THE TOP 10 WAYS TO REDUCE CONCRETE'S CARBON FOOTPRINT

INTRODUCTION

According to the U.N. Environment Global Status Report 2017, the world is projected to add 2.5 trillion sq ft (230 billion sq meters) of buildings by 2060 driven by soaring needs for housing and infrastructure development. That will double the entire current global building stock. The UN report urges building designers and owners to reduce operational carbon by designing disaster-resilient buildings for the future with zero-energy consumption. Concrete has long been the material of choice for energy efficiency and disaster resilience. The UN report also urges the building industry to reduce the embodied carbon of building materials. The challenge for the concrete industry is to offer the benefits of concrete at a lower carbon footprint.

To meet this challenge, the National Ready Mixed Concrete Association (NRMCA) adopted the Architecture 2030 Challenge in 2012, which has goals to reduce operational carbon and embodied carbon from the built environment to net zero by 2050. Reducing these emissions is the key to addressing climate change and meeting the 2015 Paris Climate Agreement, which targets a maximum increase in the global average temperature to 1.5 degrees Celsius above pre-industrial levels. In 2021, NRMCA reaffirmed its commitment to reducing its carbon footprint by supporting the Portland Cement Association roadmap to carbon neutrality.

Concrete is unique among building materials. Its formulation is highly influenced by its application. Design professionals and contractors have a greater influence on concrete formulation than they do with other building products. Concrete can be made stronger, lighter, more flowable, stiffer, less permeable, and even weaker depending on performance needs. This document looks at how designers, contractors, and concrete producers can collaborate to reduce concrete's carbon footprint today. The recommendations are broadly addressed in order of priority. All are important. In addition, the strategies are meant to achieve a lower carbon footprint without impacting other traditional performance criteria for concrete.

The Top 10 Ways to Reduce Concrete's Carbon Footprint

1. Communicate carbon reduction goals
2. Ensure good quality control and assurance
3. Optimize concrete design
4. Specify innovative cements
5. Specify supplementary cementitious materials
6. Specify admixtures
7. Set targets for carbon footprint
8. Don't limit ingredients
9. Sequester carbon dioxide in concrete
10. Encourage innovation

IMPLEMENTING THE TOP 10 CARBON REDUCTION STRATEGIES

1) Communicate carbon reduction goals

One of the basic tenets of achieving a goal is to effectively communicate that goal to everyone on the team. For concrete, that is especially important because there are so many parameters and criteria for concrete mixtures that the goal of reducing embodied carbon may get lost in the clutter. Drawings and specifications are the primary means through which project goals are communicated to the owner, contractor, and product suppliers. When it comes to embodied carbon, product manufacturing is paramount. Therefore, sustainability goals should be communicated to product manufacturers. This not only applies to concrete but to all building products.

Most product manufacturers bid on a project armed with a set of drawings and are often only provided the section of the specification affecting their work. For concrete, that is Section 03300. However, in many instances the sustainability-related requirements are placed in Section 01000. If a concrete contractor and product manufacturer do not see Section 1 of the specification, then they will be unaware of any carbon reduction goals regarding concrete.

Recommendations

Collaborate

Collaborate with concrete producers and contractors. Invite them in for a meeting or charrette with your design team. Understand what technologies and concrete ingredients are available locally. Just because a product (slag cement for example) isn't generally used in a market, it doesn't mean you should not specify or prohibit its use. Generally, the reason a product is not used is because there is no demand for it. You need to create the demand by permitting and encouraging its use.

Specification

SECTION 03300 – CAST-IN-PLACE CONCRETE
PART 1 – GENERAL | 1.1 SUSTAINABILITY GOALS

This project has a goal of reducing the embodied carbon footprint over a typical project by 20%*. To accomplish this goal, we are targeting a carbon footprint reduction for concrete of 35%* under benchmark established in the NRMCA's Cradle-to-Gate Life Cycle Assessment Version 3.2*. Specific targets for Global Warming Potential (GWP) are provided in Section 2, CONCRETE MIXTURES. To accomplish this goal, we are encouraging the use of innovative products and processes for concrete and will consider proposals for mix designs that can demonstrate they meet all performance criteria for strength, durability, constructability, and cost, in addition to reducing carbon footprint.

