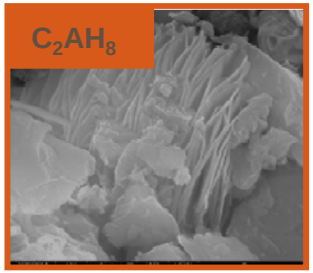

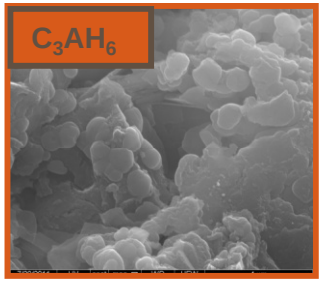

Calcium Aluminate Cements Revisited

Recent Advances in Understanding Conversion, Testing Protocols and Future Use

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Assistant Professor and Kearney Faculty Scholar

Matthew P. Adams

Graduate Research Assistant

10 November, 2011

Introduction

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Compared to ordinary portland cement (OPC) concrete, calcium aluminate cement (CAC) concrete is a considerably understudied material

- **Early-age volume change**
- **Durability**
- **Conversion**

CAC Scientific Network – established by Kerneos Aluminate Technologies (formerly Lafarge Aluminates) in 2004

- The University of Texas at Austin (2004)
  - Early-age behavior, volume change, durability
- Ecole Polytechnique Federale de Lausanne (2006)
  - Microstructural development
- University of New Brunswick (2007)
  - Durability (corrosion, salt scaling, freeze/thaw, alkali-silica reaction)
- University of Laval (2005-2011)
  - Testing strategies, rheology
- Oregon State University (2008)
  - Early-age volume change, conversion testing

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History

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1900s – sulfate attack of portland cement concrete in South of France

1908 – Patent for calcium aluminate cement granted to Jules Bied

WWI – used for gun emplacements

1945-1973 – Post WWII reconstruction, rapid hardening properties

1973-1974 - Failures force removal of CAC from UK building regulations

1997 - Concrete Society Report

Present

- continued use in building chemistry and refractory applications

Renewed interest as a

- rapid repair material
- alternative binder with lower CO_2 footprint
- durability

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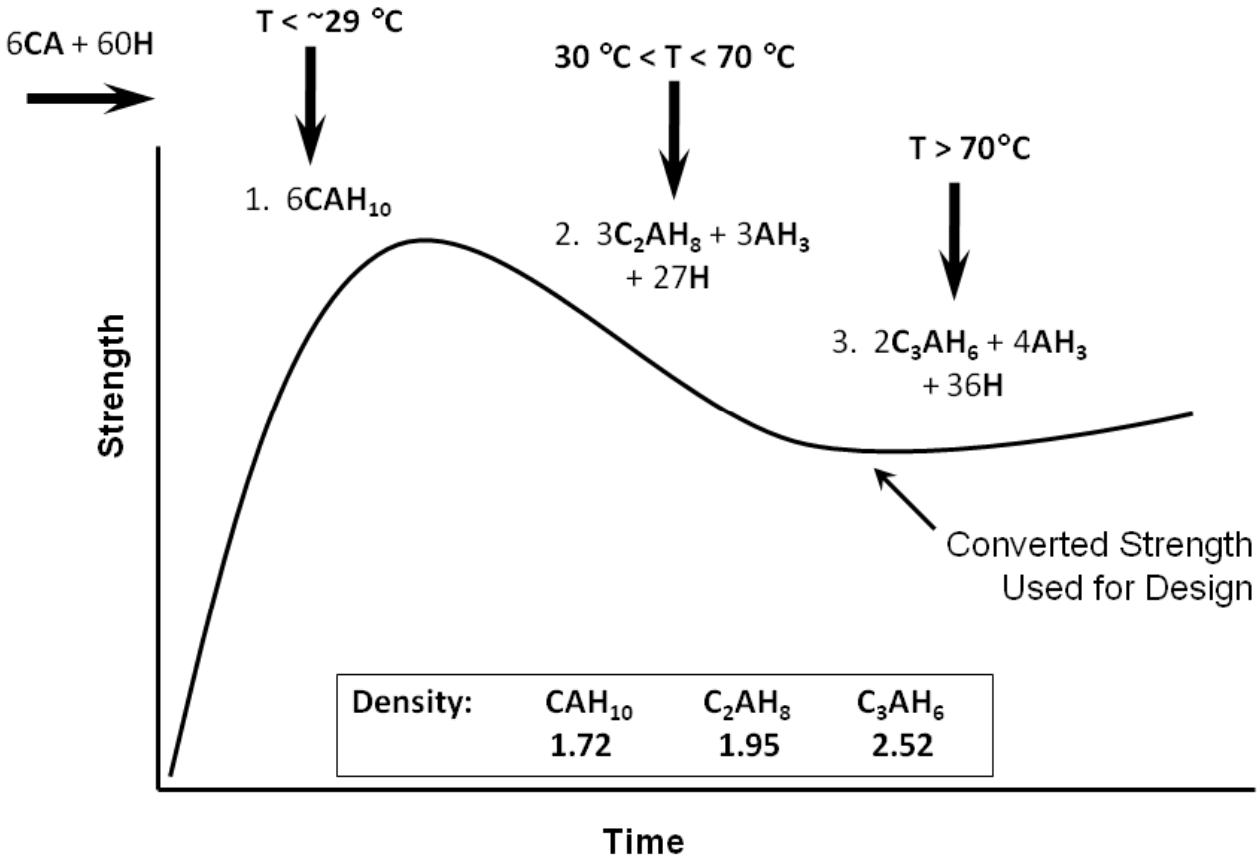
CAC Hydration and Chemistry

Conversion



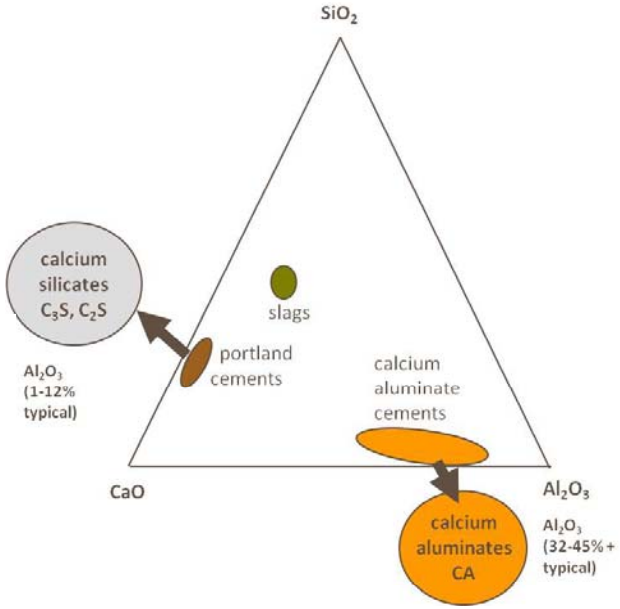


Figure - Courtesy of K. Scrivener

Juenger, M.C.G., Winnefeld, F., Provis, J.L. and Ideker, J.H., "**Advances in Alternative Cementitious Binders**," *Cement and Concrete Research,* V 41 [12], December 2011, pp. 1232-1243.

