# Creating Sustainable Concrete Through Carbon Sequestration

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# Research Topic

3 current methods of CO2 sequestration in concrete

Our approach: Combine Mineral Carbonation and Carbonation Curing

Engineering Goal: Create and optimize a **structurally sound concrete mix** that **quickly and consistently sequesters CO2** when carbonation-cured.

**Mineral Carbonation**

✅Stable carbonates

✅Sustainable additives

❌Strength tradeoffs

**Passive Carbonation**

✅Stable, long-term $CO_2$ storage

❌Long exposure periods

**Carbonation Curing**

✅Rapid $CO_2$ uptake

✅Increased strength

❌Inconsistent

(Anabela et al., 2020) (Van Roijen et al., 2024) (Li et al., 2022) (Kazemian & Shafei, 2023)

# Experimental Design - Carbonation Testing

Three carbonation curing trials; Trial 1 and 2 tested initial experimental mixes, Trial 3 tested an optimized mix

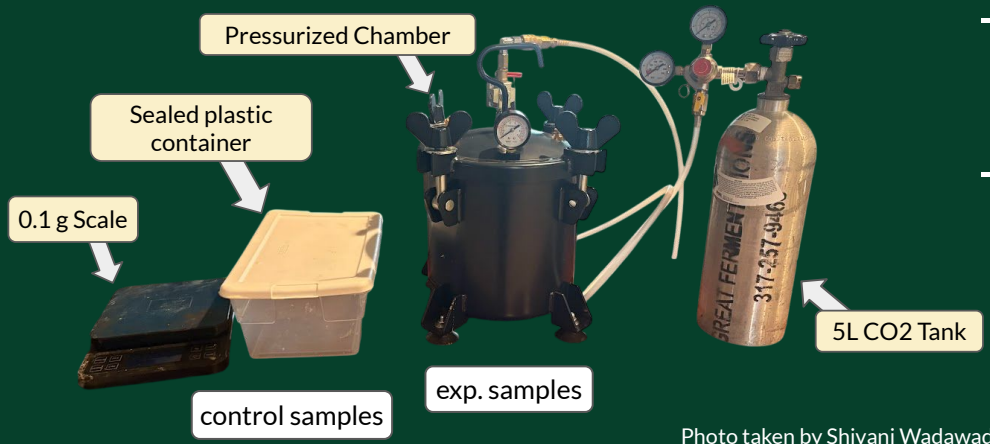



Photo taken by Shivani Wadawadigi

- A Taguchi Array was used to organize the concrete mixes
- CO2 sequestration measured via weight gain

| Factors | Level 1 | Level 2 | Level 3 |
|---|---|---|---|
| SCM | Fly ash | Slag | Hydrated Lime |
| Aggregates | Recycled | Natural | Steel Slag |
| Additives | None | Biochar | Accelerator |
| Water-Binder | 0.35 | 0.4 | 0.45 |

**Table 1.** L9 Taguchi Array showing factors and levels used

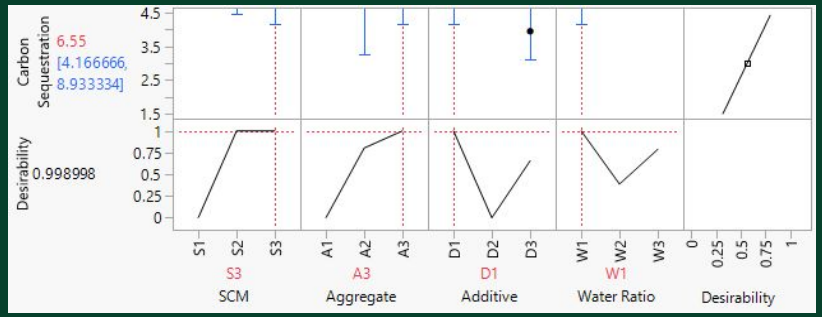
# Experimental Design - Structural Testing

Tested original mixes in a simple compression test until failure

- The max load sustained was recorded
- We lost access to the lab pre-trial 3

## Mix Optimization

Maximized $CO_2$ Sequestration and Compression Strength using regression via *JMP Student Version*




Optimal mix:

- Hydrated Lime
- Steel Slag
- Water/Binder = 0.3

Photos taken by Shivani Wadawadigi

# Results - CO2 Sequestration

- 57 samples tested Trial 1 and 2 (32 experimental, 25 control)
  - Optimal mix performed the best, sequestering 6.60% of its original mass in CO2

| | Trial 3 | |
|---|---|---|
| Mix | Avg. CO2 (%) | Avg. CO2 (g) |
| Mix Optimal | 6.60% | 6.40 |

