Creep and Shrinkage of High Performance/High Strength Concrete

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ABSTRACT

This paper presents results from creep and shrinkage tests performed on different High Strength Concrete (HSC) mixes (with compressive strengths up to 90 MPa). Results were compared with those from various Code prediction models. The effects of pozzolanic materials on the creep and shrinkage were also investigated. Results show that while fly ash increases the compressive creep of concrete, silica fume decreases it. Moreover, current creep and shrinkage prediction models need to be revised for the HSC mixture.

1. INTRODUCTION

Creep and shrinkage are highly complex phenomena that are very sensitive to the surrounding environment and gel content. Because of these complexities, the calculation for creep and shrinkage cannot be simply derived from available models that are based on data from conventional concrete. High strength concrete (HSC) properties are very different than those of conventional concrete. As a result, the creep and shrinkage of concrete changes, and therefore, new experimental data are needed to verify current models. This study investigates the creep and shrinkage behavior of HSC containing pozzolanic materials. Available creep and shrinkage models used I two design building codes are also evaluated and compared with the experimental data to determine their accuracy and validity.

Pozzolanic materials such as silica fume, fly ash, and slag have been used in the United States to improve the quality of concrete (Goodspeed et al. 1996). These materials make HSC denser and impermeable to chemical attacks and, at the same time, alter its mechanical properties. Despite advancements in concrete material, the design of HSC structures, or more specifically creep and shrinkage predictions, are still based on equations that were founded on properties of conventional concrete. Moreover, most creep and shrinkage prediction models have limitations when dealing with high strength concrete (HSC) or more specifically concrete with a compressive strength in excess of 80 Mpa. This is partly a result of the limitation of data available from the RILEM data bank, which is used by most models for their calibration and validation. Thus, more experimental data are needed for HSC.

The main focus of this paper is to investigate the effect of pozzolanic material on the creep and shrinkage behavior of HSC using readily available resources in the State of New Jersey. A total of eight mixes were cast and tested for creep and shrinkage; these mixes consisted of three mixes with varying percentages of silica fume, three mixes with varying percentages of fly ash (Class F), and two mixes with different combinations of silica fume and fly ash.

2. CODE PREDICTION MODELS

Several creep and shrinkage prediction models exist, but only two main code models are most commonly used in the United States and Europe, ACI 209 and CEB 90, respectively

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3. EXPERIMENTAL INVESTIGATION

The materials used in this project were readily available resources in the State of New Jersey. The binding materials consisted of ordinary Portland cement (OPC) Type I, silica fume (SF), and Class F fly ash (F). All mixes contained superplasticizer and air−entraining agent to ensure good workability and freeze−thaw resistance, respectively. River sand and crushed granite were used as the fine and coarse aggregate, respectively. The fine aggregate (FA) had a unit weight, fineness modulus, and water absorption of 1621 kg/m3, 2.56, and 0.36%, respectively. The coarse aggregate (CA) had a maximum size aggregate of 10 mm. Its unit weight, specific gravity, and water absorption were 1572 kg/m3, 2.81, and 1%, respectively.

Seven mixes out of a total of eight mixes were made with a constant water−to binder ratio (w/b) of 0.27. All mixes had the same amount of water, FA, and CA. Three mixes had varying SF contents of 5%, 10%, and 15%. The other three mixes had varying F contents of 10%, 20%, and 30%. The last mix was ternary blended concrete that contained 5% SF and 20% F. The concrete was made in accordance to ASTM C192. Slump and air−content tests were also performed on the fresh concrete in accordance to ASTM C143 and ASTM C173, respectively. After the concrete specimens were cast, they were sealed with plastic wrap to prevent loss of moisture. For each mix, specimens were made for compression, drying shrinkage, and creep tests.

4. RESULTS AND DISCUSSION

4.1 Drying Shrinkage

Figure 2 shows the effect of pozzolanic materials on drying shrinkage. It is observed that both SF and F concretes had similar shrinkage strains after 90 days. However, at an early age (between 1 to 7 days), F concrete shrinks less than SF concrete because SF is more reactive and has a higher water demand than F. For the ternary blended concrete mix, the F content slows the reaction at an early age, resulting in a lower shrinkage strain compared with the concrete containing SF only. It should be noted that the results presented in this paper are based on drying shrinkage and not the total shrinkage. The total shrinkage for HP/HSC would have been higher and even more for mixes containing SF because these mixes have high autogenous shrinkage. Nassif et al (2003) showed that the autogenous shrinkage of SF concrete is as high as drying shrinkage.

