CREEP BEHAVIOR OF SELF-CONSOLIDATING CONCRETE

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ABSTRACT

Estimating the creep behavior of self-consolidating concrete (SCC) is essential for successful application of this high-performance material in precast, prestressed members. To date, limited research has been published regarding the creep behavior of SCC. This paper documents creep testing of five mixtures (four SCC and one conventional), which were specifically prepared for precast, prestressed concrete applications. For each mixture, five loading ages were investigated: 18 hours, 2 days, 7 days, 28 days, and 90 days. The 18-hour samples, which had compressive strengths ranging from 5,800 psi to 8,860 psi, were cured at controlled, elevated temperatures to simulate the accelerated curing process typically used in the prestressed concrete industry. The 2-, 7-, 28-, and 90-day samples were moist cured as required by ASTM C 192. Each sample was loaded to achieve a stress level equal to 40 percent of the concrete compressive strength at loading in a creep frame that satisfied all ASTM C 512 requirements. The compliance of the SCC mixtures is compared to that of the conventional-slump concrete. All SCC mixtures exhibited creep values equal to or less than values for the conventional mixture. As concrete strength increased, creep decreased. The ground-granulated blast-furnace slag mixtures exhibited less creep than the fly ash mixtures of similar release strength.

INTRODUCTION

Contractors are currently exploring the use of SCC because it may result in homogeneous quality even in highly congested, narrow elements such as prestressed concrete members. The use of SCC may also decrease construction costs due to the reduced number of laborers required to place SCC. Producers in Alabama have experienced consolidation and finish problems with the use of conventional-slump girder mixtures. Although SCC should mitigate these problems, the Alabama Department of Transportation has not yet allowed the use of SCC for prestressed girder applications, mainly due to a lack of standardized test procedures and performance data, as well as uncertainty regarding the applicability of current design procedures to members made with SCC. From a creep standpoint this last statement is especially valid, as limited data have been published regarding the creep behavior of SCC. SCC typically has an increased paste content and sand-to-total aggregate ratio (*S/Agg*) relative to conventional-slump concrete (*1*). The main concern in prestressed concrete applications is that increases in paste content and *S/Agg* may lead to decreased modulus of elasticity, as well as increased creep and drying shrinkage—three factors that greatly affect prestress losses and member deflections. It is thus important to evaluate the creep behavior of SCC for use in prestressed concrete applications.

Relative to conventional-slump concrete, much less information is published about the creep behavior of SCC. However, much information is available about fundamental creep mechanisms in concrete and the contributing factors. Most of this information should be applicable to SCC. According to Neville (*2*) the hydrated cement paste experiences creep, and the aggregate is the only portion which resists this deformation. Therefore, creep is highly dependent on the stiffness of the chosen aggregate and its proportion within the mixture (*2*). Therefore, since creep mainly occurs in the cement paste, a concern is that SCC may exhibit increased creep because of its increased paste content. Creep increases with increasing water-cement ratio (*3*), which is an indication that creep decreases with increase in strength of the paste phase of the concrete. Cement type and content, ambient conditions like temperature and humidity, curing duration, and applied stress levels all affect the amount of creep (*2*,*3*). Neville (*2*) reports that "because of the long-term hydration, and therefore increase in strength under sustained load, of concrete containing fly ash or ground granulated blast furnace slag, the long-term rate of creep is reduced in such concrete."

The objective of this paper is to evaluate the relative creep behavior of four self-consolidating concretes and a comparable conventional-slump concrete. These mixtures were tested at a constant stress level at a variety of loading ages to better understand the creep behavior of SCC.

EXPERIMENTAL WORK

This work is a continuation of previous research conducted at Auburn University by Schindler et al. (1), thus the requirements followed here are identical to those adopted in that study. Production requirements dictated that SCC mixtures be evaluated with a compressive strength at prestress transfer (f'_{ci}) in the range of 5,000 to 9,000 psi at an age of 18 hours when cured at elevated temperatures.

