Coast-to-Coast Concrete: Exploring Hydration Control for Sustainable Construction Practices

by Mark A. Bury and Carlito Cascone

Concrete in its plastic state is perishable, as hydration (the reaction between cement and water) causes fresh concrete to lose its initial fluidity. The resulting limited working time creates challenges with concrete construction projects, especially those with extended haul times, placement delays, or multi-stage concrete placements. To address these and other challenges, a hydration-controlling admixture (HCA) can be introduced into the concrete mixture at a low dosage to temporarily suspend the hydration process. Additionally, an HCA can be used at higher dosages to keep returned fresh concrete sufficiently fluid to be recycled by combining it with newly batched concrete.

This article provides an overview of an HCA, its use for recycling returned concrete, a system addressing returned concrete process management using innovations in sensors and artificial intelligence (AI), details on a robustness evaluation of stabilization performance in a unique cross-country experiment, and information on the potential for lowering the environmental impacts of concrete production.

Hydration-Controlling (Stabilizing) Admixture

Development of an HCA began in the early twentieth century as admixture scientists sought ways to improve concrete's properties, including extending its workability. Early retarding admixtures provided hydration control, but inconsistencies in performance limited their practical use where precise control was needed for challenging construction projects.

The next generation of retarding admixtures emerged as a potential solution because of their ability to retard concrete setting time. However, these admixtures presented dosing challenges because concrete setting times could vary depending on the type and concentration of the chemistry, as well as the specific concrete mixture. To address the inconsistencies of early retarding admixtures and the challenges posed to concrete producers in dealing with returned concrete waste from projects, researchers developed a novel HCA that offers a controlled and predictable response.[1] A modern HCA (also known as a hydration-stabilizing admixture [HSA]) can regulate the hydration process more consistently, allowing producers to control concrete's setting properties, thus allowing contractors to build more effectively. An HCA achieves this by slowing or halting the hydration reactions in concrete (stabilizing the concrete or putting the concrete to sleep), providing a controlled delay in setting time without compromising the mixture's strength or durability.

HCAs meeting the performance requirements of ASTM C494/C494M, Type B, retarding, and Type D, water-reducing and retarding admixtures,[2] have become essential in modern construction. Because these admixtures provide predictable and precise results, they improve efficiency on construction sites by enabling contractors to accurately schedule work.

Reusing Returned Plastic Concrete

It is common for extra concrete to be returned to the producer's plant for disposal. Aggregates can be reclaimed from fresh returned concrete using a recovery plant, fresh returned concrete can be placed in forms to produce precast concrete blocks, or hardened returned concrete can be crushed to produce fill or recycled concrete aggregate, however, these options may not be economical or sustainable. Alternatively, adding an HCA to a returning plastic concrete mixture can preserve this concrete and keep it fresh for subsequent reuse. ASTM 1798/1798M-19, "Standard Specification for Returned Fresh Concrete for Use in a New Batch of Ready-Mixed Concrete,"[3] is the relevant industry standard. The basic steps for treating and reusing returned plastic concrete are shown in Fig. 1.

The durability aspects of reusing returned plastic concrete in subsequent composite mixtures have been evaluated,[4] including testing to assess the susceptibility of the composite concrete to cracking due to drying shrinkage. For example, a concrete testing program was conducted using concrete specimens measuring 3.5 x 3.5 x 40 in. (890 x 890 x 10,160 mm), as shown in Fig. 2. Each specimen contained a 1 in. (25 mm) diameter steel bar running through its center. The bar was pinned at the ends using steel rods for restraint, while the middle two-thirds had a rubber sleeve as a bond breaker, allowing the concrete to shrink freely.

Table 1 summarizes the results of a comparative durability study by Senbetta and Bury[4] examining the difference between traditional concrete and a combination of recycled, preserved fresh concrete with newly batched fresh concrete at a 33 to 67% ratio, respectively.

The data from this study showed that none of the durability-related parameters were adversely affected by the use of an HCA as part of a treated concrete composite mixture. On the contrary, the compressive strength, performance parameters relevant to corrosion of steel, and susceptibility of concrete to cracking were improved.

Operational Efficiency Using Digitalization Tools

Although the practice of stabilizing returned plastic concrete for reuse has been done for decades, the process has not been without its challenges for producers. Some of these challenges include measuring and monitoring the slump, temperature, and quantity of returned concrete, as well as tracking the mixture proportions. Each of these tasks can be labor-intensive and require significant administrative resources.

