Performance Concrete Specifications for Lower Carbon Footprints

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Today, structural engineers are aggressively seeking low-carbon building materials to reduce the carbon footprint of the built environment. Numerous advances in concrete technology are providing solutions in response to these goals and working toward an aspiration of net-zero carbon emissions for future new construction. Even though decades of work have been performed using advances that can move the industry in that direction, they have not always made their way effectively into project specifications. The 2014 update to ACI 318, *Building Code Requirements for Structural Concrete and Commentary*, moved toward performance-based concrete specifications, which has facilitated the ability to use some of these advances.

The design community can utilize the ACI 318-11 code updates to achieve the goal of lower embodied carbon in concrete mixtures. New tools available to the AEC industry, such as the soon to be released Embodied Carbon in Construction Calculator (EC3), are creating new opportunities for specifications that target reduced carbon.

The San Francisco airport's SFO Terminal 1 Redevelopment project provides a case study showing how a performance-based concrete mixture procurement process can lead to lower embodied carbon construction without a significant cost premium. This case study describes how the lessons learned might be applied to other projects.

Low Carbon Concrete Advances

Numerous strategies could be implemented on a project to reduce the carbon footprint of concrete. Optimization of the concrete mixture is the obvious starting place. Concrete mixtures can be proportioned to lower carbon in concrete by applying recent ACI 318 updates and incorporating them in project specification requirements.

Supplemental Cementitious Materials

Many engineers follow the format of ACI 318 and limit the maximum amount of specific types of Supplemental Cementitious Materials (SCMs) in the specifications, even when the concrete is not in an exposure class F3 environment. Furthermore, these limits are often well below the limits provided in ACI 318. The intention for lowering the limits of SCMs is not to retard the rate of strength gain. Although some SCMs can alter the rate of early-age strength development, ready-mixed concrete producers can proportion concrete mixtures to achieve the early-age strength requirements, even with cement replacement levels higher than what traditionally thought possible (e.g., 70%). To allow for the highest use of SCMs, designers should work with the contractor's construction sequencing and specify maximum design strengths at ages later than 28 days whenever possible (as allowed by 19.2.1.3 in ACI 318-14).

Specifying Proper w/c

The water-to-cement ratio (w/c) is historically one of the most commonly specified criteria for concrete and has been tied to the strength of concrete in ACI 318 since 1927. There is a strong correlation between strength and the w/c, with a lower w/c yielding higher strength. When higher strength is achieved by limiting the w/c, especially for locations within a project where it is not always needed, it typically comes at both a higher project first-cost and at a higher carbon footprint than necessary due to increased cement contents.

The main concern often expressed by design professionals is the potential of increased drying shrinkage if the w/c is relaxed. This is an appropriate concern in the typical situation where a concrete supplier does not have historical testing data or other means to control the shrinkage properties of the concrete mixtures. A key to any relaxing of w/c without detrimental shrinkage performance is having reliable testing data to support the proposed concrete mixture. Concrete producers with more established testing laboratories and active mixing quality control systems can experiment with material blends regularly to develop supporting data for their high-performing concrete mixtures.

Other Useful Methods

Other methods which could lead to a lower carbon footprint include better quality control of the aggregate supply used within a concrete mixture, using strength-boosting admixtures to reduce total cementitious content, incorporating recycled carbon dioxide as a mixture constituent, and using other alternative SCMs such as interground or interblended limestone, silica fume, metakaolin, rice husk ash, and even ground recycled glass powder. It should be noted the mere use of better aggregates, admixtures, other SCMs, or recycled carbon dioxide does not assure a lower overall carbon footprint – transportation, processing, and other pre-chain impacts need to be considered before an actual claim can be made

To encourage getting concrete mixtures responsibly but more appropriately specified for their intended strength and durability use, while keeping them financially feasible, Chapter 19 of ACI 318-14 requires the design professional to state the exposure class needed for the concrete. This change, though small, can have a significant impact on what the creator of the concrete mixtures at the batch plant can then do to produce mixes that meet an intended purpose, but with lower overall cementitious material use.

In addition to specifying the exposure class, other design professional and contractor requirements are needed to specify the parameters of a concrete mixture fully. These requirements can and typically should include strength gain date limitations, such as 3, 28, 56, or 90 days, shrinkage and modulus of elasticity limitations, pump distance abilities, finishing characteristics, etc.

All these strategies are great to consider. However, the key is to start with directly specifying the performance criteria important to the mixture proportions, and then to let the mix designers determine how to cost-effectively optimize the mixtures to meet these criteria and achieve the lowest carbon footprint.

Ensuring Success

Environmental product declarations (EPDs) provide a way for a concrete supplier to report the environmental performance of a concrete mixture and should follow industry defined Product Category Rules (PCR) established for that material. It is like the nutrition label on a box of cereal. The first North American version of the PCR for concrete was developed by the Carbon Leadership Forum (CLF) and adopted in 2012. That PCR has been significantly updated since then, and the most current version was released in February of 2019. An example of common language that can be used for requesting EPD's within a specification can be found from the CLF website at **https://bit.ly/2YNowLo**.

An EPD provides multiple environmental metrics with the most commonly used metric being global warming potential (GWP). The GWP value is useful for demonstrating the reduction in carbon footprint when comparing two concrete mix designs with the same structural performance. When comparing EPDs, an engineer needs to ensure the same PCR version is used as well as considering the whole product life cycle. For example, Central Concrete's EPDs only consider the cradle-to-grave life cycle; a life cycle analysis encompassing other life cycles stages needs to be considered for comparability.