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SEM Images of CAC Microconcrete (BSE)

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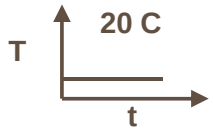
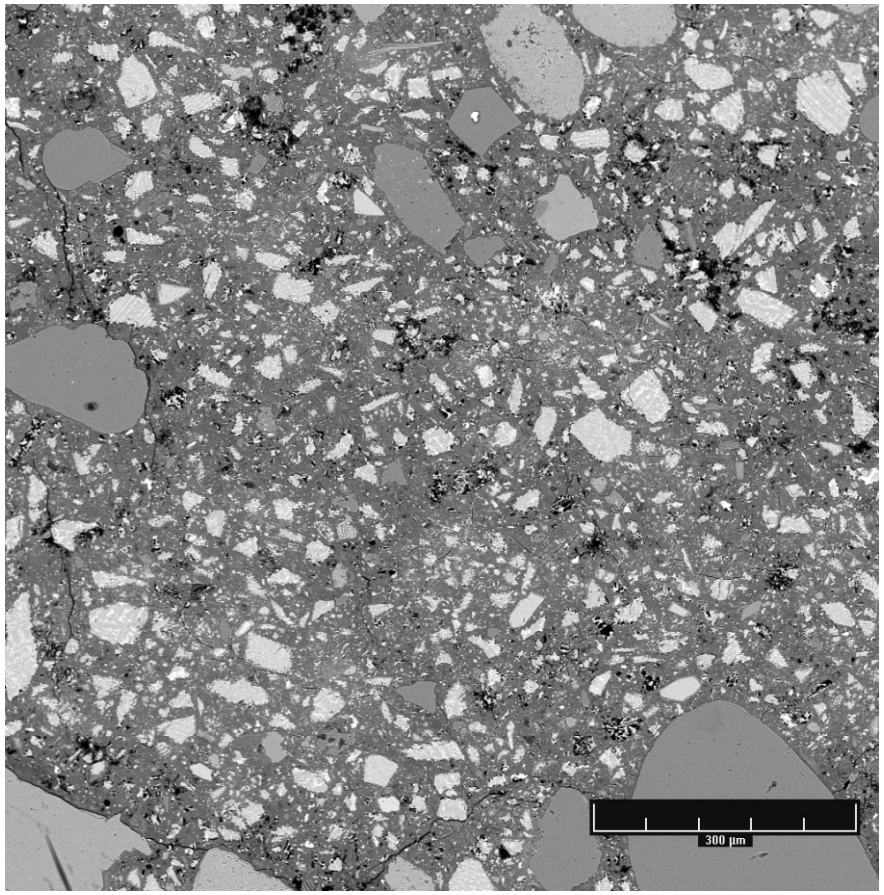
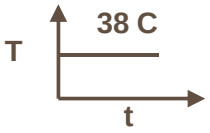


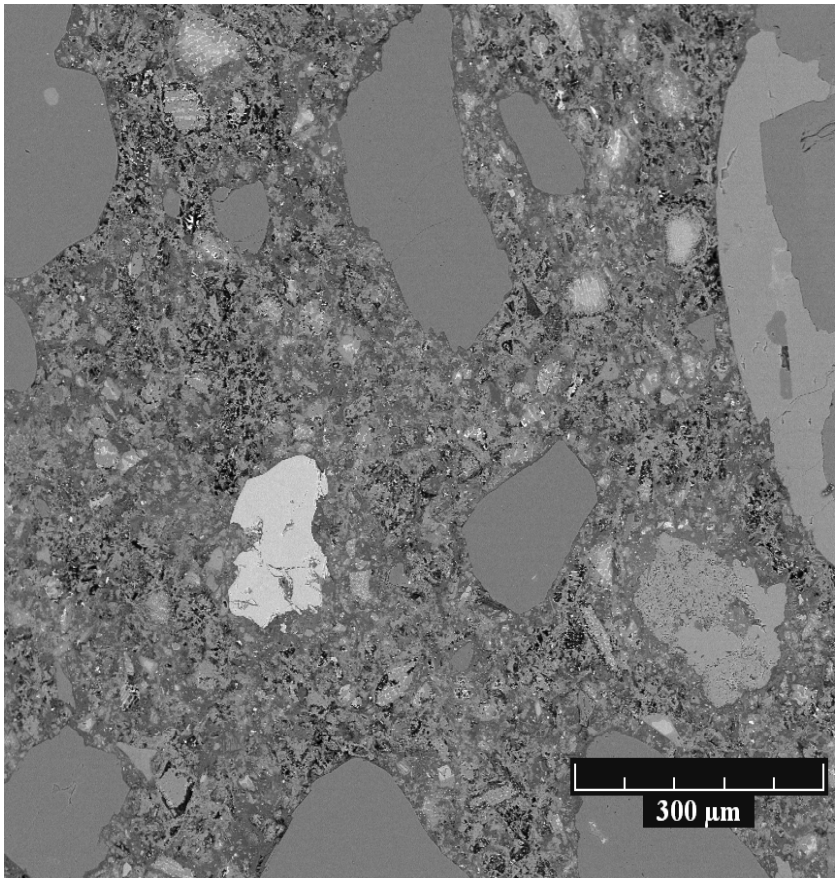


Scale Bar – 300 µm

20 C isothermal cure, 1 day, unconverted

High strength, low degree of hydration, low porosity





Scale Bar – 300 µm

38 C isothermal cure, 8 days old, fully converted

Lower strength, high degree of hydration, higher porosity

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SEM Images of CAC Paste (BSE)

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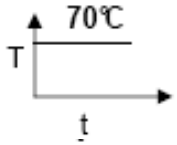

