can be obtained even in unsealed concrete specimens when fly ash was used as a supplementary cementitious material.
- The workability and passing ability of SCC got enhanced with the increase in fly ash content. Segregation was higher when the fly ash percentage was more than 40%. Super absorbent Polymer in the form of presoaked gel into SCC increased the filling ability, passing ability and segregation resistance to a greater extent.
- The compressive strength of SCC decreased with increase in fly ash content. Inclusion of SAP decreased the compressive strength when cured under unsealed ambient conditions. But a consistent gain of strength was observed even under ambient curing.
- The percentage of compressive strength gain was maximum for the mix with 40% fly ash cured in air. The strength gain increased with increase in fly ash content up to 40% and then slowly decreased.
- Chloride and sulphate exposure did not affect the air cured SCSCC specimens significantly. Also it is worthy to mention that, the rate of strength gain was greater for concrete with more than 40% replacement of fly ash.
- On exposure to acid solution the compressive strength of air cured concrete deteriorated up to 45% of its original strength against water cured SCC specimens had a strength loss of 55% at 180 days. Also the strength decreased with increase in fly ash content. A gain in mass was inferred at 28 days in air cured samples and after that a consistent loss of mass was observed. Water cured SCC specimens showed a consistent loss of mass throughout the test period. The visual appearance of specimens at various ages showed that, as the percentage of fly ash increased, the degradation of the specimen was more, since dissolution of paste

content was observed. When SAP was introduced in the mix the degradation was comparatively less and the specimens appeared denser even at later ages.

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