

Shrinkage of High Strength Concrete

S.M. Gupta, V.K. Sehgal, S.K. Kaushik

Abstract—This paper presents the results of an experimental investigation carried out to evaluate the shrinkage of High Strength Concrete. High Strength Concrete is made by partially replacement of cement by flyash and silica fume. The shrinkage of High Strength Concrete has been studied using the different types of coarse and fine aggregates i.e. Sandstone and Granite of 12.5 mm size and Yamuna and Badarpur Sand. The Mix proportion of concrete is 1:0.8:2.2 with water cement ratio as 0.30. Superplasticizer dose @ of 2% by weight of cement is added to achieve the required degree of workability in terms of compaction factor.

From the test results of the above investigation it can be concluded that the shrinkage strain of High Strength Concrete increases with age. The shrinkage strain of concrete with replacement of cement by 10% of Flyash and Silica fume respectively at various ages are more (6 to 10%) than the shrinkage strain of concrete without Flyash and Silica fume. The shrinkage strain of concrete with Badarpur sand as Fine aggregate at 90 days is slightly less (10%) than that of concrete with Yamuna Sand. Further, the shrinkage strain of concrete with Granite as Coarse aggregate at 90 days is slightly less (6 to 7%) than that of concrete with Sand stone as aggregate of same size. The shrinkage strain of High Strength Concrete is also compared with that of normal strength concrete. Test results show that the shrinkage strain of high strength concrete is less than that of normal strength concrete.

Keywords—Shrinkage high strength concrete, fly ash, silica fume & superplasticizers.

I. INTRODUCTION

SHRINKAGE is the decrease of concrete volume with time. This decrease is due to change in moisture content of the concrete and physio-chemical changes, which occur without stress attributable to actions external to the concrete. Swelling is the increase of concrete volume with time. Shrinkage and Swelling are usually expressed as dimensionless strain (in/in. or mm/mm). Under given conditions of relative humidity and temperature, shrinkage is primarily a function of the paste, but is significantly influenced by the stiffness of the coarse aggregate. The interdependence of many factors creates difficulty in isolating causes and effectively predicting shrinkage without extensive testing.

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II. LITERATURE REVIEW

A. Shrinkage of High Strength Concrete

The shrinkage properties of high strength concrete are summarized in ACI committee 363 [1]. The basic conclusions are.

- (i) Shrinkage is unaffected due to low w/c ratio[2], but is approximately proportional to the percentage of water by volume in concrete.
- (ii) Shrinkage of HSC containing high range water reducer is less than that of NSC[3].
- (iii) HSC exhibits relatively higher initial rate of shrinkage[4, 5]. After drying for 180 days, there is little difference between the shrinkage of HSC and NSC made with dolomite or lime stone aggregates. Reducing the curing period from 28 to 7 days causes a slight increase in the shrinkage[4].

Shrinkage of HSC may be expected to differ from NSC in three broad areas as:

B. Plastic Shrinkage, Autogenous Shrinkage and Drying Shrinkage

Plastic shrinkage occurs during the first few days after fresh concrete is placed. During this period moisture may evaporate faster from the concrete surface than it is replaced by bleed water from layers of the concrete mass. Paste of rich mixes such as high strength/performance concrete, will be more susceptible to plastic shrinkage than normal concrete.

Autogenous shrinkage, due to self desiccation, is perhaps more likely at very low water cement ratio. There is little data available for high strength concrete on autogenous shrinkage[6].

Drying shrinkage occurs after the concrete has already

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attained its final set and a good portion of the chemical hydration process in the cement gel has been accomplished. Drying shrinkage of high strength concrete, although perhaps potentially larger due to higher paste volumes, do not, in fact appear to be appreciably large than normal strength concrete. This is probably due to the increase in stiffness of stronger mixes. The shrinkage can be estimated from Schoree's formula [7] as :

$$\epsilon_s = 0.00125 (0.95-h) \quad (1)$$

where ϵ_s = Shrinkage strain, h = Relative humidity expressed as a fraction

The rate of shrinkage decreases with time. The tests indicate that 14 to 30 percent of 20 years shrinkage occurs in two weeks, 40 to 70 percent in three months and 65 to 80 percent in one year[7].

