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A Study on Strength Properties of Self Compacting Concrete with use of Steel Fibres

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ABSTRACT: The present study aims to investigate the fresh, strength and durability properties of self-compacting concrete (SCC), with fly ash as partial replacement of cement, incorporating steel fibres. For this purpose fly ash was used. A superplasticizer of Fosroc chemicals named 'STRUCTURO 100M' (an aqueous solution of carboxylic ether polymer) was used to increase the workability of concrete. The superplasticizer dosage was kept constant for all the SCC mixes. To make the SCC mix economical, cement was replaced with fly ash (34.5% and 28%). The proportions of coarse as well as fine aggregates were kept constant for all mixes. Steel fibres (0, 05, 1.0, and 1.5 %) were incorporated in the mixes to improve the strength properties of SCC while satisfying the fresh properties of SCC. Slump flow (diameter and T_{500}) test, V-funnel (T_{10sec} and T_{5min}) test, L-box test and U-box test were carried out to obtain the fresh properties of SCC mixes i.e. filling ability, passing ability and segregation resistance. Strength properties of hardened concrete were investigated in terms of compressive strength, split tensile strength and flexural strength. Durability properties i.e. affect of chemical action on hardened concrete was investigated in terms of compressive strength. Tests results show that compressive, split tensile and flexural strengths increased with increase of fiber content with flexural strength being most affected with increase of fibre content upto 1.5%. Test results also show that compressive strength of hardened concrete was not affected by chemical (sodium chloride and sodium sulphate) attack upto 56 days. All the mixes, satisfied most of the requirements of fresh properties as per EFNARC specifications, for SCC mix.

I. INTRODUCTION

Self-compacting concrete (SCC) is an innovative concrete that does not require vibration for placing and compaction. It is able to flow under its own weight, completely filling formwork and achieving full compaction, even in the presence of congested reinforcement. The hardened concrete is dense, homogeneous and has the same engineering properties and durability as traditional vibrated concrete. SCC consists of same components as the normal vibrated concrete. These components are cement, fine aggregate, coarse aggregate, water, additives and admixtures. These components are so adjusted so that concrete flows under its own weight, passes through narrow openings of reinforcement and finally, completely fills the form work without segregation of coarse aggregates in absence of vibration. Also, it gives strength equivalent to NVC. In this way, flow ability, passing ability and segregation resistance are essential properties of concrete to be considered as self-compacting concrete. However, the first two properties i.e. flow and passing ability are in opposition to the last one i.e. segregation resistance. So, SCC matrix should not only be sufficiently viscous to avoid segregation but also should have sufficient mobility to assure appropriate filling of form work. SCC has advantages over NC but still in hardened state it behaves same as NC. So, SCC in hardened state has some limitations due to which fibres should be added to improve its properties. The durability of concrete when reinforced with conventional rebars is a major concern in aggressive environments. To address this problem, there have been efforts, in recent years, to develop alternatives to conventional rebars. Fibre reinforced concrete have shown better behaviour because of their inherent ability to stop or delay crack propagation. The main properties of FRSCC in tension, compression and shear are influenced by the type of fibre, volume fraction fibres, aspect ratio and orientation of fibre in the matrix.

II. EXPERIMENTAL

Explains the properties of materials used for SCC mix composition, details of testing procedure used for fresh properties (such as slump flow, V-funnel, L-box, U-box), strength properties (compressive, split tensile and flexural strength) and durability properties regarding strength variation on sulphate and sodium chloride attack.

1. Cement. In the present study Ordinary Portland Cement (43 grade) conforming to IS: 8112-1989 was used. The cement was tested in accordance to test methods specified in IS: 4031-1988

2. Fly Ash. The finer quality of fly ash is obtained from the Electro-static precipitators in the plant. The physical and chemical properties of fly ash are shown in Tables 1 and 2.

3. Superplasticizer. Superplasticizer **STRUCTURO 100(M)** (Fosroc chemicals) was used as admixture. Structuro 100(M) combines the properties of water reduction and workability retention. Specifications of superplasticizer are shown in Table 3.

Table 1: Physical properties of Fly Ash.

Physical Properties	Test Results
Color	Grey(Blackish)
Specific Gravity	2.13
Lime reactivity- average compressive strength after 28 days of mixture ‘A’	4.90 MPa

Table 2: Chemical properties of Fly Ash.

Chemical properties	Percentage by weight
Calcium oxide(CaO)	2.24
Silica(SiO_2)	58.45
Alumina(Al_2O_3)	28.10
Iron oxide(Fe_2O_3)	3.45
Magnesium oxide(MgO)	0.33
Total sulphur(SO_3)	0.08
Loss of ignition	4.18
Insoluble residue	--
Sodium oxide (Na_2O)	0.60
Potassium oxide(K_2O)	1.25

The properties of fly ash conform to IS 3812:1981.