Figures 3 and 4 illustrate the comparison of the ACI 209 and CEB 90 shrinkage prediction models, specifically comparing measured and calculated shrinkage strains. Both models under−predict the drying shrinkage of HSC. However, the shrinkage strain given by the ACI 209 model is better than the CEB 90.

Figure 1. Compressive Creep Test Setup

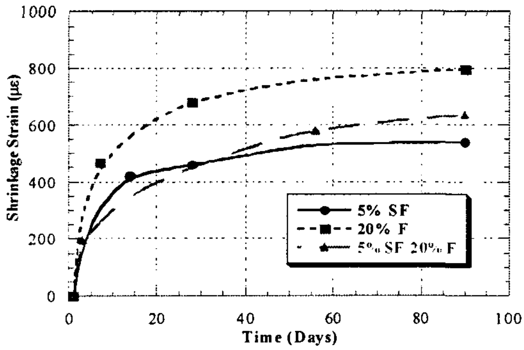

Figure 2. Drying Shrinkage of HSC

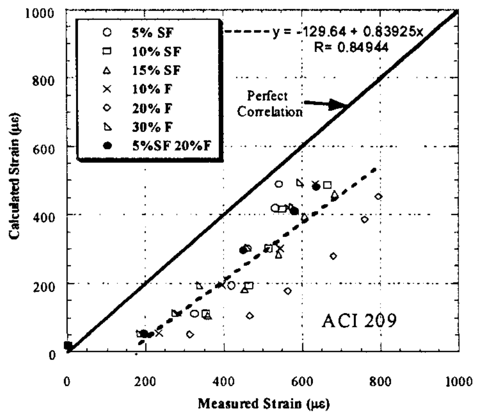

Figure 3. Comparison of Measured Drying Shrinkage to ACI 209 Prediction Models

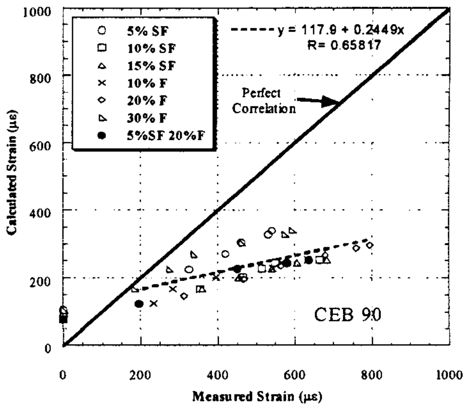

Figure 4. Comparison of Measured Drying Shrinkage to CEB 90 Prediction Models

4.2 Creep

As mentioned earlier, creep of concrete is one of the most complex phenomena to analyze because many parameters affect the results. Furthermore, there are several theories and hypotheses that lead to no definite conclusion (Neville 1970). However, one of the most common theories and hypotheses that contributed to creep is the presence of evaporable water. The presence of evaporable water is related to the seepage of the absorbed water to the outside of the concrete (only for drying creep), or the evaporable water could also undergo an internal seepage (in the direction of the load) to an absorbed layer, such as capillary voids. Therefore, seepage of water causes creep, and the presence of evaporable water can be used to explain the increase in creep with a higher content of pozzolanic materials. For SF concrete, as the amount of SF content increases, the water demand of the SF becomes higher; this causes internal tensile forces that pull the water from the load-bearing water (Powers hypothesis), which results in higher creep. However, this creep is still relatively smaller than in concrete containing F because the capillary voids in SF concrete are smaller compared with F concrete; hence, the amount of evaporable water presence in SF concrete is lower. For the F concrete, the mix with the highest F content has the highest creep because the mix has a lower water demand. Nevertheless, because the water content in all mixes remains constant, the mixes contain more evaporable water, leading to higher creep.

Figure 5 shows the comparison of results between the creep prediction models and experimental data. Both the ACI 209 and CEB 90 models provided accurate creep prediction but the ACI 209 slightly outperforms the CEB 90 model. Overall, both models over-predicted the creep of HSC.

