

A framework for specifying novel concrete technologies



Foreword

Novel concrete technologies have become increasingly popular as an effective method for reducing the greenhouse gas emissions associated with concrete construction.

Recently, many novel technologies have emerged that promise significant carbon savings. However, implementing these technologies requires change from the business-as-usual approach, and the rapidly changing landscape increases the complexity of specifying novel products. This guidance document uses past project experience with novel concrete technologies to show how they can be implemented on projects, setting forth a basic framework for designers, contractors, and owners.

Methodology

In this section:

Why do we need this framework?

Covered concrete technologies

Identifying novel concrete technologies

Understanding and mitigating risk

Steps to de-risk novel technologies

Limitations of this framework

Why do we need this framework?

In the early 1900s, an alternative type of cement known as high alumina cement (HAC) was developed. It gained popularity in the UK during the 1950s due to its rapid strength development properties. However, following several high-profile structural failures in the 1970s, it was discovered that HAC naturally undergoes a chemical reaction called “conversion.” During this reaction, the solid fraction of the reacted cement reduces in volume, increasing porosity and decreasing material strength. Exposure to water and high temperatures can significantly accelerate this reaction. As a result of the structural failures, HAC was effectively banned from use in structural applications in the UK.

Clearly, there is risk involved in adopting novel concrete technologies. However, relying on traditional concrete mixtures also carries significant risk: the longer we continue emitting greenhouse gases into the atmosphere, the greater the risk of sea level rise, uninhabitable temperatures, food shortages, and irreversible loss of ice sheets and permafrost, among other effects.¹ As cement production accounts for approximately 8% of global carbon dioxide emissions,² decarbonizing the concrete industry will be key in limiting the worst effects of climate change.³

The need to address the carbon emissions associated with cement production has been recognized across both the public and private sectors. Policies requiring or incentivizing low carbon concrete have expanded rapidly, while private sectors continue to explore financing mechanisms, such as book-and-claim models, to accelerate investment and adoption. This framework outlines how stakeholders can leverage innovative concrete technologies to drive industry decarbonization, while ensuring these solutions are rigorously vetted and carefully specified.

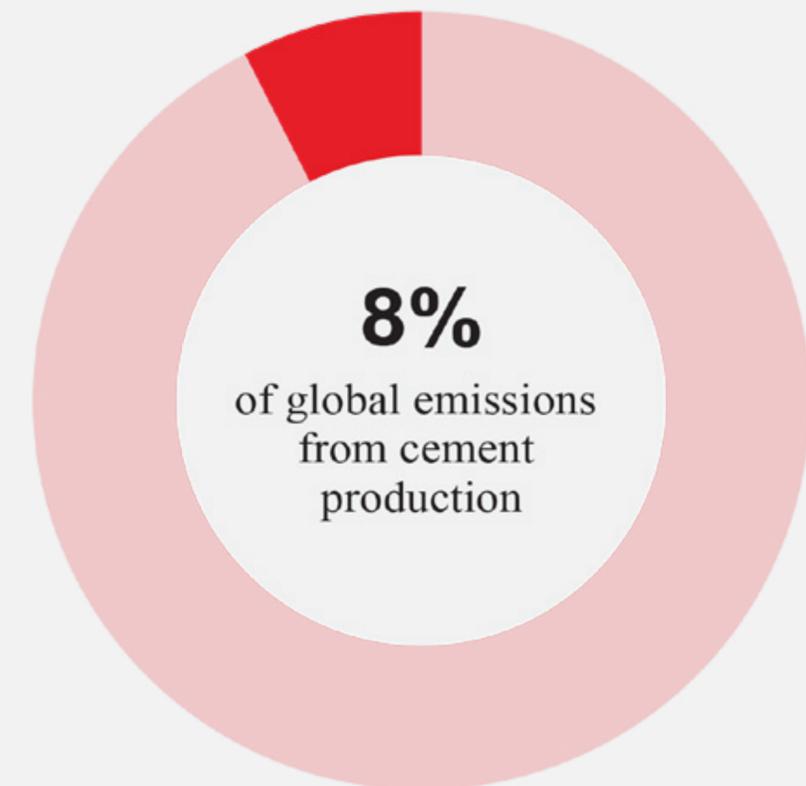


Figure 1. Share of global carbon dioxide emissions attributed to cement production²

