ASIAN JOURNAL OF CIVIL ENGINEERING (BUILDING AND HOUSING) VOL. 7, NO. 2 (2006)
PAGES 183-194

SHRINKAGE OF HIGH STRENGTH CONCRETE

S.M. Gupta*, P. Aggarwal and Y. Aggarwal
Civil Engineering Department, National Institute of Technology
Kurukshetra 136119, India

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 partial 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. 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 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: high strength concrete, fly ash, silica fume, shrinkage, shrinkage strain superplasticizers

1. INTRODUCTION

Concrete is one of the most versatile construction materials that has been widely used for almost a century now. It was the advent of prestressed concrete on the construction scene that triggered interest in higher strength of concrete. During the last two decades the development and application of high strength concrete (HSC) has greatly increased all over the last four decades. The process involved is a combination of improved compaction, improved aggregate matrix bond and reduced porosity using special additives.

The paper presents the results of an experimental investigation carried out to evaluate the shrinkage of High Strength Concrete. 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

* E-mail address of the corresponding author: smgupta@nitkkr.ac.in

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. The key factors affecting the magnitude of shrinkage are aggregate content, water-cementitious material ratio, member size, medium ambient conditions and admixtures.

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 [3-6].
(iii) HSC exhibits relatively higher initial rate of shrinkage [7,8]. After drying for 180 days, there is little difference between the shrinkage of HSC and NSC made with dolomite or limestone aggregates. Reducing the curing period from 28 to 7 days causes a slight increase in the shrinkage [7].

Shrinkage of HSC may be expected to differ from NSC in three broad areas as: 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 [9].

Drying shrinkage occurs after the concrete has already 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 [10] as given in Equation 1:

$$\in_s = 0.00125\ (0.95\text{-}h) \quad (1)$$

where $\in_s$= Shrinkage strain, h= Relative humidity expressed as a fraction .It was studied that the rate of shrinkage decreases with time. The tests indicated 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[10].

Pozzolanic materials like silica fume and Fly ash 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 [11].

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 [11].

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

2. MATERIALS USED

To study the influence of pozzolanic materials like silica fume and fly ash on the properties of concrete, the cement was partial replaced by equal amount of fly ash and Silica fume. Fibres were also added in varying percent of volume fraction. In the present investigation the parameter varied were:

(i) Fine aggregate coarse sand (Yamuna and Badarpur)
(ii) Coarse aggregate Sandstone and granite of sizes 20 mm and 12.5 mm.
(iii) Volume fraction of fibres 0.5,1.0and 1.5% with aspect ratio as 80
(iv) Supplementary cementitious Replacement of 5,10,15% cement
materials i.e. fly ash (F.A.) by equal amount of F .A. and S.F.
and silica fume(S. F.) individually and replacement of 10, 15, 15 and 20% cement by 5% F.A.+ 5% S.F., 10% F.A.+ 5% S.F, 5% F.A.+ 10% S.F and 10% F.A.+ 10% S.F. respectively.

The water over cement plus binder ratio was varied from 0.30 to 0.34 to maintain a compaction factor in the range of 0.80 to 0.87. To get the required degree of workability at lower water-cement ratios, superlasticizer was added at the rate of 2% by weight of cement. The physical properties of fine aggregate, coarse aggregate, silica fume and flyash are given in Table 1-4. The chemical properties of silica fume and fly ash are given in table 5-6 respectively.

Table 1. Physical Properties of Fine Aggregates

Sr. No.	**Properties**	**Observed Values**	
		Yamuna Sand	**Badarpur Sand**
1.	Bulk Density (Loose), kg/m^3	1595	1604
2.	Bulk Density (Compacted), kg/m^3	1793	1798
3.	Specific Gravity	2.61	2.60

4.	Water Absorption, %	0.95	0.80

Table 2. Physical properties of Coarse aggregate

Sr. No.	Properties	Observed Values	
		Sandstone	Granite
1.	Bulk Density (Loose), kg/m^3	1590	1600
2.	Bulk Density (Compacted), kg/m^3	1560	1680
3.	Specific Gravity	2.63	2.68
4.	Water Absorption, %	0.75	0.56

Table 3. Physical properties of Silica fume

Sr. No.	Physical Properties	Test Results
1.	Color	Grey
2.	Specific Gravity	2.08

Table 4. Physical properties of Flyash

Sr. No.	Physical Properties	Test Results
1.	Color	Grey (Blackish)
2.	Specific Gravity	2.13
3.	Lime Reactivity -average compressive strength after 28 days of mixture ‘A’	4.90 MPa

