Storing CO_2 in Built Infrastructure: CO_2 Carbonation of Precast Concrete Products

Award No. DE-FE0030684 (10/2017 – 09/2020)

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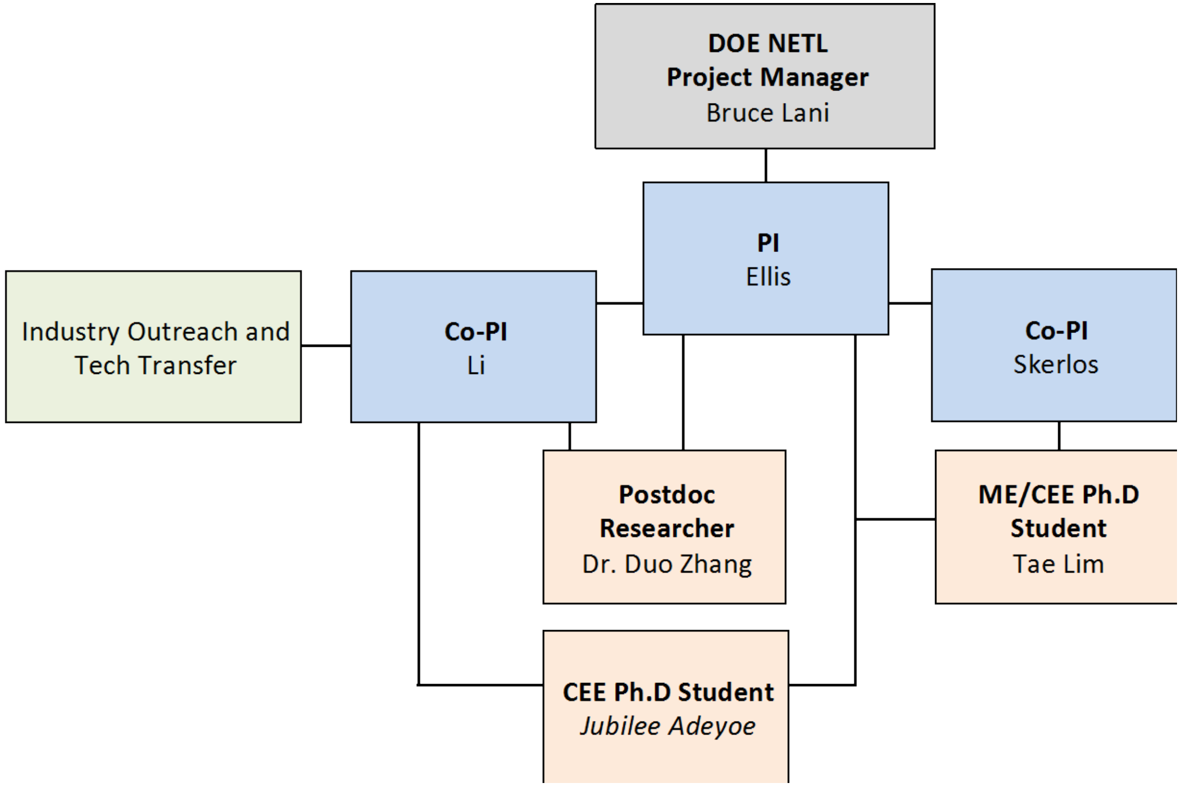
NETL Project Review Meeting, August, 2018

Project Overview



a. **Funding:**
- **DOE:** **$999,999**
- **Cost share:** **$250,000**

b. **Overall Project Performance Dates**
- **12/2017** **kickoff meeting**
- **10/2017 – 03/2019** **Budget period 1**
- **04/2019 – 09/2020** **Budget period 2**

c. **Project Participants**
- *Principal investigators*: Brian R. Ellis, Victor C. Li, Steven J. Skerlos
- *Post-doc research fellow*: Duo Zhang
- *Visiting scholar*: Alex Neves Junior
- *Graduate students*: Tae Lim, Jubilee Adeoye

d. **Overall Project Objective**
- To advance the technical understanding of CO_2 incorporation into novel cementitious materials for the development of high value products that provide a net reduction in carbon emissions.