¹ NRDC
² Nature
³ IEA

Covered concrete technologies

This framework applies to any novel technology used as a component of ready-mix concrete, whether cementitious materials, aggregates, admixtures, or water. Particular attention is given to cementitious materials due to the disproportionately high embodied carbon impact of cement, as shown in Figure 2. The novelty of a technology depends on how extensively it has been adopted, how different it is from existing technologies, and the duration over which its field performance has been verified. Whether a technology is considered novel is ultimately a subjective decision that will vary by mix design, application, and project. Generally, this framework is most appropriate for technologies with a minimum Technology Readiness Level (TRL) of 7.

While the concepts in this framework can be applied globally to de-risk novel technologies, it is written in the context of standards adopted in the United States, particularly ASTM standards. Some novel technologies, such as ground glass pozzolans, fall under their own ASTM standards. However, certain conventionally adopted ASTM standards also encompass technologies that may be considered novel. For example, while fly ash has been used in concrete mixtures since the mid-1900s, mixes containing high percentages of fly ash may still be considered novel due to a lack of demonstrated long-term performance.

Furthermore, because concrete is a localized material, the novelty of a technology can be region-specific. A 25% fly ash mix may be common in some areas but considered novel in others. In these cases, elements of the framework should still be applied to verify performance within commonly adopted local concrete mixtures and to familiarize suppliers and contractors with novel technology use.