C. Effect of Silica fume, Fly ash and Chemical Admixtures on Shrinkage of Concrete

Pozzolanic materials like silica fume Fly ash and typically increase the dry shrinkage due to several factors. With adequate curing pozzolans generally increase pore refinement. Use of a pozzolans results in an increase in the relative paste volume due to two mechanisms. Pozzolans have a lower specific gravity than Portland cement and in practice more slowly reacting pozzolans such as silica fume and Fly ash are frequently added in order to attain specified strength at 28 days. Additionally, pozzolans such as fly ash and silica fume do not contribute significantly to early age strength. Pastes containing pozzolans generally have a lower stiffness at earlier ages as well, making them more susceptible to increased shrinkage under standard testing conditions. Silica fume will contribute to strength at an earlier age than Fly ash but may still increase shrinkage due to pore refinement [8].

Chemical admixtures tend to increase shrinkage. If they are used to reduce the evaporable water content of the mix, the shrinkage will be reduced. Air entraining agents, however, are found to have little effect on shrinkage [8].

From the literature review it may be summed up that the mechanical properties of high strength concrete as the function of properties of the constituent of the concrete. The durability and other properties of the high strength concrete increases with the use of the pozzolanic materials namely fly ash and silica fume.

In our country very little work has been done on HSC. Thus in the present investigation an attempt has been made to study the behaviour of the high strength concrete using component materials as available in the country itself specially silica fume.

III. EXPERIMENTAL PROGRAMME

Shrinkage of concrete was measured with the help of 'Shrinkage Apparatus' as shown in Figure 1.

Concrete beams specimens of 75mm x 75mm in cross section and 280mm length were cast with various concrete mixes.

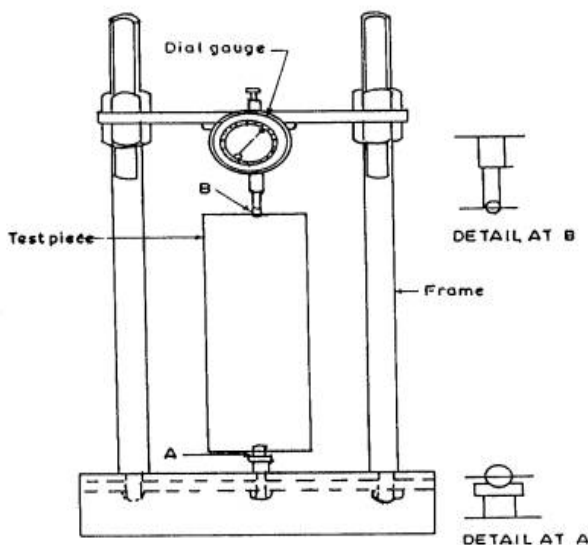


Fig. 1 Shrinkage measuring apparatus along with specimen

Pins were embedded at both ends of the specimens to hold them in the shrinkage apparatus. Specimens were cured in water for 7 days before testing for shrinkage. Initial readings of the specimens were taken with the help of dial gauge attached to the apparatus. Then the specimens were air dried for 7, 28, 56 and 90 days. Again the final reading of each specimen was taken after the specified period of air drying. The change in length of each specimens was calculated from the difference of final and initial dial gauge readings. Then the shrinkage strain was calculated.

