EXPERIMENTAL INVESTIGATION ON ROBUSTNESS OF VMA TYPE SELF COMPACTING CONCRETE

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ABSTRACT

In this experimental work, the robustness of self compacting concrete are studied. The present work analyzes the robustness of a typical SCC, in terms of the fresh properties and strength, when changes are made in the dosages of the constituents within the tolerances that could occur in ready mix concrete plants. The results indicate that the most critical changes that can render an SCC unacceptable are excess cement, excess admixtures and super plasticizers. It was also observed that the most sensitive tests for SCC evaluation is the slump flow test and T_{50} test. Also the incorporation of a viscosity modifying admixture improved the robustness of SCC significantly. The robustness of SCC was tested under the ages of specimen as 28 days, 56 days and 90 days. In this experimental work SCC was made by usual ingredients such as cement, fine aggregate, coarse aggregate, water and mineral admixture (silica fume) at various replacement levels (10%, 20%, 30%, 40%, and 50%), with that the Superplasticizer (Glenium B233) and viscosity modifying agent (Glenium Stream2) was used in appropriate amount for achieving the better flow in the concrete. The experiments were carried out by maintaining a constant water-powder ratio of 0.45.

Key words: Self compacting concrete, Robustness, Admixtures, Viscosity modifying agent

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1. INTRODUCTION

Self compacting concrete (SCC) has been one of the most significant advances in concrete technology in recent years and has been the subject of numerous research projects. SCC may be defined as concrete with the capacity to flow inside the formwork and to pass around the reinforcement and through the narrow sections consolidating simply under its own weight without the need of vibration and without showing segregation and bleeding. Self compacting concrete (SCC) was first developed in Japan in the late 1980’s as a material that can flow through congested reinforcing bars without need for additional consolidation and without undergoing any significant separation under its own weight. One of the disadvantages of SCC is its cost, associated with the use of high volumes of Portland cement and use of chemical admixtures. One alternative to reduce the cost of SCC is the use of mineral admixtures such as SF, FA and GGBFS which are finely divided materials added to concrete during mixture procedure. These mineral admixtures are industrial by-products replaces the part of PC and reduces the cost of SCC. Moreover, the use of mineral admixtures in the production of SCC not only provides economical benefits but also reduces heat of hydration. The incorporation of mineral admixtures 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.

Most articles published shows that the incorporation of a viscosity modifying admixture improved the robustness of SCC. For example, Ravindra Gettu et al. evaluated that a non-robust SCC is made robust by addition of 0.25% of VMA and a slight increase in the dosage of superplasticizer. Siwar Naji et al. investigated the robustness of SCC by incorporating various types of VEA and found that the incorporation of VEA in SCC enhances the robustness. From this view point, by incorporating VMA in SCC provides greater robustness.

In this study, it is aimed to investigate the effect of SF as mineral admixture and HRWR, VMA as chemical admixture on the fresh and robustness characteristics of SCC. Fresh concrete tests such as Slump-flow, L-box, V-funnel, U-box, required time to SCC to reach 500mm length slump-flow radius (T_{50}) and robustness tests such as Saturated Water Absorption, porosity, acid resistance, sulphate attack, carbonation depth and alkalinity measurement were conducted to achieve this objective and determine the appropriateness of using these different admixtures in SCC.

2. EXPERIMENTAL PROGRAMME

2.1. Materials used

Ordinary Portland cement of 43 grade conforming to IS: 12269 – 1987 was used in this study. The fine aggregate conforming to grading zone II of IS: 383 – 1970 was used. The maximum size of coarse aggregate was selected as 12.5mm in order to avoid any blocking effect of SCC conforming to IS: 383 – 1970 was used. Silica fume (Elkem microsilica grade 920 – D) conforming to ASTM C 1240 in a dry densified form was used as a mineral admixture. Besides, these materials Superplasticizer(Glenium B233) conforming to EN 934-2 T3.1/3.2 and Viscosity modifying agent(Glenium stream2) conforming to ENC 180VMA were used and Potable water conforming to IS: 456 – 2000 was used for both mixing and curing.