Technology Background

Coal-fire power plants

Flue gas $\underline{CO_2}$

Fly ash

Carbonation Curing

Precast Industry

CO_2 + unhydrated cement

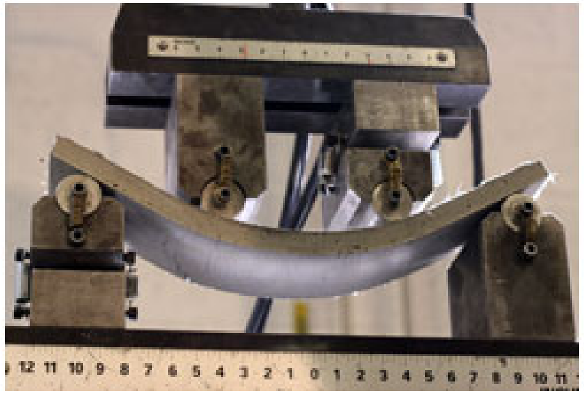
CO_2 + hydration products

Process optimization

Target product: **Railway ties**

- Faster production;
- Longer durability;
- Lower life-cycle cost

Novel Infrastructure Materials



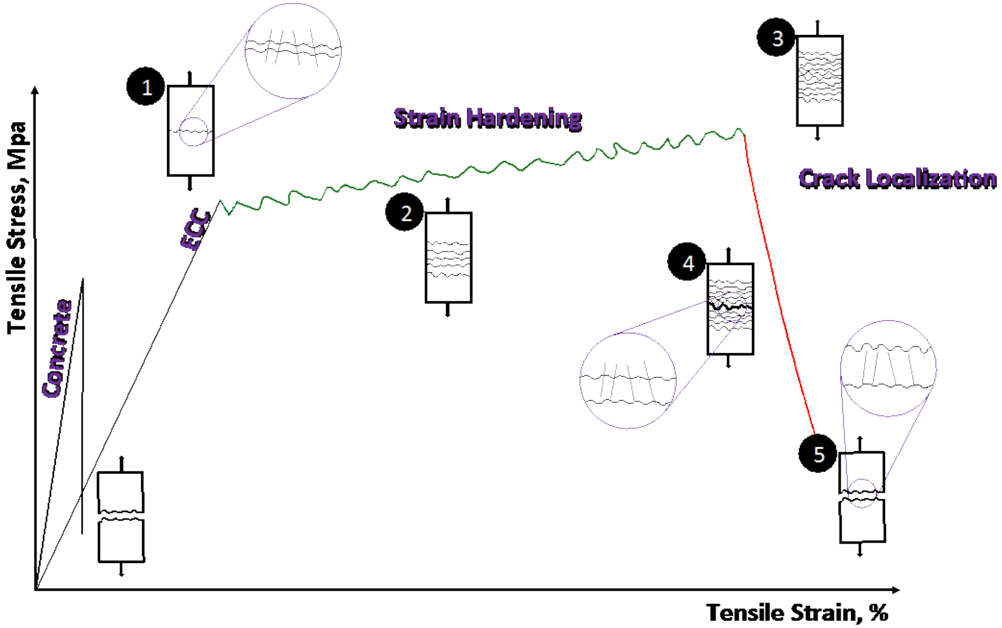
Engineered Cementitious Composite

Micromechanics modeling

Technology Background: Coupling CO_2 storage with novel cement materials to support sustainable infrastructure

Enhanced Cementitious Composite (ECC)

- Self-healing properties
- Controlled crack width < 50 μm
- ‘Bendable’ concrete
- Offers improved durability, longer lifetime of precast concrete products



Rail Ties as demonstration product

- Improve product lifetime (~50yr)
- No need for pre-stressed steel reinforcement, which has benefits from both a cost and longevity perspective

Project Scope & Current Status

Task 1: Project Management and Planning

Budget Period 1
10/2017 – 03/2019

Task 2
Development of carbonation process

In Progress

70% completed

- Bench-scale ECC materials carbonation curing *setup and process*;
- ECC with *carbonated waste-derived components*;
- *Optimization* of carbonation efficiency.

Task 3
Integration of precast ECC products

In Progress

30% completed

- *Mechanical* performance evaluation;
- *Macro-meso-micro-nano* characterization;
- *Durability* evaluation and improvement.

Budget Period 2
04/2019 – 09/2020

Task 4
Full-scale (railway tie) product integration

In Progress

10% completed

- Full-scale railway tie carbonation *setup and process*;
- *Laboratory performance* evaluation;
- *Field* performance test.

Task 5
Life-cycle CO_2 emissions analysis and TEA

In Progress

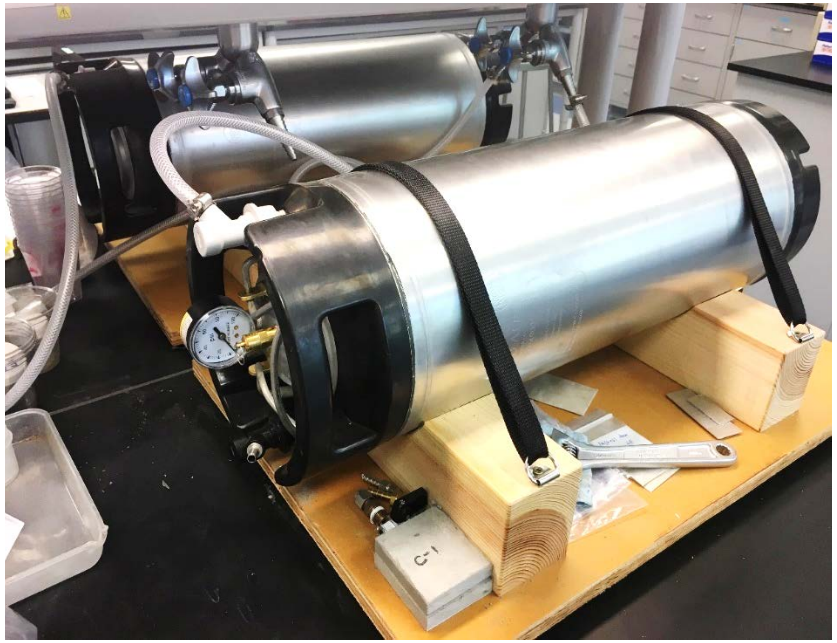
10% completed

- Separation of CO_2 from flue gas;
- *Life-cycle inventory* for carbonated ECC railway tie.

Progress - Task 2. Development of carbonation process

1. Carbonation setup

Setup 1: CO_2 pressure: 1-130 psi.



Can be heated up to 100 °C.

Setup 2: Ambient pressure

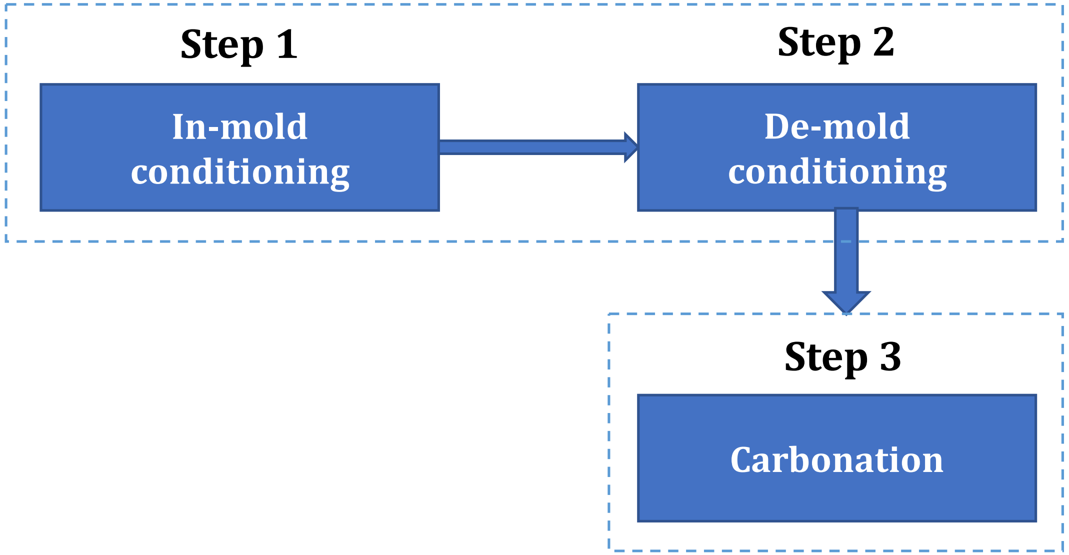
Designed for:

