Disclaimer:

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
PU-23-RP-02

FINAL REPORT

Submitted by:
Mirian Velay-Lizancos (PI), Lyles School of Civil and Construction Engineering, mvelayli@purdue.edu
Jan Olek (Co-PI), Lyles School of Civil and Construction Engineering, olek@purdue.edu
Raikhan Tokpatayeva(Co-PI), Lyles School of Civil and Construction Engineering, rtokpata@purdue.edu
Aniya Edwards, Lyles School of Civil and Construction Engineering, edwar242@purdue.edu
Department: Civil and Construction Engineering
University: Purdue University

Collaborators / Partners:
N/A

Submitted to:
TRANS-IPIC UTC
University of Illinois Urbana-Champaign
Urbana, IL

Executive Summary

CO_2 curing of concrete elements, a process well-suited for precast operations, enhances strength and reduces porosity while lowering the carbon footprint. This reduction is achieved through two primary mechanisms: (i) direct carbonation during the CO_2 curing process, and (ii) reduced amount of cement required to achieve a target performance levels, due to the strength enhancement provided by CO_2 curing. On the other hand, the addition nano-TiO_2 in cementitious composites has also shown their ability to reduce porosity and increase the strength. Furthermore, our previous studies showed that combining nano-TiO_2 addition with CO_2 curing not only increases CO2 uptake but also further reduces porosity. However, nano-TiO_2 is more expensive than other nanomaterials such as Nano-silica or Nano-carbon black. The addition of different nanoparticles can influence the hydration process and crystal structure, potentially altering the effects of CO_2 curing on precast elements. Understanding how various nanomaterials influence the CO_2 curing process can be instrumental with respect to optimizing the combined effects of nanomodification and CO_2 curing. This approach can enhance the performance of precast elements while lowering their cost by making the process more effective and preventing unexpected side effects.

This project aims to explore and understand the synergistic effects of Nano-modification and CO_2 curing on the durability and carbon footprint of precast elements. The first phase of this project aimed to elucidate the combined effects of CO_2 curing and nanomodification with alternative nano-additives on the strength, porosity, and transport properties of precast cementitious composites. The alternative nano-additives selected for Phase I were: (i) nano-silica, due to its commercial availability and cost-effectiveness, and (ii) recovered carbon black, chosen for its low cost and sustainability, as it is currently classified as a waste material. Notable differences were observed in the composition and mechanical properties of CO_2-cured and standard-cured cementitious specimens, both with and without nano-additives (rCB and nanosilica). Thermogravimetric analysis showed that CO_2 curing greatly increased the $CaCO_3$ content in samples compared to standard curing. The incorporation of nano-additives further increased the $CaCO_3$ content, particularly in higher w/c (0.48) samples at 3 days, with rCB showing the most pronounced effect under the CO_2 curing. Mortar compressive strength tests also indicated a significant strength increase in CO_2-cured specimens compared to standard-cured specimens. Results indicated that combining CO_2 curing with nano-additives yielded the highest early compressive strength among all mixtures and curing conditions studied – a critical factor for precast production. Additionally, this combination reduced calcium hydroxide concentration, thus potentially reducing the risk of durability issues such as calcium oxychloride formation. Recovered carbon black, currently considered a waste product, may not only enhance the durability of mortars by improving strength but may also reduce costs and greenhouse gas emissions through its reuse in precast elements.

The results of Phase I laid the groundwork for Phase II, which will focus on identifying the optimal conditions for the CO_2 curing process, both with and without nano-additives, to improve the durability-related properties of precast elements. Additionally, Phase II will aim to quantify and understand the combined effects of nano-additives and CO_2 curing on the corrosion of steel reinforcement and related properties.

Furthermore, outreach initiatives have been established at multiple levels. Presentations at the 1st annual *Future of Transportation Summi*t and the *TRANS-IPIC UTC Spring Workshop* were given to disseminate the initial findings of this project. Several undergraduate students have been introduced to the experimental research processes, and Annual High School outreach events were established both within and outside Purdue University. These events aim to emphasize the importance of precast construction, durability of the infrastructure, and engineering efficiency in enhancing societal well-being.

Table of Contents

TRANS-IPIC Final Report:

Statement of Problem

The application of new technologies and novel materials in precast concrete elements plays a crucial role in advancing the precast industry towards a greener future. The enhancement of durability and the reduction of carbon footprint of precast concrete elements are two of the main paths towards this advancement.

Both CO_2 curing (a precast treatment) and the use of nano-additives enhance the strength and reduce the porosity of cementitious composites, enhancing the durability of the concrete elements. However, CO_2 curing and nano-modification may interfere with each other if used simultaneously, especially considering that the addition of nanoparticles my affect the size of calcium hydroxide crystals, which react with the CO_2 during the CO_2 curing process. Thus, understanding the interactions between these two approaches is vital to leverage and maximize the advantages of combining these approaches to produce superior quality precast concrete elements in terms of durability and sustainability.

Research Tasks and Results

To achieve the objectives of Phase I of this project, a systematic research approach was followed, consisting of the following tasks:

Task 1. Characterization of the materials

Methods: This task involved the physical and chemical characterization of the nanoparticles, the aggregates, and the cement used in this study, according to the relevant standards for each type of the proposed material. Analyses of particle size, oxide composition, and mineralogical characteristics were performed.

Results and Findings:

Characterization of Nanomaterials: Four nanomaterials, two variants of nanosilica solution (NS) and two variants of carbon black, were evaluated for this project. The carbon blacks evaluated in this project were a standard carbon black (CB) powder, and a recovered carbon black (rCB) acquired from recycled materials. The nanosilica solutions evaluated in this project consisted of two different nanosilica concentrations. The purity of the carbon blacks (rCB and CB) was evaluated through loss of ignition (LOI) testing. For the LOI test, 0.5 grams of rCB and CB were heated to 900°C for 3 hours. The LOI tests results showed that the CB was purer than the rCB, burning off 100% of its initial mass compared to 71.83%, respectively (*Fig. 1*).

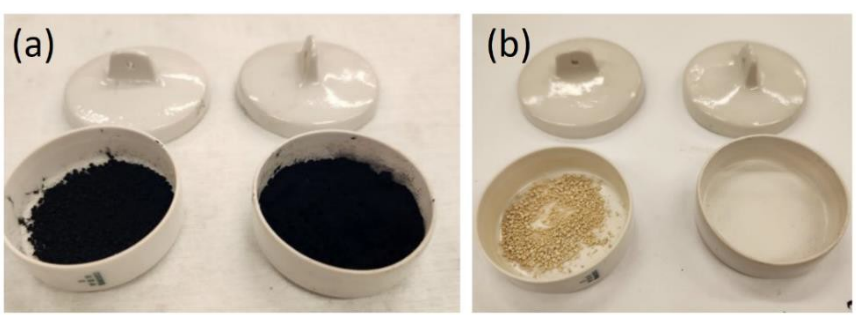

Figure 1. (a) Pre-LOI rCB (Left) and Pure CB (Right); (b) Post-LOI rCB (Left) and Pure CB (Right)

X-ray fluorescence (XRF) and x-ray diffraction (XRD) analyses were performed to examine the minerology of both NS, CB, and rCB materials. Both analyses confirmed that the rCB was less pure than that of the CB, showing higher levels of zinc and sulfur contaminants. The intensity curves for both materials closely resembled those of N774 carbon blacks. For nanosilica, these analyses showed that NS with the highest concentration of solids contained approximately 53% nanosilica, while the NS with the lowest concentration of solids had about 35%. These values align well with the range of concentration levels reported by the NS manufacturer.

