Patching of Portland Cement Concrete Pavement

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Roadmap to the Presentation

- Introduction
- Design
- Construction
- Materials for patching
- Specifications
Concrete Repairs

- Using OPC and Rapid Setting Materials
  - Partial Depth Patching
  - Full-depth Patching
Quality of Repair

- Materials
- Procedures
- Workmanship
- Long-term performance (patch survival rates)
- Long-term cost effectiveness
Causes of Patch Failure

- Lack of bond
- Compression failure
- Variability of materials
- Improper use of materials
- Insufficient consolidation
- Incompatible thermal expansion
- Weathering of material

1 week old patch
Partial Depth Repairs

- **Typical uses**
  - Repair shallow joints
  - Restore ride quality

- **Restrictions**
  - Depth < 1/3 slab thickness (INDOT: min 1 inch, max 3 inches, > 3 inches should be full depth)
  - No misaligned dowel bars
  - No D-Cracking
Patching Dimensions

Plan View
- Pavement
- Patch
- Spall

Profile View
- Pavement
- Patch
- Spall

Lengths:
- 50 mm (min.) to 150 mm
- 250 mm (min.)
- T=slab thickness

Thickness:
- Less than 300 mm
- More than 300 mm

50 mm (max.) to T/3 (max.)
**Sounding**
- To determine the extent of deterioration
- Strike concrete with solid steel rod, ball peen hammer, or chain
- Clear ringing sound = sound concrete
- Dull sound = unsound concrete
Patch Preparation Procedures

- Removing deteriorated concrete
  - Saw and patch
  - Chip and patch
  - Mill and patch
  - Water blast and patch
  - Clean and patch
Patch Preparation Procedures

- Cleaning repair area
  - Sandblasting
  - Air blasting
    - Oil and moisture filters
  - Sweeping
Patch Preparation Procedures

- Remove old sealant
- Re-saw the joint when needed
  - If using a nonflexible patch materials
  - At least 1 inch deeper than repair
  - 2 to 3 inches beyond the repair
  - Slightly compressed
  - Wash away sawing slurry
Materials Mixing

- **Materials**
  - Bonding agents
  - Patching materials

- **Methods**
  - Drum mixers
  - Mortar mixers
  - Transit mixers (ready-mix concrete)

- **Mixing**
  - Manufacturer recommendation
  - Mixing sequence
  - Amounts
  - Mixing times
  - Water content
Cement paste is brushed into the area just prior to placing concrete (INDOT: epoxy adhesive)

Placement method
- Shovel
- Pour or pump

Vibration
- Small internal vibrator
- Vibrating screed
- Rod or tamp with hand tools
Finishing

- Trowel level
- Vibrate
- Screed with stiff board
- Work toward edge of patch
- Match surface
- Broom texture
- Curing
  - White pigmented
  - Moisture vapor barrier
  - Burlap and water
Opening to Traffic

- Manufacturer recommendation

Opening criteria
- Minimum strength (INDOT)
- Minimum time (INDOT)

Opening based on actual PCC strength is preferred:
- Cylinder or beam testing
- Concrete maturity
Full-depth Patching

- **Typical Use**
  - Restore rideability and structural integrity
  - Prevent further deterioration of distressed areas
  - Preparation for an overlay

- **Restrictions**
  - Does not address structural inadequacy
  - Not a long-term solution for material-related distresses
  - Cost
Candidate Distresses

- Transverse cracking (M, H)
- Longitudinal cracking (M, H)
- Corner break (L, M, H)
- Spalling (M, H)
- Blowup (L, M, H)
- D-cracking (M, H)
- Deterioration of existing repairs (M, H)
Limitations

- Does not address structural inadequacy
- Not a long-term solution for material-related distresses
- Cost
Construction Steps

- Layout repair locations
- Saw concrete
- Remove concrete
- Prepare area
- Provide load transfer
- Place and finish concrete
- Cure
- Seal joints
Saw Cut Locations (J CP)

- Full-depth sawcut along longitudinal joint
- Partial or full-depth sawcut
- 3 inches
- 5 inches
- Full-depth sawcutter
- Pressure relief cut
Patch Dimensions

Visual deterioration of surface

Existing Joint

Dowel bar

Actual deterioration at bottom of slab
Patch Dimensions

- **Minimum dimensions**
  - Use lane-width repairs
  - Length > 6 ft

- **Long repairs (>12 ft long)**
  - Provide reinforcement, or
  - Provide intermediate doweled joint
Patch Dimensions

- Pressure to the soil due to tandem axle
  - 34,000 lbs/(12 feet in width x 6 feet in patch length)
  - = 3.3 psi < 4 psi

4 to 7 psi Allowable stress for soil
Smooth dowels 1.5 inches diameter

12 feet

2 feet

1 foot typical

6 feet min.