Table 3: Specifications of Superplasticizer.

Particulars	Properties
Appearance	Light yellow
Basis	Aqueous solution of Carboxylic ether polymer
pH	6.5
Density	1.06 kg/litre
Chloride content	Nil to IS:456
Alkali content	Less than 1.5g Na_2O equivalent per litre of admixture
Optimum dosage	0.5 to 3.0 litres per 100kg of cementitious material

4. Aggregates. Aggregates constitute bulk of the total volume of concrete. The characteristics of aggregates affect the properties of SCC.

Fine aggregates. Locally available natural river sand was used as the fine aggregate.

Coarse aggregates. Crushed stone conforming to IS: 383-1970 was used as coarse aggregate.

5. Fibres. In this study, steel fibres were incorporated in concrete. Steel fibres were added in different proportions of 0%, 0.5%, 1% and 1.5% of total concrete mass. Physical properties of steel fibres used are shown in Table 4. The mix ratio used for study is 1:1.64:1.09. Fly ash was added with 34.5% and 28% replacement by weight of cement and water-to-powder ratio used was 0.53 and 0.51 respectively. Mix composition used in study is given in Table 5. The various proportions were adjusted to satisfy most of the fresh properties, so that the mix could be designated as SCC and further maintains itself on addition of fibres. The typical range as per EFNARC for SCC mix composition is shown in Table 5.

Table 4: Physical properties of steel fibres.

Particulars	Properties
Shape	Cylindrical
Type	Straight
Length, mm	20
Diameter, mm	0.4
Aspect Ratio	50

Table 5: Typical range of SCC mix composition.

Constituent	Typical range by mass (kg/m^3)
Powder	380-600
Water	150-310
Coarse aggregate	750-1000
Fine aggregate	48-55% of total aggregate weight

Table 6: Mix composition.

Mix	SCC-I				SCC-II			
	M1	M2	M3	M4	M5	M6	M7	M8
w/c ratio	0.83	0.83	0.83	0.83	0.75	0.75	0.75	0.75
w/p ratio	0.53	0.53	0.53	0.53	0.51	0.51	0.51	0.51
Water (L/m³)	304.75	304.75	304.75	304.75	293.2	293.2	293.2	293.2
Steel fibres (Kg/m³)	0	12.14	24.3	36.44	0	12.14	24.3	36.44
Steel fibre (%)	0	0.5	1	1.5	0	0.5	1	1.5
SP (L/m³)	5.5	5.5	5.5	5.5	6	6	6	6
Coarse aggregate (Kg/m³)	600	600	600	600	600	600	600	600
Fine aggregate (Kg/m³)	950	950	950	950	950	950	950	950
Fly ash (Kg/m³)	200	200	200	200	160	160	160	160
Cement (Kg/m³)	375	375	375	375	415	415	415	415

III. RESULTS AND DISCUSSIONS

A. Fresh properties

Slump flow: The consistency and workability of self-compacting concrete was evaluated using slump flow test. The results as given in Table 12 show that the self-compacting concrete was complying with the requirements found in the literature. The limit specified by EFNARC for slump diameter was 650-800 mm and specified limit for T_{500} was 2-5 sec. For all mixes with various fibres content, slump flow was observed to be above 650 mm and T_{500} was less than 5 seconds. So, all mixes with different fibre contents hold good for filling ability as required for concrete to be SCC. V-funnel, L box and U box were used. Fresh Properties are shown in table 7.

All the mixes i.e. M_1, M_2, M_3 and M_4 gave satisfactorily results for fresh properties, except M_4 which was not according to EFNARC specifications in V-funnel T_{5min} test and L-box test.

Strength Properties: The results of strength properties for SCC mixes containing different percentages of fibres are discussed below.

Compressive strength. The mix M_1 was used as control mix i.e. fibre content as 0% and compressive strength at 28 days was 26.2 MPa.

Table 7: Fresh Properties.

Mix	SCC-I				SCC-II			
	M1	M2	M3	M4	M5	M6	M7	M8
U-box (H1-H2) (mm)	14	20	22	29	12	17	23	28
L-box (H2/H1)	0.86	0.92	0.98	0.73	0.85	0.9	0.95	0.81
V-funnel at T5min (sec)	10	12.5	13.8	20	9	11.3	12.5	15
V-funnel at T10sec (sec)	7	9.5	9.4	11	6	8.5	9	11
T500 (sec)	3.4	3.9	4.2	4.8	3.6	4	4.1	4.5
Slump flow diameter (mm)	675	668	665	660	685	678	674	668

Compressive strength of M_2, M_3 and M_4 was found to increase by 12%, 16.2% and 29% of M_1 at 28 days, respectively. At age of 3 days M_1, M_2, M_3 and M_4 achieved 50%, 47%, 46% and 48% of the at 28-day strength, respectively. At age of 7 days M_1, M_2, M_3 and M_4 achieved 62.5%, 59%, 62% and 58% times the 28-day strength, respectively. At age of 56 days M_1, M_2, M_3 and M_4, compressive strength increased by 13.25%, 5.25%, 11.2% and 3.33%, respectively.

