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Durability properties of high volume fly ash self compacting concretes

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ABSTRACT

This paper presents an experimental study on the durability properties of self compacting concretes (SCCs) with high volume replacements of fly ash. Eight fly ash self compacting concretes of various strength grades were designed at desired fly ash percentages of 0, 10, 30, 50, 70 and 85%, in comparison with five different mixtures of normal vibrated concretes (NCs) at equivalent strength grades. The durability properties were studied through the measurement of permeable voids, water absorption, acid attack and chloride permeation. The results indicated that the SCCs showed higher permeable voids and water absorption than the vibrated normal concretes of the same strength grades. However, in acid attack and chloride diffusion studies the high volume fly ash SCCs had significantly lower weight losses and chloride ion diffusion.

1. Introduction

One major challenge facing the civil engineering community is to execute projects in harmony with nature using the concept of sustainable development involving the use of high performance, environment friendly materials produced at reasonable cost. In the context of concrete, which is the predominant building material, it is necessary to identify less expensive cement substitutes. In recent years many researchers have established that the use of supplementary cementitious materials (SCM) like fly ash, blast furnace slag, silica fume, metakaolin, rice husk ash etc. can improve the various properties in fresh and hardened states of concrete, as well as curb the rise in construction costs. According to Mehta [1], the three fundamental elements for supporting an environmentally friendly concrete technology for sustainable development are the conservation of primary materials, the enhancement of the durability of concrete structures, and a holistic approach to the technology. Regarding the conservation of primary materials, reductions in the consumption of cement, aggregates and water, along with the use of waste materials and industrial by-products, are the principal actions to be taken in order to reduce the utilization of non-renewable resources and the negative impact on the environment. Along these lines, Malhotra [2] has demonstrated that high-volume fly ash concrete (HVFA) is one of the best value-added uses of a waste material.

Self compacting concrete (SCC) in general contains a large amount of powder materials, a superplasticizer and/or viscosity-modifying admixtures. The high powder content is often supplemented by mineral admixtures such as fly ash, slag etc. The use of mineral admixtures such as fly ash could increase the slump of the concrete mixture without increasing its cost. The use of fly ash also reduces the demand for cement, fine fillers and sand that are required in SCC [3]. Moreover, the incorporation of fly ash also eliminates the need for viscosity-enhancing chemical admixtures. The lower water content of the concrete leads to higher durability, in addition to better mechanical integrity of the structure. Also, the use of fly ash improves rheological properties and reduces thermally-induced cracking of concrete due to the reduction in the overall heat of hydration. It was reported that replacement of cement by about 30% fly ash helped in achieving improved rheological properties and super flowing concretes [4,5]. Researchers also attempted to produce high-volume fly ash (HVFA) SCCs by replacing up to 60% of Portland cement with class F fly ash, achieving a strength of about 40 MPa [6]. In order to extend the general concept of HVFA concrete and its applications to a wider range of infrastructure construction, this paper outlines the results of a research project aimed at producing and evaluating the durability performance of SCCs incorporating high volumes of class F fly ash. The main objective of the present investigation was to study the strength and durability performance of self compacting concretes over a wide range of concrete strengths with varying dosages of fly ash. The durability properties were investigated through micro-structure related properties of concrete, such as, permeability, water absorption, and chloride diffusion and also through chemical attack.

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2. Experimental investigations

2.1. Materials

Ordinary Portland cement (similar to ASTM Type I) conforming to the requirements of IS:12269 (53 grade) was used. Fly ash meeting the requirements of ASTM C 618 (Class F) was used. The characteristics of cement and fly ash are presented in Table 1. Crushed granite with maximum grain size of 12 mm for SCC and 20 mm for normally vibrated concrete (NC) and a good quality well graded river sand were used as coarse and fine aggregates, respectively. The coarse and fine aggregates had a specific gravities of 2.68 and 2.65, respectively. The high range water reducer (HRWR) used in this study was a commercially available sulphonated naphthalene formaldehyde (SNF) condensate.

2.2. Mix design

In the present investigation eight different self compacting fly ash concretes were designed at varying fly ash dosages. The methodology of mix design was explained in detail elsewhere [7]. In addition five different normal vibrated concretes were also designed. The details of concretes of different strengths with the different percentages of replacement are given in Table 2. To develop a comprehensive understanding, a wide spectrum of concrete strengths were taken (from 20 to 100 MPa) with fly ash replacements also ranging from 0 to 85%, depending upon the maximum replacements possible at any strength. The advantage of this methodology is that at higher replacement percentages the self compacting concretes are more economical. However, this would require specific adjustments to all the other ingredients like sand, coarse aggregate, superplasticizers and water, to arrive at an optimal mix proportion.