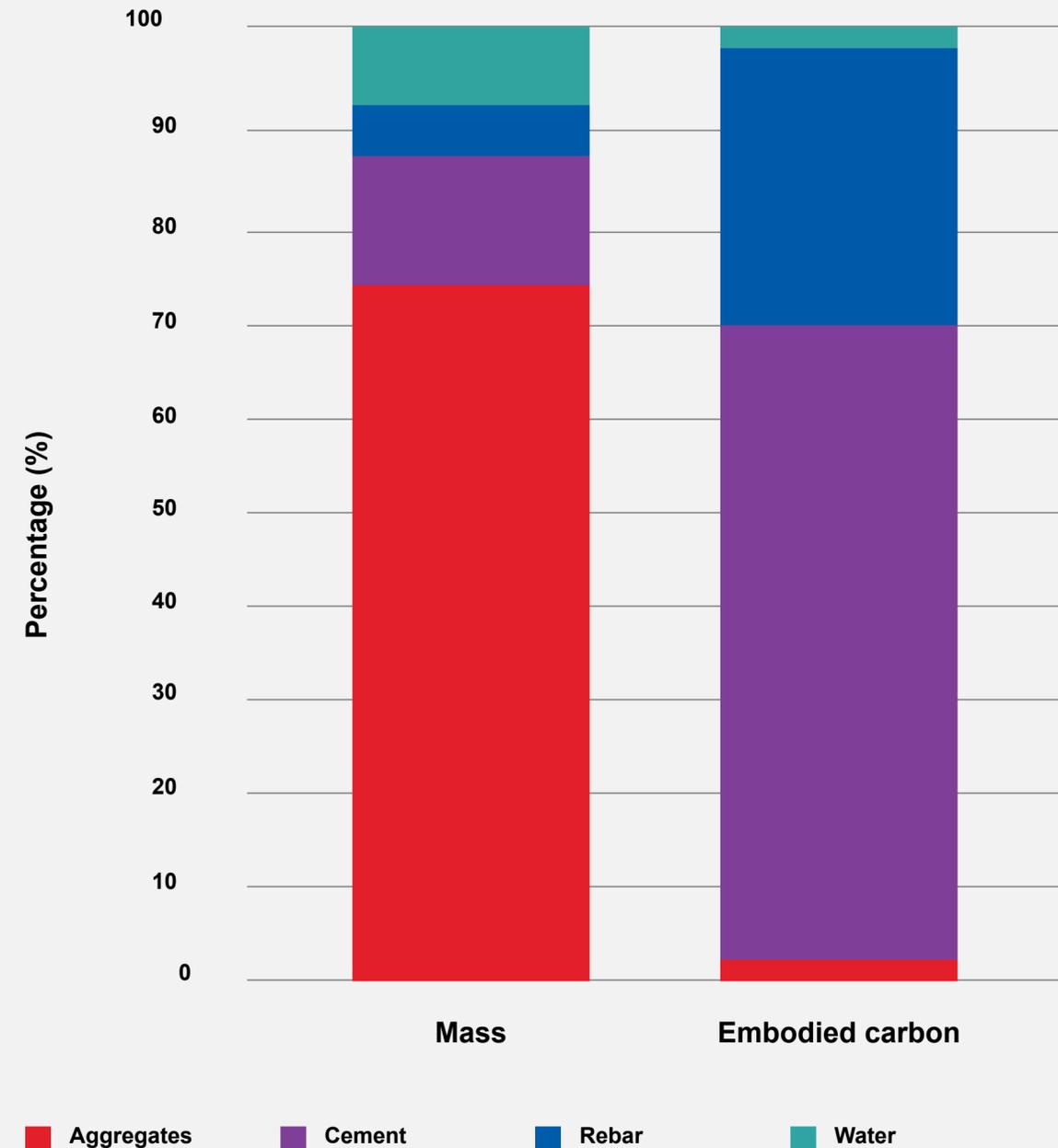


Figure 2. Breakdown of a typical concrete mix, by percent mass and percent embodied carbon

Identifying novel concrete technologies

While the designation of a technology as novel is subjective, the following questions can be used to establish whether a technology should be considered novel and utilize the proposed framework. If “no” is answered to at least one of these questions, the technology can be considered novel.

1. Is the technology commercially available in the local market?
2. Has the technology been successfully used on a completed project in the same application being considered?
3. Are the concrete subcontractor and ready-mix supplier familiar with the technology?

Table 1 lists examples of novel technologies, as well as the applicable ASTM standard. As new products are always emerging, this list is not exhaustive.

Concrete component	Technology	ASTM	Examples
Cementitious materials	Moderate sulfate resistance cement (Type II or IIA) High early strength cement (Type III) High sulfate resistance cement (Type V)	C150	Brimstone
	Ternary blended cement (Type IT) Blended cements	C595	Limestone Calcined Clay Cement (LC3)
	Fly ash and natural pozzolans (high replacement rates)	C618	
	Slag cement (high replacement rates)	C989	
	Non-traditional supplementary cementitious materials (SCMs)	C1709	Mechanically and/or chemically activated filler materials not complying with ASTM C618, Juno XP
	Performance cements	C1157	Geopolymer cements, Sublime Systems
	Ground glass pozzolans	C1866	Pozzotive
	Blended SCMs	C1697	
Admixtures	Performance SCMs	C1912	Steel slag
	Nanotechnologies	C494	
Aggregates	Carbon mineralization/sequestration	C494	
	Recycled concrete aggregates	C33	
Water	Carbonated aggregates	C33	Blue Planet
	Non-portable water	C1602	Recycled concrete water
+ Any other novel concrete technology that does not meet an ASTM			Sioneer

Table 1. Examples of technologies to be considered under this framework

Understanding and mitigating risk

When evaluating the use of a novel low carbon concrete technology, it is essential to first assess the level of associated risk. Four main factors influence this risk:

1. Importance of the structure to human welfare and functioning of society (ASCE Risk Category I, II, III, or IV).
2. Criticality of the element in which the technology is applied (nonstructural vs. structural vs. key structural element).
3. Exposure category (e.g., exposure to freeze-thaw cycles, sulfates, chlorides, and moisture, among others).
4. Novelty of the technology, based on its previous usage (e.g., only lab tested, used for a demonstration project, or incorporated into full-scale applications) and the duration and availability of in-field performance monitoring.