Particle size analysis was carried out using laser diffraction and image analysis of transmission electron microscopy (TEM) images. Results from TEM analysis show that the higher concentration NS had particle diameters ranging from 10nm to 90nm (Fig. 2.a), and the rCB had particle sizes ranging from 5nm to 100nm (Fig. 2.b).

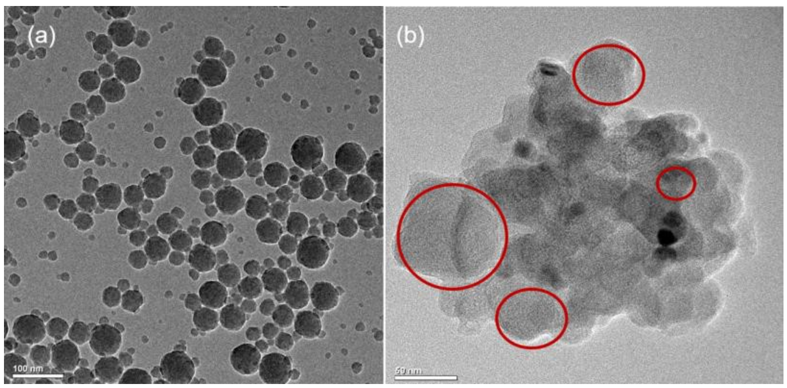

Figure 2. TEM images (a) nanosilica, (b) recovered carbon black.

Based on these analyses, the higher concentration NS and the less pure rCB were chosen for production of mixes used in this project. In the case of carbon black, the decision was also influenced by significant price difference between pure carbon black and recovered carbon black.

<u>Characterization of Aggregates</u>: ASTM C136[1] and AASHTO T27[2] were used to analyze the gradation of fine and coarse aggregates, which was determined to conform to the requirements of the Indiana Department of Transportation (INDOT) for #23 fine aggregate and #8 coarse aggregate. ASTM C127[3] and ASTM C128[4] were used to evaluate the density and absorption of fine and coarse aggregates, respectively. The absorption of fine and coarse aggregates was verified to be 1.54% and 1.39% respectively. The relative density of fine and coarse aggregates was verified to be 2.65 and 2.75. XRD was also used to analyze the mineralogy of aggregates. Coarse aggregates were made of dolomite while fine aggregates were primarily a mixture of calcite, dolomite, and quartz.

<u>Characterization of Cement</u>: XRD and XRF were performed on Type IL Cement to verify its mineralogy. Results revealed that its largest components are alite, belite, and calcite, as expected.

Task 2. Preparation of specimens and curing process

Methods: Concrete, mortar and cement paste mixtures with 0%, 0.5%, 1%, and 2% of nanoparticles by mass of cement and two different water-to-cement ratios (w/c), 0.42 and 0.48, were used in this study. Two different nanomaterials were used: nano-silica and recovered carbon black. Thus, a total of 14 different mixtures were studied for each cementitious composite (paste, mortar, and concrete). Various types of specimens were prepared and used to perform microstructural analysis, chemical analysis, and to determine the compressive strength development, transport properties and durability performance. Two different curing regimes and two different curing times were examined: (i) standard curing at 21 ± 1°C and 50% ± 5% RH (for reference) for 12 hours, (ii) CO_2 curing (20% concentration) for 12 hours (from age 24h to 36h) at a temperature of 23±1°C and 50%±5% RH.

Results and Findings:

Mix Design and Procedure: Paste and mortar samples were mixed per ASTM C305[5] in batches of sufficient volume to make eight, 1.25-inch diameter by 0.75-inch paste samples, and twenty, 2-inch mortar cube samples (Fig. 3). In total, fourteen different batches were made for both, paste and mortar mixes. Concrete samples were mixed per ASTM C192[6] in batches of sufficient volume to make thirty-two, 4-inch by 8-inch cylinders. In total, six different batches were prepared: Reference, rCB at 2% addition, NS at 2% addition for both (0.42 and 0.48) water to cement ratios.

Figure 3. From left to right; reference, rCB1, and rCB2 mortar samples.

Mix Procedure & Dispersion of Nanomaterial: NS was dispersed in each of the corresponding mixes by adding the required amounts to the batch water before mixing the water with the aggregates and cement. However, because rCB is a hydrophobic material, further dispersion methods were evaluated. The first method consisted of mixing the rCB with the cement powder before following ASTM C305 (Fig. 4a), while the second method involved high shear mixing the rCB with a portion of the batch water using a hand-held blender (Fig. 5a). Samples produced using the first method contained larger agglomerations of rCB in their cross -sections (Fig. 4b) compared to those using the second method (Fig. 5b). The high shear mixing method was therefore adopted for all mixes containing rCB.

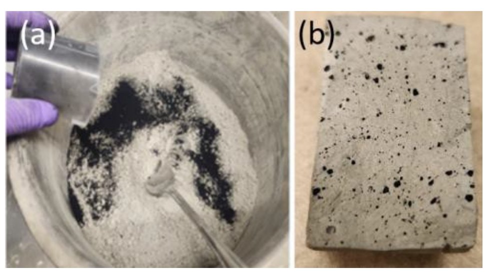

Figure 4. (a) Dry Mix Method: rCB added to cement powder; (b) paste sample made from it

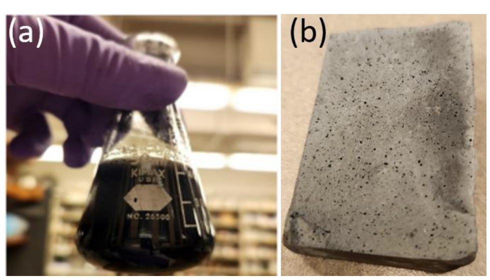

Figure 5. (a) High-Shear Mix Method: rCB blended with water; (b) paste sample made from it

Curing Procedure of Specimens: Mortar and paste samples were initially cured under a tarp in the molds for 12 hours. Samples were then transported to an environmental chamber at 50%RH and left to cure for an additional 12 hours. Next, half of the samples were placed in a VWR Symphony CO_2 curing chamber at 23°C with an RH of 95%±5% and CO_2 concentration of 20% for 12 hrs. The other half of samples were placed in a wet chamber with an RH of 95%±5% for 12 hrs. After this 12-hour period, all samples were placed in the wet chamber to cure until their corresponding tests. However, this method saturates the pores of the specimens, which is suspected to reduce CO_2 penetration.