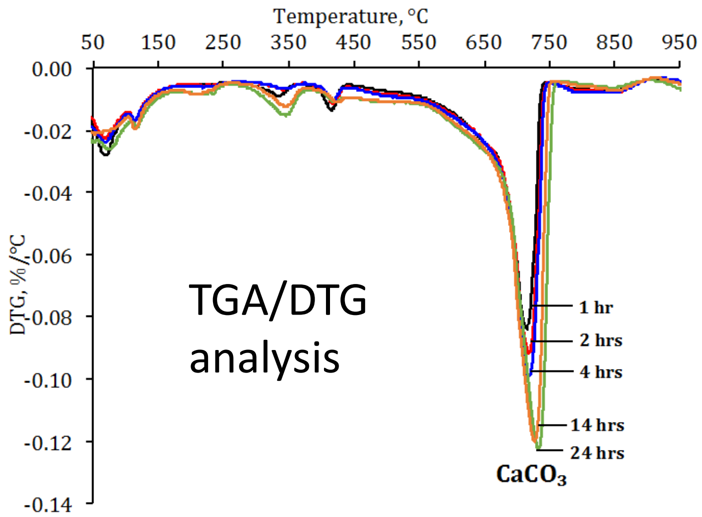
- All bench-scale ECC specimens, i.e., uniaxial tension, compression, 4-point bending, toughness measurements
- Raw materials carbonation
- Fresh ECC carbonation

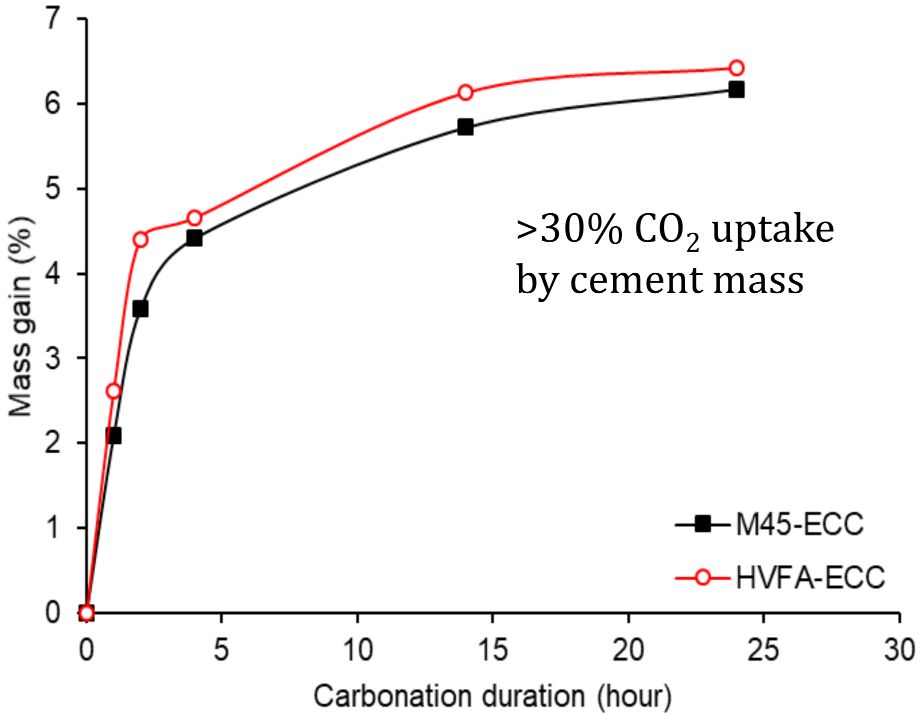
Progress - Task 2. Development of carbonation process

2. Carbonation curing process

ECC carbonation curing (optimal conditions for uniaxial tension specimens):







- Carbonation condition:
  Pure CO_2 gas, 75 psi pressure, 1-24 hours;
- Step 1-3 can be completed in 48 hours;