**Table 2.** Carbon Sequestration of Optimized Mix

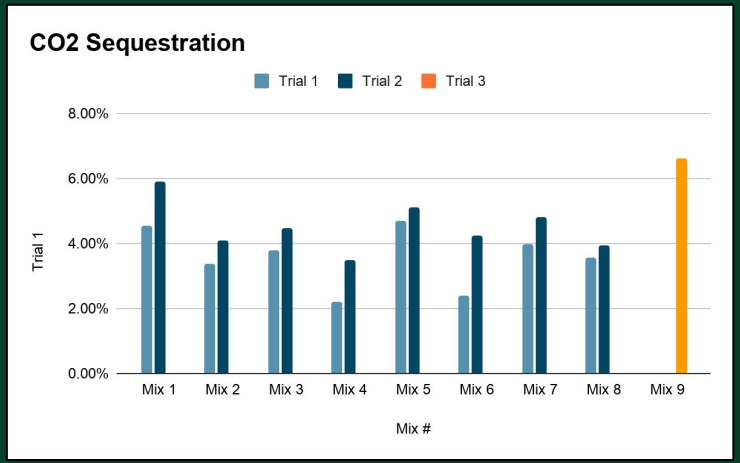



**Figure 1.** Carbon Sequestration by Mix

# Results - Compression Testing

- 32 samples tested (2 experimental, 2 control per mix)
  - One data point invalidated due to test failure

- 7 out of 8 mixes performed better than control counterpart
- 3 out of 8 mixes met standards for commercial usage (4000 psi) (National Ready MIxed Concrete Association, 2021)

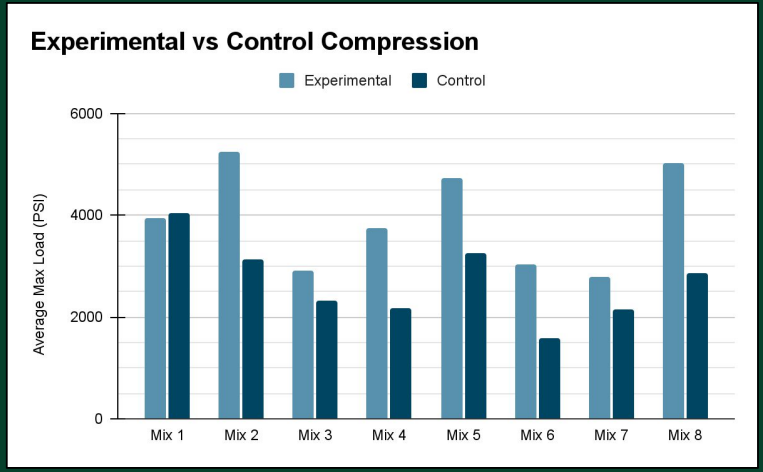



**Figure 2.** Experimental vs Control Compression Testing

# Data Analysis

1. CI and SD show Mix Optimal had the **most consistent** uptake
2. ANOVA shows **statistically significant differences** in uptake
3. Tukey Post-Hoc HSD: **Mix Optimal** significantly highest uptake

| Mix | Mean CO % | SD | 95% CI (lower, upper) | CI width |
|---|---|---|---|---|
| 1 | 5.215 | 0.869 | (3.833, 6.597) | 2.764 |
| 2 | 3.740 | 0.732 | (2.575, 4.905) | 2.330 |
| 3 | 4.123 | 0.473 | (3.371, 4.875) | 1.504 |
| 4 | 2.835 | 0.868 | (1.454, 4.216) | 2.762 |
| 5 | 4.910 | 0.376 | (4.312, 5.508) | 1.196 |
| 6 | 3.305 | 1.153 | (1.470, 5.140) | 3.670 |
| 7 | 4.390 | 0.566 | (3.489, 5.291) | 1.802 |
| 8 | 3.523 | 0.485 | (2.751, 4.295) | 1.544 |
| **Optimal** | **6.600** | **0.0258** | **(6.559, 6.641)** | **0.082** |

**Table 3:** SD and 95% Confidence Interval (CI) for $CO_2$ sequestration of each mix

| | SS | df | MS | F | p-value |
|---|---|---|---|---|---|
| Between Mixes | 42.37155 | 8 | 5.29644 | 11.09586 | **8.661e-07** |

**Figure 3:** ANOVA testing results for $CO_2$ Sequestration

# Discussion

2 key takeaways:

1. Unclear pattern between mixes which sequestered the most CO2 and mixes that gained the most compressive strength
    - Contradicts the expectation that the most carbonized mixes increase in strength the most (Kazemian & Shafei, 2023)
2. Mix optimization is essential for carbonation cured concrete

# Conclusion

- **Rapid CO2 sequestration** achieved (6.60% in 7 day period)
- Structural strength **met or exceeded industry standards** for 3 mixes
- All mixes **retained CO2** between end of carbonation and final measurement, showing **stable carbonation**
- **Recycled materials** used in optimized mix
- Created **scalable process** viable for controlled-production settings.

# References


Anabela, Elvia, et al. “Real Time 3D Observations of Portland Cement Carbonation at $CO_2$ Storage Conditions.” *Environmental Science & Technology*, vol. 54, no. 13, 11 June 2020, pp. 8323–8332, https://doi.org/10.1021/acs.est.0c00578. Accessed 10 Sept. 2023.

Kazemian, M., & Shafei, B. (2023). Carbon sequestration and storage in concrete: A state-of-the-art review of compositions, methods, and developments. *Journal of CO2 Utilization*, *70*, 102443. https://doi.org/10.1016/j.jcou.2023.102443

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