Four SCC mixtures and one conventional-slump mixture were produced. Each SCC mixture was made with the proportions and properties listed in Table 1. In Table 1, the following abbreviations are used to identify each mixture: MS for moderate strength, HS for high strength, FA for fly ash, and SG for GGBF slag. Based on previous work (*1*), a conventional-slump concrete mixture with f'_{ci} of approximately 5,500 psi was used as a control mixture (CTRL). The water-cementitious materials ratio (*w/cm*) of the SCC mixtures was less than that of the control mixture. This was because of the supplementary cementing materials (SCMs) used, which all reduced the rate of early-age strength development. The SCC mixtures used 30 percent Class C fly ash, 30 percent ground-granulated blast-furnace (GGBF) slag, or 50 percent GGBF slag. Mixture CTRL is thus used for comparison purposes based on the assumption that mixtures should be compared at comparable f'_{ci} and water content, rather than equivalent *w/cm*.

Mixture Item	CTRL	Self-Consolidating Concrete			
		MS-FA	HS-FA	MS-SG	HS-SG
Water Content (pcy)	270	270	260	270	260
Cement Content (pcy)	640	525	650	375	650
Fly Ash Content (pcy)	0	225	279	0	0
GGBF Slag Content (pcy)	0	0	0	375	279
Coarse Aggregate Content (pcy)	1,964	1,607	1,529	1,613	1,544
Fine Aggregate Content (pcy)	1,114	1,316	1,252	1,321	1,265
Air-Entraining Admix. (oz/cwt)	0	0	0	0	0
Mid-Range WRA (oz/cwt)	4.0	4.0	4.0	6.0	6.0
HRWR Admixture (oz/cwt)	5.0	6.0	6.0	7.0	5.5
VMA (oz/cwt)	0.0	2.0	2.0	2.0	2.0
w/cm	0.42	0.36	0.28	0.36	0.28
Sand/Aggregate (by volume)	0.37	0.46	0.46	0.46	0.46
Average Slump Flow(in.)	9.0 (slump)	27.5	27.75	26.25	27.0
18-hr Compressive Strength (psi)	5,430	5,800	9,190	6,250	9,600
28-day Compressive Strength (psi)	8,400	9,570	12,800	10,600	12,880

Table 1. Mixture Proportions and Properties

Constituent Materials

All mixtures were made with No. 78 crushed dolomitic limestone and natural siliceous sand. The cementitious materials consisted of Type III Portland cement, Class C Fly Ash, and Grade 120 GGBF slag in amounts shown in Table 1. The chemical and physical properties of the powdered materials are reported elsewhere (*1*). The chemical admixtures included polycarboxylate-based mid- and high-range water reducers (HRWR) and a viscosity-modifying admixture (VMA).

Test Procedures

The laboratory concrete mixing procedure matched the procedure described by Schindler et al. (*1*). It conforms to ASTM C 192 “Standard Practice for Making and Curing Concrete Test Specimens in the Laboratory” with modifications only to allow proper effect of the HRWR admixtures.

The curing procedures of ASTM C 192 were followed with one exception. For the 18-hour loading age, an elevated curing temperature profile was used to simulate the accelerated curing conditions used for plant-fabricated prestressed concrete girders. The applied temperature profile began with a four-hour period at 73˚F, then the specimens were heated to 150˚F at a rate of 20˚F/hour over an eight-hour period. This temperature was held until the specimens were 18 hours old. The samples were then removed from the match-curing system, and testing commenced in accordance with ASTM C 512 “Standard Test Method for Creep of Concrete in Compression”. The specimens for the 2-, 7-, 28-, and 90-day loading ages were all moist-cured for 7 days or until load application, whichever occurred first. After the moist-curing period, all specimens were stored at a temperature of 73.4 ± 2.0°F and at a relative humidity of 50 ± 4 % until completion of creep testing.

Six-inch (diameter) by twelve-inch cylindrical specimens were used for creep testing. Companion drying shrinkage specimens also had the same dimensions. The drying shrinkage specimens were cured and capped to match their companion creep specimens. Immediately before creep testing, cylinders were tested in compression to determine their compressive strength at the intended loading age. A sustained load equal to *40 percent* of the compressive strength at the time of loading was applied. Strain measurements for both the creep and drying shrinkage specimens were recorded with a demountable mechanical strain gauge over a 7.9-in. (200-mm) gauge length. Data were collected for a period of 365 days after loading.

RESULTS AND DISCUSSION

Fresh Properties

The slump flow values ranged between 26.0 and 28.5 in.—well within the targeted range of 27 in. ± 3 in. Also, the T-50 times showed a slight downward trend as the *w/cm* increased. The VSI for the SCC mixtures ranged from 1.0 to 1.5, indicating good stability for all the mixtures. No air-entraining admixture was used for any of these mixtures, and the total air content of all the mixtures ranged from 1.7 to 2.9 percent.

