THERMAL CONTROL OF MASS CONCRETE

The design and construction communities have shown increasing interest in high-workability, high-strength, and high-durability concrete mixtures for building massive structural elements. These mixtures usually contain a high cement content that results in high heat of hydration and thermal cracking. Therefore, Ric Maggenti’s article, “From Passive to Active Thermal Control” (Nov. 2007, pp. 24-30), on Caltrans’ experience with recently constructed massive elements for concrete bridges in California, is timely. We are concerned, however, with the approach taken by Caltrans to address the problem of high heat of hydration. We believe the real issue is that too much portland cement was used for making self-consolidating concrete mixtures, and that this led to the proposed solution of cooling pipes for mitigation of heat of hydration.

An alternative method exists for producing self-consolidating concrete mixtures of high durability and strength without excessive heat of hydration. The principles and field practices of high-performance, high-volume fly ash (HVFA) concrete technology are described by many publications, including References 1 and 2. It’s imperative that this passive thermal control method be pursued, not only for reasons of cost and durability but also from the standpoint of sustainability of the structural materials used.

Maggenti discussed the need for 30 and 45 MPa (4500 and 6500 psi) concrete mixtures for foundations and piers. HVFA concrete can meet those strength requirements. As an example, the seismic upgrade of Barker Hall—a six-story concrete building at the University of California at Berkeley—required a post-tensioned 41 x 31 m (135 x 102 ft), massive, belt foundation 4.5 m (14.8 ft) deep and 2 to 2.4 m (6.6 to 7.9 ft) wide. A HVFA concrete mixture with a 0.33 water-cementitious material ratio \(w/cm\) containing a high-range water-reducing admixture (HRWRA) and 55% fly ash by mass of total cementitious material was used for this project.

The average compressive strengths of the concrete were 14 MPa (2000 psi) at 7 days, 30 MPa (4500 psi) at 28 days, and 57 MPa (8300 psi) at 1 year. The maximum concrete temperature recorded in the center of the foundation was only 51 °C (124 °F). Note that Maggenti’s data on massive footings of the Cypress Bridge and Dublin Bridges confirmed passive controls work satisfactorily when the concrete peak temperature was held below 60 °C (140 °F) and the temperature differential to 20 °C (36 °F).

The reputation of HVFA concrete as a drag on the construction schedule does not apply to superplastized high-performance mixtures.1 Experience with Barker Hall shows that moderate strengths can be attained even at 7 and 28 days; thereafter, the strength development continues at a high rate and the 1-year strength is typically twice the 28-day strength. With HVFA concrete mixtures, a 56- or 90-day strength specification is more appropriate than the usual 28 days. Regarding the workability of HVFA concrete, the fresh concrete mixtures used for Barker Hall and other massive structures were not only easy to pump but also nearly self-consolidating.

A CANMET investigation4 found that completely self-consolidating mixtures with a low heat of hydration potential were obtained by increasing the proportion of fly ash to 60% by mass of the cementitious materials. The concrete mixtures had a \(w/cm\) of 0.35 to 0.40 and contained about 162 kg/m\(^3\) (273 lb/yard\(^3\)) portland cement, 243 kg/m\(^3\) (410 lb/yard\(^3\)) Class F fly ash, and 2 to 3 L/m\(^3\) (50 to 75 ft \(^{3}\)/yd\(^3\)) HRWRA. The average slump was 240 mm (9.5 in.), and the slump flow ranged from 600 to 650 mm (23.5 to 25.5 in.). As an added benefit, the HVFA concrete did not require expensive viscosity-modifying admixtures to control rheology.

It’s well known that conventional, high-strength concrete containing a large proportion of portland cement is prone to cracking by thermal and autogenous shrinkage. HVFA concrete (with 50 to 60% by mass cement replacement), however, remains crack-free because the low heat of hydration and slow rate of strength development at early ages allow relaxation of stresses by creep. At later ages, the hydration products generated by the pozzolanic reaction fill the voids and microcracks to create a dense, strong, and nearly impermeable microstructure.

