Low-cost Accelerator and Strength Enhancer for Cement Mortar Produced by Regulating the Carbonation of Lime Slurry

Presenter: Madeline Owens
Co-authors: Christie Arrington, Sofia Palonen, Monica Amaral, and Jialai Wang

Department of Civil, Construction, and Environmental Engineering
The University of Alabama, Tuscaloosa

ACI Fall Convention – Philadelphia, PA
November 2024

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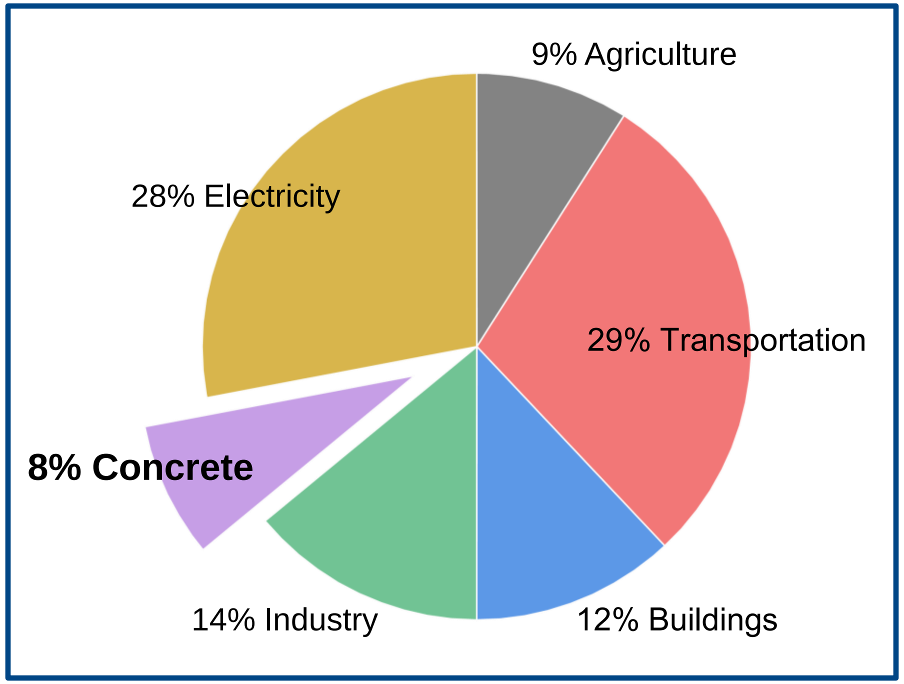
Problem Statement

Concrete is the **most used** construction material → 14 billion m^3/year

$440 billion/year



Global CO_2 emissions per sector

Concrete has a **carbon problem**

- Production of 1 lb cement ≈ 0.9 lb of CO_2
- Cement industry is responsible for 8% of global emissions caused by humans

Concrete production is **wasteful**

- 6% waste concrete (24 million yd^3/year)
- 191 lb/yd^3 washing water
- **$4 billion missed opportunity!**

Concrete as CO_2 sink

The massive volume of concrete used in construction offers one of the **largest** sinks for CO_2

CO_2 precipitates as $CaCO_3$ once in contact with calcium present in both

- Cement clinker – alite (C_3S) and belite (C_2S)
- Hydration products – calcium hydroxide (CH) and calcium silicate hydrate (C-S-H)

