Performance Screening of Concrete Materials and Proportions Using Thermal Testing

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Overview & agenda

- Thermal testing background and definitions
- Managing, processing, and interpreting thermal profile data for common applications
- Applications and examples of thermal and strength testing of paste in the lab
- Managing, processing, and interpreting thermal profile data for common applications
- Incompatibility of materials – evaluation with thermal testing, influences, remedies

Thermal testing?
Background and definitions
Some terms defined, conventions noted

**calorimetry** (kal-o-rim-e-try) n. –
Measurement of the amount of heat evolved or absorbed in a chemical reaction, change of state, or formation of a solution.

**adiabatic** (ad-i-a-bat’-ik), adj. –
Occurring without loss or gain of heat.

**isothermal** (i-so therm’-al) adj. –
Occurring with no change in temperature.

“aluminates” – convention for tricalcium aluminate (C₃A)
“silicates” – convention for tricalcium silicate (C₃S)
(Dicalcium silicate or C₂S has little influence within the timeframe of the thermal data to be studied.)
“sulfates” – convention for calcium sulfate (CaSO₄) and/or cement SO₃ level, as an indication of calcium sulfate content.

Thermal testing vs. “calorimetry”

- Thermal testing or thermal profile testing may sometimes be referred to as “calorimetry” or “semi-adiabatic calorimetry” but neither is a technically correct description.
  - Heat given off in hydration is not actually being quantified.
  - Conditions are not usually very close to adiabatic and are not precisely controlled.
- Thermal testing is simply measuring mixture temperature changes over time and plotting them as an indication of evolved heat.
- The value and use of the data is in comparison of trends for similar mixtures tested under the same conditions.

True calorimetry methods quantify heat

Isothermal or near-adiabatic calorimetry can be used to evaluate mix performance and can accurately measure the heat evolved.
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Thermal testing vs. isothermal calorimetry

Isothermal results at 73°F

Concrete Isothermal Thermal profiles

Cement hydration and heat evolution

Heat released in the first few hours as indicated in a typical thermal profile documents C3A and C3S hydration rates and CaSO₄ (gypsum) interaction.

Useful performance indications include timing and magnitude of peaks and the profile shapes, which are influenced by any abnormal hydration trends.

There are ASTM and European standards for certain calorimetry applications for concrete and cement

[Image of standard test method]

Di-1664

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A thermal testing Standard Practice document is currently under development in ASTM

Thermal profile testing variations and options

- Testing options:
  - Concrete, mortar, or paste
  - In the lab or at the plant or job site
  - Using project concrete or simulated mixtures of similar proportions
  - Manufactured or adapted equipment
  - Lab ambient temps or simulated project field temps
  - Data processing / evaluation with either special software or common spreadsheets

Inexpensive temperature sensors and loggers
Manufactured and adapted equipment

Laboratory paste mixtures (modeling concrete paste fractions) – an especially efficient evaluation tool

Data collection setups used for presented data
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Applications of thermal profile testing
- Performance evaluation, troubleshooting, & QC tool for concrete & other cementitious mixtures:
  - Setting time trends due to changes of cement source, SCM's, admixtures, dosages, project field temps
  - Evaluation / selection of cements, SCM's, admixtures
  - Checking for incompatibility potential of combinations
  - Qualifying a new mix design under field extremes
  - Evaluating material source variability or new sources
  - Substitute (w/ care…) for C 403 set time test, field or lab
  - Troubleshooting field or product problems
- Cement production QC uses:
  - Sulfates optimization, sulfate balance checks – effects of new fuels or raw materials, gyp sources, mill temps, etc.
  - Evaluation of setting time trends with SCMs & admixtures

Test method variables & considerations
- Concrete, mortar or paste?
- Mixing method / equipment
- Sample volume / mass?
- How much insulation?
- Initial mixture temperature
- Environment temperature
- Control of environment
- Sensor contact w/ sample

