MnROAD Field Demonstration of Alternative Materials for Concrete

Larry Sutter Ph.D., P.E., F.ACI, F.ASTM

Professor Emeritus and Research Professor
Materials Science & Engineering
Michigan Technological University, Houghton MI

Principal Engineer
Sutter Engineering LLC
Houghton MI 49931

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Where is the industry going?

- Sustainability – Carbon neutral by 2050
- Because…

There's something happening here

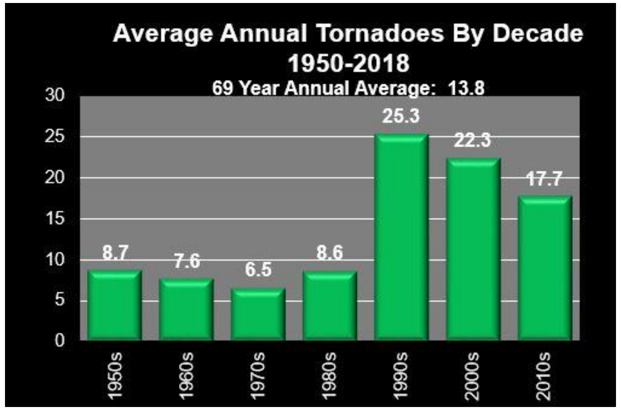
What it is ain't exactly clear

Stephen Stills, Buffalo Springfield, 1966

You may have "highly informed" explanations or just disagreee…

Scott Olson, Getty Images

“Tornados are not more common; they’re over-hyped. They just send out news crews like lice on a dog!”



National Weather Service

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Scott Olson, Getty Images

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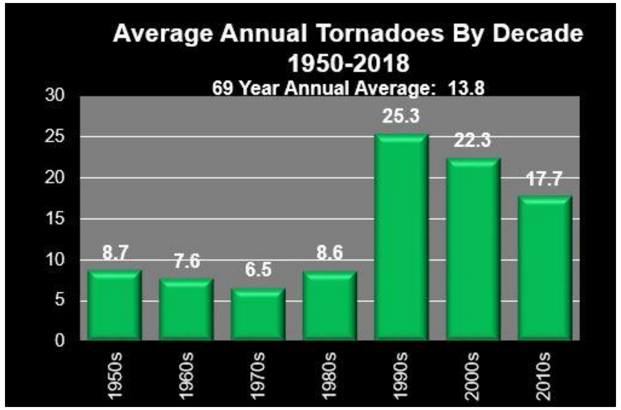

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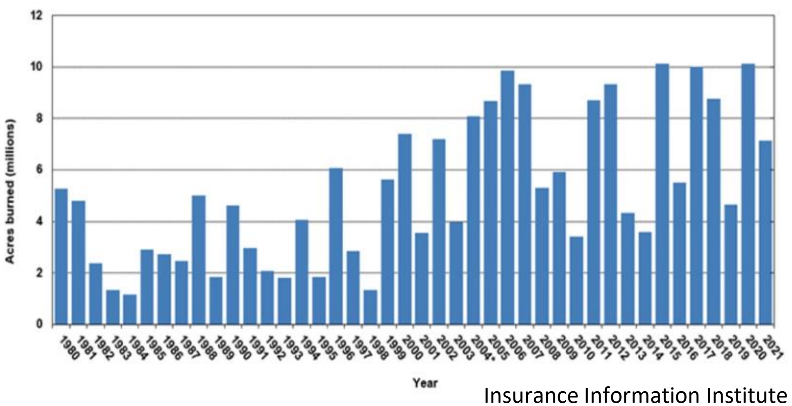
Noah Berger, AP Photo

LA Times

Annual Number of Acres Burned in Wildland Fires, 1980-2021



Insurance Information Institute

John Locher/AP

"It's those tree huggers that won't let us cut any trees!"

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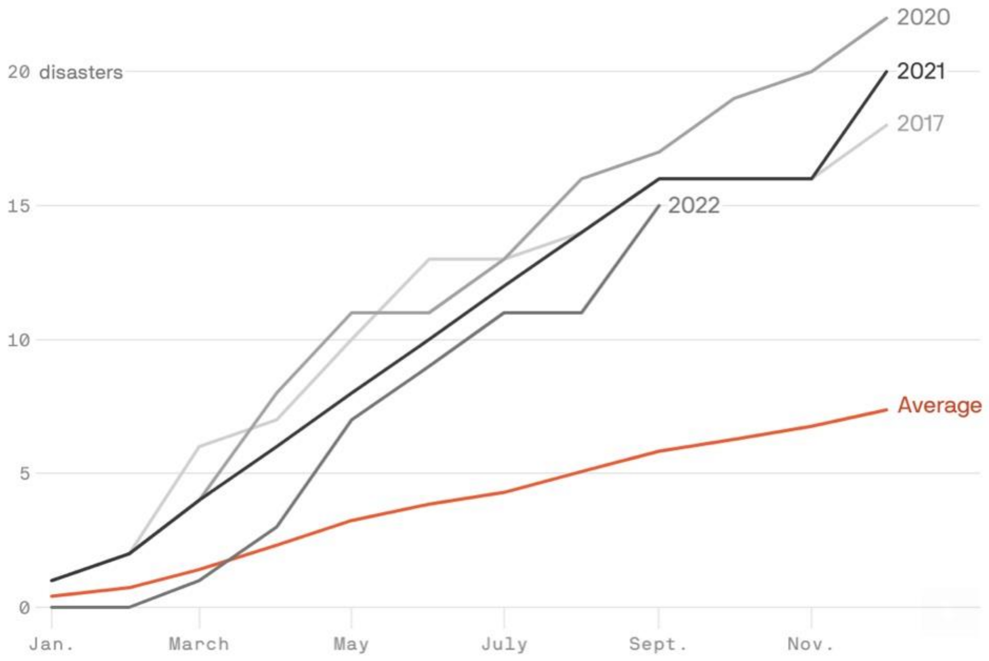
Ramon Espinosa, AP Photo

“Crazy fools that build right on the coast. What do they expect?”

U.S. cumulative billion-dollar climate and weather disasters, by year

As of Oct. 11, 2022; By month the climate event ended



Data: Climate Central, NOAA National Centers for Environmental Information. (Damages of at least $1 billion, adjusted for 2022 dollars. Average = 1980-2022.) Chart: Axios Visuals

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Where is the industry going?

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All theories are good theories – but if you are in the concrete business…

choose wisely…

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Your local Holiday Inn…

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Your local road…

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"Low Carbon" is and will be demand driven

- Many private companies see climate change as a threat to their long-term viability (2035 target – not 2050)
- Major companies are investing in strategies to reduce their carbon footprint now and into the future
  - Companies that have large infrastructure construction programs for warehousing, campuses, and data centers: Meta, Target, Amazon, etc.
- Looking for strategies to reduce the carbon footprint of concrete as part of an overall program

National/State Level Policy Initiatives

- The federal government and many state and local agencies are requesting reduced carbon concrete – lower GHG emissions
- In some cases, carbon limits are being set for classes of concrete
  - Tracking carbon footprint of construction materials using environment product declarations (EPDs) has begun
- Several NGO's and other stakeholders are working with elected officials to implement changes in policy to benchmark and reduce GHG emissions

The Path Forward for Concrete Pavements

Less clinker in cement, less cement in concrete, less concrete in construction

- Replace clinker content in cement
  - Use blended cement (ASTM C595) or replace clinker with supplementary cementitious materials (SCMs) at concrete plant
- Use less cementitious materials
  - Optimized aggregate grading
  - Lower cementitious content
- Optimize designs & new mixtures (UHPC)
- Use alternative SCMs and/or alternative cementitious materials
- Why alternative materials?

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Example: UHPC

photo credit: S. Foster

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Why Alternative Materials?

- Not the only solution
- Conventional materials in short supply
  - Fly ash (no more coal power)
  - Slag (no more blast furnaces)
- Performance
- Carbon reduction and sequestration

The Path Forward for Concrete Pavements

The Three C's

Less clinker in cement, less cement in concrete, less concrete in construction

RISK!!

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  - Optimized aggregate grading
  - Lower cementitious content
- Optimize designs & new mixtures (UHPC)
- Use alternative SCMs and/or alternative cementitious materials
- Why alternative materials?
- All require demonstration. But where? The **RISK** of trying something new…

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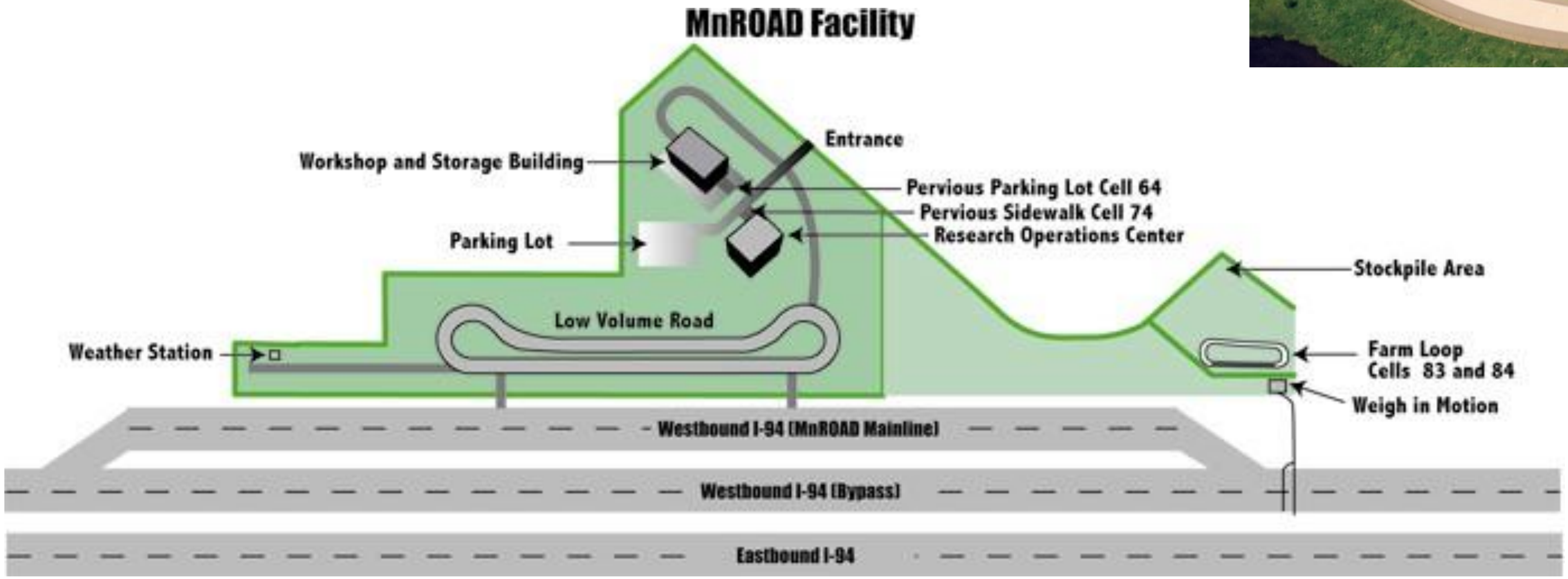
This Has Brought Us to MnROAD



Constructed 1990-93

A partnership between Minnesota Department of Transportation and the Minnesota Local Road Research Board

