INVESTIGATION OF SELF-COMPACTING CONCRETE PAVEMENTS FOR CURLING STRESS BUILDING

Udhav S. Badgire[1], Ajay Swarup[2]

[1]Research Scholar, Departments of Civil Engineering, SOE, SSSUTMS, M.P. INDIA
[2] Professors, Departments of Civil Engineering, SOE, SSSUTMS, M.P. INDIA

ABSTRACT

The SCC mixes with CS were denser than the NS mixes. The density of the demoulded cube specimen for the SCC mix with CS was 0.72% more than the density of the demoulded cube specimen for the SCC mix with NS. The density of the CS mixes cured at 3, 7, 28 and 90 days was 0.8%, 1.08%, 1.98%, and 1.67% more than the NS mixes cured at the same ages. With respect to the density of the demoulded cube specimen for NS mix, the rate of increase in density for the NS mix cube specimen at 3 days, 7 days, 28 days and 90 days was 0.92%, 2.37%, 3.33% and 4.35% respectively. Similarly, for the CS mix cube specimen, the density increase at 3, 7, 28 and 90 days was 1%, 2.72%, 4.63% and 5.32% with respect to the density of the demoulded CS cube specimen. Thus, the rate of increase in the cube density for CS mixes is relatively more than the rate of increase in the cube density for NS mixes.

1. OVERVIEW

The concrete pavements, environmental loads on concrete pavements and temperature effects on concrete pavements are presented. The second section discusses the findings from the literature survey related to SCC. The chapter concludes with the key findings from the literature review that helped define the research problem and objectives.

1.1 Rigid or Concrete pavements:

A pavement is an engineering system. Its analysis and design includes interaction of naturally available supporting layers, the constructed layers and nature and magnitude of the applied loads [1]. Rigid pavements are essentially made of Portland cement concrete. The use of cement concrete as a construction material is on account of economic reasons and ease in availability of the concrete ingredients. The concrete pavement is designed as a long lasting all weather structure for modern day high speed traffic. As per Tayabji and Lim 2007 [2], the design of long lasting concrete pavement includes:

1. Adequate structural slab thickness
2. Strong erosion resistant bases
3. Doweled transverse joints.

For the concrete pavement to achieve its functional requirement, following aspects related to design and construction of the pavements are important:

- Determination of soil properties, design, traffic loads and environmental parameters
- Selection of appropriate materials for various pavement layers
- Structural design to determine adequate thickness of pavement layer
- Design of drainage system

- Safety and geometric design.

1.1.1 Environmental Load analysis of Concrete Pavements:

The concrete pavement is designed for repeated traffic loading that influences the fatigue life of the material. The daily traffic load is a major design factor considered for concrete pavements. The fatigue failure of the concrete pavement occurs on the account of repetitive action of wheel loads, whose magnitude may be less than the failure load of the material [3]. Apart from traffic loads, environmental loads are also to be considered in the design of concrete pavements. These loads determine the plan dimensions of the pavement slab, design of the temperature reinforcement to control crack width & crack spacing and joint & joint reinforcement for effective load transfer between adjacent slab panels.

The environmental factors that affect the performance of concrete pavements include temperature, humidity, precipitation and frost/heave [4]. The environmental factors induce various types of stresses/strains in the concrete pavements. The stresses developed in the concrete pavements on account of temperature can be of two types, curling stress and thermal expansion stress [5]. The curl induces stress in the slab which is restrained by its self-weight and the slab sub-base or sub-grade interaction.

Based on the location of traffic load and time of the day, the magnitude of the curling stress can be high enough to cause failure of the slab. The non-linear temperature distribution causes higher tensile stresses than the linear temperature distribution. This difference was in the range of 3% to 13.5% of the modulus of rupture of concrete [6]. Temperature stresses can also occur in concrete slabs due to variations in the uniform temperature. The variation in the uniform temperature causes the slab to expand and contract. If this movement of slab is resisted on account of friction between the concrete slab and subgrade or sub-base, then it induces tensile stresses. These stresses are dependent on the friction factor between slab and the sub-base as well as slab geometry [7].

2. Cement:

53 grade Ordinary Portland Cement (OPC) (IS 12269: 1987) was used for all the laboratory trials performed in the present study. Various properties of the cement (as per test certificate from cement plant) have been tabulated in Table 2.1.

Table 2.1: Properties of Cement

Physical properties of Cement			
Property		**Test Result**	**IS 12269: 1987 requirement**
Fineness (m^2/kg)		290	225
Standard Consistency (%)		29	----
Initial Setting time (minutes)		180	30 (Min.)
Final Setting time (minutes)		250	600 (Max.)
Le-Chatelier Expansion (mm)		0.5	10 (Max.)
Chemical Composition of Cement			
$CaO - 0.7SO_3$ $2.8SiO_3 + 1.2Al_2O_3 + 0.65\ Fe_2O_3$		0.88	0.8 (Min.) 1.02 (Max.)
Al_2O_3/Fe_2O_3		1.24	0.66 (Min.)
Insoluble residue (% by mass)		1.88	2.00 (Max.)
Magnesia (% by mass)		0.90	6.00 (Max.)
Sulphuric Anhydride (% by mass)		1.80	3.00 (Max.)
Total loss on ignition (% by mass)		1.80	4.00 (Max.)
Total Chlorides (% by mass)		0.008	0.10 (Max.)
Mechanical Property of Cement (Compressive Strength MPa)			
3 days (72 hrs. ± 1 hr.)		38.0	27 (Min.)
7 days (168 hrs. ± 1 hr.)		51.0	37 (Min.)
28 days (672 hrs. ± 1hr.)		71.5	53 (Min.)