Table 5. Chemical properties of Silica fume

Sr. No.	Constituent Determined	Percent by Weight
1.	Loss on ignition	4.33
2.	Silica (SiO_2)	83.85
3.	Iron Oxide (Fe_2O_3)	1.88
4.	Alumina (Al_2O_3)	1.88
5.	Calcium (CaO)	2.05
6.	Magnesium Oxide (MgO)	1.28
7.	Total Sulphur ($S0_3$)	0.90
8.	Insoluble residue	-
9.	Alkalies a) Sodium oxide (Na_2O)	1.00
	b) Potassium oxide (K_2O)	4.30

Table 6. Chemical properties of Flyash

Sr. No.	Constituent Determined	Percent by Weight
1.	Loss on ignition	4.17
2.	Silica (SiO_2)	58.55
3.	Iron Oxide ($Fe_2 O_3$)	3.44
4.	Alumina ($Al_2 O_3$)	28.20
5.	Calcium Oxide (CaO)	2.23
6.	Magnesium Oxide (MgO)	0.32
7.	Total Sulphur (SO_3)	0.07
8.	Insoluble residue	-
9.	Alkalies a) Sodium Oxide (Na_2O)	0.58
	b) Potassium Oxide (K_2O)	1.26

3. EXPERIMENTAL PROGRAMME

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

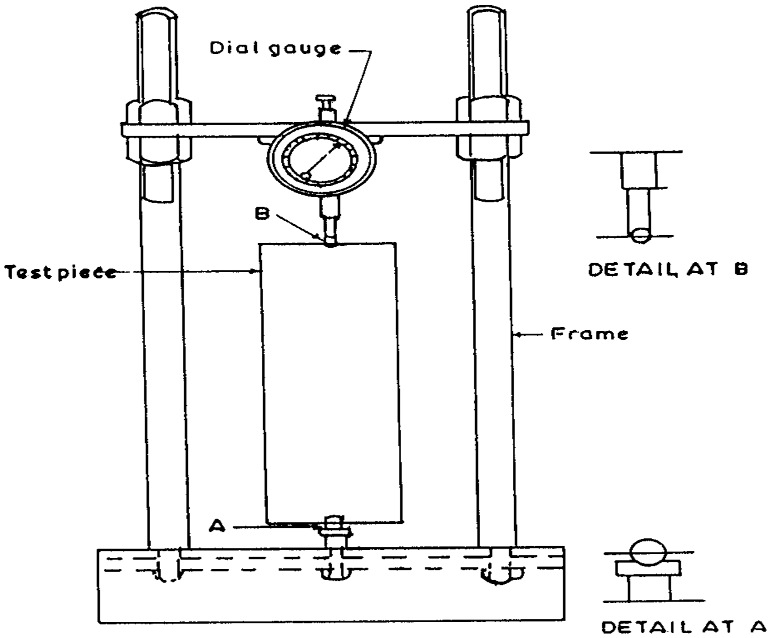

Figure. 1 Shrinkage measuring apparatus along with specimen

Concrete beams specimens of 75mm × 75mm in cross section and 280mm length were cast with various concrete mixes. 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 specimen was calculated from the difference of final and initial dial gauge readings. Then the shrinkage strain was calculated.

4. 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 7 to 10 and Figures 2 to 5 respectively.

