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Professor at Oklahoma State University for 13 y

Work experience with a contractor, DOT, and a consultant.

Research focus – Constructability, Durability, and Novel Test methods

YouTube Channel > 6M views and > 60K subscribers

CONCRETE FREAK!!!!

Fast-Setting Patching Materials

Tyler Ley, PhD, PE
Acknowledgements

National Concrete Consortium – Pooled Fund Study
Steve Tritsch

FHWA – EAR - Novel Alternative Cement Binders for Highway Structures and Pavements
Georgia Tech (lead) – K.E. Kurtis, L.E. Burris, and P. Alapati
Oklahoma State University – M.T. Ley, J. Peery, A. Hajibabaee, and M. Khanzadeh
Tourney Consulting Group (TCG) – N.R. Berke
US Army ERDC – R.D. Moser

Acknowledgements

My daughter Isabel
Who is your favorite super hero???

Overview of Synthesis Document

- Four Keys to choosing patching materials
- How do the patching materials work
- Mixing, placement, curing, grinding
- Comparison of patching material performance for strength and durability from literature
- Case studies with a focus on long term durability.
- Common testing protocols and specification
Why is this talk important?
I need the strongest, fastest, most durable concrete on the planet!!!!
Ohio DOT Research Report 134816

“In this project, the lowest cost repair material performed nearly as well as the highest price materials that cost more than 20 times as much.”

Delatte et al., 2016
How do we know which repair material to choose???

<table>
<thead>
<tr>
<th>Material</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rapid OPC</td>
<td>Latex modified</td>
</tr>
<tr>
<td>UHPC</td>
<td>Geopolymer</td>
</tr>
<tr>
<td>Mag Phosphate</td>
<td>Polyester Concrete</td>
</tr>
<tr>
<td>Calcium sulfoaluminate (CSA)</td>
<td></td>
</tr>
<tr>
<td>Calcium aluminate (CAC)</td>
<td></td>
</tr>
</tbody>
</table>

Which one do you choose?
Ask better questions and you will get better answers!

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There are four key questions with all repairs.
The *Really* Fantastic Four Questions

1. How fast do you *really* need it open?
2. What strength do you *really* need?
3. Is reinforcing steel *really* close to the surface?
4. How long do you *really* need it to last?

How fast do you *really* need it open?

The longer you can delay opening the more chance you are giving the material to gain strength.

This also reduces the pressure on the contractors.

Less pressure = more quality = longer life
What strength do you *really* need?

- The lower the strength you need the easier it is to make it happen.
- Reducing f’c by 500 psi can make a *big* difference.
- Most of our repairs are over designed

Super Maria!!!!
Compressive Strength for Opening

Structures 2000 – 4500 psi
Wisconsin

Pavements 1250 – 3500 psi
Pennsylvania

It was a trick question!!!!

Your opening strength should be a function of the stresses in the patch.

\[ f'c_1 \] \quad \downarrow \quad \quad \quad \quad \quad \quad \quad \quad \quad \downarrow f'c_2

See early opening doc from Delatte, Weiss, Taylor
The correct answer is it depends...
Who gets extra credit?

California, Georgia, Iowa, Indiana, Michigan, North Dakota, Ohio

Is reinforcing steel *really* close to the surface?

Bridge structures often have rebar close to the surface.

You want your patching material to protect that steel.
Did you know Portland cement naturally protects rebar from corroding?

Portland cement produces calcium hydroxide and this raises the pH of the pore solution.

pH > 13

Rebar will corrode in air!

But not in ↑ pH concrete

www.engineeringgavil.com
How do you measure pH?

Place a pH indicator on concrete. The most common one is phenolphthalein.

pH 8 – 12  fuscia
pH < 8  clear

Novel Alternative Cement Binders for Highway Structures and Pavements, FHWA, 2021

84 d in 7% CO₂ 0.40 w/cm
Novel Alternative Cement Binders for Highway Structures and Pavements, FHWA, 2021

84 d in 7% CO₂, 0.40 w/cm

Mean carbonation front (inches)

Square root of Exposure age (days^{0.5})

Carbonation rate (in/yr^{0.5})

- OPC: 0.06
- CAC2: 1.16
- CACT: 0.35
- CSA2: 1.72
- AA: 1.54

Two months

7% CO₂, 0.40 w/cm
Most repair materials have issues with this.

