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DETERMINATION OF THE MAXIMUM PLACEMENT AND CURING TEMPERATURES IN MASS CONCRETE TO AVOID DURABILITY PROBLEMS AND DEF

PROBLEM STATEMENT

The Florida Department of Transportation specifies a maximum differential of 35°F between the exterior and interior portions of the mass concrete elements during curing. However, the specification does not specify a maximum curing temperature or a maximum placing temperature. The FDOT mass concrete projects of the past reveal that the temperature of the core may reach from 170°F to 200°F. Some researchers have indicated that a specified temperature differential should be accompanied by a maximum curing temperature, since concrete that cures at temperatures above 160^{o} F is suspect in terms of durability and delayed ettringite formation (DEF).

OBJECTIVES

The primary objective of this project was to determine the effect of concrete curing temperature on the strength, durability, and other physical/chemical properties of concrete.

FINDINGS AND CONCLUSIONS

Researchers conducted a state-of-the-art review of work reported on heat generation in mass concrete and identified measures taken to avoid cracks and premature deterioration. The review revealed that higher curing temperatures increase the initial strength of concrete, but decrease later-age strength. Also, in plain Portland cement concretes, elevated curing temperatures result in coarser pore structure and increase total porosity, mostly in the volume of larger pores. This finding suggests that high curing temperatures could reduce the durability of plain cement concrete, since large pores have the greatest effect on permeability and reduce the concrete's resistance to chloride ion penetration. Corrosion of reinforcing steel is a result of chloride ions, and it causes premature deterioration of concrete structures. Another documented problem associated with high concrete curing temperature is early concrete distress due to DEF. Ettringite is a normal and apparently innocuous constituent of hydrated Portland cement. Its formation at the initial stages of hydration is seen as a positive effect, because it enables the setting of the cement; however, a damaging role is attributed to its formation in hardened concrete.

Researchers also conducted a survey to investigate current US Highway Agency specifications relative to mass concrete (43 states responded). The majority of respondents (28 states) agreed that mass concrete pours should be controlled by a maximum differential temperature, which most agencies currently specify, and a maximum curing temperature, which most agencies do not currently specify. The reasons given to support the need for a maximum curing temperature were to avoid durability problems, later-age strength reduction, DEF, and cracking due to expansion of concrete. Two states (Illinois and Kentucky) have specified a maximum curing temperature of 160°F, three states (North Carolina, South Carolina, and Texas) have specified a maximum placing temperature, and several others (Arkansas, Iowa, Minnesota, North

Dakota, and Nebraska) have special provisions—either a maximum curing temperature or a maximum placing temperature—for mass concrete.

The effects of concrete curing temperature on the properties of hardened concrete were evaluated using the following tests: compressive strengths, rapid chloride permeability (RCP), time-to-corrosion, volume of permeable voids, and microstructure analysis using the Scanning Electron Microscope (SEM). Class IV - Structural concrete mixes, consisting of 18% replacement by weight of cement with class F fly ash and 50% replacement by slag, were used to produce test specimens. These specimens were cast at room temperature and stored in water tanks, where they were subjected to different curing temperatures (73^{o}, 160^{o}, and 180^{o}F).

The experiments revealed the following:

- The plain Portland cement concrete samples cast and stored immediately in water tanks under isothermal curing temperatures of 160^{o} F and 200^{o} F underwent a substantial decrease in compressive strength, as compared to samples cured at room temperature (73^{o} F). This reduction was 34% and 62% for 28-day compressive strength for samples cured at 160^{o} F and 200^{o} F, respectively. In addition, RCP testing of these samples showed a significant increase in permeability of concrete cured at high temperature.

- Plain Portland cement concrete samples were introduced to a controlled ascending temperature rise simulating, approximately, conditions of mass concretes cured in the field (semi-adiabatic temperature rise); there was a moderate reduction in 28-day compressive strength of samples cured at elevated temperatures, as compared to samples cured at room temperature. The reduction was 15% and 18% for samples cured at temperatures of 160^{o} F and 180^{o} F, respectively. However, there was still a significant increase in permeability of concrete measured through the RCP test.

- Semi-adiabatic curing of fly ash cement concrete samples (18% fly ash by weight) resulted in an 8% reduction of 28-day compressive strength for samples cured at 160^{o} F and 180^{o} F, when compared to those cured at room temperature. However, permeability of concrete measured by the RCP test improved noticeably at higher curing temperatures, which suggests that at higher temperatures the fly ash becomes effective much earlier and reduces the RCP values. At normal curing temperature, the RCP reducing effect of fly ash becomes effective after approximately two months. However, the time-to-corrosion test results did not support this finding and showed reduction in time to corrosion for samples cured at higher temperatures, as compared to those cured at room temperature.

- When 50% (by weight) of Portland cement is replaced by blast furnace slag, the 28-day compressive strength of samples cured at elevated temperatures was reduced by 7% and 15% for curing temperatures of 160^{o} F and 180^{o} F, respectively, when compared to those cured at room temperature. Durability of concrete in this case again showed conflicting results between the RCP and the time-to-corrosion tests, i.e., RCP test results indicated that higher curing temperatures improve durability, while time-to-corrosion test results indicated that higher curing temperatures reduce durability.

- Results of compressive strength tests and RCP tests revealed that the addition of blended cement improves the strength and the durability of concrete.

- Microstructural analysis of mortar samples sieved from the concrete mixes using the SEM showed that the addition of pozzolanic materials reduces the possibility of the formation of delayed ettringite. It also identified the formation of delayed ettringite in samples 28 days and older where the curing temperature was 160° F and 180° F. No DEF was found in concrete samples cured at room temperature.

BENEFITS

This research provided the data needed to set a limitation on the maximum curing temperature of mass concrete structures, such as bridge piers, bridge foundations, and abutments, to make them more sound and durable. The applications of this research will result in highway bridges with longer service lives and reduced maintenance costs.

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