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Study on Durability Characteristics of Self-Compacting Concrete with Fly Ash

Dhiyaneshwaran, S. [1]***, Ramanathan, P.*** [2]***, Baskar, I.*** [3] ***and Venkatasubramani, R.*** [4]

[1] Post-Graduate Student, Department of Civil Engineering, Sri Krishna College of Technology, Coimbatore 641042, India. E-Mail: dhiyanesh89@gmail.com
[2] Assistant Divisional Engineer, Highway Department, Salem 636001, India. E-Mail: ramanathanvinayak@yahoo.co.in
[3] Assistant Professor, Civil Engineering, Sri Krishna College of Technology, Coimbatore 641042, India. E-Mail: baskar.jais@gmail.com
[4] Professor and Head, Civil Engineering, Sri Krishna College of Technology, Coimbatore 641042, India. E-Mail: rvs_vlb@yahoo.com

ABSTRACT

This paper investigates the study of workability and durability characteristics of Self-Compacting Concrete (SCC) with Viscosity Modifying Admixture (VMA), and containing Class F fly ash. The mix design for SCC was arrived as per the Guidelines of European Federation of National Associations Representing for Concrete (EFNARC). In this investigation, SCC was made by usual ingredients such as cement, fine aggregate, coarse aggregate, water and mineral admixture fly ash at various replacement levels (10%, 20%, 30%, 40% and 50%). The super plasticizer used was Glenium B233 and the viscosity modifying agent used was Glenium Stream 2. The experiments are carried out by adopting a water-powder ratio of 0.45. Workability of the fresh concrete is determined by using tests such as: slump flow, T_{50}, V-funnel, L-Box and U-box tests. The durability of concrete is tested by acid resistance, sulphate attack and saturated water absorption at the age of 28, 56 and 90 days.

KEYWORDS: Self-compacting concrete, Fly ash, Saturated water absorption, Acid resistance, Sulphate attack, Mineral admixture.

INTRODUCTION

Self-compacting concrete (SCC), requiring no consolidation work at site or concrete plants, has been developed in Japan to improve the durability and uniformity of concrete in 1988 (Okamura and Ouchi, 1999). The mix composition is chosen to satisfy all performance criteria for the concrete in both the fresh and hardened states. There is no standard method for SCC mix design, and many academic institutions as well as admixture, ready-mixed, precast and contracting companies have developed their own mix proportioning methods. As per EFNARC Guidelines for SCC mix design, one of the most important differences between SCC and conventional concrete is the incorporation of a mineral admixture. Thus, many studies on the effects of mineral admixtures on the properties of SCC have been conducted. These studies show the advantage of mineral admixture usage in SCC, such as improved workability with reduced cement content (Poppe and Shutter, 2005; Ye et al., 2007). Since cement is the most expensive component of concrete, reducing cement content is an economical solution. Additionally, the mineral admixtures can improve particle packing and decrease the permeability

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of concrete. Therefore, the durability of concrete is also increased (Assie et al., 2007). Industrial byproducts or waste materials such as limestone powder, fly ash and granulated blast furnace slag are generally used as mineral admixtures in SCC (Felekoglu et al., 2006; Unal et al., 2006). Thereby, the workability of SCC is improved and the used amount of by-products or waste materials can be increased. Besides the economical benefits, such uses of byproducts or waste materials in concrete reduce environmental pollution (Bosiljkov, 2003).

Fly ash is an industrial by-product, generated from the combustion of coal in the thermal power plants. The increasing scarcity of raw materials and the urgent need to protect the environment against pollution has accentuated the significance of developing new building materials based on industrial waste generated from coal fired thermal power stations creating unmanageable disposal problems due to their potential to pollute the environment. Fly ash, when used as a mineral admixture in concrete, improves its strength and durability characteristics. Fly ash can be used either as an admixture or as a partial replacement of cement. It can also be used as a partial replacement of fine aggregates, as a total replacement of fine aggregates and as supplementary addition to achieve different properties of concrete (Jino et al., 2012).

Viscosity Modifying Admixtures (VMA) make the concrete more tolerant to variations in the water content of the mix, so that plastic viscosity is maintained and segregation is prevented (EFNARC, 2005).

EXPERIMENTAL INVESTIGATION

Materials

Self-compacting concrete was made of cement, sand, water, fly ash and mineral admixture.