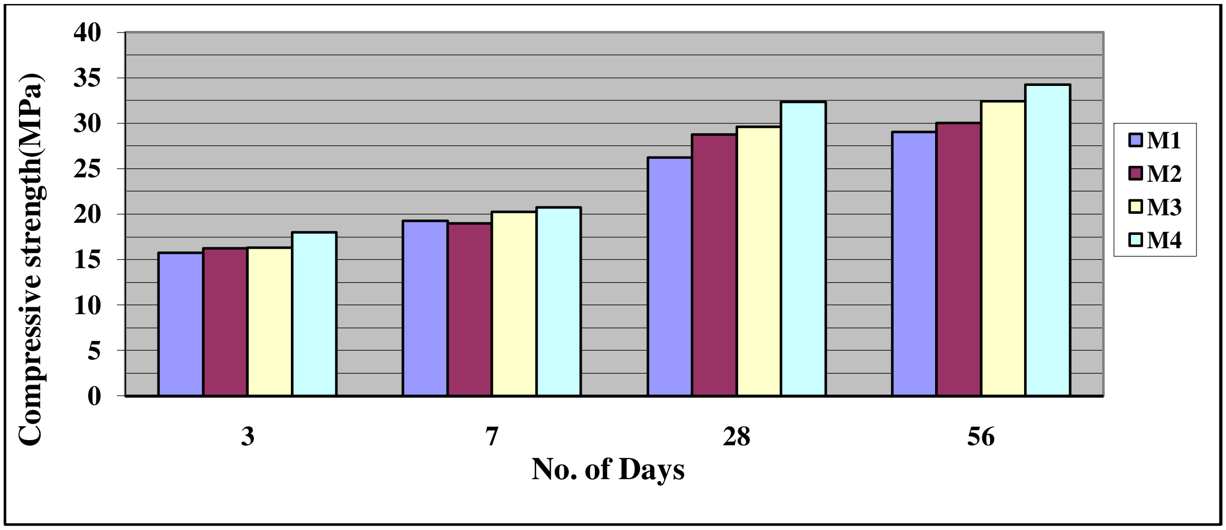

Fig. 1. Compressive Strength Test Results of SCC-I.

Table 8: Compressive strength of SCC-I mixes.

Mix	3 Days	7 Days	28 Days	56 Days
M1 (MPa)	15.78	19.25	26.20	29.01
M2 (MPa)	16.23	19.01	28.77	30.02
M3 (MPa)	16.34	20.23	29.63	32.38
M4 (MPa)	17.98	20.76	32.33	34.24

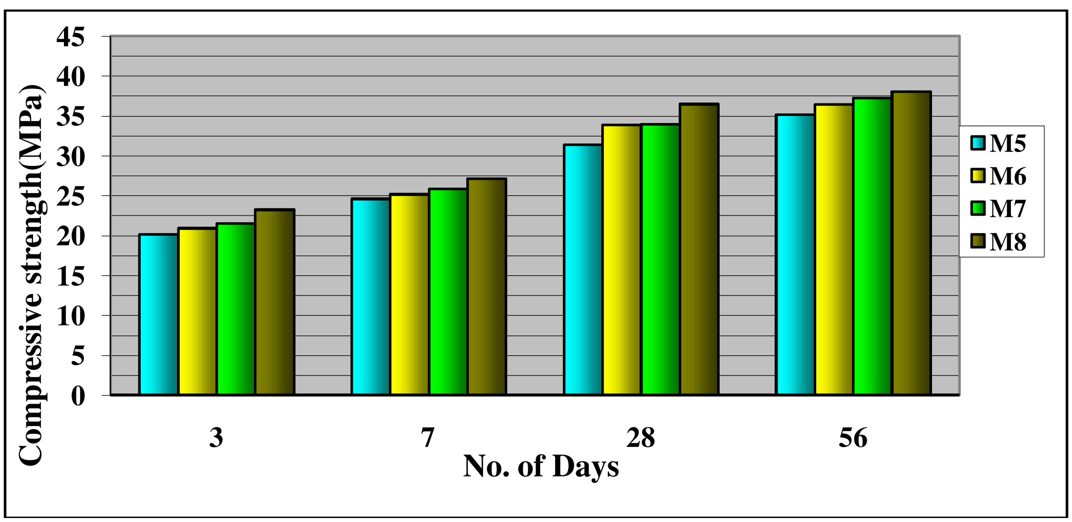

Fig. 2. Compressive Strength Test Results of SCC-II.

