International Journal of Research Available at https://edupediapublications.org/journals

e-ISSN: 2348-6848
p-ISSN: 2348-795X
Volume 03 Issue 5
March2016

Creep and Shrinkage in normal and Heavy Density concrete

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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, Super plasticizers

I. 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 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].

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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:

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

where ϵ_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..

II. METHODOLOGY

A. *Shrinkage and Creep*

The entire study has been conducted in a creep and shrinkage laboratory under controlled environmental conditions having temperature 20 2°C and relative humidity 60 5%, maintained throughout the test duration. Because of constraints of creep setup in the laboratory and to maintain appropriate stress to strength ratio at prolonged duration, the creep specimens were loaded under uniaxial compressive stress such that stress to strength ratios were 0.30 0.02 for prisms and 0.20 0.02 for cylinders, where the strengths were obtained by the testing of three respective creep specimens at the age of 28 days. The companion shrinkage for unloaded specimens was simultaneously measured for all the four HPC mixes under the same controlled environmental conditions. Three specimens each have been put under observation for shrinkage and creep measurement, and shortening of specimens was recorded at different time intervals. There was not much variation in the experimentally measured values of individual test specimens. The greatest percentage difference among the specimens was 3%, and hence average values are reported.

B. *Scanning Electron Microscope (SEM)*

The scanning electron microscopy (SEM) LEO 435 VP Instruments technique has been used to characterize pores, air voids, and hydration phase of all HPC mixes. To investigate the effects of SCMs in HPC, microscopic images have been taken from each concrete at age of 3, 28, and 110 days, respectively. The HPC cubic specimen of each mix was crushed at the age of 3, 28, and 110 days, and from the center portion small fragment samples were taken and analyzed using the SEM technique. The fragment samples ensure the conductive nature, and were coated with gold before using the SEM technique.

C. *Mechanisms of Shrinkage and Creep*

Consideration However, various terms of shrinkage and creep of concrete have been described differently in literature. Nevertheless, it is almost common in conventional practices to ignore the distinction between the autogenous shrinkage and the drying shrinkage, and the basic creep and the drying creep to find total shrinkage and creep in drying conditions (Buil and Acker 1985; Mehta and Monteiro 2006). Usually, total shrinkage is simply considered as stress free deformations (i.e., volumetric changes) of concrete specimen that is the sum of autogenous strain and drying strain, whereas creep is simply considered as the deformations of concrete specimen under constant uniaxial sustained stress that is free from elastic strain and total shrinkage at drying conditions (Mehta and Monteiro 2006).
Therefore, the factors affecting the autogenous and drying shrinkage and basic and drying creep of HPC and separate determination of these experimentally is outside the scope of the present research work. Only common conventional practices to find shrinkage and creep of HPC have been followed in drying conditions, and the results were used for a comparative study.

D. *Shrinkage*

Shrinkage refers to the reduction of the volume of a concrete associated with the evaporation of the water contained in the concrete. It is composed of two simultaneous effects, drying shrinkage and carbonation shrinkage.

1) *Drying Shrinkage*

Drying shrinkage occurs when internal water is lost through evaporation. Drying shrinkage occurs only in the cement paste Long term deflection of concrete element under sustained load. and depends on several factors associated with the cement paste. The major factors affecting drying shrinkage are cement factor, stiffness of the aggregates, water content, type of cement, curing and storage conditions and the size of the concrete member.

2) *Carbonation Shrinkage*

Carbonation shrinkage occurs due to the interaction of the internal water and C02 in the air. As a result, the calcium hydroxide in the cement paste (Ca(OH)z) is converted to calcium carbonate ($CaC0_3$). The new CaC03 forms in the voids of the hardened paste, thereby decreasing its volume. The schematic chemical reaction is as follow: The water produced from the reaction fills the voids and must diffuse out of the concrete for carbonation shrinkage to occur.