Recent developments in concrete sensor technology, AI, and digitization have enabled the development of a relevant software platform for concrete producers. This new digital tool facilitates the implementation of a returned concrete program using real-time, accurate data with minimal labor requirements, starting as early as the beginning of the truck's return trip to the plant. The innovative platform (MasterAtlas™) has the capabilities of collecting, storing, and sending concrete information, providing admixture dosage suggestions, and providing automated alerts to both dispatch teams and quality control personnel to manage the returned concrete process more easily. Furthermore, the platform has capabilities to document and report information for managing returned concrete business activities and audits, such as profitability enhancements and lowered carbon dioxide (CO_2) emissions values, thereby enhancing operational efficiency and sustainability initiatives. The software platform provides a variety of ways to analyze the data relating to returned concrete and can be customized for the producer's operation based on the desired outputs.

History-Making Experimentation

To further evaluate the performance of an HCA, a unique experiment was initiated to test the limits of cement hydration control. The concept of the experiment was to batch and keep concrete fresh (plastic) for a period of 7 days using an HCA while transporting it across the United States from coast to coast, ultimately recycling it into a fresh concrete composite mixture.

Laboratory Feasibility Study

To prepare for the long-haul experimentation, a lab feasibility study was performed to find out if concrete could be kept fluid for at least a week. The goal was to determine the required dosage of the HCA. The lab study explored innovative concrete mixing techniques and tested three distinct concrete mixtures:

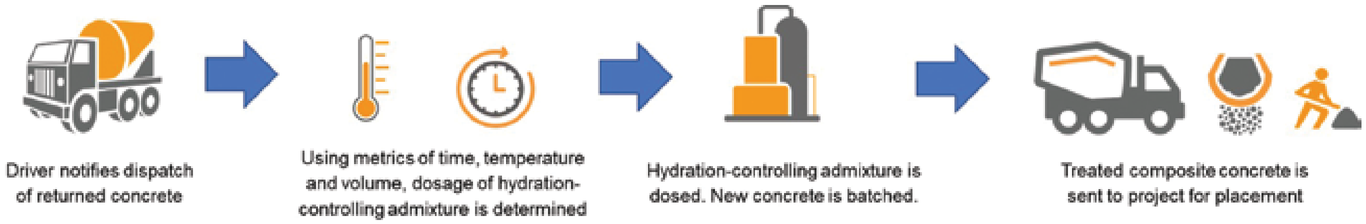

Fig. 1: Steps for treating and reusing returned plastic concrete

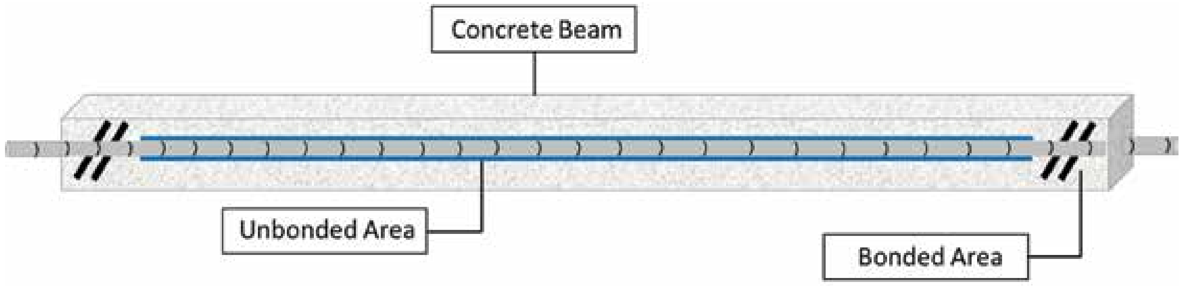

Fig. 2: Sample specimen used in the concrete testing program

- Reference concrete;
- Concrete treated with an HCA; and
- Composite concrete (25% of recycled concrete and 75% of fresh concrete).

The mixture proportions for the lab batches are shown in Table 2. The reference concrete was proportioned as a traditional mixture using Type IL cement. The reference mixture was designed to achieve good workability characterized by a high slump, a moderate concrete set, and strong compressive and flexural strength at 28 days. The second mixture had the same mixture proportions but also contained an HCA for maintaining fluidity for at least a week. The third concrete mixture was a recycled composite mixture comprising 25% stabilized recycled concrete and 75% fresh concrete by mass, which was designed to simulate returned concrete being reused in a new mixture. A unique combination of innovative admixtures was used in the composite mixture to help initiate hydration ("wake up the concrete") after being stabilized for 7 days. The admixture combination included the use of a high-range water-reducing admixture, a strength-enhancing admixture,[5] a nonchloride set-accelerating admixture, and synthetic macrofibers.

