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Investigation on Durability Properties of Self Compacting Concrete with Mineral Admixtures

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Abstract: ***Self-Compacting Concrete (SCC) or Self Consolidating Concrete is the present-day concrete that is being adopted the world over. The production of SCC involves the selection of appropriate materials and good quality control which is essential for the durability of concrete. The mineral admixtures and filler materials provide additional reduction to the porosity of the concrete. The primary objective of the present research work is to carry out the experimental investigations on durability properties of SCC with 20 different mix proportions, containing various percentages of filler materials like Limestone Powder (LP) and Marble Powder (MP), along with the mineral admixtures like Fly ash (F) and Silica Fume (SF). Experimental investigation on the durability properties for all the 20 mixes of SCC was carried out by conducting the Rapid Chloride Penetration Test (RCPT), Saturated Water Absorption Test, Acid Resistance Test, Sulphate Resistance Test, Water Permeability Test and Salt Water Resistance Test. From the experimental study, it is observed that the SCC mix with equal proportions F (10%), SF (10%), LP (10%) and MP (10%), exhibit better performance than the control mix in terms of strength and durability characteristics and thus it is concluded that the addition of mineral admixtures and filler materials have a pivotal role in the development of strength and durability aspects of SCC.***

Keywords: SCC, Durability Properties, Mineral Admixtures, Filler Materials, Limestone Powder, Marble Powder.

I. INTRODUCTION

Self- Compacting Concrete (SCC) is a flowing concrete mixture that can consolidate under its weight. The highly fluid nature of SCC makes it suitable for placing in difficult conditions and sections with congested reinforcements. The development of Self Compacting Concrete (SCC) is an important achievement in the construction industry for overcoming problems associated with conventional concrete. SCC is the improvised concrete that partly replaces the Ordinary Portland Cement (OPC) with suitable mineral admixtures and filler materials and yet retains qualities of the conventional cement concrete. SCC is segregation proof, able to flow and fill the remotest areas of the formwork, cover all the reinforced sections without any voids or honeycombs and it is good enough to fill areas from considerable heights. Apart from enhanced durability properties of SCC, the homogenous and uniform distribution of constituent's materials of SCC is its pleasing aspects.

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The high deformability of SCC and the elimination of vibration during compaction offer substantial benefits to the quality of concrete structures and in the construction process.

The noise associated with mass concreting conventionally is eliminated. In Self Compacting Concrete the costs of vibration for compaction and the additional labour involved are less when compared to the conventional concrete. It also reduces construction time. Saving in labour cost might offset the increased cost due to chemical admixtures, but the use of freely available mineral admixtures could balance the excess demand for cement which results in cost saving. Thus, the total construction cost can be reduced for large-scale structures.

II. LITERATURE REVIEW

Various mineral admixtures like fly ash, GGBS, metakaolin, silica fume which are freely available as waste material can be effectively used in Self Compacting Concrete without compromising the strength and durability properties of the concrete. A suitable mix design with various mineral admixtures for Self-Compacting Concrete needs to be developed to take this alternate concrete to the construction field and to make use of this new concrete for all kind of construction works. Significant research works are not seen on the durability aspects of SCC and the behaviour of SCC structural elements. From the review, it is also observed that there are no experimental and analytical studies available on the performance of SCC structural elements which are made from mineral admixtures and filler materials in combinations. There are only limited works done on the development of the analytical model for predicting the mix proportion and compressive strength of SCC. [1] attempted to exclusively study the rheological properties of the Self Compacting Concrete. Special emphasis has been made on the observation of curing time and early hardened state of the SCC in comparison with normal concrete, regarding durability. In this study, water permeability has been studied in detail to know the durability of SCC. Three mixes were made SCC and two for normal concrete and curing was carried out in two different ways such as air cooling and under-water curing for the period of 7, 14, 28 and 56 days. The comparison was based on flux decay as a function of time. The effects of different curing conditions and the curing at different ages were evaluated. Flux in SCC has been compared with normal concrete. There has been increased durability and productivity.

[2] studied the drying shrinkage of the concrete structures as it accounts for the major failures of the concrete structures. This is because contraction of the material is opposed by internal or external resistance which resulted in the development of tensile stress which when exceeds the normal concrete tensile strength leads to the development of cracks.