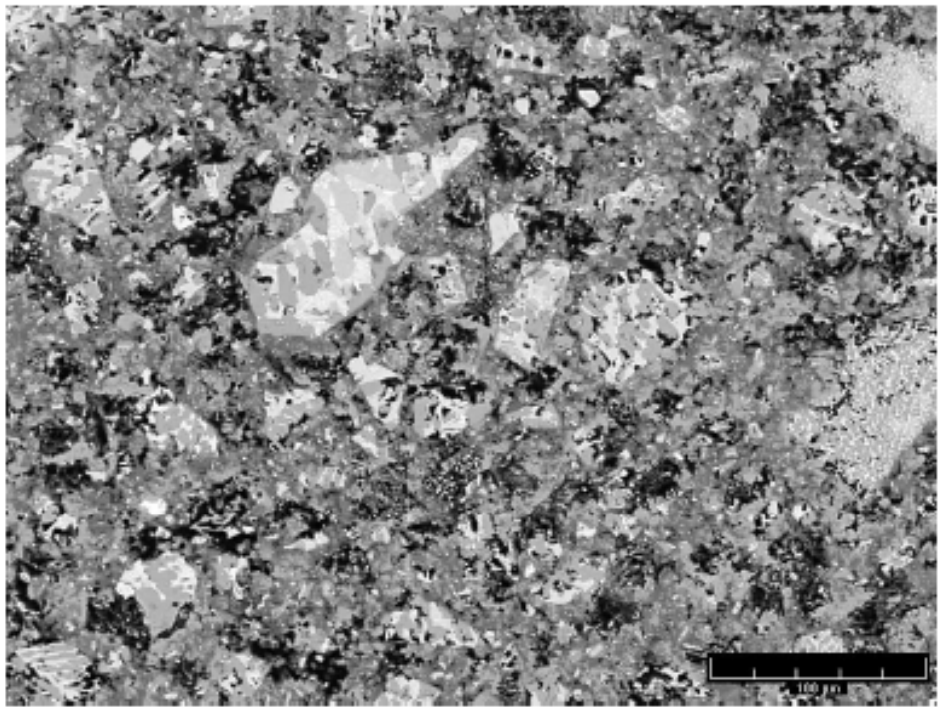

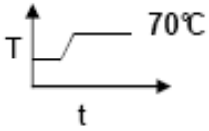

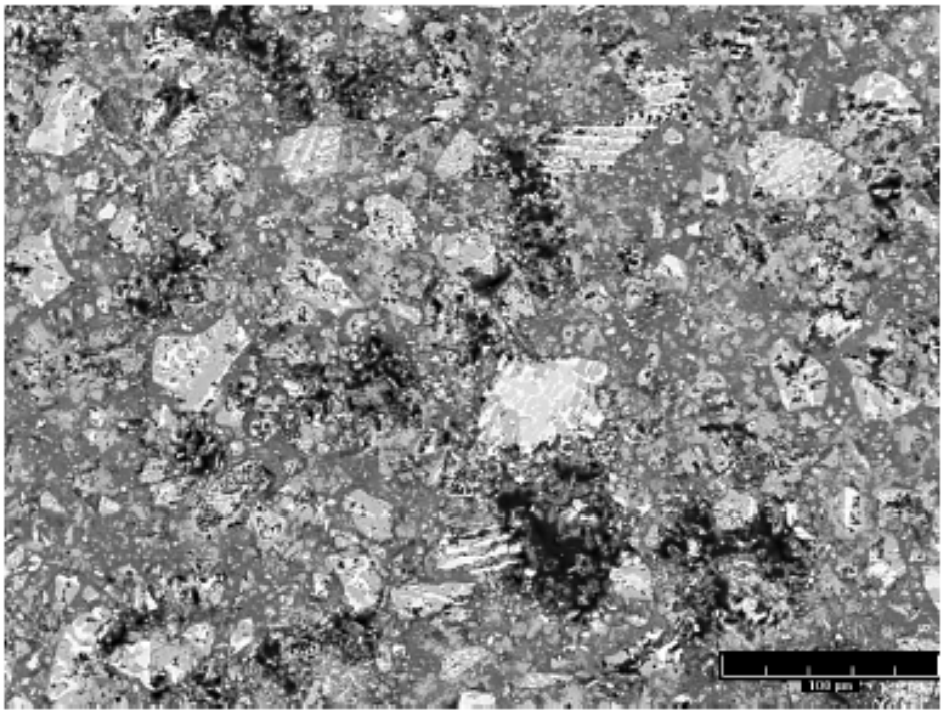

SEM Images: C. Gosselin

70 C isothermal cure, T_{off} + 8 hrs

High degree of hydration, high degree of porosity

70 C realistic ramping, T_{off} + 8 hrs

Discrete porosity, metastable phase development may limit porosity

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Rigid Cracking Frame and Free Deformation Frame Results
20 C CAC, OPC

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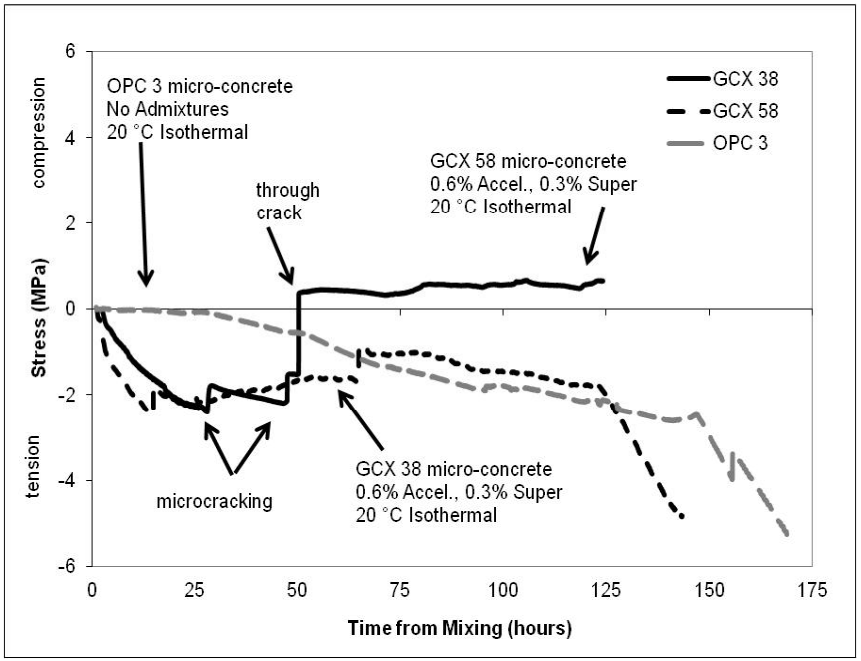