The lab results shown in Table 2 highlight several key observations:

Table 1:
Results of a comparative durability study

Performance attribute	Treated concrete relative to reference concrete			Treated concrete comparison
	3 days	7 days	28 days	
Compressive strength	+21%	+7%	+6%	Better
Freezing and thawing	101% of reference			Similar
Hardened air void analysis	Good spacing factors and specific surface			Similar
Long-term corrosion test	Lower corrosion current			Better
Short-term corrosion test	Stable passivation layer			Similar
Abrasion	+5%			Similar
Absorption	−5%			Similar
Permeable void volume	−5%			Similar
Susceptibility to cracking	75% less potential			Better

Table 2:
Laboratory concrete mixture proportions with plastic and hardened concrete properties

Concrete mixture composition and plastic and hardened concrete properties	Reference mixture	1-week hydration-controlled mixture	75% fresh concrete + 25% returned concrete mixture
Type IL cement, lb/yd^3 (kg/m^3)	705 (418)	705 (418)	529 (314)
Coarse aggregate, lb/yd^3 (kg/m^3)	1584 (940)	1583 (939)	1188 (705)
Fine aggregate, lb/yd^3 (kg/m^3)	1296 (769)	1295 (768)	972(577)
Returned concrete, lb/yd^3 (kg/m^3)	—	—	984 (584)
Water, lb/yd^3 (kg/m^3)	353 (209)	353 (209)	264 (157)
Water-reducing admixture, fl oz/cwt (mL/100 kg) cement	1 (0.65)	1 (0.65)	—
Hydration-controlling admixture, fl oz/cwt (mL/100 kg) cement	—	90 (58.5)	—
High-range water-reducing admixture, fl oz/cwt (mL/100 kg) cement	—	—	3 (1.95)
Set accelerating admixture, fl oz/cwt (mL/100 kg) cement	—	—	60 (39)
Strength enhancing admixture, fl oz/cwt (mL/100 kg) cement	—	—	40 (26)
Synthetic fiber, lb/yd^3 (kg/m^3)	—	—	1.5 (0.9)
Slump, in. (mm)	8.75 (222)	9.50 (241)	9.50 (241)
Air content, %	1.6	2.1	1.1
28-day compressive strength, psi (MPa)	6580 (45)	—	7910 (55)
28-day flexural strength, psi (MPa)	530 (4)	—	660 (5)
Initial setting time, hours	3.5	—	7.8
Final setting time, hours	5	—	11.4

- All three mixtures had high workability/slump;
- The use of different combinations of admixtures had minimal effect on the air content of the mixtures;
- The selected HCA at a 90 fl oz (5.85 L/100 kg) dosage could maintain concrete fluidity (freshness) for a week; and
- The composite mixture had a noticeably extended setting time compared to the reference mixture; however, it had much higher compressive and flexural strength performance.

The goal of the lab study to determine the dosage of the selected HCA required for keeping the concrete plastic for 7 days was achieved. The lab study further showed that a composite mixture using a portion of the highly stabilized concrete could still achieve good compressive and flexural strengths. In practice, the use of an additional accelerating admixture could have helped achieve a similar setting time compared to the reference mixture. The appropriate dosage of an accelerator for this purpose is generally achieved by performing a mockup evaluation. The extreme concrete stabilization success in the lab study confirmed that a cross-country trip with fresh concrete is possible if treated with an HCA.

Cross-Country Concrete Transport

The concrete mixture proportions used for the experimental cross-country trip were the same as those used in the 1-week hydration-controlled mixture from the lab study. The 8-day event is summarized in the following:

Day 1

The experiment began in Eastport, ME, USA, the easternmost city in the continental United States, on the Bay of Fundy. The concrete ingredients and mixing equipment were pre-shipped to that location for batching and mixing at a local hotel parking area.

Day 2

A volume of 2 ft^3 (0.06 m^3) of concrete was mixed at 5:00 a.m., stabilized (put to sleep) with the selected HCA, and loaded into a hybrid SUV for transport across the country to its destination of San Francisco, CA, USA. The concrete was mixed to a fluid consistency of 10 in. (254 mm) spread as measured by a mini-slump cone. After measuring the spread and temperature, eight 5 gal. (18.9 L) pails, each containing 0.25 ft^3 (0.007 m^3) of concrete, were loaded into the SUV and the 7-day journey began. The initial check of the concrete was a visual inspection of the fluidity at a stop at America's first inn, the Wayside Inn, in Boston, MA, USA. The journey then continued westward. After a 12-hour (total) drive to Seneca Falls, NY, USA, the concrete was still fluid, far exceeding the typical flowing concrete shelf life.