IV. RESULTS AND DISCUSSION OF RESULTS

The results of the shrinkage strains of various concrete mixes with Yamuna and Badarpur sand and 12.5mm size Sandstone and granite aggregates without fly ash and silica fume and with replacement of 10 per cent cement by equal amounts of fly ash and silica fume respectively are given in Table 1 to 4 and Figures 2 to 5 respectively. These results are discussed in detail as under :

TABLE I
TEST RESULTS OF THE SHRINKAGE OF CONCRETE WITH YAMUNA SAND AND
12.5MM SIZE SANDSTONE AGGREGATE
Length of specimen: $L = 280$ mm

Sr. No.	Mix Design	% of FA & SF	Change in length (ΔL) in mm after Days				Shrinkage strain ($\Delta L/L \times 104$ after days)			
			7	28	56	90	7	28	56	90
1.	HSC-01	0% each	0.05	0.15	0.25	0.30	1.78	5.36	8.93	10.71
2.	HSC-02	10 % FA	0.06	0.18	0.28	0.32	2.14	6.43	10.00	11.43
3.	HSC-03	10 % SF	0.08	0.20	0.30	0.35	2.86	7.14	10.71	12.50
4.	NSC-01	—	0.08	0.16	0.26	0.32	2.86	5.71	9.28	11.43

TABLE II
TEST RESULTS OF THE SHRINKAGE OF CONCRETE WITH YAMUNA SAND AND
12.5MM SIZE GRANITE AGGREGATE
LENGTH OF SPECIMEN: L = 280 MM

Sr. No.	Mix Design	% of FA & SF	Change in length (ΔL) in mm after Days				Shrinkage strain ($\Delta L/L$) x 104 after days			
			7	28	56	90	7	28	56	90
1.	HSC-04	0% each	0.04	0.14	0.24	0.28	1.43	5.00	8.57	10.00
2.	HSC-05	10 % FA	0.05	0.15	0.25	0.30	1.78	5.36	8.93	10.71
3.	HSC-06	10 % SF	0.06	0.18	0.28	0.34	2.14	6.43	10.00	12.41
4.	NSC-04	—	0.05	0.16	0.25	0.30	1.78	5.71	8.93	10.71

TABLE III
TEST RESULTS OF THE SHRINKAGE OF CONCRETE WITH BADARPUR SAND AND
12.5MM SIZE SANDSTONE AGGREGATE
LENGTH OF SPECIMEN: L = 280 MM

Sr. No.	Mix Design	% of FA & SF	Change in length (ΔL) in mm after Days				Shrinkage strain ($\Delta L/L$) x 104 after days			
			7	28	56	90	7	28	56	90
1.	HSC-07	0% each	0.04	0.14	0.22	0.26	1.43	5.00	7.86	9.28
2.	HSC-08	10 % FA	0.05	0.16	0.25	0.30	1.78	5.71	8.93	10.71
3.	HSC-09	10 % SF	0.06	0.18	0.28	0.32	2.14	6.43	10.00	11.43
4.	NSC-07	—	0.05	0.15	0.25	0.30	1.78	5.36	8.93	10.71

TABLE IV
TEST RESULTS OF THE SHRINKAGE OF CONCRETE WITH BADARPUR SAND AND
12.5MM SIZE GRANITE AGGREGATE
Length of specimen: L = 280 mm

Sr. No.	Mix Design	% of FA & SF	Change in length (ΔL) in mm after Days				Shrinkage strain ($\Delta L/L$) x 104 after days			
			7	28	56	90	7	28	56	90
1.	HSC-10	0% each	0.03	0.13	0.20	0.25	1.07	4.64	7.14	8.93
2.	HSC-11	10 % FA	0.04	0.1	0.24	0.28	1.43	5.36	8.57	10.00
3.	HSC-12	10 % SF	0.05	0.16	0.25	0.30	1.78	5.71	8.93	10.71
4.	NSC-10	—	0.04	0.14	0.22	0.28	1.43	5.00	7.86	10.00

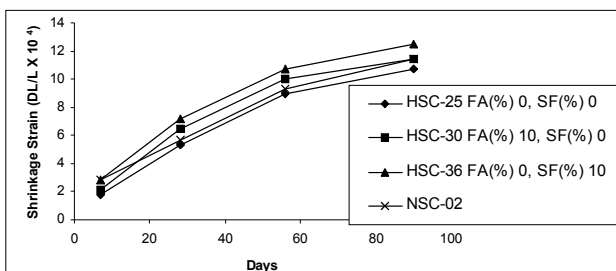


Fig. 2 Variation of Shrinkage Strain of Concrete with Yamuna Sand and 12.5 mm Sandstone with Age