Progress - Task 2. Development of carbonation process

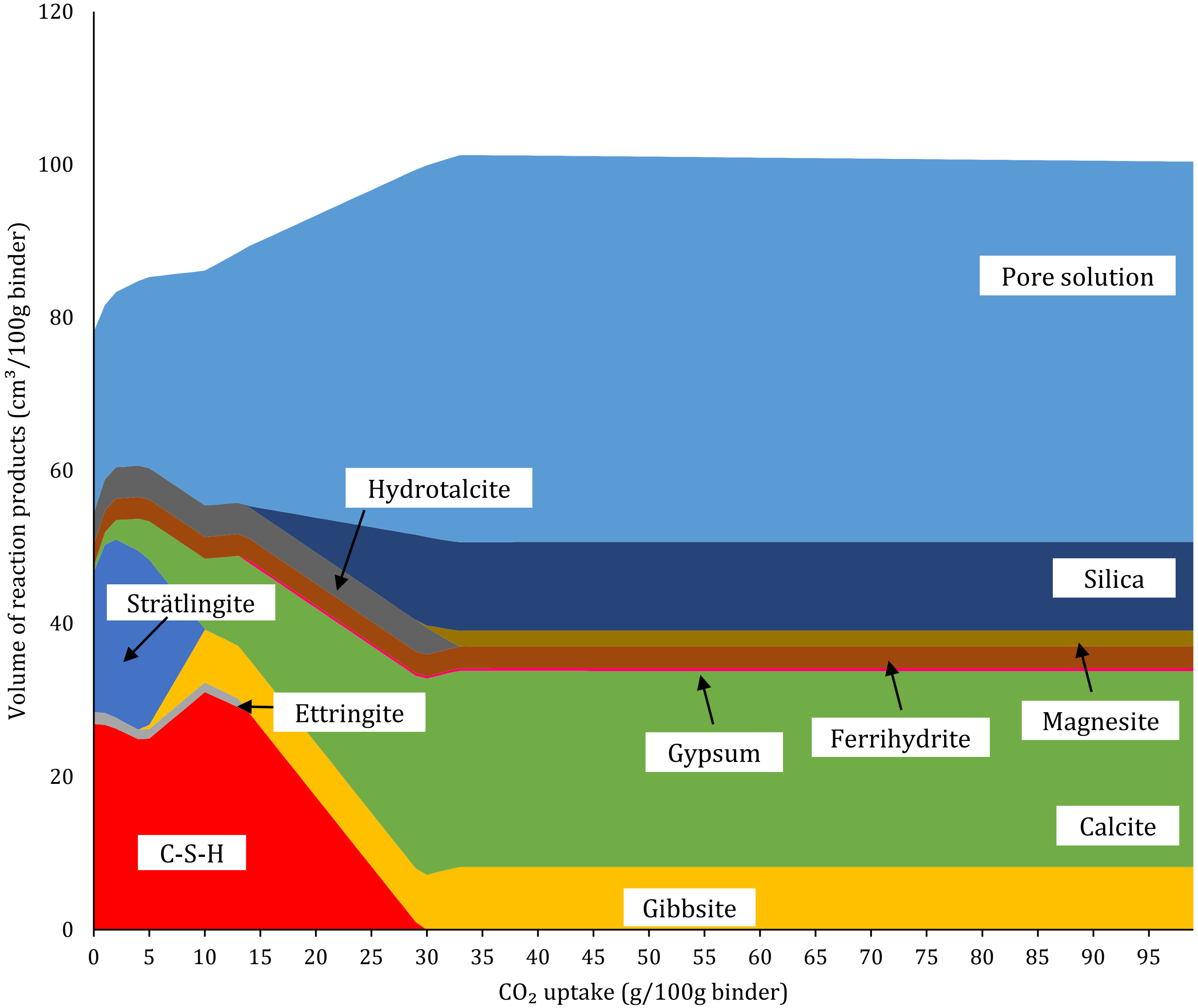
3. Thermodynamic modeling

Equilibrium state:

- CO_2 sequestration capacity is > 30% by cement mass, i.e., >14% by binder mass
- After reaching the max. carbonation degree, the reaction products include: gibbsite, calcite, magnesite, silica and ferrihydrite

To be further investigated with:

- Powder XRD
- Pore structure characterization
- ^{29}Si NMR on C-S-H and SiO_2



Progress - <u>Task 2</u>. Development of carbonation process

<u>4. Raw materials carbonation</u>

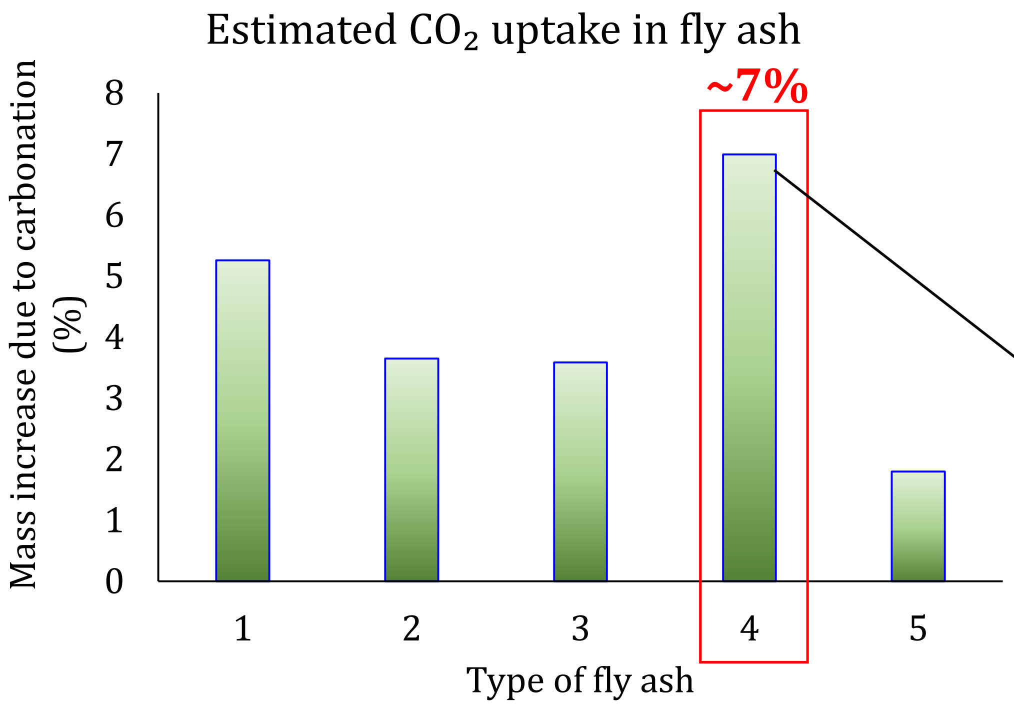
<u>Material source:</u>

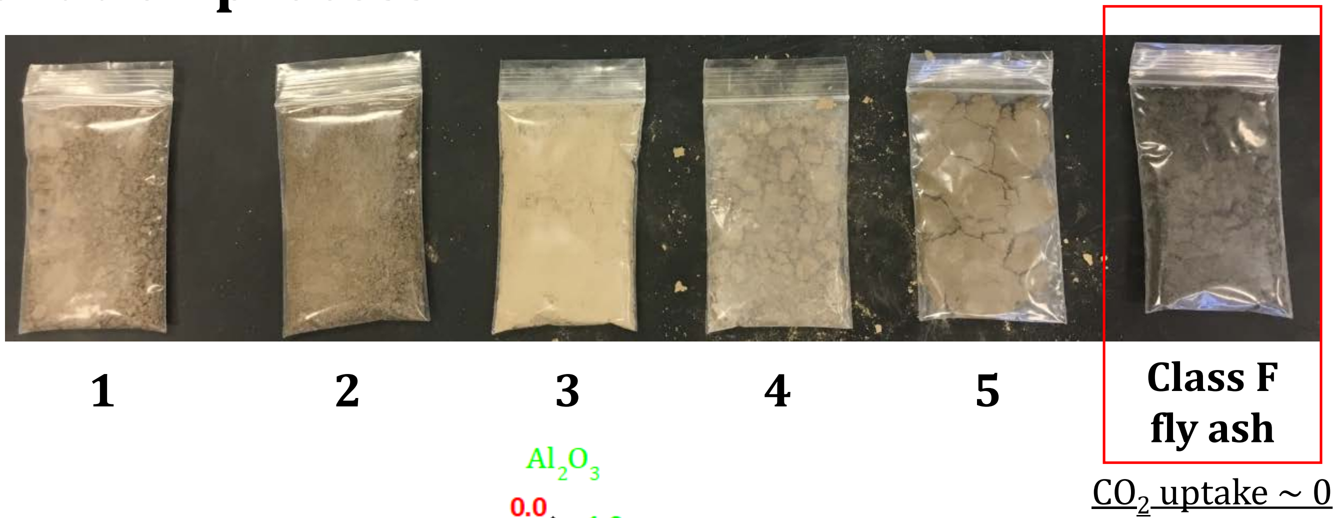
Carbonation reactivity of waste-derived materials largely varies on the source of materials