** These values are for demonstration purposes only.*

Pre-bid Meeting

It is also important to communicate carbon reduction goals in other ways. Most projects have pre-bid meetings, which can be opportunities to communicate carbon reduction goals for all products to all potential bidders.

Case Study

Background

960 W. 7th Street is a distinctive multifamily high-rise development located in the heart of downtown Los Angeles. This 64-story tower has 780 residential units totaling 807,000 square feet.

960 W. 7TH STREET, LOS ANGELES, CA
Developer: Brookfield Properties
Design Architect: Marmol Radziner
Executive Architect: Large Architecture
Structural Engineer: MKA
Contractor: Webcor
Concrete Supplier: NRMCC
Photo: Courtesy of Brookfield Properties

Challenges

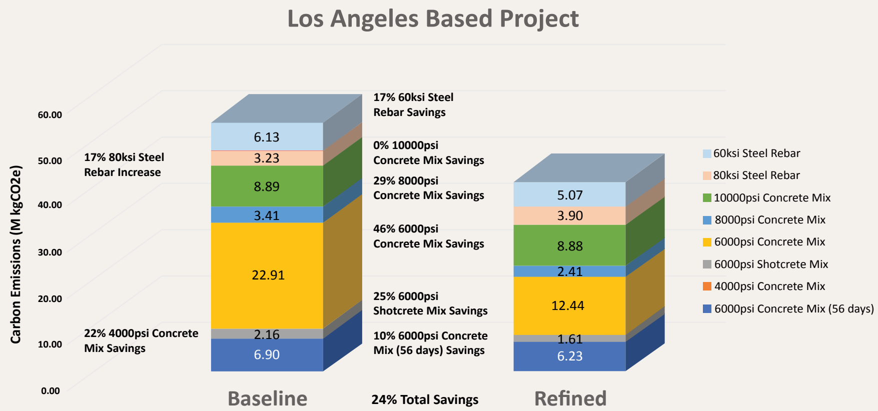
Projects of this magnitude have challenges when it comes to balancing cost, long-term value, energy efficiency, occupant comfort, and sustainability. The design team, developer, contractor, and product suppliers need to have the same goals in mind when it comes to reducing environmental impact, including carbon footprint.

Sustainable Solutions

Structural engineers play a key role in selecting the structural system for most buildings, especially for a high-rise in a high seismic zone. In working with the design team to best meet project goals, the engineering firm proposed cast-in-place post-tensioned slabs, with a centralized buttressed concrete core that tapered with height. This system optimized floor-to-floor heights, eliminated transfers, and worked with unit and public spaces to optimize net/gross floor ratios while preserving unobstructed views at the building perimeter.

The structural engineer also developed a low-carbon performance-based specification and procurement strategy with the architect and developer, which worked closely with the use of the new Embodied Carbon in Construction Calculator (EC3) tool. "After you know your quantities, the math for performance oriented like material comparisons is simple," states Don Davies, president of the engineering firm. "It's as straight-forward as multiplying material quantities by their carbon footprint from comparable Environmental Product Declarations (EPD) and adding it up. This is becoming increasingly easier for concrete, where today there are over 38,000 EPD's within the EC3 tool database."

Engagement with the contractor and concrete supplier early on also helped "tighten up" the mix designs, where the single change of the aggregate being used, moving to imported and higher-quality aggregates, improved quality control and variation in the mix performance. This allows the same specified compressive strength reliability to be achieved with a lower quantity of cementitious materials. They worked with the contractor to determine where faster strength gain was really needed and adjusted testing age accordingly to accommodate higher volumes of SCMs.



"We reduced 24% of the total project embodied carbon footprint, at no cost add, that's after accounting for the carbon from barging rock from the Pacific NW down to LA," says Davies. "On the PT slab mixes alone, we reduced the carbon footprint of that mix by 47%."

2) Ensure good quality control and assurance

This is important for all products, but it's especially critical for concrete. Concrete is made from local materials and its performance can be affected by weather conditions, variability of materials, delivery, placing, handling, and testing. Although the materials used to make concrete meet rigorous standards, the variability can be quite high.

Quality Control

Almost all concrete has compressive strength as one performance criterion. Concrete producers design concrete mixtures to meet the needs of the contractor in terms of workability (flowability, pumpability, finishability, etc.) based on their local aggregates, and then using sufficient quantities of cementitious materials—usually a combination of portland cement and supplementary cementitious materials—to achieve the required compressive strength, which is higher than the specified compressive strength.