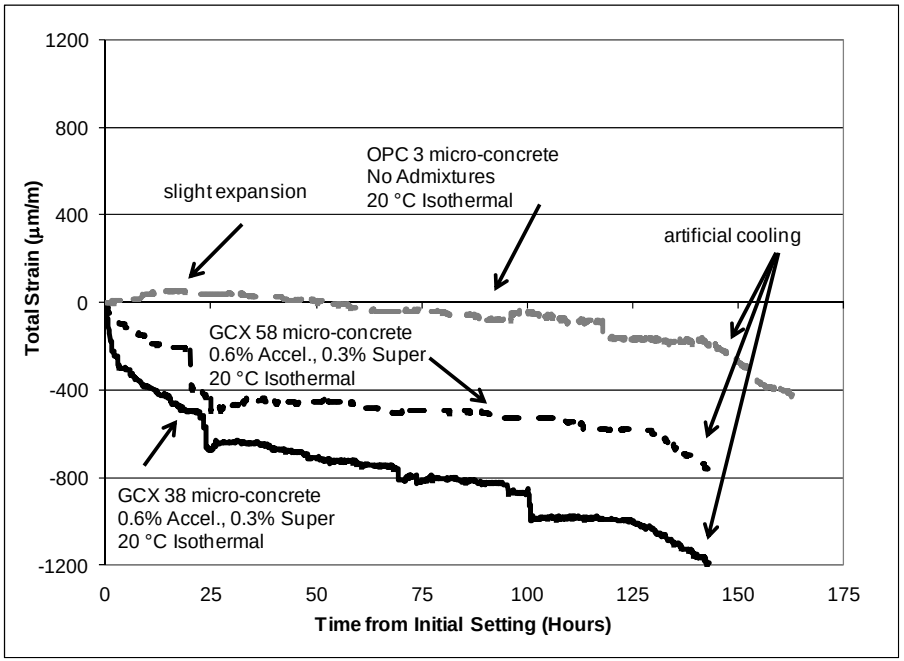

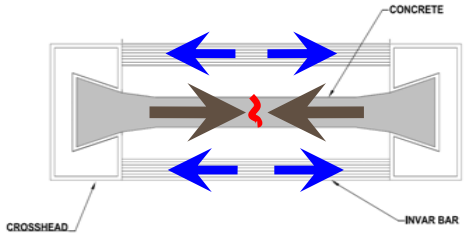

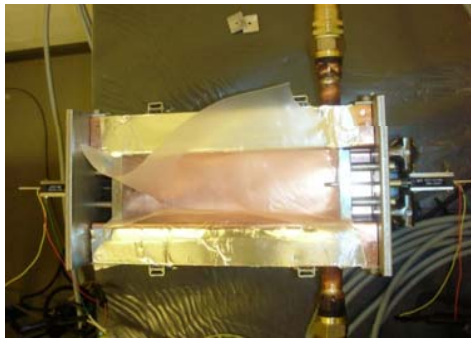

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Rigid Cracking Frame and Free Deformation Frame Results
38 C CAC andOPC

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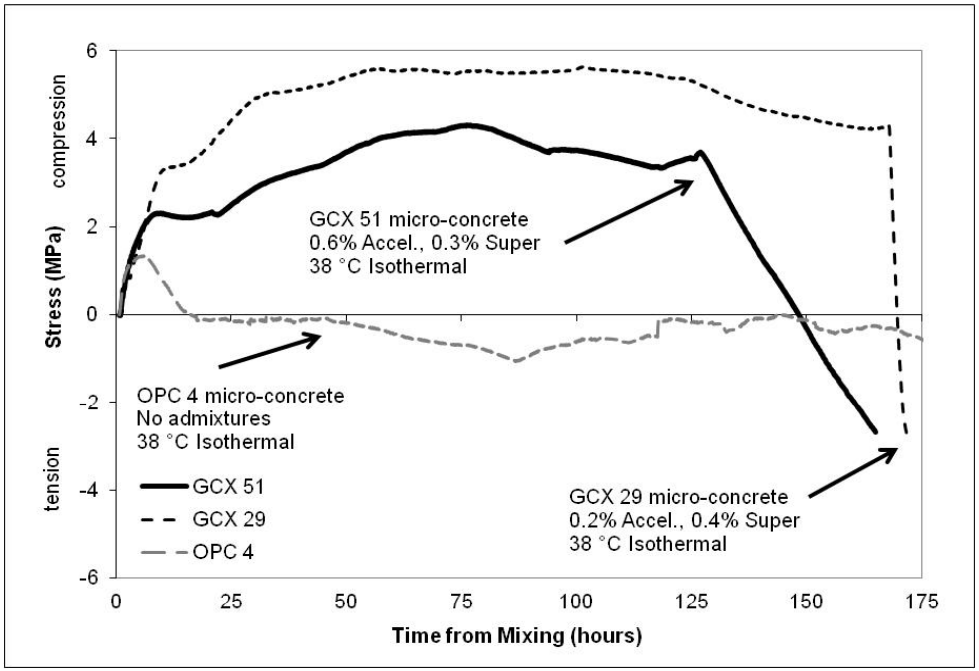

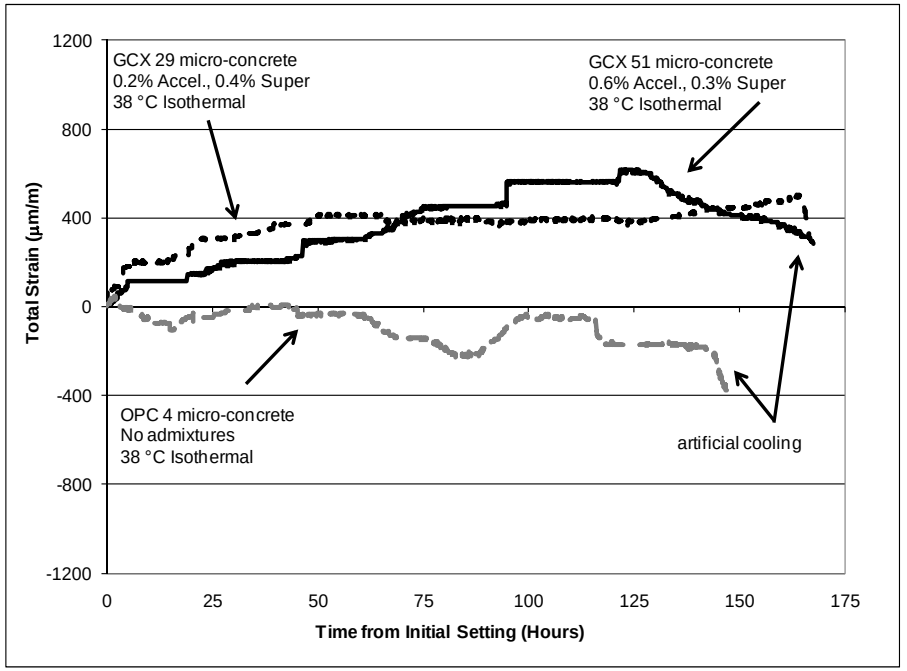

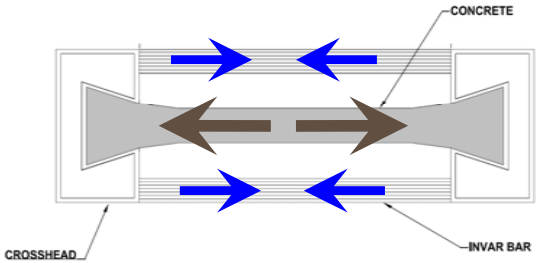

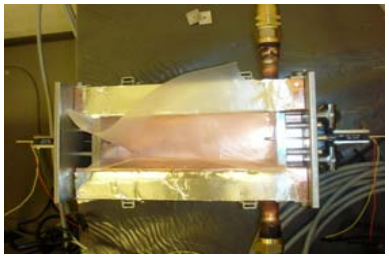

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Interim Summary – Early Age Properties