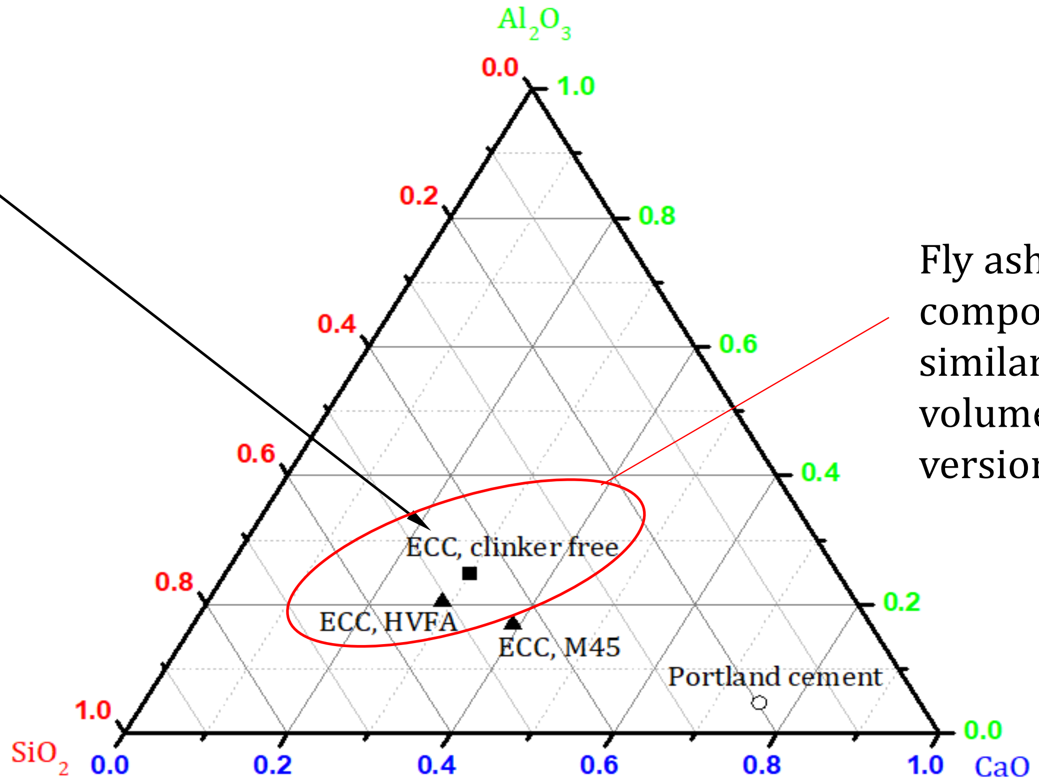
- Coal power plant: fly ash (high CaO)
- Coal power plant: fly ash (low CaO)
- Steel slag

Progress - Task 2. Development of carbonation process

5. Fly ash carbonation







Carbonation condition:

Pure CO_2, 75 psi, for 24 hours

Fly ash #4 shows compositional similarity to high-volume fly ash ECC version.

Progress - Task 2. Development of carbonation process

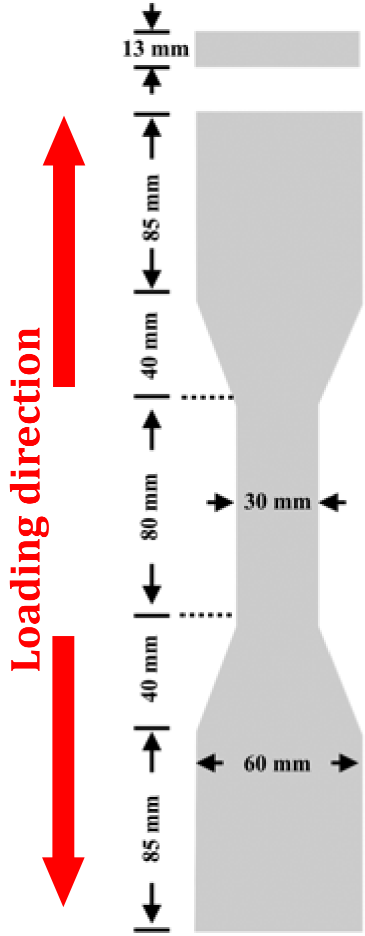
6. Steel slag carbonation

Sample ID	Slag 1	Slag 2
Moisture content	9.8%	3.2%
CO_2 uptake, by mass	7.7%	1.9%

- Steel slag will be further investigated and optimized for contribution to bonding strength
- Carbonated slag could potentially be used as alternative to sand in ECC