This means that if you have rebar 2” from the surface and the repair material is a low pH then the rebar will start corroding within the structure in < 2y!!!!

The corrosion will cause cracks in your patching material and section loss in your rebar.

How do repair materials compare?

<table>
<thead>
<tr>
<th>Good for carbonation (Good for bridges)</th>
<th>Bad for carbonation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rapid OPC (non chloride!)</td>
<td>CAC</td>
</tr>
<tr>
<td>UHPC</td>
<td>Geopolymer</td>
</tr>
<tr>
<td>Polyester Concrete</td>
<td>Mag phosphate</td>
</tr>
<tr>
<td>Latex modified</td>
<td>CSA</td>
</tr>
</tbody>
</table>
How long do you *really* need it to last?

As long as possible!!!!

State report says 10 – 15 years.

Some last +20 y. (I think this is very doable.)
One of the keys is shrinkage!

One of the keys is shrinkage!
One of the keys is shrinkage!

This causes debonding and premature cracking.
Shrinkage Basics

Watch out for the CAD Monkey!
Shrinkage Basics

Watch out for the CAD Monkey!

Chemical
Autogenous
Drying
Shrinkage Basics

<table>
<thead>
<tr>
<th>type of shrinkage</th>
<th>timing</th>
<th>cause</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chemical</td>
<td>hours</td>
<td>free water consumed by hydration</td>
</tr>
<tr>
<td>Autogenous</td>
<td>days</td>
<td>hydration taking water from pores</td>
</tr>
<tr>
<td>Drying</td>
<td>months</td>
<td>water leaving pores from drying</td>
</tr>
</tbody>
</table>

Mixture designs

Concrete mixtures with a w/cm = 0.40 and a 4” to 6” slump with 2 h to 4 h initial set time were developed.

These were used for drying shrinkage testing.

An equivalent paste from these mixtures were used for the other tests.
Shrinkage Testing

**Chemical shrinkage**
ASTM C1608  
(Dilatometry method)

**Autogenous shrinkage**
ASTM C1698  
(Corrugated tube method)

**Drying shrinkage**
ASTM C157 (Linear drying shrinkage)

![Photo credit: pitt.edu PMML](Image)

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**Chemical Shrinkage Results**

![Graph showing chemical shrinkage results over time for various cement types](Graph)

- OPC
- CSA2
- CAC2
- CAC3
- AA1

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![Yes/No criterion](YesNo)
Chemical Shrinkage Results

Autogenous Shrinkage Results
Autogenous Shrinkage Results

Drying Shrinkage Results

Samples were wet cured for 7 days
Drying Shrinkage Results

How does it compare to OPC??

<table>
<thead>
<tr>
<th>Shrinkage:</th>
<th>Chemical</th>
<th>Autogenous</th>
<th>Drying</th>
</tr>
</thead>
<tbody>
<tr>
<td>CSA</td>
<td>✗</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>CAC blend</td>
<td>=</td>
<td>=</td>
<td>✗</td>
</tr>
<tr>
<td>CAC</td>
<td>✗</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>AA</td>
<td>✗</td>
<td>✓</td>
<td>✓</td>
</tr>
</tbody>
</table>
What does this mean?

- The Geopolymer, CSA, and CAC showed a lower amount of autogenous and drying shrinkage than OPC.

- Less strain should mean less cracking and/or curling and warping.

What does this mean?

- These repair materials have an increase in chemical shrinkage in comparison to OPC.

- Based on limited concrete and paste testing no detectable damage occurred at w/cm = 0.40.

- Lower w/cm mixtures should be investigated.
Can repair materials really resist freeze thaw, ASR, sulfate attack, corrosion?

www.youtube.com/tylerley
Can repair materials really resist freeze thaw, ASR, sulfate attack, corrosion?

YES!!!
(If they are designed right!)

Novel Alternative Cement Binders for Highway Structures and Pavements, FHWA, 2021

Conclusion

• Start with the really fantastic four questions to help improve your rapid patching designs.

• Beware of products with low pH if you are protecting rebar.

• Minimizing shrinkage is helpful and most patching materials are better at this than OPC.
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Questions???
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I ❤️ Concrete