$$Ca^{2+}_{(aq)} + CO_3^{2-}{}_{(aq)} \rightarrow CaCO_{3\ (s)}$$

$CaCO_3$ is incorporated into the matrix

- Permanent storage of CO_2 in concrete

Utilizing CO_2 in Concretes

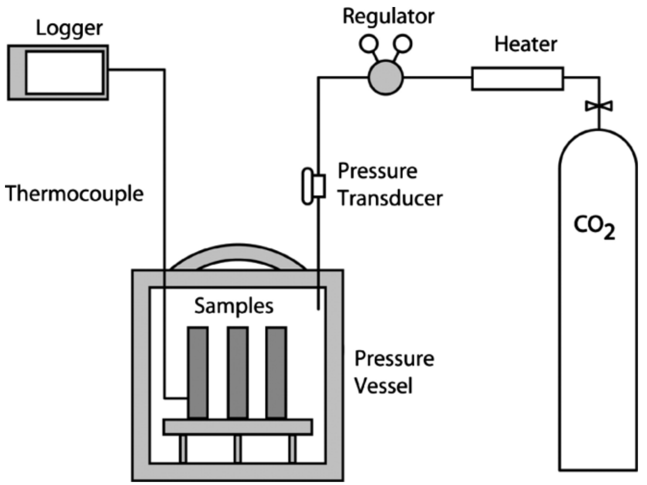
Carbonation Curing

- Replacing water/steam with purified CO_2 for curing **after** concrete mixing

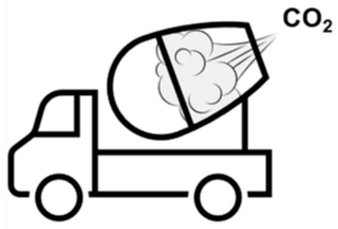
Improved strength at early-age

Limited applicability

→ Small members like concrete blocks
→ Precast (chamber required)



Utilizing CO_2 in Concretes



Mixing Carbonation

- Injecting purified CO_2 **during** concrete mixing

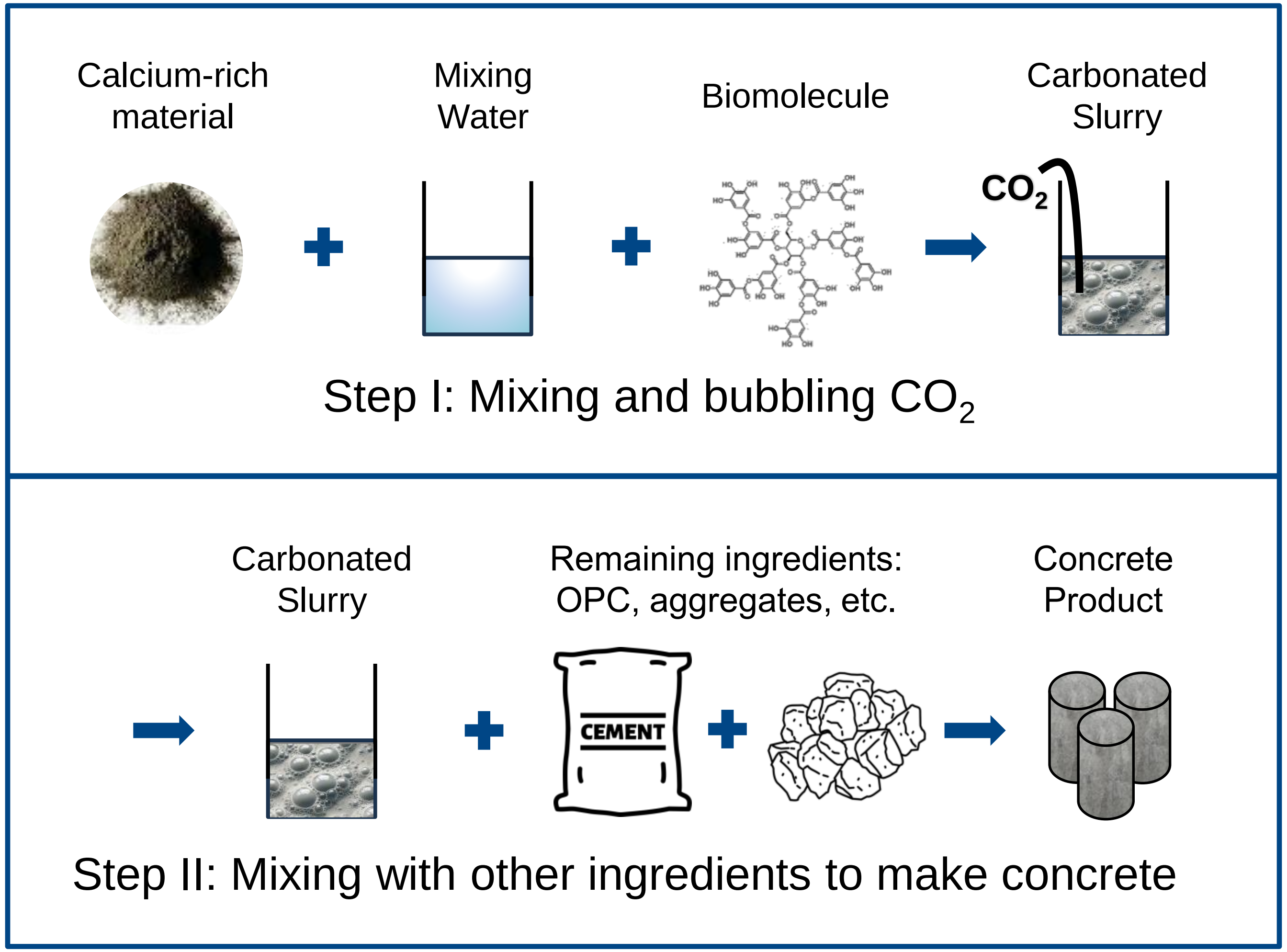
Precast and ready mix

Strength improvement
(5 – 8% cement saved)