Mid-depth slab

Traffic Direction

Patch Dimensions

Smooth dowels or deformed rebars
Patch Dimensions (INDOT)

**SECTION A-A**

Where Existing Subbase must be removed
Recommended repairs for distress shown

Some typical distress conditions noted with
L = low     M = medium     H = high

No repair required
Replace entire slab-outer lane

d = 6 feet (min.)
Multilane Considerations

- **Adjacent lanes can be repaired independently**
  - Matching joints is not essential
  - Avoid small offsets
- **If blowups occur in the adjacent lane**
  - Delay repair work until cooler weather
  - Cut pressure relief joints at 1,000 ft intervals
Example Repair (What’s Wrong?)
Example Repair (What’s Wrong?)
Saw Cut
Concrete Breakup
Concrete Removal
Concrete Removal

Lift Out Method
Area Preparation
Gang Drill Dowel Holes
Cleaning Holes (Air Blast)
Dowel Bar Placement

Grout-retention disk (optional)

Existing slab

Anchoring material

Hole dia. = d+a

Repair area

dowel diameter

a = 1/10" for epoxy
a = 1/4" for cement grout

Subbase

Subgrade Soil
Injecting Grout (or Epoxy)
Placing Dowels
Finished Patch Preparation
Foam Spacer - Temperature Effect

- A 60°F temperature variation results in the following change in slab length:
  - 10-ft slab: 0.042 in
  - 40-ft slab: 0.170 in
- ¼ inch foam spacer will cover 60 feet of concrete patching expansion
- This movement accounts for expansion of the PCC due to temperature and contraction due to drying shrinkage
## Materials Mixing

<table>
<thead>
<tr>
<th>Mix Component</th>
<th>Type I INDOT</th>
<th>Fast Track I</th>
<th>Fast Track II</th>
<th>RSPC</th>
<th>RSC</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cement, kg/m³</td>
<td>390</td>
<td>381</td>
<td>441</td>
<td>363</td>
<td>386</td>
</tr>
<tr>
<td>Flyash, kg/m³</td>
<td>–</td>
<td>43</td>
<td>48</td>
<td>–</td>
<td>–</td>
</tr>
<tr>
<td>Coarse agg., or kg/m³</td>
<td>55-65%</td>
<td>828</td>
<td>776</td>
<td>1011</td>
<td>1070</td>
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<tr>
<td>Fine agg., % or kg/m³</td>
<td>35-45%</td>
<td>808</td>
<td>774</td>
<td>832</td>
<td>595</td>
</tr>
<tr>
<td>w/c ratio</td>
<td>0.40</td>
<td>0.40 to 0.48</td>
<td>0.40 to 0.48</td>
<td>0.41</td>
<td>0.45</td>
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<tr>
<td>Water reducer</td>
<td>yes</td>
<td>yes</td>
<td>yes</td>
<td>–</td>
<td>–</td>
</tr>
<tr>
<td>Air entraining agent</td>
<td>As needed to obtain air content of 6.5 ± 1.5%</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CaCl₂, % wt. cement</td>
<td>2 max</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>–</td>
</tr>
<tr>
<td>Opening time, hrs</td>
<td>5-30</td>
<td>24 - 72</td>
<td>12 - 24</td>
<td>4</td>
<td>4 - 6</td>
</tr>
</tbody>
</table>
Material Placement

- **Curing compound**
  - Most common (INDOT: curing compound + polyethylene sheet)
  - Provides adequate cure

- **Insulation blankets**
  - Generally not needed in summer time
  - Requires special care during cold periods to avoid cracking
Concrete Placement
Concrete Finishing
Application of Curing Compound
Opening to Traffic

- Opening criteria
  - Minimum strength (INDOT: 300 psi flexural)
  - Minimum time (INDOT: where CaCl₂ is used in mix, temperature and ADT, 5-30 hours)

- Opening based on actual PCC strength is preferred:
  - Cylinder testing
  - Concrete maturity
Criteria for Opening to Traffic

- **Compressive strength:**
  - 2,000 psi

- **Modulus of rupture:**
  - 300 psi center-point loading
  - 250 psi third-point loading

- **Minimum time**
  - Depends on mix, slab thickness, ADT, and ambient temperature (INDOT: only allowed for mixes containing CaCl₂)
Joint Sealing

