Early Age Creep and Shrinkage of Concrete with Shrinkage Reducing Admixtures (SRA)

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ABSTRACT

Early age creep and shrinkage are primary factors that influence premature cracking of concrete affecting the durability and performance of concrete structures. Shrinkage of concrete causes tensile stress development while tensile creep works as a stress relaxing mechanism and relieves part of the stress developed due to shrinkage. Shrinkage Reducing Admixtures (SRA) have been effectively used to reduce the potential for cracking, particularly at early age. However, the effects of SRA on stress development and tensile creep require more testing. This study provides experimental data on early age creep and shrinkage of normal and high performance concrete. Concrete mixtures with and without SRA were tested using a uniaxail test configuration that allowed to measure creep and shrinkage under constant load as well as under increasing load (restrained condition). Concrete containing a Shrinkage Reducing Admixture (SRA) has been evaluated using a constant load creep-shrinkage test. SRA was added at a dosage rate of 3.71 l/m3 (0.75 gal/yd3). The results showed that the SRA at the tested dosage significantly reduced the early age shrinkage of concrete. The results also indicated that the SRA influenced the shrinkage and creep in a different manner.

KEYWORDS: Concrete, Creep, Shrinkage, SRA.

INTRODUCTION

Shrinkage of concrete, particularly at early age, is a major cause for premature cracking and the associated degradation of concrete durability and performance during service life. This issue has been a concern for engineers and technologists for many years, especially for flat structures. The new advents in the cement and concrete technology and the use of High Performance Concrete (HPC) generally using a low water to binder ratio have raised this concern as a result of the increase in the vulnerability of concrete to shrinkage cracking.

Tensile creep and shrinkage of concrete are primary factors that influence the risk of cracking, particularly during the early age when the concrete strength is still developing. The drying shrinkage is the driving force for stress development if the concrete is restrained, while the role of tensile creep is beneficial as a stress relaxing mechanism, relieving part of the tensile stress that develops due to shrinkage. Furthermore, creep and shrinkage are fundamentally interrelated and additional creep associated with drying has been observed and is commonly referred to as the Pickett effect (Pickett, 1942). Therefore, both creep and shrinkage should be carefully considered in order to properly address the issue of concrete cracking.

The fundamental mechanism of drying shrinkage in concrete as described by the Guass-Laplace equation is influenced by the size of the pore and the surface tension of the pore solution (Grasley, 2003). Lowering the surface tension of the pore solution reduces the

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capillary pressure associated with drying and thus decreases the potential for shrinkage. One way to lower the surface tension of the pore solution is to use the Shrinkage Reducing Admixtures (SRA). These water soluble liquids were originally developed in Japan (Nmai et al., 1998) and generally added to concrete at 1 or 2 percent by weight. Research on shrinkage of concrete with SRA showed a reduction in shrinkage of lab specimens varying between 30% and 80% (Nmai et al., 1998; Folliard and Berke, 1997; Shah et al., 1997). However, the influences of SRA on early-age stress development and creep mechanisms are not well understood and more research is required in this field. This study aimed at studying the effects of SRA on early age shrinkage and tensile creep characteristics of normal and high performance concrete mixtures.

EXPERIMENTAL WORK

Tensile creep and shrinkage tests were performed in this study. The tests utilized a uniaxial tensile loading device developed originally to test restrained shrinkage (Altoubat and Lange, 2001). The system tests two identical dog-bone samples; one is loaded and the other is free of load. Each sample is 1000 mm long and 76.2x76.2 mm in cross section. The specimen cross section is gradually enlarged to fit into the end grips; a configuration that provides full restraint and minimizes stress concentration at contact surfaces. The two specimens were horizontally laid in a controlled environmental chamber that was maintained at a relative humidity of 50% and a temperature of 23°C. A general view of the experimental device is shown in Figure 1.

In each test series, two linear specimens were cast; one was loaded to measure elastic and creep strains, and the other was free of load to measure free shrinkage. Three standard prisms 76x76x300 mm were also cast, two of them were used to measure free shrinkage and weight loss in time, and one was used to monitor the temperature of concrete in time. In addition, two standard 101.6x203.2 mm cylinders were cast to determine the split tensile strength at the time of loading (24 hours after casting).