The "overdesign" (the difference between the actual average compressive strength and the specified compressive strength) is based on well-established statistical methods described in the codes and standards for concrete. If a concrete producer has a good quality control process and a history of consistent test results for a mix design, the overdesign can be relatively small, say 400 to 600 psi for 4,000 psi concrete. But if quality control is poor, or there is no history of test results, then the overdesign can be much higher: 1,200 psi or higher for 4,000 psi concrete.

Lower overdesign means lower cementitious materials content. For example, going from 1,200 psi to 600 psi overdesign would likely require 60 lbs. less cementitious material, potentially an 8% decrease in GWP. The key here is to minimize the overdesign through good quality control. Having manufacturing equipment in good working order, using proven quality management principles, and qualified personnel who can design, manage, and manufacture quality concrete consistently equate to good quality control.

Quality Assurance

Testing concrete is not an exact science. Every project has specifications that require independent testing laboratories to ensure that concrete meets the specified performance criteria. Placing concrete is a dynamic process and thus sampling concrete for testing can be challenging. There are well-established procedures for taking concrete samples, preparing test specimens, storing them on site, transporting them to a laboratory, and finally testing them in a compression testing machine or other apparatus. If sampled and prepared incorrectly, stored incorrectly, transported incorrectly, or tested incorrectly, the results are meaningless. This also impacts the perceived variability of the overdesign the producer is permitted for future projects.

Concrete rarely tests well when testing protocols are not followed. If test results consistently show lower strength, then the only way to overcome that is to increase overdesign, which generally raises cementitious material content. For example, if poor testing increased the overdesign from 600 to 1,000 psi the cementitious materials content would increase by roughly 40 lbs. for 4,000 psi concrete, increasing the embodied carbon footprint by as much as 6%.

Recommendations

One way to provide some assurance that a concrete producer has good quality control is to require certifications for their manufacturing facilities (plants), mixer trucks, concrete technicians, and plant operators. The same can be said for installers and independent testing laboratories and their personnel.

Specification

SECTION 03300 – CAST-IN-PLACE CONCRETE
PART 1 – GENERAL

1. QUALITY ASSURANCE

    A. Installer Qualifications: At least one person on the finishing crew must be certified as an ACI Flatwork Finisher.

    B. Manufacturer Qualifications:

        1. Concrete shall be supplied from concrete plants with current certification under the NRMCA Certification of Ready Mixed Concrete Production Facilities.

        2. Quality Control personnel with responsibility for concrete mixtures shall document qualifications demonstrating knowledge and experience with concrete technology and development of performance-based concrete mixtures certified as an NRMCA Concrete Technologist Level 2.

        3. Documentation that the concrete supplier participated in supplying data to the NRMCA Cradle-to-Gate Life Cycle Assessment of Ready-Mixed Concrete.

    C. Testing Agency Qualifications: Independent testing agency shall meet the requirements of ASTM C1077 for testing indicated and employing an ACI-certified Concrete Quality Control Technical Manager.

        1. Personnel conducting field tests for acceptance shall be certified as ACI Concrete Field Testing Technician Grade I, or equivalent.

        2. Personnel conducting laboratory tests for acceptance shall be certified as ACI Concrete Strength Testing Technician or ACI Concrete Laboratory Testing Technician Level I, or equivalent.

        3. Test results for the purpose of acceptance shall be certified by a registered design professional employed with the Testing Agency.

3) Optimize concrete design

This strategy is about employing good design practices. If a structural element such as a column or beam is designed larger than required, then excessive concrete is being used, which increases embodied carbon. Alternatively, for a high-rise building, reducing the size of the columns might be critical to keeping the rentable space to a maximum. That means using high-strength concrete, which generally means higher carbon footprint.

However, higher-strength concrete does not always mean the concrete has to have a high carbon footprint. Most high-strength concrete uses considerable amounts of supplementary cementitious materials such as fly ash, slag cement, and silica fume to achieve high strength. Since those materials have relatively low footprints, they help lower the embodied carbon of concrete. Regarding carbon footprint, however, lower strength is usually better.

Recommendations

Use life cycle analysis software to quickly calculate the embodied carbon of concrete elements (structural or architectural). Consider exposing concrete wherever possible. Finished materials have a considerable carbon footprint, and since exposed concrete can be attractive and is fire resistant without the need for additional protection, this is an excellent strategy for reducing the carbon footprint of the building.