1) *Cement:* Ordinary Portland cement, 43 Grade conforming to IS: 12269 – 1987.
2) *Fine aggregate:* Locally available river sand confined Grading zone II of IS: 383-1970.
3) *Coarse aggregate:* Locally available crushed blue granite stones conforming to graded aggregate of nominal size 12.5 mm as per IS: 383 – 1970.
4) *Mineral admixture:* Dry Class F-Fly ash confined as per IS 3812-2000.

Table 1. Chemical Properties of Fly Ash

Chemical properties	(%)
SiO_2	45.98
Al_2O_3	23.55
Fe_2O_3	4.91
CaO	18.67
MgO	1.54
Na_2O	0.24
K_2O	1.80
SO_3	1.47
Loss of ignition	2.31
Cl	0.0053

5) *Chemical admixture:* Super plasticizer Glenium-B233 as per EN 934-2 T3.1/3.2.and viscosity modifying agent Glenium stream -2 as per ENC 180VMA.

Table 2. Properties of Pce-Gleniumb233

Aspect	Light brown liquid
Relative density	1.09 ± 0.01 at 25°C
pH	>6
Chloride ion content	< 0.2%

Table 3. Typical Properties of VMA

Aspect	Colourless free flowing liquid
Relative density	1.01 ± 0.01 at 25°C
pH	>6
Chloride ion content	< 0.2%

6) *Water:* Water used was fresh, colorless, odorless and tasteless potable water free from organic matter of any type.

Mix Proportions

One control and five SCC mixes with different replacements of mineral admixture were prepared and examined to quantify the properties of SCC. Table 4 presents the composition of SCC mixtures. The replacement was carried out at levels of 10%, 20%, 30%, 40% and 50% of cement content. After iterative trial mixes the water/powder mass ratio (w/p) was selected as 0.45. The total powder content was varied as 450kg/m^3, 500 kg/m^3, 530 kg/m^3 as iterative values and finally fixed as 530 kg/m^3. Some design guidelines have been prepared from the acceptable test methods. Many different test methods have been developed in attempts to characterize the properties of self-compacting concrete. So far, no single method or combination of methods has achieved universal approval and most of them have their adherents. Similarly, no single method has been found which characterizes all the relevant workability aspects. So, each mix design should be tested by more than one test method in order to obtain different workability parameters.

Table 4. Mixture Proportions for Fly Ash Self-Compacting Concrete (kg/m^3)

Materials	Control	Fly Ash 10%	Fly Ash 20%	Fly Ash 30%	Fly Ash 40%	Fly Ash 50%
Cement	530	477	424	371	318	265
Fly ash	-	53	106	159	212	265
Water/Powder	0.45	0.45	0.45	0.45	0.45	0.45
Sand	768	768	768	768	768	768
Coarse aggregate	668	668	668	668	668	668
Super plasticizer	0.86	0.86	0.86	0.86	0.86	0.86
VMA	0.082	0.082	0.082	0.082	0.082	0.082

Workability Test Methods

For determining the self-compactability properties; slump flow, T_{50} time, V-funnel flow time, L-box blocking ratio, U-box difference in height tests were performed. In order to reduce the effect of workability loss on variability of test results, fresh state properties of mixes were determined within a period of 30 minutes after mixing. The order of testing was as below, respectively.

1. Slump flow test and measurement of T_{50}cm time;
2. V-funnel flow test;
3. L-box test;
4. U-box test.

Durability Test Methods

Durability studies were conducted at 28, 56 and 90 days for various mixes to find out the resistance to acid attack, sulphate attack and saturated water absorption.

Acid Resistance

Acid resistance was tested on 150 mm size cube specimens at the age of 28 days of curing. The cube specimens were weighed and immersed in water diluted with one percent by weight of sulphuric acid for 28, 56 and 90 days. Then, the specimens were taken out from the acid water and the surfaces of the cubes were cleaned. Then, the weight and the compressive strength of the specimens were found out and the average percentage of loss of weight and compressive strength were calculated.

Sulphate Attack

The sulphate attack testing procedure was conducted by immersing concrete specimens of the size 100x100x100 mm over the specified initial curing in a water tank. Then, they were cured in 5% Sodium sulphate solution for 28, 56 and 90 days, respectively. This type of testing represents an accelerated testing procedure, which indicates the performance of particular concrete mixes to sulphate attack on concrete. The degree of sulphate attack was evaluated by measuring the weight losses of the specimens at 28, 56 and 90 days, respectively.