- Reduces spalling and moisture infiltration
  - Transverse joints
  - Longitudinal joints
- Saw and seal as soon as possible after concrete placement
Patching with Hot Mixed Asphalt

- **Elastic moduli**
  - HMA = 400,000 psi
  - Concrete = 4 Million psi

- **Patching concrete with HMA of the same thickness?**
  - A recipe for a huge failure
Is this going to last long?
What a good decision making!
Materials

- Conventional concrete
- Rapid-setting patching materials
  - Type III PCC
  - Set-45
  - Rapid Set Cement
  - Jet Set Cement
  - Other proprietary products
- Polymer concrete
Materials

- **Rapid-setting Patching Materials**
  - Cementitious concrete
    - Type III PCC
    - Fastrack
    - Five Star, etc
  - Polymer concrete
    - MC-64
    - SikaPronto
    - Penatron, etc.
  - Bituminous concrete
Cementitious Material

Characteristic for patching

**Window of Opportunity**

![Graph showing rate of heat evolution over time with stages I to V and their characteristics]

- **Stage I**: Rapid Heat Evolution (<15 mins)
- **Stage II**: Dormant Period
- **Stage III**: Accelerating Stage Begins with initial set (4-8 hrs)
- **Stage IV**: Deceleration Stage No longer workable (12-24 hrs)
- **Stage V**: Steady State
Materials

- Characteristics and selection of materials
  - Characteristics
    - Little or no shrinkage
    - Rapid strength development
    - Thermal compatibility
    - Freeze and thaw durability
    - Good bond to the substrate concrete
  - Selection
    - Most of the partial-depth patching materials will work
    - Opening time
    - Lab testing is recommended
INDOT full depth patching materials specification, SHORT patches (6’)

Mix Requirements

Mix Design, Criteria & Trial Batch (per 506)

Option 1 – use of CaCl₂ as accelerator
  - Very common, short “pot life”, batch at jobsite

Option 2 – Chemical admixture (Type F), or System
  - Batch at plant, longer “pot life”

Flexural Strength Requirement

- 300 psi in 24 hours
- 500 psi in 3-days
INDOT full depth patching materials specification, **LONG** patches (18’+)

- Mix requirements for HES, Modified
  - Unique special provision
    - Liquidated damages for late OTT
  - Flexible requirements for design
    - Based on HES 502 with Chemical Admixture System
    - LS CA, no material “adjustments” or “changes”
    - Trial batch required
  - Flexural strength requirement for mix
    - 450 psi in ? hours to meet job OTT, 550 psi in 2-days
    - Maturity per ITM 402 as backup information
Materials

- INDOT full depth patching materials specification
  - OTT requirements Conventional 506
    - 300 psi flexural strength or sooner if...
      - Maturity per ITM 402 for mixes with ad mix sys
      - Table 506.11, Only for mixes w/ CaCl$_2$ (time, temp & ADT)
  - OTT requirements HES, Modified Concrete
    - 425 psi flexural strength w/ Maturity per ITM 402
Materials

- INDOT full depth patching materials specification
  - Trial batch for HES, Modified Concrete
    - Same as 506.05
  - Conduct maturity
    - Test beams at 4, 8, 12, 24 hours, & 2-days or ?
    - Preparation, organization & attention are critical
Quick Review of Maturity

- Nurse-Saul Maturity Function (ITM-402)

\[ \Sigma \text{TTF} = \Sigma [\left(\frac{T_2 + T_3}{2}\right) - 14] \times (A_1 - A_2) \]

- TTF = Time Temperature Factor in °F-h
- \( A_1 \) = age in hours, at end of interval
- \( A_2 \) = previous age in hours, beginning of interval
- \( T_2 \) = concrete temperature in °F, at end of interval
- \( T_3 \) = concrete temperature in °F, at beginning of interval
Example: Mix 1

- Type III cement content 658 lbs
- Target W/C=0.429, Admix: AEA & Type A
- FA is 41 % of total agg. weight

<table>
<thead>
<tr>
<th>Time Hours</th>
<th>Temp °F</th>
<th>TTF °F-h</th>
<th>Strength (psi)</th>
</tr>
</thead>
<tbody>
<tr>
<td>4</td>
<td>87</td>
<td>264</td>
<td>132</td>
</tr>
<tr>
<td>8</td>
<td>101</td>
<td>584</td>
<td>452</td>
</tr>
<tr>
<td>12</td>
<td>87</td>
<td>904</td>
<td>525</td>
</tr>
<tr>
<td>17.5</td>
<td>77</td>
<td>1278</td>
<td>543</td>
</tr>
<tr>
<td>24</td>
<td>73</td>
<td>1716</td>
<td>679</td>
</tr>
</tbody>
</table>