The other benefit of leaving concrete exposed is that concrete sequesters carbon over time through a process called carbonation. Carbon dioxide (CO_2) from the atmosphere combines with the cement hydration products to form calcium carbonate (limestone), which permanently sequesters CO_2.

4) Specify innovative cements

There are several alternatives to ordinary portland cement (OPC), but the most common are called blended cements. These combine OPC with other materials. The most common type of blended cement is portland-limestone cement (PLC) or, technically, ASTM C595 Type IL (pronounced "one el") cement. This blended cement combines up to 15% limestone interground with OPC to make a cement with a carbon footprint that is up to 10% lower than OPC with performance that is identical to—and in some cases better than—OPC.

There are four types of blended cements in ASTM C595:

CEMENT TYPE	DESCRIPTION	NOTES
Type IL (X)	Portland-Limestone Cement	Where X can be between 5% and 15% limestone
Type IS (X)	Portland-Slag Cement	Where X can be up to 70% slag cement
Type IP (X)	Portland-Pozzolan Cement	Where X can be up to 40% pozzolan (fly ash is the most common)
Type IT (AX)(BY)	Ternary Blended Cement	Where X and Y are the amounts of slag cement, pozzolan, or limestone, and A and B are the types of ingredients (S, P, or L)

There is also another standard, ASTM C1157, for performance-based hydraulic cements with no limits on cement composition, which allows considerably more flexibility. There are rigorous testing standards by which manufacturers demonstrate they meet the performance criteria but are not limited to certain percentages of OPC substitution.

Both ASTM C595 and ASTM C1157 have been permitted in national standards such as ACI 318 and 301, ASTM C94 (ready mixed concrete), and MasterSpec for at least two decades, but most project specifications inadvertently prohibit their use by not listing them in the specification. Many legacy project specifications only list ASTM C150 (portland cement) and don't list ASTM C595 and ASTM C1157, mainly because project specifications are rarely updated.

Recommendations

Specification

PART 2 – GENERAL | 2.5 CONCRETE MATERIALS

A. Cementitious Materials: Use materials meeting the following requirements:

1. Hydraulic Cement: ASTM C150, ASTM C595, or ASTM C1157.

5) Specify supplementary cementitious materials

Nearly all concrete used today has some amount of supplementary cementitious material. The most common are fly ash, slag cement, and silica fume, listed in order from most common to least. However, there are others such as metakaolin, volcanic ash, rice husk ash, and ground glass pozzolan, just to name a few. Some are waste by-products of other industrial processes and others are naturally occurring materials that require little processing and therefore have small carbon footprints. All enhance the performance of concrete when combined with portland cement, including increased strength, increased durability, and enhanced workability. There is a complex chemical process that occurs between the SCMs and the portland cement hydration by-products that contributes to these enhanced properties.

In the U.S., it is the general practice that the concrete producer combines SCMs with portland cement at the batch plant, but in some cases, a producer can use a blended cement (see previous section) and combine additional SCMs at the batch plant. For example, if a producer is using an ASTM C595 Type IP (30), which contains 30% pozzolan, then he or she may be able to add more fly ash, slag, or other SCM, if the mix meets all the performance criteria.

SCMs offer the greatest opportunity for the reduction of carbon footprint today. In theory, concrete can be made with certain SCMs (slag cement for example) or geopolymer concrete, which uses fly ash and alkaline activator without any portland cement. This is unlikely, mainly because of the available supply of these SCMs and cost. Fly ash is relatively abundant, with some fly ash going unused each year. Slag cement is the second most abundant, but the current supply represents only a fraction of the fly ash available. Others have even less supply. Hence, they are used mainly when concrete performance needs to be enhanced.

To give an idea of how effective the use of SCMs are in reducing carbon footprint, going from a 100% portland cement mix to a 50% fly ash/slag cement mix can reduce carbon footprint by roughly 40%.

