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

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EXECUTIVE SUMMARY

A major obstacle that limits the widespread use of High-Volume Fly Ash (HVFA) concrete is its lower early-age strength 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 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^{o}C (60^{o}F) to 7.5^{o}C (45^{o}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; and
4. Field-cured cylinders.

Compressive strength of the concrete mixtures using standard-cured cylinders was tested at several ages.

Based on this study the following preliminary conclusions are made:

1. Match-cured compressive strength data have clearly demonstrated that HVFA concretes in actual structural members achieve much higher early-age strengths than the strength indicated by testing field-cured cylinders. This observation will allow for further mixture optimization and possibly increased content of fly ash without negative impact on construction operations.

2. A maturity-based approach has been developed to estimate in-place strength in the actual structure from temperature measurement with time.