After casting, the samples were covered with wet burlap for 24 hours, and then demolded. The top surface of the dog-bone specimens was sealed by self-adhesive aluminum foil to allow for symmetrical drying from two sides. The standard prisms were sealed from top and bottom to produce similar drying surface area as the dog-bone specimens. One hour after demolding, the creep sample was loaded to 40 % of split tensile strength, and strain measurements of both the free shrinkage sample and the creep sample were recorded for 7 days thereafter. A one-hour waiting period was chosen to avoid interference with cooling associated with formwork removal. Evaporative cooling has been shown to cause significant changes during early age testing (Altoubat, 2000; Kovler, 1995). The supplementary free shrinkage and weight loss measurements from the standard prisms continued for up to 28 days or longer.

MATERIALS

Normal concrete (OPC) and High Performance Concrete (HPC) were tested in this study. Materials used were crushed limestone aggregates with a maximum size of 19 mm, natural sand, Type I Portland cement, Silica fume, Class F fly ash (MBT ProAsh), High-range-water-reducing agent (MBT Rheobuild 3000 FC), Air entraining admixture (MBT MicroAir) and Shrinkage reducing admixtures (MBT Tetraguard). The w/c ratio of the OPC mixture was 0.45 and that of the HPC mixture was 0.35. The two concrete mixtures were tested with and without shrinkage reducing admixture (SRA). The dosage of the SRA was 0.75 gal/yd^3 as recommended by the manufacturer. The slump of the fresh concrete was between 4 and 6 inches, and the air content was maintained between 4% and 6 %. The OPC and HPC mixture proportions are shown in Table 1.

EXPERIMENTAL RESULTS

The results for the four concrete mixtures tested in this study are presented in this section and discussed thereafter.

Table 1: Proportions of the concrete mixtures

	OPC-NO SRA	OPC-SRA	HPC-NO SRA	HPC-SRA
Cement	611	611	674	674
Fly Ash (SG=2.40)	--	--	50	50
Silica fume (SG=2.20)	--	--	76	76
Coarse Aggregate (SSD,	1779	1779	1710	1710
Fine Aggregate (SSD,	1256	1256	1112	1112
Water	275	275	280	280
W/C Ratio	0.45	0.45	0.35	0.35
MBT MicroAir *	0.35	0.1	0.25	0.25
HRWR *	--	--	5.00	5.00
SRA- Tetragaurd*	--	15.7	--	15.7

Length Change and Weight Loss of Prisms

The concrete prisms were used to measure length change (free shrinkage) according to ASTM C490 and weight loss. Curing regime and drying conditions were identical to that for the dog-bone specimens. Both length change and weight loss were measured daily, and this interval increased after one week of testing. Two prisms were tested for each concrete mixture, and the results from the two prisms were averaged for both length change and weight loss measurements. The length changes for concrete mixtures with and without SRA are shown in Figures 2 and 3 for both OPC and HPC mixtures, respectively. The corresponding weight losses are shown in Figures 4 and 5.

Free Shrinkage from Dog-bone Specimens

The free shrinkage was also measured from the dog-bone samples in the creep test. The results for the OPC mixture that includes SRA and that does not include SRA are shown in Figure 6. It should be noted that irregularities in the free shrinkage from the dog-bone test for the HPC mixtures were observed and hence the results are not reported herein. Instead, the free shrinkage strains from the standard prisms were used in the analysis and discussion for the HPC mixtures.

Total Tensile Creep

The total tensile creep for the OPC and HPC mixtures was measured in this study. The creep tests were performed under a tensile load leading to a stress/strength ratio of 0.4 for both mixtures. The load was applied at the age of 25 hours after casting in all tests. The tensile creep compliance functions obtained in this study are shown in Figures 7 and 8 for the OPC and HPC mixtures, respectively. The creep compliance combines the elastic and creep strains in one function. It is defined as the elastic and creep strain per unit stress, and can be written as follows:

$$Creep\,Compliance = \frac{1}{E} + \frac{\varepsilon_{cr}}{\sigma} \qquad (1)$$

where σ is the applied stress, E is the elastic modulus at the time of loading and ε_{cr} is the creep strain.