Recommendations

Specification

PART 2 – PRODUCTS | 2.5 CONCRETE MATERIALS

A. Cementitious Materials: Use materials meeting the following requirements:

1. Portland Cement: ASTM C150/C150M
2. Blended Hydraulic Cement: ASTM C595/C595M, excluding Type IS(>70) and Type IT(S>70)
3. Hydraulic Cement: ASTM C1157/C1157M
4. Fly Ash or Natural Pozzolan: ASTM C618/C618M
5. Slag Cement: ASTM C989/C989M
6. Silica Fume: ASTM C1240/C1240M
7. Ground Glass Pozzolan: ASTM C1866/C1866M

6) Specify admixtures

Nearly every concrete made today uses some sort of admixture. Most affect the plastic properties in order to make concrete more workable, economical, shorten or lengthen set time, and so on. Without admixtures, concrete could not be pumped hundreds of feet into the air or transported hundreds of miles, and many architectural finishes could not be achieved. There are water-reducing admixtures that in effect reduce cement demand, accelerators that improve strength gain, and viscosity modifiers that permit concrete to flow into very tight spaces. All admixtures that meet an ASTM standard should be permitted, and those that do not meet a standard should still be considered.

As an example of how effective admixtures can be, using a water-reducing admixture that reduces water content in a mixture by 12% will result in a reduction of cement content by 70 lbs., with an equivalent slump and strength and in a carbon reduction of roughly 10% for 4,000 psi concrete. High-range water-reducing admixtures can reduce water content by as much as 40%, but the potential reduction in cementitious materials may not be feasible because of constructability needs.

Recommendations

Specification

PART 2 – PRODUCTS | 2.5 CONCRETE MATERIALS

F. Chemical Admixtures

1. Air-Entraining Admixture: ASTM C260/C260M
2. Water-Reducing Admixture ASTM C494/C494M Type A
3. High-Range Water-Reducing Admixture: ASTM C494/C494M Type F or G
4. Accelerating Admixture: ASTM C494/C494M Type C or E
5. Retarding Admixture: ASTM C494/C494M Type B or D
6. Hydration Control Admixture: ASTM C494/C494M Type B or D
7. Workability-Retaining Admixture: ASTM C494/C494M Type S
8. Shrinkage-Reducing Admixture: ASTM C494/C494M Type S
9. Viscosity Modifying Admixtures: ASTM C494/C494M Type S
10. Alkali-Silica Reaction Inhibiting Admixture: ASTM C494/C494M Type S
11. Corrosion-Inhibiting Admixture: ASTM C1581/C1581M
12. Admixtures for Corrosion Inhibition: ASTM C1582
13. Admixtures with no standard (ASTM or other) designation shall be used with the permission of the engineer of record when its use for specific properties is required.

7) Set targets for carbon footprint

Resist the temptation to set carbon footprint limits for individual classes of concrete. In effect, this is the same as providing prescriptive limits on materials and leaves little room for the contractor and producers to innovate and meet the project performance requirements, including budget and schedule. The best approach is to use a whole building life cycle assessment to set a carbon budget for all the concrete on the building. It is still necessary to have a general idea of what the carbon footprint of each mix will be to set a carbon budget for the building.

Many concrete companies have published EPDs for concrete, and most would be willing to publish EPDs specifically for a project. NRMCA has published A Cradle-to-Gate Life Cycle Assessment of Ready-Mixed Concrete report and an Industry Wide EPD for concrete. Armed with this information, you can conduct a life cycle assessment (LCA) to determine the embodied impacts of concrete of a benchmark building using typical concrete mixes with typical amounts of SCMs, and a proposed building using concrete mixes with high volumes of fly ash and slag.

The first step in the analysis is to identify typical concrete mixtures for the benchmark building. The Benchmark Report lists mix designs and their environmental impacts for eight different regions in the United States.

The next step is to identify mix designs that have significantly lower GWP than the benchmark mixes that will meet the performance criteria (strength, durability, etc.). Keep in mind that concrete requiring high early strength should be limited to around 30% replacement of fly ash or slag. Concrete that does not require early age strength such as footings, basement walls, and even some vertical elements such as columns and shear walls, could have as much as 70% fly ash and/or slag and could be tested at 56 or 90 days instead of 28 days to account for slower strength gain. High-volume SCM mixes can be identified from the NRMCA Industry-Wide EPD or from published product-specific EPDs from different regions.