2.3. Mixing, demoulding and curing

Thorough mixing and adequate curing are most essential for achieving a good self compacting concrete. In the laboratory the concrete was mixed in a pan mixer of 100 l capacity. The mixing time was kept to about 3–4 min for normal concretes. It was increased to about 5–6 min for self compacting concretes made with superplasticizers for realizing the complete potential of the superplasticizer.

Generally, the demoulding was done between 12 and 24 h of casting. There were no problems in demoulding for concretes up to 30% replacement of cement by fly ash after 12–24 h. For fly ash replacements 50% and above, problems like material sticking to the mould and loss in edges and corners were noticed, if the demoulding was done between 12 and 24 h period. After a few trials, it was found that the demoulding had to start only

Table 1
Characteristics of cement and fly ash

Chemical composition	Cement	Fly ash
Silica (SiO_2)	21.78	58.29
Alumina (Al_2O_3)	6.56	31.74
Ferric oxide (Fe_2O_3)	4.13	5.86
Calcium oxide (CaO)	60.12	1.97
Magnesium oxide (MgO)	2.08	0.14
Sodium oxide (Na_2O)	0.36	0.76
Potassium oxide (K_2O)	0.42	0.76
Sulphuric anhydride (SO_3)	2.16	0.15
Loss on ignition (LOI)	2.39	0.31
Blaine (m^2/kg)	307	350
Specific gravity	3.15	2.10

Table 2
Mix details, fresh and strength properties of the concretes developed

No	Concrete grade(MPa)	Concretename	TCM(p)kg/m^3	Fly ash (%)	Cement kg/m^3	Total Aggregate kg/m^3	w/p ratio	HRWR liquid weight (%)	Fresh properties				Compressive strength (MPa)		
									Slump /Slump flow(mm)	J-ring flow (mm)	J-ring (h2–h1) (mm)	V-funnel flow time(s)	28 days	90 days	180 days
1	20	NC20	234	0	234	1874	0.79	0	75	–	–	–	29.0	35.6	38.85
2		SCC558	550	85	83	1418	0.41	2	800	750	0	6	14.64	22.07	27.74
3	30	NC30	319	0	319	1681	0.58	0	30	–	–	–	43	44.5	45.0
4		SCC557	550	70	165	1491	0.34	2	800	740	3	5	34.9	45.52	57.25
5		SCC757	750	70	225	1107	0.33	2	800	755	0	6	34.83	44.96	55.81
6	60	NC60	500	0	500	1462	0.37	0	45	–	–	–	74	76	76
7		SCC555	550	50	275	1571	0.34	2.5	770	720	5	11	57.9	66.72	79.50
8		SCC655	650	50	325	1388	0.34	2	800	745	0	7	50.07	60.63	72.05
9	90	NC90	552	0	552	1465	0.29	1	90	–	–	–	78.00	80	84
10		SCC553	550	30	385	1663	0.31	2.5	680	630	10	12	77.08	91.95	103.25
11		SCC530	500	30	350	1608	0.36	1.75	630	570	9	10	71.62	75.26	89.53
12	100	NC100	659	0	659	1334	0.22	1	120	–	–	–	87	86	88
13		SCC551	550	10	495	1718	0.29	3	560	505	15	15	86.41	90.75	102.5

after 3 days for self compacting fly ash concretes above 50% replacement level. For 85% replacement, the demoulding started only after 6 days.

In general, potable water was used for curing all the concretes. All the concretes were kept in moist environment immediately after the initial set and before the demoulding. Self compacting fly ash concretes up to 30% replacement were kept in water immediately after demoulding. However, for concretes above 50% replacement the immersion curing was adopted only after 7 days of moist curing.

2.4. Properties of fresh concrete

In the present study, the slump flow, V-funnel and J-ring tests are used for evaluating the flowability and passing ability of the concrete. Broken split tensile test specimens were used for evaluating the segregation and uniformity in the distribution of the aggregates.

3. Test program

3.1. Compressive strength studies

The compressive loading tests on concretes were carried out on a compression testing machine of capacity 2000 kN. For the compressive strength test, a loading rate of 2.5 kN/s was applied as per IS: 516–1959. The specimen used was 100 mm cube. The test was performed at 28, 90 and 180 days. The specimens were tested immediately after taking the cubes from curing tank in wet condition.