While some applications may present higher levels of risk, this does not preclude the use of the technology. As illustrated in Figure 4, there are multiple opportunities to mitigate risk throughout the design and construction process. In this document, these processes have been split into three phases: prescreening, prequalification, and quality control and monitoring.

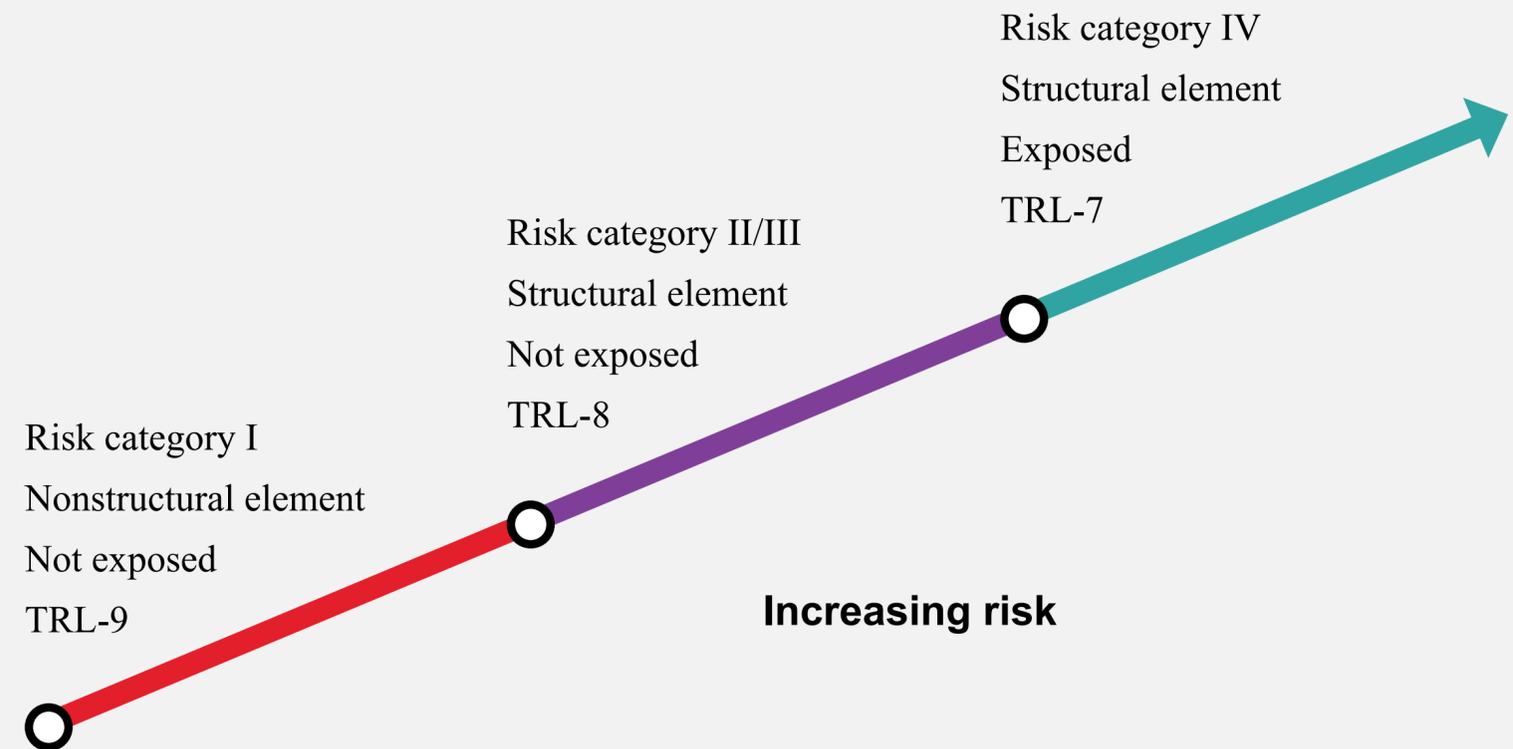


Figure 3. The main factors that increase risk when using a novel concrete technology