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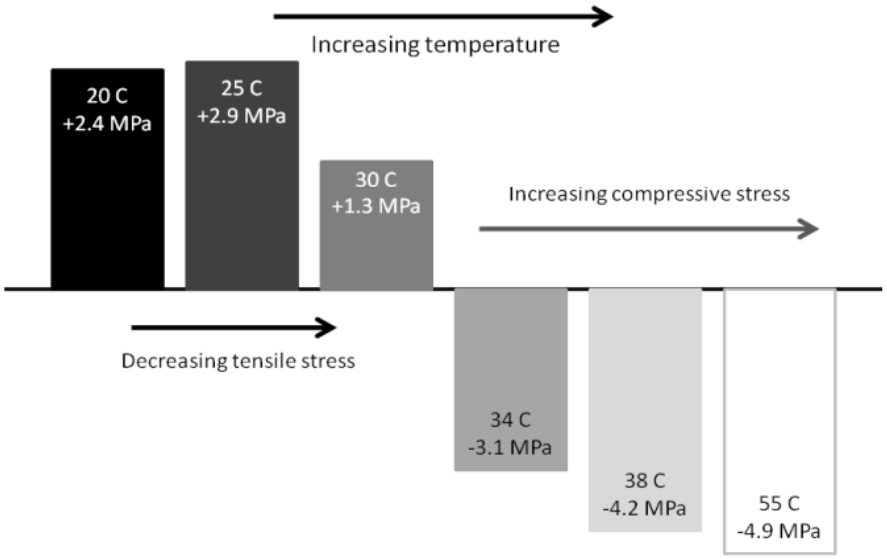
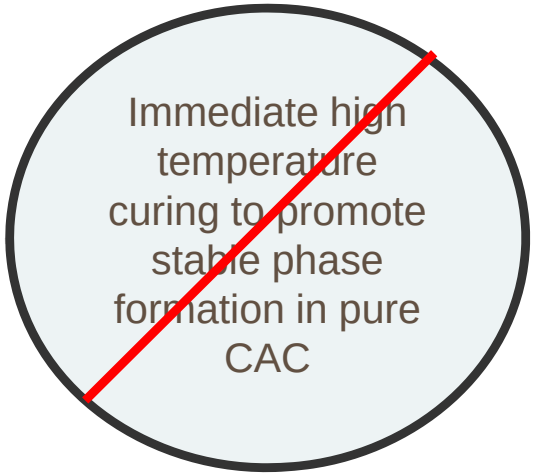


Rigid Cracking Frame Stress

Highly temperature dependent



CAC – early-age volume behavior vastly different than OPC

Some benefits (expansion)

Some challenges (shrinkage)

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CAC Research and Testing at OSU

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- Working with CACs since 2008 (Ciment Fondu, GCX, CAC+SCMs)
  - Early-age volume change: chemical shrinkage, autogenous deformation
  - Strength of mortar cubes
  - Minor durability testing – ASR related
  - **Development of a standardized lab procedure for predicting conversion**

- Conversion testing since August 2011 – Ciment Fondu
  - 24 hr cure in ambient, 24 hr cure in highly insulated box
    - 50C submersion at 24 hr for all cylinders – monitor strength
    - 38C submersion at 24 hr for all cylinders – monitor strength
    - 38C direct submersion – QC check

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CAC – Curing Regimes

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Ambient

- Mixtures of metastable and stable hydrates
- Curing concrete cylinders roughly around 23 °C
- May be typical of smaller elements in the field

Self-heating

- *Direct* formation of stable hydrates
- Temperatures seen in larger elements and/or hot-weather concreting

Isothermal (38 °C)

- Increased conversion rate from metastable to stable hydrates
- Lab evaluation protocol for high and low strength determination

What is conservative? What is realistic? How do we best simulate?