3.2. Permeable voids and water absorption studies

It is a usual practice to assess the water permeability characteristics when assessing the durability characteristics. Permeability can be measured by conducting water permeability test as per standards, percentage of water absorption test and initial surface absorption test. In the present investigation, percentage of water absorption and percentage of permeable voids were determined as per the procedure given in ASTM 642–82 [8]. The absorption and permeable voids were determined on two 100 mm cubes. Saturated surface dry cubes were kept in a hot air oven at 105 °C till a constant weight was attained. The ratio of the difference between the mass of saturated surface dry specimen and the mass of the oven dried specimen at 105 °C to the volume of the specimen (1000 ml) gives the permeable voids in percentage as given below:

$$\text{Permeable voids} = [(A - B)/V] \times 100 \quad (1)$$

where A = weight of surface dried saturated sample after 90 days immersion period. B = weight of oven dried sample in air. V = Volume of sample (considered as 1000 ml).

The oven dried cubes after attaining constant weight, were then immersed in water and the weight gain was measured at regular intervals until a constant weight was reached. The absorption at 30 min (initial surface absorption) and final absorption (at a point when the difference between two consecutive weights at 12 h interval was almost negligible) was determined. The final absorption in all cases was determined at 96 h. The absorption characteristics indirectly represent the volume of pores and their connectivity.

3.3. Acid attack studies

The chemical resistance of the concretes was studied through chemical attack by immersing them in an acid solution. After 90 days period of curing the specimens were removed from the curing tank and their surfaces were cleaned with a soft nylon brush to remove weak reaction products and loose materials from the specimen. The initial weights were measured and the specimens were identified with numbered plastic tokens that were tied around them. The specimens were immersed in 3% H_2SO_4 solution and the pH (~4) was maintained constant throughout. The solution was replaced at regular intervals to maintain constant concentration throughout the test period. The mass of specimens were measured at regular intervals up to 90 days, and the mass losses were determined.

3.4. Chloride permeability test

The chloride permeability test was conducted to assess the concrete quality as per ASTM C 1202 [9]. For this test 100 $\phi \times 50$ mm length specimens were used. A potential difference of 60 V DC was maintained across the specimen. One of the surfaces was in contact in a sodium chloride solution (NaCl) and the other with a sodium hydroxide solution (NaOH). The total charge passing through in 6 h was measured, indicating the degree of resistance of the specimen to chloride ion penetration. In addition resistivity or conductivity can also be determined from the initial current reading, since the resistance of the disk can be calculated immediately from Ohm's law:

$$R = V/I \quad (2)$$

where R is resistance, V is voltage, and I is current. The resistivity is determined from:

$$\text{Resistivity} = RA/l \quad (3)$$

where A is area of the disk, and l is thickness of the disk.

Table 3
Durability properties of the concretes investigated

No	Name	30 Min.Abs. (%)	Final Abs.(96 h)(%)	Permeable voids (%)	Weight loss in acid attack (90 days)	Chloride permeability results		
						Initial current (mA)	Resistivity at 60 V (Ω m)	Total charge (coulombs)
1	NC20	0.86	4.92	12.7	−25.73	121.2	77.76	3413
2	SCC558	2.51	8.84	16.7	−4.31	43.5	216.67	1424
3	NC30	1.23	4.93	13.3	−15.19	102.4	91.89	2983
4	SCC557	0.83	4.91	17.1	−1.37	16.5	569.91	352
5	SCC757	1.49	4.12	15.8	−11.09	20.5	458.44	500
6	NC60	0.86	2.98	11.1	−23.12	71.7	130.31	1688
7	SCC555	1.30	4.61	15.5	−23.26	29.4	320.28	659
8	SCC655	1.19	4.06	15.8	−38.90	28.5	329.70	740
9	NC90	0.55	1.68	8.5	−24.16	42.5	221.37	1008
10	SCC553	1.21	4.69	12.6	−37.86	20.8	452.16	737
11	SCC530	0.78	4.33	12.8	−57.29	27.7	339.12	629
12	NC120	0.69	2.15	7.6	−23.35	52.1	180.55	1115

