A Brief Introduction to: Prevention of Thermal Crack in Mass Concrete by Reducing the Peak Temperature with Phase Change Material

Jaime SK Yeung
What is “Phase Change Material”?

- PCM is a substance having high heat of fusion. It is capable of storing and releasing large amounts of energy in the form of heat during its melting and solidifying processes at the specific transition temperature.
Phase Change of Materials

- SOLID
- LIQUID
- GAS

Temperature vs. Heat Energy Diagram:
- Freezing
- Melting
- Condensing
- Vaporizing
Application of phase change material in CONCRETE

* Lower peak temperature in mass concrete pour
* When being incorporated in external concrete walls, concrete blocks, gypsum blocks, etc., PCMs absorbs heat energy (by melting) in hot weather and releases heat energy (freezing) in cool weather.
Prevention of thermal crack in mass concrete

- Increasing number of large pours for pile caps, bored piles, large diameter columns, transfer plate, etc.
- Very high peak temperature at the core of the concrete pour increase the temperature gradient throughout the concrete element from core to surface
- Excessive temperature gradient induces thermal crack in concrete
- PCM changes from solid state to liquid state when the concrete temperature reaches its melting point and absorbs heat energy from surrounding concrete due to its latent heat of fusion
- Peak temperature of concrete is therefore lowered
Mechanism for PCMs Acting as Thermal Energy Storage (TES)

- PCMs absorb energy when temperature rises
- Energy is stored in PCMs with latent heat during phase change
- Energy is released during a reverse cooling process when ambient temperature drops down

**External wall unit without PCM**

**External wall unit with PCM**
Local trial with PCM for Lowering Peak Temperature in Large Volume Concrete Pours
Local trial with PCM for lowering peak temperature in large volume concrete pours

* Concrete mix for trial:

<table>
<thead>
<tr>
<th>Concrete Mix</th>
<th>Mix 75/25</th>
<th>Mix 65/25</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total cementitious content</td>
<td>500 kg/m³ of concrete</td>
<td>500 kg/m³ of concrete</td>
</tr>
<tr>
<td>OPC (52.5 N)</td>
<td>375 kg (75%)</td>
<td>325 kg (65%)</td>
</tr>
<tr>
<td>PFA (Class 1)</td>
<td>125 kg (25%)</td>
<td>175 kg (35%)</td>
</tr>
<tr>
<td>TRET No.</td>
<td>A1 (no PCM)</td>
<td>B1 (no PCM)</td>
</tr>
<tr>
<td></td>
<td>A2 (with PCM)</td>
<td>B2 (with PCM)</td>
</tr>
</tbody>
</table>
Empirical Calculation of Adiabatic Temperature Rise
(based on “Properties of Concrete” by A.M. Neville and CIRIA Report 91 by Dr. T.A. Harrison)

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<td>325</td>
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<td>PFA content:</td>
<td>125</td>
<td>175</td>
</tr>
<tr>
<td>Heat of hydration of Cement (kJ/kg): (from cement test report)</td>
<td>340</td>
<td>340</td>
</tr>
<tr>
<td>Total heat of hydration of 1 m³ concrete (kJ):</td>
<td>375 x 340 = 127,500</td>
<td>325 x 340 = 110,500</td>
</tr>
<tr>
<td>Specific heat capacity of concrete (J/kg/°C): (Properties of concrete, A.M. Neville)</td>
<td>1170</td>
<td>1170</td>
</tr>
<tr>
<td>Density of concrete (kg/m³):</td>
<td>2300</td>
<td>2300</td>
</tr>
<tr>
<td>Estimated adiabatic temperature rise of concrete due to OPC only (°C):</td>
<td>(127500/1170/2300) x 1000 = 47.4</td>
<td>(110500/1170/2300) x 1000 = 41.1</td>
</tr>
<tr>
<td>Assumed fresh concrete placing temperature (°C):</td>
<td>30</td>
<td>30</td>
</tr>
<tr>
<td>Peak temperature of concrete due to OPC only (°C)</td>
<td>47.4 + 30 = 77.4</td>
<td>41.1 + 30 = 71.1</td>
</tr>
<tr>
<td>Temperature rise due to PFA (°C): (Table 7 of CIRIA Report 91)</td>
<td>8.2 x (125/100) = 10.3</td>
<td>7.1 x (175/100) = 12.4</td>
</tr>
<tr>
<td>Estimated adiabatic peak temperature of concrete mix (°C) = (5)+(6)+(8)</td>
<td>77.4 + 10.3 = 87.7</td>
<td>71.1 + 12.4 = 83.5</td>
</tr>
</tbody>
</table>
Empirical Calculation of Temperature drop due to dissolution of PCM in concrete