Creep coefficient was also calculated to characterize the creep behavior and to study the effect of SRA on the tensile creep. It is defined as the ratio of the creep strain at any time to the elastic strain at the time of loading, and can be written as follows:

$$Creep\,Coefficient = \frac{\varepsilon_{cr}}{\varepsilon_{elastic}} \qquad (2)$$

Figure 1: Creep-Shrinkage Test Set-up

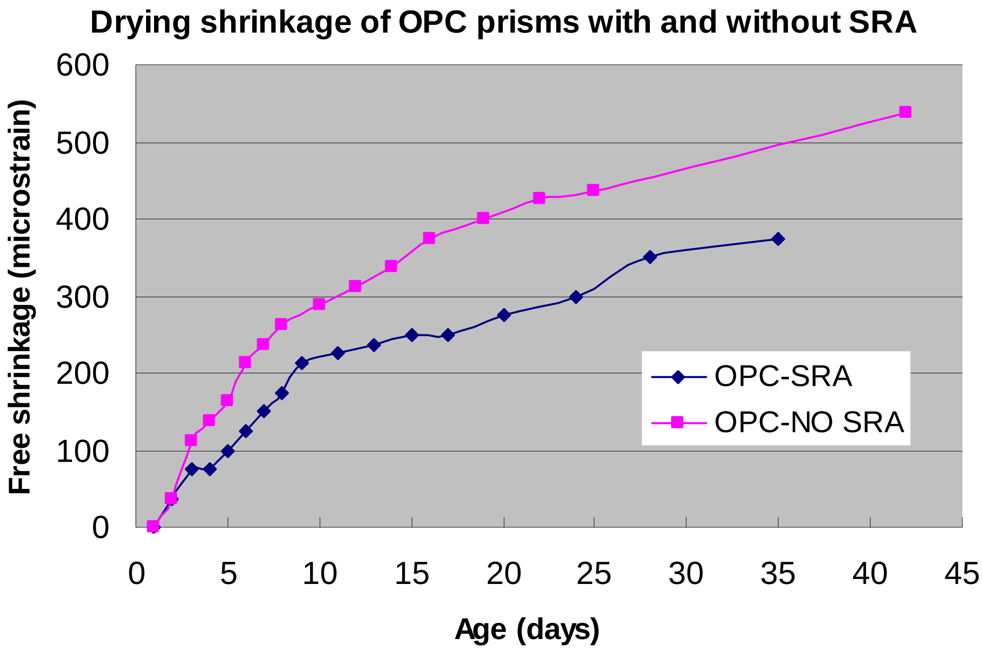

Figure 2: Free Shrinkage of Prisms for OPC Mixtures with and without SRA

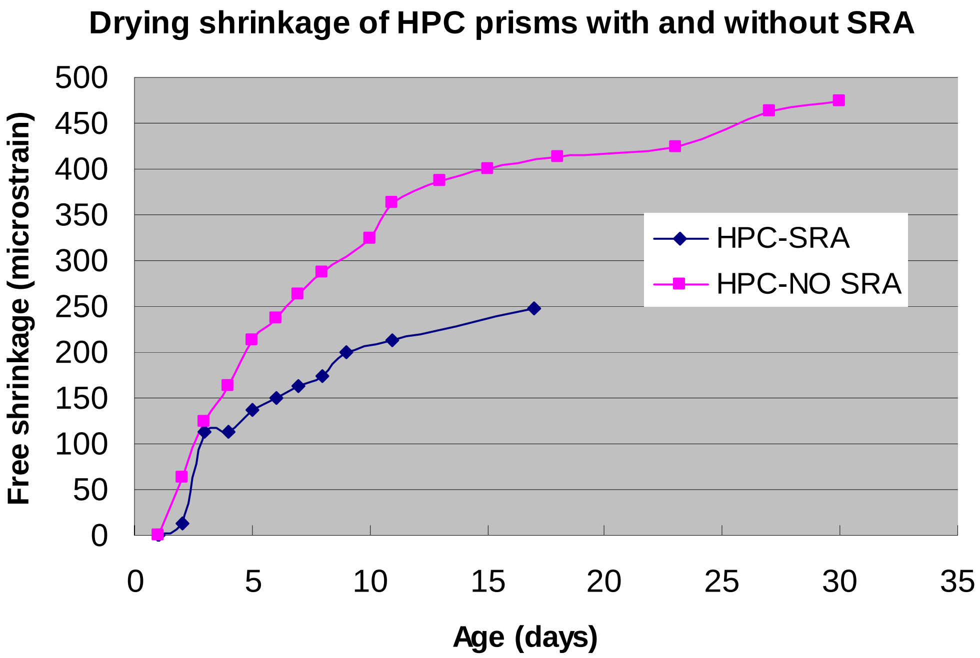

Figure 3: Free Shrinkage of Prisms for HPC Mixtures with and without SRA

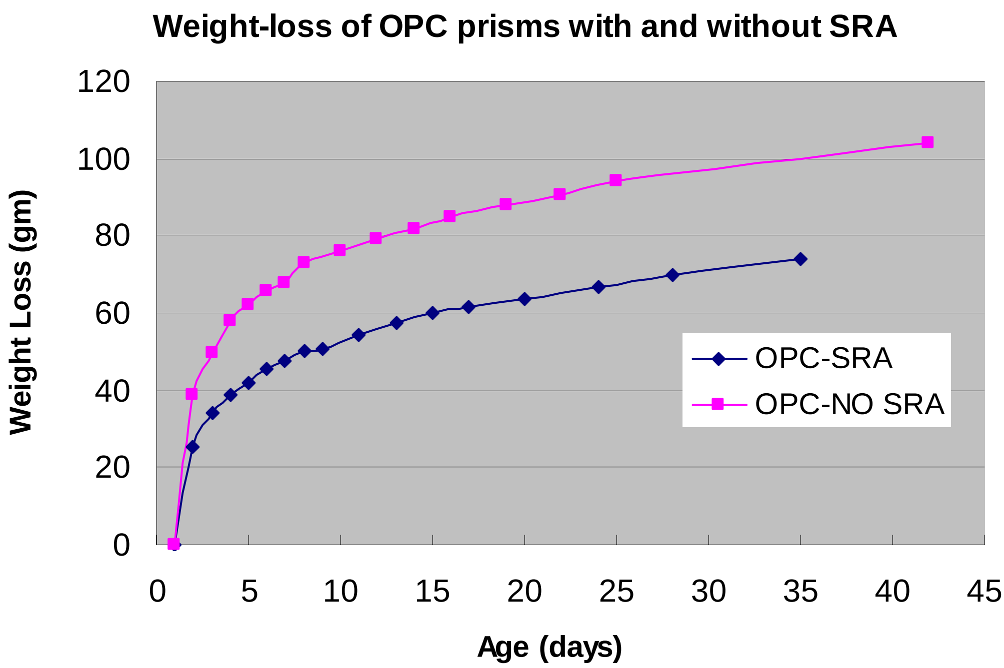

Figure 4: Weight Loss of Prisms for OPC Mixtures with and without SRA

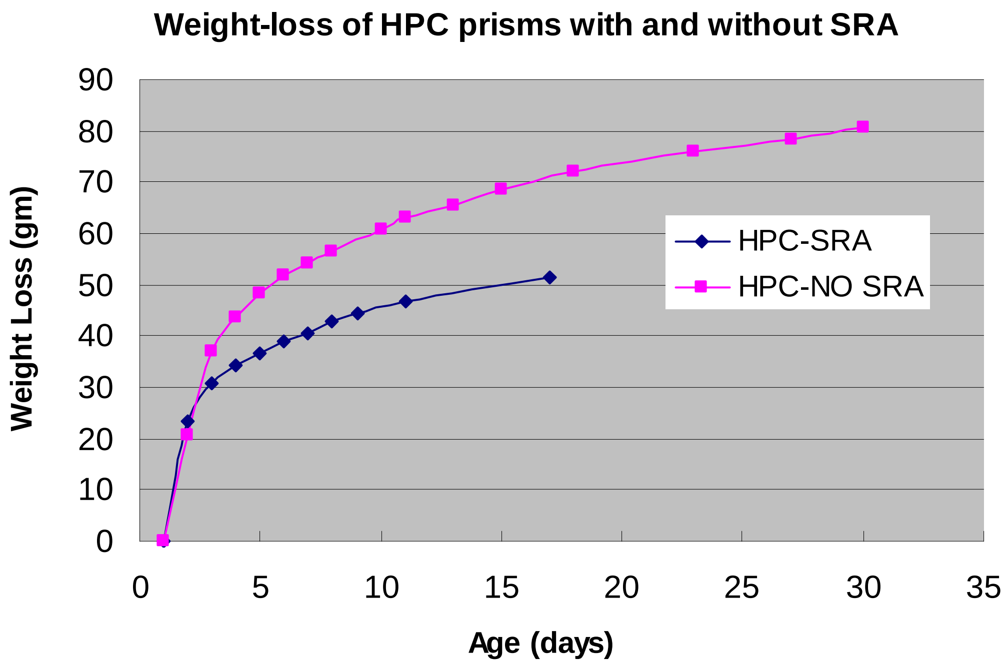

