Transportation Infrastructure Precast Innovation Center (TRANS-IPIC)

University Transportation Center (UTC)

Unveiling synergistic effects of Nano-modification and CO_2 curing on the durability and carbon footprint of precast elements - Phase II
PU-23-RP-02

Quarterly Progress Report
For the performance period ending *10/01/2025*

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N/A

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TRANS-IPIC Quarterly Progress Report (Section 1 – 7, 5 pages max.):

Project Description:

1. Research Plan - Statement of Problem

The overall objective of the second phase of this project is to improve the quality of precast elements while reducing carbon footprint by (i) determining the optimum conditions for CO_2 curing process with and without nano additives to improve durability-related properties, and (ii) quantifying and understanding the combined effects of nano-additive usage and CO_2 curing on the surface wettability, chloride ingress resistance and corrosion of steel reinforcement. The determination of the optimum CO_2 curing conditions (humidity and CO_2 concentration) to enhance durability-related properties is key to defining an optimized precast CO_2 curing process to enhance durability. Considering preliminary data from phase I on the unchanged pH during CO_2 curing and the reduction of porosity produced by both the use of nano-additives and CO_2 curing, in phase II, the potential reduction of corrosion risk due to CO_2 curing of nano-modified concrete will be assessed. Over the subsequent phases, the general aims of this project will be to: (i) assess the effect of these combined approaches on freeze-thaw resistance and water penetration; (ii) in collaboration with a precast plant, study and test the adaptation of their current curing beds/rooms to include the CO_2 injection process and test different methods of nanomaterials dispersion to determine the best application method in a precast plants' settings; (iii) compare the lab results with precast plant results and understand potential opportunities and challenges to provide guidance for the implementation of these combined approaches and conduct economical and life cycle assessments of different approaches and their combination for comparative evaluation of the effects of applying CO_2 curing for precast elements with nanomodified concrete vs plain concretes.

2. Research Plan - Summary of Project Activities

Task 1. Mixture selection and Trial batches for Phase II study. Based on the results of Phase I, the research team will select the nano-additives and mixture design parameters for concrete mixtures to be used in Phase II. This task also entails the preparation of the trial batches to validate the efficacy of the selected mixtures

Task 2. Investigation of the influence of relative humidity and temperature on the levels of carbonation, values of accessible porosity, and the resulting strength of the CO_2-cured material. Selected mixtures will include, at minimum, a standard mixture with no nano-additives and two mixtures containing nano-additives. For each mixture, there will be three groups of samples cured for 24 hours at different levels of relative humidity (RH) and temperature and a constant CO2 concentration. Then, all samples will be cured in a standard curing room with 95%±5% RH, and 21°C±2°C. At age 28 days, for each type of mixture and group, the accessible porosity as well as the flexural and compressive strength, and the thickness of the layer of material affected by a substantial drop in pH value will be determined.

Task 3. Investigation of the influence of the concentration of CO_2 on the effectiveness of the CO_2 curing process in terms of the degree of carbonation, levels of accessible porosity, and strength. The mixtures used in this task will be the same as those used in Task 2. For each mixture, there will be three groups of samples cured for 24 hours at three different CO_2 concentrations and at constant RH and temperature based on the results of Task 2. At 28 days, the accessible porosity, the flexural and compressive strength, and the thickness of the carbonated layer with low pH will be determined for each type of mixture within each group.

Task 4. Analysis of data and determination of the optimal CO_2 curing conditions for various cementitious systems. In this task, the research team will analyze and crosslink data from tasks 2 and 3. The need for further testing to elucidate potential variations between nanomodified and reference cementitious systems will be determined. If needed, additional testing will be conducted, and the results will be analyzed, facilitating a comprehensive understanding of their performance under different curing conditions.

Task 5. Casting and preparation of corrosion test samples. As per the original proposal, three concrete mixtures were planned: one without nano-additives and two with nano-additives. Four beams measuring 11 × 6 × 4.5 in. were to be cast, each reinforced with three #5 rebars. One rebar, positioned near the top of the beam, was to serve as the anode, while the other two acted as cathodes. The beams would be divided into two curing regimes: standard curing and CO_2 curing, the latter using the optimized process identified in previous tasks. Mix designs for corrosion test specimens have been established. However, ASTM G109 requires specimens too large for the available CO_2-curing equipment. To overcome this limitation, we adopted an accelerated corrosion test using "lollipop" mortar specimens (see Fig. 1). For each mix type, six 2 × 4 in. mortar cylinders will be cast, each embedded with a single #4 rebar (Figure 1). The intentionally low concrete cover is expected to shorten the time to corrosion initiation. After casting, the cylinders will be split into two curing groups: optimal CO_2 curing (100% RH, 20% CO_2, 23 °C) and standard wet curing (100% RH, 23 °C). Following curing, specimens will be submerged in a chloride solution to promote corrosion. In this setup, a steel sleeve will act as the counter electrode, the embedded rebar as the working electrode, and a silver/silver chloride electrode as the reference. Corrosion measurements will include the determination of changes in half-cell potential and performing linear polarization experiments. Corrosion performance will be assessed following ASTM C876 and a modified ASTM G109 procedure. Parameters including corrosion current, corrosion potential, and current density will be used to quantify performance differences between CO_2-cured and nano-modified mixtures.