E. Definition of Creep

According to ACI Committee 2095, the main mechanisms which describe creep are:

- Viscous flow of the cement paste caused by sliding or shear of the gel particles lubricated by layers of absorbed water,
- Consolidation due to seepage in the form of absorbed water or the decomposition of interlayer hydrate water,
- Delayed elasticity due to the cement paste acting as a restraint on the elastic deformation of the skeleton formed by the aggregate and gel crystals, and
- Permanent deformation caused by local failure (microcracking and crystal failure) as well as recrystalization and formation of new physical bonds.

This research study does not involve the study of the mechanisms of creep, but rather of the overall creep characteristics of concrete containing fly ash. In a simplistic definition, creep is the internal strain associated with the effects of a constant applied stress.

F. Definition of Creep Recovery

The designation creep recovery is given by analogy to creep; however, the two phenomena are different. The mechanisms proposed for creep recovery are as contradictory as the ones proposed for creep; nevertheless, they agree on the fact that it is caused by the reentry of the water to the concrete matrix and the slipping back of the broken bonds to the original position. In this study creep recovery refers to the partial recovery of the total deformation created by a constant sustained load.

III. RESULTS AND DISCUSSION

A. Shrinkage

Shrinkage of LWC depends on water-to-cement ratio (w/c), type of cement, degree of cement hydration, characteristics, amount, and elastic modulus of aggregate used, and water content in the aggregate. When exposed to a dry environment after an initial moist curing, total shrinkage of concrete may be divided into two components - drying shrinkage and autogenous shrinkage. The autogenous shrinkage is a consequence of the withdrawal of water from the capillary pores by the hydration of cement, a process known as self-desiccation.

For HPC, the autogenous shrinkage may consist of a significant portion of the total shrinkage at early age due to their low w/c. However, after 28 days of moist curing, any subsequent autogenous shrinkage should be nearly negligible relative to drying shrinkage total shrinkage of HPLWC published in recent years in comparison to that of HPNWC. These data were obtained from concrete specimens after initial moist curing of various lengths, thus the data are a combination of drying and autogenous shrinkage. Lightweight aggregate concretes generally has lower shrinkage rates and values at early age, but the ultimate shrinkages are higher than those of normal weight concrete. Lower shrinkage of LWC at earlier age is also reported by other researchers. Approximately the same 500day total shrinkage for NWC and LWC with prewetted LWA was reported by Lopez However, if dry LWA was used, total shrinkage of the LWC was higher than that of the NWC at 500 days.

The lower shrinkage of LWC at early age may be attributed to water absorbed inside the LWA which contributes to “internal curing” of concrete and compensates for water loss when concrete specimens are exposed to dry environment. This "internal curing" contributes to reduced autogenous shrinkage and drying shrinkage of LWC in comparison with NWC. Numerous papers on the use of presoaked LWA to reduce shrinkage and improve concrete performance were published in recent years. Higher ultimate shrinkage of LWC may be explained by the lower modulus of elasticity of the LWA that have less restraint effect on the shrinkage compared with the normal weight aggregate (NWA) particles.

Comparing lightweight and normal weight concrete of similar 28-day strength, the lightweight concrete would probably have lower risk of shrinkage cracking under the same restraint conditions at early age due to its lower shrinkage and modulus of elasticity. Incorporation of 5% silica fume reduced the total shrinkage of concrete significantly, and its effect on HPLWC is more substantial than that on the HPNWC.

B. Creep

Creep Similar to shrinkage, creep behaviour of LWC is also affected considerably by elastic properties of aggregates and their relative proportions in concrete. Due to length of testing, there is less information available on creep behaviour of HPLWC. Some limited information available from literature.

A brief literature review for creep of HPLWC was presented in a paper by Lopez et al. Berra and Ferrara investigated creep behaviour of LWC with 28-day compressive strength of 47.6 – 59.4MPa (cured in 95% RH) and 49.2–61.4MPa (cured in 50% RH). They reported specific creep of the LWC twice that of NWC of the same strength. Lopez et al. investigated creep behavior of LWC stored at 50% RH and 21^{o}C for a period of 620 days. Compressive strength of the LWC at 56 days was from 68.5 to 75.4MPa. One half of the specimens were loaded to 40% and the other half to 60% of the compressive strength. Within each group of specimens, some were loaded at 16 hrs and the rest at 24hrs after casting. They found that time under load and compressive strength at the age of loading are significant parameters for the creep.