General guidance:
- Concrete or mortar vs. paste:
  - Concrete or mortar: more convenient on the job site, representative set times
  - Paste: better for multi-variable lab studies
- Sample size (mass):
  - Larger samples for mortar & concrete:
    - 3” x 6” cylinders work well for mortar
    - 4” x 8” or larger for concrete
  - Smaller samples (2” x 4”) for paste
- Insulation of container:
  - Accentuates peaks, amplifies hydration
  - Little to none for paste samples
  - More for mortar, most for concrete
  - Choice depends somewhat on objectives but mostly to produce reasonable curves
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**Test method variables & considerations**

**Sample mass and insulation:**
- Should be balanced for the application
- Consider sample type and ambient temps

**Objectives:**
- Drive sufficient hydration peaks for clean data signal and adequate signal-to-noise
- Peak temps should be representative of in-place application but no higher

**Test method variables & considerations**

**Mixing equipment and procedures:**
- **Mortar**
  - Wet-sieved concrete
  - C 305 (4 min.)
  - Others
- **Paste**
  - C 305 (2½ min.)
  - Hand-held kitchen mixer
  - 1 minute or less may be adequate mixing time
  - Blender mixing
- **Mixing shear differences may influence results**

**Strength data is also recommended**

- Hardened specimens strength tested after thermal testing
- Extra samples can be used for strengths at different ages
- Parallel mortar cubes – another option
- Strength bars presented with thermal profiles may be helpful with data interpretation
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Effects of test method variables

Mortar vs. paste, equal volume specimens, no insulation

90° F mixtures with 25% Class F ash and water reducer

Paste @ 0.52 w/cm, 500g powder content
Mortar @ 0.52 w/cm, 1425g SSD concrete sand, mixed via C305

Effects of test method variables

Mortar vs. paste, all specimens in 3” x 6” cylinder molds, no insulation

73° F mixtures:
A) no ash or admix, w/c = 0.54
B) 25% C ash + 3 oz/cwt type A WR, w/cm = 0.51
C) 25% F ash + 4 oz/cwt MR WR, w/cm = 0.51

Effects of test method variables

Sample mass effects (minimal insulation)

Paste samples of increasing mass, with 25% Class C ash and water reducer at 73° F - cylindrical samples of similar h/d
Mortar samples of different mass at 73° F, same proportions as paste mixtures + sand @ 2.75 x cementitious mass
Insulation effects

Mortar mixture with 25% Class C ash and water reducer at 73°F in 3"x6" cylinders with varying levels of insulation

Managing, processing, and interpreting thermal profile data for common applications

General guidelines

- Data should include an accurate mix time for each channel
- Plotting can be done with special software or a spreadsheet
- Plot several (3 to 8, typically) profiles on a single graph for comparison, synchronized to a common time scale
  - Zero time = first wetting of cement at mixing
- Consider effects of ambient temp changes during test period
  - Review reference temp (inert specimen) & evaluate the effects of ambient changes on data
  - Plotting the data with reference temperatures subtracted for each point (T_{sample} - T_{reference}) usually improves comparisons
- Plotting profiles from different days or testing events on the same graph is not generally recommended
  - Unless ambient controls were especially good
  - Repeat controls and referenced mixtures with each new series
The “reference” channel is a synched temp record of an inert specimen of similar mass (sand and water, etc.).

These graphs show the same data plotted without (at left) and with (below) subtraction of the reference channel, to essentially remove influences of the changing ambient temps.

- For any thermal profile of a normally hydrating mixture, the time at which setting begins is simply indicated by the onset of the main peak (C at left)
- “Thermal” set times of concrete or mortar may be used to approximate C 403 set times
- Setting comparisons of different mixtures can be visually made or spreadsheet quantified as long as the records use a common time scale relative to mixing

ASTM work toward a “thermal” alternative to C403
- ASTM Subcommittee C09.23 “round robin” testing event – Atlanta, November 2008
- 12 teams from suppliers, testing labs, universities
- 3 different concrete mixtures
- C403 in triplicate, each mixture, each team
- Thermal set determinations – devices provided by each team as per a draft Standard
Thermal setting terms and use of data

- Common thermal setting time convention – the hydration time at which a given fraction of the main hydration peak temperature rise occurs.
- Shown below are 20% and 50% fraction times (about 4.9 and 6.4 hours).
- Using fractions, thermal setting times can be visually estimated, scaled from graphs, or calculated in data spreadsheets.
- 50% is a convenient fraction for visual estimates.