Some CO_2 released back to air

0.15 – 0.2% wt. of
cement in CO_2 storage

New Pathway: The BioCarb Method



Carbonation **before** mixing

5 to 50% of cement is added into the total mixing water

Low dosage of a biomolecule like tannic acid is added

CO_2 gas is bubbled into the slurry for up to 60 minutes

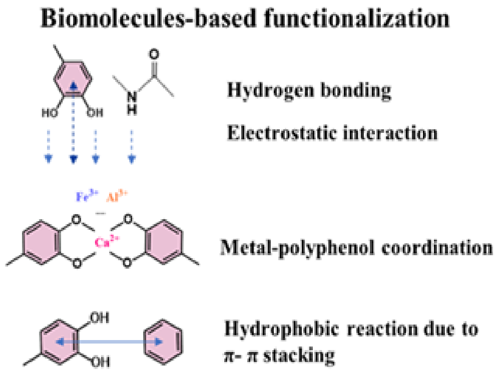
Working Mechanism

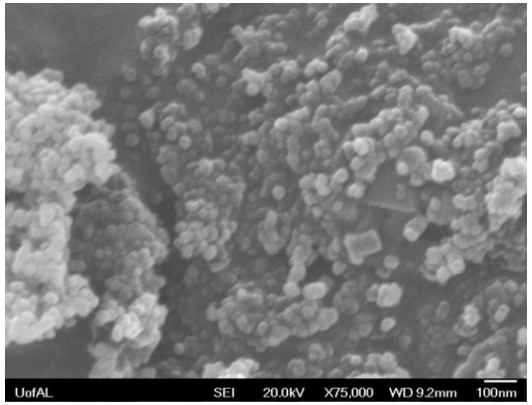
NanoCaCO$_3$ is produced in-situ

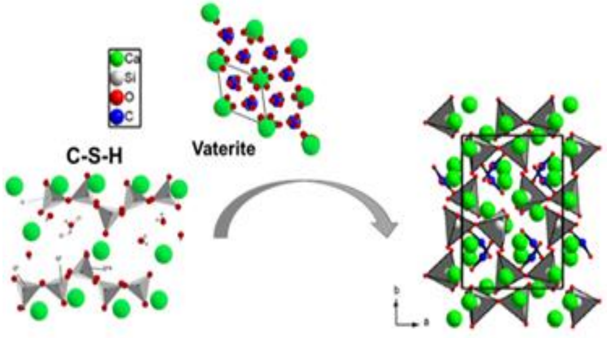
- Filler effect
- Seeding effect

Multi-functional biomolecule

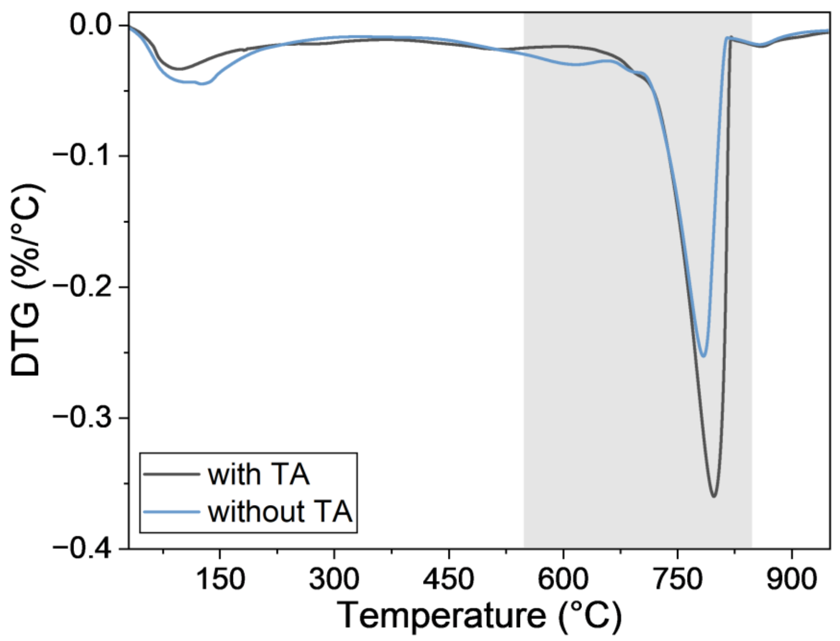
- Regulate the crystal nucleation, orientation, size, and phase
- Disperse the produced CaCO$_3$ nanoparticles
- Refine final microstructure
- Possible formation of C-S-H-CaCO$_3$ composites like **scawtite** and **tilleyite**