TTF 680 °F-h for 425 psi
Example: Mix 1

Maturity Curve (All Flexural Strengths)

\[ R^2 = 0.889 \]

curve no.: 1.0

Flexural Strength (PSI)

Log of TTF

\[ RS-33665 \]
Example: Mix 2

- Type III Cement Content 705 lbs
- Target W/C=0.390, Admix: AEA & Type F
- FA is 40 % of total agg. weight

<table>
<thead>
<tr>
<th>Time Hours</th>
<th>Temp °F</th>
<th>TTF °F-h</th>
<th>Strength (psi)</th>
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<tbody>
<tr>
<td>4</td>
<td>105</td>
<td>308</td>
<td>240</td>
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<td>8</td>
<td>122</td>
<td>705</td>
<td>500</td>
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<tr>
<td>12</td>
<td>117</td>
<td>1126</td>
<td>578</td>
</tr>
<tr>
<td>24</td>
<td>90</td>
<td>2193</td>
<td>635</td>
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</tbody>
</table>

TTF 625 °F-h for 425 psi
Example: Mix 3

- Type I Cement Content 752 lbs
- Target W/C=0.343, Ad Sys: AEA, A, F & C$_{60}$
- FA is 37 % of total agg. weight

<table>
<thead>
<tr>
<th>Time Hours</th>
<th>Temp °F</th>
<th>TTF °F-h</th>
<th>Strength (psi)</th>
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<tr>
<td>4</td>
<td>100</td>
<td>303</td>
<td>213</td>
</tr>
<tr>
<td>5</td>
<td>103</td>
<td>392</td>
<td>337</td>
</tr>
<tr>
<td>6</td>
<td>106</td>
<td>482</td>
<td>472</td>
</tr>
<tr>
<td>8</td>
<td>106</td>
<td>671</td>
<td>555</td>
</tr>
<tr>
<td>12</td>
<td>101</td>
<td>1008</td>
<td>690</td>
</tr>
</tbody>
</table>

TTF 473 °F-h for 425 psi
Example: Mix 3

Maturity Curve (All Flexural Strengths)

\[ R^2 = 0.940 \]

- Flexural Strength (PSI)
- Log of TTF

- Crosses (Fx)
- Target Strength
- Regression

[Graph showing the relationship between Flexural Strength and Log of TTF with an R^2 value of 0.940]
Example: Mix 4

- Type III Cement Content 705 lbs
- Target W/C=0.430, Ad Sys: AEA, F & C_{15}
- FA is 43 % of total agg. weight

<table>
<thead>
<tr>
<th>Time Hours</th>
<th>Temp °F</th>
<th>TTF °F-h</th>
<th>Strength (psi)</th>
</tr>
</thead>
<tbody>
<tr>
<td>4</td>
<td>112</td>
<td>303</td>
<td>?</td>
</tr>
<tr>
<td>8</td>
<td>115</td>
<td>702</td>
<td>?</td>
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<tr>
<td>12</td>
<td>98</td>
<td>1061</td>
<td>?</td>
</tr>
<tr>
<td>24</td>
<td>76</td>
<td>1911</td>
<td>?</td>
</tr>
</tbody>
</table>
Example: Mix 4

- Type III Cement Content 705 lbs
- Target W/C=0.430, Ad Sys: AEA, F & C15
- FA is 43% of total agg. weight

<table>
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<th>Time Hours</th>
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<tbody>
<tr>
<td>4</td>
<td>112</td>
<td>303</td>
<td>250</td>
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<td>8</td>
<td>115</td>
<td>702</td>
<td>370</td>
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<td>12</td>
<td>98</td>
<td>1061</td>
<td>395</td>
</tr>
<tr>
<td>24</td>
<td>76</td>
<td>1911</td>
<td>422</td>
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</tbody>
</table>

Lesson – mix design & trial batch important
Field Performance

- Mix 3 review
  - Type I Cement Content 752 lbs
  - Target W/C=0.343, Ad Sys: AEA, A, F & C<sub>60</sub>
  - FA is 37% of total agg. weight

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<td>106</td>
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<td>671</td>
<td>555</td>
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<tr>
<td>12</td>
<td>101</td>
<td>1008</td>
<td>690</td>
</tr>
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TTF 473 °F-h for 425 psi
### Field Performance

