Transportation Infrastructure Precast Innovation Center (TRANS-IPIC)

University Transportation Center (UTC)

New Simplified and Adaptive Method for Quality Control of Precast Elements through Advanced NDT Evaluation
PU-25-RP-02

Quarterly Progress Report
For the performance period ending 06/30/2026

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

Project Description:

1. Research Plan - Statement of Problem

Premature removal of precast elements from the formwork, or transferring loads to pre-stressed elements before the concrete develops adequate strength, can result in damage to the precast element, as well as lead to significant accidents in extreme cases. Even in the cases where the damage is not visible, these premature operations cause microcracks and minor flaws that, while not initially affecting the serviceability of the element, will lead to reduced durability. These production-induced cracks are especially relevant for the durability of precast elements used in transportation infrastructure, as these elements are frequently exposed to moisture and deicing salts. When present, even small early cracks can accelerate deterioration from water ingress, freeze-thaw cycles, and chlorides, more so than in precast elements used in more sheltered applications (e.g, building components). On the other hand, performing these operations later than needed will result in a reduction of the productivity of the precast factories. Therefore, accurately determining the optimal timing for these operations is crucial for producing more durable concrete precast elements by preventing damage from premature handling while maintaining or even increasing production volume. Some methods, such as the maturity method [1,2], which relies on internal temperature measurements at single points [3], can estimate the evolution of compressive strength from limited data [4]. However, these approaches have significant drawbacks because they do not capture strength development across the entire element and therefore cannot detect heterogeneity between different regions of the elements.

Furthermore, methods that rely on internal sensors are impractical for implementation in every precast element produced because installing sensors in each unit requires significant labor and costly consumables (the internal sensors themselves). As a result, sensors are typically placed in only one or two elements, leaving the uniformity of strength development across the entire production unverified. Continuous, automated monitoring of early-age compressive strength in all precast elements would support more accurate decisions on form removal and load transfer, enabling producers to optimize production schedules and ensure durability. Therefore, a simplified, scalable, and cost-effective approach, that can be implemented in precast plants of any size, would significantly improve the timing of production operations and enhance the overall durability of transportation precast concrete elements.

2. Research Plan - Summary of Project Activities (Tasks)

Task 1: Materials acquisition, characterization, and mixture design selections. The first task involves acquiring the raw materials necessary to produce several concrete mixtures, characterizing each compound, and completing the mixture design of the cementitious composites, which will be used in subsequent tasks. Furthermore, trial batches will be conducted to adjust the mixtures and obtain reasonable parameters for a typical concrete used in the precast production of transportation elements. Relevance: This task is required to complete the following tasks.

Task 2: Empirical determination of the correlation between the evolution of the internal temperature(with a single sensor) and the external temperature measured with a thermal camera when the ambient temperature is 70°F. To be able to implement thermal cameras as part of an extended maturity method that tests every point of the precast element, a correlation between the internal temperature of the same and the surface temperature over time needs to be established.

To achieve this, Task 2 is divided into three subtasks:

Task 2.1. Cast of different sizes and shapes. Cubic specimens in at least three different sizes and cylindrical specimens in two different sizes will be cast to provide a range of sample volumes. In addition, to better represent the geometry of precast concrete elements such as girders or beams, custom molds, simulating common bridge-girder profiles (for instance bulb-tee or T-section geometries), will also be fabricated and used to cast scaled-down version of these elements in an attempt to capture the influence of aspect ratio, surface-to-volume effects, as well as potential temperature and moisture gradients encountered in full-scale precast members. Each specimen, regardless of shape, will be equipped with an internal sensor positioned at its geometric center to monitor temperature, moisture, and other relevant parameters during curing and testing.

Task 2.2. Temperature monitoring. The internal and external temperatures will be monitored and recorded using the internal sensor with a datalogger and an infrared thermal camera.

Task 2.3. Analyzing the data and determining the correlation between the external temperature and the internal temperature based on the volume of the sample and the distance between the internal sensor and the surface. Relevance: Task 2 will lay the foundation for simplifying the maturity method by utilizing external temperature monitoring instead of internal temperature, while accounting for internal temperature evolution through the use of these correlations. Further tasks are needed for that; this task is just providing the input data for the model to be developed in future tasks.