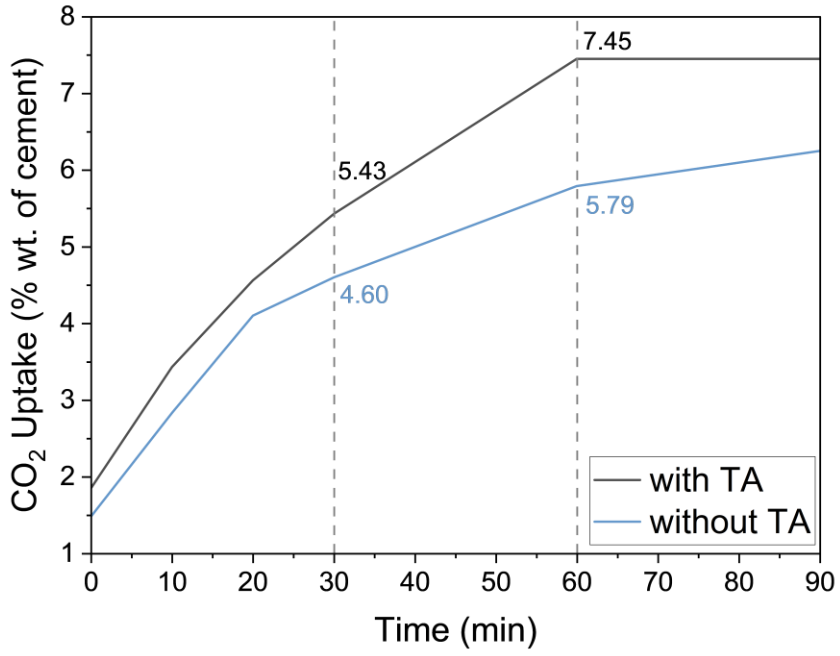






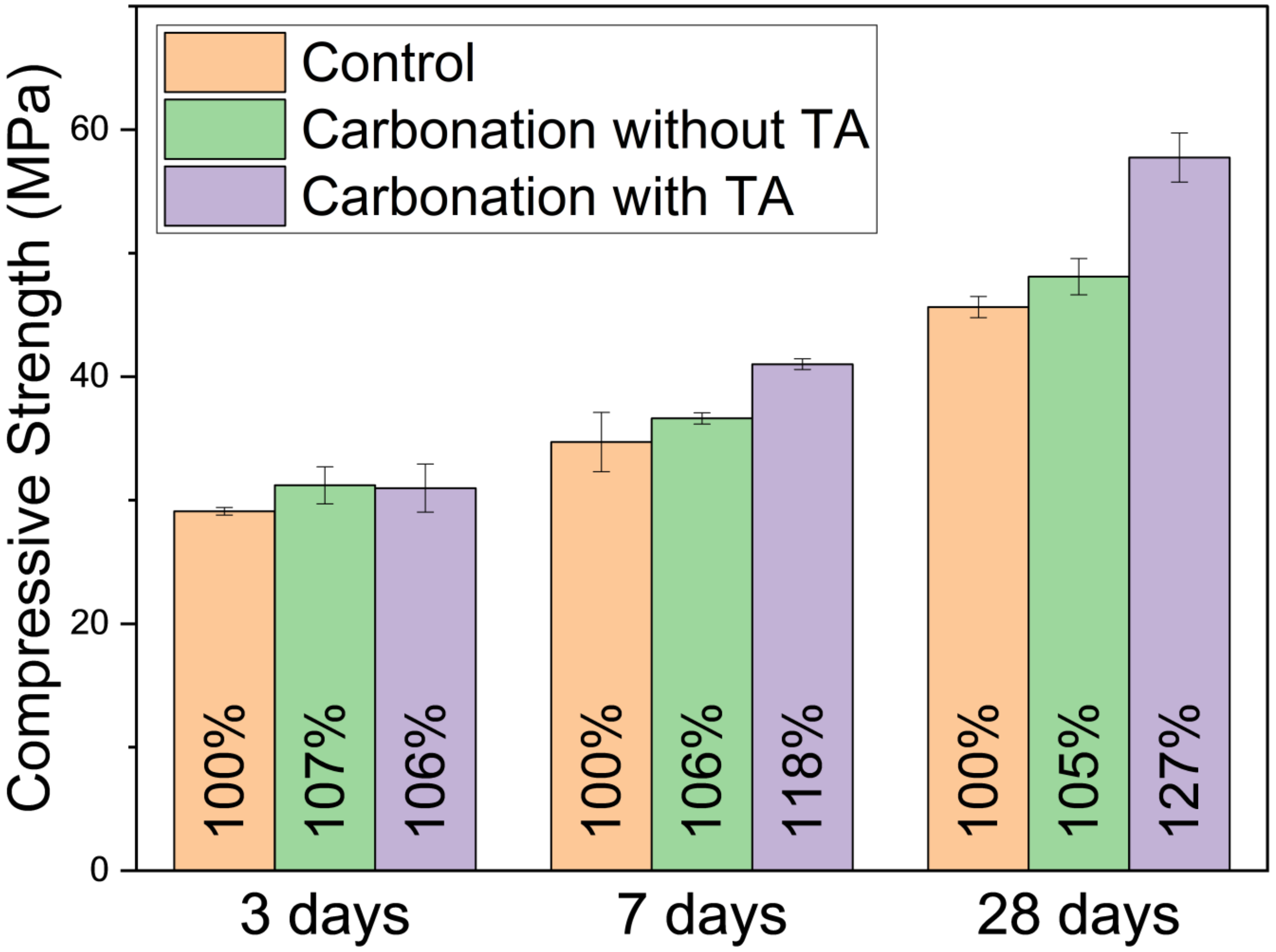
CO_2 Uptake





- CO_2 Uptake after 60 min = 7.45% (**30x better** than the existing technology)
- Carbonation duration depends on the added biomolecule
  - 30 – 60 min is sufficient for most applications

Strength Improvement



Water : Cement : Sand = 1:2:5

Production: half of cement mixed with all mixing water and carbonated with a biomolecule as a small dose additive

Over 25% strength improvement

Over 20% reduction on carbon intensity

Slaked Lime as an Alternative Calcium Source

- Slaked lime production is less energy-intensive than cement
  ≈ 900 ºC required v. 1450 ºC
- More expensive than cement only because of production scale
- Slaked lime is carbonated replacing 5% of OPC
- The carbonated slaked lime becomes a low-cost accelerator
- Ideal for quick turnover required by pre-cast industry