Using excessive amounts of portland cement in concrete mixtures is not sustainable because of large CO\(_2\) emissions associated with portland clinker production, especially when this can be avoided by using excellent alternative methods. We believe that HVFA concrete is a sustainable construction material, and leaders setting standards for the rest, such as Caltrans, should make every effort to promote sustainability.

Harvey Haynes, Oakland, CA; Kumar Mehta; Berkeley, CA; and Dushyant Mannmohan, Oakland, CA

References


**Author’s response**

I enjoyed this letter very much and found it informative. The points regarding sustainability and the information on the actual use and the properties attained with HVFA concrete are of interest. The nature of technology, including material sciences, is that it evolves, and HVFA concrete may very well be something used much more as time goes on for the reasons given, including the ease of using passive thermal control. But increased use of HVFA concrete will only come through education, experience, and communication, with your letter contributing to this process.

Certainly much more fly ash and other supplementary cementitious materials such as slag are being used on Caltrans projects compared to a decade ago. In 1996, fly ash was limited to 15% by standard specifications and used only in a small percentage of structural concrete, while by 1999 we were requiring, with only some exceptions, a minimum of 25% in all structural concrete. During the Caltrans transition to the mandatory 25% fly ash to address reactive aggregate, it was asserted more than once from both within and outside our department that the “proper” amount was 15%. Only through education, experience, and communication was there a general acceptance of using fly ash at 25% and more. Indeed, one coauthor of your letter played a role in educating Caltrans to overcome the 15% maximum limit. Around that time, I remember a presentation by Mehta on the use of some approximately 70% fly ash mixtures. Present in the audience were people who were not sure if more than 15% fly ash was appropriate and if 25% was some outlandish amount.

The purpose of my article was to describe the active thermal control measures for mass concrete used on some recent Caltrans bridge projects and the events that led to it. Using what you call “conventional” high-strength concrete mixture designs, the active thermal control prevented high temperatures. Education, experience, and communication were needed before active measures were accepted as a possible solution. And the active measures were, with the exceptions noted, not mandated but chosen. Whether or not there was a better solution for any particular element, the chosen solution did work, resulting in a successful project.

However, I do not wish to imply that passive measures, such as using high percentages of fly ash, were abandoned. The very large SAS footings referred to in the article (and shown in Fig. 1, 5, and 6) incorporated 40% fly ash though they also used active thermal control consisting of cooling pipes to keep the maximum temperature below 50 °C (122 °F), a limit specified for reasons other than cracking. We have used and are planning to use mixtures containing as much as 50% fly ash in elements where strength gain and maximum temperatures are such that this passive control eliminates the need for active measures.

The current (conventional) material practices, current designs, and current demand by the community at large to build at some expected pace are factors that play into the approach to solve a particular problem at hand at any particular time. Design strengths are going up and construction schedules have accelerated to where strength gain is sometimes measured in hours to keep a construction process on pace. When under such constraints where mass concrete is at issue, I believe active measures, particularly cooling pipes, have shown to be not only effective, but almost indispensable.

Ric Maggenti, Sacramento, CA
DURABILITY AND BLENDED CEMENTS

I found some issues of concern in the article, “Ternary Cement in Canada,” by Michael Thomas, Donald S. Hopkins, Martin Perreault, and Keven Cail (July 2007, pp. 59-64). First, it’s not always possible to know with certainty whether statements in the article refer to factory-blended cements or to any and all “ternary” cements. Second, the following paragraph (pp. 62-63) contains very broad statements with no supporting documentation:

“Generally, flatwork produced using ternary cement has provided satisfactory field performance when exposed to freezing and thawing in the presence of deicing salts. There have been isolated cases, however, of salt-scaling problems in sidewalks produced with ternary cement. Further studies are underway to determine whether these problems are due to the cementitious materials, concrete quality at placing, or finishing and curing practices. In our opinion, particular attention must be paid to concrete quality and construction practices when concrete containing SCMs [supplementary cementitious materials] is used in flatwork and exposed to deicing salts.”