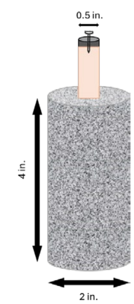

Figure 1. Graphic for Lollipop Mortar Specimen

Task 6. Corrosion testing. The potential for corrosion of reinforcing steel will be evaluated following the general procedure given in ASTM G-109[1] specification using the samples prepared in Task 5. The primary parameters that will be monitored during this experiment include: macrocell potential, half-cell potential, the corrosion current and depth of chloride penetration. The process of the specimens will be accelerated by exposing beams to alternating wetting-drying cycles to accelerate the corrosion.

Task 7. Determination of the effect of nano-additives and CO_2 curing on the wettability of cementitious composites and on the rate of water absorption. The wettability test will be performed on the surfaces of CO_2 -cured and standard-cured cementitious composites with and without nano-additives. Besides, a rate of absorption test according to ASTM C1585[2] will be performed.

Task 8. Outreach activities related to the project. The preparation and diffusion of short videos and presentations for different audiences (middle school, high school, and university student level) on the following: (i) the importance of sustainable and durable construction practices in transportation and the role of precast concrete elements in the transportation sector (ii) video-tutorials of some tests used in the project for training & workforce development. These videos will be used in addition to the video series in year one of this project to foster interest in engineering and construction research and make engineering practices easily accessible. Annual events will be held in at least one high school of an underserved community for youths interested in civil engineering, construction, and materials science. An activity will be organized for university students interested in research with a hands-on interactive approach. A presentation will be organized for at least one event for industry professionals interested in the use of CO_2 curing, nanomaterials, and sustainable building practices.

Task 9. Preparation of quarterly reports, draft final report and review. This task will involve the preparation of quarterly progress reports as well as drafting the final report summarizing the research effort.

Project Progress:

3. Progress for each research task:

Task 1. Mixture Selection and Trial Batches. [100% completed to date]
Completed in Quarter 2.

Task 2. Investigation of the Influence of Relative Humidity and Temperature on the Levels of Carbonation, Values of Accessible Porosity, and the Resulting Strength of the CO_2-Cured Material. [100% completed to date]. Completed in Quarter 2.

Task 3. Investigation of the Influence of CO_2 Concentration on the Levels of Carbonation, Values of Accessible Porosity, and the Resulting Strength of the CO_2-Cured Material. [100% completed to date] Completed in Quarter 2.

Task 4. Analysis of Data and Determination of the Optimal CO_2 Curing Conditions for Various Cementitious Systems. [100% completed to date]

Flexural strength, compressive strength, and pH analysis of specimens have been evaluated. Due to page limitations imposed on quarterly project reports, select data is presented in Figures 2 and 3 below. Findings from the tests conducted reveal three major trends in 3-day compressive strength of specimens*:* *(i)* For mixtures cured with RH of 70% and 100%, the higher the CO_2 concentration, the higher the early strength, with RH of 50%, 10% CO_2 present higher strength (Fig. 2), *(ii)* RCB specimens perform better than Reference specimens when cured in 70% RH and low CO_2 concentrations (0%-10%) (Fig. 2), and *(iii)* focusing on samples cured at 100% RH, while specimens cured at 23°C present lower compression strength than samples cured at 50°C, 20% CO_2 curing at 23°C can provide compressive strengths equal to or better than 50°C cured specimens for both reference and 1% RCB (Fig. 3). This implies a potential energy efficiency of CO_2-curing cementitious composites, as it reduces the need for heating mechanisms during manufacturing to increase the early strength of the element. The results of the flexural strength test show similar trends to those of the compressive strength test. The different effect of CO_2 curing on the strength depending on the relative humidity is not reflected in changes in the carbonation depth, according to the pH test.

