As seen in the January/February 2009 Edition

New Technology-Based Approach to Advance Higher Volume Fly Ash Concrete with Acceptable Performance

Ready Mixed Concrete Truck used to Prepare the Concrete

Match Cured Specimens being Cured in the Laboratory

Concrete Block Cast and In-Place Strength Measured by Match Curing, Maturity, Pull-out and Field Cured Cylinders

Final Report and Guide for the Construction Team

This is a summary of the final report of the 2 year project that was funded by the Department of Energy's Combustion Byproducts Research Consortium (West Virginia University) and the RMC Research and Education Foundation.

By Karthik Obla, Ph.D., P.E., Managing Director, Research & Materials Engineering, NRMCA

The 2006 fly ash use survey conducted by the American Coal Ash Association indicates that out of the 72.4 million tons of fly ash produced annually 45% was beneficially utilized; 59% of this was used in cement and concrete applications. Concrete is the largest market for fly ash and offers the highest potential for increased fly-ash utilization. While fly ash is routinely used in concrete, the actual use of high-volumes of fly ash (> 30% of total cementitious materials content) in ready mixed concrete is limited due to perceived lower early-age strengths as documented in research studies conducted in the laboratory with standard cured strength specimens.

The objective of this study was to demonstrate, using maturity-based techniques, that the actual in-place strength of High-Volume Fly Ash (HVFA) concrete in a structure is higher than that indicated by strength measured on field-cured cylinders due to the higher in-place temperature resulting from the slower dissipation of heat of hydration due to the greater mass of structural members. The in-place strength of concrete in the structure can be determined by monitoring its temperature history over time, calculating the maturity, and by estimating the in-place strength from the pre-calibrated strength-maturity relationship. The maturity concept assumes hydraulic cement concrete of the same maturity will have similar strengths, regardless of the combination of time and temperature yielding the maturity. Maturity concepts are well established for portland cement concretes but they are not so established for HVFA concrete mixtures containing chemical admixtures. The Arrhenius and Nurse-Saul maturity functions are commonly used to establish the maturity index. The Arrhenius maturity function is considered more accurate and was used in this study. The Arrhenius maturity function requires the use of mixture-specific activation energy to improve predictions of strength. The activation energy quantifies the temperature sensitivity of the concrete mixture.

An initial task was to determine the activation energy of each of the concrete mixtures using the procedure outlined in ASTM C1074. Various fly ashes (Class C and Class F fly ash meeting the standard ASTM C618) with multiple dosages (20% to 50% by mass of cementitious materials) were used in this study. Activation energies of these mixtures were determined. Some unexpected trends of strength based on curing temperature were observed for these fly ashes mixtures. The fly ash mixtures cured at elevated temperatures demonstrated higher long-term strengths than anticipated in comparison to the strength of specimens cured at lower temperatures.

The next step was to develop strength-maturity relationships in the laboratory for four of the concrete mixtures. Additionally, pullout load versus compressive strength correlations were developed. To validate the strength predictions based on maturity, four concrete blocks and slabs were prepared in the field during the period of October to December, when the ambient temperature ranged from 15.5°C (60°F) to 7.5°C (45°F). The in-place compressive strength of the concrete blocks and slabs were predicted based on the following approaches:

1. Match-cured cylinders
2. Pullout testing using the pullout versus compressive strength relationship previously developed
3. Maturity based on the activation energy and strength-maturity relationship previously measured
4. Field-cured cylinders. Compressive strength of the concrete mixtures using standard-cured cylinders was tested at several ages.

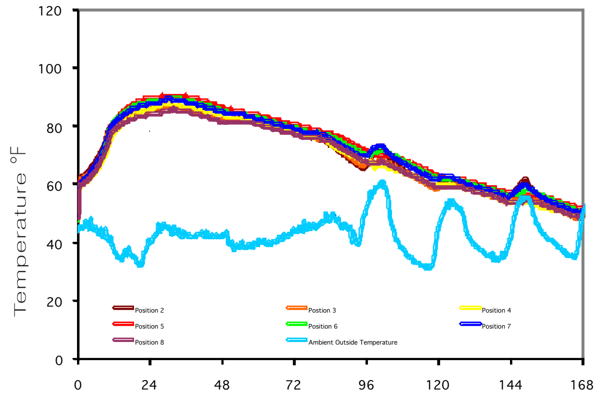
Based on the study the following preliminary conclusions were made:

- For HVFA concrete, the large volume of structural elements will result in higher in-place temperatures and in increased early-age in-place strengths (measured by match-cured cylinders and pullout tests) compared with strength gain by cylinders under standard laboratory conditions. As a result, construction schedules may not have to be extended.
- Field-cured cylinders underestimated in-place strength development, and standard-cured cylinders must not be used for estimating in-place early-age strengths. Field cured and standard cured conditions are discussed in ASTM C31/C31M.
- The maturity method and the pullout test are applicable to estimate the early-age concrete strength in structures made with HVFA concretes. The use of these methods will allow for increased fly ash content without adverse effects on the safety of early-age construction operations.

A guide for the construction team (contractor, concrete producer and engineer) that complements the report has also been developed. The guide provides a step by step procedure on the application of the maturity method to support the use of optimized HVFA concrete mixtures by providing a simple method to estimate in-place strength development. The seven steps of the guide are as follows:

1. Identify the early-age strength requirements for the specific structural application (such as for removal of forms, application of prestressing, early opening of pavements, etc.), and identify the age at which this strength needs to be attained; for example, a requirement of 2800 psi in 72 hours.
2. Choose appropriate concrete ingredient materials and establish HVFA concrete mixture proportions that will achieve the required early-age strength and other performance requirements.
   Select the activation energy (AE) for strength development that most closely matches the selected cementitious materials.
3. Develop the strength-maturity relationship for the selected HVFA concrete mixture following the procedure in ASTM C1074.
4. Select the hydration parameters that most closely match the selected materials.
5. Conduct a thermal analysis and strength development simulation (with a computer program such as ConcreteWorks) using the selected HVFA concrete mixture, the appropriate member geometry, the proposed construction sequence and the anticipated ambient temperatures.
6. Evaluate whether the selected HVFA mixture will meet the early-age strength requirements.
7. Once the project starts, the engineer oversees measurement of in-place maturity in accordance with ASTM C1074 and uses the strength-maturity relationship to estimate in-place strength during construction.

Both the final report and guide can be found at http://www.nrmca.org/research/eng_articles.asp. ■



Temperature profile of block (50% low CaO fly-ash mixture)

References

1. Obla, K.H., Upadhyaya, S. Goulias, D., Schindler, A.K., and Carino, N.J., "New Technology-Based Approach to Advance Higher Volume Fly Ash Concrete with Acceptable Performance," Final Report, National Ready Mixed Concrete Association, Silver Spring, MD, August 2008, 218 pp. (available at www.nrmca.org).

2. Obla, K.H., Schindler, A.K., and Carino, N.J., "New Technology-Based Approach to Advance Higher Volume Fly Ash Concrete with Acceptable Performance," Guide for the Construction Team, National Ready Mixed Concrete Association, Silver Spring, MD, October 2008, 17 pp. (available at www.nrmca.org).

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