Day 3

An early morning check of the concrete on Day 3 revealed that the concrete was stiffer than expected, perhaps due to settling and particle packing induced by the continuous vibration in the SUV. The concrete was restored to its original, homogeneous, fluid state by stirring the concrete for approximately 1 minute using a paddle mounted on a battery-driven drill. From this point forward, the concrete was mixed each morning, and the concrete fluidity and temperature measurements were taken. Day 3 of the experiment ended in Portage, IN, USA.

Day 4

On Day 4, the concrete was transported through Chicago, IL, USA, and Madison, WI, USA, finally reaching Mitchell, SD, USA. Along this route, many traffic delays were encountered.

Day 5

The day began with a visit to Mount Rushmore, where stabilized concrete in a pail nicknamed "Concrete Connie" quickly became a second tourist attraction (Fig. 3). Because of the unique face affixed to the pail and after hearing about the experimental trip by the author in real time, visitors took photos with the now famous stabilized concrete. Before the day ended, the concrete was transported for an additional 14 hours to Denver, CO, USA.

Day 6

At 4:00 a.m., the concrete was mixed, and the temperature recorded. The temperature and fluidity measurements revealed hydration was dormant, as the data showed no reaction activity. The cross-country journey resumed with Las Vegas, NV, USA, as the Day 6 destination.

Day 7

The final day of travel had the stabilized concrete visiting Hoover Dam, an iconic landmark for the concrete industry, before ultimately arriving in San Francisco, CA. The concrete was mixed and found to be plastic after 7 days of transporting.

Day 8

The final morning of the experiment began at 5:00 a.m., where the concrete's fluidity was confirmed. A local concrete producer in San Jose, CA, helped evaluate the week-old concrete by treating it like returned stabilized concrete and simulating the recycling process by mixing it with fresh concrete at a 25% recycled concrete and 75% fresh concrete ratio by mass. The proportions of the fresh concrete are shown in Table 3. The fresh concrete, (the "wake-up mixture"), was the same as that used in the lab evaluation but also contained a concrete conditioning admixture (CCA) to help facilitate the workability of the composite mixture.

A CCA is a new class of liquid admixture developed to enhance and expand the robustness of all properties associated with handling fresh concrete. This includes but is not limited to the production, delivery, pumping, placement, consolidation, and finishing of concrete. A CCA will reduce the plastic viscosity of a concrete mixture while maintaining a constant slump (static yield stress value). This reduced viscosity results in mixtures that can be handled with significantly lower expenditure of energy and effort. A CCA can be used in any concrete mixture but should be a consideration in reusing returned concrete, especially when blending two or more different concrete mixture designs at varying ratios into a single composite mixture.

Fig. 3: The pail containing the stabilized concrete was nicknamed "Concrete Connie"

Table 3:
Proportions of the fresh concrete mixture made with local materials

Concrete mixture made with local materials	Amount
Cement, lb/yd^3 (kg/m^3)	529 (314)
Coarse aggregate, lb/yd^3 (kg/m^3)	1188 (705)
Fine aggregate, lb/yd^3 (kg/m^3)	987 (586)
Water, lb/yd^3 (kg/m^3)	264.5 (157)
Macrofiber, lb/yd^3 (kg/m^3)	1.5 (0.9)
Design air, %	2.5
High-range water-reducing admixture, fl oz/cwt (mL/100 kg)	3 (195)
Accelerator, fl oz/cwt (mL/100 kg)	90 (5870)
Strength-enhancing admixture, fl oz/cwt (mL/100 kg)	7 (455)
Concrete-conditioning admixture, fl oz/cwt (mL/100 kg)	1.5 (98)

Test cylinders were cast from the composite mixture to evaluate the strength of the concrete. The extended fresh concrete journey aimed to test the limits of hydration control and promote a zero-waste concept for concrete by recycling. Some interesting statistics of the cross-country trip, as well as the route driven, are shown in Fig. 4. Visit **https://master-builders-solutions.com/en-us/news/blog/concrete-riding-shotgun/** for more details about the trip.

Test Results

The slump and temperature measurements of the concrete, taken daily throughout the experimental trip, were measured using a mini slump cone and a digital thermometer. The values are plotted in Fig. 5. The results indicate that the slump of concrete can be maintained for an extended period. In addition, the minimal change in concrete temperature also indicated that hydration is controlled.

At 90 days after batching, the average compressive strength of the composite concrete was measured at 10,890 psi (75.1 MPa).