Sophisticated LCA software can be used for this exercise, which would permit "what-if" scenarios, or the simple math is as follows:

$$GWP_{actual} = \sum_{i=1}^{n}[GWP_{actual\ i} \times VOL_i]$$

$$GWP_{benchmark} = \sum_{i=1}^{n}[GWP_{benchmark\ i} \times VOL_i]$$

$$R_{gwp} = (GWP_{benchmark} - GWP_{actual})/GWP_{benchmark})$$

Where:

GWP_{actual} = Total global warming potential of all concrete mixtures proposed for use on project

$GWP_{benchmark}$ = Total global warming potential for industry average benchmark measurement index

$GWP_{actual\ i}$ = Global warming potential for individual (i) concrete mixtures proposed for use on project for mixture

$GWP_{benchmark\ i}$ = Global warming potential for industry average benchmark measurement index for individual concrete mixture class representative of proposed individual mixture (i)

n = Number of classes of concrete mixtures for benchmark and mixtures proposed for use on project

R_{gwp} = Reduction in GWP

VOL_i = Volume of concrete for concrete mixture class (i)

Recommendations

Specification

2.12 CONCRETE MIXTURES

B. Supply concrete mixtures such that the total Global Warming Potential (GWP) of all concrete on the project is less than or equal to 4,298,000* kg of CO_2 equivalents.

** Values are for demonstration purposes only.*

Case Study

Background

The Oracle Waterfront Campus in Austin is a corporate office building with 550,750 square feet of floor space with a 147,000-square-foot attached ground level parking garage and 646,800-square-foot detached parking garage.

ORACLE WATERFRONT CAMPUS, AUSTIN, TX

Owner: Oracle
Architect: STG Design
Structural Engineer: Walter P Moore
General Contractor: Ryan Companies
Concrete Contactor: Keystone Concrete
Concrete Producer: Centex Materials
Photo: Casey Dunn

Challenges

The entire design and construction team was challenged to have the project blur the lines between public and private property and be welcoming to the pedestrian-friendly community that surrounds it, while meeting challenging sustainability criteria of LEED and Austin Energy Green Building (AEGB) standards.

Sustainable Solutions

The structural engineers worked closely with the design-build team to meet a demanding schedule, structural challenges, and environmental criteria for this concrete building. The design required oversized floor plates to accommodate open office spaces, expansive balconies and terraces, and large meeting spaces. They also made the designer's vision for a truly unique lobby space come to life with a floating stair and bridge that lead visitors to large meeting spaces.

To meet their sustainability goals, the structural engineers incorporated several key strategies to help lower carbon footprint. "The story of Oracle is one of getting in early and talking to the concrete sub and the ready-mix supplier to communicate the carbon reduction goals," says Dirk Kestner, principal and director of sustainable design with the structural engineering firm. They discussed optimizing cement content with the supplier and iterated mix designs to lower carbon footprint. "One thing we did was to consider the construction cycle to use different mixes for the floors based on when they were stressing versus using the two-day mix for all floor placements since the strength at stressing was what governed and not 28-day strength," according to Kestner. This permitted lower cementitious materials content than would normally be used for post-tension floor mixes.

Structural engineers conducted an LCA using software that considers the embodied impacts of all materials of the structure and enclosure for the project. Since this was such a concrete-intensive project, they focused on improving concrete mix designs to meet the LEED Whole Building LCA criteria for lowering environmental impacts.

They also varied the age for testing concrete to allow for higher volumes of fly ash. For example, since the foundations do not see the full design load until construction is complete, they specified testing concrete at 56 days for the drilled piers. As a result, the project met the rigorous LEED Whole Building LCA credit by showing at least a 10% reduction in Global Warming Potential (12% in this case) along with at least a 10% reduction in at least two other environmental impact categories:

Impact Measure	Units	Estimated % Reduction
From Baseline to Proposed	kg SO_2eq	13%
Eutrophication Potential	kg Neq	3%
Global Warming Potential	kg CO_2eq	12%
Ozone Depletion Potential	CFC-11eq	11%
Smog Formation Potential	kg O_3eq	12%
Non-Renewable Energy	MJ	6%

The design-build team's work netted several accolades. Austin Business Journal awarded the project The 2019 Commercial Real Estate Award. Other awards included Urban Land Institute Impact Award for the Most Influential Project, a Golden Trowel Award for excellence in the Industrial/Commercial category and an Austin Green Award for outstanding sustainable design and innovation as well as design strategies that respond to rapidly evolving environmental, social, and health imperatives. The project has also been awarded USGBC LEED Gold and an AEGB 4-Star rating.