2.2 Fly ash:
The chemical composition of the fly ash sample (as per the test certificate received from the supplier) is presented in Table 2.2

Table 2.2: Chemical Composition of Fly ash

Component	Percentage
SiO_2	56.54%
Al_2O_3	23.66%
CaO	11.61%
Na_2O	2.18%
K_2O	2.85%
MgO	0.92%
Fe_2O_3	4.65%
Mn_3O_4	0.13%
TiO_2	1.37%
P_2O_5	1.58%
SO_3	0.48%

As per IS: 3812 (Part I) 2003, fly ash can be classified as a calcareous pulverized fuel ash (reactive CaO not less than 10% by mass) and siliceous pulverized fuel ash (reactive CaO less than 10% by mass). As per ASTM standards, fly ash is classified as Class C fly ash (obtained from combustion of lignite or sub-bituminous coal) and Class F fly ash (obtained from combustion of bituminous coal). Class C fly ash possesses pozzolanic as well as hydraulic properties, while Class F fly ash exhibits pozzolanic properties only. Both the classes of fly ash help in improving the workability of the concrete mix. However, Class C flyash contributes to the gain in later age (beyond 28 days) strength on account of its hydraulic properties (Berry et al. 1980, Price, 1975). The reactivity of fly ash and its contribution in strength development of concrete depends on flyash properties, its chemical composition, particle size along with temperature and curing conditions. Apart from workability improvement and reduction in HRWR dosage, addition of flyash also helps in reducing the heat of hydration and minimizes the adverse effect of alkali aggregate reaction [1-2].

2.3 Aggregates (Coarse and Fine):
The aggregates were procured from a local quarry. Various tests prescribed in IS 2386 (Part I to IV), 1963, were performed on the sample considered in the study. The summary of test results is summarized and presented in Table 2.3.

Table 2.3: Properties of Aggregates

Properties of Coarse Aggregates			
Property	**IS Code**	**Test Result**	
Flakiness Index (%)	IS 2386 (Part I) – 1963	7.87	
Elongation Index (%)	IS 2386 (Part I) – 1963	30.71	
Specific Gravity	IS 2386 (Part III) – 1963	2.62	
Water Absorption (%)	IS 2386 (Part III) – 1963	0.8	
Bulk Density (Loose) kg/m3	IS 2386 (Part III) – 1963	1472.83	
Bulk Density (Compacted) kg/m3	IS 2386 (Part III) – 1963	1489.13	
Aggregate Impact Value (%)	IS 2386 (Part IV) – 1963	25.02	
Aggregate Crushing Value (%)	IS 2386 (Part IV) – 1963	30.24	
Los Angeles Abrasion Value (%)	IS 2386 (Part IV) – 1963	19.41	
Properties of Fine Aggregates			
		NS	**CS**
Specific Gravity	IS 2386 (Part III) – 1963	2.68	2.70
Bulk Density (Loose) kg/m3	IS 2386 (Part III) – 1963	1630.44	1648.23
Bulk Density (Compacted) kg/m3	IS 2386 (Part III) – 1963	1739.31	1751.14

Fineness Modulus		2.56	2.67

2.4 HRWR Admixture or Superplasticizer:

The properties of HRWR superplasticizer used in the present study as received from the supplier are summarized and tabulated below in Table 2.4

Table 2.4: Properties of Superplasticizer

Property	Test Result
Colour	Light brown
Relative density	1.08 ± 0.01 at 25 ^{o}C
pH	≥ 6
Chloride ion content	< 0.2%

2.5 Fresh state properties of SCC mix with NS and CS

As per EFNARC guidelines, the filling ability and stability of the SCC mixes, in fresh state, is defined by four characteristics as explain in chapter 3. It also prescribes the testing protocols suitable to measure these characteristics.

The slump flow and J-ring spread for SCC mix with NS is cohesive and uniform. The mortar halo (bleed water) at the periphery of the spread is negligible. On the contrary, for SCC mix with CS, the slump flow and J-ring spread is segregated with pronounced mortar halo at the periphery. The V-funnel test also showed a relatively cohesive mix at the end of the test indicating negligible segregation. Table 2.5 presents the results of fresh state properties of SCC mixes with NS and CS.