2.2. Mix design

Mix Design is the process of selecting suitable ingredients of the concrete and determining their relative proportion with an objective of producing concrete possessing certain minimum desirable properties like workability in fresh state, minimum desirable strength and durability in hardened state. Further information on mix design and the methods of evaluating the properties of SCC are found in the European Federation of National Associations Representing for Concrete (EFNARC) Guidelines for SCC. The Guidelines in

EFNARC are not intended to provide specific advice on mix design but it is tabled and indicated the typical range of constituents in SCC by weight and by volume. The proportions are no way restrictive and many SCC mixes will fall outside this range for one or more constituents. Initially T_{50} slump flow test was carried out for various trials to determine the flowability of SCC. The trials was shown in the table 1.

2.3. Casting, curing and testing

Before casting the fresh properties of SCC such as slump flow test, T_{50} test, L-box, V-funnel and U-box tests were conducted to characterize the workability of the fresh concrete to access filling and passing abilities. During the slump flow test, the time required for SCC to reach 500mm length slump flow radius (T_{50}) and the final diameter of the concrete circle through two directions were measured. In the L-box test, the test was started by removing the control gate at once to allow the flow of SCC through the horizontal part of the L-box. After this, the flow times were measured. When the flow of fresh SCC stopped, the heights of the concrete at the end (h_2) and the beginning (h_1) of the horizontal section were measured. Then the blocking ratio was calculated as the ratio "h_2/h_1". The minimum acceptable value is 0.8. In the V-funnel test, the freshly prepared SCC was filled in the v-funnel and the bottom shutter of the v-funnel was made open and the time required to flow were taken. The maximum time taken by SCC mix in V-funnel is 10 sec. The U-box test method is used to measure the filling ability of self-compacting concrete. The height of the concrete in both the compartments is measured and this test gives a direct measurement of filling ability. The difference in height h_1-h_2 is the filling height. The acceptable value of filling height is 30mm maximum as suggested by European standards. Specimens (cubes and prisms) were then casted in steel moulds and were not subjected to any compaction other than their own self weights. After the specimens get hardened, the moulds were removed and it was placed in the water for curing. After 28 days curing, the robustness of the specimens were determined.

3. RESULTS AND DISCUSSION

In this study, fresh and hardened properties of SCC were investigated at five replacement rates for cement with silica fume. The ability of such studies is done according to appropriate criteria given by European standards. For fresh properties of SCC the limitations specified by European standards are represented in the table 2. In the present study, such properties of self-compacting concrete produced with silica fume were investigated based on fresh concrete tests, specifically workability tests.

3.1. Workability

3.1.1 Slump flow and T_{50} tests

The slump flow values and T_{50} for SCC at various replacement levels are presented in table 3. The conventional slump test is not appropriate to quantify the workability of SCC. The slump flow test is a value system for the ability of concrete to deform under its own weight against the friction of the surface with no external restraint present. All mixtures exhibited good workability with flow values of at least 690mm. Slump flows of 650mm to 800mm are typically required for SCC and all the mixtures under investigation fall into this category.

The results obtained for slump flow tests shows that the higher replacement of the mix with highly fine powdered materials have given higher value of slump as shown in fig 1 and 2 and also achieved self compaction.

3.1.2 L – Box test

The L-box ratio characterizes the filling and passing ability of SCC. There is generally a blocking risk of the mixture when the L-box blocking ratio is below 0.8. The blocking ratios of SCCs produced are given in fig. 2. The blocking ratio (h_2/h_1) should be between 0.8 and 1.00. All mixtures of SCC are within this target range. When mineral admixture content have increased, it has not negatively affected the blocking ratio because of the concurrent decrease in viscosity. However, it can be noted that for each replacement of SCC investigated in the present study has adequate filling capability and passing ability. The test results are shown in table 4 and fig 3.

3.1.3 V – Funnel test

The V-funnel test was performed to assess the flow ability and stability of the self compacting concrete. The inverted cone shape restricts flow, and prolonged flow time may give some indication of the susceptibility of the mix to blocking. For SCC, a flow time of 10 seconds is considered appropriate. Hence the value obtained from the experimental investigation is within the limit of European standards. And the values obtained are shown in table 5 and fig 4.

3.1.4 U – Box test

The U-box test was used to assess the self-compactability of concrete. If the concrete flows as free as water, then the difference between the heights (H_2-H_1) will be zero. As per European standards the difference between the heights (H_2-H_1) should be 0 to 30. Hence the value obtained from the investigation is within the limit of European standards. And the test results are presented in table 6 and fig 5.

