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 *07/01/2025*

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TRANS-IPIC Quarterly Progress Report:

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. Three different concrete mixtures (one with no nano-additives and two with nano-additives) will be used in this task. For each mixture, a total of four 11 x 6 x 4.5 in. concrete beams will be cast. Each beam will contain three #5 reinforcing bars, one serving as an anode and two serving as the cathode. The samples will be divided into two groups; one group will be standard cured, while the other group will be cured using the optimized CO_2 curing process determined in previous tasks. The two cross-section sides of the sample will be covered or coated to avoid carbonation of the side ends of the samples that would not be representative of the actual CO_2 curing in a full-scale element.

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]

Based on the findings from prior research, recovered carbon black (RCB) was selected as the nanomaterial to be evaluated for this phase. Three types of mixes have been formulated for each task: a reference mixture with no nanomaterial (Ref.), a mixture with 1% RCB addition by weight of cement (RCB1), and a mixture with 2% RCB addition by weight of cement (RCB2). Type IL cement and the Indiana Department of Transportation (INDOT) No.23 fine aggregate sand will be used for all mortar mixes, while INDOT's No.8 coarse aggregate will be used additionally for concrete mixes. A 48-hour curing procedure has been developed for both CO_2-cured and normal-cured (no CO_2) specimens (Figure 1). Mortar mixes were tested at 3 days instead of 28 days, to more closely reflect stripping strengths attained by precasters immediately after curing.

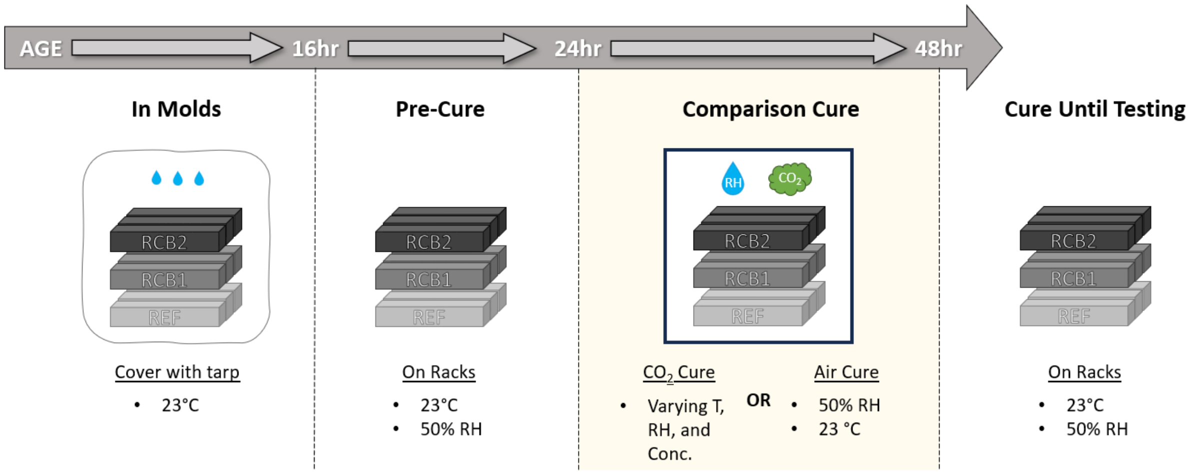

Figure 1. Method of Curing Samples over the First 48 Hours of Hydration

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]

Four curing methods, each designed to be performed at 23°C, were formulated to compare the effects of relative humidity (RH) during CO_2 curing on material properties: 50% RH (representative of precast elements exposed to ambient conditions, 70% RH and 100% RH (analogous to steam-cured precast elements). Additionally, a subset of specimens subjected to 100% RH CO_2 curing was cured at 50°C to evaluate the influence of temperature (T) on specimens.

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]

Four curing regimes were designed to evaluate the influence of CO_2 concentration on the material properties during CO_2 curing: 0%, 5%, 10%, and 20% CO_2. The combined curing conditions applied in Tasks 2 Task 3 are summarized in Figure 2. Mortar specimens were assessed for flexural strength, compressive strength, and cross-sectional pH to characterize their mechanical performance and carbonation extent.