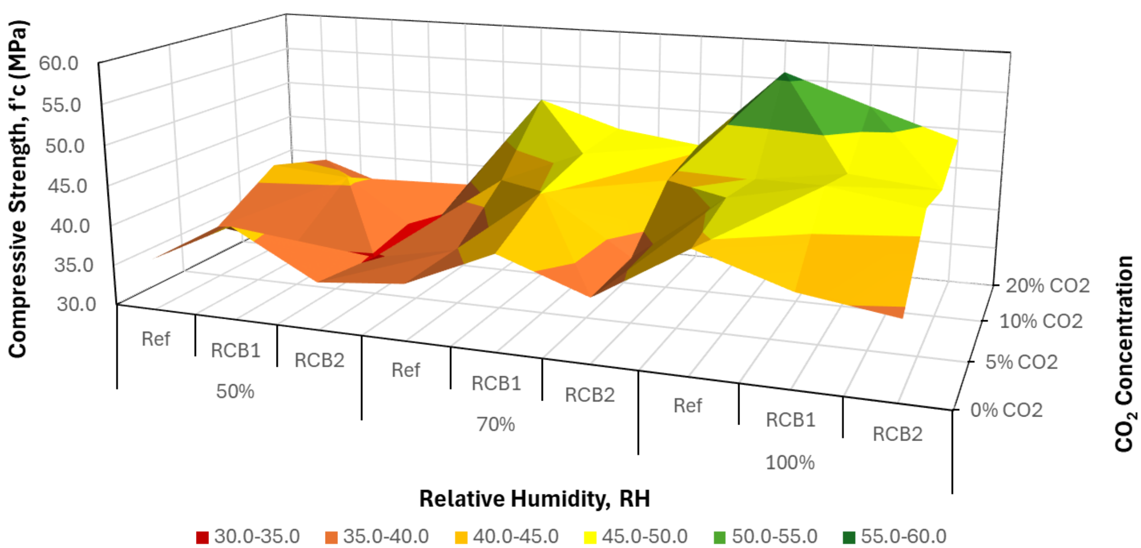

Figure 2. 3-Day Compressive Strength of Mortar Specimens Cured at 23°C with varying Relative Humidities and CO_2 concentrations

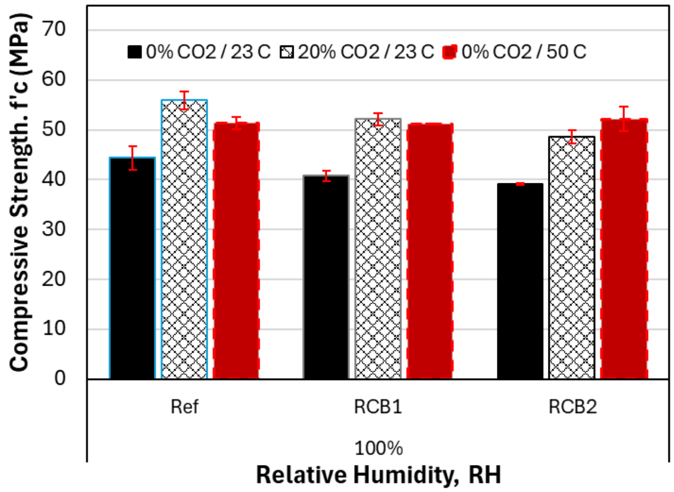

Figure 3. Compressive strength at 3 days (RH 100%) with varying temperature and CO_2 concentration.

Task 5. Casting and Preparation of Corrosion Test Samples. [60% completed to date]
During this quarter, work focused on developing a modified testing plan to produce specimens compatible with the available carbonation chamber, as well as acquiring molds, and rebars and preparing the reinforcement. In addition, the parameters required for the polarization resistance experiment were investigated, and a detailed plan was established for specimen curing and testing frequency. Procurement of the reference and counter electrodes was also completed. In the next reporting period, activities will include casting the specimens, implementing the designated curing procedures, and conducting the corrosion tests.

Task 6. Corrosion testing. [20% completed to date]
Material needed for corrosion testing has been acquired and setup is ready. Testing is set to begin this month.

Task 7. Determination of the effect of nano-additives and CO_2 curing on the wettability of cementitious composites and on the rate of water absorption. [35% completed to date]
Mix designs for concrete cylinder specimens were formulated and material for testing were acquired. Specimens are to be cast next week.