Progress - Task 3. Integration of precast ECC products

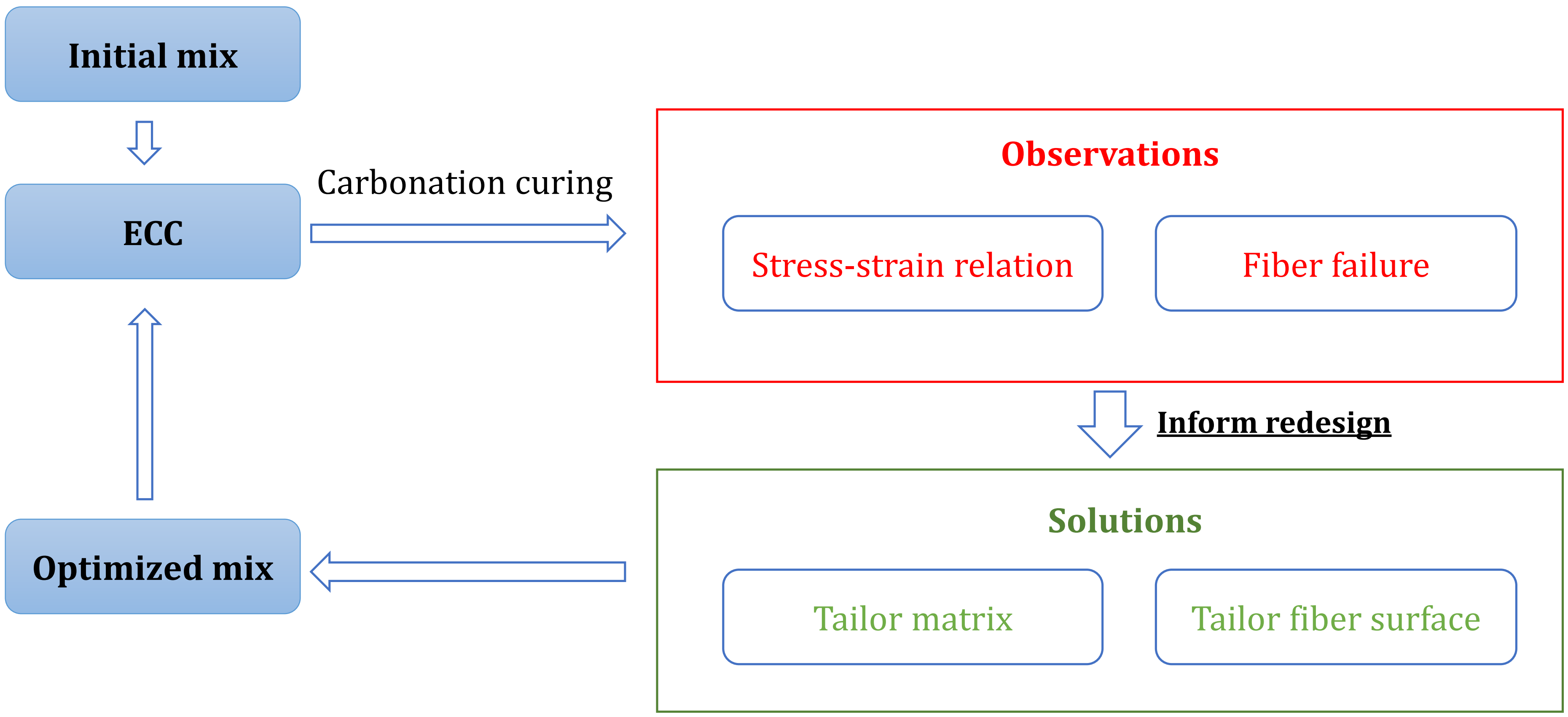
1. Mechanical performance



- Testing age: early (48 hours) and 28 days
- Uniaxial tension loading rate: 0.5mm/min