Saturated Water Absorption

Saturated water absorption test was conducted on 100mmx100mmx100mm cubes at the age of 28 and 90 days. The specimens were weighed before drying in a hot air oven at 1050ºC. The drying process was continued, until the difference in mass between two successive measurements at a 24 hour interval closely agreed. The dried specimens were cooled at room temperature and then immersed in water. The specimens were taken out at regular intervals of time, surface dried and weighed. The difference between the saturated mass and the oven dried mass expressed as a percentage of the oven dried mass gives the saturated water absorption.

RESULTS AND DISCUSSION

In this study, fresh, hardened properties and durability of self-compacting concrete were investigated by using waste materials (class F fly ash) at five replacement rates for cement. The investigations were carried out according to appropriate criteria given by European standards. In the present study, such properties of self-compacting concrete produced with fly ash were investigated based on fresh concrete tests, specifically workability, strength and durability tests.

Fresh Properties

Slump Flow Test and T_{50} Test

The slump value plays a major role in SCC. By the value of slump, it is possible to know the effectiveness of flow in SCC; i.e., flowability of SCC under congested reinforcements can be studied at site through this test. The slump values also determine the durability of the mix, segregation and bleeding in the mix. The minimum value of slump is to be 650mm and the maximum value 800 mm for a fresh SCC. The slump values and T_{50} values for different mixes are shown in Fig.1. This helps us know the filling ability of SCC.

Table 5. Slump Flow and T_{50} Time of SCC with Fly Ash

Mix proportions (%)	Slump (mm)	T_{50} (Sec)
MFA-0	660	5
MFA-10	675	4
MFA-20	685	3.6
MFA-30	690	3.1
MFA-40	685	3.4
MFA-50	678	3.7

From slump flow and T_{50} tests, 30% replacement of fly ash behaves better compared with other ratios.

L-Box Test and U-Box Test

Using L-box test, the passing ability of SCC beyond the reinforcing bars can be found. The mix having high powder content and lesser coarse aggregate passes easily through the reinforcing bars. The ratio of $\frac{H_2}{H_1}$ is used to indicate the value of the result of L-box. The minimum value of $\frac{H_2}{H_1}$ can be 0.8 and the maximum value 1.0.

U-box test is used to find the passing ability of SCC through the reinforcing bars, similar to that of the L-box test. The limitation of U-box test as specified by EFNARC guidelines is the difference in height $H_2 - H_1$ to be within the limit of 0-30 mm. The passing ability of L-box and U-box test is shown in Fig.2.

From this U- Box and L- Box Test the passing ability of the concrete is tested and concludes that with increase in fly ash the passing ability increases. In this mix, 30% replacement by fly ash behaves better in passing ability of concrete.

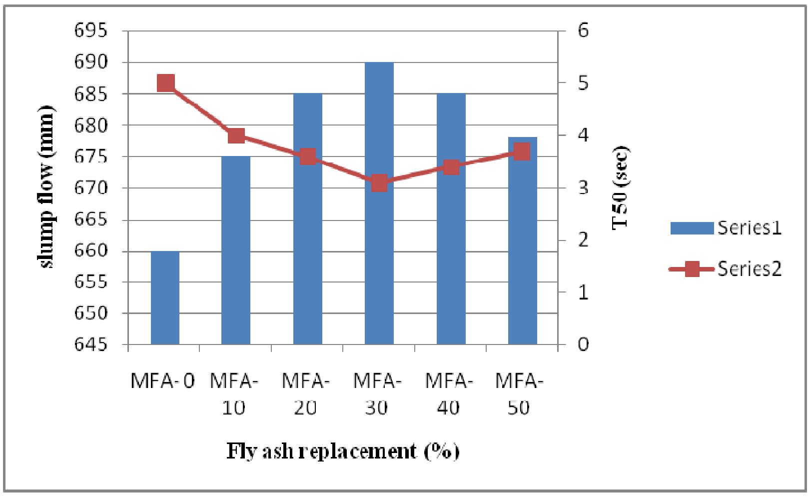

Figure 1: Slump Flow and T_{50} Time of SCC with Fly Ash

Table 6. U- Box and L- Box Tests of SCC with Fly Ash

Mix proportions (%)	U-Box (h_2-h_1) mm	L-Box (h_2/h_1)
MFA-0	28	0.920
MFA-10	24	0.933
MFA-20	22	0.946
MFA-30	19	0.953
MFA-40	19.5	0.950
MFA-50	20	0.946