What should a design professional do with mix specific EPD information? Tools are available from several different sources and are being further developed for designers and contractors to utilize EPD data for design and construction decisions. Tally and Athena both use EPD data within their Life Cycle Analysis tools. Since these tools target design, before specific material suppliers on a project are typically identified, they are restricted to industry average data comparisons for most projects.

Climate Earth's Concrete Selector is available for free to look at the range and average GWP of concrete mixes for a selected strength and cement replacement in their database of concrete mixtures developed using the concrete PCR mentioned above. Promising for the future and to be released in the fall of 2019, an interdisciplinary team under the umbrella of the Carbon Leadership Forum, with key initial input coming from Skanska, C-Change Labs, and Magnusson Klemencic Associates, is developing what will also be a free and openly accessible tool titled the Embodied Carbon Construction Calculator (EC3).

Case Study: SFO Terminal 1

The San Francisco International Airport (SFO) Terminal 1 (T1) redevelopment project was an excellent opportunity to test many of the strategies identified above. The project started with an owner who, from the outset, requested the design and construction teams evaluate, monitor, and lower the embodied carbon footprint of the project as an overall objective.

Given that mandate, the design team architect (Gensler), structural engineer (Magnusson Klemencic Associates (MKA)), sustainability consultant (Urban Fabric), and contractor (Hensel Phelps) met early to evaluate lower

Mix design table for SFO Terminal 1.

Member	Nominal f'_c *	Max W/C ratio	Shrinkage Limit	Max Aggregate Size	GWP**	Quantities Estimate ***
Piles	5.0 ksi @56	0.45	--	1″	yyy $kgCO_2$	xxx yd^3
Pile Caps (mix to achieve 75% f′c at 28 days)	6.0 ksi @56	0.45	--	1″	yyy $kgCO_2$	xxx yd^3
Spread Footings	4.0 ksi @56	0.45	--	1″	yyy $kgCO_2$	xxx yd^3
Basement Walls	4.5 ksi @56	0.45	--	1″	yyy $kgCO_2$	xxx yd^3
Slab of Grade	5.0 ksi @28	--	0.040	1″	yyy $kgCO_2$	xxx yd^3
Slab on Metal Deck (120pcy LWC)	4.0 ksi @28	--	0.040	¾″	yyy $kgCO_2$	xxx yd^3
Shearwalls	6.0 ksi @90 8.0 ksi @90	-- --	0.035 0.035	¾″ ¾″	yyy $kgCO_2$ yyy $kgCO_2$	xxx yd^3
Misc. curbs / mech. pads	4.0 ksi @28	--	0.045	1″	yyy $kgCO_2$	xxx yd^3
Topping slabs exposed to weather	4.5 ksi @28	--	0.040	1″	yyy $kgCO_2$	xxx yd^3

* Dates of acceptance may be adjusted after further concrete supplier and contractor input
** GWP = Global Warming Potential, as established by mix specific EPD, provided by concrete supplier
*** Estimated material quantities from Revit model and Tally analysis, TBD, at interim project milestones

embodied carbon alternatives, and to establish targets for where to invest their efforts. This quickly moved to concrete being one of the critical topics to address. A progressive concrete supplier in the area, Central Concrete, was brought in to consult with the team on opportunities to effectively lower the carbon footprint of the concrete mixes while maintaining other performance characteristics. That effort led to the creation of the *Table* identifying the characteristics of the project's concrete.

The SFO T1 project saw embodied carbon reductions within the project materials across the board, with the concrete supply as one of the leading areas. A project concrete embodied carbon reduction of 40% (as compared to NRMCA benchmark EPDs) was achieved with minimal to no cost increase through a combination of: specifying performance-based mix designs that identified criteria the design team was really after, requesting mix specific EPDs, and letting it be known the embodied carbon or Global Warming Potential (GWP) would be a double bottom line decision-making criterion within the project's material procurement.

Lessons Learned

Building upon the success of the SFO T1, a similar approach was utilized on a campus re-development project in the Pacific Northwest. For that project, a similar concrete procurement strategy was followed after a "Low-To-No CO2" concrete strategy workshop hosted by MKA to consider what was possible within the Puget Sound regional market. This included several different architect/engineer/contractor teams, all working on this re-development, agreeing to follow the same criteria for their parts of the design. The resulting specifications included the latest ACI 318-11 exposure class designations instead of specifying water-cement ratios, and targeted Pacific Northwest concrete durability needs and material opportunities. Furthering a focus on using EPD's and embodied carbon data to inform an owner decision-making process, this project is piloting the EC3 tool mentioned earlier as a case study effort. As a result of this concrete procurement process following this performance-based strategy, with a double bottom line consideration of cost and GWP, the winning concrete supplier provided mix designs that were, on average, 30% below NRMCA industry average EPD values and at no cost premium over the competing supplier bids.

Summary

The goal of this article was to supply actionable information to assist building designers in seeking out lower-carbon alternatives for concrete on their next project, with a path to successfully include lower-carbon alternatives and tools to measure and compare those alternatives. The authors believe by starting a collaborative discussion with their ready-mix partners, along with partners from the rest of the design and construction teams, a project can achieve a lower carbon footprint, at lower first-cost, while maintaining and often improving the structural performance of the concrete.▪

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