Risk mitigation timeline



Prescreening

The structural engineer should engage with the owner to communicate the benefits and risks of using a novel concrete technology, and to establish a risk mitigation strategy tailored to the specific project where the technology is being considered. In early cost and schedule estimates, include allowances for additional testing and performance mockups that may be required, as well as potential impacts to the construction schedule. The novel concrete technology should be evaluated by the design team in coordination with a materials specialist to:

- Determine which ASTM standard is applicable.
- Research previous applications.
- Perform outreach to the supplier and request past field and laboratory testing data.

Prequalification

The structural engineer should further vet the technology based on the performance requirements of the project mixes. This phase can start as soon as the mix requirements are known. Additionally:

- Collaborate with the construction manager, ready-mix supplier, and novel technology supplier to perform additional testing.
- Consider creating a performance mockup.
- Support efforts led by the construction manager to onboard and educate the concrete installer about the mix.
- Add relevant lab and field tests to the concrete specifications.

Quality control & monitoring

The structural engineer should continue to monitor the performance of the novel technology in the field by creating a plan for continued monitoring of the elements that incorporate the technology.

Any lessons learned and observations about the performance should be shared with the broader industry to mitigate risk of adoption for future projects.

Figure 4. Suggested timeline and procedures for de-risking novel concrete technologies

Steps to de-risk novel technologies

Before diving into the technical steps required to de-risk a technology, owner participation and support are essential. The owner should be involved from the outset and must be informed of the risks and costs associated with using a novel concrete technology. The procurement process may need to be modified to enable some de-risking steps. Hosting an initial meeting between the design team, owner, and construction manager offers a valuable opportunity to establish a risk management approach for adopting novel technologies.

Prescreening

The first step in evaluating a novel concrete technology is a prescreening process to determine whether it is sufficiently mature for project use. The design team should engage with a concrete materials specialist during prescreening to assist in reviewing test data and researching the novel technology. The prescreening process involves first verifying compliance with the relevant ASTM standard listed in [Table 1](#), demonstrated through certification by an independent, accredited laboratory.⁴

The prescreening process should not proceed forward if the novel material supplier is unable to provide certification by an independent, accredited laboratory.

ASTM standards set minimum requirements for a material but are by no means exhaustive, so the design team should ask the supplier for any additional available information that supports the use of the material. This may include additional laboratory test results but may also include field test results and field observations. Field test results and project team observations from a completed project can give more confidence in the technology and identify key considerations. Keep in mind that the exposure of the structural element in which the technology is being used matters. A technology that performs well indoors does not necessarily perform well in harsher environments.

Novel concrete technologies are often available only in certain markets. During prescreening, the design team should review local product availability with the supplier, including expected volumes and compatibility with ready-mix concrete equipment.

The prescreening process should be initiated as soon as possible. The earlier a novel technology is considered, the easier it is to implement. Waiting until later design stages to consider novel concrete technologies may limit the available options. Throughout prescreening, the design team should engage with a materials specialist to review submitted data and determine whether the technology should be considered for use on the project.



⁴ Laboratories can be accredited by AASHTO or CCRL for specific tests

Prequalification

Once the approximate mix quantities and their performance requirements are established (typically following the Design Development phase), the technology should be tested within the mixes specified for the project. The required testing will depend on intended application. [Appendix Table 2](#) provides recommended tests for various element types, while [Appendix Table 3](#) gives additional tests based on the element's exposure. The engineer should work with the materials specialist to determine which tests should be requested based on the type of technology and its usage on the project. These testing requirements should be added to the project's concrete specification as action submittals and/or field tests so that they become a contractual requirement.