Comparisons for concrete – time of set by thermal methods vs. C403

- Fractions of 21% and 42% have found to be good default values for using thermal testing to estimate C403 times (initial and final set).

Using lab paste mixtures to study concrete setting

- Paste proportions identical to concrete mix designs, without aggregates.
- Example to follow uses 50% fraction thermal set indications of paste for simplicity, but lower fractions could be used to better estimate C403.
- 50% fraction values can be spreadsheet-calculated or estimated (visually).
- Useful approach for quick evaluation of multiple variables.

<table>
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<th>Mix</th>
<th>18X-A</th>
<th>70-8-25C</th>
<th>75-6-25C</th>
<th>75-6-25F</th>
<th>75-6-25P</th>
<th>75-6-35C</th>
<th>50% C ash</th>
<th>50% F ash</th>
<th>50% G/BM %</th>
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<tbody>
<tr>
<td>SCM(M)</td>
<td>——</td>
<td>20% C ash</td>
<td>20% C ash</td>
<td>20% F ash</td>
<td>8% f ash</td>
<td>9% G/BM</td>
<td>50%</td>
<td>50%</td>
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<td>AD/WR</td>
<td>——</td>
<td>3 h onset</td>
<td>3 h onset</td>
<td>4 h onset</td>
<td>4 h onset</td>
<td>4 h onset</td>
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<td></td>
<td></td>
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</tr>
<tr>
<td>w/cm</td>
<td>0.34</td>
<td>0.31</td>
<td>0.31</td>
<td>0.31</td>
<td>0.31</td>
<td>0.31</td>
<td></td>
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</tr>
<tr>
<td>Slump (in.)</td>
<td>4 in.</td>
<td>6 in.</td>
<td>5.25 in.</td>
<td>5 in.</td>
<td>5.75 in.</td>
<td>5.75 in.</td>
<td></td>
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<td></td>
</tr>
<tr>
<td>Air content (%)</td>
<td>1.2%</td>
<td>1.3%</td>
<td>1.6%</td>
<td>2.4%</td>
<td>1.7%</td>
<td>2.4%</td>
<td></td>
<td></td>
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</tr>
<tr>
<td>Initial set (min.)</td>
<td>229 min.</td>
<td>304 min.</td>
<td>353 min.</td>
<td>302 min.</td>
<td>291 min.</td>
<td>365 min.</td>
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</tr>
</tbody>
</table>

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Set time comparisons: C403 concrete initial set times vs. paste 50% fraction times

Thermal profiles with indicated 50% fractions, lab paste mixtures

Paste 50% fractions compared with concrete C403 initial set times

Lab set time studies using paste mixtures

- Paste “thermal set” responses to key influences are similar to those in concrete
  - Mix temperature
  - Admixtures and dosages
  - SCM's and replacement rates
  - Comparing different cements
- Exceptions:
  - Water-cementitious ratio effects on concrete set times are not reflected in paste mixtures
  - Retardation effects of certain admixtures may be slightly exaggerated in paste

Applications and examples of thermal and strength testing of paste in the lab
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- **Set time effects of \( \Delta w/c \) are not reproduced**
  - Similar neat paste mixtures ranging in w/c from 0.38 to 0.54

- **Relative set time example with lab paste**
  - Thermal profiles with 50% fraction markers, all mixtures @ 90°F with 25% F ash and indicated doses of type A/D water reducer & retarder
  - Influence of admix dose & retarder

- **Relative set time example with lab paste**
  - Influence of Class C and Class F fly ash
  - Thermal profiles of paste mixtures @ 90°F with and without 25% ash and 3.75 oz/cwt of type A/B/D WR
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Relative set time example with lab paste

Two admixtures compared for temperature & dosage effects

Thermal profiles of lab paste @ 0.40 w/c cement-only mixtures @ 73 or 50°F, with 3 or 6 oz/cwt of two different mid-range admixtures

Selection of a water reducer for minimal set time impact in a 30% Class C ash mix

- 5 different WR admixtures (2 Type A/D, 2 Type A/F, 1 MR)
- Dosages selected for approx. 6% water reduction
- A single Type II cement sample, w/cm = 0.40
- Paste mixtures @ 70°F mix and cure temps

“A/F 1” is clearly has the least retardation influence.