8) Don't limit ingredients

All too often, there are seemingly random limits on material ingredients in project specifications that limit the concrete producer's ability to meet performance criteria, let alone reduce carbon footprint. Having unnecessary limits on the water to cementitious materials ratio (w/cm) is one example. In most cases, requiring a maximum w/cm is unnecessary and drives up cement content. There are times when a maximum w/cm makes sense, mostly for cases of concrete exposed to freezing and thawing, but it is not necessary to call it out in the specification. Identifying the exposure class of the concrete per ACI 318 and ACI 301 will suffice. The requirements for w/cm for concrete exposed to freezing and thawing are outlined in the specification.

The same is true for air content. There are concretes that must be air entrained, but that is based on the exposure class of the concrete; mainly for concrete exposed to freezing and thawing. Calling out the exposure class for each concrete application or class of concrete on the project will invoke the necessary air content requirements. Air entraining decreases concrete strength, which means increased cement content to maintain the same strength level. For instance, a 10% increase in cementitious materials content for 4,000 psi air entrained concrete compared to non-air entrained concrete of the same strength would roughly translate to a 9% increase in carbon footprint for the concrete.

Do not list a maximum or minimum cement content, maximum or minimum SCM content, or quantity of admixtures. Do not limit water used for making concrete to potable water (there is an ASTM specification for water used to make concrete). Do not limit the aggregate gradation but do limit the maximum aggregate size based on rebar spacing and member dimensions.

Recommendations

Specification

PART 2 – PRODUCTS | 2.11 CONCRETE MIXTURES

A. Prepare design mixtures for each class of concrete on the basis of laboratory trial mixtures or field test data, or both according to ACI 301. Design mixtures shall meet the specified strength requirements listed below:

Class	Location	Nominal Max. Aggregate Size*	Exposure Class*	f'c, psi @ age*
1	Mat Foundation	3"	F0, S1, W0, C0	6,000 at 90 days***
2	Basement Walls	1-1/2"	F0, S1, W0, C0	4,000 at 56 days***
3	Shear Walls	3/4"	F0, S0, W0, C0	6,000 at 56 days***
4	Columns Level B2-L6	3/4"	F0, S0, W0, C0	6,000 at 28 days
5	Columns Level L7-L12	3/4"	F0, S0, W0, C0	4,000 at 28 days
6	Slabs	3/4"	F0, S0, W0, C0	5,000 at 28 days
7**	Exterior Pavements	3/4"	F3, S1, W0, C0	4,000 at 28 days

** Values are for demonstration purposes only.*

*** In the table above, only class 7 concrete (exterior pavements) would have a w/cm and air content limit because of its exposure to freezing and thawing, which is spelled out in ACI 318 and ACI 301.*

**** Concrete that will not be stressed for significant time periods can be tested at later ages, which means higher volumes of SCMs can be used, resulting in a lower carbon footprint.*

9) Sequester carbon dioxide in concrete

Like most man-made materials, concrete is considered a CO_2 emitter, mainly due to the cement manufacturing process. However, that process can be reversed: CO_2 can be captured or sequestered in concrete through natural processes or carbon capture technologies.

Carbonation is a naturally occurring process by which CO_2 penetrates the surface of hardened concrete and chemically reacts with cement hydration products to form carbonates. For in-service concrete, carbonation is a slow process with many dependent variables. The rate decreases over time. This is because carbonation decreases permeability and carbonation occurs from the surface inward, creating a tighter matrix at the surface that makes it more difficult for CO_2 to diffuse further into the concrete. While slow, the carbonation process does result in an uptake of some of the CO_2 emitted from cement manufacturing, a chemical process called calcination. Theoretically, given enough time and ideal conditions, all the CO_2 emitted from calcination could be sequestered via carbonation.

The rate of CO_2 uptake depends on exposure to air, surface orientation, surface-to-volume ratio, binder constituents, surface treatment, porosity, strength, humidity, temperature, and ambient CO_2 concentration. Predicting how much CO_2 is absorbed by in situ concrete is difficult. What is known is that rates of CO_2 uptake are greatest when the surface-to-volume ratio is high, such as when concrete has been crushed and exposed to air.