Shrinkage of Concrete with Yamuna Sand and 12.5 mm Sandstone Aggregate

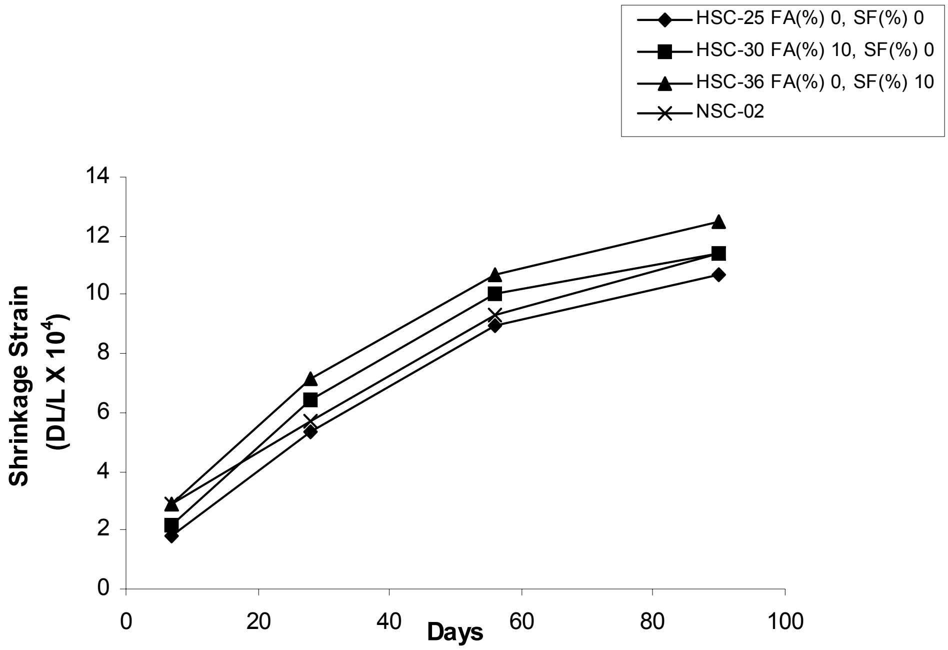

Figure 2. Variation of Shrinkage Strain of Concrete with Yamuna Sand and 12.5 mm Sandstone with Age EMBED Excel.Chart.8 \s

Table 7. 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 (ΔL/L) x 10^4 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

The shrinkage strains of various concrete mix 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. 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. The shrinkage strain of fly ash concrete is slightly less (1.08 x 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.

Table 8. 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 (ΔL/L) x 10^4 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	–	005	0.16	0.25	0.30	1.78	5.71	8.93	10.71

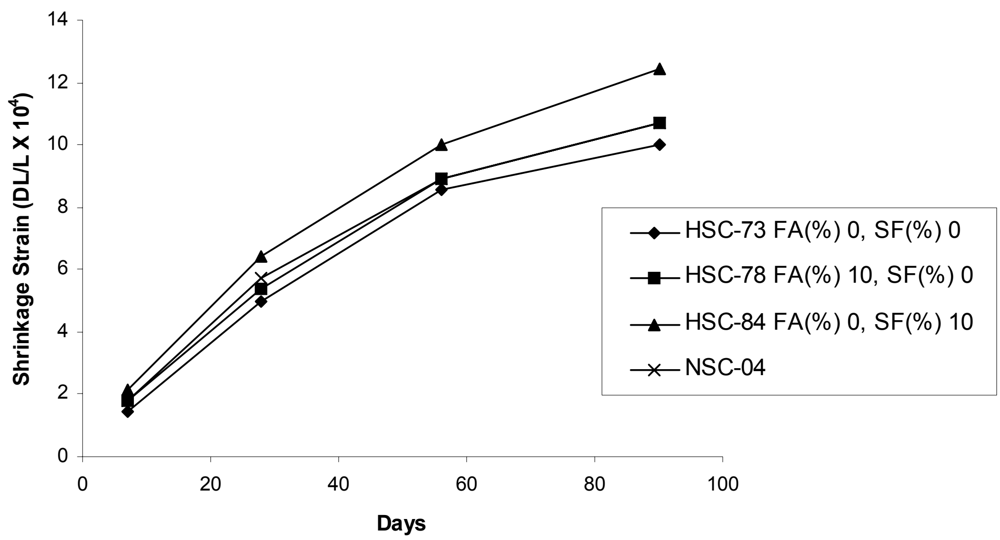

Figure 3. Variation of Shrinkage Strain of Concrete with Yamuna Sand and 12.5mm Granite with Age

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 10per 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).

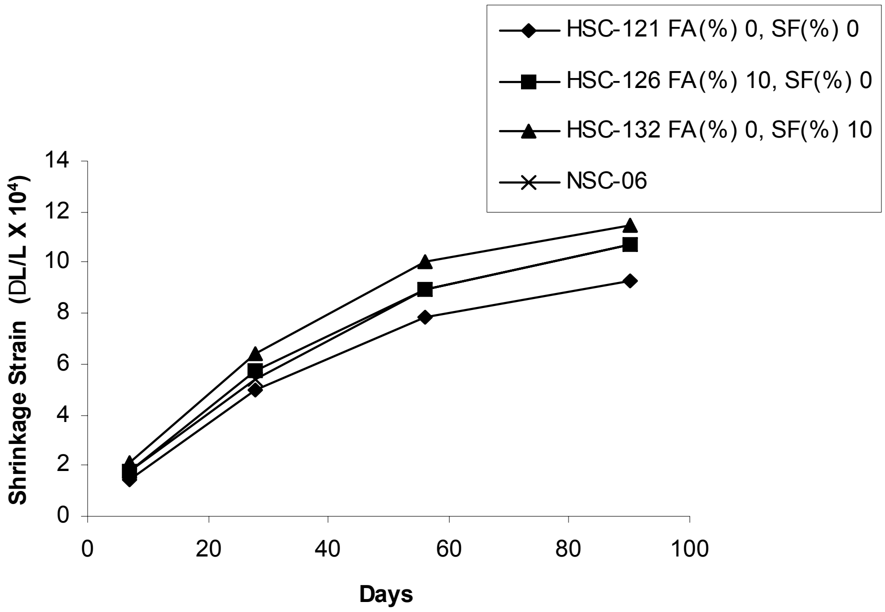

Figure 4. Variation of Shrinkage Strain of Concrete with Badarpur Sand and 12.5mm andstone with Age

Shrinkage of Concrete with Badarpur Sand and 12.5 mm 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).