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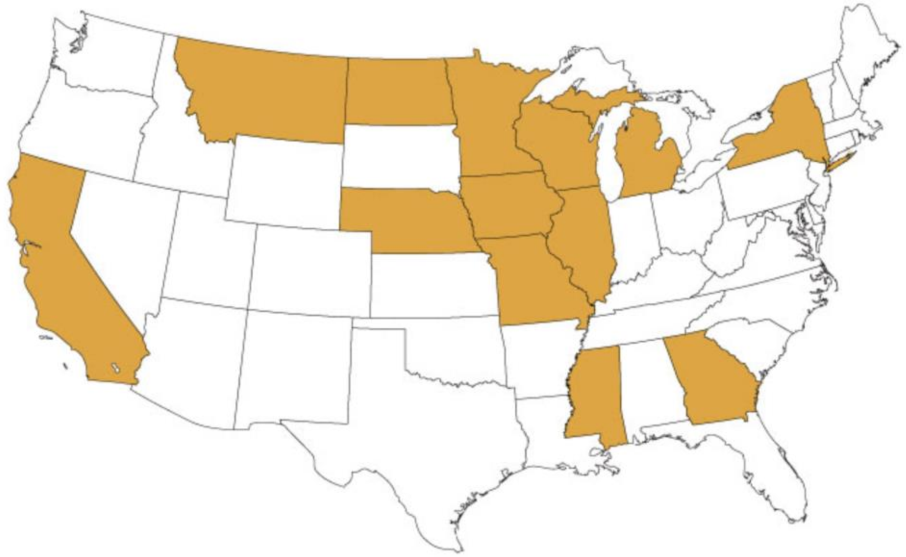
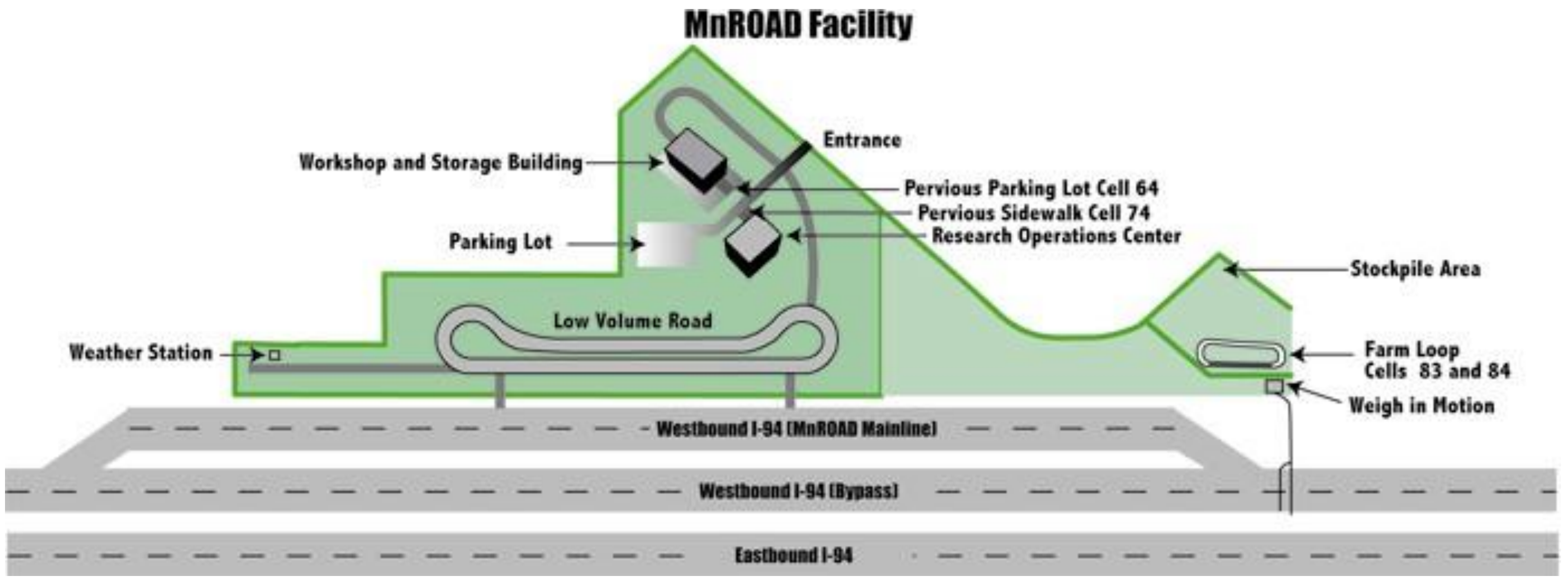
MnROAD - NRRA

- 3.5 mile of I-94 operated by **MnDOT**
- Partnership with the **National Road Research Alliance (NRRA)**
- 11 states, 50 industries, associations, and academia
- Designed to test new technologies in a real-world environment





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Project Ramp-Up

- MnDOT contracted with NCE and Sutter Engineering LLC to help structure and execute the experiment
  - Identify materials providers
  - Establish mixture requirements
  - Manage trial batching
  - Coordinate logistics (i.e., herd cats)
  - Structure the testing program to support the desired research

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NRRA Research Projects

- Use of Carbon Dioxide for Sustainable and Resilient Concrete Pavements – *Iowa State University*
- Use of Alternative Pozzolanic Materials Towards Reducing Cement Content in Concrete Pavements – *APTech*
- Use of Alternative Cementitious Materials in Concrete Pavements – *NCE*

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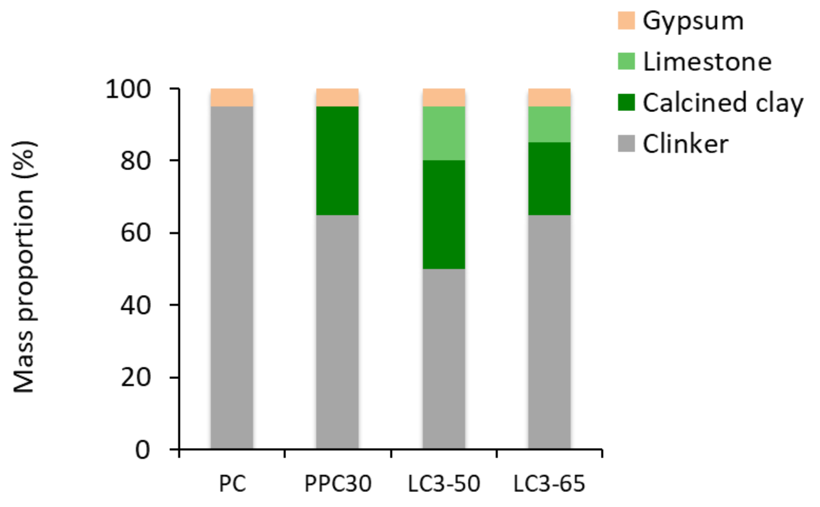
Possible Technologies - Alternative SCMs

- Harvested coal ash
  - From landfills and ponds
  - Mix of fly ash and bottom ash
  - Requires processing
- Ground glass pozzolan
  - ASTM C1866
- Manufactured SCMs
  - ASTM is working on standards for alternative SCMs

Possible Technologies - Alternative Cements

- Non-traditional blended hydraulic cements
  - LC3 – portland cement, ground limestone, calcined clay,
  - High-limestone replacement blended cements
- Alkali-activated hydraulic cements
  - Alkali activator – liquid or powder; hydration occurs
  - Precursor containing calcium and alumino-silica minerals
    - e.g., Class C fly ash, slag cement
- Alkali-activated non-hydraulic cements (geopolymers)
  - Alkali-activated non-hydraulic reaction based on low calcium alumino-silica minerals
  - Dissolution and polymerization process



LC^3 is a family of cements, the figure refers to the **clinker** content

K. Scrivener, 2020

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Project Requirements

- General Requirements
  - Portland cement mixtures will use an ASTM C595 Type IL(10) blended cement
  - Mixtures shall meet performance requirements based on AASHTO R 101 Developing Performance Engineered Concrete Pavement Mixtures *(required 500 psi flex @ 28 days, 5-8% air)*
  - Batched and mixed at a central plant and paved using conventional slip-form paving equipment

Final Test Site Construction

- Test cells were constructed at MnROAD to evaluate strategies to reduce GHG emission in concrete paving
- 16 test cells
  - 2 control cells
  - 1 optimized mixture (based on control)
  - 3 CarbonCure™ cells
  - 7 alternative SCM cells *(nominal)*
  - 3 alternative cements *(nominal)*
- Construction completed August 2022

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Project Specific Mixtures

- **Control Mixtures** – Standard MnDOT paving mixture
  - 570 pcy total cementitious with 30% Class F fly ash (Coal Creek)
  - Water-to-cementitious materials ratio of 0.40
- Two control mixtures were needed to accommodate carbon mineralization study
  - One control mixture and the three CarbonCure™ cells will use one set of constituent materials
  - Other control mixture and remaining cells will use another set of constituent materials

Project Specific Mixtures

- **Optimized Mixture** – designed with conventional materials with reduced cementitious materials content
  - Mixture Design by Iowa State University (P. Taylor)
  - Mixture Design – 501 pcy total cementitious; 30% Coal Creek Class F
- **CarbonCure™**
  - One mixture designed by CarbonCure™ with CO_2 injection – 558 pcy total cementitious; 30% Coal Creek Class F
  - Same mixture as above without the CO_2 injection
  - Control mixture with CO_2 injection

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Project Specific Mixtures - ASCMs

- **Carbon Upcycling**
  - Fly ash processed by grinding in a pressurized carbon-rich environment
  - Mixture Design – 500 pcy total cementitious; 30% treated ash
- **Urban Mining**
  - Ground-glass pozzolan meeting ASTM C1866
  - Mixture Design – 570 pcy total cementitious; 30% GGP
- **TerraCO2**
  - Manufactured SCM resembling fly ash
  - Mixture Design – 570 pcy total cementitious; 35% manufactured ASCM

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Project Specific Mixtures - ASCMs

- **Carbon Limit**
  - Proprietary material, ground limestone, natural pozzolan
  - Mixture Design – 570 pcy total cementitious; 30% ASCM
- **Hess Pumice**
  - Pumice-based natural pozzolan meeting ASTM C618
  - Mixture Design – 570 pcy total cementitious; 30% pozzolan
- **3M**
  - Baghouse dust from shingle granules; natural pozzolan meeting ASTM C618
  - Mixture Design – 570 pcy total cementitious; 15% 3M pozz, 15% Portage Station Class F
- **Burgess Pigments**
  - Metakaolin natural pozzolan
  - Mixture Design – 570 pcy total cementitious; 12% metakaolin, 18% Coal Creek Class F

Project Specific Mixtures - ACMs

- **Ash Grove – IP(30)**
  - Thought we were getting LC3 using 50% clinker, 30% calcined clay, 15% limestone
  - Mixture Design – 570 pcy total cementitious using calcined clay as the pozzolan
- **Continental Cement – High Limestone Type IL(20)**
  - Blended cement with 20% limestone, 30% Class F ash
  - Mixture Design – 570 pcy total cementitious
- **UltraHigh Materials**
  - 0% portland cement clinker-based hydraulic cement (meets ASTM C1157)
  - Mixture Design – 650 pcy total cementitious

Alternative SCMs - Examples

- ***Carbon Upcycling***
- Patented technology (reactor)
- Ball milling of the material in a CO_2 environment
- Size reduction plus carbonation of components in the ash
- Claim the process works with fly ash, bottom ash, slag, ground glass, natural pozzolans and other natural minerals (e.g., talc)

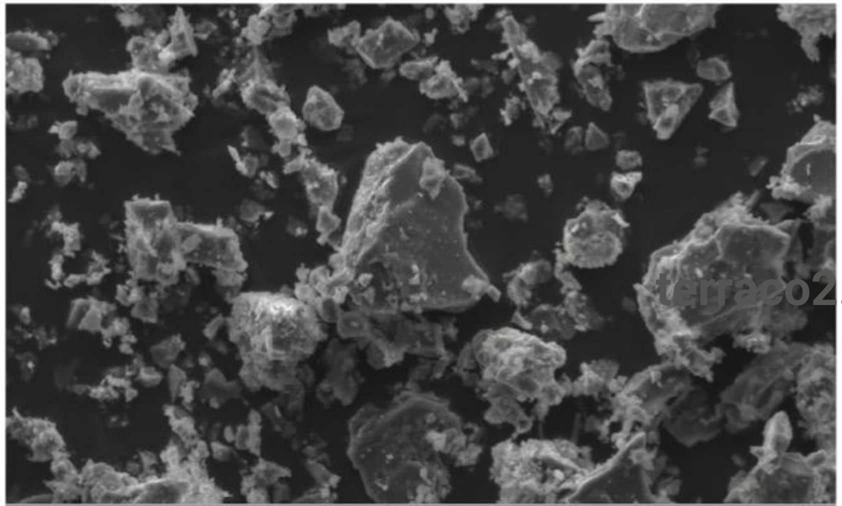
20 tonne reactor

Alternative SCMs - Examples

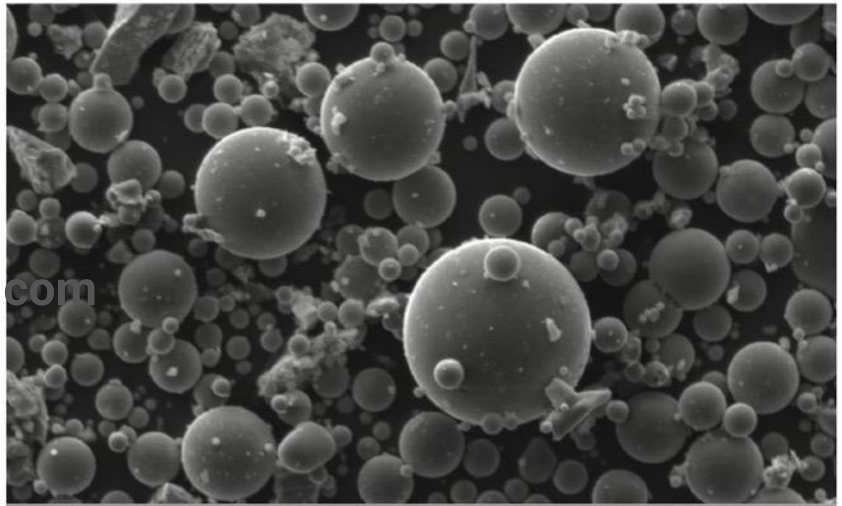
- ***Company: TerraCO2***
- Synthetic fly ash
- Taking rock with a composition similar to Class F ash, partially melting, cooling in an air stream to form spherical glass particles
- Composition, structure, morphology, particle size all mimic Class F ash

WHAT ARE THE BENEFITS OF HAVING A NEW LOW COST SCM LIKE OPUS SCM?

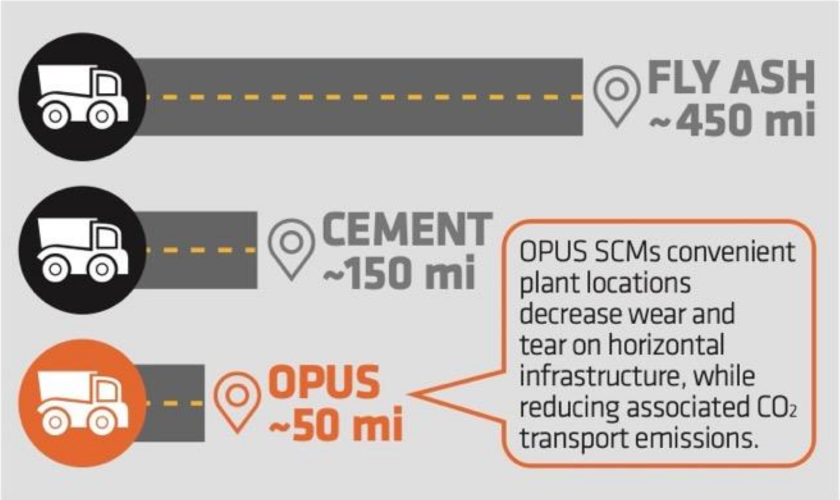
1. OPUS SCM is potentially cheaper than fly ash (depending on haul distance).
2. OPUS SCM manufacturing scales to meet increasing demand, unlike coal fly ash.
3. OPUS SCM does not use coal energy. Carbon-neutral production will be possible when industrial renewable energy sources become feasible.