This aspect of drying and cracking is studied by the team in the Self- Compacting Concrete made by partial replacement of Portland cement by the binary, ternary and quaternary blends consisting of cement, Fly ash (F), Ground Granulated Blast Furnace Slag (GGBFS), Silica Fume (SF) and Metakaolin (MK). The team prepared as many as sixty-five different SCC mixtures keeping at two different water/binder ratios 0.32 and 0.44. It was concluded that the addition of SF had a positive effect on drying shrinkage than other mineral admixtures. [4] tried five different mix proportions of SCC with class F fly ash (15% to 35%). The self-compatibility parameters were investigated like J-ring, L-Box, U-Box and slump flow, strength properties like compressive strength and split-tensile strength and durability properties like deicing salt surface scaling, carbonation and rapid chloride penetration resistance. Carbonation depth increased with increase in the age and the pH value for all the mixes above 11. Generally, the weight loss was almost consistent at 365 days age for all percentage of fly ash in the SCC. It was established that the SCC mixed with fly ash exhibited very low chloride permeability resistance at the ages of 90 and 365 days. [3] tested SCC specimens for fresh and hardened concrete properties which could be compared with M25 grade concrete. Proposed five SCC mixes were prepared with a replacement percentage of fly ash with cement in the range of 15% to 55%. Maximum strength was observed for the mix with 15% fly ash replacement, which was higher than the all other mixes. It was reported that the SCC mixes showed better durability performance than the conventional concrete. [6] conducted experiments to study the combined effect of Marble Sludge Powder (MSP) and Crushed Rock Dust (CRD) on the mechanical properties such as compressive strength, split tensile strength and durability properties such as water absorption, water permeability, rapid chloride permeability; electrical resistivity and half-cell potential of Self Compacting Concrete. MSP or CRD is just a dump in the fields that spoils the fertility. If these two materials could be admixtures for SCC, then the total voids content in the concrete gets reduced to improved workability. The addition of MSP up to 15% and replacement of F by CRD in the SCC resulted in the augmentation of the compressive strength properties. The experimentation showed that split tensile strength is directly proportional to the compressive strength. For a given water/powder ratio, MSP reduced the viscosity of the SCC and further increased the segregation resistance of the concrete if it formed 15% of the mixture. It is recommended that the replacement of natural sand with 85% of CRD and 15% of MSP will yield better mechanical, physical and durability properties. The team has compiled a ready reckoner for arriving at the amount of MSP and CRD for a cubic meter of SCC. [5] experimented the three durability indicators such as sorptivity, porosity and chloride ion penetration. The research team has used variable fillers (limestone powder and silica fume) for the SCC and compared the test results with those made out of conventional concrete. The team has also exposed a fact that there exists a linear correlation between the three durability indicators for the particular additive used in the SCC mixture. It was concluded that the added filler materials improved the durability potential of the mixture due to pozzolanic reaction which significantly improves the packing of particles within the microstructure. The different additives in the SCC will play a role in the microstructure of the concrete and accordingly the linear correlations between all three durability indicators [7] examined the sorptivity and chloride ion penetration of SCC. The SCC has both excellent deformability and segregation resistance. SCC generally requires a large amount of binder and chemical admixtures than the normal concrete. This spells cost implication and which is put at 20-50% higher. However, incorporating higher volumes of mineral admixtures and micro fillers in the SCC can reduce the cost. But the durability performance of the SCC has to be established. In this study, they made use of silica fume (SF) as an active filler and quarry dust (QD) as an inert filler. The SCC with SF and QD were separately made for fresh concrete and hardened concrete tests. The pozzolanic filler increased the mechanical and durability properties of the SCC. [8] attempted to make use of cement, fly ash, manufactured sand and coarse aggregate as the main ingredient in Self-Compacting Concrete (SCC). The fresh concrete tests done on such SCC have yielded results acceptable to the EFNARC (2005) standards. Similarly, performance studies of water absorption, sorptivity, sulphate resistance, shrinkage and rapid chloride penetration tests on all the mixes of SCC were carried out and it revealed reasonable results. Physiochemical studies such as absorption, diffusion and permeability were conducted and they confirmed the standards set in the French Association of Civil Engineering. It was opined by the team that the SCC with manufactured sand and fly ash will serve the construction sector in all its applications [9] compared the effects of the partial replacement of Portland cement by High- Volume Natural Pozzolan (HVNP) and High Volume Class F Fly Ash (HVFAF) on strength and durability properties of Self Compacting Concrete. Relevant to the study, Limestone (LS) was also used in replacing Portland cement along with HVNP or HVFAF to examine the ternary blends. Non-steady state chloride migration test and permeability tests were conducted along with compressive strength tests as they indicated the durability of the SCC. Two index points were selected namely, concretes with one 100% Portland cement and another with 85% Portland cement with 15% LS. The SCC made out of HVNP and HVFAF blends exhibited strength and durability comparable with those of the selected indicator concretes. From the test results, it was reported that low-cost and environment-friendly concrete could be made out of HVNP and HVFAF.