Semi-Adiabatic Curing Box

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Montogmery Data

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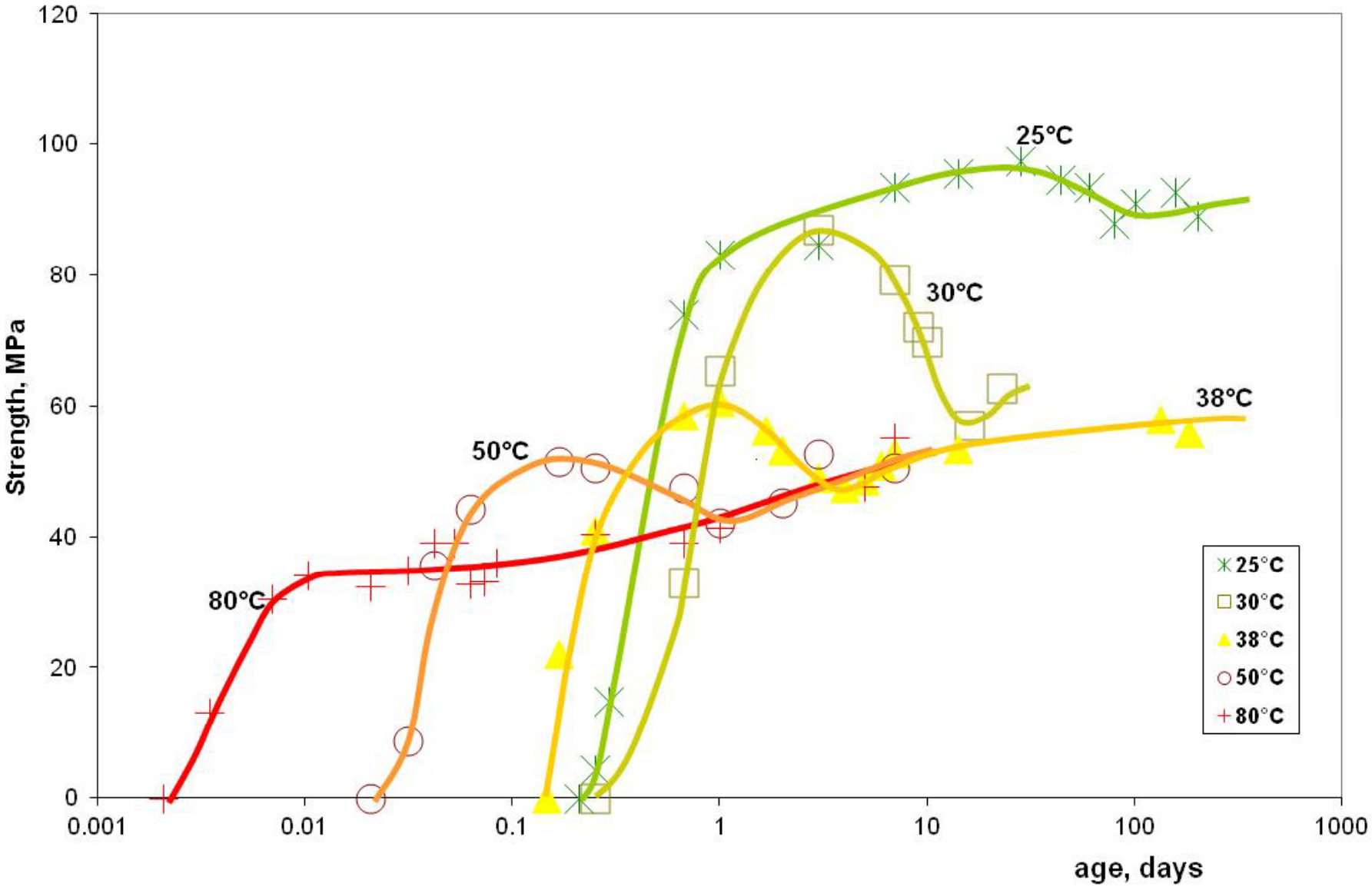

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Accelerated Conversion Testing - CAC

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Equipment Used

Eirich Concrete Mixer and Control Panel

Temperature and Humidity Controlled Mixing Room

Insulated Curing Box

Temperature Controlled Curing Bath

Cylinder End Grinder and Compression Testing Machine

Temperature Data Logger

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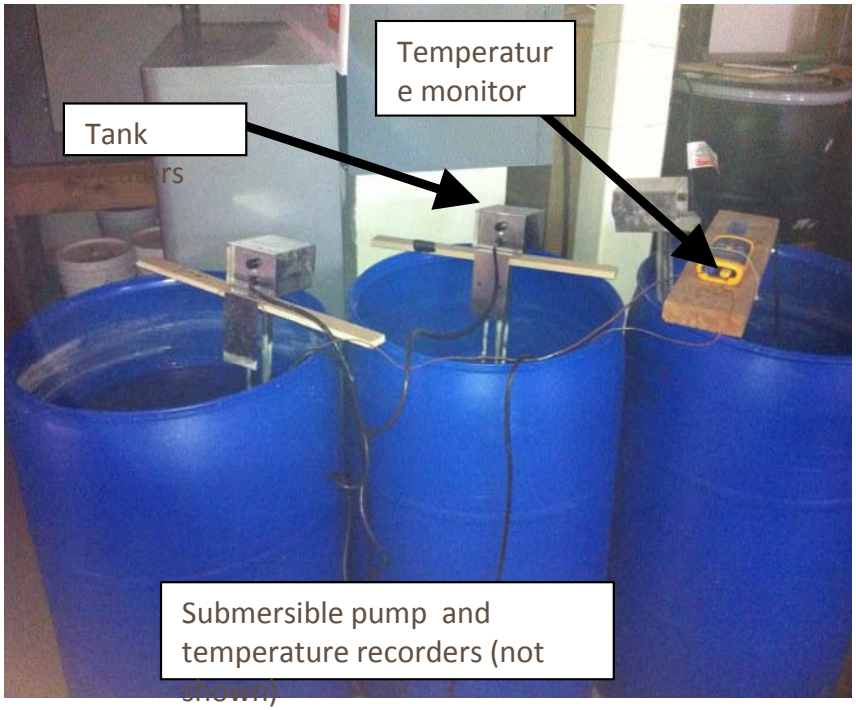
Accelerated Conversion Testing - CAC

POWERED BY ORANGE

Inexpensive Laboratory Water Baths

- Passive heating coils
- Must be monitored regularly
- Temperature easily affected by ambient temperature



Heavily Insulated Curing Box

- 12” of dense styrofoam surround 16 – 100x200 mm cylinders
- Placed immediately after casting
- Cured for 24 hours

Insulated Curing Box

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Accelerated Conversion Testing – Preliminary Results