To address this issue, a revised method was instead used for all mortar and paste samples to be analyzed. Mortar and paste samples were in-mold cured and precured in the same conditions. However, following that, half of the samples were placed in a VWR Symphony CO_2 curing chamber at 60°C with an RH ranging from 60%-90% and CO_2 concentration of 20% for 12 hrs. This CO_2 curing method is abbreviated as C. The other half of samples were placed in the environmental chamber with an RH of 50%±5% for 12 hrs. This method is referred to as alternative curing, and is abbreviated with the letter A. After this 12-hour period, all samples were cured in open-air at room temperature and approximately 40%RH after the comparison stage until their corresponding tests. A diagram of this process is shown in Figure 6, and it is the one used for the results summarized in this report. Note that the curing process is the same for both alternative curing and CO_2 curing except during the 12 hours of curing (from age 24 hours to age 36 hours), to be able to assess the effect of the 12-hour CO_2 curing.

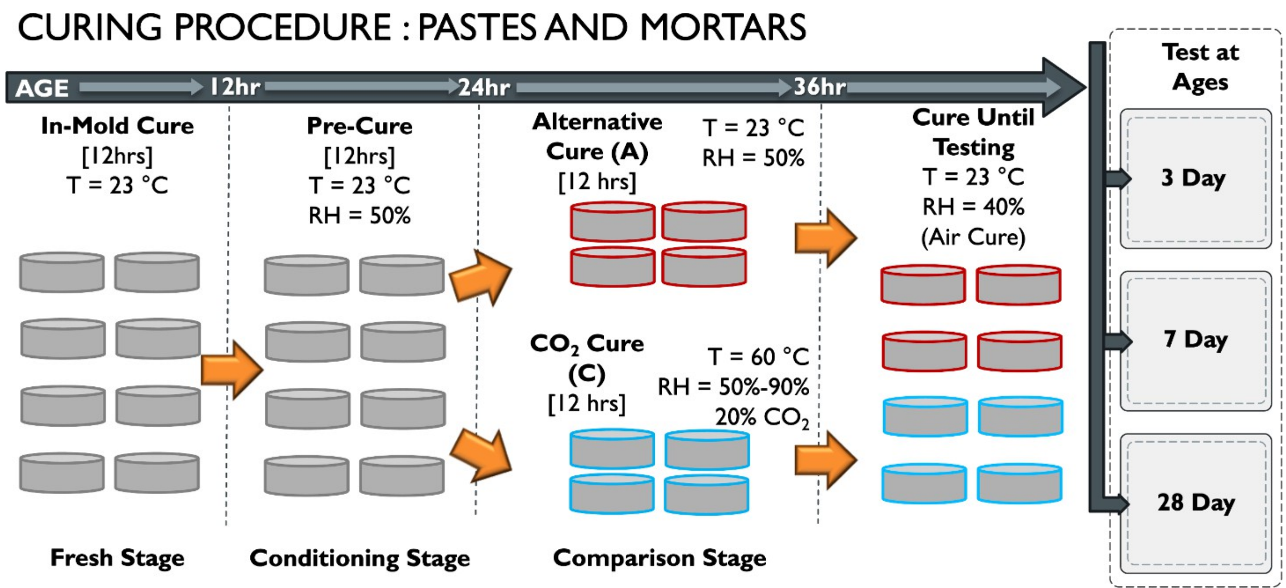

Figure 6. Curing Procedure for Pastes and Mortars

The curing procedure for concretes was adjusted to assess if a short CO_2 curing at 50°C (12 hours) followed by air curing can be a substitute for a longer period (24 hours) of 50°C wet curing process (emulating steam curing). After mixing and casting, the concrete samples were cured in covered plastic molds for 12 hours. Half of the samples were then transported to an environmental chamber at 50%RH and left to cure for an additional 24 hours, while the other half was submerged in a container of water at 50°C to imitate steam curing for 12 hours. This steam curing method is abbreviated as S. Following this 12-hour period, the samples were placed into a TR-HTX CO_2 chamber at 50°C with an RH ranging from 70%±5% and CO_2 concentration of 20% for 12 hrs. At

36 hours of age, all samples were cured in open-air at room temperature and approximately 40%RH after the comparison stage until their corresponding tests. A diagram of this is shown in Figure 7.

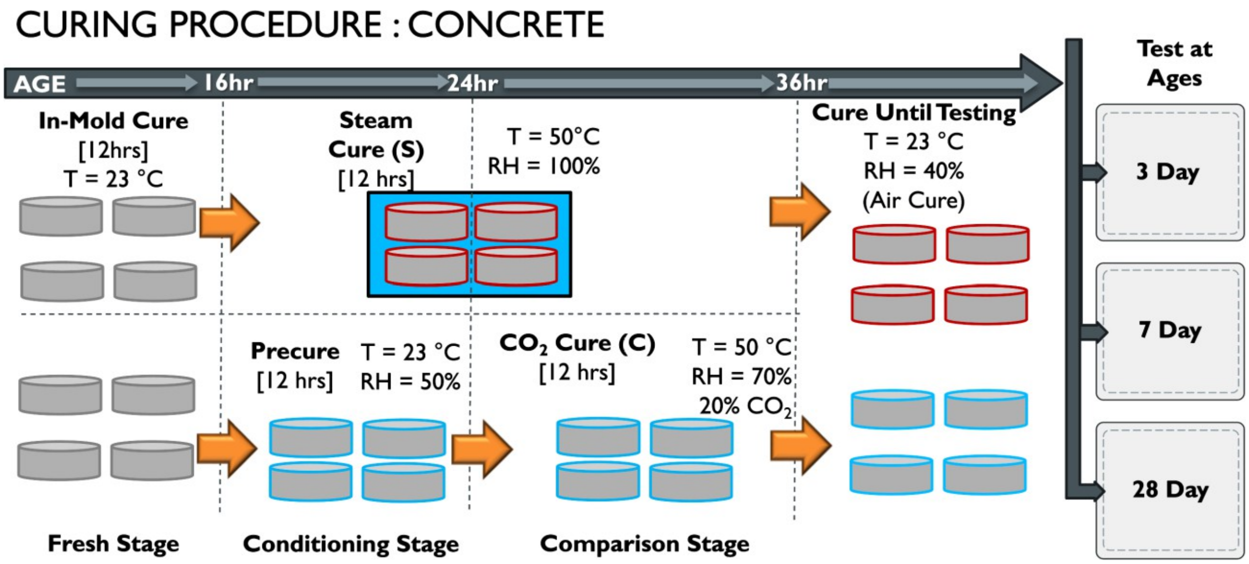

Figure 7. Curing Procedure for Concrete

Naming Conventions: The naming conventions of samples are organized by nanomaterial-percent concentration-(w/c)-curing condition. For example, R(0.42)C refers to a reference mixture with no nanomaterials at a 0.42 w/c that was CO_2 cured. NS1(0.48)A refers to a sample with 1% Nanosilica concentration at 0.48 w/c that was alternatively cured.