Task 3: Assess the effect of the ambient temperature on the correlation between the evolution of the internal temperature (with a single sensor) and the external temperature measured with a thermal camera. As many precast production facilities are not temperature-controlled, understanding the role of the ambient temperature on the correlations between surface temperature and internal temperature is required to develop a simplified method that can serve many different types of precast plants. To achieve this, we will need to repeat tasks 2.1 to 2.3, keeping the samples in a temperature-controlled chamber at both lower and higher temperatures than the reference temperature specified in Task 2.

Task 4. Train a model to estimate the internal temperature of concrete using the surface temperature history, the distance from the element's mass center to surface points, ambient temperature, volume of concrete, and the expected heat of hydration based on mixture design and binder type. The model will be trained with the data collected in Tasks 2 and 3.

Task 5. Test and validate the temperature model. A new batch of concrete will be prepared, and samples of sizes different from those used previously will be used to evaluate model accuracy. Additional samples will be cast if needed to refine, retest, and validate the model.

Task 6. Adapt the maturity method to estimate the compressive strength at internal and external points of the precast element using the estimated internal temperature values predicted by the model in Task 5, rather than assuming a uniform internal temperature. Validate these strength estimates by cutting the precast elements and performing compressive strength tests on both interior and exterior sections. The maturity of each cut piece of the element will be calculated using a spatially varying temperature history prediction from Task 5 rather than a single point internal temperature history that is commonly used in the maturity method. Then, the cut samples will be tested, and the measured strengths will be compared to the strengths predicted by the modified maturity method to assess the accuracy of the estimation.

Task 7. Develop guidelines for implementing the proposed simplified method to estimate early-age compressive strength at representative points of a precast element. Based on the results of previous tasks, develop guidelines for using thermal cameras instead of internal temperature sensors to apply the modified maturity method to the entire element. The model developed in Task 4 and tested and validated in Tasks 5 and 6, will be used to build a proof-of-concept tool that will automatically translate the data from a thermal camera and ambient temperature histories, along with mixture design information, into estimated compressive strength at any point of the element.

Task 8. Develop workforce training materials and make them publicly available on platforms such as YouTube and the TRANS-IPIC website. In addition to the written guidelines from Task 7, we will record and distribute videos covering: (i) the importance of timely removal of precast elements from forms, including the risks of premature or excessively delayed operations, (ii) the fundamentals of established methods for estimating early-age concrete strength in precast elements, and (iii) tutorials explaining the new simplified method developed in this project, including its advantages, limitations, and guidance for adapting it when mixture designs differ significantly from those used during model calibration.

Task 9. PI Submits Final DRAFT report to TRANS-IPIC for editing and publication

Task 10. Report Posted to TRANS-IPIC website

Project Progress:

3. Progress for each research task

   Task 1 [100% completed to date] *This task was completed in February 2026.* **Progress:** Three concrete mixtures were designed, and the raw materials (binders and aggregates) used for these mixtures were characterized in terms of density, gradation, chemical composition, and other relevant properties. Furthermore, trial batches were successfully completed, resulting in the identification of reasonable mix design parameters representative of concrete commonly used in the precast manufacturing of transportation infrastructure elements.

Task 2 [100% completed to date] *This task started in February, as scheduled, and all sub-tasks were completed by May 2026.* **Progress** details for sub-tasks 2.1-2.3 are described below.