Testing the technology in the project-specific mixes requires coordination with the construction manager, ready-mix supplier, and novel technology supplier. This coordination provides more time to de-risk the technology through lab and field testing, as well as performance mockups. It will also give the supplier more lead time to procure the necessary quantities.

Performance mockups are recommended to familiarize the concrete subcontractor with mix behavior and performance not captured in testing prior to a full-scale pour. Mockups should be created as early as possible to allow for extended monitoring and used to evaluate key performance attributes relevant to both the design team and subcontractor, including but not limited to pumpability, workability, finishability, set time, and strength gain rate.

Quality control & monitoring

Quality control during and monitoring after construction can verify that the intended performance is met in the field and can inform future applications of the technology. For example, long-term compressive strength can be verified by casting extra cylinders and testing them at 90 days or more. Maturity metering or temperature match curing can also be used to more accurately predict the in-field strength. Visual inspections up to six months after placement can identify cracking, joint openings, curling, or other forms of deterioration. Non-destructive and destructive testing can be used to further evaluate in-field performance.

A continued monitoring plan of the elements utilizing the novel technology is recommended. This plan should be developed by the design team in conjunction with the owner and contractor and then followed by the owner after construction completion. This may include performing periodic visual inspections.

Testing and inspection data, as well as any lessons learned, should be documented and disseminated to the broader industry to de-risk the use of the technology on future projects and accelerate the adoption of low carbon concrete technologies.



Limitation of this framework

While this framework recommends methods to mitigate risk of novel technology adoption, it is important that the engineer and owner are aware that the risk of using a novel concrete technology cannot be fully eliminated. Testing cannot replicate all of the real-world conditions that the material will experience.

In the example of high alumina cement, there is now accelerated testing that can simulate the behavior that initially caused structural failures. However, it is not feasible to rapidly design and adopt reliable accelerated testing for every new material, unless a failure mechanism has already been identified for the material. For this reason, technologies that can be considered more novel (e.g., technologies still in research and development and not yet certified to a relevant ASTM standard) should not be implemented in critical structural elements.



Case studies

In this section:

Meta low carbon concrete pilot pours

David Rubenstein Treehouse at Harvard University

Case Study

Meta low carbon concrete pilot pours

Working with Meta and a regional materials supplier, Arup provided key technical support from project inception to delivery, to culminate in several field trials around the country.

Phase 1

In the first phase, Arup started by engaging concrete suppliers and contractors local to each build site, analyzing their typical mix designs and specifications and then creating a phased program to introduce lower carbon concrete. Arup considered different approaches to introduce cement replacement in higher proportions while accounting for supplier familiarity and schedule and cost impacts. Arup also identified where use of concrete can be significantly reduced or eliminated in the structural design.

Arup then worked closely with Meta and local partners to implement a technical risk reduction strategy, recommending alternative mix designs, writing test specifications to measure fresh and hardened properties, analyzing results, and monitoring performance in-situ before trialing larger volumes. Arup traveled to build sites to oversee construction pilots, troubleshoot issues, and document lessons learned.

These efforts helped deliver a 35% reduction in carbon intensity in trial slabs, a structural element where carbon abatement is hard to achieve. Upon evaluation of results, Arup has helped Meta then incorporate lower carbon concrete requirements into template specifications.

Phase 2

Arup is now leading a second phase to test additional novel technologies to enable even more aggressive carbon reductions. These include materials that may help Meta achieve net zero emission concrete. Function, criticality, exposure, technical and commercial readiness, and potential performance variability due to sources of other materials in the mixtures have all been key considerations while advising on next steps for these materials within Meta's facilities. Arup will continue to capture lessons learned and help Meta embed guidance in project team resources, which will be critical to future success.