3.2 Robustness studies

The robustness or durability of cement concrete is defined as the ability to resist weathering action, chemical attack, abrasion, or any other process of deterioration. Durable concrete will retain its original form, quality and serviceability when exposed to its environment. The following are some of the tests which are carried out for determining the durability of concrete.

3.2.1 Saturated water absorption

Saturated water absorption (SWA) tests were carried out on 100 mm cube specimen at the ages of 28 days, 56 days and 90 days as per ASTM C 642. The specimens were weighed before drying. The drying was carried out in a hot air oven at a temperature of 105^{o}C. The dried specimens were cooled at room temperature and immersed in water. The specimens were taken out at regular interval of time, surface dried using a clean cloth and weighed. This process was continued till the weights became constant. The difference between the measured water saturated mass and oven dried mass expressed as a percentage of oven dry mass gives the SWA. The water absorption was calculated as,

Percentage water absorption $= (Ws - W_d) \times 100 / W_d$

Where,

W_s = weight of specimen at fully saturated condition

W_d = weight of oven dry specimen

The test results for saturated water absorption are shown in the table 7 and the graph is shown in the fig 6. As the ages of specimen increases the water absorption capacity gets decreases which alternatively increases the robustness of SCC.

3.2.2 Porosity

The test for porosity was carried out by 100mm cube specimens. The saturated water absorption of concrete was measure of the pour volume or porosity in hardened concrete which is occupied by water in saturated conditions. It denotes the quantity of water which can be removed on drying a saturated specimen. The porosity obtained from absorption tests is designed as effective porosity. It is determined from the following formula:

Effective porosity = (Volume of voids / bulk volume of specimen) x 100

The volume of voids is obtained from the volume of water absorbed by an oven dried specimen or the volume of water lost on oven drying a water saturated specimen at 105^0 C to constant mass. The bulk volume of specimen is given by the difference in mass of the specimen in air and its mass under submerged condition in water.

$$\text{Effective porosity, } n = (W_s - W_d) / (W_s - W_{sub}) \times 100$$

Where,

W_s = Weight of specimen at fully saturated condition

W_d = Weight of oven dried specimen

W_{sub} = Submerged weight of specimen in water

The test results for porosity are shown in the table 8 and the graph is shown in the fig 7. As the ages of specimen increases the porosity gets decreases due to the finer material silica fume is replaced with cement and the addition of VMA increases the robustness of SCC significantly.

3.2.3 Acid resistance

The acid resistance were carried out on 150 mm size cube specimen at the age of 28, 56 and 90 days curing. The cube specimen were weighted and immersed in water diluted with one percent by weight of sulphuric acid. 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 the average percentage of loss of weight and compressive strengths were calculated.

The results of acid resistance tests of various replacement levels of silica fume are presented in table 12 and graph is shown in fig 11 and 12. The test results obtained shows that when the replacement levels of silica fume increases and consisting of VMA in SCC, reduces the attack of acid in the concrete.

3.2.4 Sulphate attack

The sulphate attack testing procedure was conducted by immersing concrete cube of size 100mm over the specified initial curing in a water. Then they were also 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.

The results of sulphate attack tests are presented in table 9 and graph is shown in fig 8. From the results obtained when the silica fume content is increased and the VMA is added with SCC the weight reduction of specimen gets decreased when compared to the control mix. It is clear that when silica fume and VMA is added with SCC it enhances sulphate resistance in the concrete.

3.2.5 Carbonation depth

The carbonation depth was carried out in a concrete prism of cross section 100mm x 100mm x 500mm which can be roughly split into a length of 70mm. The method of making specimen and curing was based on RILEM recommendation CPC – 18. Carbon dioxide which penetrates the surface of the concrete can react with alkaline components in the surface in the cement paste. This process (carbonation) leads to a reduction of pH value of the pore solution to less than 9. The depth of the carbonated surface layer is called the depth of carbonation. And the depth of carbonation was obtained by the penetration of phenolphthalein solution in the concrete. The results of carbonation depth are presented in table 10 and graph is shown in fig 9. From the results obtained, when the ages of specimen increases the depth of penetration becomes decreases due to the presence of silica fume and VMA in the concrete.