Task 2.1. Cubic specimens of three sizes (100 mm, 150 mm, 200 mm) and cylindrical specimens of two sizes (4”x8” & 6”x12”) were fabricated. Additionally, an I-shape geometry mold was manufactured, and a beam specimen (4”x4”x15”) was produced to represent a scaled-down version of common precast bridge-girder profile. **Task 2.2.** The measurements were performed inside a controlled environmental chamber. The chamber is a 4 ft × 4 ft × 10 ft fully enclosed space designed to enable regulated experimental conditions, including temperature, humidity, and airflow. Its walls, floor, and ceiling are constructed from a multilayer fabric system consisting of black Oxford 600D nylon, 340 g lightproof PF material, and a 16 µm Mylar layer. Within this chamber, an infrared thermal camera and temperature sensors with data loggers were used to monitor the external and internal temperatures of the reference mixture across all 7 listed specimen sizes over 7 days at 90-second intervals. Additionally, the chamber's ambient temperature was recorded at 90-second intervals for 7 days. **Task 2.3.** Analysis of the external and internal temperature histories for all 7 listed mold sizes of the reference mixture was completed. The analysis established a correlation between specimen volume, the distance from the embedded temperature sensor to the specimen surface, and the resulting thermal gradients. Figure 1 shows the temperature difference between the internal sensor and the maximum and minimum surface temperatures over 7 days. As shown in Figure 2a, specimens with higher volume generally exhibited a greater temperature difference between the internal and external surfaces, except for the cylinders. Furthermore, specimens with centroids farther from the surface (larger d_{top}) generally exhibited larger differences, except for beams (Figure 2b). The observed deviations for the cylinders and beams are likely attributable to their aspect ratios, which differ significantly from the 1:1:1 geometry of cubic specimens. To account for these geometric effects, the distance parameter (the physical distance between the surface and the center of the specimen, labeled d_{top}) was normalized by multiplying d_{top} by the width-to-height ratio as a scaling factor. This normalization (d_{norm}) produced a stronger correlation between specimen geometry (volume and normalized sensor-to-surface distance) and the measured temperature differentials, as shown in Figure 2c.

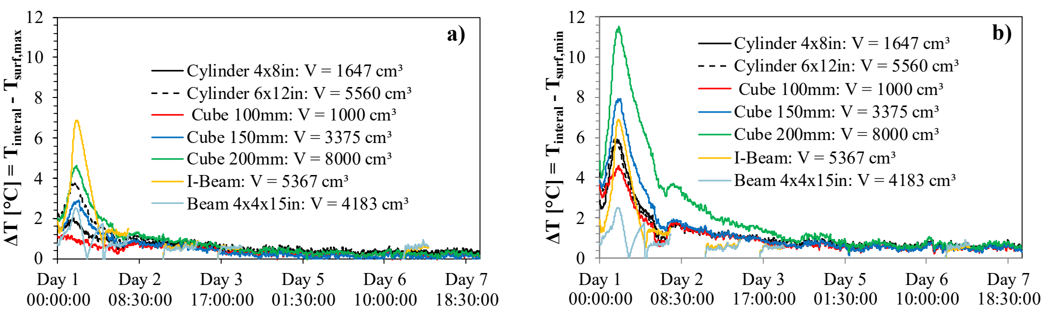

Figure 1. Evolution of the temperature difference between the internal temperature and the (a) maximum and (b) minimum external surface temperatures.

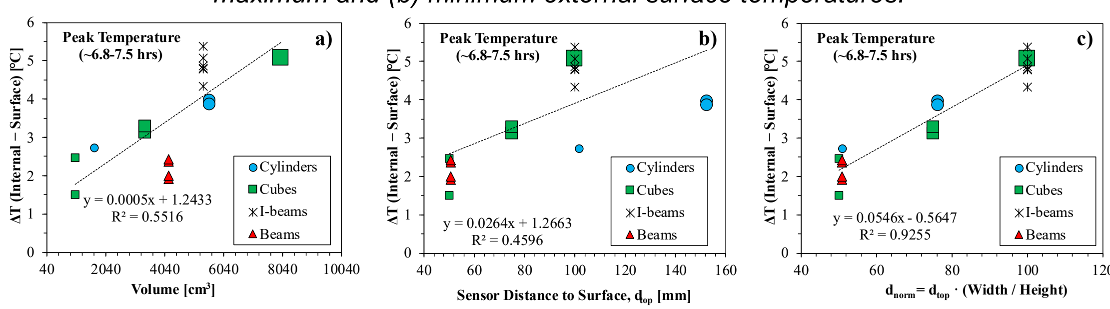

Figure 2. Correlation of internal and surface temperature difference at peak internal temperature with a) sensor distance to surface (d_{top}); b) volume; c) d_{top} normalized using the width/height ratio.