Table 2.5: Fresh state properties of SCC mixes with NS and CS

Property	SCC mix with NS	SCC mix with CS
Slump flow (mm)	610	590
T50 (s)	5.2	5.6
V-Funnel time (s)	13	14.5
VSI	0	2
J-ring flow (mm)	605	580

From the results of the fresh state properties it was observed that,

1. The slump flow of SCC mix with CS was 3.28% less than the slump flow for SCC mix with NS.
2. The T50 times were almost comparable. Due to round shape and smooth texture of NS particles, the T50 time required for SCC mix with NS was lower than CS mixes.
3. The V-funnel emptying time was 11.5% more for SCC mix with CS than SCC mix with NS.
4. VSI indicates SCC mix with CS had a pronounced mortar halo.
5. With the introduction of J-ring, the flow of the concrete reduced due to the obstructions. However the, rate of flow reduction was low in SCC mix with NS (0.8%) as compared to CS mixes (2.59%). This was attributed to the particle shape and texture of the fine aggregates used in the respective mix. The NS was mainly composed of rounded smooth particles. These particles aid in uniform spread of the mix without segregation. The CS particles were angular and have rough surface texture leading to inter-particle friction (Sideris. 2007) which affects the flow spread

2.6 Hardened state properties of SCC mix with NS and CS:

As discussed earlier, the cube specimens were first subjected to NDT tests and then tested for compressive strength. The tests were performed at 3 days, 7 days, 28 days and 90 days. The flexural strength tests were performed at 7 days and 28 days. The cube and beam specimens were subjected to wet curing by submerging the sections in the water tank as shown in Fig. 2.1.

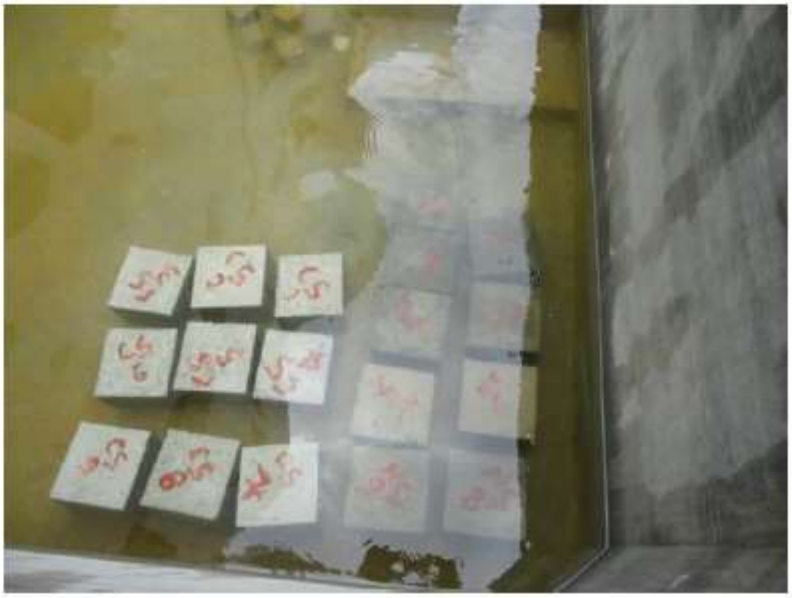

Fig. 2.1: Curing of SCC mix specimens

Fig. 2.2 a, 2.2 b, 2.2 c, 2.2 d and 2.2 e presents the graphs for the test results on the experimental trial undertaken.

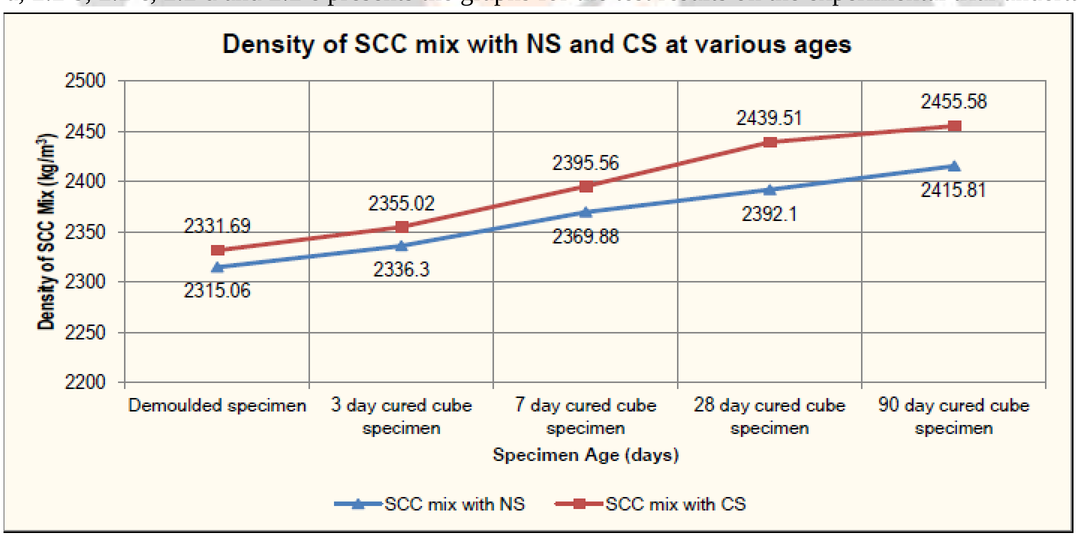

Fig. 2.2a: Variation in the density of the SCC mixes with NS & CS at various ages