3.2.6 Alkalinity measurement

The cube specimens were tested for compressive strength after 28, 56 and 90 days. The broken pieces of tested specimen were again broken into small pieces using hammer and ball mill and then powdered. Each of the powdered samples (say 20gm) was put into100ml distilled water. The aqueous solution was allowed to stand for 72 hours and more and was agitated often, to enable more of free lime of hydrated cement paste to get dissolved in water. The pH of the aqueous solution were measured by pH meter.

The results of alkalinity measurement are presented in table 11 and graph is shown in fig 10. From the results obtained the alkalinity of concrete mixes containing silica fume and VMA was little less when compared with that of concrete mixes without silica fume and VMA. This indicates that the addition of silica fume and VMA to concrete mixes reduces the pH of the pore solution to a limited extent only. Hence replacement of cement with silica fume and SCC containing VMA did not cause more loss of alkalinity.

TRIAL	CEMENT Kg	F.A Kg	C.A Kg	WATER Kg	SP ml	VMA ml	MIX RATIO
1	3.25	4.94	4.55	1.46	28.30	2.66	1:1.52:1.4
2	3.42	4.86	4.10	1.54	29.75	2.80	1:1.42:1.30
3	3.62	5.14	3.98	1.63	31.49	2.97	1:1.42:1.10
4	**3.50**	**5.08**	**4.42**	**1.58**	**30.45**	**2.87**	**1:1.45:1.26**
5	3.58	5.23	3.94	1.61	31.15	2.95	1:1.46:1.10

Table 1 Procedure adopted to arrive mix proportion

(Water/Powder ratio = 0.45)

Test methods	**Units**	**Minimum**	**Maximum**
Slump flow	mm	650	800
T_{50}	sec	0	7
L - Box	h_2/h_1	0.8	1
V - Funnel	sec	0	10
U - Box	h_2-h_1	0	30