Task 3 [60% completed to date] *This task began on the proposed schedule for April 2026 and is projected to be completed by August 2026.* **Progress:** The experimental campaign has been finalized, and additional equipment (a space heater and a fan) has been acquired. The high-temperature experiment (35 °C) is currently in progress, having started on 6/30/2026, and is scheduled to be completed on 7/7/2026. The lower-temperature experiment (15 °C) is scheduled to begin 7/13/2026 and conclude on 7/20/2026. Therefore, the entire task 3 will be completed on 7/21/2026.

Task 4 [60% completed to date] *This task began in April 2026, 2 months ahead of the proposed June 2026 start date, and is projected to be completed by the proposed September 2026 date.* **Progress:** A finite difference method (FDM) model based on the transient heat conduction equation (Figure 3) has been developed using ambient temperature, external concrete surface temperature, heat of hydration, concrete geometry, concrete volume, and the thermal properties of concrete (thermal conductivity, diffusivity, and specific heat capacity). The model can fully reconstruct the dimensional temperature field of a concrete specimen, with the temperature at any interior location predicted from the measured surface temperatures (Figure 4). The model has been trained using 13 specimens, using two specimens of each size except for one 200 mm cube, for which only one specimen was available. Additional model training and refinement will be performed as needed based on the results obtained from Task 3.

Rate of thermal energy storage | Thermal Conduction | Equivalent Heat generated from hydration

$$\rho c_p \left(\frac{\partial T}{\partial t}\right) = k\nabla^2 T + \dot{Q}_{\text{node}}(t)$$

1. $k_T(T) = \exp\left(-\frac{E_A}{R}\left(\frac{1}{T_{air}} - \frac{1}{T_{REF,K}}\right)\right)$
2. $t_{eq}(t + dt) = t_{eq}(t) + dt \cdot k_T(T_{local})$
3. $\dot{Q}_{node} = Q_{IC}(t_{eq}) \cdot k_T(T_{local})$

Figure 3. Governing heat-transient equation for the finite difference (FDM) model.

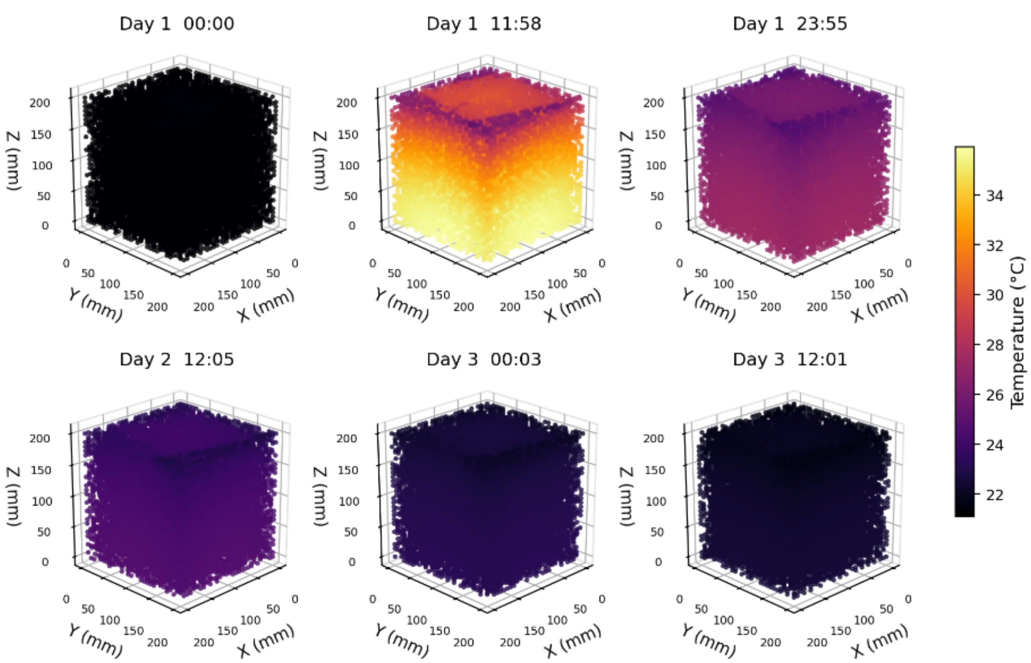

Figure 4. 3D reconstruction (200 mm cube) obtained using the surface temperature field and model.