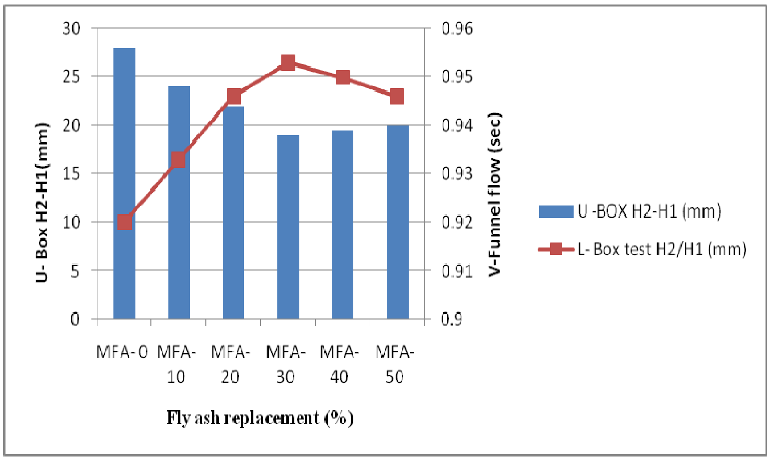

Figure 2: U- Box and L- Box Tests of SCC With Fly Ash

V-Funnel Test

V-funnel test is used to find out the flowing ability of the SCC. The test results show that the time taken for a higher replacement is much less due to fineness in the mix. The influence of time is shown in Fig.3. The minimum time for the flow of the entire concrete dumped in the V-funnel is 6 sec and the maximum time to fall completely is 12 sec.

Using V- Funnel test, the flowing ability of the concrete is investigated, and it is concluded that with the increase in fly ash the flowability increases. In this mix, 30% replacement by fly ash behaves better in respect to flowability of concrete.

Mechanical Properties

Compressive, split and flexure study results at different ages are shown in Figures (4, 5 and 6). When compared to the control mixture, increasing amounts of mineral admixtures generally decrease the strength. In this mix, 30% replacement by fly ash behaves better in respect to mechanical properties of concrete.

Table 7. V- Funnel Test of SCC with Fly Ash

Mix proportions (%)	V-funnel (Sec)
MFA-0	12
MFA-10	10.6
MFA-20	9.8
MFA-30	8.5
MFA-40	7.9
MFA-50	7.6

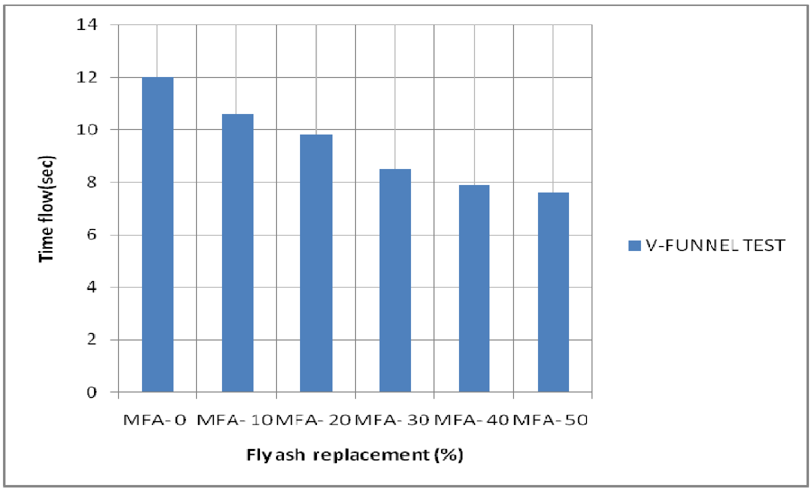

Figure 3: V- Funnel Test of SCC with Fly Ash

Table 8. Compressive Strength

Mix proportions (%)	Compressive Strength (MPa)	
	7 days	28 days
MFA-0	20	30
MFA-10	23.40	32.19
MFA-20	26.70	37.89
MFA-30	29.16	41.42
MFA-40	28.60	37.18
MFA-50	27.20	35.90