Table 9: Compressive strength of SCC-II mixes.

Mix	3 Days	7 Days	28 Days	56 Days
M5 (MPa)	20.21	24.67	31.43	35.22
M6 (MPa)	20.98	25.23	33.91	36.48
M7 (MPa)	21.56	25.89	34.01	37.34
M8 (MPa)	23.31	27.23	36.55	38.12

In the present study, the increase in strength for mix containing 1% fibre was observed to be approx. 15% at 7-day strength and 16.2 % at 28-day strength, when compared to mix containing 0% fibre content. Also, the increase in strength for mix containing 1.5% fibre was observed to be 29% at 28-day strength, when compared to mix containing 0% fibre content.

Split tensile strength. The split tensile strength of M_1 was 1.08 MPa. Split tensile strength of M_2, M_3 and M_4 was found to increase by 21%, 23% and 30% at 28 days respectively, when compared to M_1. At age of 3 days, M_1, M_2, M_3 and M_4 achieved 74%, 56%, 60% and 69% of the strength at 28 days, respectively. At age of 7 days, M_1, M_2, M_3 and M_4 achieved 85%, 90%, 80% and 80% of the strength at 28 days, respectively. At age of 56 days, M_1, M_2, M_3 and M_4, split tensile strength was increased by 14.5%, 22.8%, 19% and 21%, respectively.

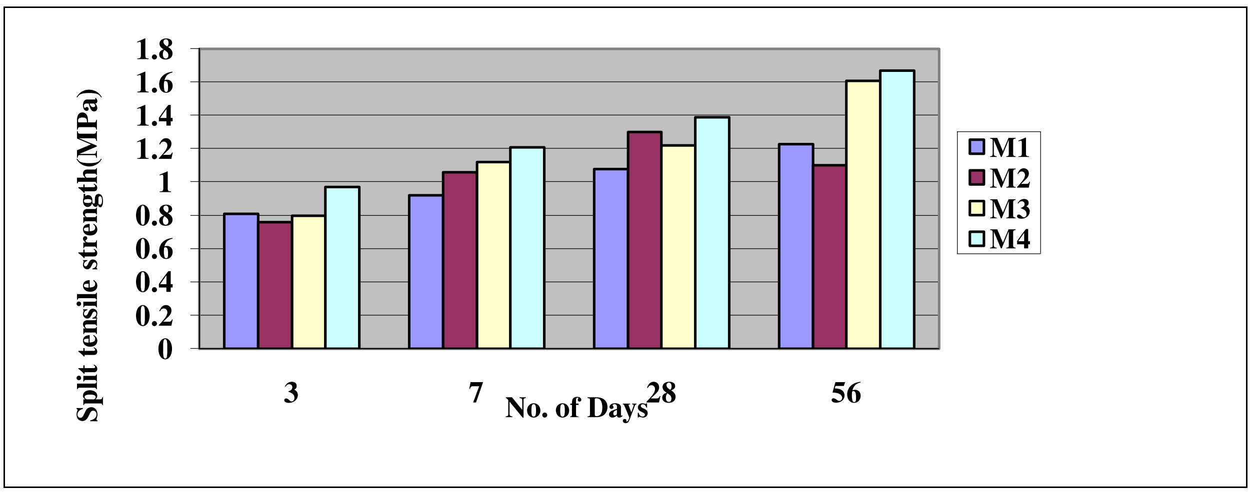

Fig. 3. Split-Tensile Strength Results of SCC-I.

Table 10: Split tensile strength of SCC-I mixes.

Mix	3 Days	7 Days	28 Days	56 Days
M1 (MPa)	0.81	0.92	1.08	1.23
M2 (MPa)	0.76	1.06	1.30	1.10
M3 (MPa)	0.80	1.12	1.22	1.61
M4 (MPa)	0.97	1.21	1.39	1.67

Split tensile strength of M_6, M_7 and M_8 was found to increase by 18%, 21% and 25% at 28 days respectively, when compared to M_5. At age of 3 days, M_1, M_2, M_3 and M_4 achieved 71%, 59%, 60% and 64% of the strength at 28 days, respectively. At age of 7 days, M_1, M_2, M_3 and M_4 achieved 88%, 94%, 87% and 86% of the strength at 28 days, respectively. At age of 56 days, M_1, M_2, M_3 and M_4, split tensile strength was increased by 10%, 24%, 20.7% and 22% respectively.