Thermal profile testing used in the concrete mix design development process

Example: development of a sustainable, high SCM mix with acceptable performance for flatwork applications

- Materials selection – avoiding incompatibility influences, maximizing synergies, minimizing retardation contributions
- Screening tests with lab paste, thermal profiles & strengths:
  - Establishment of performance targets via reference mixes
  - Effects of increasing SCMs to proposed levels
  - W/cm adjustments with admixtures to restore early strengths
  - Compensating for retardation effects with admixtures
  - Sulfate balance checks at field temps
- Concrete trials & final mix refinement
- Additional adjustments, if needed, for changing temps
Performance of traditional low-SCM mixtures

- "Reference" mixtures to establish performance targets for mix development
- 15% C ash, 15% F ash, 30% slag cement with mild WR dosages
- For these examples, criteria to be based on these mixtures (green bands), 50% fraction thermal set indications and 1-day strengths in bar charts

Effects of SCM replacement rate increased to 50%

- Same temps & admix dosages, with the addition of an F ash mix w/ A/F WR
- Set time with F ash and A/D WR driven by admix
- Good set performance with slag and F ash + A/F
- C ash set time goes quite long (indication of potential issues)
- 1-day strengths all now unacceptable

Effects of lower w/cm using HRWR dosages

- Lower w/cm needed to restore early strengths, A/F WR dose increased
- All 1-day strengths now marginally acceptable, slag mix healthiest
- 60% replacement mix with slag added, still acceptable strength
- All set times now unacceptable, need help from accelerators (esp. C ash)
Compensating for delayed set with accelerators

- All mixtures repeated with varying & incremental dosages of non-chloride accelerator (NCA)
- Moderate dosages restore acceptable set for F ash and slag
- NCA less effective with C ash and seems to create sulfate balance issues (incompatibility) at higher dosages (in pursuit of restored set)
- 1-day strengths benefit from NCA

Verification of proportions at extreme field temps

- F ash and slag mixtures with same A/F dose & max NCA dose repeated at highest envisioned concrete field temps: 36°C (96°F) mix and cure temps
- No sulfate balance issues indicated; NCA dosages could be reduced
- OK to proceed to trial concrete mixtures

Incompatibility of materials – evaluation with thermal testing, influences, remedies
What is incompatibility of materials?

- What we're talking about:
  - Mild to extreme deviations from normal set time, rheology, and/or early strength development that result from abnormal early cement hydration due to inadequate available calcium sulfate.
  - "Incompatibility" has sometimes been used in reference to some other issues (not discussed):
    - Air void system issues
    - Early-age cracking
    - Other durability issues (ASR, ACR, DEF, etc.)

What is incompatibility of materials?

- Incompatibility examples from the field:
  1. Severely delayed set:
     No problems were experienced all week with several pours on a big project. On Friday, with good weather, a morning pour of the same mix design used all week had not set up by 7 pm (finishing had been completed by lunch time every other day). Related issues included plastic shrinkage cracking and poor surface durability and appearance.

  2. Flash set with delayed strength gain:
     A new project required a high-strength mix which had not been used since cement sources were changed. The project began on a hot day and the first loads poured began to set up right out of the chute. The pour was stopped, as finishing was severely impacted, but the next day the concrete was still so green that a screwdriver could easily be tapped into the concrete several inches deep.

  3. Slump loss:
     In the middle of a large project with no other issues, excessive slump loss began to occur in transit, along with a noticeable trend toward lower early strengths. Higher dosage of the mid-range water reducing admixture raised initial slump but did not change the slump loss or early strength trends. The problem went away after a few days. 28-day strengths were unaffected.