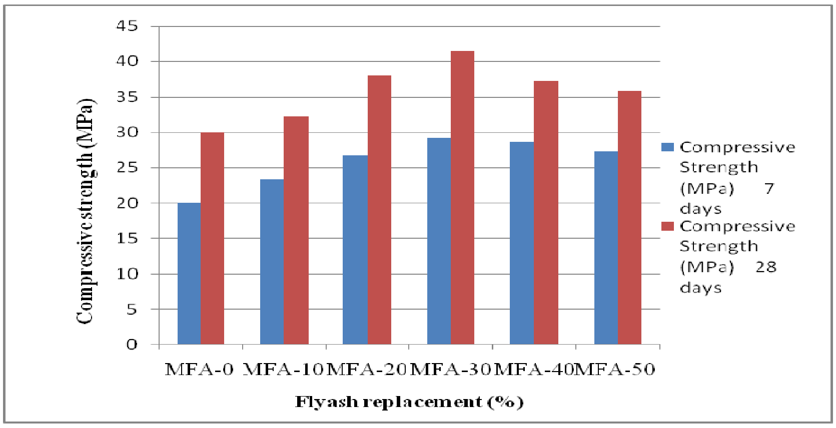

Figure 4: Compressive Strength Results

Table 9. Split Tensile Strength

Mix proportions (%)	Split Tensile Strength (MPa)	
	7 days	28 days
MFA-0	1.08	1.74
MFA-10	1.23	1.88
MFA-20	1.34	2.01
MFA-30	1.47	2.06
MFA-40	1.36	1.96
MFA-50	1.28	1.84

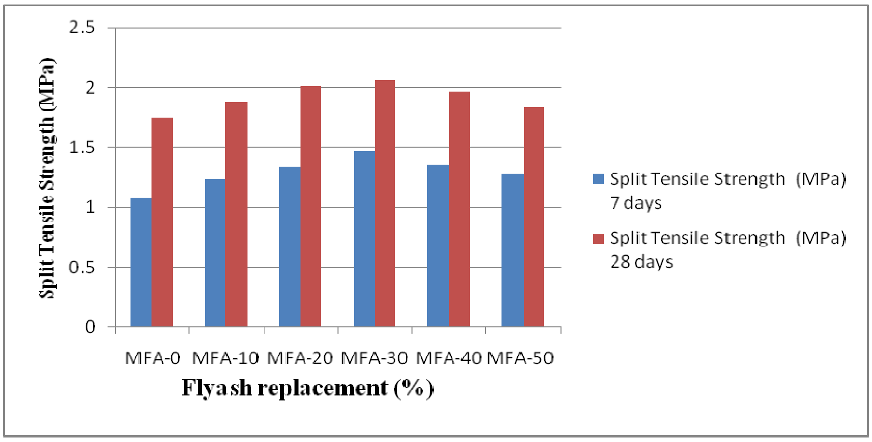

Figure 5: Split Tensile Strength Results

Table 10. Flexural Strength

Mix proportions (%)	Flexural Strength (MPa)	
	7 days	28 days
MFA-0	2.14	3
MFA-10	2.87	4.20
MFA-20	3.59	5.01
MFA-30	4.58	5.80
MFA-40	4.20	5.20
MFA-50	3.20	4.70

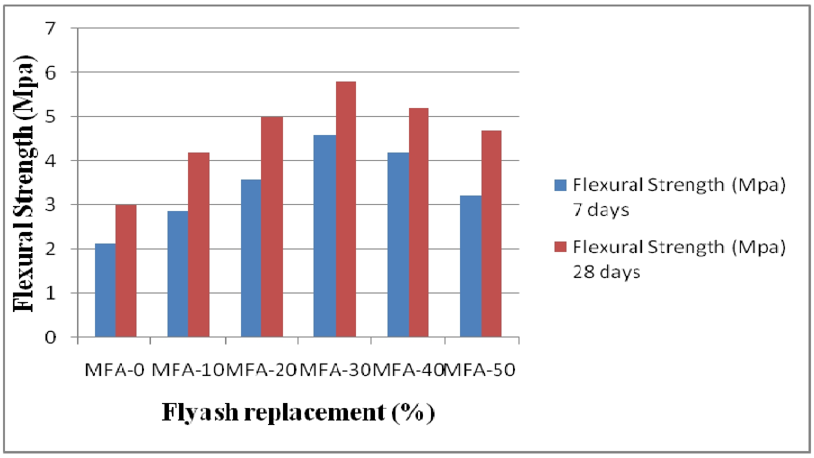

Figure 6: Flexural Strength Results

Durability Study

Acid resistance

Weight and compressive strength values of the specimens were found out for the age of 28, 56 and 90 days. The average percentage of weight loss and compressive strength were calculated for acid test as shown in Table 11, and Fig.7 shows the graph for the acid resistance.