- **Mix 3 July 2013 Patch #1, 10” slump**

<table>
<thead>
<tr>
<th>Time (hours)</th>
<th>Temp (°F)</th>
<th>TTF (°F-h)</th>
<th>Strength (psi)</th>
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</thead>
<tbody>
<tr>
<td>1</td>
<td>85</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>89</td>
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<tr>
<td>3</td>
<td>96</td>
<td></td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>109</td>
<td></td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>120</td>
<td>412</td>
<td>220*</td>
</tr>
<tr>
<td>6</td>
<td>127</td>
<td>521</td>
<td>300*</td>
</tr>
<tr>
<td>7</td>
<td>134</td>
<td>637</td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>139</td>
<td>759</td>
<td></td>
</tr>
<tr>
<td>11</td>
<td>144</td>
<td>1143</td>
<td>450*</td>
</tr>
</tbody>
</table>

38 °F hotter than curve, 5 h delay in OTT strength
Field Performance

- **Mix 3 July 2013 Patch #2, 1” slump**

<table>
<thead>
<tr>
<th>Time (hours)</th>
<th>Temp (°F)</th>
<th>TTF (°F-h)</th>
<th>Strength (psi)</th>
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</thead>
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<tr>
<td>1</td>
<td>91</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>98</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>110</td>
<td></td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>119</td>
<td></td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>128</td>
<td><strong>457</strong></td>
<td>195*</td>
</tr>
<tr>
<td>6</td>
<td>134</td>
<td>574</td>
<td>300*</td>
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<td>136</td>
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<td>405* @ 7 ¼ h</td>
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<td></td>
<td>495*</td>
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30+ °F hotter than curve, 5 h delay in OTT strength
**Field Performance**

- **Mix 3 Aug 2013 Patch #3**

<table>
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<tr>
<th>Time (hours)</th>
<th>Temp (°F)</th>
<th>TTF (°F-h)</th>
<th>Strength (psi)</th>
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</thead>
<tbody>
<tr>
<td>1</td>
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<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>103</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>121</td>
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<td></td>
</tr>
<tr>
<td>4</td>
<td>134</td>
<td>375</td>
<td>250*</td>
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<td>5</td>
<td>141</td>
<td><strong>498</strong></td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>145</td>
<td>627</td>
<td>300*</td>
</tr>
<tr>
<td>7</td>
<td>146</td>
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<td>460*</td>
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<td>8</td>
<td>145</td>
<td>890</td>
<td>540*</td>
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</tbody>
</table>

40 °F hotter than curve, 2 hour delay in OTT strength

TTF 303 = 213 psi, TTF 392 = 337 psi, TTF 482 = 472 psi, TTF 681 = 555 psi
Field Performance

- **Mix 1 review**
  - Type III Cement Content 658 lbs
  - Target W/C=0.429, Admix: AEA & Type A
  - FA is 41% of total agg. weight

<table>
<thead>
<tr>
<th>Time Hours</th>
<th>Temp °F</th>
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<th>Strength (psi)</th>
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<tbody>
<tr>
<td>4</td>
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<td>87</td>
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<td>524</td>
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<tr>
<td>17.5</td>
<td>77</td>
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<td>543</td>
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</table>

TTF 680 °F-h for 425 psi
Field Performance

**Mix 1 May 2013**

<table>
<thead>
<tr>
<th>Time (hours)</th>
<th>Temp (°F)</th>
<th>TTF (°F-h)</th>
<th>Strength (psi)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>79</td>
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<tr>
<td>2</td>
<td>83</td>
<td>130</td>
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<tr>
<td>3</td>
<td>93</td>
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<tr>
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</table>

36 °F hotter than curve, 4 h delay in OTT strength
Field Performance

Mix 1 June 2013

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<th>Temp (°F)</th>
<th>TTF (°F-h)</th>
<th>Strength (psi)</th>
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<tbody>
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<tr>
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<td>225* @14 ½ hr</td>
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<tr>
<td>15 ¾</td>
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<td>355* 545*</td>
</tr>
</tbody>
</table>

60 °F hotter than curve, 9 h delay in OTT strength
So What’s Going On? Observations

- Mix 3 gained OTT fastest at trial batch
- Maturity TTF does not account for QC problems
- Maturity TTF typically over estimates flexural strength
- The more the temperature of the mix varies from the Maturity curve, the greater effect on flexural strength
- Work is needed to improve accuracy of Maturity for use with HES Concrete, Modified
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TROUBLE

Luck Can’t Last a Lifetime unless You Die Young.