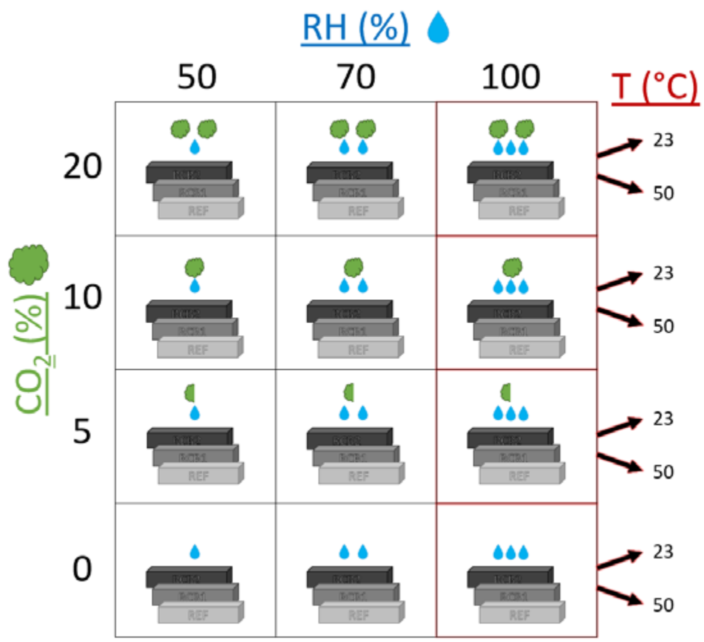

Figure 2. Curing Conditions Between 24-48 Hours of Hydration for Task 2 and 3

Task 4. Analysis of Data and Determination of the Optimal CO_2 Curing Conditions for Various Cementitious Systems. [90% completed to date]
Flexural strength, compressive strength, and cross-sectional pH analyses were conducted on wet cured specimens.

Task 5. Casting and Preparation of Corrosion Test Samples. [30% completed to date]
Preliminary mix designs for corrosion concrete test specimens have been formulated.

Task 6. Corrosion testing. [10% completed to date]
Material needed for corrosion testing will be acquired and prepared for casting of specimens.

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. [15% completed to date]
Preliminary mix designs for concrete cylinder test specimens have been formulated.

Task 8. Outreach activities related to the project. [15% completed to date]
Educational video tutorials on sample testing will be prepared.

Task 9. Preparation of Quarterly Reports and Draft Final Report. [40% completed to date]
The reports for quarter 2 and quarter 1 have been submitted.

4. Percent of research project completed
Approximately 55% of this project has been completed to date.

5. Expected progress for next quarter
By the end of the next quarter, 10/01/2025, 85% 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]
An optimal curing system will be selected and the relationship between RH, CO_2, and temperature during CO_2 curing will be analyzed.

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

Task 6. Corrosion Testing. [75% 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. [75% complete]
Educational video tutorials on sample testing will be posted for public viewing. Correspondence between research group and educators will be initiated.

Task 9. Preparation of Quarterly Reports and Draft Final Report. [80% complete]
The report for the third quarter will be complete. A draft for the final report will be nearly complete

6. Educational outreach and workforce development

Workforce development through research experience: A master's student and a third-year undergraduate student are engaged in this project through distinct educational initiatives. The master's student, who began her graduate studies under this project, graduated with her MS thesis in civil engineering and is continuing on the project as a PhD student. In her new role, she has also mentored a third-year undergraduate student participating as an Office of Undergraduate Research (OUR) Scholar. Following the conclusion of this quarter, the undergraduate student secured an internship with a major engineering design company.

Educational outreach efforts will be realized through the development and distribution of short videos and presentations tailored for middle school, high school, and university-level audiences. These materials will focus on (i) the significance of durable and efficient construction practices in transportation, with an emphasis on the role of precast concrete elements, and (ii) tutorial demonstrating selected experimental methods used in this project to support training and workforce development. Status: Preparation of the first set of videos has begun. These videos will be used to spark interest in engineering and construction research while enhancing accessibility to practical engineering concepts.

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:

   No papers were published during this reporting period. However, a draft of a research paper is currently in progress, and is expected to be submitted by the end of the summer semester. Based on the data collected during the first and current project years, we anticipate the publication of at least two peer-reviewed articles in leading journals within the field.

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).*

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 (accepted – extended abstract)

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.

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 = 7
     - No. lead = 1
   - 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 = 3
     - No. lead = 0

H. Number of relevant awards received during the grant year
   - No. awards received = 5

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