Figure 5: Weight Loss of Prisms for HPC Mixtures with and without SRA

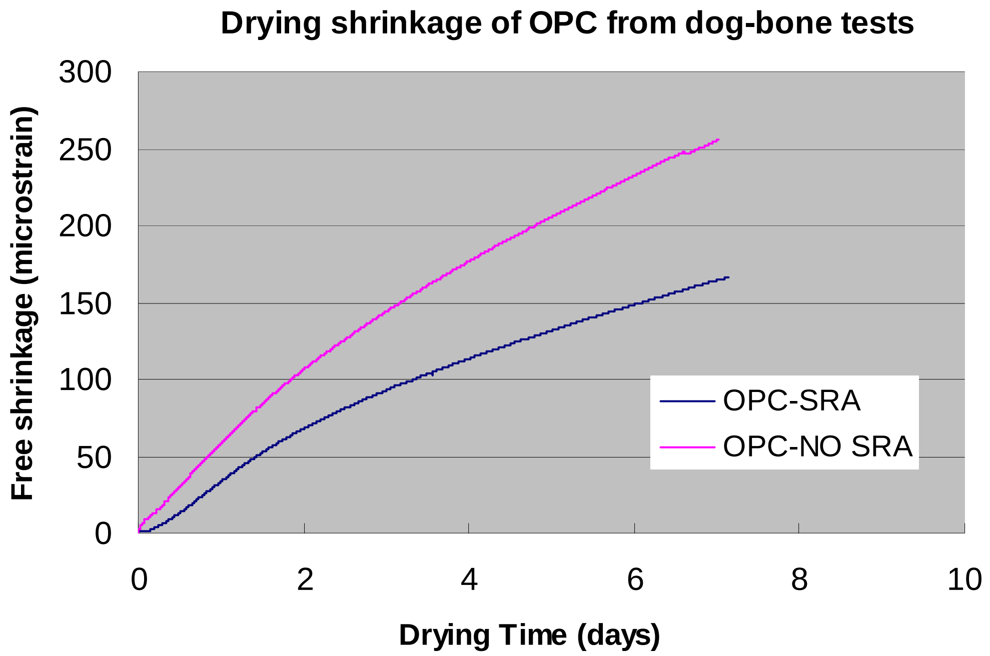

Figure 6: Free Shrinkage Results of Dog-bone Samples for OPC Mixtures

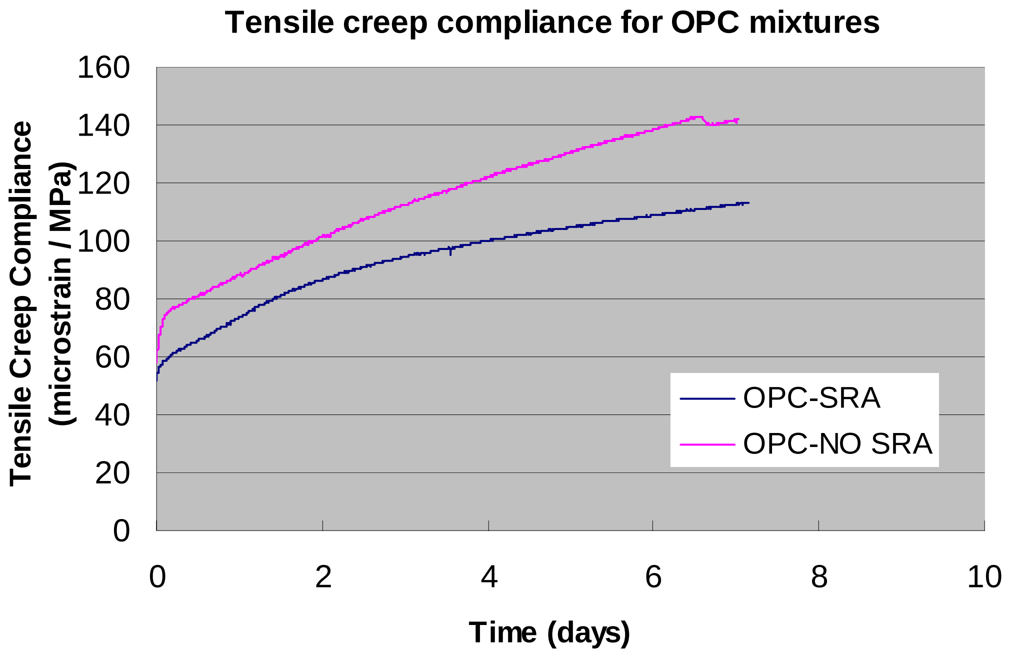

Figure 7: Tensile Creep Compliance for OPC Mixtures

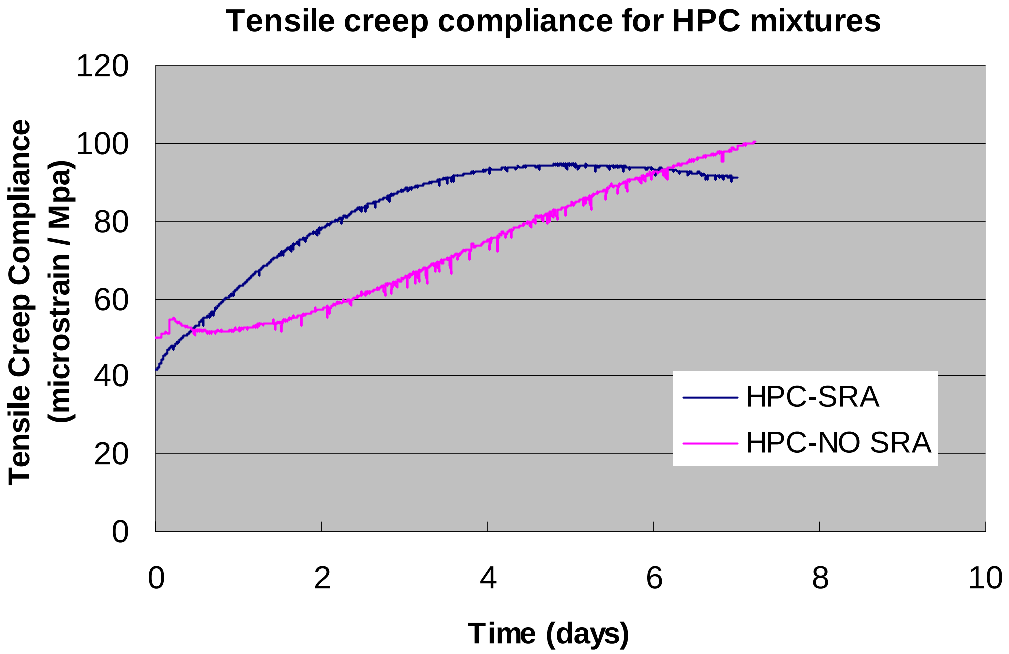

Figure 8: Tensile Creep Compliance for HPC Mixtures

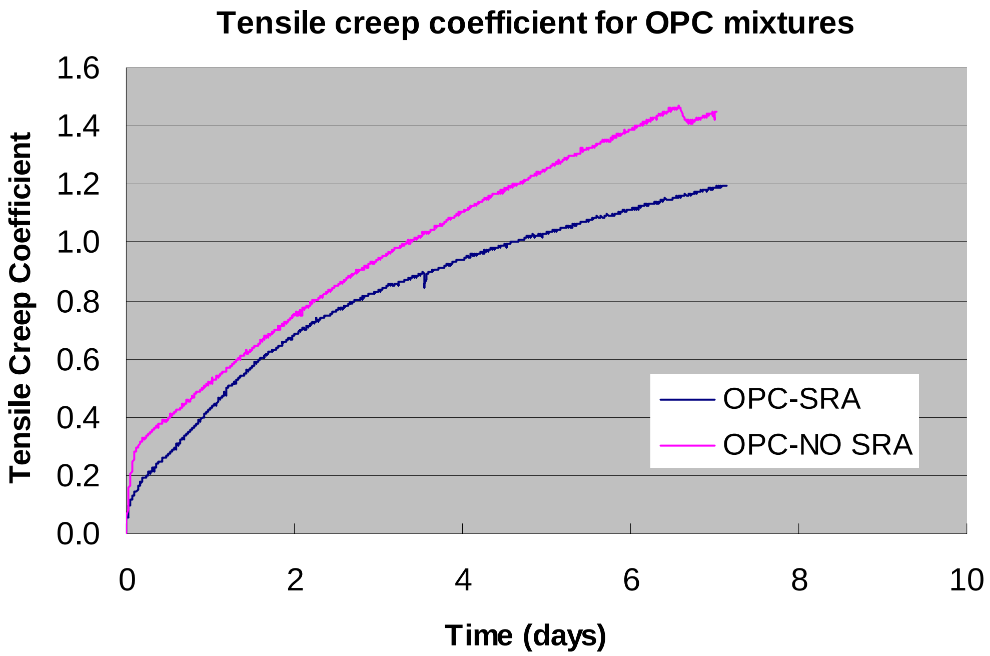

Figure 9: Tensile Creep Coefficient for OPC Mixtures

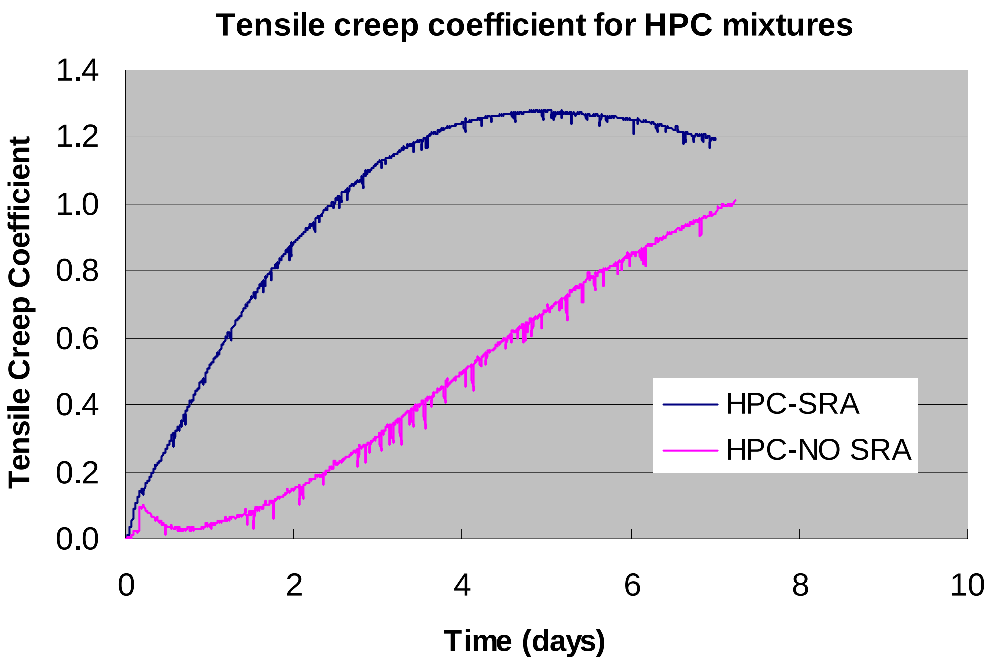

Figure 10: Tensile Creep Coefficient for OPC Mixtures

The results of the creep coefficient for all mixtures are shown in Figures 9 and 10 for the OPC and HPC mixtures, respectively.

DISCUSSION