SEM image of raw feedstock at 1600x



SEM image of OPUS SCM at 1600x



Transport emissions: State of Colorado example

OPUS Supplementary Cementitious Material (OPUS SCM):

- is classified as a Class N pozzolan
- is an alternative to Class F fly ash
- reduces Portland cement emissions by 8-23% (at 10-30% substitution)

Cement is responsible for ~5 to 7% of global carbon emissions.

Alternative SCMs - Examples

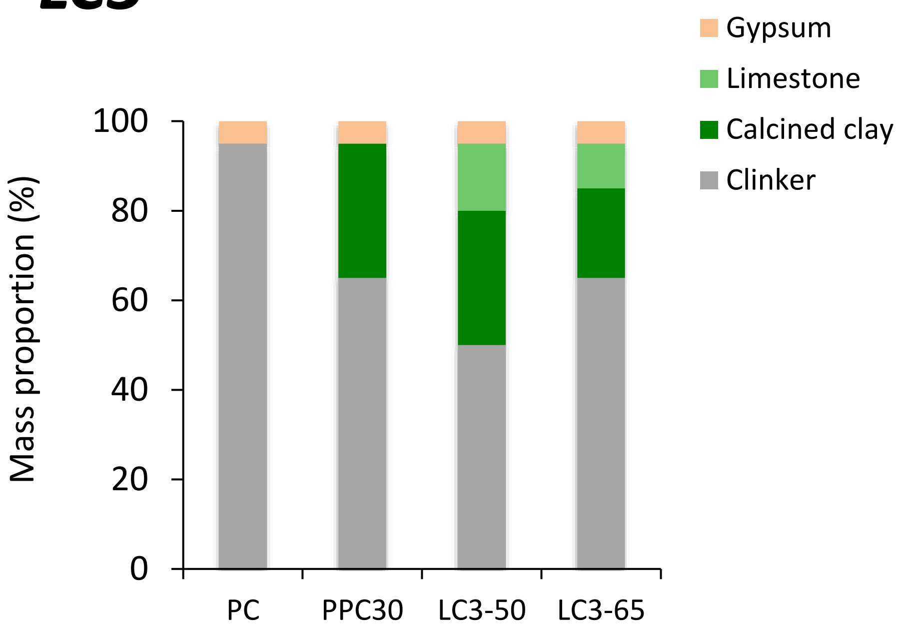
- ***Company: Carbon Limit***
- Non-calcined mineral admixture
- Replaces cement
- Adds a catalyst to increase CO_2 uptake
- Claims to adsorb more CO_2 in hardened state than portland cement concrete

Alternative Cements - Examples

- ***Company: UltraHigh Materials***
- Proprietary blend of materials
- Available as a hydraulic formulation or a geopolymer formulation
- Capable of very high strength concrete, ~25,000 psi compressive

Alternative Cements - Examples

- ***LC3***



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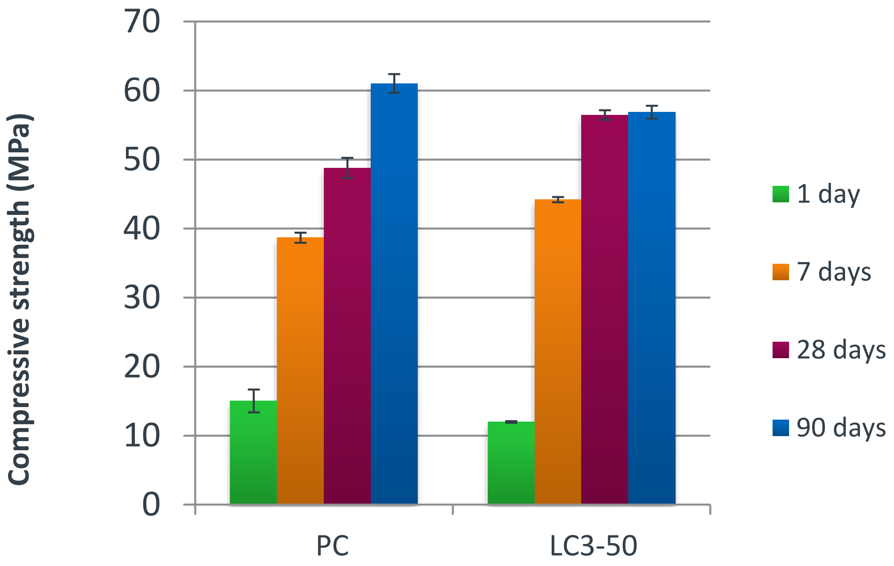

- 50% less clinker
- 40% less CO_2
- Similar strength
- Better chloride resistance
- Resistant to alkali silica reaction

K. Scrivener, 2020

Alternative Cements - Examples

- ***Company: Continental Cement***
- Blended cement with 20% limestone replacement

4. Classification

4.1 This specification applies to the following types of blended cement that generally are intended for use as indicated.

4.1.1 Blended hydraulic cements for general concrete construction.

4.1.1.1 *Type IS*—Portland blast-furnace slag cement.

4.1.1.2 *Type IP*—Portland-pozzolan cement.

4.1.1.3 *Type IL*—Portland-limestone cement.

4.1.1.4 *Type IT*—Ternary blended cement.

ASTM INTERNATIONAL

Designation: C595/C595M – 21

Standard Specification for Blended Hydraulic Cements[1]

7.1.5 *Portland-limestone Cement*—Portland-limestone cement shall be a hydraulic cement in which the limestone content is more than 5 % but less than or equal to 15 % by mass of the blended cement.

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The Research

- Three research teams have been selected by NRRA
- Data from construction obtained by local testing firm and FHWA Mobile Trailer
- Post-construction testing will be performed by local firm and FHWA Turner-Fairbank
- Research teams will monitor pavement performance over 2 years
- Teams will report on performance including LCA

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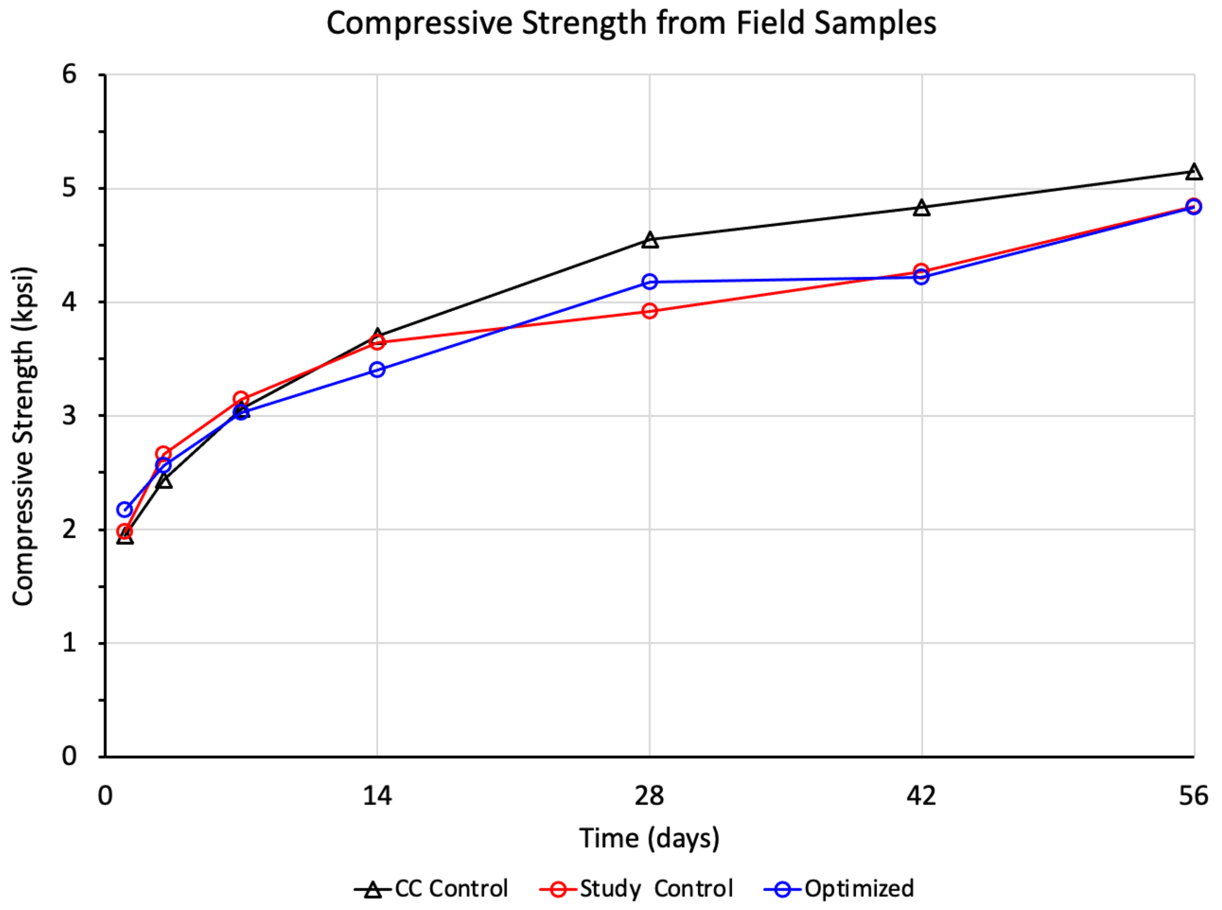
A Note on Environmental Impact

- Environmental Product Declarations (EPDs) are not currently available for many of the alternative materials
  - Would need to use ISO 21930 core PCR to develop EPD
- This will limit ability to assess environmental impact
  - Will gather data, draw boundaries, and do the best we can
- FHWA is working on the LCA Commons to provide the necessary LCI data for EPD development

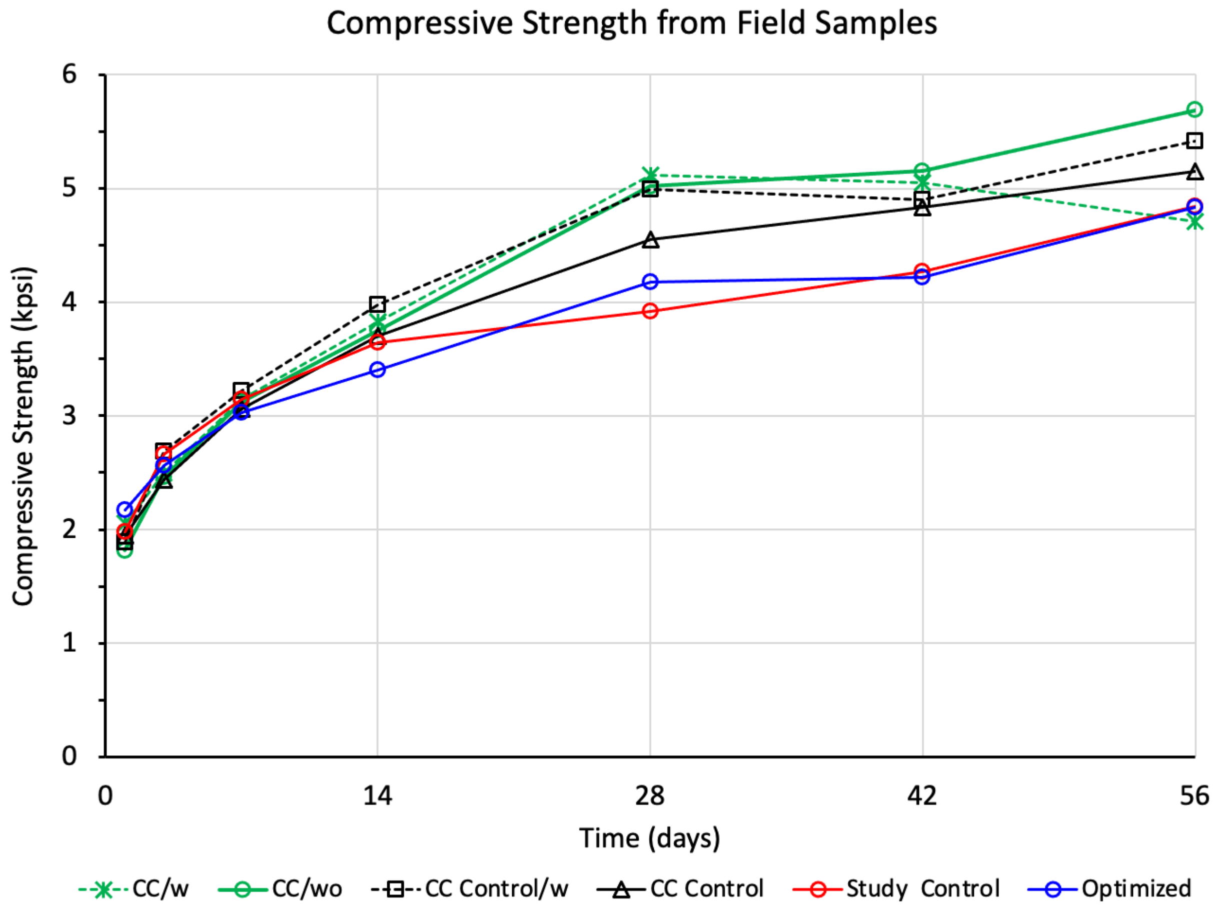
Preliminary Results – Compressive Strength