4. Results and discussion

4.1. Properties of fresh concrete

The results of fresh properties of all self compacting fly ash concretes are included in Table 1. The table shows the properties such as slump flow, J-ring flow, J-ring height differences and V-funnel flow times. In terms of slump flow all SCCs exhibited satisfactory slump flows in the range of 550–800 mm, which is an indication of a good deformability. High strength concretes have shown lower and low strength concretes showed higher slump flows. Similarly in V-funnel test all SCCs showed flow time values in the range of 5–15 s. Both the slump flow values and the V-funnel flow times are in good agreement to that of the values given by European guidelines [10] for range of applications and for different viscosity classes. In J-ring test SCCs exhibited the difference in heights of the concrete inside and outside of the ring in the range of 0–15 mm. It was also observed that the difference of values between the slump flow without and with J-ring ring was observed to be around 50–60 mm, which is in good agreement of the value of 50 mm as suggested earlier by Reinhardt [11].

4.2. Compressive strength studies

The compressive strength results presented in Table 1 are the average values for 3 specimens. In the case of 20 MPa grade concrete, self compacting fly ash concrete at 85% replacement of fly ash (SCC558) showed lower strengths at all ages compared to normal concrete. However, SCC558 reached its design strength at 90 days. In 30 MPa concretes even at 70% replacement the strength gain rate of SCC was almost similar to that of normal concrete. At the 70% replacement level, both the self compacting fly ash concretes obtained their designed target strength of 30 MPa at 28 days and both were performing similarly. However, at 180 days, the strengths obtained for SCCs were greater than the normal vibrated concrete. The strength development of normal vibrated concrete almost came to a complete stop after 90 days, whereas the SCCs continued to gain strengths even after 90 days. In 60 MPa grade concrete, both the self compacting fly ash concretes achieved their design strengths at 90 days. Normal concrete had shown slightly higher strengths at all ages. At 180 days the strengths of both normal vibrated concrete and SCCs were comparable. In the case of high strength normal vibrated and self compacting fly ash concretes of 90 MPa and 100 MPa, it can be noticed that the normal vibrated concretes, even at 180 days, have not achieved their design strengths and the strength gain rate is comparatively low after 28 days for 90 MPa concrete whereas it was low from 7 days in case of 100 MPa concrete. But in the case of self compacting fly ash concretes the results indicate that there was continuous and significant improvement in strength beyond the age of 28 days. It was also observed that both the self compacting fly ash concretes designed for 90 and 100 MPa achieved their design strengths at 180 days.

4.3. Permeable voids and water absorption

The results of water absorption in 30 min (initial surface absorption) as well as the absorption after 96 h (final absorption) and the permeable voids for all the concretes are presented in Table 3. From these results it can be seen that the low strength concretes were showing higher absorption than high strength concretes. Fig. 1 presents the values of 30 min (initial) absorption of all the concretes. The initial absorption values of all the self compacting fly ash concretes were slightly higher than the normal vibrated concretes and the absorption increased with an increase in percentage of fly ash replacement. Fig. 1 also presents the recommendations given by Concrete Society (CEB, 1989) for absorption 30 min [12]. This shows that all the self compacting fly ash concretes as well as normal vibrated concretes had lower absorption than the limit specified for "good" concretes. The final absorption at the end of 96 h also followed a similar trend. The 20 MPa SCC (SCC558) showed the highest absorption (8.84%) than any other concrete. This may be due to the very high amount of fly ash (85%) in the system. Except 20 MPa SCC, the final absorption values of all the other grades of SCC (30–100 MPa) were similar, but these were always higher than the normal vibrated concretes at any particular strength. Except 20 MPa grade, the final absorption values of SCCs lie in the range 4.06–4.91%, whereas the corresponding normal vibrated concretes showed absorption values around 1.68–4.93%.

Water absorption is mainly influenced by the paste phase; primarily, it is dependent on the extent of interconnected capillary porosity in the paste. Concrete mixes with higher paste contents are bound to have higher absorption values than concretes with lower paste content (at consistent w/c). The lower water absorption thus observed for normal vibrated concretes is attributed to the relatively lower paste volume i.e., smaller capillary pore volume. It is noted that self compacting concretes with fly ash have higher water absorption. The increase in paste volume due to the lower specific gravity of fly ash contributes to an increased capillary pore volume and increased water absorption.