It is observed that with the increase in fly ash content the weight reduction of the specimens gets reduced and the compressive strength loss is also reduced.

Sulphate Attack Test

The sulphate attack was evaluated by measuring the weight losses of the specimens at 28, 56 and 90 days, respectively. The results for sulphate attack test are shown in Table 12 and in Fig.8.

Table 11. Acid Resistance Test Results

Mix proportions (%)	Average reduction in weight (%)			Average loss of Compressive strength (%)		
	28 days	56 days	90 days	28 days	56 days	90 days
MFA-0	3.94	4.54	5.62	10.6	12.1	13.2
MFA-10	2.16	3.71	4.88	6.7	7.8	8.66
MFA-20	1.83	3.28	4.32	5.9	7.12	8.02
MFA-30	1.61	2.89	3.96	5.35	6.51	7.43
MFA-40	2.02	3.14	4.38	6.45	7.16	8.87
MFA-50	2.35	3.36	4.96	7.3	7.62	9.05

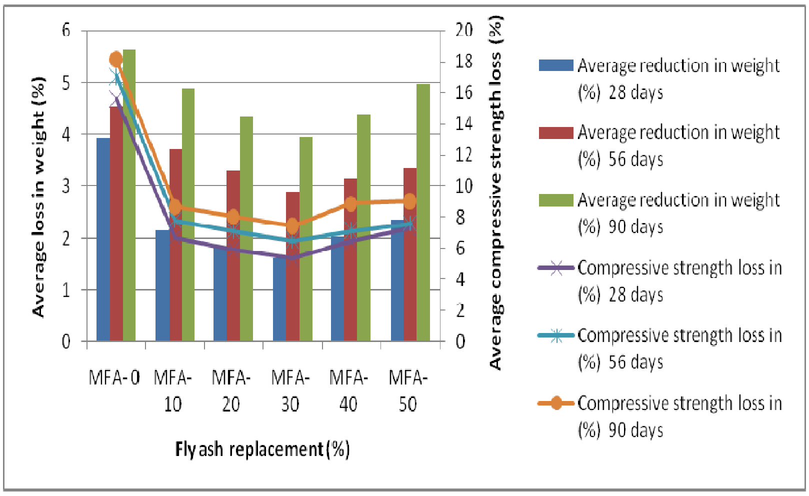

Figure 7: Acid Resistance

Table 12. Sulphate Attack Test Results

Mix proportions (%)	Average reduction in weight (%)		
	28 days	56 days	90 days
MFA- 0	2.14	2.8	3.35
MFA- 10	2.05	2.75	2.98
MFA- 20	1.96	2.64	2.74
MFA- 30	1.9	2.48	2.56
MFA- 40	2.02	2.71	2.98
MFA- 50	2.32	2.98	3.24