- Control Mixtures



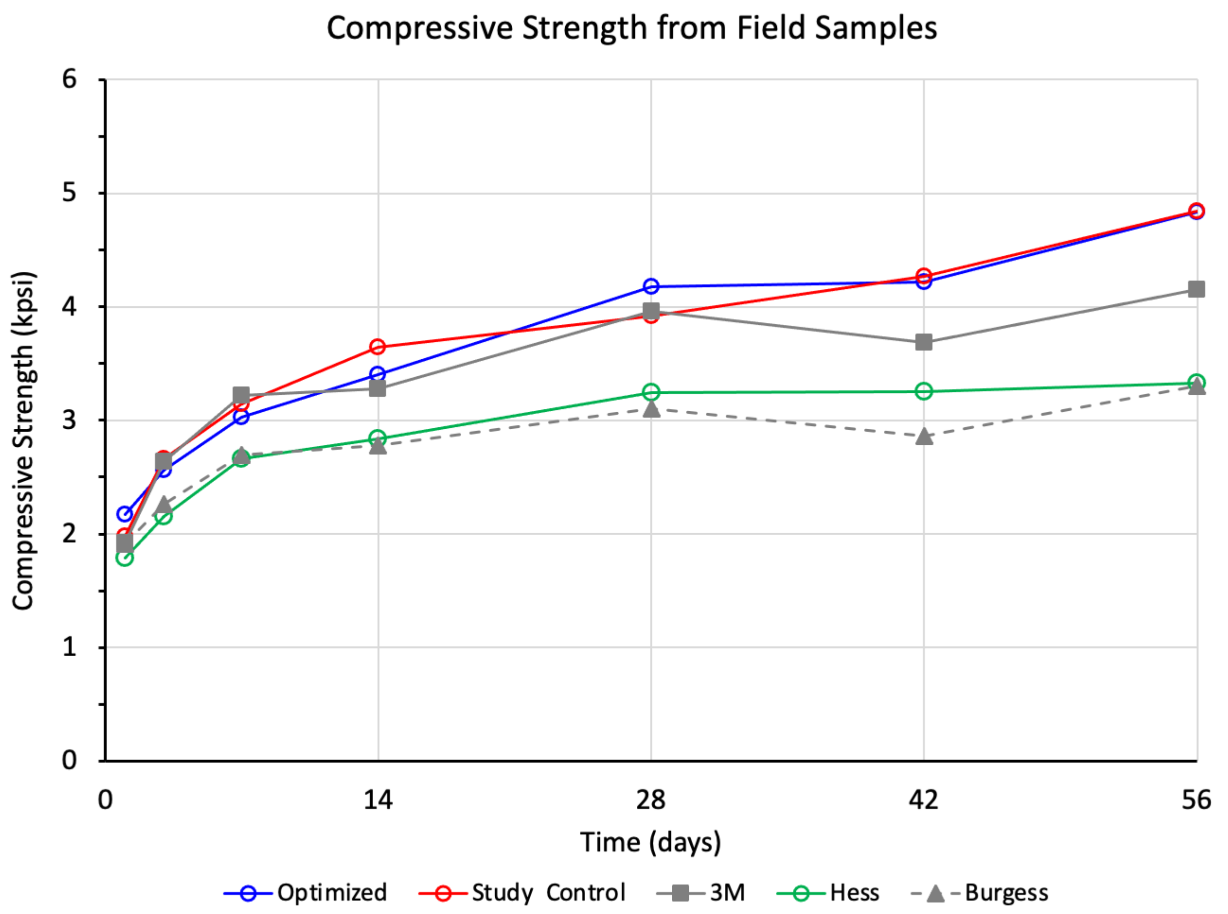
Preliminary Results – Compressive Strength

- CarbonCure™ Mixtures



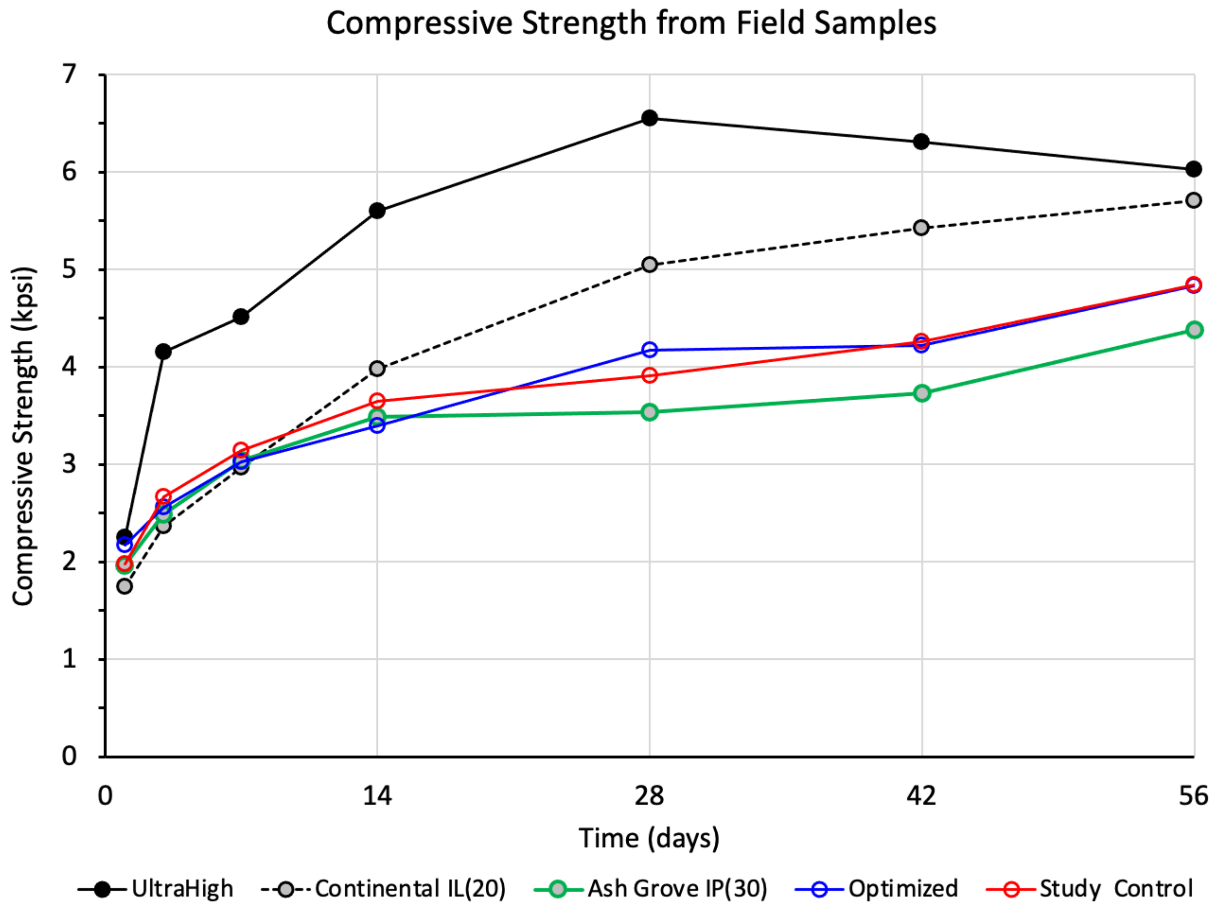
Preliminary Results – Compressive Strength

- Natural Pozzolan Mixtures



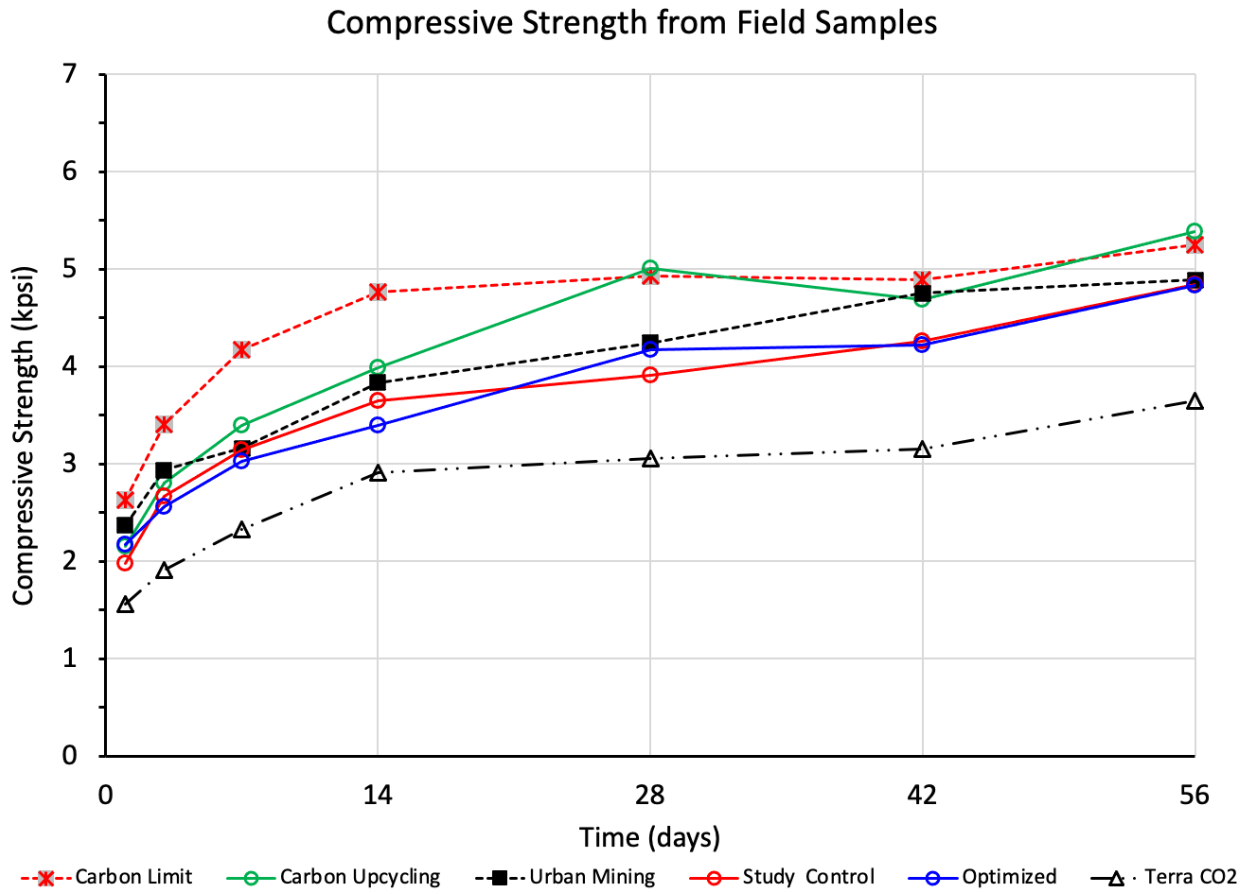
Preliminary Results – Compressive Strength

- Other Cements Mixtures



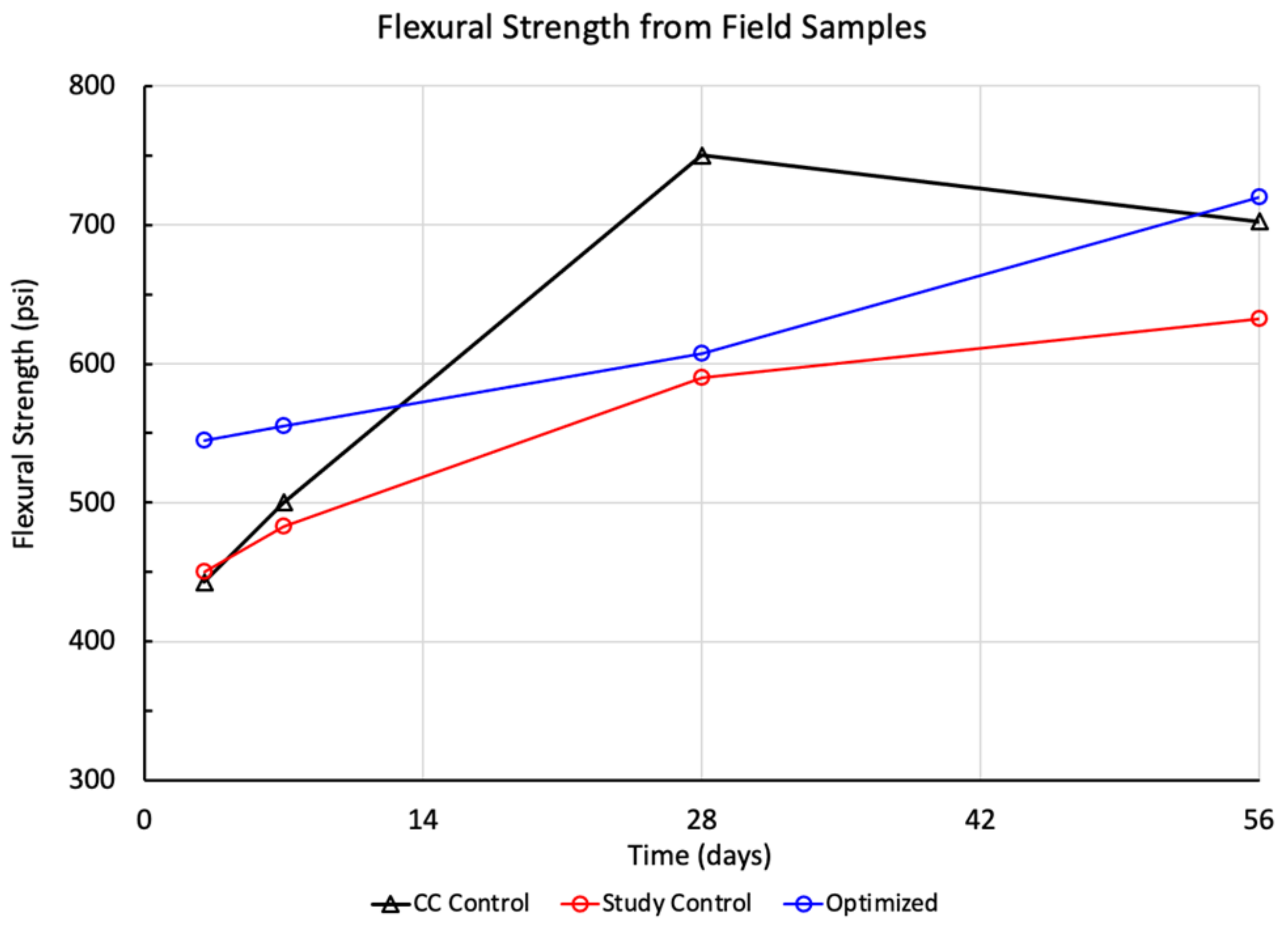
Preliminary Results – Compressive Strength