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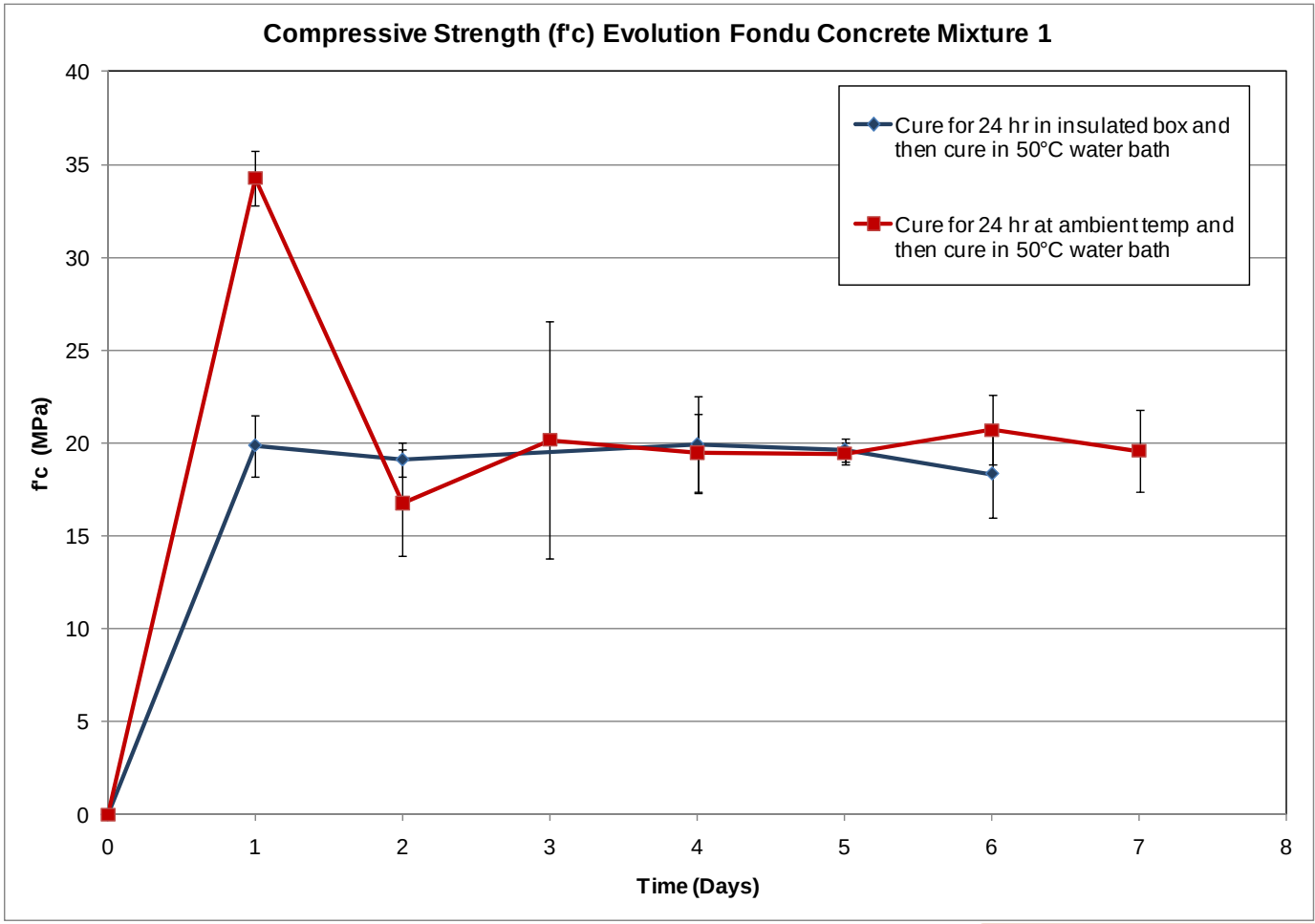
Cylinders (100 mm x 200 mm) : 24 Hours of Ambient Curing or 24 Hours of Insulated Box Curing followed by submersion at 50 C

CAC - Ciment Fondu Mixture Design: Mix 1

Cement: 400 (kg/m^3)
Water: 160 (kg/m^3)
w/cm: 0.4
Stone: 950 (kg/m^3)(MC - 1.4%, AC - 2.6%)
Sand: 740 (kg/m^3) (MC - 3.6%, AC - 3.1%)
Super: Opt 203, 1% by mass cement



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Accelerated Conversion Testing – Preliminary Results

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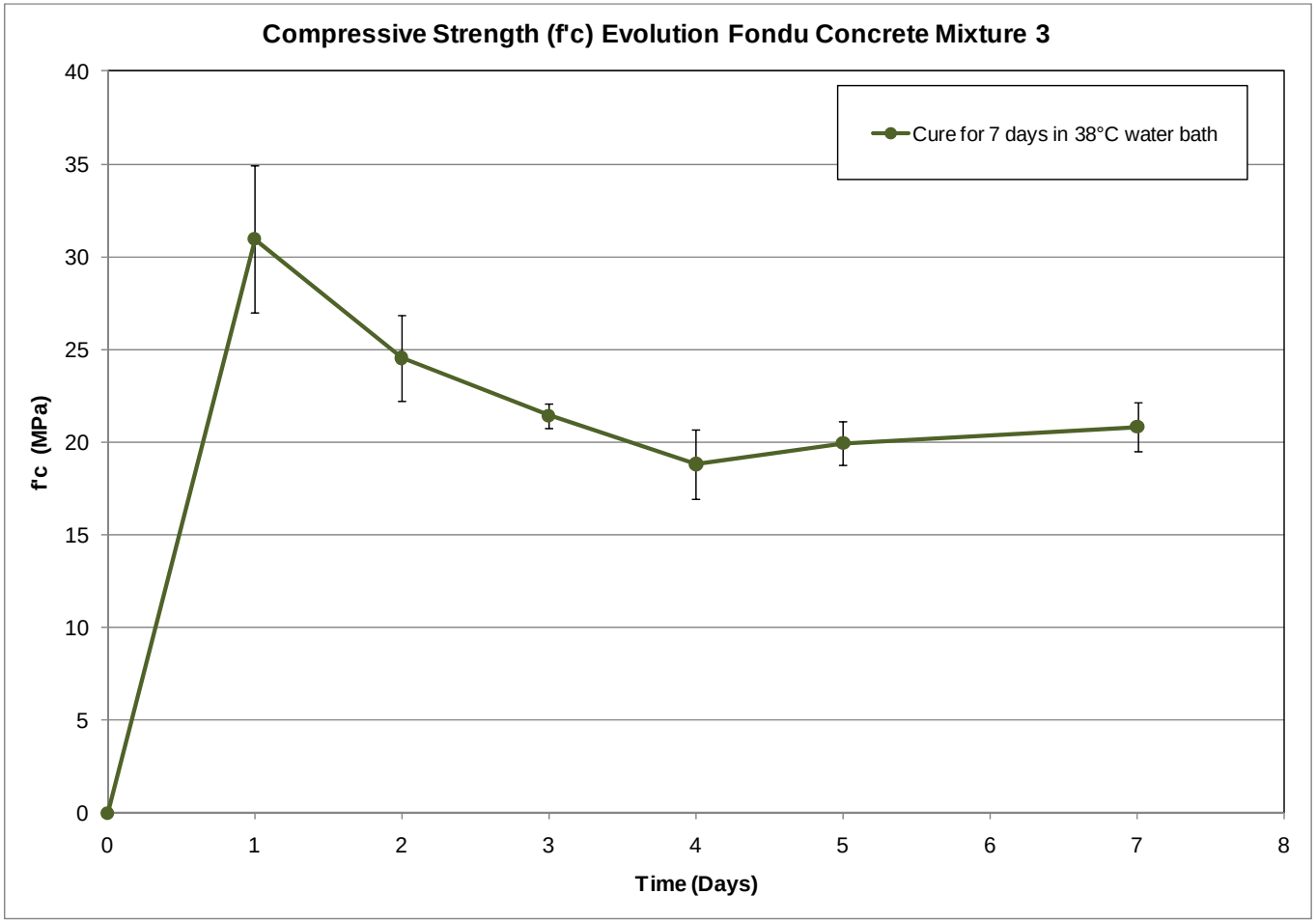
Mixture 3: Compressive strength: 100 x 200 mm cylinders Submerged in 38° C Water Bath Directly After Casting