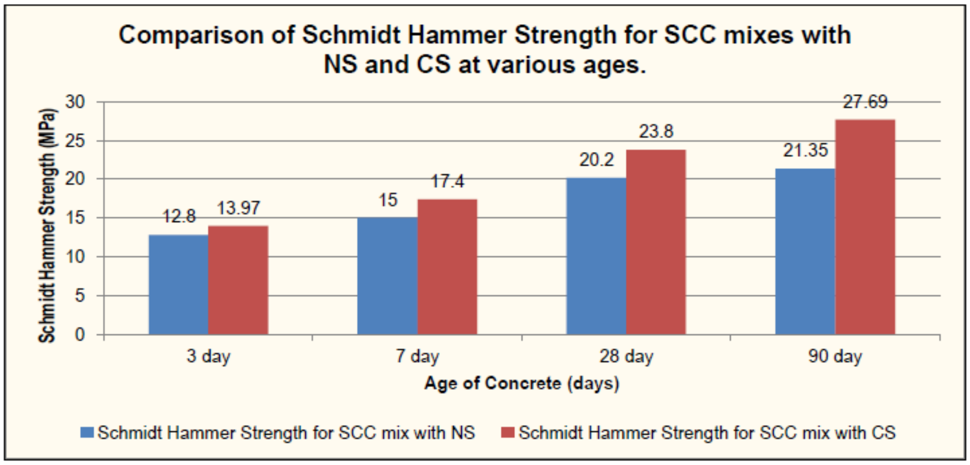

Fig. 2.2b: Variation in the Schmidt Hammer Strength for the SCC mixes with NS & CS at various ages

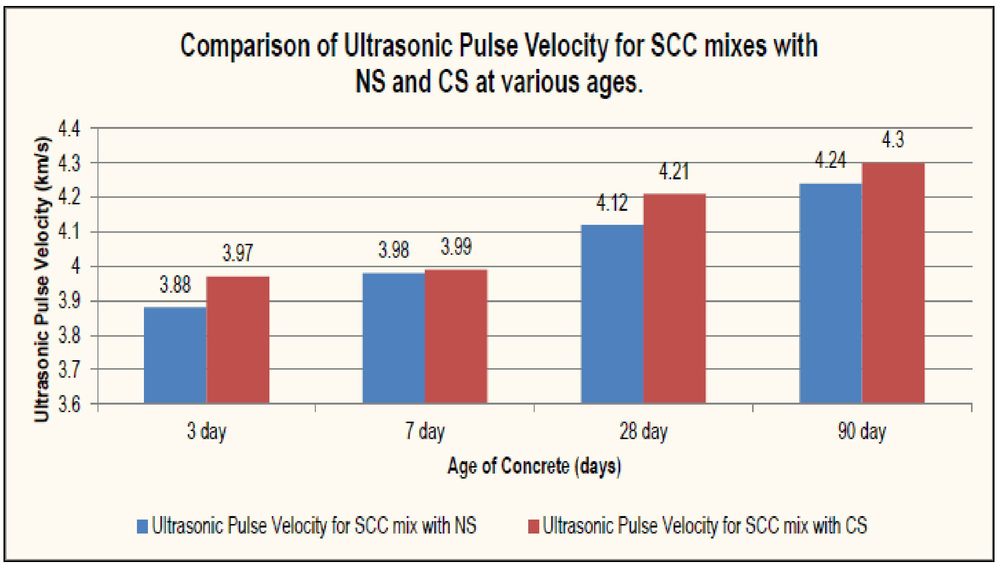

Fig. 4.2c: Variation in the Ultrasonic Pulse Velocity for the SCC mixes with NS & CS at various ages

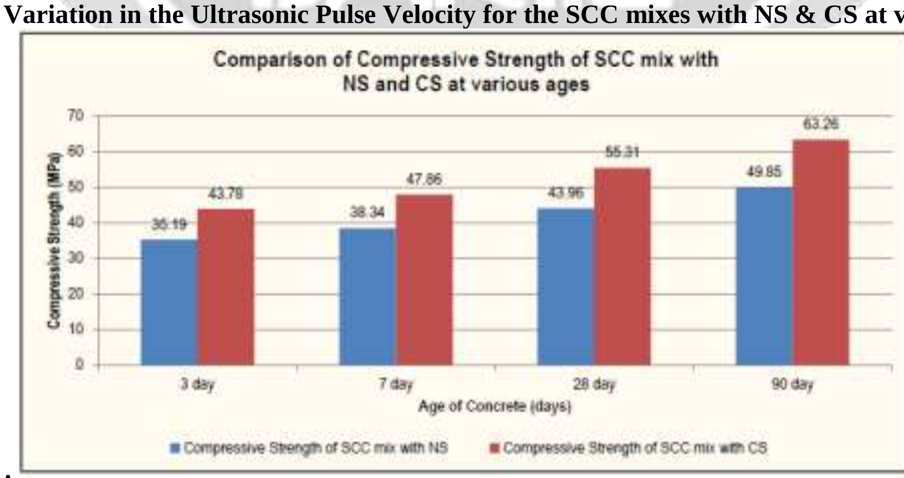

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Fig 2.2d: Variation in the Compressive Strength of the SCC mixes with NS & CS at various ages