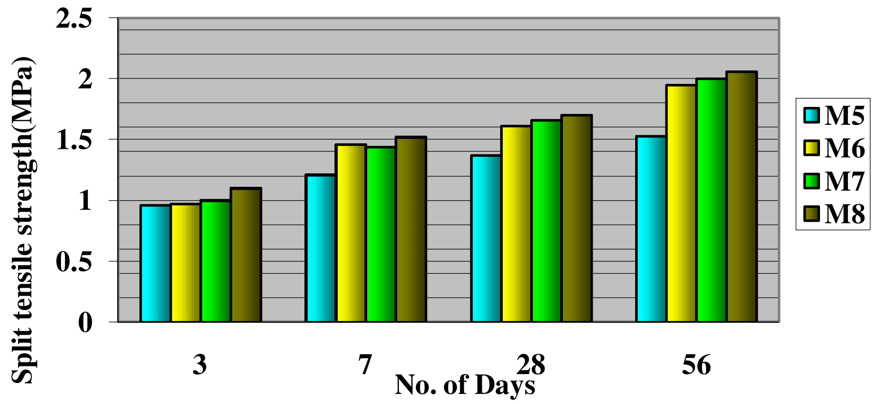

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Fig. 4. Split-Tensile Strength Results of SCC-II.

Table 11: Split tensile strength of SCC-II mixes.

Mix	3 Days	7 Days	28 Days	56 Days
M5 (MPa)	0.96	1.21	1.37	1.53
M6 (MPa)	0.97	1.46	1.61	1.95
M7 (MPa)	1	1.44	1.66	2
M8 (MPa)	1.1	1.52	1.7	2.06

In the present study, with fibre content of 1%, increase of approx. 17% and 24% at 7-day and 28-day strength was achieved respectively, when compared to mix containing 0% fibre content. On addition of 1.5% fibres, increase of approx. 30% at 28-day strength was achieved when compared to mix containing 0% fibre content.

Pons et al.(2007) reported increase of approximately 11.5% at 7-day strength and approximately 31.2% at 28-day strength, on addition of fibres content of approx. 1%(approx.). Sengul *et al.*(2006) reported, using high performance SCC(cement content of 350 kg/m^3), increase of 15.3% at 28-day strength with fibre content of 1.5%(approx.).

It is observed that increase in split tensile strength, in the present study, was less at 1% fibre content and almost double at 1.5% fibre content, as compared to increase in strength reported in the literature. Also, strength achieved, in the present study, at 7 days and 56 days was more for 0.5% fibre content as compared to 1% fibre content.

Flexural strength. The strength of M_1 at 28 days was 1.10 MPa. Flexural strength of M_2, M_3 and M_4 was increased by 63%, 92% and 115% at 28 days respectively, when compared to M_1.

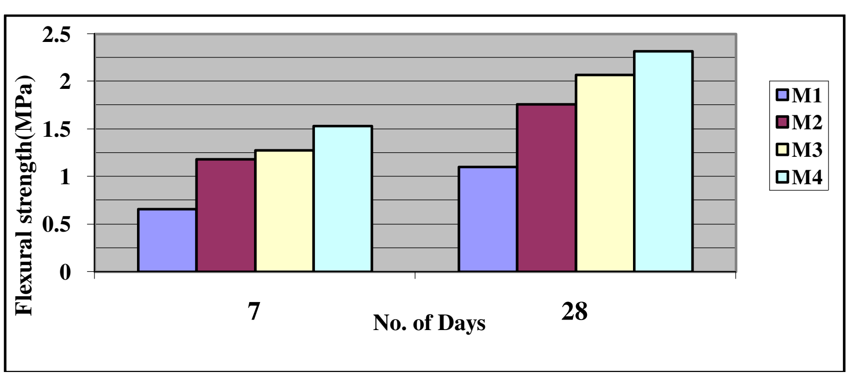

Fig. 5. Flexural Strength Test Results of SCC-I.

Table 12: Flexural strength of SCC-I mixes.

Mix	7 Days	28 Days
M1 (MPa)	0.66	1.10
M2 (MPa)	1.18	1.76
M3 (MPa)	1.28	2.07
M4 (MPa)	1.53	2.32

At age of 7 days M_1, M_2, M_3 and M_4 achieved 58%, 61%, 66% and 65% of the strength at 28 days, respectively. Flexural strength of M_6, M_7 and M_8 was increased by 50%, 72% and 92% at 28 days respectively, when compared to M_5. At age of 7 days M_1, M_2, M_3 and M_4 achieved 65%, 64%, 72% and 67% of the strength at 28 days, respectively.