* PCM used: Strontium Hydroxide Octahydrate (Sr(OH)$_2$·8H$_2$O)
* Melting point: ~ 68°C (from manufacturer)
* Dissolution heat: ~343 kJ/kg (from manufacturer)
* Dosage used: 5% of cementitious materials (25 kg/m$^3$ of concrete)
* Dissolution heat absorbed: 343 x 25 = 8,575 kJ
* Expected temperature drop in concrete: 8,575 x 1000/1170/2300 = 3.2°C
TRET for Verifying the Temperature Reduction Properties of PCM

TRET Blocks (A1, A2, B1 & B2)
Concrete Temperature Development 25% PFA Concrete

Drop in peak temperature after introduction of PCM

Without PCM

With PCM

Ambient Temperature

Elapsed Time (Hrs)

Temperature (°C)

A1(Point 1)
A1(Point 2)
A1(Point 3)
A2(Point 1)
A2(Point 2)
A2(Point 3)
Amb
Poly. (A1(Point 2))
Poly. (A2(Point 2))
Concrete Temperature Development of 35% PFA Concrete

Drop in peak temperature after introduction of PCM

Without PCM

With PCM

Ambient Temperature

Elapsed Time (Hrs)

Temperature (°C)

B1(Point 1)  B1(Point 2)  B1(Point 3)  B2(Point 1)  B2(Point 2)  B2(Point 3)  Amb  Poly. (B1(Point 2))  Poly. (B2(Point 2))
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<tr>
<td>PCM</td>
<td>No</td>
<td>Yes</td>
</tr>
<tr>
<td>Fresh concrete temp.</td>
<td>30.3°C</td>
<td>29.8°C</td>
</tr>
<tr>
<td>Measured slump</td>
<td>160 mm</td>
<td>145 mm</td>
</tr>
<tr>
<td>Adiabatic temp. from empirical calculation</td>
<td>87.7 °C</td>
<td>--</td>
</tr>
<tr>
<td>Measured Av. Peak Temp.</td>
<td>83 °C</td>
<td>74 °C</td>
</tr>
<tr>
<td>Drop in Peak Temp. in TRET Block</td>
<td>9 °C</td>
<td>9 °C</td>
</tr>
<tr>
<td>Elapsed time for peak temp. to occur</td>
<td>~25.5 hours</td>
<td>~56 hours</td>
</tr>
<tr>
<td>28-day cube strength</td>
<td>60.4 Mpa</td>
<td>50.3 Mpa</td>
</tr>
</tbody>
</table>
Findings from TRET & Cube Strength Results

When PCM is incorporated:

* There is basically no change in workability (in terms of measured slump)
* Stiffening time of concrete is largely extended with increasing % of PFA
* Actual reduction in peak temperature (≈9 °C for both concrete mixes) is larger than that from empirical calculation (3.2 °C). Further verification tests are required.
* 28-day cube strength of both concrete mixes after addition of PCM are substantially reduced by up to ≈18 - 20% (cube strengths at later ages of 56 days and 90 days are still outstanding).
Findings from TRET & Cube Strength Results

Adverse effect to be resolved:

* Extended stiffening time
* Reduction in 28-day cube strength (cube results at later ages are still outstanding)
* Compatibility with PFA should be further explored
Further Study Plan

* Dosage of PCM should be lowered
* Admixtures with less retarding effect should be chosen when PCM is present
* W/B ratio of concrete with PCM may have to be lowered to compensate the loss in strength (at least at 28-day)
* Method(s) of encapsulation for PCM before adding to concrete can be explored
* Application in precast wall units (PCM used as TES)
THE END
for this presentation
(but this is just a beginning of the study for PCMs)