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[10] studied the different durability properties of SCC prepared with different amounts of fly ash, limestone powder and metakaolin. In all the six mix proportions formulated, by keeping the water/binder ratio constant at 0.41 and superplasticizer of 1% by weight of cement. Initial surface absorption test [ISAT] and capillary suction test were determined to arrive at the compressive strength and durability properties. It was seen that the durability properties were very much dependent on the addition of mineral admixtures.

Metakaolin attributed to the permeability resistance, coupled with strength and absorption.

[11] experimented with sorptivity aspects of SCC prepared with fly ash, silica fume and limestone powder. It was seen that a combination of silica fume and fly ash in SCC could absorb less surface water at a water/binder ratio of 0.38. This contrasted with the sorptivity if fly ash alone is used in the SCC, which is about 20% fly ash. The SCC with the combination of silica fume and fly ash yields good cube strength at 28 days and produces less surface water absorption. It has been observed that the sorptivity does not correlate with the compressive strength.

III. RESEARCH SIGNIFICANCE

To keep the concrete more cohesive and achieve high flowability, a proper design of Self Compacting Concrete possesses high powder content when compared to the conventional concrete. Use of high volume of cement remarkably increases the cost of the concrete and also it is more vulnerable to drying shrinkage. Hence, the SCC can be replaced for conventional concrete, but it should not be very expensive. One of the alternatives to overcome these drawbacks is to use industrial by-products or waste materials which are finely divided materials added to the concrete as partial replacement material in SCC. As these additives replace part of the OPC, the cost of SCC will be reduced. Addition of these materials will increase the workability, strength, and durability properties of SCC.

Utilizing the waste mineral admixtures and filler materials as the substitute for cement in SCC will fulfil the expectations of providing greater sustainability in the construction industry.

IV. SIGNIFICANCE OF DURABILITY STUDIES

The need for the present study arises from the requirement to improve the overall utilization of the mineral admixtures and filler materials in correct proportions in SCC particularly to structures in the aggressive environment depending upon the requirements. The effect of those mineral admixtures and filler materials towards the enhancement of the strength and durability of SCC needs to be researched. A simple mix design procedure is also needed to be developed for SCC with fly ash content. The main aim of this study is to investigate the durability properties for all 20 mixes by conducting various durability tests.

V. MATERIALS AND MIX PROPORTIONS

A. Materials Used

The basic components of the mix composition of SCC are the same as used in Normal Vibrated Concrete (NVC). However, to achieve the required rheological properties in the fresh state, a higher proportion of fine materials and the incorporation of Superplasticizers (SP) are needed. In this research work, the materials used were Ordinary Portland Cement (OPC), mineral admixtures such as Fly ash (F), Silica Fume (SF), filler materials such as Limestone Powder (LP) and Marble Powder (MP), fine aggregate, coarse aggregate, superplasticizer and water.

B. Mix Proportions

A total of 20 concrete mixes were designed having a constant water/binder ratio of 0.35, fine aggregate content of 1000 kg/m3, coarse aggregate content of 790 kg/m3 and total binder content of 520 kg/m3. Among the 20 mixes, one is the control mix with 60% OPC and 40% F content. The other 19 mixes were designed with varying quantities of F, SF, MP and LP but keeping the OPC constant at 60%. The percentage of SF, LP and MP were varied as, 5%, 10% and 15% by weight of F to get 9 mixes and the combinations of SF&LP, SF&MP and LP&MP showed variations as, 5%, 10% and 15% by weight of F resulting in another 9 mixes. A mix with 60% OPC and 10% SF, MP and LP each in place of F, was studied with specific importance. Since the specific surface area of different binders varies, the water requirements in SCC will not be the same for all types of binders (Kursat Esat Alyamaç et al 2009). Therefore, the requirement of Superplasticizer (SP) varies from 2.25% to 3.0% of the total binder content was adopted to improve the workability of SCC. The EFNARC (2005) guidelines and the arrived mix proportion for the control mix are listed in Table 5.1. The composition of binder contents and labelling of the SCC mixes are given in Table 5.2.