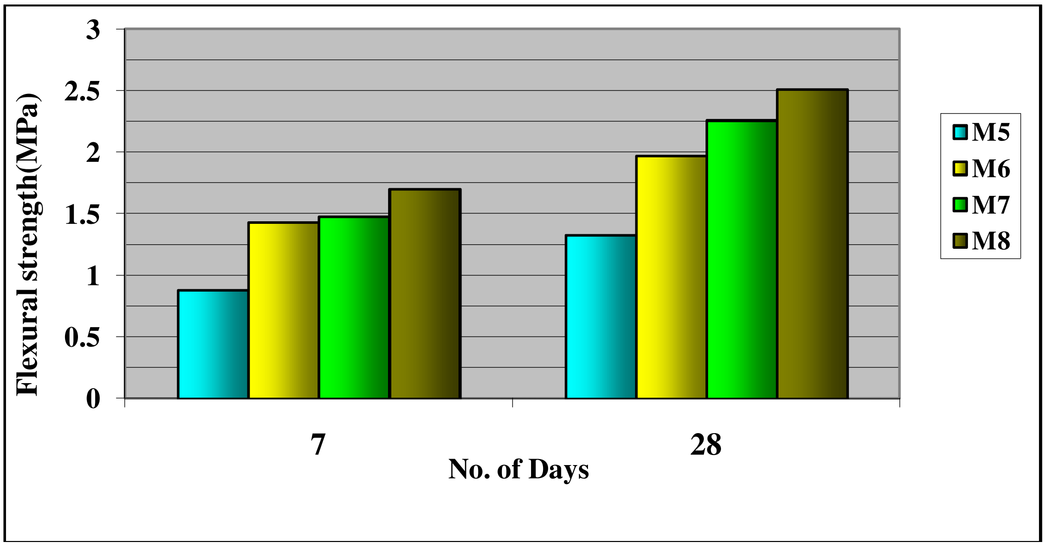

Fig. 6. Flexural Strength Test Results of SCC-II.

Table 13: Split tensile strength of SCC-II mixes.

Mix	7 Days	28 Days
M5 (MPa)	0.88	1.33
M6 (MPa)	1.43	1.97
M7 (MPa)	1.48	2.26
M8 (MPa)	1.70	2.51

On addition of 1.5% fibre content, increase of 115% and 92% in flexural strength at 28 days was achieved when compared to mix containing 0% fibre content.

Sengul et al. (2006) reported, using high performance SCC (cement content of 350 kg/m^3), increase of 27% at 28-day strength with fibre content of 1.5% (approx.).

Increase in flexural strength achieved at 7 and 28 days, is very high as compared to increase in strength reported in literature.

Various strengths of concrete such as compressive, split tensile, flexural are affected by many factors. These are compaction, curing conditions, aggregate size and mineralogy, admixture types, specimen geometry and moisture conditions, type of stress and rate of loading. Thus, the strengths are found to vary at various ages. In the present study, locally available materials were used. The variation in properties of the materials could be the reason for its variation from the results reported in literature.

Durability studies. Durability of concrete means its resistance to deteriorating influences, which may reside inside the concrete itself, or to the aggressive environments. The ability of concrete to resist weathering action, chemical attack, and abrasion is known as durability.

Factors affecting durability are surface wear, cracking due to crystallization of salts in pores, exposure to temperature extreme such as during frost action/ fire. Expansion reaction involving sulphate attack, alkali aggregate reaction and corrosion of embedded steel in concrete.

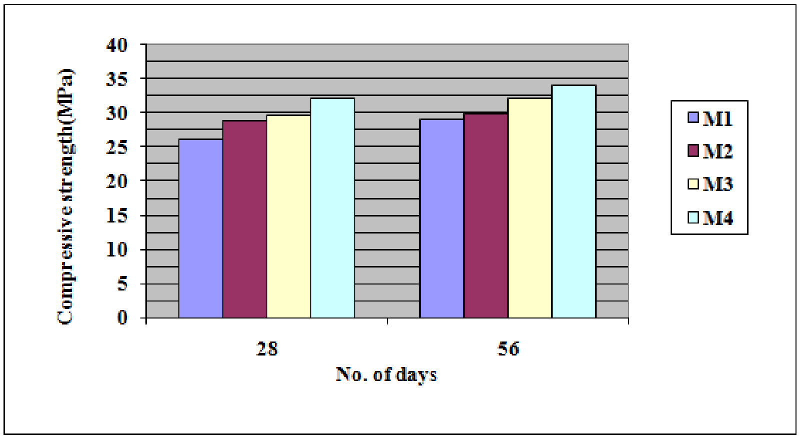

Fig. 7. Durability Test Results of SCC-I (1% Solution).

Table 14: Durability(1% solution) results of SCC-I.

Mix	28 Days	56 Days	56days/28days
M1 (MPa)	26.14	28.97	1.12
M2 (MPa)	28.81	29.91	1.04
M3 (MPa)	29.58	32.22	1.10
M4 (MPa)	32.21	34.03	1.05

The ratio between compressive strength for mixes M_1, M_2, M_3 and M_4 at ages 56days-to-28days was found to be vary from 1.05-1.12 as shown in Table 19, when cured in 1% sodium chloride and sodium sulphate solution. The decrease in 56-day compressive strength of M_1, M_2, M_3 and M_4, cured in 1% solution, was found to be 0.16%, 0.44%, 0.58% and 0.71%, when compared to specimen cured in water.