Case Study

David Rubenstein Treehouse at Harvard University

Embodied carbon reduction was a project-wide goal for Harvard University's David Rubenstein Treehouse, a mass timber conference center in Allston, MA.

To help meet these carbon reduction goals, the project team sought to use ground glass pozzolans (GGPs) from Urban Mining, a novel material made from recycling post-consumer glass that can replace cement and may also help address foreseeable global shortages in fly ash and slag.

The project

Arup worked with the owner to understand the level of risk in using GGPs in key structural elements on the project. Although it is a relatively novel concrete technology, it had been used in structural elements in previous case studies and there was an ASTM created for it (ASTM C1866). After vetting the material, which also included reviewing relevant testing data, the project team agreed it would be appropriate to use GGPs in many concrete elements that do not require early strength (foundations, retaining walls, grade beams, interior columns, and shear walls).

After DD, the structural engineer (Arup) provided performance-based concrete mix requirements to the contractor (Consigli and Smoot Construction Washington, D.C.) and ready-mix supplier (Boston Sand and Gravel) so that they could engage with Urban Mining. These included concrete quantities, strength requirements, and exposure classes.

The project specifications were also edited to include the necessary performance testing and to incorporate relevant durability requirements. The ready-mix supplier ran a trial batch of the mix after CDs and ran several tests to verify performance ahead of traditional mix approvals. This included testing for chlorides, shrinkage, and concrete resistivity.

The results

The final mix contained 30% Portland cement, 35% ground glass pozzolans, and 35% slag, as well as an air entraining admixture. By replacing 70% of the cement with slag and ground glass pozzolans, the mix achieved a 56% carbon reduction from the NRMCA Eastern Regional benchmark mix.



Appendix

Type of concrete element	Suggested testing/Applicable standard	Purpose of testing	Testing duration
Any	ASTM C138 (NWC) ASTM C567 (LWC)	Unit weight and indirect assessment of air content	Measurement of the density of concrete while still in a fresh state. It is commonly used in the field for quality control.
	ASTM C39	Compressive strength over time	Common lab test. Duration depends on the strength age (typically 28 or 56 days). Some cases may warrant longer term strength monitoring.
	ASTM C469	Elastic modulus	Can be performed simultaneously to compressive strength (typically 28 or 56 days).
	ASTM C143	Workability after mix and at time of placement (e.g., 30 minutes after mix)	Typically monitored up to 90 minutes after mixing, or as required by project hauling time.
	ASTM C231	Air content of freshly mixed concrete	Test performed at the end of concrete mixing and at placement.
	ASTM C403	Initial and final set time	Typical test lasts between 6 and 8 hours from initial concrete mixing.
	ASTM A944	Test bond between concrete and rebar	Concrete needs to be cured first. Test itself lasts only a few minutes.
	ASTM C856	Aggregate distribution, signs of segregation, paste-aggregate bond quality, entrapped air, microcracking, unrelated cement particles	28-56 days
Flatwork	ASTM C39	Strength at sawcut time	Test performed between 8 and 12 hours from initial concrete mixing.
	ASTM C157	Drying shrinkage	Shrinkage limits will depend on project and on the structural element. Typical tests duration ranges between 28 and 35 days.
Any element that must be loaded fast or concrete to be poured in hot/cold weather conditions	ASTM C1074	Calibrating the maturity curve so that the maturity age method can be used to more accurately predict concrete strength gain	Calibrating the curve involves testing at least 15 cylinders. Duration depends on the strength age (typically 28 or 56 days).

Table 2. Typical suggested testing for concrete mixes that use novel concrete technologies during prescreening and/or prequalification. This list is not exhaustive.