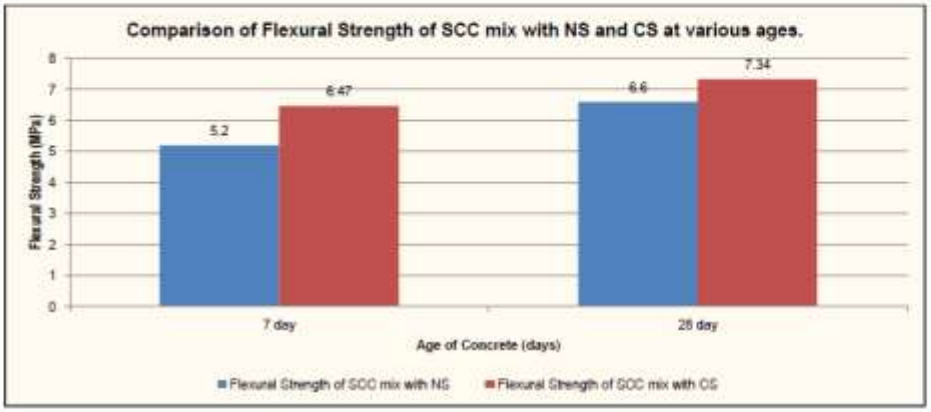

Fig. 2.2e: Variation in the Flexural Strength of the SCC mixes with NS & CS at various ages

From the above test results, following points were inferred,

3. DENSITY

1. SCC mixes with CS were denser than the NS mixes. The density of the demoulded cube specimen for the SCC mix with CS was 0.72% more than the density of the demoulded cube specimen for the SCC mix with NS. The density of the CS mixes cured at 3, 7, 28 and 90 days was 0.8%, 1.08%, 1.98%, and 1.67% more than the NS mixes cured at the same ages.
2. With respect to the density of the demoulded cube specimen for NS mix, the rate of increase in density for the NS mix cube specimen at 3 days, 7 days, 28 days and 90 days was 0.92%, 2.37%, 3.33% and 4.35% respectively. Similarly, for the CS mix cube specimen, the density increase at 3, 7, 28 and 90 days was 1%, 2.72%, 4.63% and 5.32% with respect to the density of the demoulded CS cube specimen. Thus, the rate of increase in the cube density for CS mixes is relatively more than the rate of increase in the cube density for NS mixes.
3. The variation in the densities of the NS and CS mixes is attributed to the particle shape, size and packing of the fine materials in the matrix phase of the concrete mixes. For the given mix design, the NS mixes exhibited lower densities due to large sized, round shaped and smooth textured particles of the fine aggregates.

This reduced the density of the matrix phase and overall density of the concrete. On the contrary, in the CS mixes, the fine aggregate particles were uniform sized, angular and rough textured leading to efficient particle packing arrangement in the matrix phase. This resulted in overall denser matrix leading to higher densities for the cube specimen.

4. Apart from the particle shape and size, the packing of the particles in the matrix phase affects its overall service life performance also. The NS mix beam specimen shows voids in the cross section, while the CS mix beam showed a denser matrix with negligible voids.

3.1 Schmidt Hammer test:

For the Schmidt hammer test, the compressive strength values obtained (by correlating the rebound index and compressive strength values from the calibration chart supplied by the equipment supplier) for CS mixes was 8.38%, 16%, 17.82% and 29.69% more than the NS mixes at 3, 7, 28 and 90 days respectively. The rebound hammer or Schmidt hammer test results indicated that the CS mixes had a hard surface as compared to the NS mixes.

3.2 Ultrasonic Pulse Velocity:

The test results for the ultrasonic pulse velocity tests indicated that the test results were relatively comparable. As per IS 13311 (Part 1) 1992, both the concrete mixes (NS as well as CS) can be termed as good quality.

3.3**Cube Compressive Strength:**

1. The compressive strength values recorded for the CS mix was more than the NS mix.
2. The compressive strength values for the SCC mix with CS was 24.41%, 18.09%, 23.02% and 22.01% more than the compressive strength values for NS mixes at 3, 7, 28 and 90 days.
3. With respect to the 3 day compressive strength, the rate of increase in the compressive strength at 7, 28 and 90 days for the SCC mix with NS was 8.95%, 24.92% and 41.66% respectively. Similarly for the CS mixes, the rate of strength gain for CS mixes at 7, 28 and 90 days, was 9.32%, 26.34% and 44.49% respectively.

3.4Beam Flexural Strength:

The flexural strength performance of the SCC mix with CS was better than the NS mix. The 7 and 28 day flexural strengths for CS mixes were 24.42% and 11.21% more than the NS mixes.

From the above observations it was inferred that the compressive strengths of the SCC mix with CS was higher than the compressive strength of the SCC mix with NS. This was supported by the microstructure images obtained from the thin section petrographic analysis.
Thus, it was observed that though SCC mix with NS satisfied the flexural strength criteria for pavement application, it did not conform to the compressive strength requirement prescribed.
Hence, from the above experiment trial, it was concluded that the SCC mix with CS satisfied the flexural strength as well as compressive strength requirement for pavement application and hence, for the subsequent experimental studies, M-40 grade SCC mix with CS was adopted. This mix was termed as Mix A.