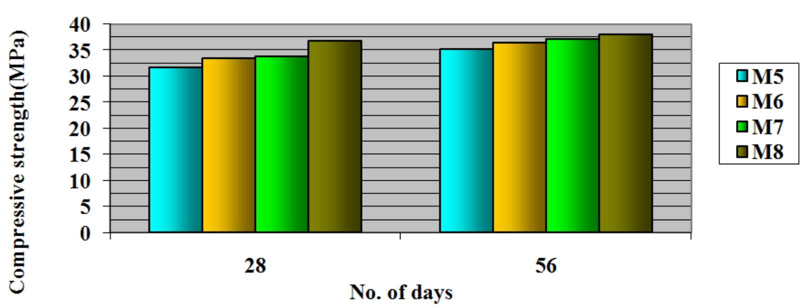

Fig. 8. Durability Test Results of SCC-II (1% Solution).

Table 15: Durability (1% solution) results of SCC-II mixes.

Mix	28 Days	56 Days	56days/28days
M5 (MPa)	31.63	35.18	1.11
M6 (MPa)	33.51	36.38	1.08
M7 (MPa)	33.81	37.21	1.10
M8 (MPa)	36.75	37.96	1.03

The ratio between compressive strength for mixes M_5, M_6, M_7 and M_8 at ages 56days-to-28days was found to be varying from 1.03-1.11 as shown in Table 20, when cured in 1% sodium chloride and sodium sulphate solution. The decrease in 56-day compressive strength of M_5, M_6, M_7 and M_8, cured in 1% solution, was found to be 0.12%, 0.32%, 0.41% and 0.48%, when compared to specimen cured in water.

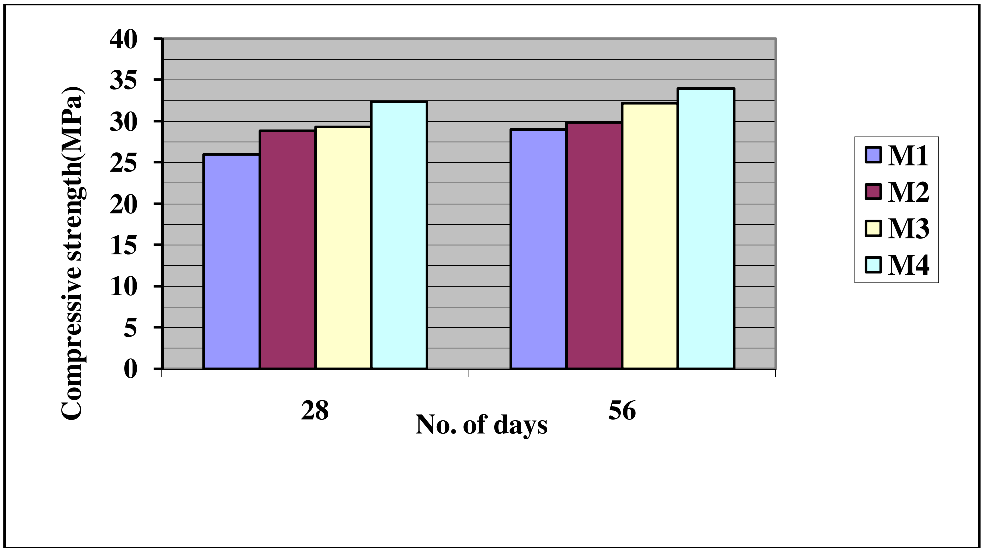

Fig. 9. Durability Properties of SCC-I (5% Solution).

Table 16: Durability (5% solution) results of SCC-I mixes.

Mix	28 Days	56 Days	56days/28days
M1 (MPa)	25.95	28.96	1.12
M2 (MPa)	28.87	29.85	1.03
M3 (MPa)	29.33	32.14	1.09
M4 (MPa)	32.35	33.96	1.05

The ratio between compressive strength for mixes M_1, M_2, M_3 and M_4 at ages 56days-to-28days was found to be varying from 1.05-1.12 as shown in Table 4.10, when cured in 5% sodium chloride and sodium sulphate solution. The decrease in 56-day compressive strength of M_1, M_2, M_3 and M_4, cured in 5% solution, was found to be 0.2%, 0.64%, 0.88% and 0.97%, when compared to specimen cured in water.