5. CONCLUSIONS

The mechanism of creep and shrinkage (especially creep) is highly complex because of the nature of concrete. Concrete is a composite material that comprises different ingredients that affect creep. In addition, other parameters, such as the surrounding environment, loading age, and applied stress, all contribute to creep. Because of this complex nature, its mechanism is difficult to understand; therefore, it is challenging to conclude the actual behavior of creep using available theories. The best way to understand creep is through measured data.

An experimental program was conducted to determine the effect of pozzolanic material on the creep and shrinkage of HP/HSC. From the experimental results, the following conclusions could be made:

(1) The drying shrinkage of concrete is influenced by the loss of water. The water loss is a

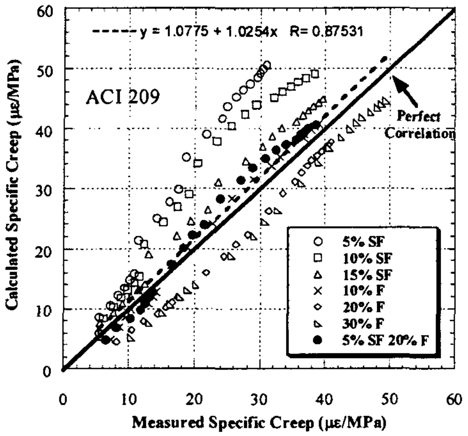

Figure 5. Comparison of Measured Specific Creep to ACI 209 Prediction Model.

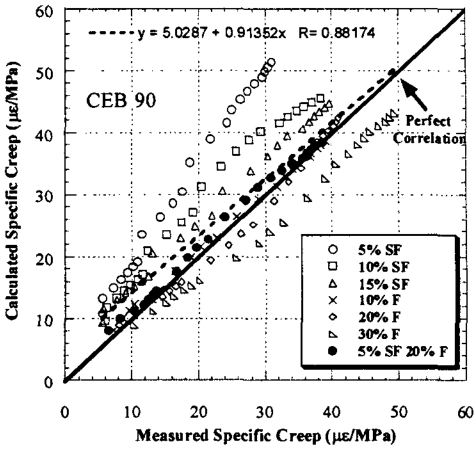

Figure 6. Comparison of Measured Specific Creep to CEB 90 Prediction Model.

result of drying, as well as the hydration process. Because SF has a high water demand, the drying shrinkage increases as the SF content increases. For F concrete, the F content has a lower water demand; therefore, the drying shrinkage is reduced as the F content increases.

(2) The creep of concrete is also highly dependent on the loss of water, or more specifically the presence of evaporable water. Because SF concrete has a lower capillary void than F concrete, the former has lower creep than the latter. Hence the creep in F concrete could also be reduced by adding SF.

(3) The Code models for creep and shrinkage do not include parameters that take the properties of HSC into account. A correction factor is needed to account for the additional pozzolanic constituents of HSC.

REFERENCES

1. ACI Committee. 209 1992. Prediction of creep, shrinkage and temperature effects in concrete structures.. *Report No. ACI 209 R-92*, ACI Publication: 47.
2. Branson, D.E., & Christianson, M.L. 1982. Time-dependent concrete properties related to design-strength and elastic properties, creep, and shrinkage", *Designing for Creep and Shrinkage in Concrete Structures : A Tribute to Adrian Pauw*, SP-76, ACI Publication: 257-277.
3. Comité Euro-International du Béton (CEB), CEB-FIP Model Code 1990: Design Code. London, Thomas Telford, 1993, p. 480.
4. Goodspeed, C.H., Vanikar, S., & Cook, R.A., 1996. High-performance concrete defined for highway structures. *Concrete International*, 18(2): 62-67.
5. Muller, H.S. & Hillsdorf, H.K. 1990. CEB bulletin d' information, No. 199, evaluation of the time dependent behavior of concrete, summary report on the work of general task group 9
6. Nassif, H.H., Suksawang, N., and Mohammed, M. 2003. "Effect of curing methods on the early-age and drying shrinkage of high-performance concrete", *Transportation Research Record*, No. 1804, TRB, National Research Council, Washington, D.C.:48-58.
7. Neville, A.M. 1970 *Creep of Concrete: Plain, Reinforced, and Prestressed.* North-Holland Publishing Company, Amsterdam.