Task 3. Analysis of hydration process, porosity and microstructure

Methods: Image analysis of microstructure of concrete, captured via optical microscope, was used to directly quantify the characteristics of observable porosity. At the same time, water absorption and density tests were used to evaluate volume of porosity and the connectivity of the pores (ASTM C642[7], ASTM C1585[8]). Besides, the microstructure of samples was investigated through Scanning Electron Microscopy (SEM). The hydration kinetics and type of hydration products present in the pastes were evaluated by Isothermal Calorimeter test (IC), Thermogravimetric analysis (TGA) and X-ray diffraction (XRD) analysis.

Summary of main results: Isothermal calorimetry analysis of pastes at 0.42 w/c and 0.48 w/c was conducted for a 7-day initial hydration period. Results showed that in paste samples, nanomodification generally increases the peak heat flows. However, in mortars at 0.48 w/c, the peak heat flow is reduced with rCB nanomodification. An increase in rCB concentration reduces final setting time, however an increase in NS concentration increases the final setting time, varying from reference setting time by no more than 15 minutes.

TGA was performed on 0.42 w/c and 0.48 w/c pastes at 3 ,7, and 28 days of hydration. The Kim-Olek method[9] was used to quantify prominent compounds like $CaCO_3$ and Calcium Hydroxide (CH). Thermogravimetric analysis showed that CO_2 curing greatly increased the $CaCO_3$ content compared to standard curing. The incorporation of nano-additives is shown to increase the $CaCO_3$ content in higher w/c (0.48) samples at 3 days (Fig. 8) when used with CO_2 curing. The increase in $CaCO_3$ in samples translates into a prominent decrease in CH concentration. This reduction of CH resulting from carbonation can increase the durability of concrete, since CH is a harmful component in many durability issues (sulfate attack[10–12] , Calcium oxychloride formation[13–15] , Alkali Silica Reaction[15,16], CH leaching[17]). However, a CH reduction can affect the ability of concrete to protect steel reinforcement from corrosion due to the reduction of pH of concrete. Thus, reduction of CH content can be especially beneficial for the durability of non-steel reinforced precast elements, such as concrete blocks and concrete pavers, among others. Additional testing planned for phase II will determine the effects on the corrosion risk of steel reinforced concrete elements. The effects of CO_2 curing at early ages on the $CaCO_3$ content are not as prominent in samples with low water-to-cement ratio. This can be explained by the fact that the low porosity of low w/c mixtures combined with the reduction of porosity produced by the addition of nanoparticles (filling effect), can lead to a very low porosity that decreases the efficiency of CO_2 curing due to the lack of space for the diffusion of CO_2. Thus, the results indicate that higher w/c mixtures can benefit more for the combined effects of CO_2 curing and the use of nanoparticles.

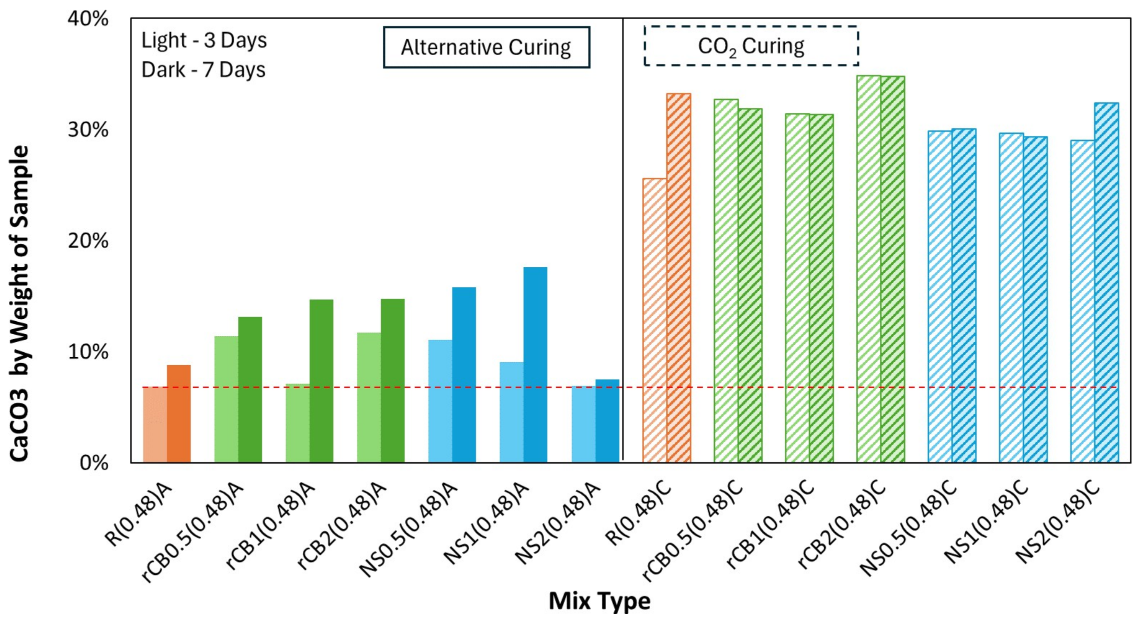

Figure 8. Concentration of $CaCO_3$ in the surface of 0.48 w/c pastes at 3 and 7 days of hydration

Scanning Electron Microscopy (SEM) of Pastes

Paste samples with 0.42 w/c and 0.48 w/c at 28-day age were epoxy impregnated and prepared as polished surface specimens for SEM analysis.

There is a visible difference between the cross-sections of the CO_2 cured and non-CO_2 cured samples. CO_2 cured samples generally have a distinct white layer at approximately 0.2 inches deep, whereas non-CO_2 cured samples either had a much thinner, fainter layer or lacked one entirely (Fig. 9). This transition zone is observable via SEM, where the white layer gradually changes from a denser more uniform structure to a more irregular one (Fig. 10).