There exists a good correlation between the percentage of permeable voids and absorption (Fig. 2). As the permeable voids increase the absorption also increases correspondingly. From Fig. 2

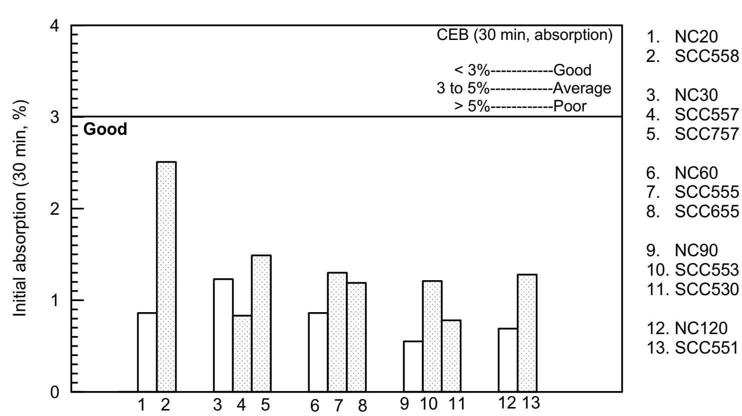

Fig. 1. Initial absorption values of the concretes investigated.

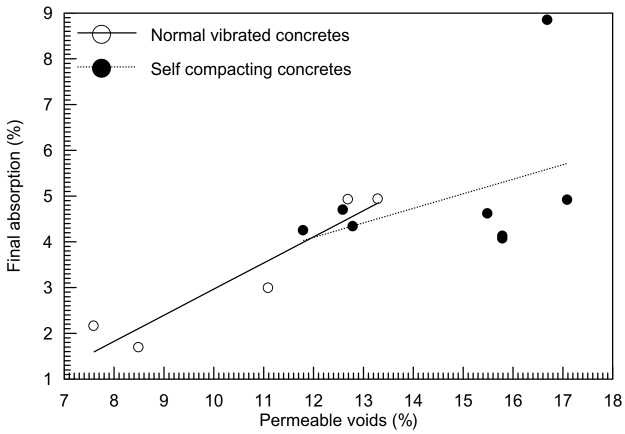

Fig. 2. Variation of final absorption with permeable voids.

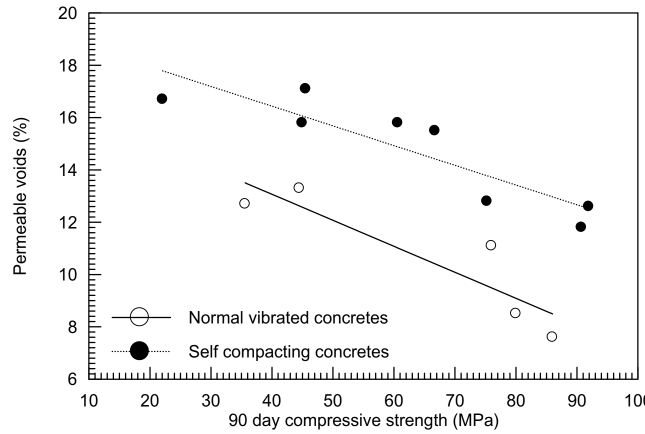

Fig. 4. Variation of permeable voids with compressive strength.

it can be observed that similar to absorption, the percentage permeable voids are also higher for self compacting fly ash concretes than normal vibrated concretes. Also, fly ash has a significant bearing on the permeable voids in the concretes. For all the SCCs, which were developed with high volume replacements of fly ash, the corresponding permeable voids were also found to be higher. This is well depicted in Fig. 3. This may be due to the high paste volumes (due to high replacements of fly ash), high water contents and high superplasticizer dosages adopted in producing self compacting concretes, which result in increased porosity. The relationships between the percentage of voids with 90 days strength, was shown in Fig. 4. It can be seen that the voids were decreasing with increasing compressive strength. There exists a linear relation between the two parameters, as shown in the figure.