- ASCM Mixtures



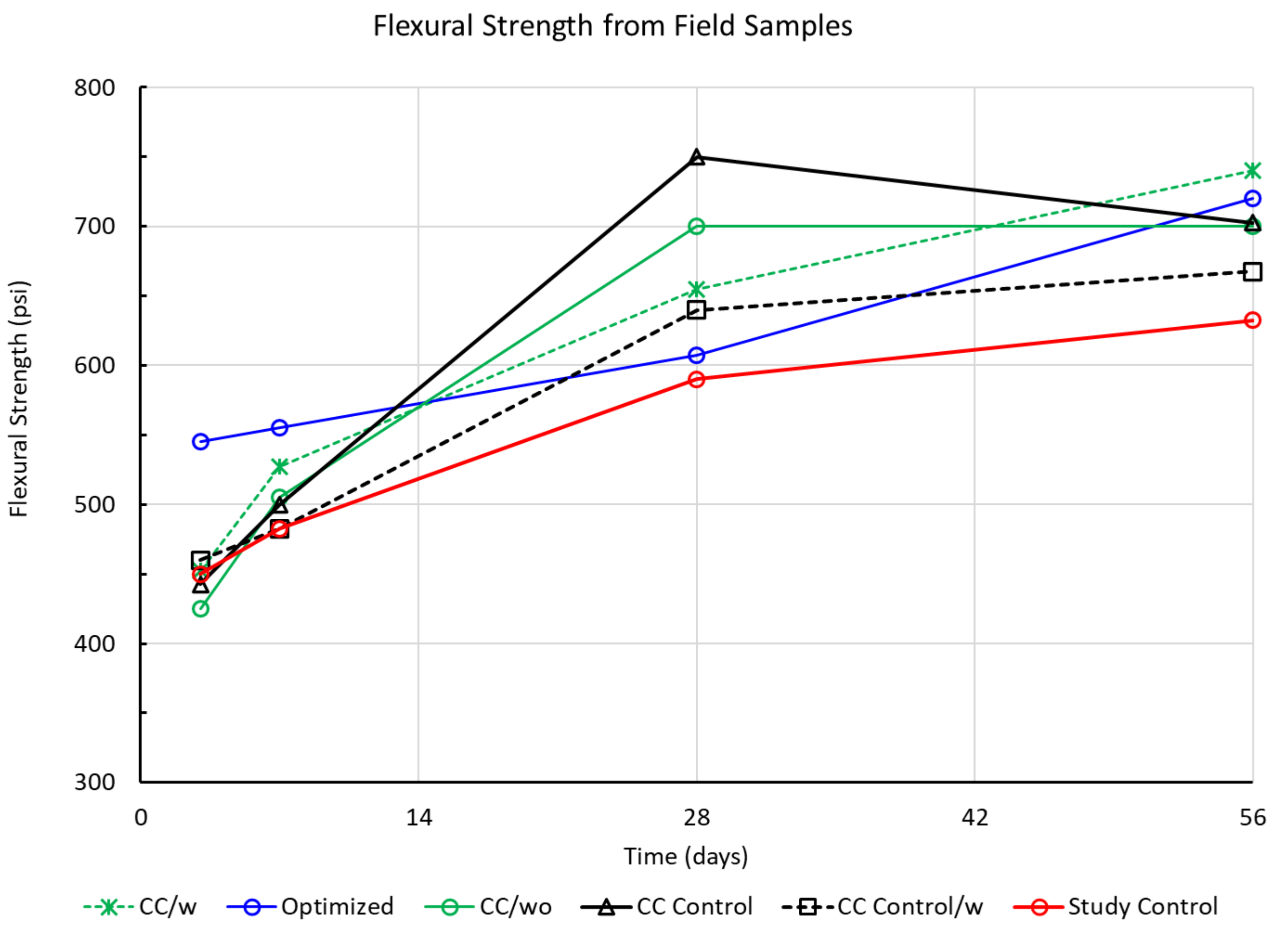
Preliminary Results – Flexural Strength

- Control Mixtures



Preliminary Results – Flexural Strength

- CarbonCure™ Mixtures



Preliminary Results – Flexural Strength

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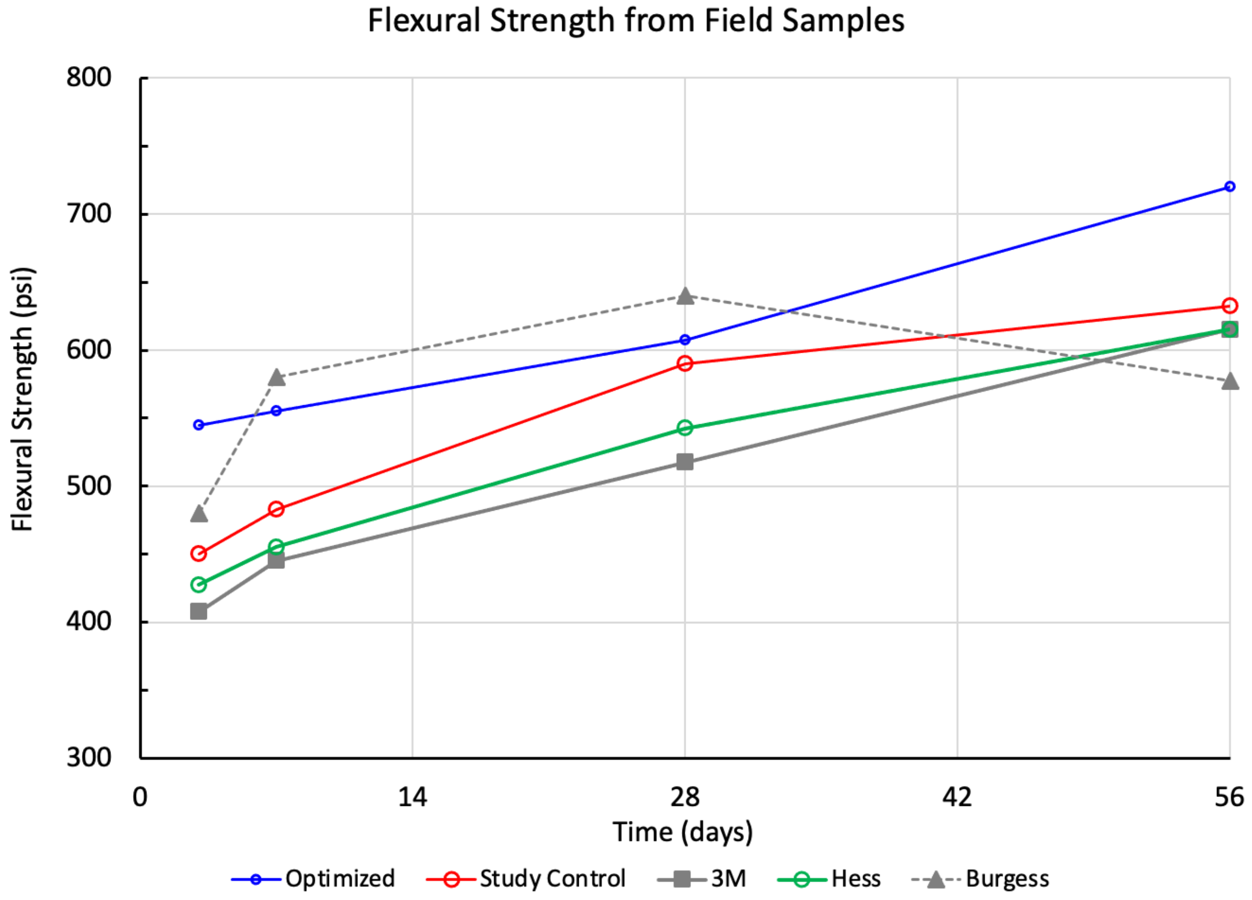
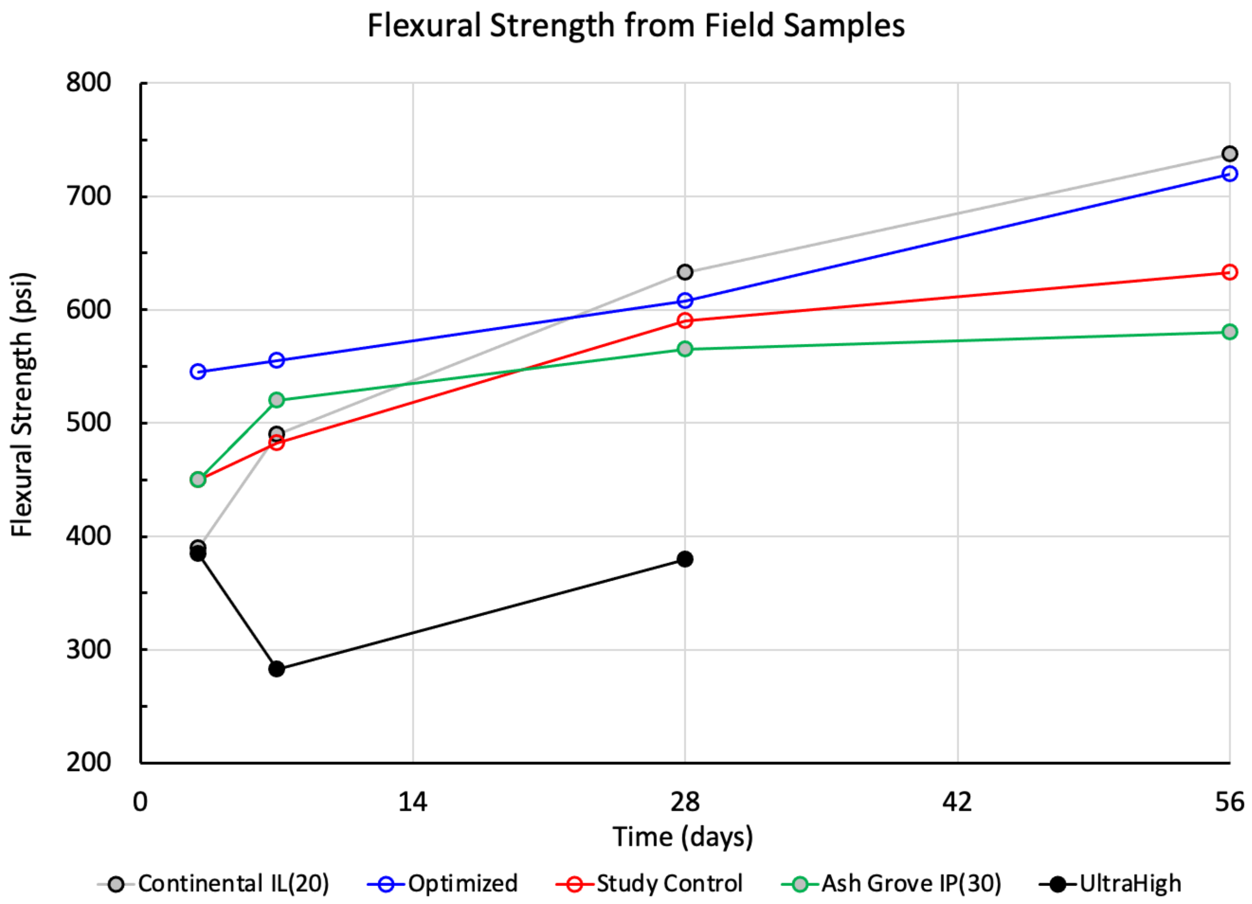