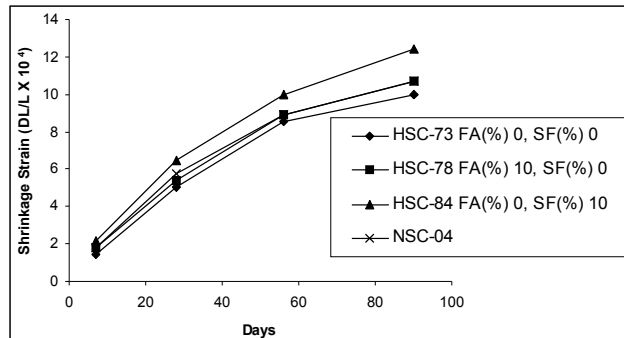


Fig. 3 Variation of Shrinkage Strain of Concrete with Yamuna Sand and 12.5 mm Granite with Age

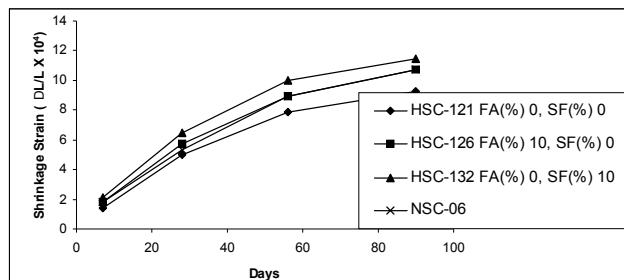


Fig. 4 Variation of Shrinkage Strain of Concrete with Badarpur Sand and 12.5 mm Sandstone with Age

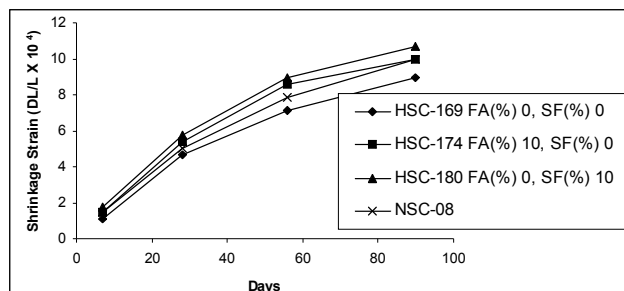


Fig. 5 Variation of Shrinkage Strain of Concrete with Badarpur Sand and 12.5 mm Granite with Age

A. Shrinkage of Concrete with Yamuna Sand and 12.5 mm Size Sandstone Aggregate

The shrinkage strains of various concrete mixes with Yamuna sand and 12.5mm size Sandstone aggregate are shown in Table 1 and Figure 2. From the test results it is concluded that the shrinkage strain of concrete mix HSC-01 increases with time. Further the shrinkage-strain of HSC-01 at 90 days is 6 times the 7 days shrinkage strain. The shrinkage strains of concrete mixes with replacement of 10 per cent cement by equal amount of fly ash and silica fume i.e. HSC-2 and HSC-3 also increases with time. Further the shrinkage strains of fly ash and silica fume concretes are more at 7, 28 56 and 90 days in comparison to the shrinkage strain of concrete without fly ash and silica fume. Further the shrinkage strain of fly ash

concrete is slightly less (1.08×10^{-4}) than the shrinkage strain of silica fume concrete. The shrinkage strain of normal strength concrete is slightly more than that of high strength concrete.