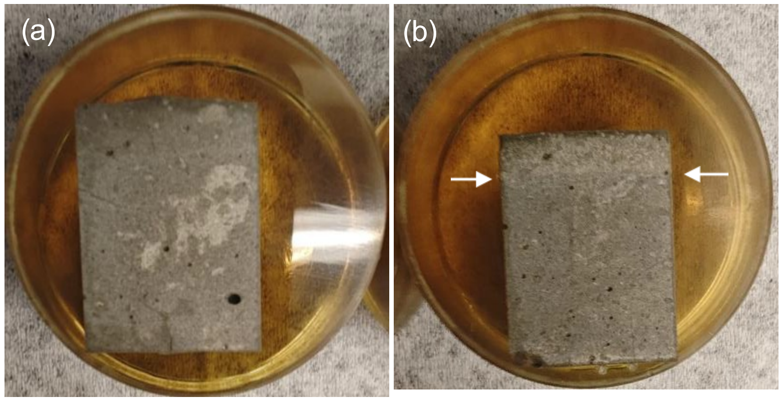

Figure 9. (a) Cross Section of NS2(0.48)A and (b) NS2(0.48)C paste samples

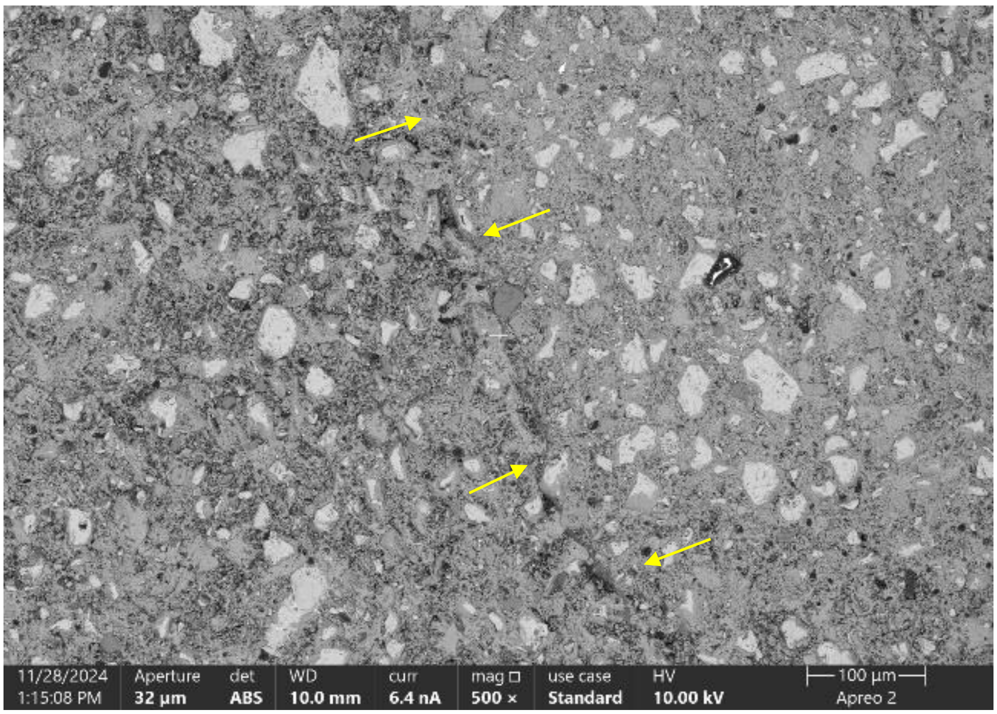

Figure 10. Transition zone in rCB2(0.48)C paste sample. The boundary between the white layer and the rest of the sample is indicated by the yellow arrows.

Energy dispersive x-ray (EDX) was used to assess the elemental composition of different samples. The results showed an increase in calcium content in CO_2-cured specimens, particularly in the transition zones. The more evenly dispersed calcium deposits can be seen in Figure 11.

Concrete samples at 0%, 2% rCB, and 2% NS nanomaterial concentrations were mixed and sliced into cylinders corresponding to sizes described in ASTM 1585 and are being conditioned for water absorption, density, and porosity testing. Cement paste samples have been prepared for XRD testing and analysis. The changes in the curing process, based on the results of previous tasks, led to additional testing that was not included in the initial plan. Additionally, while outreach activities were not part of Phase I initially, they were later incorporated. As a result of the extra testing and outreach efforts, the completion of the XRD test and analysis is now expected around the end of period for Phase I of the project.

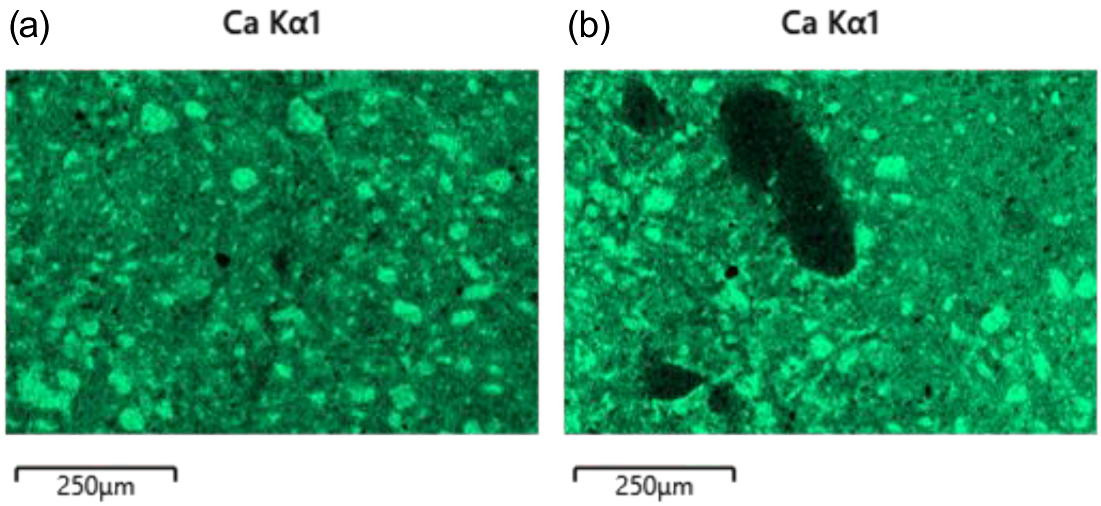

Figure 11. (a) Calcium detection map of rCB2(0.48)A; (b) rCB2(0.48)C at boundary locations, approximately 0.2 inches from sample surface

Task 4. Evaluation of transport properties

Methods: The bulk electrical resistivity and formation factor of the concrete samples will be estimated as per ASTM C1876-19[18]. The Rapid Chloride permeability test (ASTM C1202[19], AASHTO T357[20]) will be used to evaluate the resistance of the concretes to chloride ions ingress. The transport properties will be assessed through the analysis of the results of this section in combination with the results from the water absorption test performed in task 3.

Summary of main results: Concrete samples at 0%, 2% rCB, and 2% NS nanomaterial concentrations were mixed and sliced into cylinders corresponding to sizes described in ASTM 1202, ASTM C1876 and AASHTO TP 119 to be used for future bulk electrical resistivity, formation factor, and rapid chloride permeability testing. The changes in the curing process, based on the results of previous tasks, led to additional testing that was not included in the initial plan. Additionally, while outreach activities were not part of Phase I initially, they were later incorporated. As a result of the extra testing and outreach activities, the completion of this task is now expected by the end of December, right before the end of period for Phase I of the project.

Task 5. Compressive strength of mortars and concretes.

Methods: Compressive strength (f'c) tests have been performed for each mortar and concrete mixture at 3, 7, and 28 days, according to ASTM C109[21] and ASTM C39[22].