Table 5.1. EFNARC (2005) Specifications and the Arrived Mix Proportions

Constituents	EFNARC (2005) specifications		Mix proportion arrived
	Typical range by mass (kg/m3)	Typical range by volume (litres/m2)	
Powder	380-600	-	520 kg/m3
Paste		300-380	364 litres/m2
Water	150-210	150-210	182 kg/m3
Coarse aggregate	750-1000	270-360	790 kg/m3
Fine aggregate (sand)	Content balances the volume of the other constituents, typically by 48-55%		55% of the total weight of aggregate
Water/powder ratio in volume	-	0.85-1.10	1.10

Table 5.2. Binder Contents used in the Mixes of SCC

S.No	Mix ID	Binder Contents in %					W/b ratio
		OPC	F	SF	LP	MP	
1	CM	60	40	-	-	-	0.35
2	5SF	60	35	5	-	-	0.35
3	10SF	60	30	10	-	-	0.35
4	15SF	60	25	15	-	-	0.35
5	5LP	60	35	-	5	-	0.35
6	10LP	60	30	-	10	-	0.35
7	15LP	60	25	-	15	-	0.35
8	5MP	60	35	-	-	5	0.35
9	10MP	60	30	-	-	10	0.35
10	15MP	60	25	-	-	15	0.35
11	5SFLP	60	30	5	5	-	0.35
12	10SFLP	60	20	10	10	-	0.35
13	15SFLP	60	10	15	15	-	0.35
14	5SFMP	60	30	5	-	5	0.35
15	10SFMP	60	20	10	-	10	0.35
16	15SFMP	60	10	15	-	15	0.35
17	5LPMP	60	30	-	5	5	0.35
18	10LPMP	60	20	-	10	10	0.35
19	15LPMP	60	10	-	15	15	0.35
20	10SFLPMP	60	10	10	10	10	0.35

VI. EXPERIMENTAL PROGRAMME

A. Saturated Water Absorption (SWA) Test

The saturated water absorption test was carried out as per ASTM C642-13 standards on 100 mm cube specimens after 28 days of curing. The specimens were weighed before drying. The drying was carried out in a hot air 100 oven at a temperature of 105°C as shown in Figure 6.1. The drying process was continued, until the difference in weight between two successive measurements had a closer agreement. The dried specimens were cooled at room temperature and then immersed in water. The specimens were taken out and the surface dried using a clean cloth and weighed. The difference between the measured water-saturated weight and the oven-dried weight expressed as a percentage of oven-dry weight gives the saturated water absorption (SWA).

Fig.6.1Specimens in the oven for drying

B. Water Permeability Test

Permeability of concrete is the most important aspect while dealing with durability. The test was performed on 150 mm cube specimens at the age of 28 days of water curing. The specimens were surface dried and the dimensions measured to the nearest 0.5 mm. The cubes were clamped between two flanges with spherical circular gaskets. The experimental set up for water permeability test is shown in Figure 6.2. The water, under controlled pressure of 50 kg/cm2, is then applied to the surface of the concrete specimen. A constant 50 kg/cm2 pressure head of water was applied to the inflow side of the permeability cell and the pressure throughout the test was continuously monitored. The duration of the test was 48 hours. It was ensured that the permeability apparatus was filled with de-aired water and contains no air pockets or bubbles. The penetration of water was measured, after the testing period, by breaking the specimens. The water permeability of the developed SCC mixes was evaluated by measuring the water penetration depth that is a reliable indirect assessment of the water permeability of concrete. Figure 6.3 shows the depth of water penetration after breaking the cube specimen. More penetration of water refers that the concrete specimen is more permeable and has enormous voids which allow water to pass through it and making it less durable. 102 102 Figure 6.2 Water permeability test set up Figure 6.3 Depth of water penetration after breaking the cube specimen