- In each case, as part of routine troubleshooting, all materials were sampled and tested; plant records and delivery tickets were reviewed.
- There were no out of spec materials, deviations from normal procedures, or batching errors!
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**Technical background - cement chemistry**

- Compounds in portland cement clinker:
  
  \[ \begin{align*}
    \text{C}_3\text{S} &= 3\text{CaO} \cdot \text{SiO}_2 \\
    \text{(Tricalcium silicate)} \\
    \text{C}_2\text{S} &= 2\text{CaO} \cdot \text{SiO}_2 \\
    \text{(Dicalcium silicate)} \\
    \text{C}_3\text{A} &= 3\text{CaO} \cdot \text{Al}_2\text{O}_3 \\
    \text{(Tricalcium aluminate)} \\
    \text{C}_4\text{AF} &= 4\text{CaO} \cdot \text{Al}_2\text{O}_3 \cdot \text{Fe}_2\text{O}_3 \\
    \text{(Tetracalcium aluminoferrite)}
  \end{align*} \]

  - Hydration of these compounds produces significant, measurable heat during the first 24 hours of hydration.

  - Ample CaSO\(_4\) (gypsum) interaction for several hours is necessary for normal set and strength!

    The interaction of CaSO\(_4\) with C\(_3\)A not only delays and controls set but is necessary for normal C\(_3\)S hydration. Less CaSO\(_4\) availability = less C\(_3\)A control = interrupted or abnormal C\(_3\)S hydration.

    Three mixtures with incrementally higher admixture dosages
So why wouldn’t there be enough gypsum in cement?

- It’s not just about the amount – there are different specific forms of CaSO₄ and they vary in solubility.
- The test for cement CaSO₄ “optimization” is usually done using cement-only mortars, and other materials in concrete (SCM’s and admixtures) may increase “demand” for sulfate.
- CaSO₄ forms and purity vary among gypsum sources, which may change from time to time at any given plant.
- CaSO₄ level is not a sensitive parameter to performance for most typical cement applications.
- Optimum sulfate determination practices vary widely.

Sulfate demand factors in cementitious mixtures

- Sulfate demand is low in neat paste / mortar mixtures at standard lab ambient temperatures
  - Under-sulfated cements work fine and appear normal
  - Thus C563 may be an unrealistic procedure
- Most chemical admixtures raise sulfate demand
  - By accelerating aluminate hydration and other mechanisms
  - Some more than others, dosage effects also critical
  - No useful sulfates contributed by admixtures
- Class C fly ash, other aluminate-rich additives raise sulfate demand
  - Contain C₃A (some C ash sources as much as 20 to 30%)
  - No useful sulfates are generally contributed by SCM’s & additives
- High temperatures raise sulfate demand
  - Sulfate solubility decreases as temperature increases
  - Cement is usually the only source of soluble sulfate in the mix

Sulfate demand and hot weather

A counter-intuitive trend:

- Higher temperatures increase the solubility of most materials
  - i.e. sugar in hot coffee
- But gypsum solubility decreases with higher temperature
  - Especially the most soluble form (hemihydrate, or plaster)
- Higher temps also increase aluminate hydration rates
Sustainability implications

- Sustainability-related trends in concrete projects:
  - Blended cements and/or
  - Multiple SCM’s with higher replacement rates
  - More aggressive admixture use may be needed
- These influences contribute to greater variability of setting and early strength and potential for incompatibility.

What happens when sulfates are inadequate?

Baseline mix - 20% ash, Superpl. WR, 90°F

- Mild cases:
  - Increased slump loss and water demand
  - Admixtures are less effective
  - Set time delays
  - Poor early strengths
- Severe cases:
  - No set for days
  - or… flash set (!)
  - No measurable strength gain for several days

“Threshold” zone is quite narrow!