2.6.1 Fresh state properties:

Table 2.7 presents the fresh state properties for the 9 mixes tested

Table 2.7: Summary of fresh state properties of SCC mixes for fly ash dosage trials

Mix Details	Slump flow (mm)	T50 (s)	V-Funnel (s)	VSI	J-ring flow (mm)
Mix1	590	5.6	14.5	2	580
Mix2	590	5.6	14.5	1	580
Mix3	595	5.6	14.2	1	585
Mix4	596	5.6	14.1	1	585
Mix 5	597	5.5	14	0	590
Mix6	590	5.5	14	0	590
Mix7	600	5.2	13.7	0	596
Mix8	603	5.2	13.5	0	597
Mix9	610	5	13.0	0	600

Based on the above results, following points were inferred for the fresh state properties of SCC mix with CS and varying fly ash dosages;

1. The addition of fly ash to the SCC mix helped in reducing the HRWR dosage. This is on account of improved particle size distribution in the cement fly ash mix which improves paste fluidity and decreases its viscosity.
2. It was observed that the effect of addition of fly ash on the improvement of the fresh state properties was observed from 10% dosage levels (Mix 3).
3. With the increase in fly ash dosages, the slump flow values increased steadily. With respect to Mix 1 (0% fly ash), the increase in slump flow values were 0.85%, 1.02%, 1.2%, 1.36%, 1.7%, 2.2% and 3.4% from Mix 3 to Mix 9 respectively.
4. The J-ring flow patterns were also similar to the slump flow pattern.
5. The T50 time was comparable up to Mix 5. At 30% and 35% addition level (Mix 7 and 8), the decrease in T50 time was 7.14% with respect to Mix 1. For Mix 9, this decrease was 10.7%. The fly ash addition also helps in reducing the V-funnel emptying time.
6. The improvement in the fresh state properties of the SCC mix was on account of the spherical shape (Hanneson et al. 2012 and Burgos-Montes et al. 2012) of the fly ash particles which impart lubrication effect to the matrix phase during the flow of the mix. This reduces the friction between the particles and ensures uniform, cohesive and speedy flow.
7. The addition of fly ash, in stages, helped to minimize the mortar halo (VSI = 0) from Mix 5 onwards. The addition of fly ash absorbs the excess bleed water thereby decreasing the tendency of segregation [3-5].

Graphical representation of variation in the slump flow values and T50 time with increase in fly ash dosage from Mix 1 to Mix 9 in presented through Fig. 2. 3.

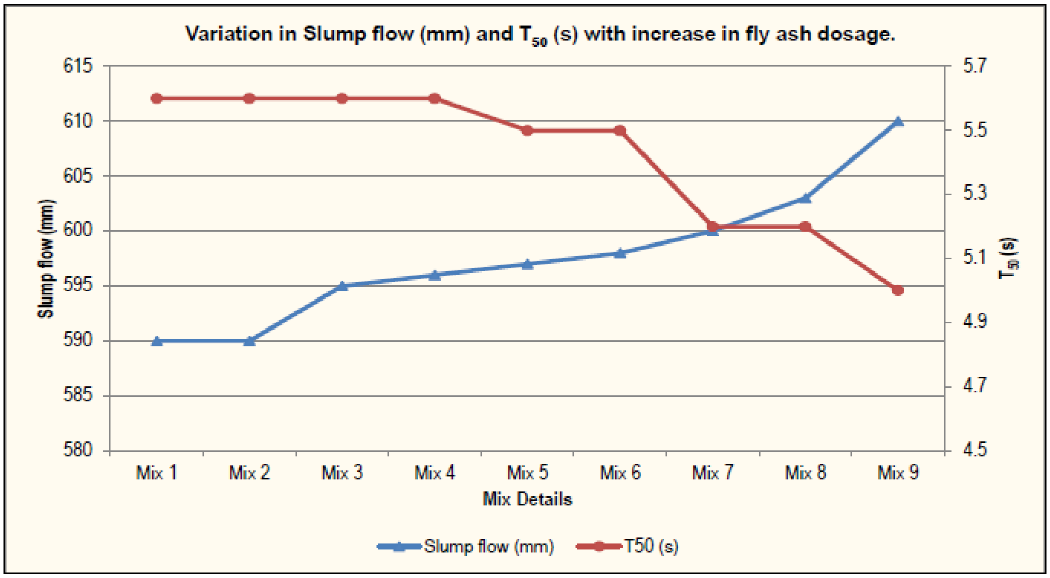

Fig. 2.3: Variation in slump flow and T50 time for SCC mix with CS and varying fly ash dosage

Thus, the addition of fly ash to SCC mix offers a dual advantage of reduced cement usage and lower dosage of HRWR admixture for achieving a particular degree of workability and other fresh state properties of the SCC mix.

Table 2.8 (a) presents the summary of density of the SCC mixes tested for determination of appropriate dosage of fly ash as a cement replacement additive.