Summary of main results: Compression strength tests over time prove to yield different results on mortars and concretes, due to both their different compositions, and the difference in curing conditions. In mortars, CO_2 curing improves strength for all specimens relative to non-CO_2 cured samples at early ages of 3 (Fig. 12) and 7 days. While nanomodification alone is not showing an increase of early strength, in combination with CO_2 curing shows an increase on early strength compared to non-nanomodified samples under the same CO_2 curing conditions, especially for high contents of rCB and low contents of NS.

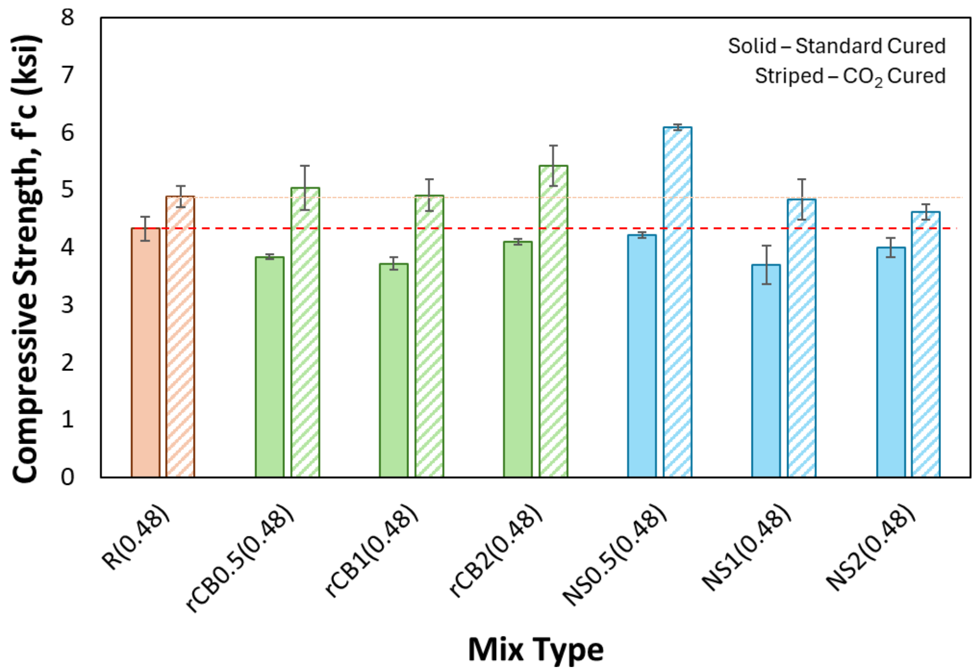

Figure 12. 3-Day f'c of 0.48 w/c Mortars

While for mortars were keep in the same curing conditions for all samples except during the 12 hours of CO_2 curing (Fig. 6), for concretes, we decided to compare a short CO_2 curing at 50°C (12 hours) followed by air curing vs a longer period (24 hours) of 50°C wet curing process (emulating steam curing) (Fig. 7), to assess if a short CO_2 curing followed by air curing can be a substitute of a longer period high temperature wet curing process. For concrete we observed that, while for non-nanomodified samples the CO_2 curing followed by air curing shows slightly lower 7-day strength than 24-hour 50°C water cured samples, when adding nanoparticles and CO_2 curing, we are able to achieve an early strength comparable or even higher than the strength of the reference mixtures (no nanomodified) cured with the 24-hour 50°C wet curing (Fig. 13). Thus, the combination of nanoparticles addition and 12-hour 50°C CO_2 curing process can provide comparable strength than non-nanomodified concretes with a 24-hour 50°C wet curing; reducing the time of high curing temperatures required into half.

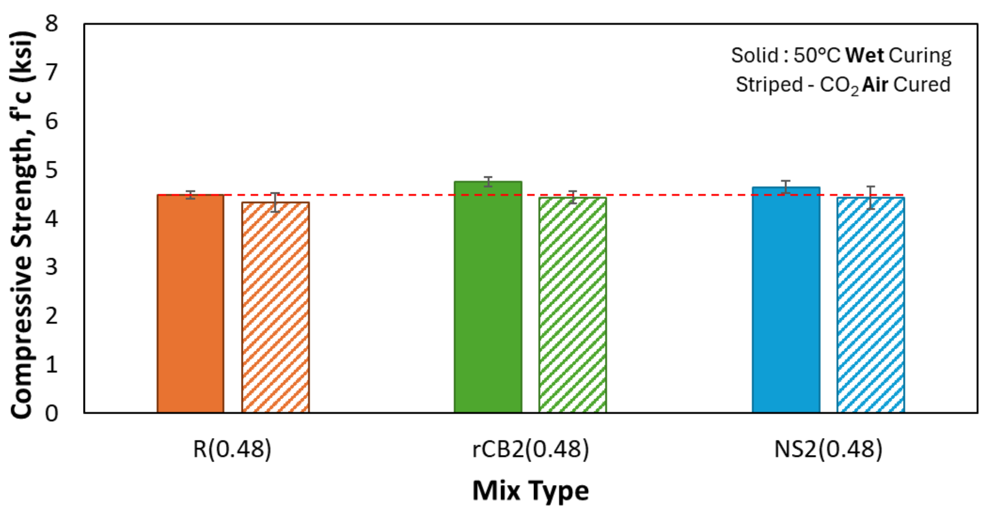

Figure 13. 7-Day f'c of 0.48 w/c Concretes

Recovered carbon black as a waste valorizing product may not only prolong the durability of mortars by improving strength but may also reduce greenhouse gas emissions through its reuse in precast structures. In combination with CO_2 curing, the use of rCB can provide similar strength to reference concretes with a continuous 24-hour 50°C wet curing process; thus, the combination of CO_2 curing and the use of rCB can reduce the curing time and avoid the need of high temperature wet curing for high w/c mixtures, while keeping or increasing the early strength of the precast element. The reduction of the curing time, avoiding a longer 50°C wet curing process, and enhancing the early strength of the precast elements can be very beneficial for the precast industry to increase the efficiency of their production process. Additional testing to optimize the CO_2 curing process is required to explore the full potential of this combination and to set the guidelines of the curing process for standard and nanomodified precast elements. These required testing and analysis is part of the Phase II of the project.

Task 6. Analysis of the results

Methods: A comparative analysis of the test results from tasks 1 to 5 for samples with and without nanoparticles and with and without CO_2 curing was carried out and described in tasks 1 to 5.

Summary of main results: Please, check the section "Conclusions and contributions" for additional information.

Task 7. Draft of the report, Review, and submission of Final report

This task was completed through the preparation and submission of this document.

<u>Educational Outreach</u> (additional tasks not included in the plan for Phase I):

<u>Minority in Engineering Program's "Purdue Promise"</u>: Purdue University's Minority in Engineering Program hosts "Purdue Promise" annually to encourage high school application and enrollment to Purdue university engineering schools.