Figure 6.2 Water permeability test set-up

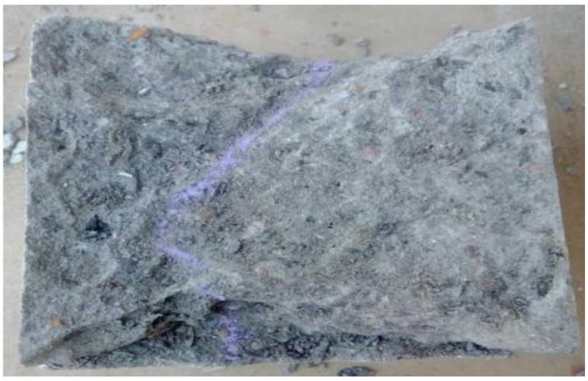

Figure 6.3 Depth of water penetration

C. Acid Attack Test

The acid resistance test was carried out on 100 mm size cube specimens after 28 days of curing. The cube specimens were weighed and immersed in water diluted with 5% by weight of Sulphuric Acid (H_2SO_4) and 5% by weight of Hydrochloric Acid (HCl). Then the specimens were taken out from the acids, washed with diluted water and the surfaces of the cubes were cleaned. Then the weight and the compressive strengths of the specimens were found out and the average percentage of loss of weight and compressive strengths were calculated. The compressive strength test was carried out for each specimen after 30, 60 and 90 days of immersion periods. In each test period, the average value of the three specimens was tested and reported. The specimens in H_2SO_4 and HCl solutions are shown in Figure 6.4.

Figure 6.4 Specimens immersed in 5% H2SO4 and 5% HCl solutions

D. Sulphate Resistance Test

The sulphate resistance test was carried out on the concrete cubes of size 100 mm × 100 mm × 100 mm. The specimens were cured in water for 28 days after which they have immersed in 5% Magnesium Sulphate ($MgSO_4$) solution. The specimens were positioned so that all sides were in contact with the solution. The pH of the solution was regularly monitored and adjusted to keep it constant. The specimens immersed in $MgSO_4$ solution is shown in Figure 6.5. The initial weight and the weight of concrete specimens after the immersion period of 30, 60 and 90 days were measured for finding the change in weight of concrete specimens. The average value of three specimens was considered for assessment.

Figure 6.5 Specimens immersed in MgSO4 solution

E. Alkalinity Measurement Test

SCC cube specimens of size 150 mm were tested for compressive strength after 28 days of water curing. The crushed pieces of tested specimens were again broken into small pieces using the hammer and then powdered using a ball mill. The powder sample (about 20 grams) was put into 100 ml of distilled water. The aqueous solution was allowed to stand for more than 72 hours. It was agitated often, to enable more of free lime of hydrated cement paste to get it dissolved in water. The pH of the aqueous solution was measured by pH meter and also by adding pieces of pH indicating papers into the solution. The colour of the pH paper in the solution was matched with the standard colour chart supplied by the manufacturer to get the pH of the solution. The test was performed as the procedure given by Pazhani et al (2010). Figure 6.6 shows the samples for alkalinity measurement.

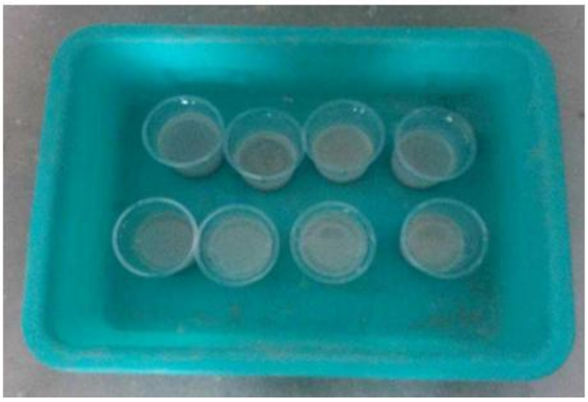

Figure 6.6 Samples for alkalinity measurement

F. Rapid Chloride Penetration Test

Rapid Chloride Penetration Test (RCPT) was performed as per ASTM C1202-12 to determine the electrical conductance of the SCC mixes at the age of 28 days curing and to provide a rapid indication of its resistance to the penetration of chloride ions. The test method consists of monitoring the amount of electrical current passing through 50 mm thick disc of 100 mm nominal diameter of cylindrical specimens for six hours. After 28 days curing, the concrete specimens were subjected to rapid chloride penetration by impressing a voltage of 60 V.