The main objective of this discussion is to evaluate the effect of SRA on early age behavior of concrete. Therefore, the effectiveness of the SRA needs to be evaluated based on two material aspects. First, the degree of reduction in the early age shrinkage; when the concrete is more prone to shrinkage cracking, and second, the effect of SRA on tensile creep and relaxation characteristics. The following discussion addresses these aspects.

Effect of SRA on Free Shrinkage

The free shrinkage measured in this study indicates a significant reduction in shrinkage when the SRA is added to the concrete. Both the prisms and the dog-bone tests concluded this behavior. The dog-bone test for the OPC indicated a free shrinkage strain of 255 microstrains after 7 days of drying, whereas 164 microstrains were measured when SRA was included as can be inferred from Figure 6. This resembles a reduction in shrinkage of 36 % after 7 days of drying. The prisms' measurements presented in Figure 2 indicate a similar reduction of 33 % after 7 days of drying (175 compared to 262 microstrains). The reduction was not only in the early age but also continued at later ages as the prism measurements indicated. A similar reduction in shrinkage was also observed after 24 days of drying.

The free shrinkage of the HPC mixtures presented in Figure 3 indicates that the HPC, after 7 days of drying, shrinks by 287 and 175 microstrains for the HPC-NO SRA and the HPC-SRA mixtures, respectively. This resembles a reduction in shrinkage due to SRA by 39 % after 7 days of drying. A reduction in shrinkage by 39 % due to SRA was also observed after 16 days of drying, suggesting that the SRA is consistently effective in reducing the shrinkage of concrete. The extent of shrinkage reduction due to SRA seems to be more in HPC than in OPC, which is probably attributed to the higher rate of shrinkage.

Effect of SRA on Weight Loss

The weight loss of the same prisms used for free shrinkage measurement indicated a consistent trend that is worthy of attention and further investigation. The results presented in Figures 4 and 5 consistently indicate a reduction in the weight loss induced by adding the SRA to the concrete. This suggests that the SRA helps retain water in the microstructure, and hence may be viewed as a curing agent that is beneficial in concrete. The SRA in this sense becomes of dual benefit: reduction of shrinkage and as a curing agent.