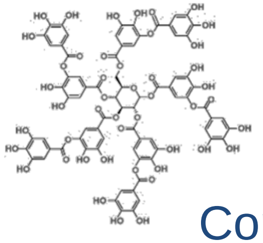
Experimental Plan

→ Slaked lime was used as the calcium source in the slurry

→ Two main factors were analyzed

1. Tannic Acid concentration
2. Carbonation time

xT yL zmC



Tannic Concentration

Lime Concentration

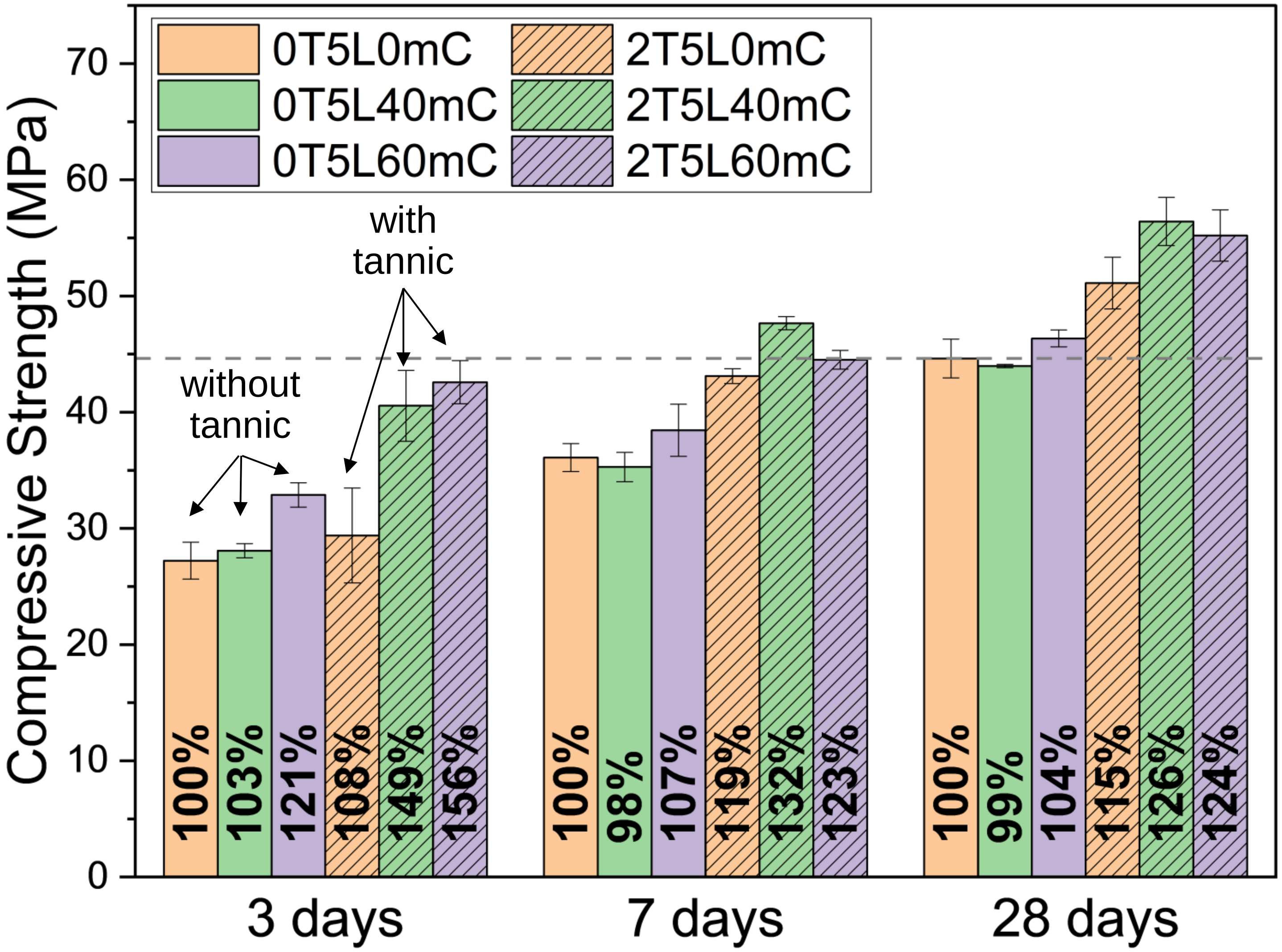
Carbonation time in minutes

0 minutes

40 minutes

60 minutes

Early-age Improvement



By 3 days, strength has reached 95% of control at 28 days

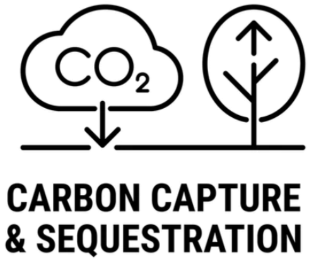
By 7 days, strength has reached or surpassed control at 28 days

No loss on late-age strength
≈ 25% improvement at 28 days

Potential Industry Impacts

Environmental Benefits: Enormous sustainability benefits can be generated if fully deployed:

- In the U.S.
    - Permanently storing 6Mt/year CO_2 in concretes
    - Save 20 Mt/year cement
    - Avoid 18 Mt/year CO_2
    - Total 24 Mt/year CO_2 emission reduced
- Worldwide,
    - 0.25 Gt/year CO_2 stored in the concrete
    - 2.03 Gt/year CO_2 is avoided every year
    - Total 2.28 Gt/year CO_2 emission reduced



Conclusions

1. BioCarb method can enhance concrete's CO_2 sequestration capacity (30x more than state-of-the-art)
2. Early-age improvement is maintained at later age
3. Slaked lime is a viable less energy-intensive calcium source
4. Slaked lime is a low-cost and sustainable alternative to other nanotechnology accelerators
5. BioCarb method enables quick turnover needed by precast industry

Thank you!

NSF's Convergence Accelerator

National Science Foundation through #1761672, #2236331, #2331381, #2328044, and #2418355

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Department of Energy through DE-FE0032263

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