Two halves of the specimens were sealed with PVC container of diameter 90 mm. One side of the container was filled with 3% NaCl solution (that side of the cell will be connected to the negative terminal of the power supply), the other side was filled with 0.3 N NaOH solution (which will be connected to the positive terminal of the power supply). The current was measured at every 30 minutes up to 6 hours. Chloride contamination and temperature at every 30 minutes was also monitored. From the results obtained from observations of current and time, chloride permeability was calculated in terms of coulombs at the end of 6 hours. The interpretation is that the larger the coulomb value or the charge transferred during the test, the greater the permeability of the sample. The rating of chloride permeability based on the charge passed is given in Table 6.1. The test set up for RCPT with necessary settings is shown in Figure 6.7.

Figure 6.7 Test setup for RCPT

VII. RESULTS AND DISCUSSION

A. *Saturated Water Absorption (SWA) Test*

The results of the Saturated Water Absorptions (SWA) test of various SCC mixes after 28 days are given in Tables 7.1. From the test results, it was observed that the percentage of SWA of SCC mixes containing SF with F exhibited lower value when compared to all other mixes.

Table 7.1 Saturated Water Absorption (SWA) test results

S.No.	Mix ID	Saturated Water Absorption (%)	Difference in SWA compared to the control mix (%)
1	CM	2.36	-
2	5SF	2.17	-8.05
3	10SF	1.87	-20.76
4	15SF	1.54	-34.75
5	5LP	2.45	3.81
6	10LP	2.98	26.27
7	15LP	3.21	36.02
8	5MP	2.39	1.27
9	10MP	2.58	9.32
10	15MP	3.16	33.90
11	5SFLP	2.35	-0.42
12	10SFLP	2.14	-9.32
13	15SFLP	2.09	-11.44
14	5SFMP	2.29	-2.97
15	10SFMP	2.22	-5.93
16	15SFMP	2.14	-9.32
17	5LPMP	2.98	26.27
18	10LPMP	3.09	30.93
19	15LPMP	3.14	33.05
20	10SFLPMP	1.68	-28.81

By considering the replacement of SF with F, it was observed that there was a systematic reduction in water absorption as SF increased (5%, 10% and 15%) (Mostafa et al 2015 and Jalal et al 2015). The addition of silica fume reduces the water absorption by 34.75% than that of the control mix. This may be due to the high pozzolanic effect of silica fume mineral admixture and observed that the water absorption is increased with the increase in limestone powder marble powder (Shahul et al 2012). It is also noted that the mix 15LP showed the highest SWA of 3.21% which is 36.02% higher than that of the control mix and lowest value observed for the mix 15SF was 1.54%. The water absorption observed for the mix 10SFLPMP was 1.68% which is 28.81% lesser than that of the control mix.

B. *Water Permeability Test*

The test results of water permeability are presented in Table 7.2. It is observed from the test results that the SCC mixes with SF & F blends exhibited lower water penetration depth. Since the mixes with both LP&F and MP&F combinations reported higher penetration depth which signifies the presence of more pores. The low penetration depth was observed for the SCC mixes with LP+F+SF and MP+F+SF combinations may be due to the positive effect of SF rather than LP and MP. The mix 10SFLPMP recorded the least penetration value among all mixes which indicated that better packing and lesser voids are observed. The decrease in depth of penetration in the mix 10SFLPMP may be attributed due to the filler effect of the addition of mineral admixtures and filler materials in combination. When the materials in different size of particles are added to the SCC, it fills the voids between the particles. This physical phenomenon is known as the filler effect which reduces the porosity, which in turn reduces the permeability of SCC.