Table 2.8 (a): Summary of density of SCC mixes for variation in fly ash dosage

Mix Details	Fly ash dosage (%)	Density of Cube Specimen (kg/m^3)				
		Demoulded	3 days	7 days	28 days	90 days
Mix1	0	2331.69	2355.02	2395.56	2439.51	2455.58
Mix2	5	2329.30	2354.57	2392.27	2413.32	2424.34
Mix3	10	2321.48	2354.34	2380.12	2409.34	2412.11
Mix4	15	2318.52	2334.82	2378.15	2398.54	2409.34
Mix 5	20	2316.07	2326.92	2375.29	2396.72	2409.07
Mix6	25	2310.12	2322.93	2369.34	2388.64	2396.54
Mix7	30	2307.66	2320.18	2363.83	2388.64	2396.54
Mix8	35	2306.76	2317.64	2359.22	2375.81	2385.34
Mix9	40	2306.16	2312.09	2354.81	2365.34	2382.22

Fig. 2. 4 presents the graphical trend of variation in the density of SCC mix with CS and varying dosage of fly ash as a cement replacement additive.

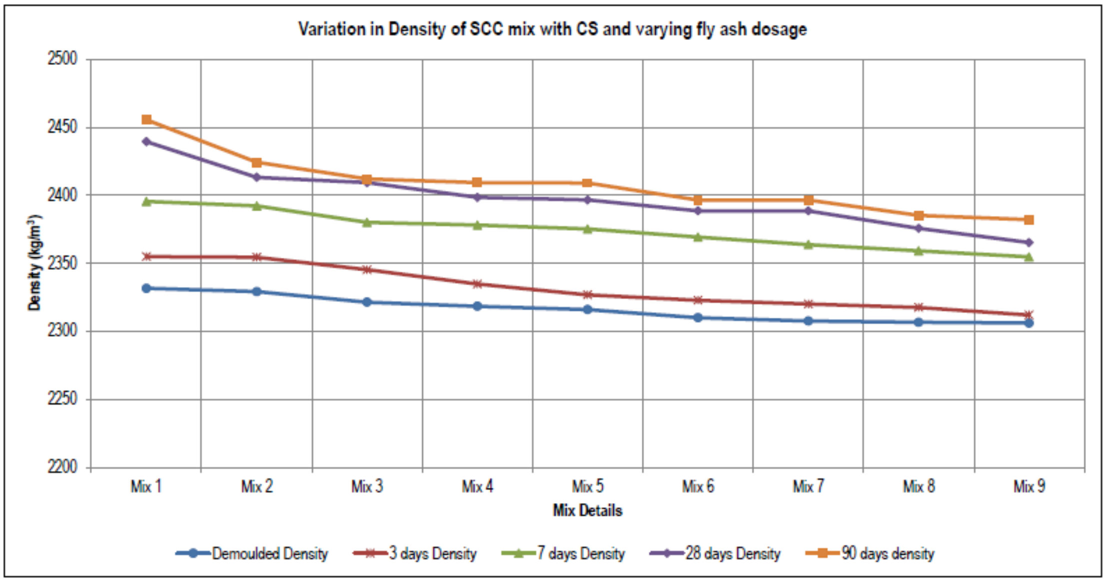

Fig. 2.4: Variation in density for SCC mix with CS and varying fly ash dosage

Table 2.8 (b) presents the comparison of demoulded density values for SCC mixes with varying fly ash dosage (Mix 2 to Mix 9) with respect to the demoulded density of Mix 1. It highlights the trend of decrease in the demoulded densities with increase in the fly ash dosage.

Table 2.8 (b): Comparison of demoulded densities of SCC mix with varying fly ash dosage with respect to the control mix

Mix Details	Fly ash dosage (%)	% drop in demoulded density with respect to Mix 1
Mix1	0	----
Mix2	5	0.11
Mix3	10	0.44
Mix4	15	0.57
Mix 5	20	0.67
Mix6	25	0.93
Mix7	30	1.03
Mix8	35	1.07
Mix9	40	1.09

Table 2.8 (c) presents the comparison of gain in the 28 day and 90 day densities with respect to the demoulded density of each mix.

Table 2.8 (c): Comparison of 28 day and 90 day densities with demoulded density

Mix Details	Fly ash dosage (%)	% gain in 28 day density with demoulded density	% gain in 90 day density With demoulded density
Mix1	0	4.62	5.32
Mix2	5	3.61	4.08
Mix3	10	3.78	3.91
Mix4	15	3.45	3.91
Mix 5	20	3.48	4.02
Mix6	25	3.40	3.74
Mix7	30	3.12	3.6