Compressive Strength

The 18-hr and 28-day compressive strength values are listed in Table 1. The f'_{ci} values for the SCC mixtures ranged between 5,800 and 9,600 psi, which is slightly higher than the 5,000 to 9,000 psi range specified in Schindler et al. (*1*); the conventional-slump mixture had a f'_{ci} value of 5,430 psi.

Creep Behavior

At the time this paper is written, creep results for more than 365 days of loading are available for 22 of the 25 creep tests. Testing is still ongoing for 3 of the 25 test specimens; however, enough data have been collected to allow formation of some preliminary conclusions. ACI Committee 209 (*4*) recommends the use of compliance $J(t, t')$ to characterize and compare the creep behavior caused by a unit uniaxial sustained load. ACI Committee 209 (*4*) defines compliance follows:

$$J(t,t') = \frac{\text{Total strain} - \text{drying shrinkage strain} - \text{autogenous shrinkage strain}}{\text{stress}}$$

where, $J(t, t')$ = compliance at age t caused by a unit uniaxial sustained load applied at age t' (1/psi),

t = age of the concrete, and

t' = age of the concrete at loading.

The data gathered for all mixtures were grouped according to the loading age, and are presented in Figure 1. ACI Committee 209 (*4*) states that typical long-term compliance values range from 0.2 to 2.0 microstrain/psi. The measured 365-day compliance ranged from as low as 0.22 microstrain/psi for HS-SG to as high as 0.69 microstrain/psi for MS-FA, which is at the lower end of the typical range mentioned by ACI Committee 209.

For the 18-hour loading age (i.e. accelerated curing conditions), the compliance values of all the SCC mixtures are less than the conventional-slump mixture values. The compliance values at all loading ages are also less for the moderate-strength GGBF slag SCC and both high-strength SCC mixtures as compared to the control mixture.