Table 7.2 Water Permeability Test Results

S.No.	Mix ID	Depth of penetration (mm)
1	CM	68
2	5SF	55
3	10SF	47

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4	15SF	34
5	5LP	70
6	10LP	85
7	15LP	92
8	5MP	66
9	10MP	80
10	15MP	88
11	5SFLP	69
12	10SFLP	72
13	15SFLP	75
14	5SFMP	70
15	10SFMP	55
16	15SFMP	49
17	5LPMP	74
18	10LPMP	85
19	15LPMP	89
20	10SFLPMP	35

C. Acid Attack Test

Figures 7.1 and & 7.2 shows the graphs of weight loss, compressive strength loss and days of immersion of all the SCC mixes in H2SO4 and HCl solutions respectively. Results showed that all the specimens immersed in H2SO4 solution exhibited maximum weight loss than those immersed in HCl solution. Weight loss and compressive strength loss for the mix containing SF with F was less when compared to those incorporating MP and LP. Mixes incorporating limestone powder revealed to disintegrate more when compared to those mixes with marble powder. The SCC mixes (5LP, 10LP and 15LP) with limestone filler addition produced the maximum weight loss in comparison with the other mixes (Siad et al 2009).

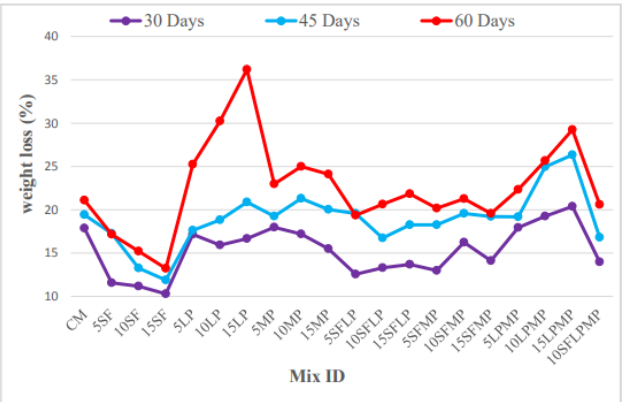

Figure 7.1 Variation of weight loss % of all SCC mixes in 30, 45 and 60 days of immersion in H2SO4

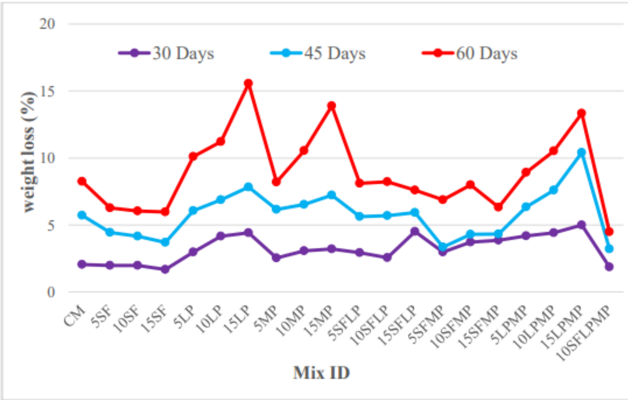

Figure 7.2 Variation of weight loss % of all SCC mixes in 30, 45 and 60 days of immersion in HCl

By comparing the aggressiveness of sulphuric acid medium and hydrochloric acid medium, it was observed that the extent of deterioration is different for the same concentration. For the SCC mixes with limestone filler addition along with F, the loss of weight is more in both the solutions than all other mixes. For the same type of concrete, degradation mechanisms due to H2SO4 attack and HCl attack are different. All SCC mixes exhibited maximum weight loss in the Sulphuric acid than in the hydrochloric acid solutions. Sulphuric acid leached the layers of the paste in the exposed surface, while Hydrochloric acid penetrates inwards to the concrete by the interval of porosity.

D. Sulphate Resistance Test

After the immersion of the concrete specimens in the sulphate solution for the entire test duration of 30, 45 and 90 days, a white patch was formed on the concrete specimens. The weight loss percentages of all the mixes exposed to 5% of Magnesium Sulphate solution are presented in Table 7.3.

Table 7.3 Sulphate resistance test results

S.No.	Mix ID	Change in weight (%)		
		30 days	45 days	60 days
1	CM	0.51	0.64	0.7
2	5SF	0.24	0.46	0.66
3	10SF	0.36	0.62	0.71
4	15SF	0.40	0.69	0.69
5	5LP	0.41	0.57	0.67
6	10LP	0.45	0.52	0.65
7	15LP	0.73	0.88	0.86
8	5MP	0.42	0.73	0.74
9	10MP	0.54	0.64	0.88
10	15MP	0.73	0.91	1.04
11	5SFLP	0	0.32	0.63
12	10SFLP	0.3	0.57	0.63