Progress - Task 3. Integration of precast ECC products

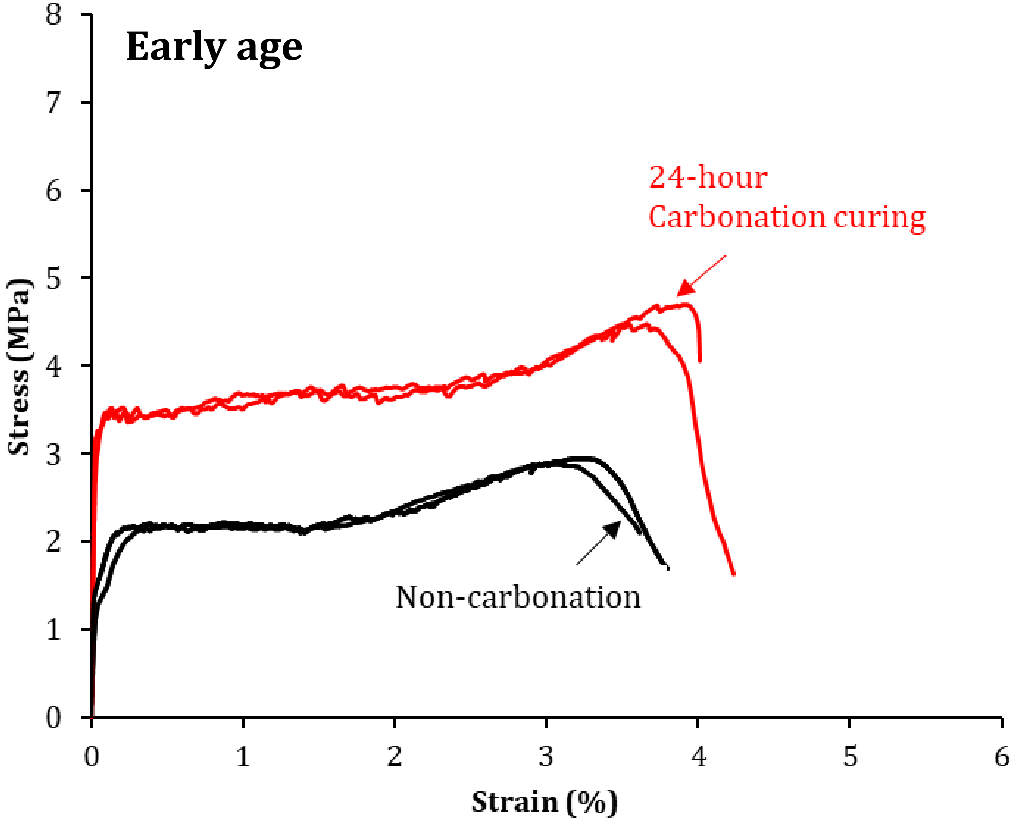
1. Mechanical performance

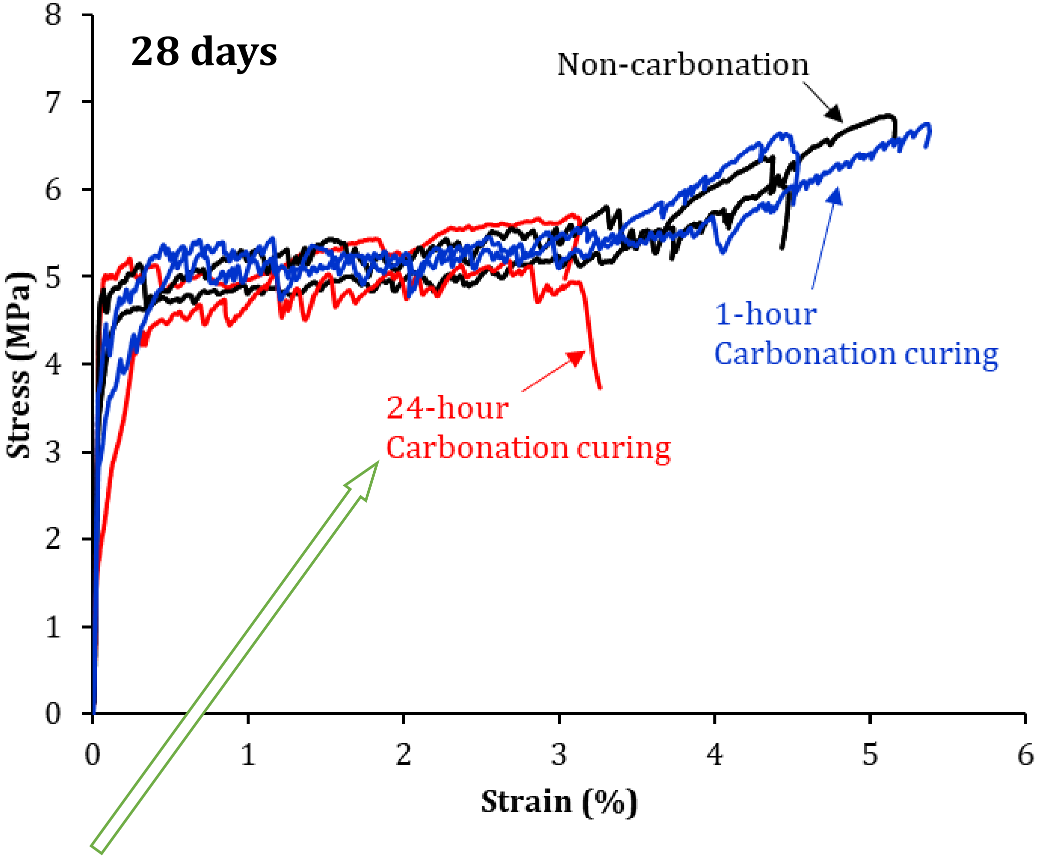


Progress - Task 3. Integration of precast ECC products

1. Mechanical performance

Conventional ECC carbonation at early age and 28 days.



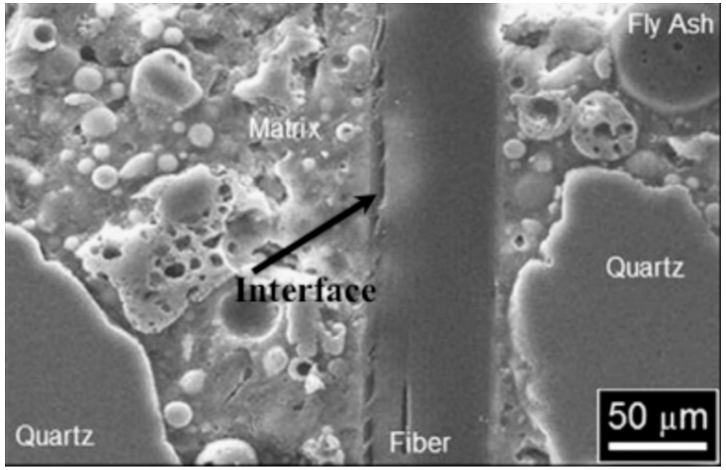


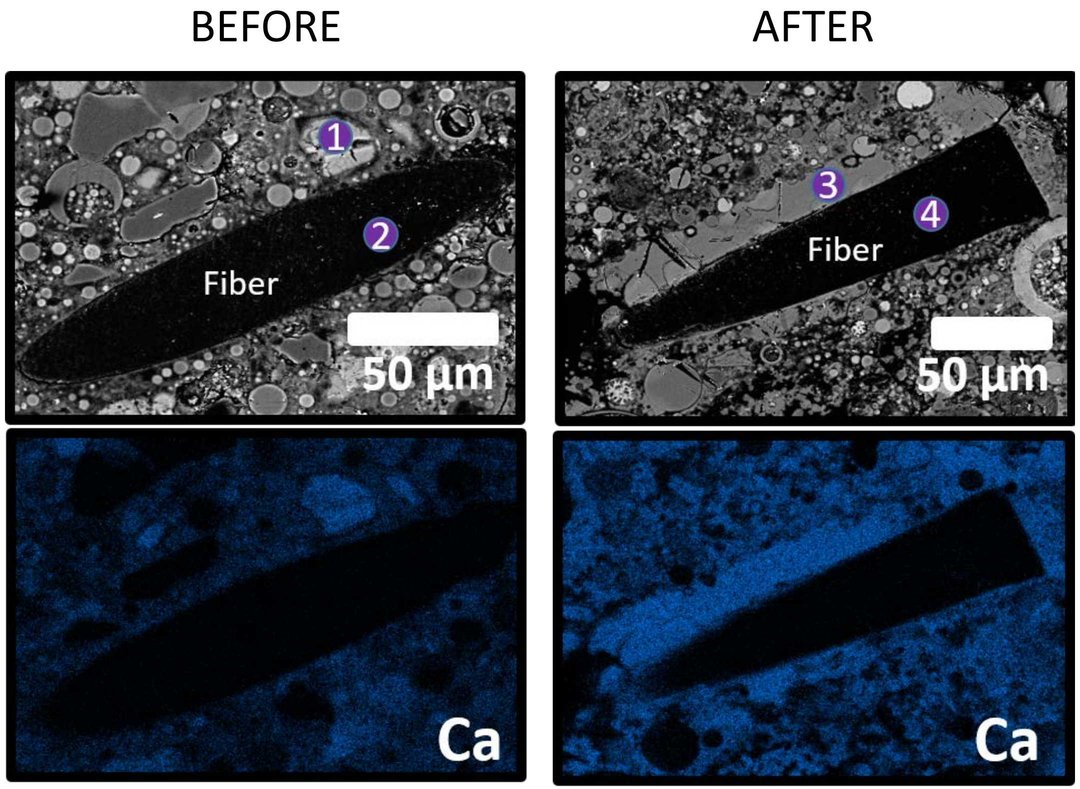
- Carbonation curing accelerates early-age development of tensile strength and strain capacity.
- At 28 days, carbonation-cured ECC achieves comparable tensile strength but slightly lower tensile strain capacity.