Difference in creep coefficient between loading at 16 and 24hrs were 2.5% and between loading to 40 and 60% of initial strength was 1.5%. The 620-day creep coefficient of a LWC with 56-day strength of 75.4MPa was 22% lower than that of a LWC with 56-day strength of 68.5MPa. The former had a specific creep similar to that of a NWC of the same grade but less cement paste and significantly lower specific creep than a NWC of the same grade and similar paste content. Malhotra investigated creep behaviour of HPLWC with or without fly ash and silica fume moist cured for 1 year. After 370 days under loading, the concretes with fly ash and silica fume had lower creep strains than the reference Portland cement concretes. He attributed the lower creep strains of the former to large amount of residual unreacted fly ash which would act as aggregate and provide restraint to deformation. Effect of internally stored water in LWA on creep of HPC with w/cm of 0.23 was investigated by Lopez eta al. The experiments included a concrete with prewetted coarse LWA (LWW), a concrete with dry coarse LWA (LWD), and a reference concrete with NWA. Natural sand was used for all three concretes. They found that LWW mixture showed lowest specific creep among the three concretes after 500 days under load. However, without internally stored water in the LWA, the LWD mixture had higher creep than the reference NWA mixture.

It was also found that basic creep was much higher than drying creep for all these concretes. They attributed the reduction of creep in the LWC with pre wetted aggregate to three mechanisms: enhanced cement hydration, expansion of microstructure, and water seepage inhibition due to the internally stored water in LWA. Comparing the results from these three concretes, they concluded that a higher compressive strength did not necessarily ensure lower creep because compressive strength and creep did not depend on the same factors to the same extent.

IV. CONCLUSIONS

From the above review on high-strength high-performance LWC, some of the significant conclusions are summarized as follows:

1) High strength high-performance LWC (compressive strength workability, mechanical properties, and durability can be produced by using quality LWA, low w/c, silica fume, and chemical admixtures in the concrete. Such concrete has been used in structures in practice.

2) If the difference between the particle density of LWA and the density of mortar matrix is relatively large, caution should be exercised to avoid overdoses of super plasticizers and air entraining admixtures in order to reduce potential segregation of fresh concrete.

3) Lightweight aggregate concretes generally have lower shrinkage rates and values at early age, but the ultimate shrinkages are higher than those of normal weight concrete. The lower shrinkage of LWC at early age may be attributed to water absorbed inside the LWA which contributes to “internal curing” of concrete and compensates for water loss when concrete specimens are exposed to dry environment.

4) Reported results on creep of HPLWC in comparison to that of HSNWC do not always agree. It is found that LWC with pre-wetted LWA has lower specific creep after 500 days under load than NWC. However, the LWC with dry LWA has higher creep than the NWC. The reduction of creep in the LWC with pre wetted aggregate is attributed to enhanced cement hydration, expansion of microstructure, and water seepage inhibition due to the internally stored water in LWA.

5) Lightweight concrete had lower water sorptivity, water permeability and higher resistance to chloride-ion penetration than the NWC of similar 28-day strength. The LWC with only coarse LWA had similar transport properties compared to NWC of similar w/c. However, the resistance of the LWC to chloride-ion penetration decreased with the increase in the cumulative LWA content in the concrete.

6) High-performance LWC has more spalling than their normal weight counterpart when exposed to hydrocarbon fire. However, the properties of the concrete in the middle of the testing blocks were not significantly affected by the fire exposure. Low w/c LWC made with silica fume blended cement requires more polypropylene fibers than for a higher w/c concrete.

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e-ISSN: 2348-6848
p-ISSN: 2348-795X
Volume 03 Issue 5
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