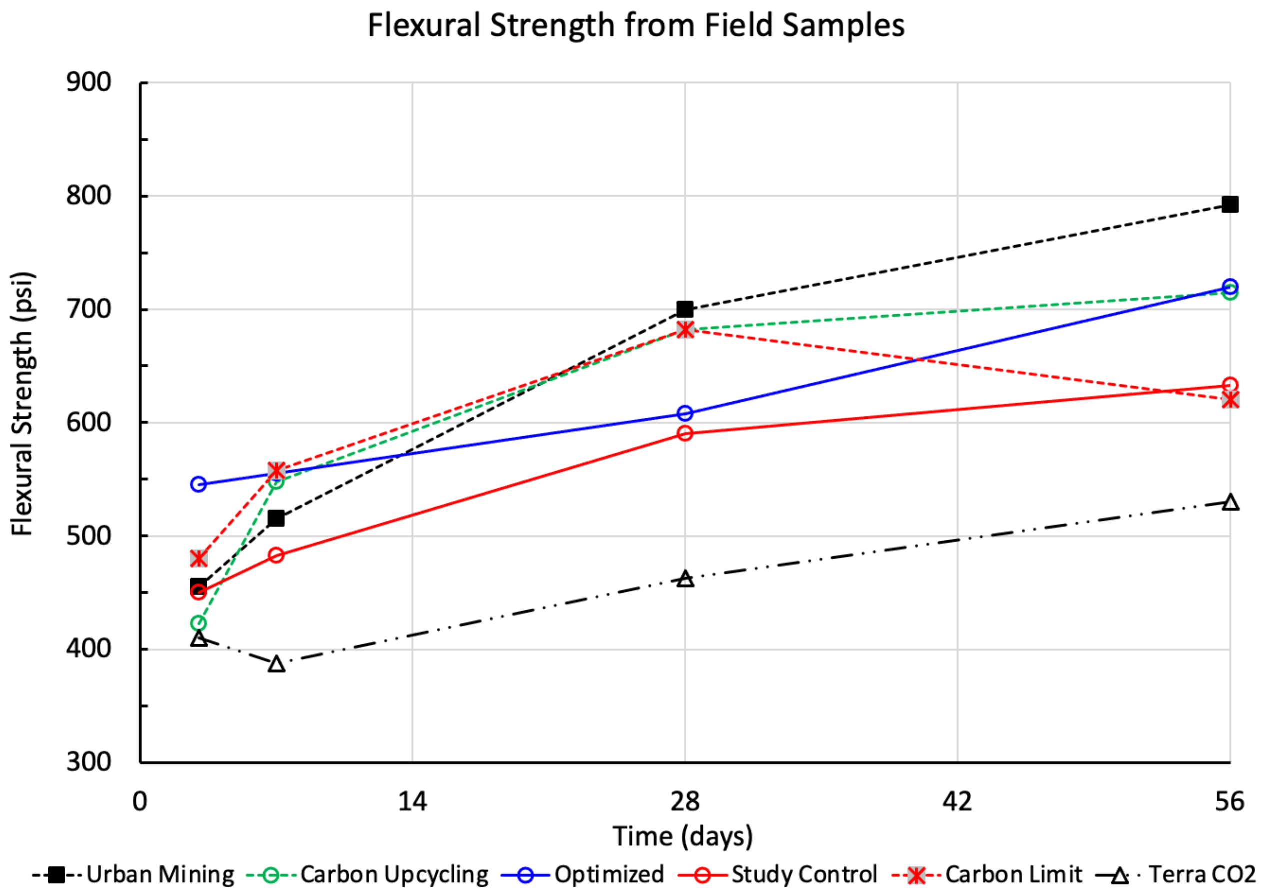
Preliminary Results – Flexural Strength

- Other Cements Mixtures



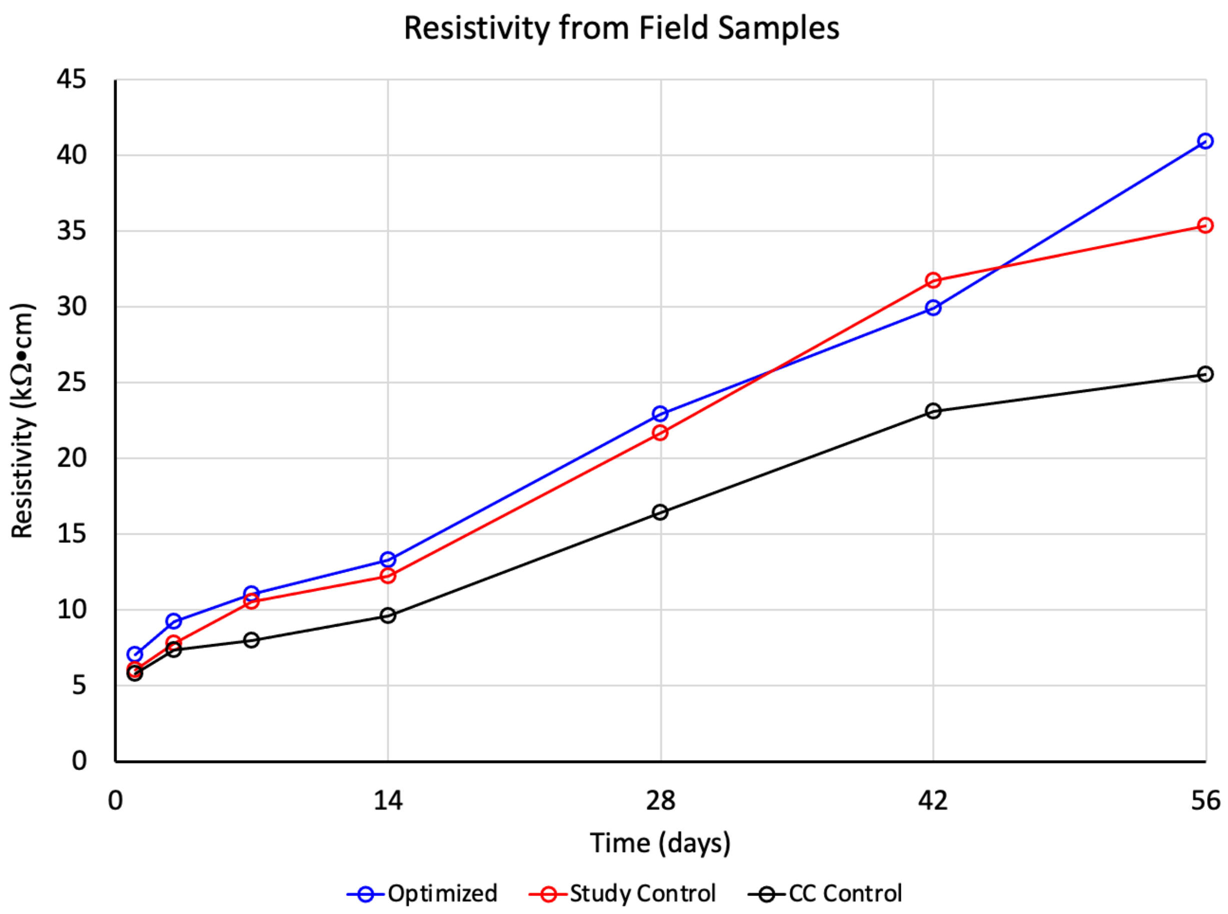
Preliminary Results – Flexural Strength

- ASCM Mixtures



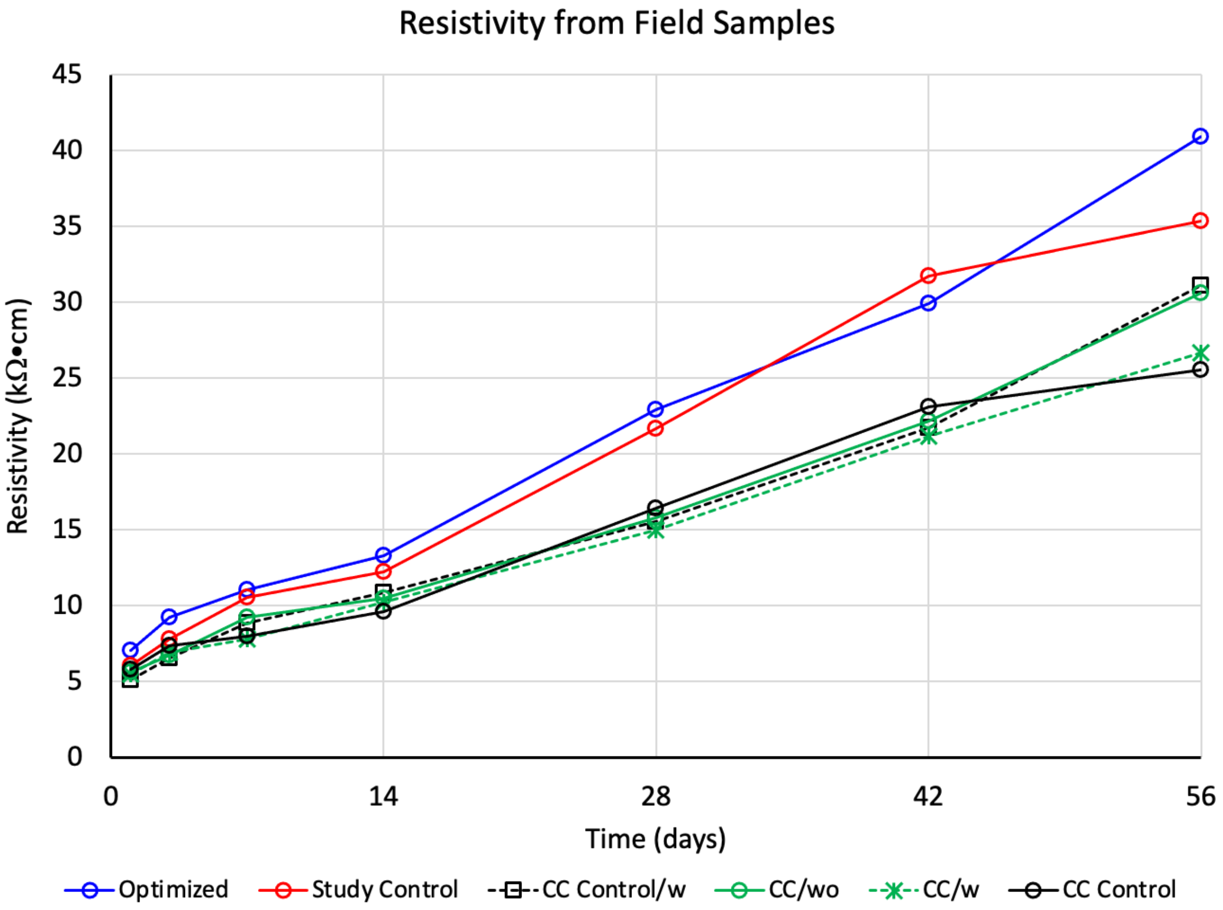
Preliminary Results – Resistivity

- Control Mixtures



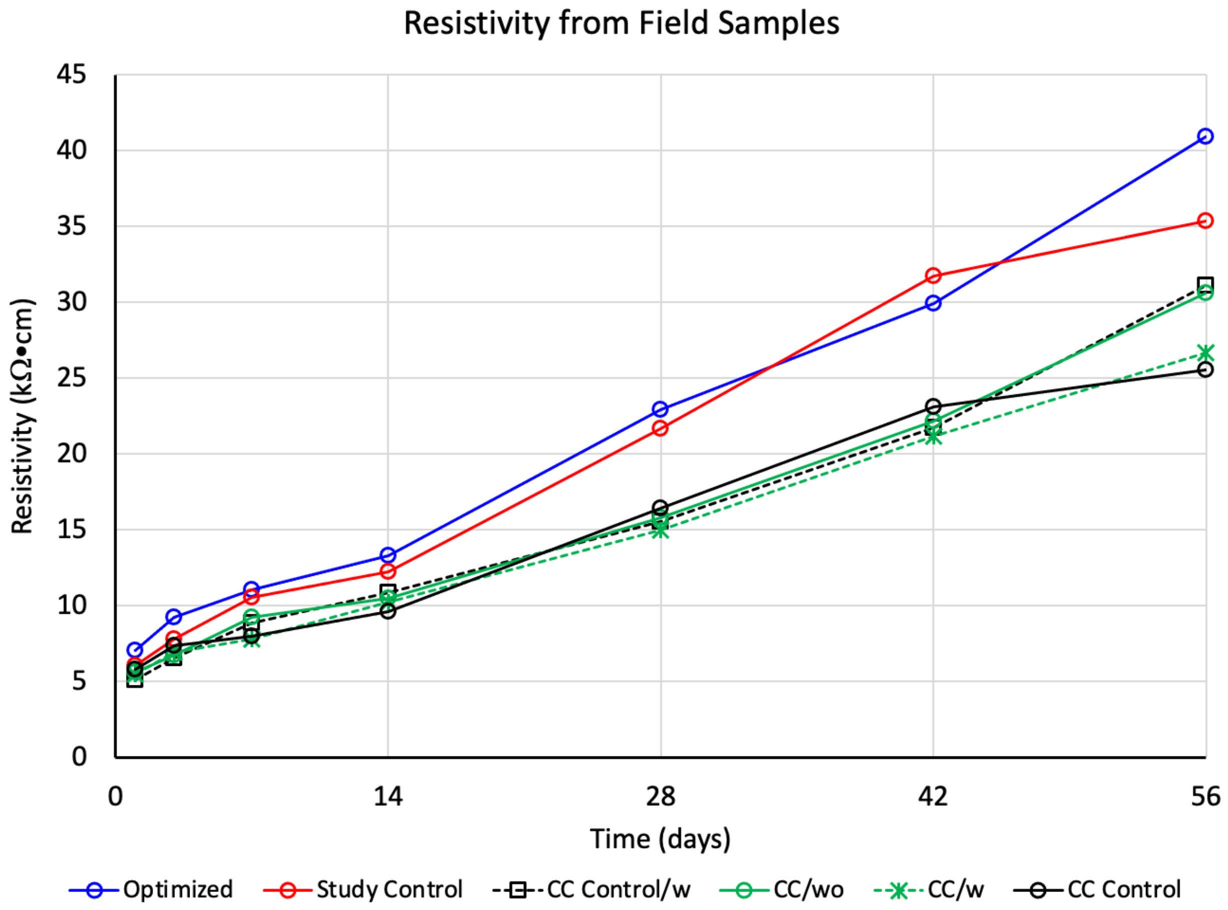
Preliminary Results – Resistivity

- CarbonCure™ Mixtures



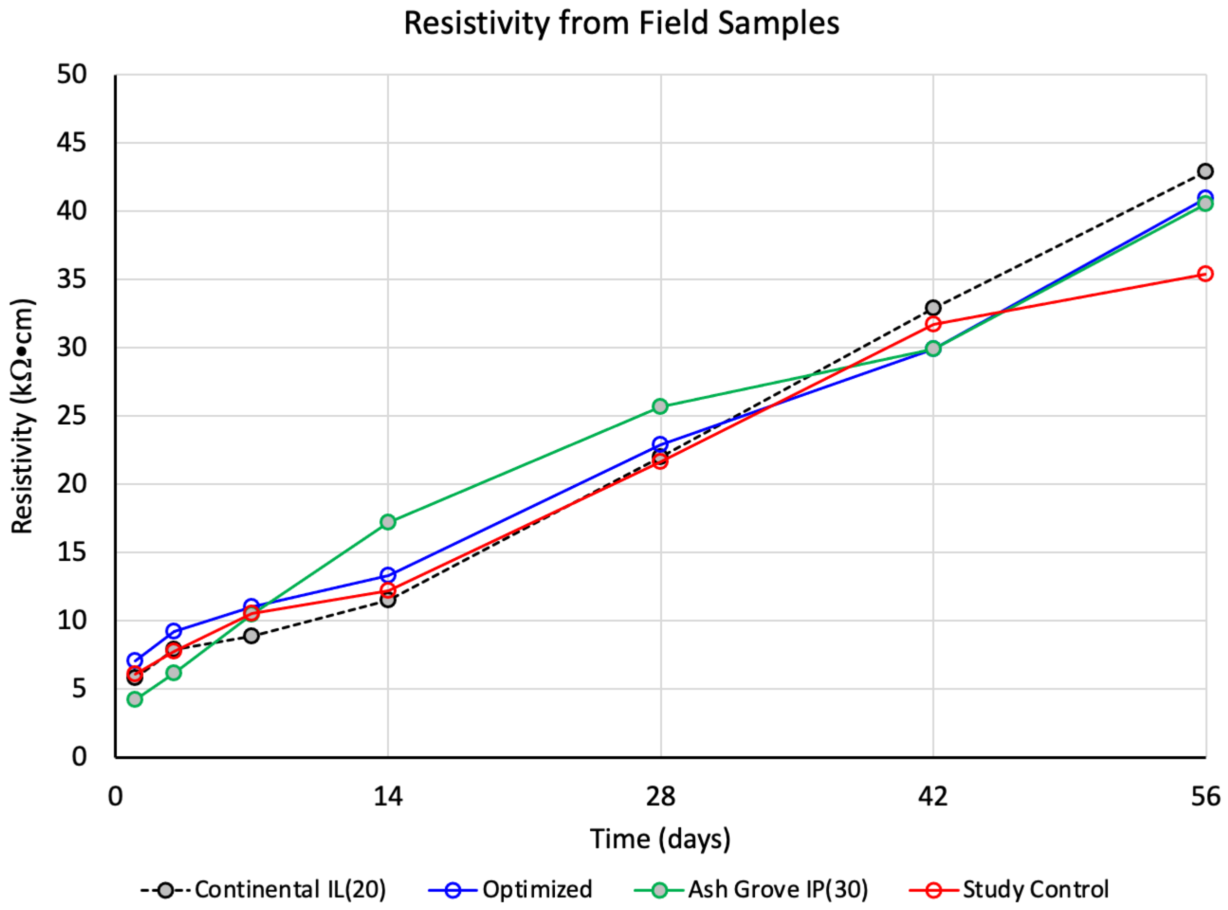
Preliminary Results – Resistivity

- Natural Pozzolan Mixtures



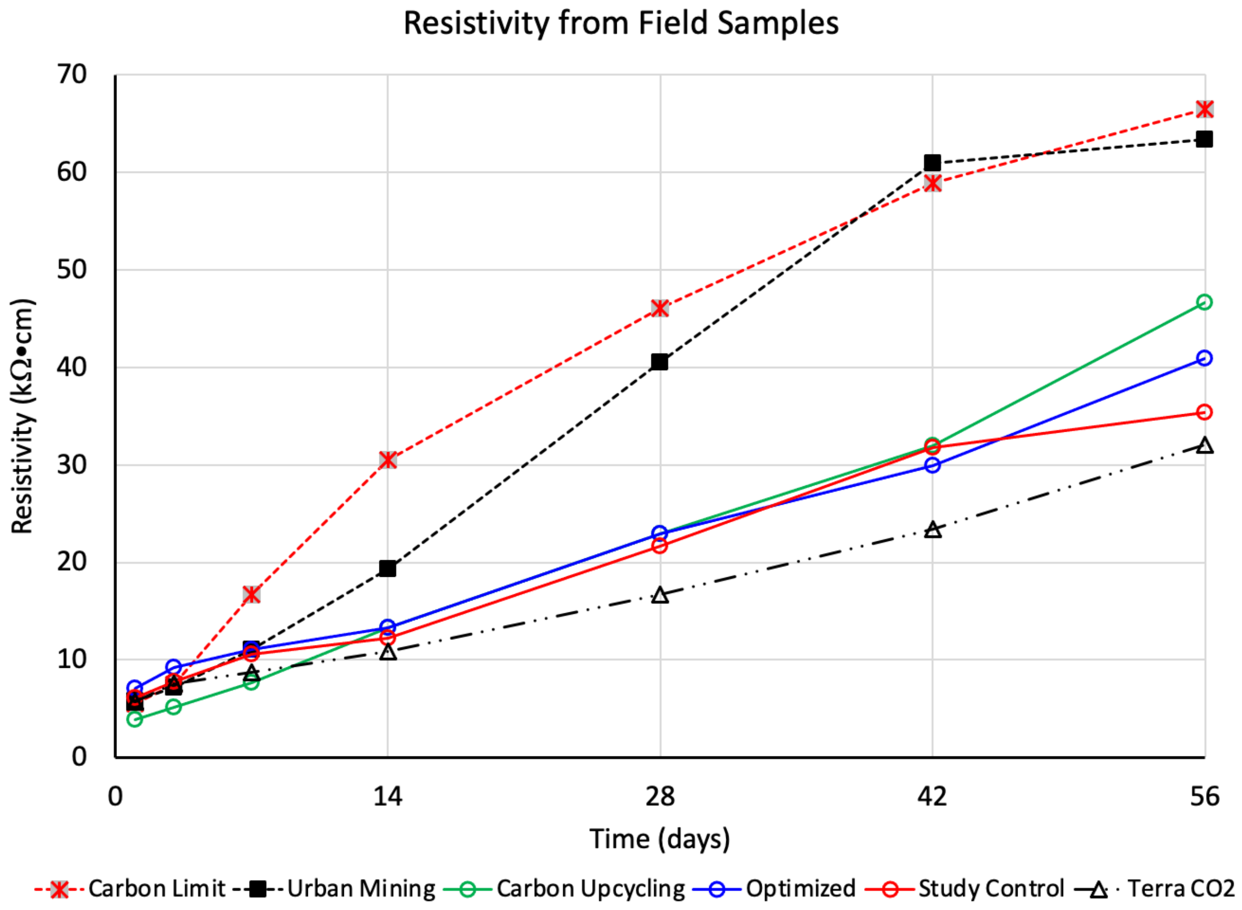
Preliminary Results – Resistivity

- Other Cements Mixtures