4.4. Acid attack

The results of acid attack studies in terms of the weight loss after 90 days for all the concretes are reported in Table 3. It can be seen that in the concretes of lower strength (20 and 30 MPa) the weight loss decreased with increasing percentage of fly ash replacement. But concretes of higher strengths show a marginally higher weight loss particularly at higher exposure times. This was probably due to the fact that the acid attack as is known is primarily related to the actual cement contents in these concretes. In view of this the weight loss was studied in terms of the cement contents and the replacement percentages at this stage. The relationship between weight loss at 90 days and cement content is shown in Fig. 5. This shows that the weight loss due to acid attack increased up to a cement content of 400 kg/m^3, after which there was a marginal decrease. It can also be seen that both normal concretes (the experimental points with unfilled symbols) as well as the self compacting fly ash concretes (the experimental point with filling) have all been following the same trend. Obviously, the low strength concretes with low amount of cement show better resistance against acid attack. This could be due to the low amount of reaction compounds like $Ca(OH)_2$ at lower level of cement content for deterioration process. Similar conclusions were reported earlier by Fattuhi and Hughes [13]. They subjected cement paste and concrete to 2% H_2SO_4 attack in continuously flowing hydraulic channel for 50 days and assessed the performance using the weight loss with time. They concluded that the acid attack decreased with decrease in cement content. The 90 days weight loss with fly ash replacement percentage was also shown in Fig. 6. Evidently, the weight loss of self-compacting concrete decreased as the fly ash percentage increased (for levels of replacement >30%). At low replacement level, the behaviour was similar to normal concrete (without fly ash). This suggests that, at higher replacement levels of fly ash self-compacting concretes will result in superior concretes with higher resistance. Torri and Kawamura [14] also reported similar observations. They examined the effect of 2% H_2SO_4 solution on fly ash and silica fume mortars. Fly ash mortars with 70% replacement were studied for 3 years. They observed that the acid attack decreases with increase in fly ash replacement.

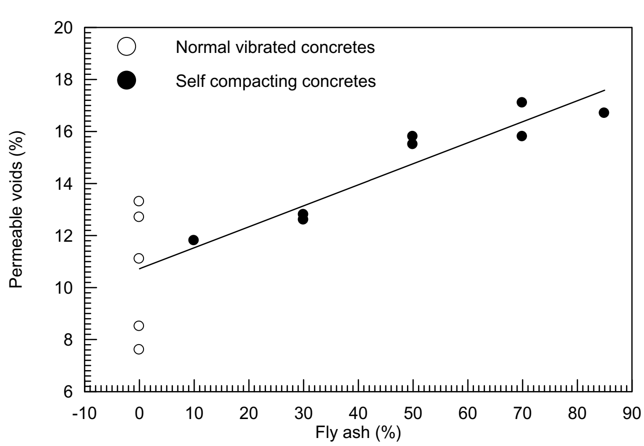

Fig. 3. Variation of permeable voids with fly ash replacement.

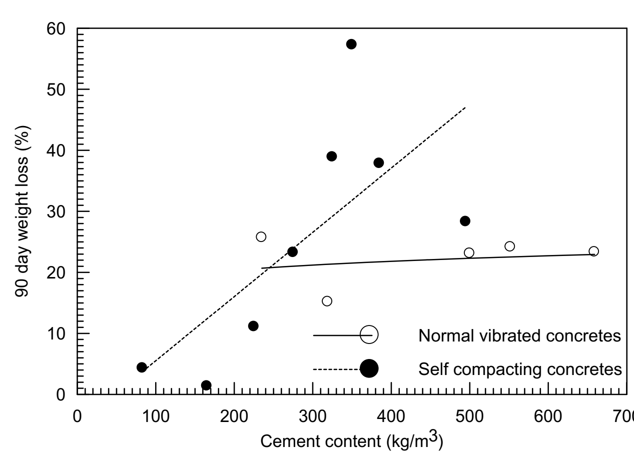

Fig. 5. Weight loss with cement content in acid attack test.

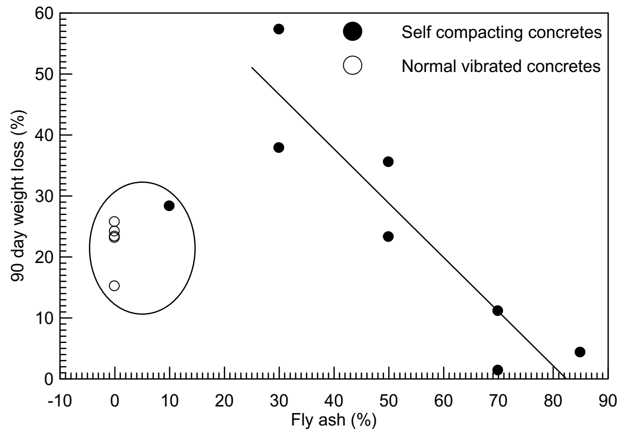

Fig. 6. Weight loss with fly ash replacement in acid attack test.