On October 13th,2024, the graduate student (Aniya Edwards) working on this project and other members of the Lyles School of Civil and Construction Engineering hosted a tour for visiting highschoolers to give them a preview of the innovative engineering technologies. What was expected to be a group of 10 turned into 22 high school tourists by request. This project was featured with many others as a talking point for the tours. *Event information:* Minority in Engineering Program's "Purdue Promise": Civil Engineering Tours. Purdue University West Lafayette, Indiana. October 13th, 2024. (Fig. 14).

Figure 14. Highschool students that attended Purdue Promise 2024, almost half of which participated in the lab tours supported by this project. (Courtesy of the Minority in Engineering Program, Purdue University)

Civil Engineering (CE) Experience correspondence: A STEM education event hosted by the graduate student (Aniya Edwards) working on this project has been scheduled and confirmed by high school administration. This event has been planned to involve over 50 students and take place in the high school's new STEM and trades facility. *Event information:* Civil Engineering Experience: Merrillville High School, Merrillville, Indiana; December 2024. Note: The results of this event will be included in the first quarterly progress report of Phase II of this project.

Office of Undergraduate Research (OUR) Scholars: Three undergraduate 3rd-year Purdue students, all from minority or underrepresented groups, have earned university credit through this project, two of which have received scholarships through the OUR scholarship program at Purdue. For this program, students participate in research experiments, analysis, and create reports and presentations for their end of the year research symposium.

Workforce Development

Our team has had the opportunity to participate in several workforce development events through this project. A variety of presentations were given at these events, which provided clarity to industrial professionals interested in sustainable concrete practices. Examples:

TRANS-IPIC UTC 2024 Spring Workshop: 2024 Trans-IPIC UTC Workshop. 2024 TRANS-IPIC UTC Workshop. https://trans-ipic.illinois.edu/workshop (Fig. 15).

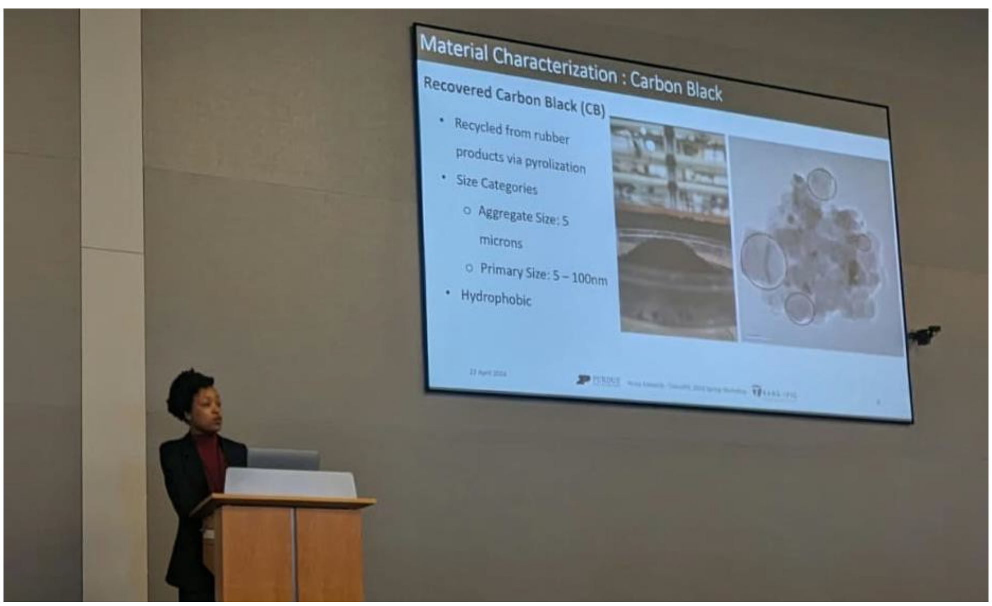

Figure 15. Research presentation by, Aniya Edwards (graduate student on this project), presenting the project results at TRANS-IPIC UTC Spring Workshop 2024, Rosemont,IL.

Future of Transportation Summit : *United Stated Department of Transportation Future of Transportation Summit – August 13th, 2024. List of Posters. FoT Summit. (n.d.). https://fot-summit.org/?page_id=692 (Fig. 16).*

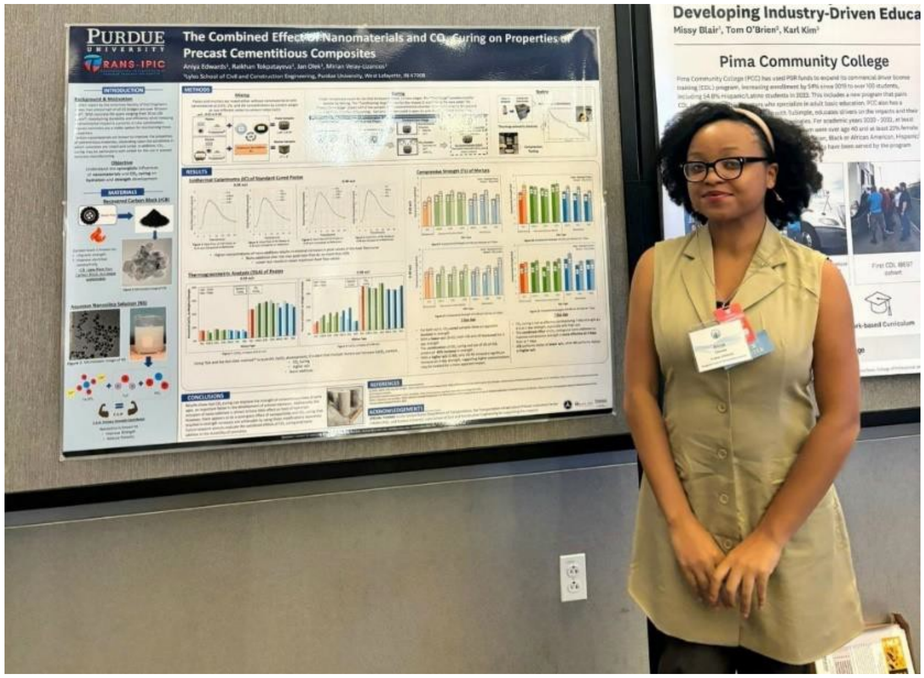

Figure 16. Poster presentation by the graduate student Aniya Edwards presenting the project results at the Future of Transportation Summit hosted by the USDOT at their headquarters in Washington D.C. in August 2024.

<u>TRANS-IPIC UTC Monthly Research Webinar:</u> Trans-IPIC Monthly Research Webinar - June, 2024. Illinois Media Space. (n.d.). https://mediaspace.illinois.edu/media/t/1_xt7op9zl

A fifteen-minute presentation was prepared and presented for the monthly research webinar hosted by TRANS-IPIC on June 17th, 2024. This presentation was made available to the public.