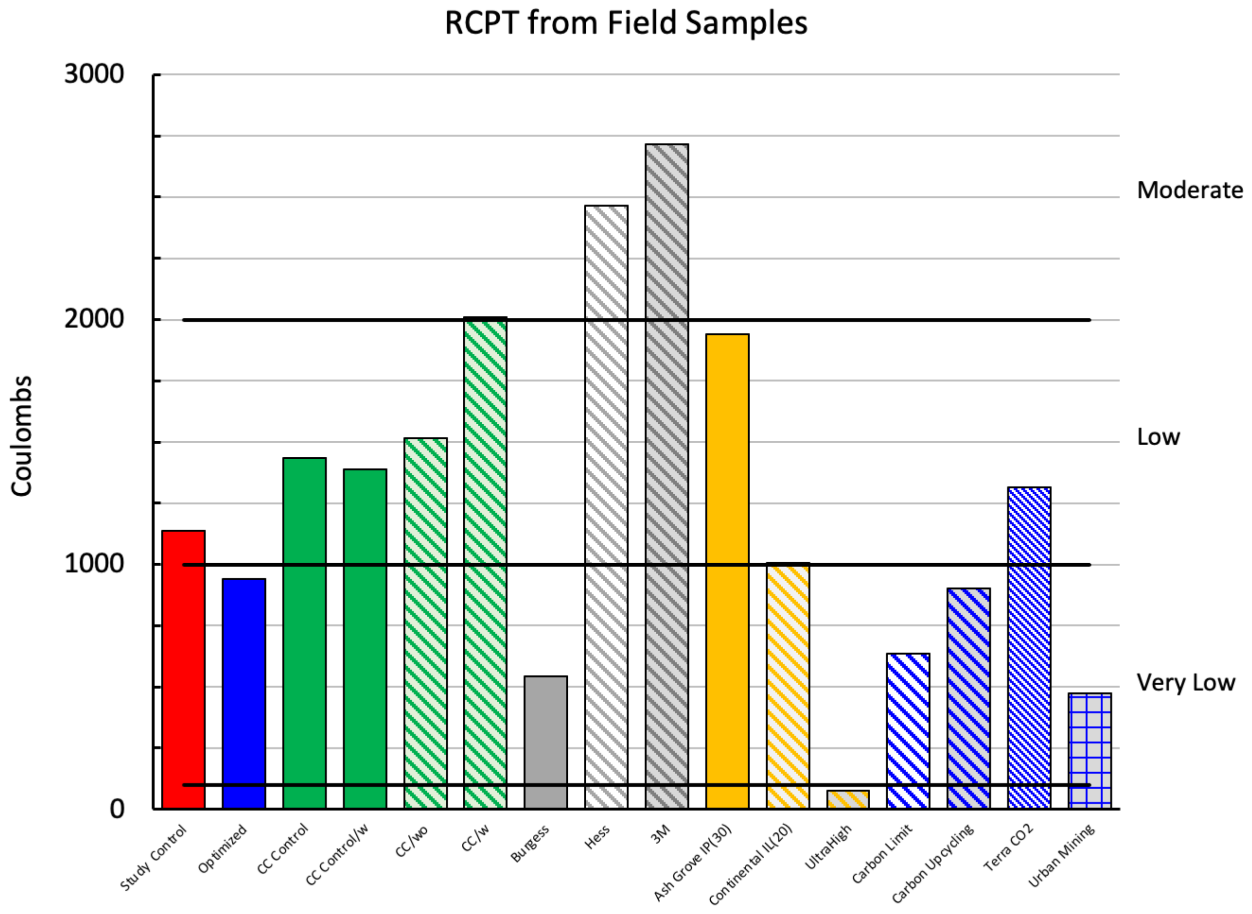
Preliminary Results – Resistivity

- ASCM Mixtures



Preliminary Results – RCPT

- All Mixtures



Closing Thoughts

- This MnROAD demonstration project is a critical step towards a transition to new materials for road and infrastructure construction
- Strong support from FHWA, MnDOT, and industry
- After construction is completed, performance will be monitored for three years under a separate contracts – Stay tuned!
- Preliminary results show good to excellent performance
- Notable: IL(20), Carbon Upcycling, Carbon Limit

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Questions?