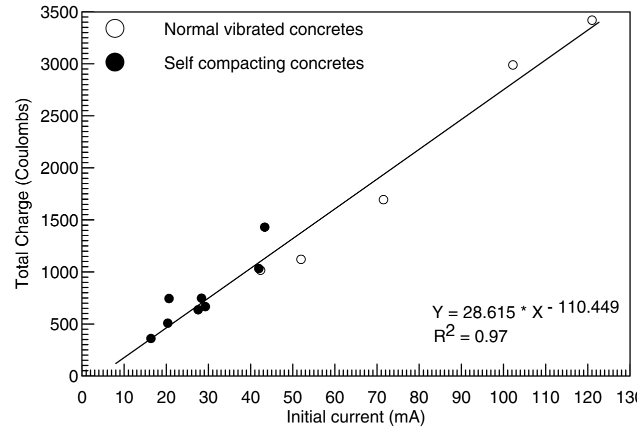

Fig. 8. Variation of charge with initial current.

4.5. Chloride permeability

Accelerated chloride permeability test was conducted on all the concretes. The results of all these are presented in Table 3. The total charge passing in 6 h as a measure of the chloride permeability is presented in Fig. 7. The chloride ion penetrability limits suggested by ASTM C1202 were compared with the results. It can be seen that (except 20 MPa SCC) all self compacting fly ash concretes showed less than 1000 Coulombs total charge passing and these were assessed as "very low" chloride permeability concretes as per ASTM C 1202–94 assessment criteria. The corresponding normal concretes showed values in the range 'low' to 'moderate' according to the assessment criteria. The chloride diffusion values obtained for self compacting concretes of grades 20, 30 and 60 MPa, which had high volumes of fly ash (85, 70 and 50%), were about 2 to 8 times less than the corresponding normal vibrated concretes. The higher grades 90 and 100 MPa which had fly ash replacements at 30 and 10% performed almost similar to normal vibrated concretes. This clearly indicates that the high volume fly ash self compacting concrete mixes performed much better with respect to chloride penetrability.

The resistivities calculated by considering the initial current at 60 V potential also followed a similar trend as the total charge. The self compacting fly ash concretes showed higher resistance compared to normal vibrated concrete and also the resistance increased with an increase in replacement percentage of fly ash. The relationships between the initial current and resistivity with the total charge are presented in Figs. 8 and 9, respectively. From the figures it can be seen that as initial current increases the total charge increases and with increased resistivity the total charge decreases.

The results of chloride permeability are contradictory to the results of other permeability related parameters. Self compacting fly ash concretes showed higher absorption and higher permeable voids compared to normal vibrated concretes. However, the same self compacting concretes, in the chloride permeability test, showed better performance. This could be due to the fact that the chloride ion penetration depends on the chloride binding capacity of the constituent materials. Usually chlorides penetrate in concrete by diffusion along water paths or open pores. Some of these chlorides can react with the cement compounds, mainly tricalcium-aluminates (C_3A), forming stable chloro complexes. The excess of chloride is free and leads to the initiation of the corrosion process. The presence of fly ash leads to an increase in the amount of C_3A due to the higher amount of alumina present in the mix and to an increase in the content of calcium silicate hydrate that is formed in the pozzolanic reactions. Thus, the chloride binding capacity of concrete tends to increase with fly ash addition and consequently less free chloride is available to initiate the corrosion process, as observed by Koulombi et al. [15]. This view is well supported by the data in Fig. 10. It can be clearly observed that the alumina content has a significant influence on the total charge of the concrete. As the alumina (Al_2O_3) content increases the total charge decreases. Self-compacting concretes with high volume replacements of fly ash (with high amounts of alumina contents) result in increased resistance against chloride ion penetration. Significant reduction of chloride diffusivity of self compacting concrete with fly ash was also reported earlier by Zhu and Bartos

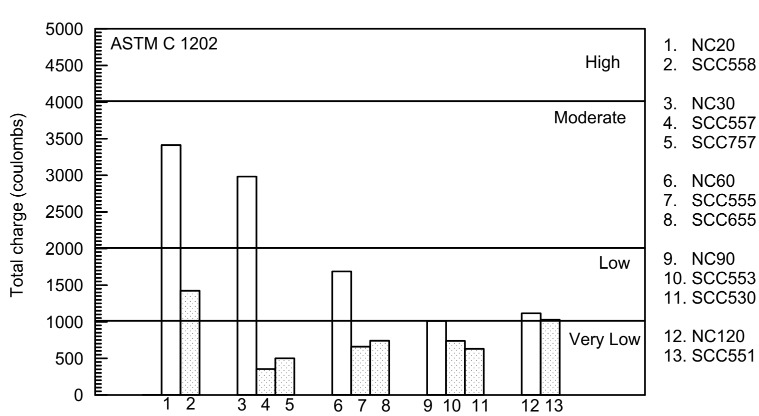

Fig. 7. Chloride permeability values of the concretes investigated.