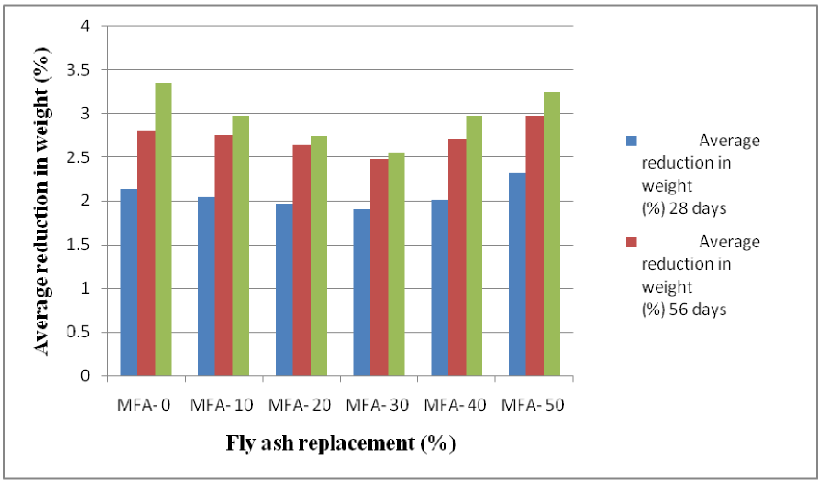

Figure 8: Sulphate Attack

Table 13. Saturated Water Absorption Test Results

Mix proportions (%)	Average reduction in weight (%)		
	28 days	56 days	90 days
MFA-0	3.63	3.45	3.28
MFA-10	3.31	3.21	3.12
MFA-20	3.00	2.87	2.74
MFA-30	2.64	2.48	2.32
MFA-40	2.75	2.55	2.46
MFA-50	2.84	2.66	2.58

It is observed that with the increase in fly ash content the weight reduction gets decreased when compared with the control mix. It is clear that fly ash added as cement replacement in concrete enhances the sulphate resistance in concrete.

Saturated Water Absorption Test

The results of saturated water absorption (SWA) tests of various self-compacting concrete mixes at the age of 28, 56 and 90 days are given in Table 13. The influence of different ratios of fly ash in concrete specimens is shown in Fig .9.

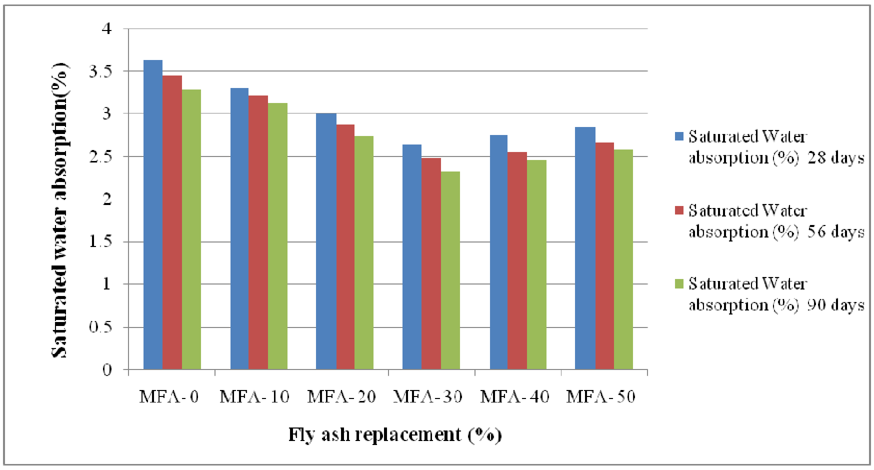

Figure 9: Saturated Water Absorption Test

It is noted that with the increase in fly ash content the saturated water absorption gets decreased when compared with the control mix. Fly ash acts as a filler material which fills the pores and thereby reduces water absorption.

CONCLUSION

- In this study, it has been found that with the increase in super plasticizer dosage the workability is increased. So, the required slump value fulfilling the criteria of EFNARC can be obtained.
- For 30% fly ash replacement, the fresh properties observed were good as compared to 10%, 20%, 40% and 50% fly ash replacement. Hence, if we increase the FA replacement we can have a better workable concrete.
- The dosage of VMA should be properly designed as it may change the basic criterion of SCC. In other words, the flowability may fall below 500 mm slump if the dosage of VMA is more than desired.
- The locally available Viscosity Modifying Admixture (VMA) has a substantial influence on the fresh properties of SCC. A small change in VMA dose makes a substantial change in SCC properties; i.e., flowing ability, passing ability, stability and segregation resistance.
- The results of the mechanical properties (compressive, split and flexure strength) have shown significant performance differences, and the higher compressive strength has been obtained for fly ash replacement. Also, the increase in replacement level has resulted in a decrease in strength for the increase in fly ash. So, 30% replacement level could be of optimum consideration for flowability, mechanical properties and durability study.
- The acid resistance of SCC with fly ash was higher when compared with concrete mixes without fly ash at the age of 28, 56 and 90 days.
- Compressive strength loss decreases with the increase in fly ash in concrete.
- When the specimen is immersed in sodium sulphate solution for 28, 56 and 90 days, respectively, the average reduction in weight increases and the weight is decreased when fly ash is increased in the concrete.
- Saturated water absorption percentage decreases with the increase in fly ash. For 30% replacement of fly ash, the low water absorption level is a good indicator of limited open porosity that can inhibit high flow of water into the concrete.

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