Task 8. Outreach activities related to the project. [85% completed to date]
The graduate student interviewed two precast companies, one of which are NPCA affiliates, to discuss industrial precast practices in the Midwest. After the interview, the graduate student had a personal tour at County Materials in Maxwell, Indiana, for an in-depth review of precast operations (Figure 4). During the tour, the student spent the afternoon viewing the active casting and storage of precast manhole bases and pipes, discussing various mixing and curing conditions of different precast products, and interacting with staff at multiple levels from quality-control to business outreach. This visit had a great influence on the current and future mix design and curing procedures of the project, as it provided insight into the safety, feasibility, and efficiency of incorporating nanoadditives and CO_2 curing at large-scale manufacturing facilities. The graduate student is

Figure 4. Graduate Student Touring One of the Precast Facilities

currently in talks with County Materials for additional site visits, as she has been invited to be the student technical advisor of the Purdue Student Chapter of the Precast/Prestressed Concrete Institute (PCI).
Task 9. Preparation of Quarterly Reports and Draft Final Report. [70% completed to date]
The reports for quarter 3, 2, and 1 have been submitted.

4. Percent of research project completed
Approximately 73% of this project has been completed to date.

5. Expected progress for next quarter
By the end of the next quarter, 12/01/2025, 95% of this project is expected to be completed.

Task 1. Mixture Selection and Trial Batches. [100% complete]. Completed in Quarter 2.

Task 2. Investigation of the Influence of Relative Humidity on the Levels of Carbonation, Values of Accessible Porosity, and the Resulting Strength of the CO_2-Cured Material. [100% complete] Completed in Quarter 2.

Task 3. Investigation of the Influence of CO_2 Concentration on the Levels of Carbonation, Values of Accessible Porosity, and the Resulting Strength of the CO_2-Cured Material. [100% complete] Completed in Quarter 2.

Task 4. Analysis of Data and Determination of the Optimal CO_2 Curing Conditions for Various Cementitious Systems. [100% complete]. Completed in Quarter 3

Task 5. Casting and Preparation of Corrosion Test Samples. [100% complete]. Corrosion specimens will be cast and prepared.

Task 6. Corrosion Testing. [100% complete]. Specimens will undergo corrosion testing.

Task 7. Determination of the Effect of Nano-Additives and CO_2-Curing on the Wettability of Cementitious Composites and on the Rate of Water Absorption. [100% complete]
Specimens cured with the optimized curing method will be tested for wettability and absorption.

Task 8. Outreach Activities Related to the Project. [100% complete]
At least 3 educational video tutorials on sample testing will be posted for public viewing in November.

Task 9. Preparation of Quarterly Reports and Draft Final Report. [100% complete]. The report for the fourth quarter will be complete. The final report will be nearly complete.

6. Educational outreach and workforce development
Workforce development through research experience: A PhD student is involved in this project. She began her graduate studies in this project as a master's student, and graduated with a master's thesis in civil engineering and is continuing on the project as a PhD student. The student mentored an undergraduate student, who participated in this project as an Office of Undergraduate Research (OUR) Scholar. Educational video tutorials on sample testing have been prepared and are to be published within the next month. These videos will be used to foster interest in engineering and construction research and make engineering practices more easily accessible.

7. Technology Transfer
No progress has been made on technology transfer at this time.

Research Contribution:

8. Papers that include TRANS-IPIC UTC in the acknowledgments section:

"Water-to-Cement Ratio: A Factor that Modifies the Effect of Nanoadditives on the Hydration Kinetics and Strength Development of CO_2-Cured Cementitious Composites" – Aniya Edwards, Raikhan Tokpatayeva, Jan Olek, Mirian Velay-Lizancos (To be submitted to Construction and Building Materials by December 2025).

"Optimizing the Curing Conditions of Early-Age CO_2-cured Mortars" – Aniya Edwards, Raikhan Tokpatayeva, Jan Olek, Mirian Velay-Lizancos (To be submitted to Transportation Research Record by January 2026).

"The Effects of Recovered Carbon Black on the Early-Age Hydration Kinetics, Microstructure, and Mechanical Properties of CO_2 Cured Cementitious Composites" – Aniya Edwards, Raikhan Tokpatayeva, Jan Olek, Mirian Velay-Lizancos (To be submitted to Construction and Building Materials by March 2026)

9. Presentations and Posters of TRANS-IPIC funded research:

Sustainable Transportation Infrastructure Systems" at the Workshop 1045 "The Role of Precast Concrete in the Sustainability of Transportation Infrastructure: Approaches and Challenges", Transportation Research Board (TRB) Annual Meeting. Washington, DC. 01/05/2025. https://annualmeeting.mytrb.org/OnlineProgramArchive/Details/22610