Task 5 [25% completed to date] *This task was started in June 2026, 1 month earlier than the proposed July 2026 start date, and is projected to be completed by the proposed October 2026 end date.* **Progress:** Initial testing of the model has been completed through validation using the internal concrete temperatures measured by the sensors. By calculating the predicted centroid temperature with the measured internal sensor temperature for all 13 specimens over the entire 7-day duration. Low errors were observed (Figure 5). Additional validation will be conducted using new batches of concrete.

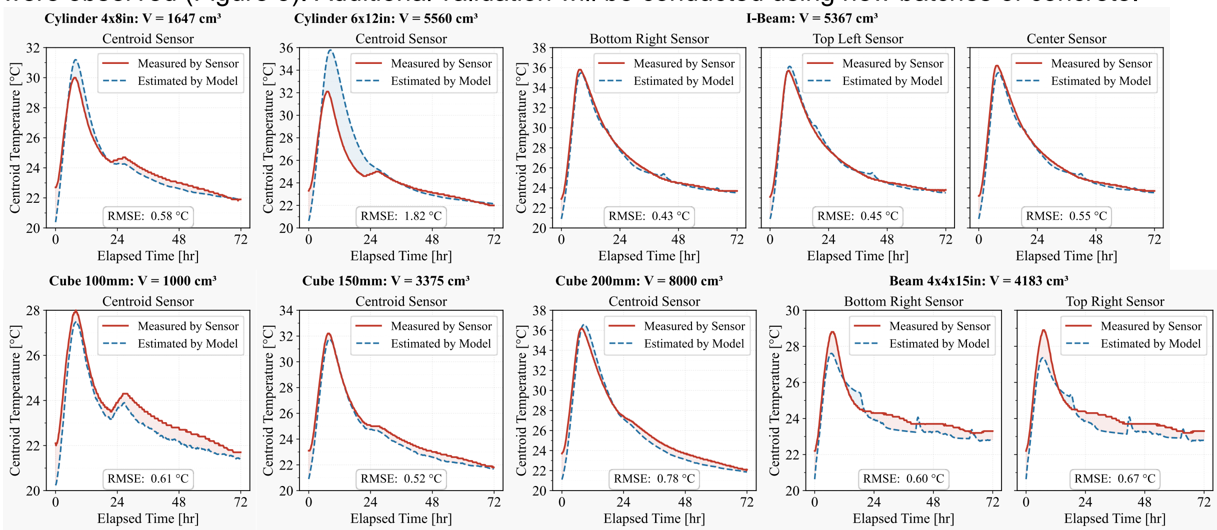

Figure 5. Validation of the FDM heat-transient model through comparison of measured and predicted internal temperatures at the specimen centroids.

Task 6 [50% completed to date] *This task was started in February 2026, 5 months earlier than the proposed July 2026 start date, and is projected to be completed by the proposed October 2026 date.* **Progress:** We have begun this task by performing the experiment to obtain activation energy (ASTM C1074). The materials and equipment for the experiment were acquired. We also finalized the experimental design and logistics for the activation energy experiment. Besides, we have completed the activation energy and datum temperature determination for Reference and Fly Ash (Table 1). Results for the third mixture will be completed by August 2026.

Table 1. Activation energy and datum temperature of the 1st (reference) and 2nd (25% fly ash) mixtures.

Mixture	Datum Temperature (T_0)	Q	Activation Energy (E_a)
Reference	-2.64 °C	3,283 K	27,295 *J/(mol·K)*
25% Fly Ash	1.74 °C	4,168 K	34,653 *J/(mol·K)*

Task 7 [10% completed to date]. *This task was started on the proposed schedule for June 2026 and is projected to be completed by the scheduled end date of November 2026.* **Progress:** Began documentation of procedures for the proposed model. This includes information on camera usage and settings; material property (physical, thermal, and hydration) selection based on mixture design; required data measurements; and an explanation of the FDM model and 3D thermal reconstruction.
Task 8 [0% completed to date]: *The proposed schedule has this task beginning in July 2026.*
Task 9 [0% completed to date]: *The proposed schedule has this task beginning in November 2026.*
Task 10 [0% completed to date]: *The proposed schedule has this task beginning in December 2026.*

4. Percent of research project completed

   An additional 25% of the project was completed this quarter, bringing the total to 50% completed.