- For an “on the edge” mixture, even a slight change in mix temperature or in the properties of any one material can quickly cause extreme performance issues...
- Thus, compatibility issues can come and go mid-project
A simulated “on the edge” mix in mortar cubes
- Testing performed to investigate cement role in a field issue
- Cements from 11 sources
- 25% Class C fly ash from project
- Type A/D water reducer from project @ 6 oz/cwt
- Mix and cure temps 90° F to approximate field temps

Testing for incompatibility & its potential
- Useful test methods:
  - Modified C109 mortar cubes & C191 Vicat set times
  - Mini-slump paste mixtures
  - Isothermal calorimetry
  - Thermal profile testing
- Testing plan should include:
  - Baseline cases with normal performance
  - Increments of SCM’s & admixtures bracketing envisioned project levels, significantly higher & lower
  - Field temps & 1 or 2 levels higher
  - Alternative SCM’s or admixtures
  - Multiple samples of cement chosen so as to include extremes of normal SO₃ variability

Normal vs. abnormal hydration behavior
Sulfates-related abnormalities are clearly evident in thermal profiles:
- Normal behavior = traditional thermal profiles with normally timed peaks
- Abnormal behavior = mishapen profiles or non-traditional behavior, indicating a mixture sulfate imbalance (incompatibility)
Flash set from uncontrolled aluminates

- Flash set can occur when sulfates in solution are immediately depleted and aluminates hydrate uncontrolled (rare but occasionally reported).
- Can happen with under-sulfated cements and high sulfate-demand mixtures.

Sulfate demand & SCM’s

At left, thermal profiles and 1-day strengths comparing 3 SCM’s (C ash, F ash, and slag cement) in otherwise identical mixtures, with incremental cement replacement rates. The Type A/D WR admix was selected because of its known high sulfate-demand tendencies.

A single sample of Type I/II cement was used, w/cm = 0.40, upper-limit dosage of admixture, 32°C (90°F) mix and cure temps.

C ash mixtures – incompatibility detected at higher replacement rates – symptoms at 20%-25%, true incompatibility beyond 25%.

Thermal profiles of paste with parallel mortar cubes, high-sulfate demand mix with 10% to 35% C ash

6 oz/cwt type A/D water reducer dose, 90°F mix and cure temps, a single Type I/II cement sample, Class C ash at 10%, 25%, and 35%
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Thermal profiles of paste with parallel mortar cubes, high-sulfate demand mix with different A/D WR’s
25% C ash, 90°F mix and cure temps, a single Type I/II cement sample, admix dosages at upper end of Type A recommended range

Thermal profiles of paste with parallel mortar cubes, high-sulfate demand – admix dosage comparison
25% Class C fly ash replacement, 90°F mix and cure temps, a single Type I/II cement sample, Type A/D admixture used at 6 or 9 oz/cwt

Flash set occurs at around 25 minutes – sudden aluminate excursion indicates sulfate depletion
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Incompatibility influences of a NCA: high-volume Class C fly ash mixture with HRWR
Paste mixture with 50% Class C fly ash replacement, 74°F mix and cure temps, a single Type I/II cement sample, w/cm = 0.32, sulfate balance-friendly Type A/F (polycarboxylate) admixture used at 14 oz/cwt, non-chloride accelerator dosages 0-40 oz/cwt.

If the profile shape changes and lack of strength improvement are truly related to sulfate depletion, this could be confirmed with CaSO₄ additions.

Sulfate balance of this mix to be explored using CaSO₄ additions (next slide).

30 oz/cwt NCA mixture (previous slides) repeated with incremental additions of Terra Alba gypsum (+0.33%, +0.67%, and +1.0% SO₃).
Note that the additions restore normal profile shapes and improve 1-day strengths.
Evaluation of performance questions using repeated mixtures with incremental sulfate additions

A 90°F paste mixture with 25% Class C ash and upper-limit dosage of Type A/D admixture is repeated with sulfate additions to evaluate possible sulfate balance issues.

Investigated mix - no added sulfate

Influence of initial mixture and cure temps on behavior of similar mixtures with wide range of sulfate demand

Two different mix / cure temp ranges: 70°F and 93°F
4 paste mixtures, same materials and proportions for each temp range series:
- 100% OPC, no WR, w’c = 0.45
- 25% C ash, no WR w/cm = 0.45
- 25% C ash, 4 oz/cwt WR, w/cm = 0.40
- 25% C ash, 6 oz/cwt WR, w/cm = 0.40

WR admix is a high sulfate-demand Type A/D with a recommended dosage range of 3-6 oz/cwt on total cementitious content.

Note that higher temps alone drive incompatible behavior in the mixtures with WR!