Studies by Bleszynski, et al.1; Talbot, Pigeon, and Marchand2; and others have indicated an increased risk of scaling in exposed flatwork concretes that contain SCM replacements for portland cement (particularly when slag cements comprise more than 25% of the weight of the total cementitious material), so why not cite them? Third, the following statements on p. 64 appear to contradict the paragraph’s opening statement:

- “Ternary cement…may render flatwork more vulnerable to salt scaling if the concrete is not proportioned and placed properly”;
- “Too high of a slag cement content… can lead to problems with early-age strength development and deicing salt scaling.”

There is no attempt in the article to explain why these concretes are more vulnerable to scaling than others, and there are no recommendations for changes in materials, proportions, or installation procedures to overcome this vulnerability. Until such answers are forthcoming, it would appear that both the suppliers and the users of concretes for exposed flatwork applications are at risk.

David Lankard, Columbus, OH

References


Author’s response

David Lankard’s letter raises two issues: factory blends versus mixer blends of cementitious materials and the deicing salt scaling resistance of concrete containing SCMs. As indicated by the subtitle of our paper and in the introduction, the data presented are for factory blends of portland cement, slag, and silica fume. However, the findings of our study are generally consistent with findings from studies where these cementitious materials are added as separate ingredients to the concrete mixer.

There have been a great many papers published on the deicing salt scaling resistance of SCM concrete, but it was not our intention to provide a review of the published literature on this topic. It is fair to say that the findings from these studies are equivocal. Accelerated laboratory tests such as ASTM C672 are very aggressive, and it has been shown that the results from such tests do not correlate well with field performance, especially for concrete containing fly ash and slag.1,2 Reference 1 reported satisfactory field performance for a number of fly ash concrete structures exposed to deicing salts where laboratory tests on the same concrete mixtures indicated poor performance. Reference 2 reported similar discrepancies between laboratory and field performance for slag concrete. Despite the severity of the test, concretes produced with factory-blended ternary cement gave satisfactory performance (scaled mass < 800 g/m² [0.16 lb/ft²] after 50 cycles) in the ASTM C672 salt scaling test provided the water-cementitious material ratio (w/cm) was at or below 0.45. Marginal performance (scaled mass = 874 g/m² [0.17 lb/ft²]) was observed for concrete with w/cm of 0.47 and unsatisfactory performance (scaled mass = 1311 g/m² [0.26 lb/ft²]) for concrete with a w/cm of 0.63. This confirms the importance of maintaining a low w/cm for concrete exposed to deicing salts (the limit in ACI 318 for concrete exposed to deicing salts is w/cm ≤ 0.45). Concrete mixtures that perform well in this accelerated test would be expected to perform well in the field. Indeed, the satisfactory field performance of concrete containing similar ternary blends of portland cement, slag, and silica fume have been documented by Bleszynski et al.1 and Rogers et al.4

In the article, we confirm that the field performance of concrete produced with the factory-blended ternary cement and exposed to deicing salts has been satisfactory. However, it would have been remiss of us if we did not mention that there have been isolated cases of salt-scaling problems in concrete sidewalks produced with...
this cement. What does this mean? It is difficult with isolated cases of scaling to determine whether the problem is due to the materials used or construction practices. In the Fredericton, NB, Canada area, it is not easy to walk more than 1/2 mile without crossing some badly scaled concrete sidewalk despite the fact that the “city mixture” does not contain SCMs and is supposedly batched to meet a C-2 exposure class (nonreinforced concrete exposed to freezing and thawing in the presence of deicing salts, which requires $w/cm \leq 0.45$ and a 28-day strength of 32 MPa [4600 psi]). Does this mean that air-entrained, 32 MPa (4600 psi), portland cement concrete is not resistant to deicing salt scaling? No, but it does indicate that a concrete mixture proportioned to resist scaling can be rendered nonresistant in hand-finished flatwork due to improper construction practices such as the on-site addition of water, excessive or poorly-timed finishing, and inadequate curing. In my opinion, the scaling resistance of concrete (especially hand-finished flatwork) that contains more than moderate levels of SCMs may be more sensitive to improper proportioning and construction practices.

Michael Thomas, Fredericton, NB, Canada

References