Exposure category	Class	Condition		Suggested testing/Applicable standard	Testing duration
Freezing and thawing	F0	Not exposed to freeze-thaw cycles		None	
	F1	Exposed to freeze-thaw cycles with limited exposure to water		ASTM C666 ASTM C457	C666: 3 months C457: Typically performed at 14 or 28 days from initial mix
	F2	Exposed to freeze-thaw cycles with limited exposure to water		ASTM C666 ASTM C457 ASTM C672 or CSA A23.2-22C	C666/C457: As above C672 or CSA A23.2-22C: approx. 78 days
Sulfate		Water-soluble sulfate in soil, percent by mass	Dissolved sulfate in water, ppm		
	S0	$SO_4^{2-} < 0.10$	$SO_4^{2-} < 150$	None	
	S1	$0.10 \leq SO_4^{2-} < 0.20$	$150 \leq SO_4^{2-} < 1500$	ASTM C1012	At least 6 months
	S2	$0.20 \leq SO_4^{2-} \leq 2.00$	$1500 \leq SO_4^{2-} < 10,000$	ASTM C1012	As above
	S3	$2.00 < SO_4^{2-}$	$10,000 < SO_4^{2-}$	ASTM C1012	As above
In contact with water	W0	Dry in service		None	
	W1	In contact with water where low permeability is not required		ASTM C157 (water storage) ASTM C1567 or ASTM C1293	C157: 28 days to 1 year C1567: 16 days C1293: 1-2 years
	W2	In contact with water where low permeability is required		ASTM C1876 or ASTM C1202 or AASHTO T358 or AASHTO T402 or CRD C48 ASTM C1567 or ASTM C1293	C1876/C1202/T402: Typically performed at 28 or 56 days CRD C48: Up to several weeks C1567/C1293: as above

Table 3. Suggested testing for novel concrete technologies during prequalification based on ACI 318-25 exposure category. This list is not exhaustive.

Exposure category	Class	Condition	Suggested testing/Applicable standard	Testing duration
Cementitious materials	C0	Dry or protected from moisture	ASTM C1218	C1218: 14-28 days
	C1	Exposed to moisture but not to an external source of chlorides	ASTM C1567 or ASTM C1293 ASTM C1218	C1567: 16 days C1293: 1-2 years
	C2	Exposed to moisture and an external source of chlorides from de-icing or other chemicals, salt, brackish water, seawater, spray, or airborne chlorides from these sources	ASTM C1876 or ASTM C1202 or ASTM C1556 or AASHTO T358 or AASHTO T402 ASTM C1218 ASTM C672 or CSA A23.2-22C	C1876/C1202/T402: Typically performed at 28 or 56 days C1556: 56-931 days C672: approx. 78 days
Exposures or cases not covered in ACI 318		Mass concrete	ASTM C1702 (or other approved methods) AASHTO T336 ASTM C496	C1702: Typically performed over first 144 hours from contact between cement and water T336: Typically tested at 14 or 28 days C496: Typically tested at 14 or 28 days
	XC4	Aggressive carbonating environment (Cyclic wet and dry in presence of excess CO ₂ , e.g. parking garages)	Fib bulletin 34 accelerated carbonation test	28 days
		When using reactive aggregates per ASTM C1293 or ASTM C1260	ASTM C1567 or ASTM C1293	As above
		When using for vertical work (walls, columns, footings) where deflections are critical	ASTM C512	Up to 1 year
		When exposed to hot weather curing conditions during placement (i.e. evaporation rate greater than 0.2 lbs/ft ² per ACI 305)	ASTM C232	Until cessation of bleeding (usually less than a day)
		When resistance to abrasion is a relevant property	ASTM C779 or ASTM C944	

Table 3. (continued) Suggested testing for novel concrete technologies during prequalification based on ACI 318-25 exposure category. This list is not exhaustive.

Contact:

Adam Jaffe
Materials Specialist
e: adam.jaffe@arup.com

Luca Montanari
Concrete Materials Specialist
e: luca.montanari@arup.com

Frances Yang
Associate Principal
e: frances.yang@arup.com

Lauren Wingo
Associate
e: lauren.wingo@arup.com

Contributors:

Maggie Smith
Engineer

Bryce Tanner
Associate Principal