Progress - Task 3. Integration of precast ECC products

1. Mechanical performance

- **Evaluation of fiber-matrix interface after carbonation demonstrates densification**





Progress - Task 3. Integration of precast ECC products

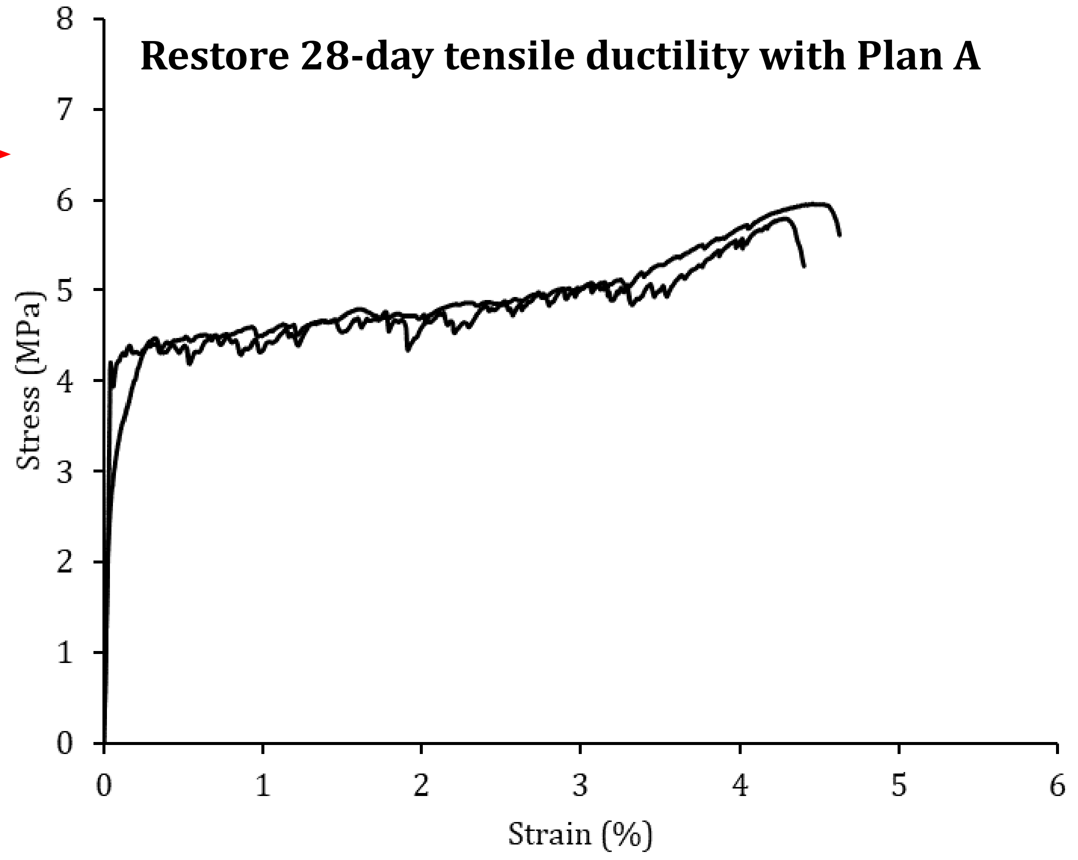
1. Mechanical performance

To restore tensile ductility at 28 days, we attempted:

A. Incorporation of artificial flaws
B. Incorporation of high volume fly ash
C. Incorporation of MgO mineral
D. Fiber surface modification

Plan A proved to be the most effective approach to restore tensile ductility of carbonation-cured ECC

Compressive strength:	**50 MPa**
Ultimate tensile strength:	**5.8 MPa**
Tensile strain capacity:	**4.5% > 2% (proposed goal)**



Progress Summary

1. ***Equipment***
    - Laboratory setups for carbonation at:
        - atmospheric pressure
        - up to 130 psi
    - TGA/DSC
    - Full-scale carbonation chamber: in progress
2. ***Carbonation process***
    - Developed optimal carbonation condition (within 48 hours) and achieved ~30% CO_2 uptake
3. ***Performance evaluation***
    - Mechanical properties (ECC-M45):
        - Tensile strength: accelerated by carbonation curing at early age
        - Tensile strain capacity (28 days): slightly reduced by carbonation curing but restored through using artificial flaw (>4%)
    - New classes of ECC:
        - Fly ash-based ECC
        - MgO-based ECC
    - Chemical analysis:
        - Raw materials compositions
        - CO_2 uptake and phase identification through TGA, XRD and SEM

Next Steps

Year 2: 10/2018 – 09/2019

Task 1: Project Management and Planning

Task 2
Development of carbonation process

Current: 70% completed

Target: 100% completed

- To complete development of ECC with carbonated ingredients;
- To complete thermodynamic and reactive transport modeling.

Task 3
Integration of precast ECC products

Current: 30% completed

Target: 100% completed

- To finalize microstructural characterization;
- To complete durability evaluation.

Task 4
Full-scale (railway tie) product integration

Current: 10% completed

Target: 65% completed

- To build full-scale chamber;
- To complete mechanical testing.

Task 5
Life-cycle CO_2 emissions analysis and TEA

Current: 10% completed

Target: 55% completed

- To finalize ECC railway tie LCA/LCC inventory.

Thank you!

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