llsutter@mtu.edu

or

sutter.engineering@gmail.com

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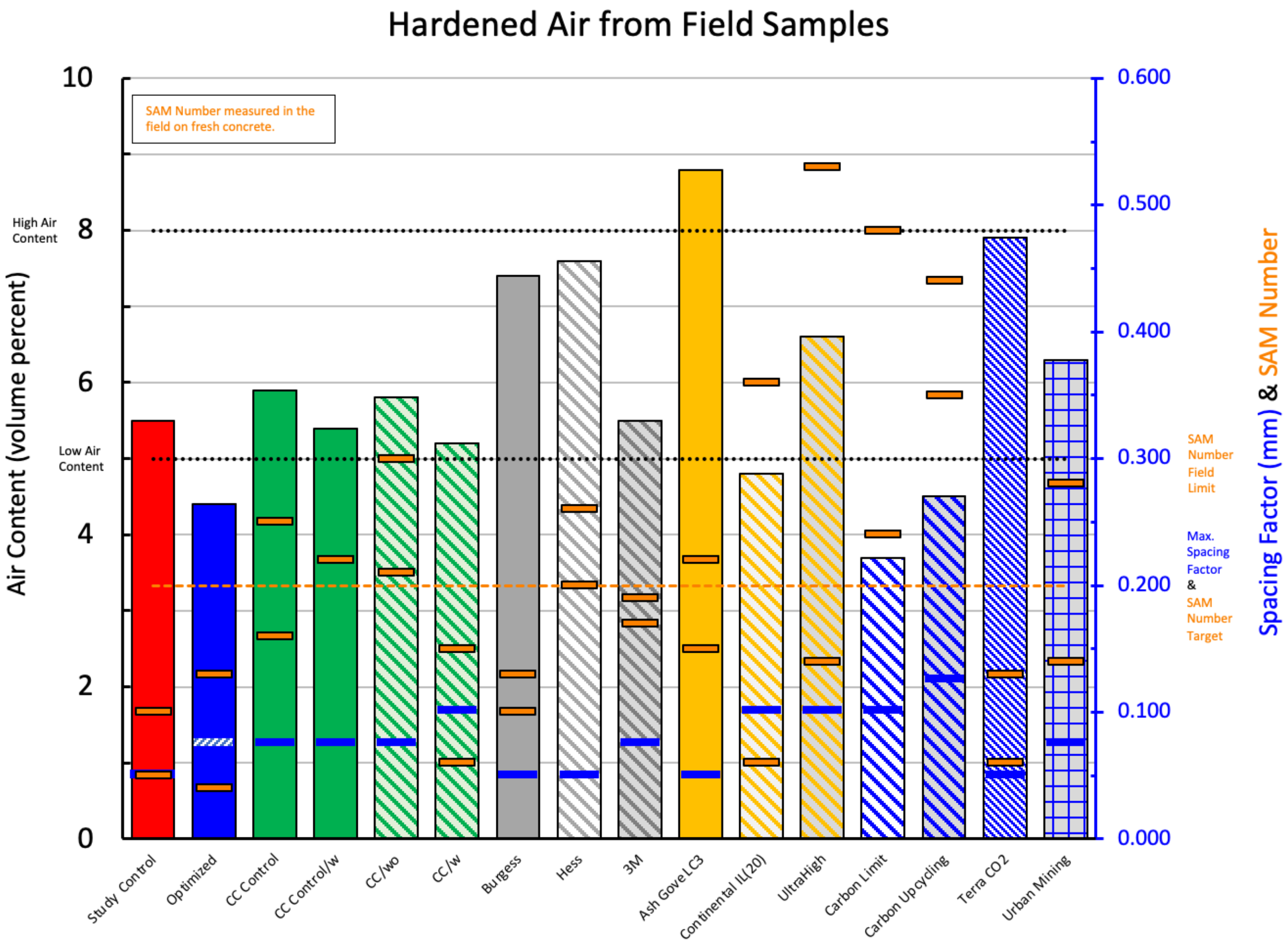
periculosum est tempus indoctus

All Mixtures

Preliminary Results – Air–Void System



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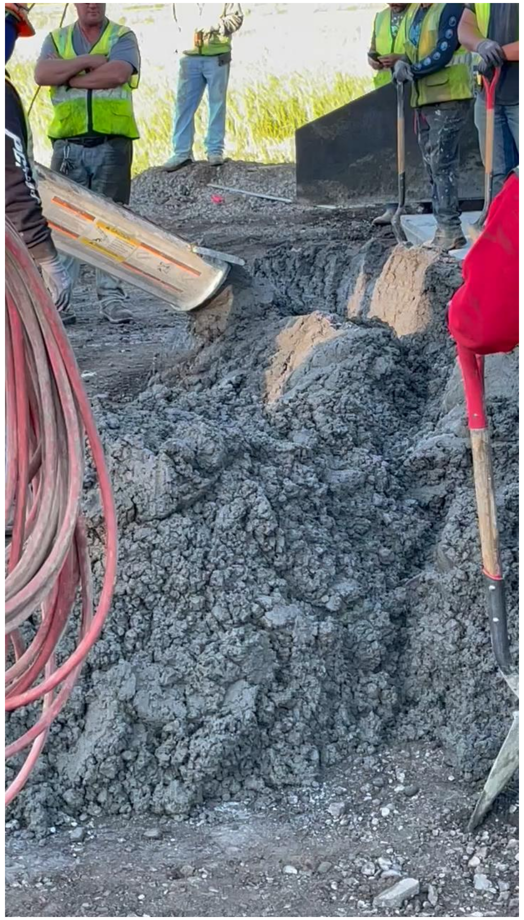
Some Inside Baseball…



- Carbon Upcycling
- Lowest total cementitious
- 500 pcy with 30% fly ash replacement

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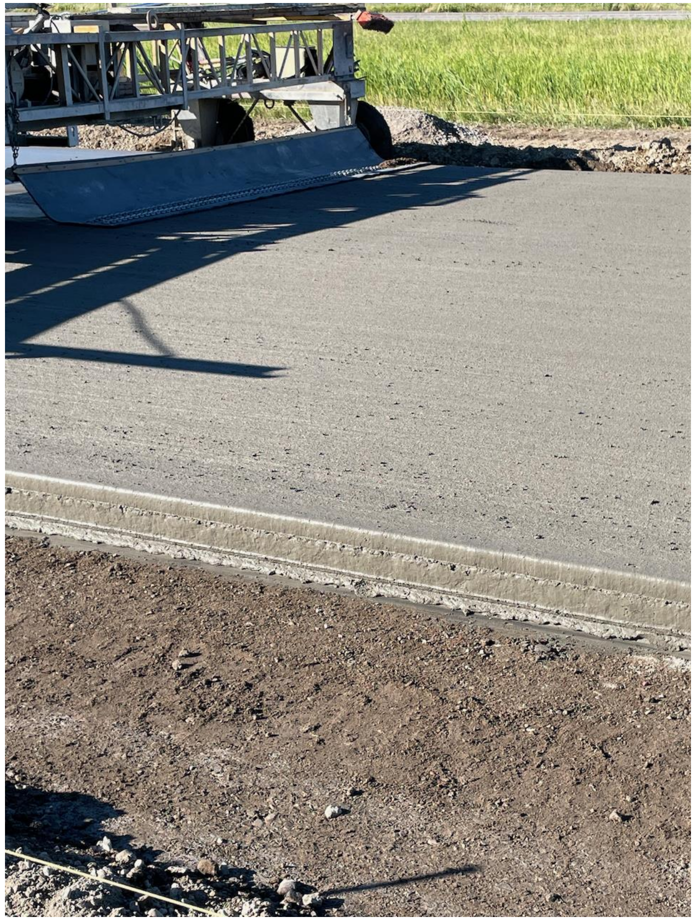

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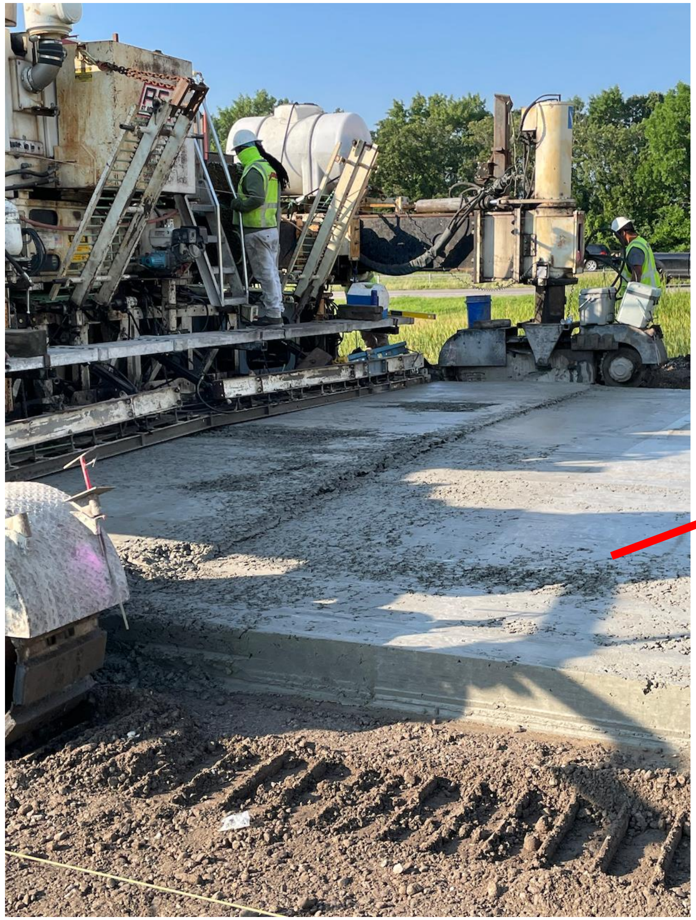

- GGP
- Batch plant left out the admixture package

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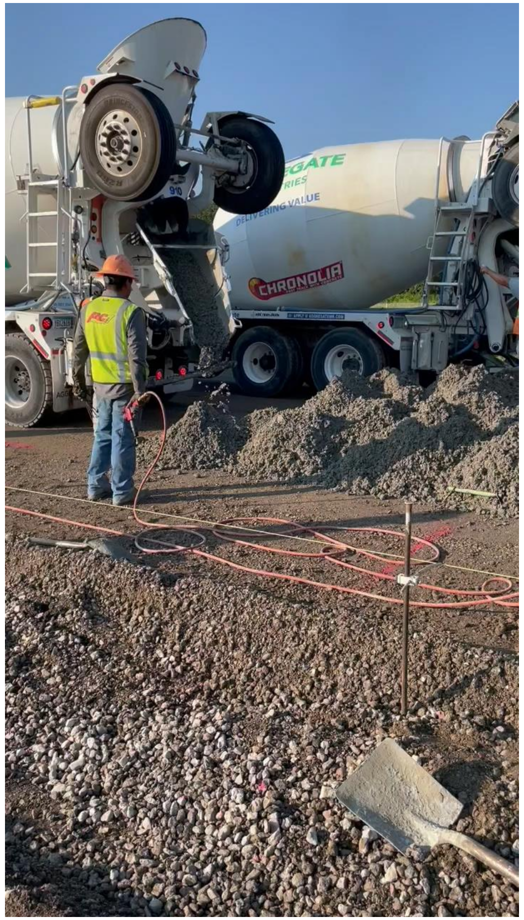
Some Inside Baseball…



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Some Inside Baseball…

- Metakaolin
- Extremely high water demand.
- Should have been blended with the fly ash but was added separately into the truck

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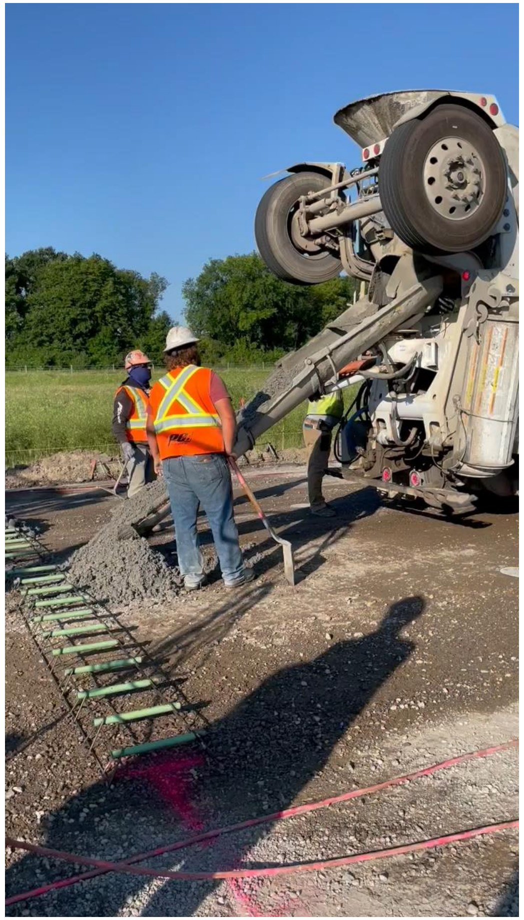
Some Inside Baseball…



- Metakaolin
- High water demand.
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Some Inside Baseball…

- Once dialed in it paved well

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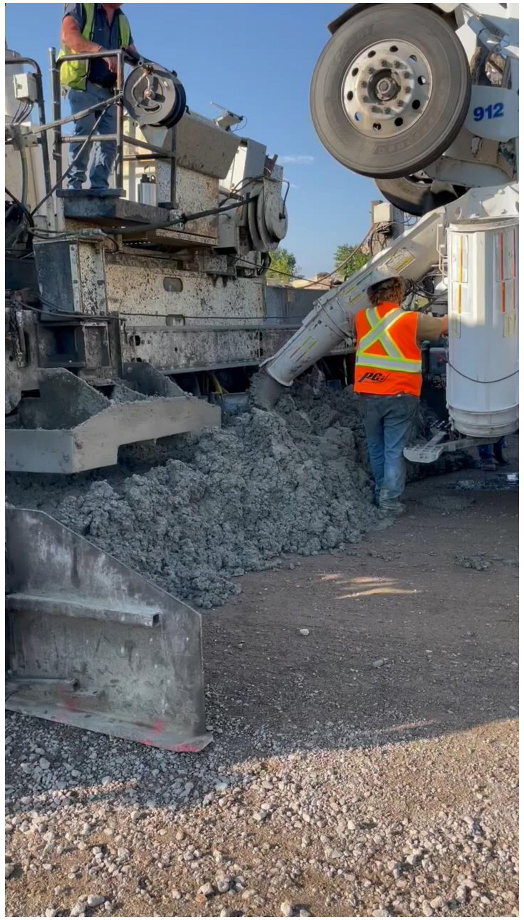
Some Inside Baseball…



- Carbon Limit
- Catalyst + Limestone + Natural Pozzolan

Some Inside Baseball…

- Dialed in (25 gal water added)

Some Inside Baseball…

- No Texture

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