Technology Transfers

There is no progress on technology transfer yet.

Research Contributions

A draft of a research paper is in progress, and we expect to submit it by the beginning of 2025. It is expected that out of the data acquired during this first year, at least two peer-reviewed research papers will be published in top journals of our field.

Conclusions and Contributions

We have observed notable differences between the composition and mechanical characterization of CO_2-cured and standard-cured cementitious specimens with and without nano-additives (rCB and nanosilica). Thermogravimetric analysis showed that CO_2 curing greatly improved the $CaCO_3$ content in samples compared to standard curing. The incorporation of nano-additives is shown to increase the $CaCO_3$ content in higher w/c (0.48) samples at 3 days, especially for rCB when used with CO_2 curing. Results indicated that the combination of both CO_2 curing and nano additives resulted in the highest early compressive strength among all mixtures and curing conditions studied (which is very important for the precast production) while reducing the concentration of calcium hydroxide, thus potentially reducing the risk of durability issues such as calcium oxychloride formation. <u>Thus, results indicate that this combination can enable accelerated precast</u>

production while reducing the risk of durability issues of calcium oxychloride formation. Recovered carbon black, currently as waste product, may not only prolong the durability of mortars by improving strength but may also reduce costs and greenhouse gas emissions through its reuse in precast elements.

Outreach initiatives have been established across multiple levels. Presentations at the first annual *Future of Transportation Summi*t and the *TRANS-IPIC UTC Spring Workshop* were given to disseminate the initial findings about the effectiveness of these processes on early-age strength development for precast applications. Several undergraduate university students have been introduced to the experimental research processes through this project, mentored by the graduate student who is working on this project. Annual High School outreach events were established both within and outside of Purdue University to emphasize the importance of the precast construction, durability of the infrastructure, and engineering efficiency on well-being of our society.

References

1. ASTM C136 Standard test method for sieve analysis of fine and coarse aggregates. ASTM Int. Accessed December 30, 2023. https://www.astm.org/standards/c136.

2. Sieve analysis of fine and coarse aggregates AASHTO T 27 - in.gov. Accessed December 30, 2023. https://www.in.gov/indot/div/mt/aashto/testmethods/aashto_t27.pdf.

3. ASTM C127 Standard test method for relative density (specific gravity) and absorption of coarse aggregate. *ASTM Int*. Accessed December 30, 2023. https://www.astm.org/standards/c127.

4. ASTM C128-22 Standard Test Method for Relative Density (Specific Gravity) and Absorption of Fine Aggregate. *ASTM Int*. Accessed February 29, 2024.

5. ASTM C305-20 Standard Practice for Mechanical Mixing of Hydraulic Cement Pastes and Mortars of Plastic Consistency. *ASTM Int.* Accessed March 31, 2024. https://compass.astm.org/document/?contentCode=ASTM%7CC0305-20%7Cen-US

6. ASTM C192/C192M-19 Standard Practice for Making and Curing Concrete Test Specimens in the Laboratory. *ASTM Int.* Accessed September 30, 2024 https://compass.astm.org/document/?contentCode=ASTM%7CC0192_C0192M-19%7Cen-US

7. ASTM. C642-21 Standard Test Method for Density, Absorption, and Voids in Hardened Concrete. *ASTM Int*. Published online 2021:1-3. doi:10.1520/C0642-21.2

8. 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

9. T. Kim, J. Olek, “Effects of Sample Preparation and Interpretation of Thermogravimetric Curves on Calcium Hydroxide in Hydrated Pastes and Mortars”, *Transp. Res*. Rec. J. Transp. Res. Board, 10-18, 2290 (2012).

10. D. Bonen, M.D. Cohen, Magnesium sulfate attack on portland cement paste-I. Microstructural analysis, Cem. Concr. Res. 22 (1992) 169–180. https://doi.org/10.1016/0008-8846(92)90147-N.

11. D. Bonen, M.D. Cohen, Magnesium sulfate attack on portland cement paste — II. Chemical and mineralogical analyses, Cem. Concr. Res. 22 (1992) 707–718. https://doi.org/10.1016/0008-8846(92)90023-O.

12. M. Santhanam, M.D. Cohen, J. Olek, Mechanism of sulfate attack: A fresh look: Part 1: Summary of experimental results, Cem. Concr. Res. 32 (2002) 915–921. https://doi.org/10.1016/S0008-8846(02)00724-X.

13. P. Suraneni, J. Monical, E. Unal, Y. Farnam, J. Weiss, Calcium oxychloride formation potential in cementitious pastes exposed to blends of deicing salt, ACI Mater. J. 114 (2017) 631–641. https://doi.org/10.14359/51689607.

14. C. Jones, S. Ramanathan, P. Suraneni, W.M. Hale, Calcium oxychloride: A critical review of the literature surrounding the formation, deterioration, testing procedures, and recommended mitigation techniques, Cem. Concr. Compos. 113 (2020). https://doi.org/10.1016/J.CEMCONCOMP.2020.103663.

15. S. Chatterji, The role of Ca(OH)2 in the breakdown of Portland cement concrete due to alkali-silica reaction, Cem. Concr. Res. 9 (1979) 185–188. https://doi.org/10.1016/0008-8846(79)90024-3.

16. T. Kim, J. Olek, H.G. Jeong, Alkali-silica reaction: Kinetics of chemistry of pore solution and calcium hydroxide content in cementitious system, Cem. Concr. Res. 71 (2015) 36–45. https://doi.org/10.1016/J.CEMCONRES.2015.01.017.

17. C. Carde, R. François, Effect of the leaching of calcium hydroxide from cement paste on mechanical and physical properties, Cem. Concr. Res. 27 (1997) 539–550. https://doi.org/10.1016/S0008-8846(97)00042-2.

18. ASTM C1876 Standard test method for bulk electrical resistivity or bulk conductivity of concrete. (2024). *ASTM Int.* https://doi.org/10.1520/c1876

19. ASTM. C39/39M-21 Standard Test Method for Compressive Strength of Cylindrical Concrete Specimens. *ASTM Int.* Published online 2021:1-5. doi:10.1520/C0039

20. AASHTO. (2022). Predicting Chloride Penetration of Hydraulic Cement Concrete by the Rapid Migration Procedure. Techstreet viewer. https://online-viewer.techstreet.com/virtualviewer/launchViewer.jsp

21. ASTM. (2024, February 13). ASTM C109/C109M-23 Standard Test Method for Compressive Strength of Hydraulic Cement Mortars (Using 50 mm [2 in.] Cube Specimens). *ASTM Int.* Published online 2023:2-13 ASTM C109/C109M. https://compass.astm.org/document/?contentCode=ASTM%7CC0109_C0109M-23%7Cen-US

22. ASTM. C39/39M-21 Standard Test Method for Compressive Strength of Cylindrical Concrete Specimens. *ASTM Int*. Published online 2021:1-5. doi:10.1520/C0039