5. Expected progress for next quarter

   We expect to continue achieving 100% completion of tasks 3 and 4, and 75% completion of task 5, 90% completion of task 6, and 67% completion of task 7. Furthermore, we will begin and expect to have 60% completion of task 8. Thus, the project is and will be on track with the proposal's schedule.

6. Educational outreach and workforce development

   N/A

7. Technology Transfer

   N/A

Research Contribution:

8. Papers that include TRANS-IPIC UTC in the acknowledgments section (2026):

   [1] Aniya Edwards, Rui Bai, Raikhan Tokpatayeva, Jan Olek, Mirian Velay-Lizancos, "Effect of relative humidity on the effectiveness of CO_2 in recovered carbon black nanomodified mortars", Trans-IPIC Workshop (Conference paper), 2026 [Submitted]

   Note: Papers for this new project that started in January are being prepared, but not finished yet.

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

   [1] Aniya Edwards, Raikhan Tokpatayeva, Jan Olek, Mirian Velay-Lizancos, "Advanced curing methods and nanomodification for accelerated production of durable precast elements: Opportunities and challenges." Presentation, Trans-IPIC Workshop, Rosemont 2026.

10. Please list any other events or activities that highlights the work of TRANS-IPIC occurring at your university (please include any pictures or figures you may have). Similarly, please list any references to TRANS-IPIC in the news or interviews from your research.

    N/A

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. = 1 (from January 2026) + 7 (from the beginning of the UTC)

B. Number of peer-reviewed publications submitted based on outcomes of UTC funded projects
   - No. = 1

C. Number of peer-reviewed journal articles published by faculty.
   - No. = 1

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 = 2 (in progress)
   - No. citations of each of the above = N/A (the dissertation is not public yet)

F. Number of research tools (lab equipment, models, software, test processes, etc.) developed as part of TRANS-IPIC sponsored research
   - Research Tool #1 (Name, description, and link to tool) = Radiometric and FDM Code (pending finalizing workflow and improved interactiveness)

G. Number of transportation-related professional and service organization committees that TRANS-IPIC faculty researchers participate in or lead.
   - Professional societies
     - No. participated in = 7
     - No. lead = 1
   - Advisory committees (No. participated in & No. led)
     - No. participated in = 3
     - 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 = 1
     - No. lead = 0

H. Number of relevant awards received during the grant year
   - No. awards received = 1

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 = 0
   - No. of full-time positions = 1

References:

[1] V.M. Malhotra, N.J. Carino, Handbook on nondestructive testing of concrete, CRC Press, 2004.

[2] ASTM Committee C09.64, ASTM C1074-11 Standard Practice for Estimating Concrete Strength by the Maturity Method, in: Annual Book of ASTM Standards Volume 04.02, 2015: p. 10. https://doi.org/10.1520/C1074-11.

[3] M. Velay-Lizancos, I. Martinez-Lage, P. Vazquez-Burgo, The effect of recycled aggregates on the accuracy of the maturity method on vibrated and self-compacting concretes, Archives of Civil and Mechanical Engineering 19 (2019) 311–321. https://doi.org/10.1016/J.ACME.2018.11.004.

[4] A. Luke,W. Konon, S. Punurai. Maturity method in prestressed concrete applications, FHWA NJ 2004-022; New Jersey Department of Transportation Bureau of Research and Technology and U.S. Department of Transportation Federal Highway Administration, 2004.

[5] ASTM C33 – 24: Standard Specification for Concrete Aggregates, ASTM International Journal (2024).

[6] ASTM C127 - 25: Standard Test Method for Relative Density (Specific Gravity) and Absorption of Coarse Aggregate, ASTM International Journal (2025).

[7] ASTM C136 - 25: Standard Test Method for Sieve Analysis of Fine and Coarse Aggregates, ASTM International Journal (2025).

[8] ASTM C33 – 24: Standard Specification for Concrete Aggregates, ASTM International Journal (2025).

[9] ASTM C604 - 18: Standard Test Method for True Specific Gravity of Refractory Materials by Gas 644 Comparison Pycnometerr, ASTM International Journal (2023).