Table 2 Limitations specified by European standards

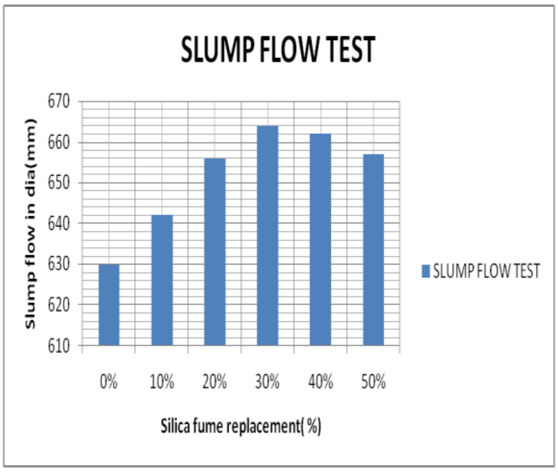

Fig 1 Slump flow Vs Mix proportions

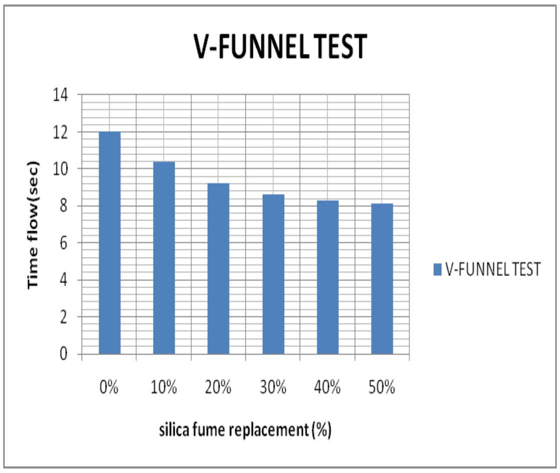

Fig 4 V – Funnel Vs Mix proportions

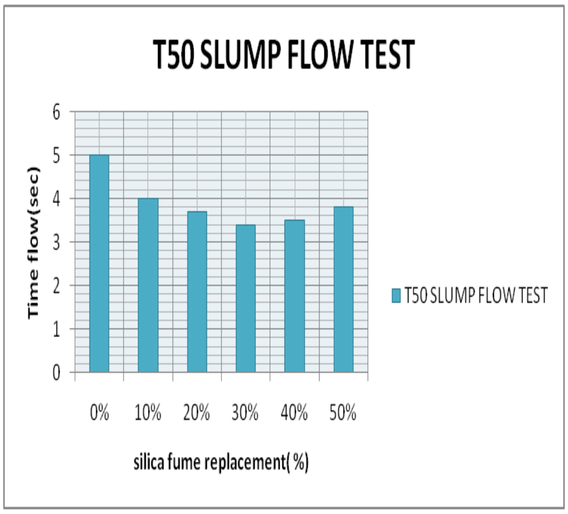

Fig 2 T_{50} Slump flow Vs Mix proportions

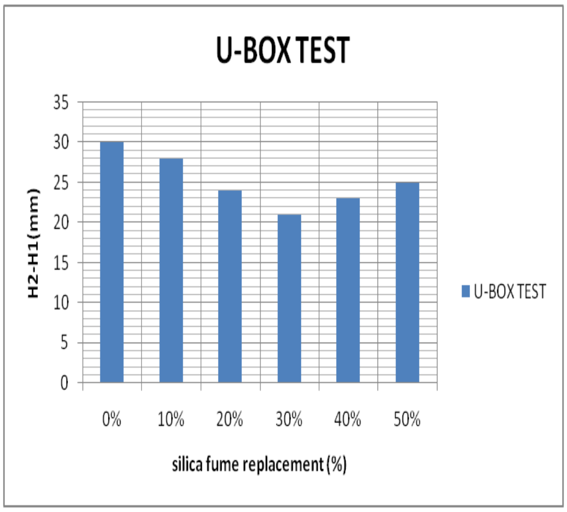

Fig 5 U – Box Vs Mix proportions

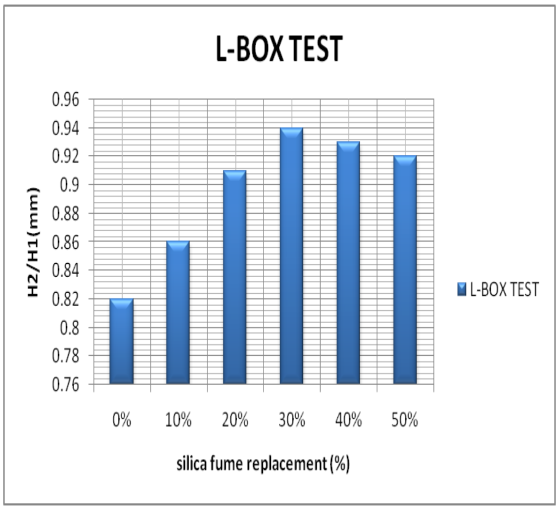

Fig 3 L – Box Vs Mix proportions

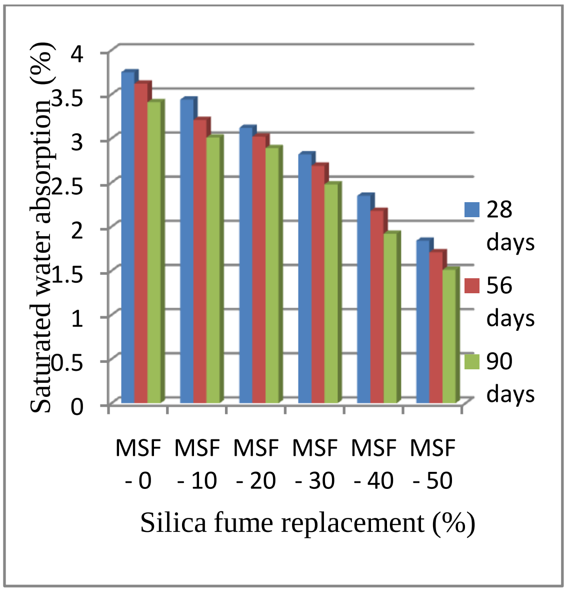

Fig 6 Graph for SWA

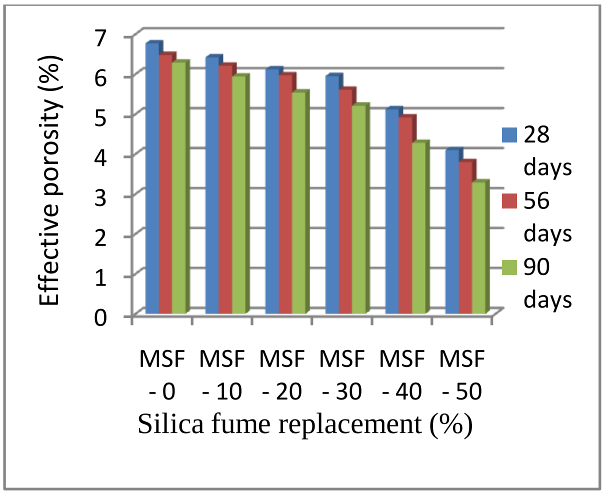

Fig 7 Graph for Porosity

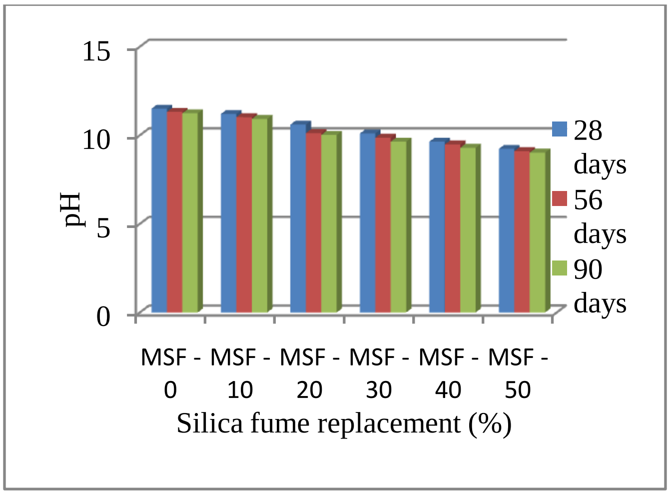

Fig 10 Graph for alkalinity measurement

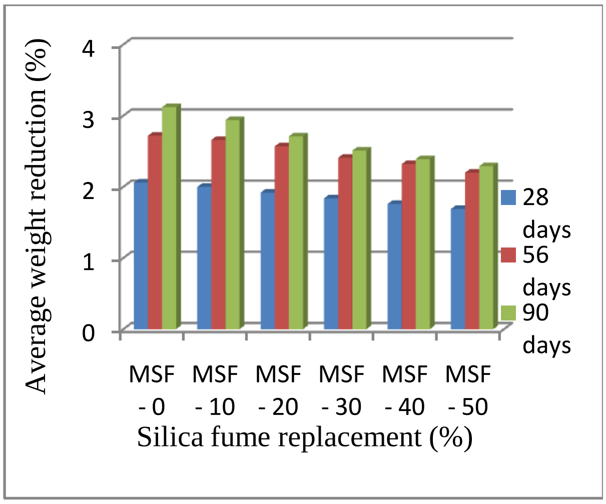

Fig 8 Graph for sulphate attack

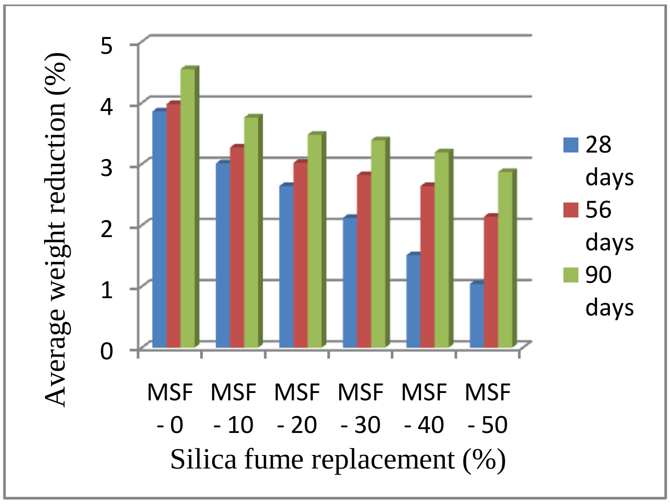

Fig 11 Graph for acid resistance

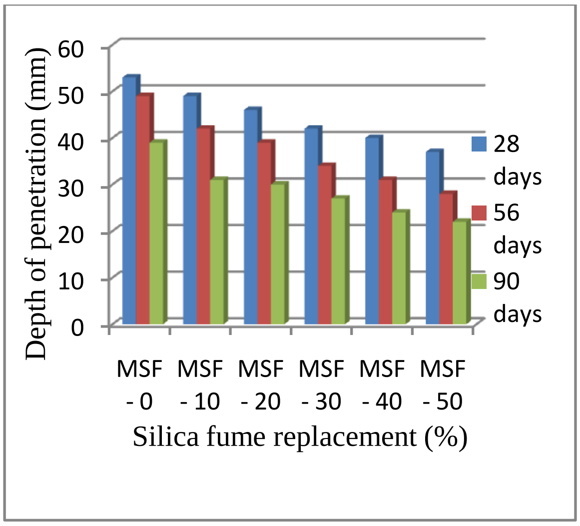

Fig 9 Graph for carbonation depth

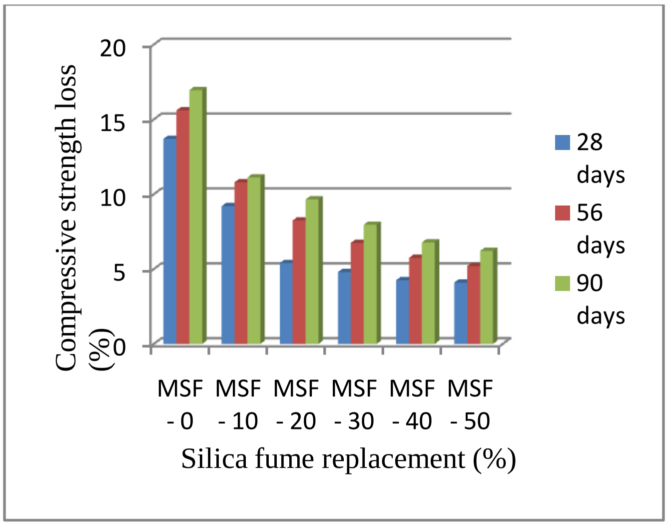

Fig 12 Graph for acid resistance