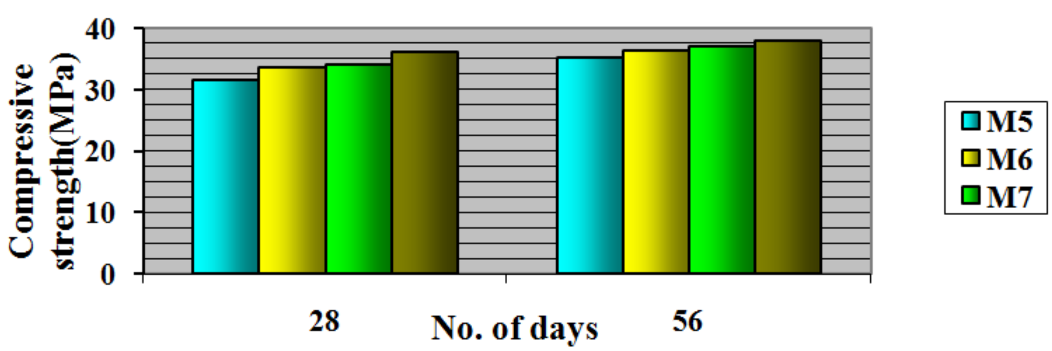

Fig. 10. Durability Properties of SCC-II (5% Solution).

Table 17: Durability (5% solution) results of SCC-II mixes.

Mix	28 Days	56 Days	56 days/28 days
M5 (MPa)	31.48	35.16	1.12
M6 (MPa)	33.71	36.31	1.07
M7 (MPa)	33.96	37.10	1.09
M8 (MPa)	36.15	37.85	1.05

The ratio between compressive strength of mixes M_5, M_6, M_7 and M_8 at ages 56days-to-28days was found to be varying from 1.05-1.12 as shown in Table, when cured in 1% sodium chloride and sodium sulphate solution. The decrease in 56-day compressive strength of M_5, M_6, M_7 and M_8, cured in 1% solution, was found to be 0.18%, 0.57%, 0.75% and 0.83%, when compared to specimen cured in water.

El-Dieb A.S. (2009) reported ratio between compressive strength (5% solution of sodium sulphate and sodium chloride) at 56days-to-28days was 1.1 at both 0% and 0.5% fibre content.

CONCLUSIONS

1. The fresh properties of all SCC mixes satisfied the ranges specified by EFNARC except M_4 as shown in Table 12.
2. The 28-day compressive strength of SCC-I mixes with fibre content of 0.5%, 1% and 1.5%, were found to be increased by 12%, 16% and 29%, when compared to strength at 0% fibre content.
3. The 28-day compressive strength of SCC-II mixes with fibre content of 0.5%, 1% and 1.5%, were found to be increased by 9%, 9.7% and 19.4%, when compared to strength at 0% fibre content.
4. The 28-day split tensile strength of SCC-I mixes with fibre content of 0.5%, 1% and 1.5%, were found to be increased by 21%, 23% and 30%, when compared to strength at 0% fibre content.
5. The 28-day split tensile strength of SCC-II mixes with fibre content of 0.5%, 1% and 1.5%, were found to be increased by 18%, 21% and 25%, when compared to strength at 0% fibre content.
6. The 28-day flexural strength of SCC-I mixes with fibre content of 0.5%, 1% and 1.5%, were found to be increased by 63%, 92% and 115%, when compared to strength at 0% fibre content.
7. The 28-day flexural strength of SCC-II mixes with fibre content of 0.5%, 1% and 1.5%, were found to be increased by 50%, 72% and 92%, when compared to strength at 0% fibre content
8. The ratio between compressive strength of mixes M_1, M_2, M_3 and M_4 at ages 56days-to-28days wad found to be vary from 1.02-1.14 as shown in Table 4.8 and 4.10, when cured in 1% and 5% sodium chloride and sodium sulphate solution.
9. The ratio between compressive strength of mixes M_5, M_6, M_7 and M_8 at ages 56days-to-28days was found to be varying from 1.04-1.13as shown in Table 4.9 and 4.11, when cured in 1% and 5%sodium chloride and sodium sulphate solution.
10. The decrease in 56-day compressive strength of M_1, M_2, M_3, M_4, M_5, M_6, M_7 and M_8, cured in 1% solution, was found to be 0.16%, 0.44%, 0.58%, 0.71%, 0.12%, 0.32%, 0.41% and 0.48%, when compared to specimen cured in water.
11. The decrease in 56-day compressive strength of M_1, M_2, M_3, M_4, M_5, M_6, M_7 and M_8, cured in 5% solution, was found to be 0.2%, 0.64%, 0.88%, 0.97%, 0.18%, 0.57%, 0.75% and 0.83%, when compared to specimen cured in water.
12. Thus, it could be concluded that SCC with fibres is an alternate to the normal concrete with fibres, with other advantages of SCC being used.

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