Poster Presentation – A. Edwards, R. Tokpatayeva, J. Olek, and M. Velay-Lizancos, "A Comparative Analysis of Pure and Recycled Carbon Black on the Mechanical, Thermal, and Microstructural Properties of Mortars" Office of Undergraduate Research Spring Undergraduate Research Conference. West Lafayette, IN. 04/08/2024 https://www.purdue.edu/undergrad-research/conferences/spring/index.php

Poster and Oral Presentation - A. Edwards, R. Tokpatayeva, J. Olek, and M. Velay-Lizancos, "Unveiling synergistic effects of Nano-modification and CO2 curing on the durability and carbon footprint of precast elements": TRANS-IPIC 2025 UTC Workshop. Rosemont, IL.04/22-24/2025. https://trans-ipic.illinois.edu/UTC-Workshop

Thesis Defense Presentation – A.Edwards. "Enhancing Cementitious Composites Through Waste Valorization: The Effect of Multiscale Recycled Materials on the Properties of Mortars". Purdue University Graduate School. https://doi.org/10.25394/PGS.28899938.v1

Extended abstract and Oral Presentation - A. Edwards, R. Tokpatayeva, J. Olek, and M. Velay-Lizancos, "Synergistic Effects of CO_2 Curing and Recovered Carbon Black Nano additives on Early Age Performance of Cementitious Composites": C3 Symposium 2025. Chicago, IL. 10/02-05/2025. https://carbonconscconcrete.com/#key-dates-4095 (Accepted).

TRANS-IPIC UTC Monthly Research Webinar – August 22nd, 2025

Trans-Ipic Monthly Research Webinar - August, 2025. Illinois Media Space. (n.d.). https://trans-ipic.illinois.edu/August-2025-Webinar

Appendix 1: Research Activities, leadership, and awards (cumulative, since the start of the project)

A. Number of presentations at academic and industry conferences and workshops of UTC findings
   - No. = 5

B. Number of peer-reviewed publications submitted based on outcomes of UTC funded projects
   - No. =1 (and another one to be submitted)

C. Number of peer-reviewed journal articles published by faculty.
   - No. = 0 (2 papers to be submitted)

D. Number of peer-reviewed conference papers published by faculty.
   - No. = 0

E. Number of TRANS-IPIC sponsored thesis or dissertations at the MS and PhD levels.
   - No. MS thesis = 1
   - No. PhD dissertations = 0 (+1 in progress)
   - No. citations of each of the above = 1

F. Number of research tools (lab equipment, models, software, test processes, etc.) developed as part of TRANS-IPIC sponsored research
   - Research Tool #1 = New method of carbon black dispersion to allow its homogeneous incorporation into concrete as an additive.
   - Research Tool #2 = Optimization of curing conditions for CO_2-cured mortars modified with recovered carbon black

G. Number of transportation-related professional and service organization committees that TRANS-IPIC faculty researchers participate in or lead.
   - Professional societies
     - No. participated in = 2
     - No. lead = 1
   - Advisory committees (No. participated in & No. led)
     - No. participated in = 1
     - No. lead = 0
   - Conference Organizing Committees (No. participated in & No. led)
     - No. participated in = 2
     - No. lead = 1
   - Editorial board of journals (No. participated in & No. led)
     - No. participated in = 4
     - No. lead = 1 (*Associate Editor)
   - TRB committees (No. participated in & No. led)
     - No. participated in = 2
     - No. lead = 0

H. Number of relevant awards received during the grant year
   - No. awards received = 2

I. Number of transportation related classes developed or modified as a result of TRANS-IPIC funding.
   - No. Undergraduate = 0

- No. Graduate = 1

J. Number of internships and full-time positions secured in the industry and government during the grant year.
   - No. of internships = 1
   - No. of full-time positions = 0

References:

1. ASTM G109-23 Standard Test Methods for Determining Effects of Chemical Admixtures on Corrosion of Embedded Steel Reinforcement in Concrete Exposed to Chloride Environments. ASTM Int. Accessed April 1, 2025. https://www.astm.org/standards/c136.
2. ASTM. C1585-20 Standard Test Method for Measurement of Rate of Absorption of Water by Hydraulic Cement Concretes. *ASTM Int*. Published online 2020:1-6. doi:10.1520/C1585-20.2
3. ASTM C876-22b Standard Test Method for Corrosion Potentials of Uncoated Reinforcing Steel in Concrete. *ASTM Int.* Published online 2022:10-11. https://compass.astm.org/content-access?contentCode=ASTM%7CC0876-22B%7Cen-US