13	15SFLP	0.7	0.84	0.79
14	5SFMP	0.58	0.76	0.77
15	10SFMP	0.61	0.83	0.83
16	15SFMP	0.67	0.77	0.9
17	5LPMP	0.32	0.45	0.72
18	10LPMP	0.35	0.53	0.65
19	15LPMP	0.7	0.90	0.82
20	10SFLPMP	0.4	0.56	0.68

E. Alkalinity Measurement Test

The pH values of the aqueous solution prepared from the powder sample of various SCC mixes are presented in Table 7.4. From the Table, it was observed that the pH values of SCC mixes are marginally affected by the addition of mineral admixtures and filler materials. The alkalinity values of all the mixes were almost the same. The incorporation of mineral admixtures and filler materials in different proportions did not affect the alkalinity values considerably.

Table 7.4 Alkalinity test results

S.No.	Mix ID	pH value of samples (after 28 days)
1	CM	11.39
2	5SF	11.48
3	10SF	11.50
4	15SF	11.62
5	5LP	11.17
6	10LP	11.26
7	15LP	11.36
8	5MP	11.42
9	10MP	11.57
10	15MP	11.70
11	5SFLP	11.43
12	10SFLP	11.52
13	15SFLP	11.44
14	5SFMP	11.45
15	10SFMP	11.31
16	15SFMP	11.17
17	5LPMP	11.21
18	10LPMP	11.33
19	15LPMP	11.26
20	10SFLPMP	11.31

F. Rapid Chloride Penetration Test

The results of the Rapid Chloride Penetration Test (RCPT) of the SCC mixes containing different replacement levels of mineral admixtures and filler materials along with OPC at the age of 28 days are shown in Figure 7.2. The charge passed for the control specimen is 700 coulombs and the charge passed for the specimens with 5%, 10% and 15% addition of silica fume is 633, 600 and 599 coulombs respectively. Similarly, the addition of marble powder yields a reduction in the charge passed (Shahul et al 2012). From the RCPT test results, it is observed that the addition of FA, SF and LP or MP combinations reduces the rapid chloride penetration compared to the binary use of FA and LP or MP (Guneyisi et al 2013). Also, it is observed that all the mixes exhibited low permeability and among all the mixes of SCC, 10SFLPMP mix recorded the least value of the charge passed, which signifies that this mix has lesser permeability when compared with the other mixes of SCC. The filler effect of different size of particles which reduces the porosity, which in turn reduces the permeability of the concrete. One of the most important factors affecting the permeability of concrete is the internal pore structure, which in turn is dependent on the extent of hydration of the cementation's materials. The curing conditions and the age of the concrete thus largely determine the ease with which chloride ions can move into a concrete.

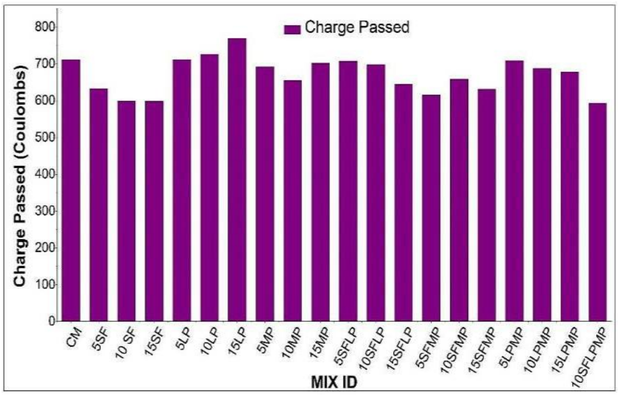

Figure 7.3 Results of RCPT

VIII. CONCLUSIONS

The results of various tests carried out on durability characteristics such as saturated water absorption, acid resistance, sulphate resistance, rapid chloride penetration and alkalinity measurement are reported. The influence of mineral admixtures and filler materials on various durability characteristics were analysed and reported. The optimum combinations of admixtures were also found out.

The saturated water absorption of SCC mixes containing silica fume was lower when compared with that of the concrete mixes without silica fume.

From the test results, it is observed that the lowest value of charge passed was obtained for the mix 10SFLPMP which signifies that it is less permeable

The incorporation of mineral admixtures and filler materials in different proportions did not affect the alkalinity values considerably. From the test results of water permeability and RCPT test for all the 20 mixes considered in the present research, it is observed that there is no much variation in the permeability properties and which indicate that there won"t be significant variation in the porosity and alkalinity properties of the mixes

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