The transportation of fresh concrete over 7 days and 4295 miles (6912 km) has likely never been done before and has undoubtedly set a record for testing the limits of hydration control. Real-world requirements for maintaining fresh concrete would fall well under this parameter.

Sustainable Practices

Reusing returned plastic concrete as part of a new composite mixture has a positive, sustainable impact by reducing the need for fresh concrete production. This reduction has a two-fold effect: lowering CO_2 emissions by requiring less virgin concrete and potentially extending the service life of structures due to enhanced durability. Additionally, composite mixtures using recycled concrete can be optimized for economics and performance using statistical techniques described by Luciano and Bobrowski.[6] An example of the potential CO_2 emissions savings for different annual plant production volumes, assuming the reuse of a 4% returned concrete, is shown in Table 4. These values are calculated based on a typical 4000 psi (27.6 MPa) concrete mixture (includes CO_2 emissions from transporting materials) and will vary based in the actual strength, mixture design, and region. The values provided are indicative of potential savings. In addition to CO_2 emissions savings, Table 5 also shows the potential volume of returned concrete that can be diverted from landfills through recycling.

Fig. 4: Journey statistics and the driven route

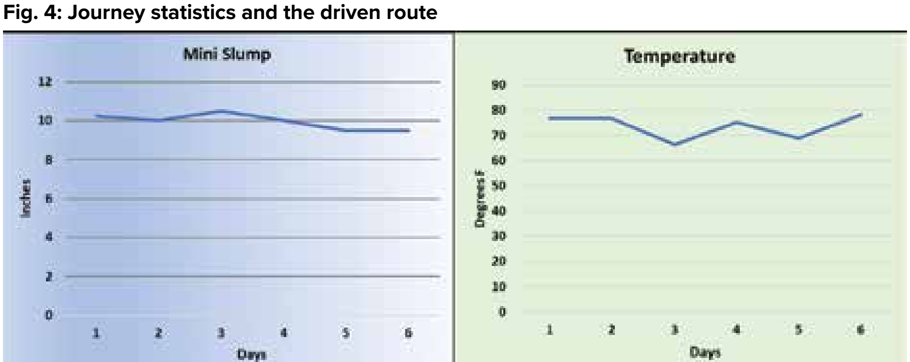

Fig. 5: Slump and temperature of stabilized concrete measured during its trip across the United States

Concluding Remarks

The successful completion of the cross-country trip with fluid concrete demonstrates the robust effectiveness of the tested HCA in extending the plastic state of concrete. Maintaining constant slump and temperature values throughout the trip confirmed minimal, if any, hydration activity within the concrete mixture.

This experiment has significant implications for the construction industry. By predictably extending concrete workability, an HCA can:

- Facilitate extended transportation times—The ability to keep concrete fluid for longer durations allows for transportation over greater distances without compromising its usability;
- Manage delays in placement—Construction schedules affected by

weather, mechanical breakdowns, or other events can benefit from the flexibility offered by controlling hydration for concrete placement;

- Minimize concrete waste—Leftover (returned) concrete from a project can be preserved using an HCA and reused in other projects; and
- Enhance sustainable construction practices—Reusing returned concrete will not only keep material from entering landfills but reduce overall CO_2 emissions by minimizing the need for producing additional virgin concrete.

The possibilities offered by hydration control, set-control, strength-enhancing, and concrete-conditioning admixtures have contributed valuable insights for future research, provided solutions for challenging construction obstacles, and facilitated the development and use of sustainable practices.

Table 4:
Potential CO_2 emissions savings for different annual plant production volumes (assuming reuse of 4% returned concrete)

	Annual returned concrete at 4%					
Annual production, yd^3	60,000	50,000	40,000	30,000	20,000	10,000
Returned concrete, yd^3	2400	2000	1600	1200	800	400
Annual CO_2 emissions savings, lb	1,619,352	1,349,460	1,079,568	809,676	539,784	269,892

Note: 1 yd^3 = 0.76 m^3; 1 lb = 0.45 kg

Table 5:
Potential CO_2 emissions savings for different fresh to recycled concrete ratios

	Fresh to recycled concrete ratio				
	90:10	80:20	70:30	60:40	50:50
CO_2 emissions savings, lb/10 yd^3 (kg/7.65 m^3) truck	675 (306)	1349 (612)	2024 (918)	2699 (1224)	3374 (1530)

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Selected for reader interest by the editors.

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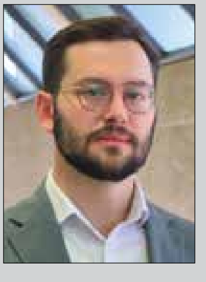

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