Mix8	35	2.99	3.41
Mix9	40	2.57	3.29

From the above test results following points were concluded,
1. Increment in the fly ash dosage has resulted in the decrease in the density of test specimen.
2. Comparing the demoulded densities of the SCC mixes with fly ash dosages with the demoulded density of Mix 1, the reduction in the demoulded densities was steady up to 20% fly ash dosage. At 25% fly ash dosage a significant reduction was observed which remains steady up to 40% fly ash dosage.
3. The gain in 28 day density of cube specimen with respect to the demoulded density, was maximum in case of Mix 1. The rate of gain in 28 day density dropped steadily up to 25% fly ash dosage (Mix 6). Further, the rate of gain in 28 day density for remaining mixes (Mix 7, 8 and 9) dropped significantly.
4. In case of 90 day density, the rate of gain in density with respect to the demoulded density was high in case of Mix 1. With increasing fly ash dosage, the rate of gain in the 90 day density dropped at a steady rate up to Mix 5. From Mix 6 onwards, again a steady decrease in the rate of density gain was observed.
5. The replacement of cement with light weight additive like fly ash [3-5] decreased the density of the matrix phase.
6. Thin section petrographic image of SCC mix is presented in Fig. 4.15. The specimens used for the petrographic analysis were cured for 28 days. Two representative specimens were selected viz. specimen without any fly ash addition (Mix 1) and the specimen containing 20% fly ash as a cement replacement additive. The image on the left side represents SCC mix without any fly ash (Mix 1). The matrix is dark coloured and dense. The image on the right side represents the specimen with 20% fly ash in the matrix. The colour of the matrix is brown coloured. It indicates the relative effect of replacing the cement with fly ash leading to lighter matrix as reflected from the density values.

Schmidt Hammer Test:

Before the samples were subjected to the destructive testing, they were subjected to Schmidt Hammer test. The test observations for all the mixes were are summarized in Fig below.

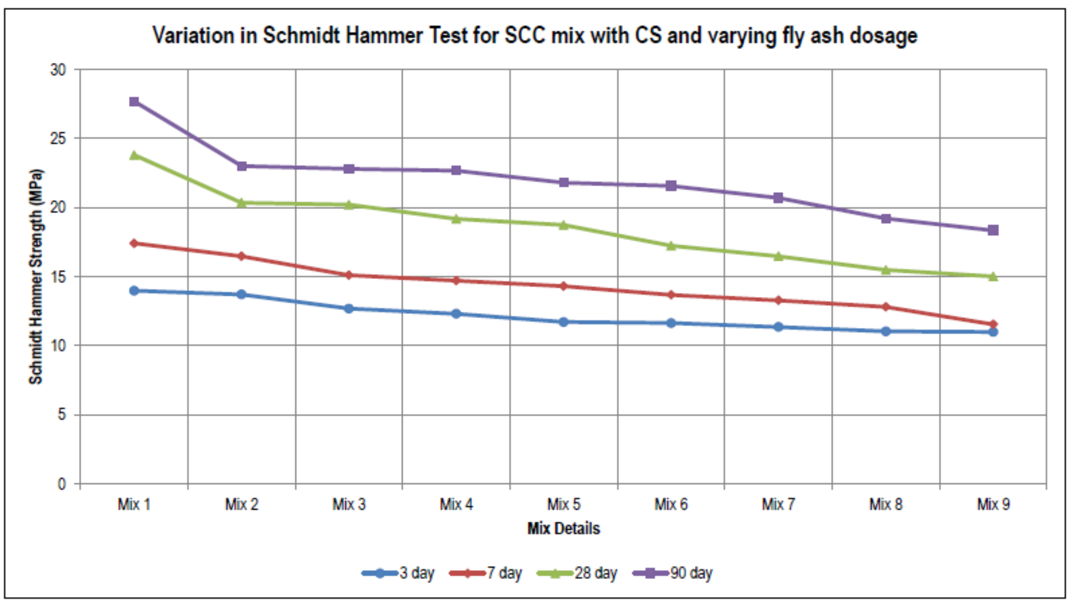

Fig. 2.5: Variation in Schmidt Hammer Test for SCC mix with CS and varying fly ash dosage

Table 2.9 presents the % drop in the 28 day and 90 day Schmidt Hammer test results for SCC mix with varying fly ash dosage with respect to the corresponding Schmidt hammer test result for Mix 1 (control mix).

Table 2.9: Comparison of 28 day and 90 day Schmidt Hammer test for SCC mix with varying fly ash dosage with respect to the control mix

Mix Details	Fly ash dosage (%)	% drop in 28 day Schmidt Hammer test with respect to Mix 1	% drop in 90 day Schmidt Hammer test with respect to Mix 1
Mix1	0	--	--
Mix2	5	14.54	16.94
Mix3	10	15.13	17.66
Mix4	15	19.45	18.13
Mix 5	20	21.30	21.27
Mix6	25	27.61	22.10
Mix7	30	30.79	25.24
Mix8	35	35	30.55
Mix9	40	36.98	33.77

4. CONCLUSION

It is observed that with increasing dosage of fly ash, the Schmidt Hammer strength is decreasing. A steady drop in 28 day Schmidt hammer values was observed up to Mix 5 (20% fly ash dosage). With further increase in fly ash dosage, the drop was more pronounced (27.61% less) with respect to the Schmidt Hammer values for the control mix. This indicated that the appropriate fly ash dosage as a cement replacement was in the range of 20% to 25% cement replacement level. The trend in the drop of the 90 day Schmidt Hammer values was uniform with respect to the 90 day Schmidt Hammer values for the control mix .The results indicated that the SCC mixes with fly ash require more time to develop hard surface. This is an indicator of later age (beyond 28 days) strength gain of concrete mixes with fly ash addition.

5. REFERENCES

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