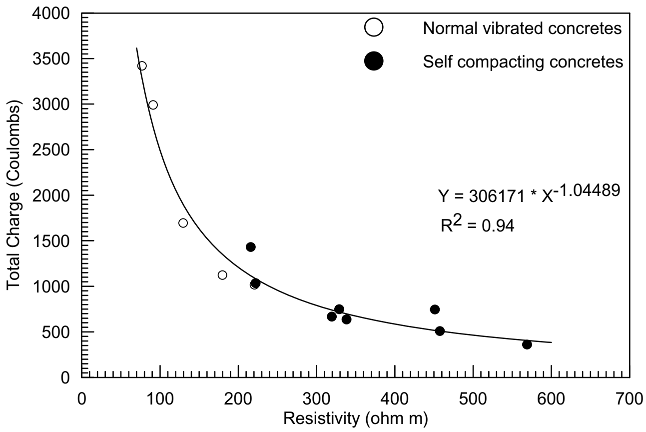

Fig. 9. Variation of charge with resistivity.

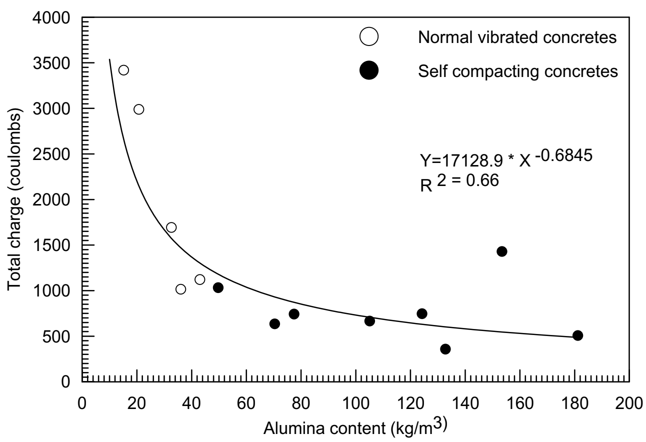

Fig. 10. Variation of charge with alumina (cement + fly ash) content.

[16]. The present results reveal that the amount of fly ash added to self compacting concrete should be chosen according to the environments where the structure will be exposed. Thus, in aggressive chloride environment, such as seacoast or structures where deicing salts are used, the addition of fly ash is beneficial.

5. Conclusions

1. All the high volume fly ash concretes have satisfied the norms that were set to qualify them as self compacting concretes and the fresh properties were in good agreement with the various consistency classes defined by European guidelines. [17] The developed self compacting concretes were highly segregation resistant and had good flowability and passing ability.
2. From the above studies it can be concluded that self compacting concretes of lower strength grades (20–30 MPa) can be produced at a fly ash replacement of about 70–85%, while higher strength grades of about 60–90 MPa can be produced with about 30–50% fly ash replacement.
3. The absorption characteristics, which indirectly reflect the permeability, show that the initial 30 min absorption values for all the concretes were lower than the limit specified for "good concrete" by Concrete Society (CEB, 1989). In self compacting fly ash concretes the maximum absorption observed was in the range of 4.06–4.91% (except 20 MPa concrete with 85% replacement) and the normal vibrated concretes concretes showed values in the range of 1.68–4.93%.
4. The permeable voids present in the concrete, indirectly representing the permeability, decreased with an increase in strength and increased with increase in fly ash dosage. The absorption decreased with a decrease in permeable voids. Self compacting fly ash concretes showed higher permeable voids compared to vibrated normal concretes of any strength grade.
5. The deterioration of concrete subjected to 3% H_2SO_4 solution showed that the weight loss significantly decreased with increasing fly ash replacement percentage in self compacting concretes. In particular, high volume fly ash self compacting concretes performed better than normal concretes. It was also found that the weight loss due to acid attack increased up to a cement content of 400 kg/m^3.
6. The high volume fly ash SCCs showed significantly lower chloride ion permeability than normal concretes. All the SCCs were assessed as "very low" chloride permeability concretes as per ASTM C 1202–94 assessment criteria, with less than 1000 coulombs of total charge passing.

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