CAC - Ciment Fondu Mixture Design: Mixture 3

Cement: 400 (kg/m^3)
Water: 160 (kg/m^3)
w/cm: 0.4
Stone: 900 (kg/m^3)(MC - 2.4%, AC - 2.6%)
Sand: 645 (kg/m^3) (MC - 3.8%, AC - 3.1%)
Super: Opt 203, 1% by mass cement



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Interim Summary – Conversion Testing

POWERED BY ORANGE

Overall both 50C and 38C submersion provide rapid conversion of cylinders cured in ambient temperatures

After ambient cure

38C – conversion at about 6 days

50C – conversion at about 2 days

Values converge to uniform value for converted strength in both tests

Immediate submersion at 38C confirms roughly 100 hours to conversion

Highest temperature in insulated box - ~90C

Highest temperature in ambient cured cylinders - ~50C

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Conclusions and Future Work

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Early-age volume change

- Vastly different behavior than portland cement
- Highly temperature dependent

Early-age volume change

- Continued characterization of autogenous deformation, chemical and drying shrinkage, thermal influences
- Realistic time/temperature histories
- Making the link between laboratory and field (Bentivegna Dissertation UT Austin)

Conversion Testing

- Immediate high temperature curing not applicable due to microstructural changes
- Curing at 38 C immediately gives good predictor of converted test, not field compatible
- Ambient curing for 24 hours followed by submersion at high temp give also good predictions of converted strength
  - 38 C (6 days to conversion)
  - 50 C (2 days to conversion)

Conversion Testing

- Varying material parameters (w/cm, cement content, aggregate type)
  - pure CAC systems to start
  - more complex systems after initial test developed, verified
- Propose as new ASTM Standard

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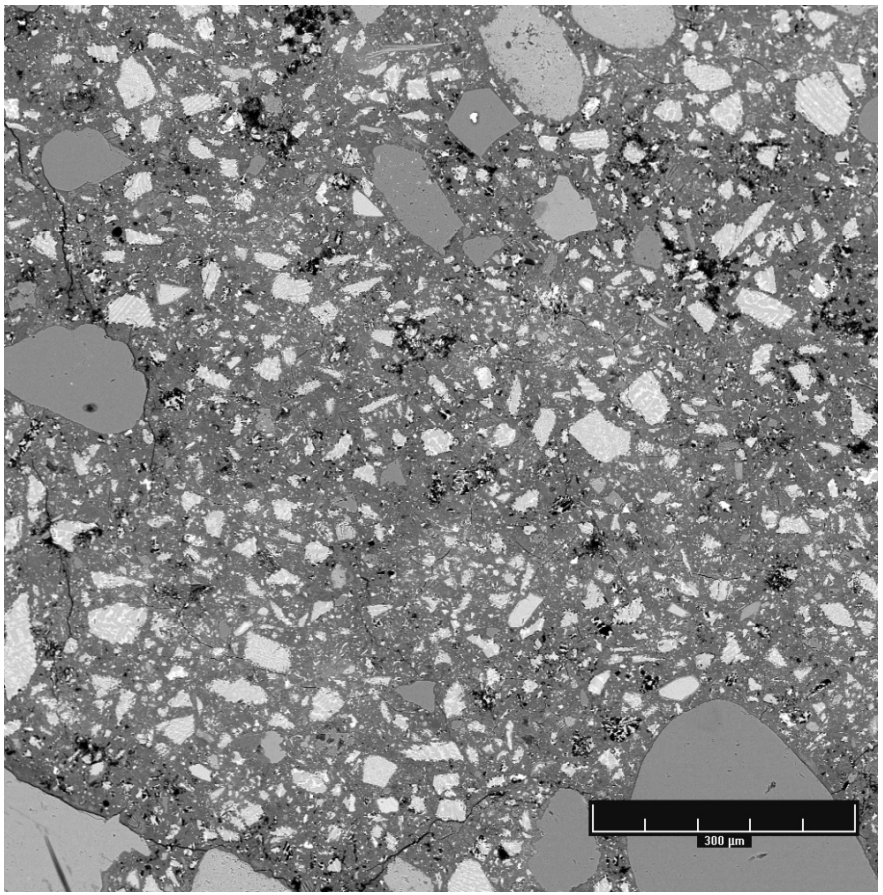
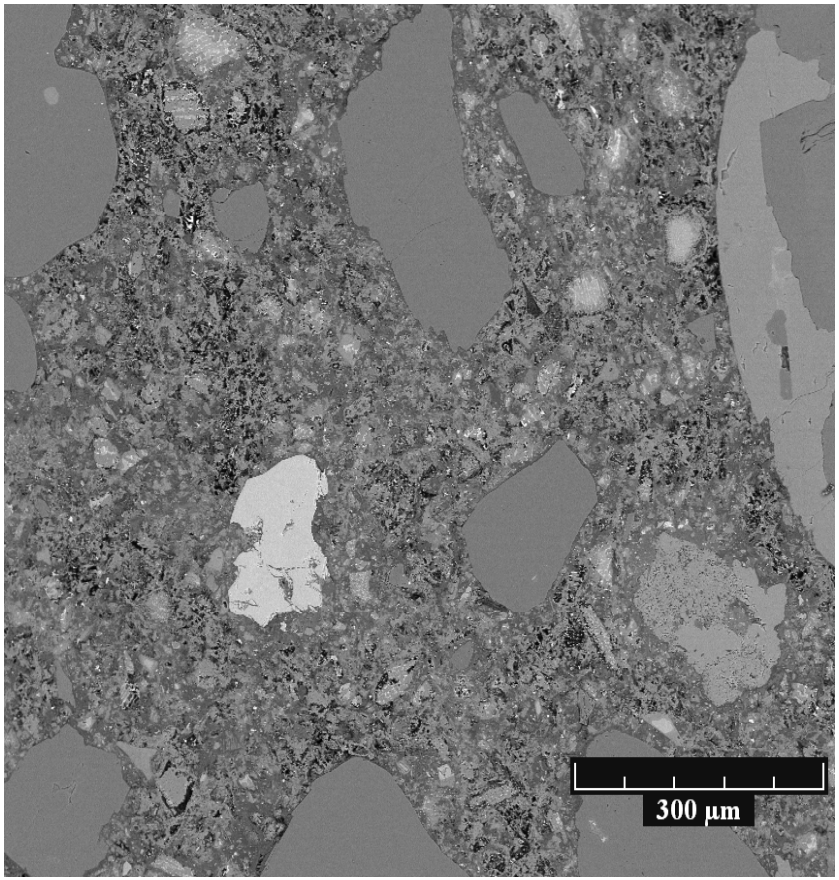
Thank you!

http://web.engr.oregonstate.edu/~idekerj/
http://gbml.oregonstate.edu/





Questions?