Mix proportions	Saturated water absorption (%)		
	28 days	56 days	90 days
MSF – 0%	3.75	3.62	3.41
MSF – 10%	3.44	3.21	3.01
MSF – 20%	3.12	3.02	2.89
MSF – 30%	2.82	2.69	2.48
MSF – 40%	2.35	2.18	1.92
MSF – 50%	1.84	1.71	1.51

Table 7 Test results for Saturated water absorption

Mix proportions	Effective porosity (%)		
	28 days	56 days	90 days
MSF – 0%	6.77	6.48	6.29
MSF – 10%	6.42	6.21	5.94
MSF – 20%	6.12	5.97	5.54
MSF – 30%	5.95	5.61	5.21
MSF – 40%	5.12	4.92	4.28
MSF – 50%	4.1	3.8	3.29

Table 8 Test results for porosity

Mix proportions	Average reduction in weight (%)		
	28 days	56 days	90 days
MSF – 0%	2.06	2.72	3.12
MSF – 10%	2	2.66	2.94
MSF – 20%	1.92	2.57	2.71
MSF – 30%	1.84	2.41	2.51
MSF – 40%	1.76	2.32	2.39
MSF – 50%	1.69	2.2	2.29

Table 9 Test results for sulphate attack

Mix proportions	Depth of penetration (mm)		
	28 days	56 days	90 days
MSF – 0%	53	49	39
MSF – 10%	49	42	31
MSF – 20%	46	39	30
MSF – 30%	42	34	27
MSF – 40%	40	31	24
MSF – 50%	37	28	22

Table 10 Test results for carbonation depth

Mix proportions	pH		
	28 days	56 days	90 days
MSF – 0%	11.5	11.32	11.24
MSF – 10%	11.2	11.02	10.92
MSF – 20%	10.6	10.12	10.02
MSF – 30%	10.1	9.86	9.64
MSF – 40%	9.64	9.48	9.29
MSF – 50%	9.23	9.1	9.02

Table 11 Test results for alkalinity measurement

4. CONCLUSION

As a result of this experimental investigation, the following conclusions can be drawn:

- In this investigation it is found that with the increase in dosage of superplasticizer and VMA the workability is also increased. Also it satisfies the criteria given in EFNARC.
- For 30% silica fume replacement, the fresh properties observed were good when compared to 10%, 20%, 40% and 50% replacement.

- VMA makes a substantial change in SCC properties i.e., flowing ability, passing ability, segregation resistance and improves the robustness of SCC.

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