B. Shrinkage of Concrete with Yamuna Sand and 12.5 mm Size Granite Aggregate

The shrinkage strains of the various concrete mixes with Yamuna sand and 12.5mm size granite aggregate are shown in Table 2 and Figure 3. From the test results it can be concluded that the shrinkage strain of concrete mix with 12.5mm size granite (HSC-04) at 7, 28, 56 and 90 days are 0.803, 0.932, 0.957 and 0.934 times respectively the shrinkage strain of concrete mix HSC-01. The shrinkage strains of concrete mixes with 12.5 mm size granite aggregate and replacement of 10 per cent cement by equal amount of fly ash and silica fume i.e. HSC- 05 and HSC-06 at 7, 28, 56, 90 days are 0.831, 0.834, 0.893, 0.937 and 0.748, 0.900, 0.933, 0.993 times respectively the corresponding values of shrinkage strains of concretes mixes with 12.5 mm size Sandstone i.e. HSC-02 and HSC-03. The shrinkage strains of normal strength concrete with 12.5 mm size granite (NSC-04) at 7, 28, 56 and 90 days are 0.748, 1.0, 0.962 and 0.937 times respectively the shrinkage strain of normal strength concrete with 12.5 mm size Sandstone (NSC-01).

C. Shrinkage of Concrete with Badarpur Sand and 12.5 mm Size Sandstone Aggregate

The shrinkage strains of the various concrete mixes with Badarpur sand and 12.5 size Sandstone aggregate are shown in Table 3 and Figure 4. From the test results it is concluded the shrinkage strain of concrete mix HSC-07 at 7, 28, 56 and 90 days are 0.803, 0.933, 0.880 and 0.866 times respectively the shrinkage-strain of concrete mix with Yamuna sand and 12.5 mm size Sandstone aggregate (HSC-01). The shrinkage strains of concrete mixes with Badarpur sand and 12.5 mm size Sandstone aggregate with replacement of 10 per cent cement by equal amount of fly ash and silica fume i.e. HSC-08 and HSC-09 at 7, 28, 56, 90 days are 0.832, 0.888, 0.893, 0.857 and 0.748, 0.900, 0.933, 0.914 times respectively the corresponding values of shrinkage strains with Yamuna sand with 12.5 mm size Sandstone i.e. HSC-02 and HSC-03. The shrinkage strains of normal strength concrete with Badarpur sand and 12.5 mm size Sandstone (NSC-07) at 7, 28, 56 and 90 days are 0.822, 0.939, 0.962 and 0.937 times respectively the shrinkage strains of normal strength concrete with Yamuna sand and 12.5 mm size Sandstone (NSC-01).

D. Shrinkage of Concrete with Badarpur Sand and 12.5 mm Size Granite Aggregate

The shrinkage strains of the various concrete mixes with Badarpur sand and 12.5mm granite aggregate are shown in Table 4 and Figure 5. From the test results it is concluded that the shrinkage strains of concrete mix HSC-10 at 7, 28, 56 and 90 days are 0.748, 0.928, 0.831 and 0.883 times respectively the shrinkage-strain of concrete mix with Yamuna sand and 12.5 mm size granite aggregate (HSC-04). The shrinkage

strains of concrete mixes with Badarpur sand and 12.5 mm size granite aggregate with replacement of 10 per cent cement by equal amount of fly ash and silica fume i.e. HSC-11 and HSC-12 at 7, 28, 56, 90 days are 0.803, 0.900, 0.960, 0.933 and 0.831, 0.888, 0.893, 0.862 times respectively the corresponding values of shrinkage strains with Yamuna sand with 12.5 mm size granite i.e. HSC-05 and HSC-06. The shrinkage strains of normal strength concrete with Badarpur sand and 12.5 mm size granite (NSC-10) at 7, 28, 56 and 90 days are 0.831, .875, 0.880 and 0.933 times respectively the shrinkage strains of normal strength concrete with Yamuna sand and 12.5 mm size granite (NSC- 04).

V. CONCLUSION

On the basis of test results the following major conclusions can be drawn :

- (i) The shrinkage strain of the concrete increases with time.
- (ii) The shrinkage strains of concrete with replacement of 10% cement by fly ash and silica fume at different ages are more (6 to 10%) than the shrinkage strains of concrete without fly ash and silica fume.
- (iii) The shrinkage strain of concrete with Badarpur sand at 90 days is slightly less (10%) than the shrinkage strain of concrete with Yamuna sand.
- (iv) The shrinkage strain of concrete with granite aggregate at 90 days is marginally less (7%) than the shrinkage strain of concrete with sandstone aggregate

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