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

Table 9. 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 (ΔL/L) x 10^4 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	0.96	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

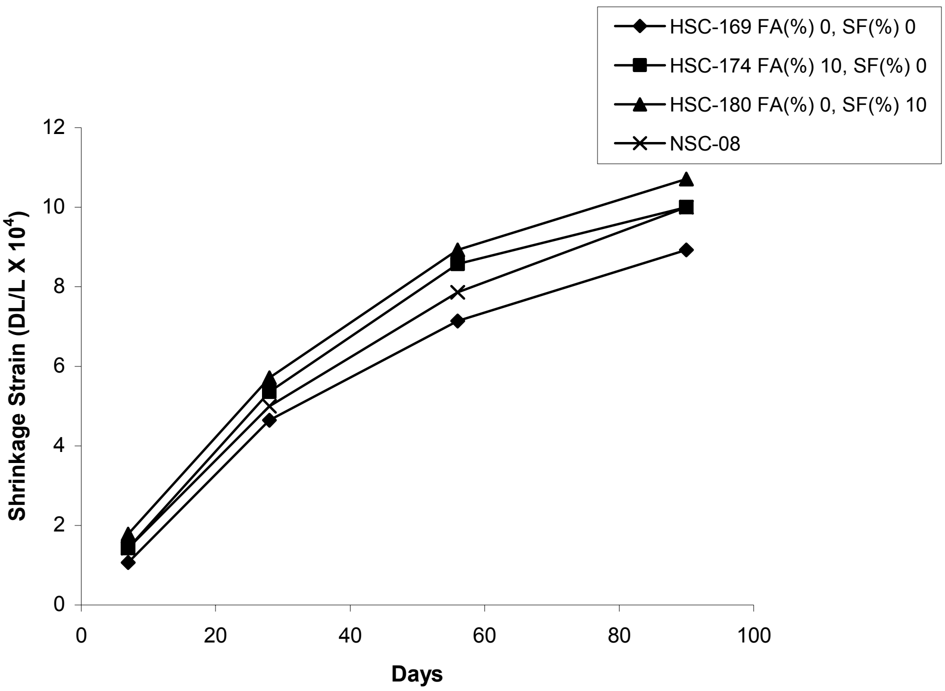

Figure 5. Variation of Shrinkage Strain of Concrete with Badarpur Sand and 12.5 mm Granite

with Age

Table 10. 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 (ΔL/L) x 10^4 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

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).

5. CONCLUSIONS

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.

REFERENCES

1. ACI committee 363, State of the Art Report on High Strength Concrete, *ACI Journal proceedings,* 81-4(1884)364-411.
2. Freedmon, S., High Strength Concrete, *Modern Concrete*, 34-6(1970)29-36.
3. Freedmon, S., High Strength Concrete, *Modern Concrete*, 34-7(1970)28-32.
4. Freedmon, S., High Strength Concrete, *Modern Concrete*, 34-8(1970)21-24.
5. Freedmon, S., High Strength Concrete, *Modern Concrete*, 34-9(1971)15-23.
6. Freedmon, S., High Strength Concrete, *Modern Concrete*, 34-10(1971)16-23.
7. Nagataki, S., and Yonekura, A., Studies of the Volume Changes of High Strength Concrete with Superplastizer, *Journal, Japan Prestressed Concrete Engineering Association (Tokyo)*, 20(1978)26-33.
8. Parrot, I.J., Properties of High Strength Concrete, Technical Report No. 42.417, *Cement and Concrete Association*, (Wexham Springs), 1969, 12.
9. Swamy R.N., and Anand K.L., Shrinkage and Creep of High Strength concrete, *Civil Engineers and Public Works Review (London),*68- 807,(1973)162-163.
10. Swamy R.N., and Anand K.L., Shrinkage and Creep of High Strength concrete, *Civil Engineers and Public Works Review (London),*68- 807,(1973)859-868.
11. Aitcin, P.C., Saikae S.L. and Laplnte, P., Long term characteristics of a very high concrete, *Concrete International*, (1990)40-44.
12. Gambhir, M. L. *Concrete Technology*, (Tata McGraw Hill Publishing Company Ltd.), India,1988.
13. ACI Committee 209, *Prediction of Creep, Shrinkage and Temperature Effects in Concrete Structures*, Manual of Concrete Practice Part-I, , *American Concrete Institute*, 209 R, (1990)1-92.