On the other hand, one could infer that the reduction in shrinkage due to the addition of SRA is primarily due to the less water removed from the system. The reduction in weight loss due to SRA after 7 days of drying was 31% and 25% for the OPC and HPC mixtures, respectively. The percentage of weight loss reduction is comparable to the percentage of shrinkage reduction for the OPC, but it is far below that for the HPC mixture. This might suggest that the SRA mechanisms are not limited to the water retention and that other mechanisms possibly exist. However, further investigations are required to support extensive commentary, and at this point both the shrinkage reduction and the water retention are viewed beneficial for performance.

Effect of SRA on Tensile Creep

Tensile creep was determined under constant stress of 100 psi for OPC mixture and 140 psi for HPC mixture, resembling a stress/strength ratio of 0.3 for the OPC and 0.4 for the HPC according to the split tensile strength performed in the lab, but the ratio was similar for the mixtures with and without SRA. Besides, the split tensile strength does not necessarily correlate similarly to the direct tensile strength for both HPC and OPC, particularly at this early age. The total tensile creep compliance (Figure 7) after 7 days of loading is 142 and 113 microstrains for the OPC-NO SRA and OPO-SRA, respectively. This indicates that the addition of SRA to the OPC mixture reduces the creep compliance by 20%. One could infer that this reduction may be attributed to the lower shrinkage strain when the SRA is added. But since the reduction in shrinkage (36%) is different from the reduction in creep (20%), one may suggest that the shrinkage reducing admixtures affect both the shrinkage and the creep, but in different capacities. To quantify the real effect of SRA on tensile creep, it is essential to perform basic creep tests that eliminate the shrinkage interaction and provide a better picture. The creep coefficient after 7 days of loading (Figure 9) provides similar information. The SRA reduced the creep coefficient by 17%, which also suggests that the SRA is influencing the creep in a manner that is different from that related to shrinkage.

The results of the creep compliance and creep coefficient for the HPC mixture support the above discussion. The tensile creep compliance after 7 days of loading for the HPC-NO SRA and the HPC-SRA mixtures (Figure 8) is quite similar, and the variation lies within the intrinsic scatter for the creep. However, giving the high reduction in shrinkage due to SRA (39 %), the results strongly suggest that the SRA influences the tensile creep behavior of the HPC. It can be inferred that the SRA increased the tensile creep of the HPC, which is an additional benefit that contributes to reducing the risk of early age cracking of HPC. Both the reduction in shrinkage and the increase in tensile creep are favorable when the early age cracking is to be avoided. The creep coefficients in Figure 10 clearly support this finding.

CONCLUSIONS

- The results from both dog-bone samples and prisms clearly indicated that the SRA is effective in reducing the early shrinkage of concrete. The reduction in shrinkage is substantial (30-40%), which decreases the potential of early age cracking of concrete and improves the performance.
- The weight loss measurements indicated that the SRA reduced the rate of weight loss from drying, which in part explains the associated reduction in shrinkage. Retention of water in the hydrating microstructure

should contribute to improved development of mechanical properties. To the extent that it slows the drying process, SRA may be viewed as a curing agent in addition to being a shrinkage reducing agent. Both aspects enhance early age performance and reduce the risk of cracking.

- The SRA affects the total tensile creep of the concrete, but in a manner that is probably different from that of shrinkage. The OPC test results suggest that the SRA affects both the creep and the shrinkage, but in different capacities. The HPC results suggest that the SRA increases the tensile creep of the concrete, thus increasing the early age stress relaxation which reduces the potential for shrinkage cracking. However, it is recommended to perform basic creep tests to support this finding.

Recommended Further Works

New questions have arisen from the work in this study, and three areas that deserve further consideration were identified. First, the observation that SRA influences drying rate should be reproduced and further studied. Second, the components of creep and their relative contribution to the overall observed behavior are not entirely clear. It is recommended that future work should include basic creep tests to characterize the effect of SRA on this pure material property (basic creep). In this test, the effect and interaction with shrinkage will be eliminated leading to more informative results on the creep behavior. Third, restrained shrinkage tests in addition to the basic creep are recommended in order to determine the effectiveness of SRA in relaxing early age shrinkage stresses and reducing the risk of cracking. In a restrained shrinkage test, the combined effect of SRA on shrinkage and creep will be reflected on the stress development and cracking of the concrete.

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