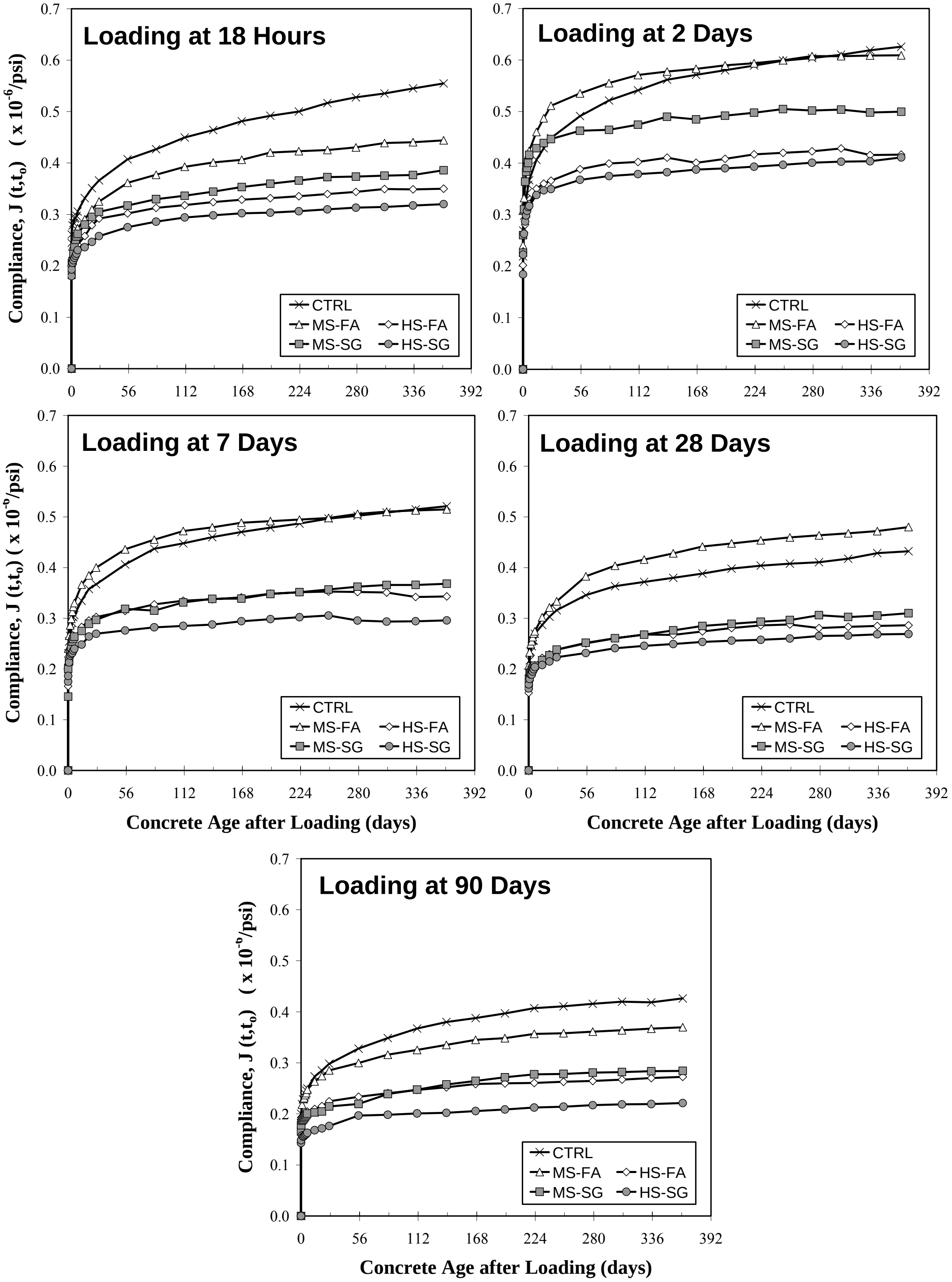

Figure 1. Compliance Data

At loading ages of 2- and 7-days, the long-term compliance of Mixture MS-FA is slightly larger than—but still comparable to—that of the control mixture. At loading ages of 28- and 90-days the long-term compliance is approximately 18% greater and 13% less, respectively, for Mixture MS-FA when compared to the control mixture. These differences are not very large. Thus, for practical purposes when curing is *not* accelerated, the creep behavior is similar for the moderate-strength fly ash SCC and the conventional-slump concrete.

From the data presented in Figure 1, it may further be concluded that the high-strength mixtures exhibit less creep than any of the three moderate-strength mixtures. This can be attributed to the increased strength and decreased permeability of the hydrated cement paste of these low *w/cm* mixtures.

The data presented in Figure 1 also clearly indicate that, at a fixed *w/cm*, the SCC mixtures with GGBF slag creep less than those with fly ash, regardless of loading age.

CONCLUSIONS

The creep response obtained from testing four SCC mixtures and one conventional-slump mixture at five loading ages is presented in this paper. All mixtures were produced under laboratory conditions and include samples cured under elevated temperatures typically used in the prestressed concrete industry in the Southeastern U.S. Based on the results, the following conclusions can be drawn:

- When curing is accelerated and the load is applied at 18 hours, the creep of all the SCC mixtures is less than the conventional-slump mixture. Since this curing condition simulates plant conditions, excessive creep is not expected for full-scale members constructed with these SCC mixtures.
- All SCC mixtures cured under elevated or standard laboratory temperatures exhibited creep values similar to or less than the conventional-slump concrete mixture.
- When curing is *not* accelerated, the creep behavior of the moderate-strength fly ash SCC and conventional-slump concrete mixture is similar.
- The high-strength mixtures had the highest paste content, but exhibited less creep than any of the moderate-strength mixtures. This behavior is attributed to the increased strength and decreased permeability of the hydrated cement paste of these low *w/cm* mixtures.
- At a fixed *w/cm*, SCC mixtures made with GGBF slag creep less than those made with fly ash, regardless of the age at loading.

REFERENCES

1. Schindler A.K., R.W. Barnes, J.B. Roberts, S. Rodriguez. Properties of Self-Consolidating Concrete for Prestressed Members. *ACI Materials Journal*, V.104, No.1, 2007, pp. 53-61.
2. Neville, A. M. *Properties of Concrete*, 4th Edition. John Wiley and Sons, Inc., New York, New York, 1996, 844 pp.
3. Mindess, S., J.F. Young, and D. Darwin. *Concrete*, 2nd Edition. Prentice Hall, Upper Saddle River, New Jersey, 2003, 644 pp.
4. ACI Committee 209. *Report on Factors Affecting Shrinkage and Creep of Hardened Concrete (ACI 209.1R)*, American Concrete Institute, Farmington Hills, Michigan, 2005, 12 pp.