Field Issue – 15% C ash, multiple admixtures, low 1-day strengths, summer temps – sulfate balance issue?

90° F paste mixes, 4 oz/cwt admix dose, varying SO₃ cement samples:

Cement source “A” is the project source to be evaluated – 5 samples obtained at different times vary slightly in SO₃ within normal variability.

A sample of cement source “B”, which is known to be well balanced, is included for comparison.
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Field Issue – in otherwise identical mixes, to check mix sensitivity to sulfate demand, WR dose was doubled.
90°F paste mixes, 8 oz/cwt admix dose, varying SO3 cement samples:

In the higher sulfate-demand mix, incompatibility is evident for essentially all but the highest SO3 level sample of "B"; control cement "A" still appears normal.

Conclusion: At lower SO3 levels, cement source "A" may be under-sulfated for use in aggressive mixes at higher temperatures.

Evaluation of different cements for sulfate adequacy
Paste with no SCM's, no admixture, w/cm = 0.40, 90°F mix & cure temps

7 different cement sources compared in neat paste mixtures

Evaluation of different cements for sulfate adequacy
Paste with 25% C ash, 8 oz/cwt Type A/D WR, w/cm = 0.40, 90°F mix & cure temps

Same cements in high sulfate-demand paste mixtures
Cement production – gypsum source evaluation: grinds at the same SO$_3$ levels with different gyps, high sulfate-demand mixes

- Gyp "A", 9 oz/cwt
- Gyp "A", 6 oz/cwt
- Gyp "B", 9 oz/cwt
- Gyp "B", 6 oz/cwt

90°F paste with 25% C ash + Type A/D WR (6 or 9 oz/cwt)

- Incremental sulfate demand approach (overdose admixtures, increase SAC %, higher mix temps)
- Incremental sulfate supply approach (different cement samples at varied SO$_3$, sulfate additions to mixtures)

- Change one or more of the key influences:
  - Replacement rate of Class C fly ash
  - Admixture dosage or type
  - Review / evaluate retardation strategy
  - Cement SO$_3$ level
  - Mix temperatures
- Re-evaluate in the lab under the most extreme field conditions envisioned

Conclusions and recommendations:

Resolution process - compatibility issues in concrete

- Confirm sulfates influences with thermal profiles and/or strength testing (paste or mortar cubes)
- Incremental sulfate demand approach (overdose admixtures, increase SAC %, higher mix temps)
- Incremental sulfate supply approach (different cement samples at varied SO$_3$, sulfate additions to mixtures)

- Change one or more of the key influences:
  - Replacement rate of Class C fly ash
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  - Mix temperatures
- Re-evaluate in the lab under the most extreme field conditions envisioned

Conclusions and recommendations:

Thermal testing for concrete QC – when to test?

- Evaluate unfamiliar materials and the proposed mix(es) under all extremes of possible project temperatures
  - Compare against controls (materials from other projects)
  - Check set time and main peak variability with temperature
- Check sensitivities of proposed materials to incompatibility
  - Test at highest expected mix temp
  - Include overdoses of admixtures and SCM's
  - Compare against known mixtures with familiar materials
- Test regularly to gage materials variability
- Test when materials sources are changed or a new mix design is first used
- Troubleshoot unexplained trends in set time, slump loss, early strengths

Conclusions and recommendations:
References, suggested reading

Cost, Tim, "Thermal Measurements of Hydrating Concrete Mixtures – A Useful Quality Control Tool for Concrete Producers," MIMCA Publication 2PE004, National Ready Mixed Concrete Association, 900 Spring Street, Silver Spring, MD, August 2009.
Cost, Tim, "Optimization of Concrete Paving Mixtures for Sustainability and Performance," accepted for the 19th International Conference on Concrete Pavements, Quebec City, Quebec, July 8-12, 2012

References, suggested reading (continued)

Wang, K., Ge, Z., Grove, J., Ruiz, M., Rasmussen, R., and Ferragut, T., Developing a Simple and Rapid Test for Monitoring the Heat Evolution of Concrete Mixtures for Both Laboratory and Field Applications, National Concrete Pavement Technology Center, Ames, IA, January 2007, 58 pp.