Two areas of research and commercialization offer considerable enhancements to this CO_2 uptake process. The most basic approach is enhanced carbonation at end-of-life and second-life conditions of concrete. If conditions are right and particle size is small, crushed concrete can potentially absorb significant amounts of CO_2 over a short period, such as one or two years, therefore leaving crushed concrete exposed to air before re-use would be beneficial. Research conducted by Possan, et al., indicates that during its lifetime, concrete can uptake anywhere from 40 to 90% of CO_2 emitted in its manufacturing process. In some cases, considering a structure's demolition (leaving crushed concrete exposed to air), its uptake can approach 100%. For most projects, the total CO_2 uptake is generally 20% of emissions from the cement manufacturing process. Other commercially viable technologies accelerate carbonation. This is accomplished either by injecting CO_2 into concrete, curing concrete in CO_2, or creating artificial limestone aggregates using CO_2.

Recommendations

Consider permitting the use of recycled aggregates made of demolished concrete on the project and possibly require that those recycled aggregates be exposed to air for one year before being used. In some cases, a certain percentage of aggregate used in concrete to be recycled can be permitted or it can simply be required that all aggregate base or fill be made of crushed concrete. The use of carbon mineralization processes such as injecting CO_2 into concrete or curing in CO_2 environments should be encouraged as well as the use of artificial limestone aggregates.

It is also worth considering the use of exposed concrete on the project, both on the interior and exterior. This has the added benefit of reducing the amount of finished material in addition to absorbing CO_2 throughout the lifetime of the building. The following are examples of specification language that would encourage carbon sequestering technologies:

Specification

PART 2 – PRODUCTS | 2.2 CONCRETE MATERIALS

A. Normal-weight Aggregate: ASTM C33

B. Lightweight Aggregate: ASTM C330

C. Recycled concrete aggregate (crushed concrete) meeting the requirements of ASTM C33 or ASTM C330 may be used in structural concrete up to 10%* of the total aggregate. Crushed concrete shall have been crushed and exposed to air at least 1 year before use in concrete (to maximize CO_2 sequestration).

D. Artificial limestone aggregate meeting the requirements of ASTM C33 or ASTM C330 is permitted.

E. Carbon mineralization by injecting CO_2 into concrete during manufacturing or curing in CO_2 atmosphere shall be permitted.

** Values are for demonstration purposes only.*

10) Encourage innovation

Of the 10 strategies, this is probably the most difficult. Throughout this article, it has been stated not to list specific products or name certain technologies. Instead, simply list the standards that one must meet. The problem with this approach is that it permits innovation but does not necessarily encourage it. If a standard has been met, likely the product is considerably past the innovation stage. The product or process was likely invented, worked within a standard, modified the standard, or modified to meet a standard. All these processes translate to years of research and development work, which means it is difficult and expensive to innovate. For an innovative product or process to be successful, demand must be created, but the current design-bid-build process discourages innovation. However, there are some things that can be done to help create demand for innovative products.

Recommendations

The recommendation here goes back to Strategy 1. Communicating the carbon reduction goals to contractors and producers during the design process is critical. Let them know that you are looking for innovative solutions. Design charrettes would be a great place to engage engineers, contractors, and concrete producers. Ask them to provide solutions. Most sophisticated producers are experimenting on new formulations all the time. Ask them to discuss some of their low-carbon concretes. Will they meet all the performance criteria set by the design team and the contracting team?

Conclusions

There is no silver bullet to making concrete with zero carbon footprint. It can be done, but not at the volume and cost demanded by today's building owners. For some concretes on a project, the carbon reduction might be 90%, others closer to 70%, and still others around 30%. All these reductions lead to concrete with a significantly lower footprint than most concrete projects. If you choose to set carbon footprint targets, this will lead to the greatest reduction, but you cannot expect to meet these targets without implementing these top 10 ways to reduce concrete's carbon footprint.

NRMCA Resources

A Cradle-to-Gate Life Cycle Assessment of Ready Mixed Concrete Manufactured by NRMCA Members – Version 3.2, **www.nrmca.org/sustainability**.

NRMCA Member Industry Average EPD for Ready Mixed Concrete, **www.nrmca.org/sustainability**.

Guide to Improving Specifications for Ready Mixed Concrete with Notes on Reducing Embodied Carbon Footprint, **www.nrmca.org/sustainability**.

Quantifying and Reducing the Carbon Footprint of a Concrete Building, **www.nrmca.org/sustainability.**

NRMCA Plant and Truck Certification, **www.nrmca.org/certifications/plant-and-truck-certification-program**.

NRMCA Concrete Technologist Training and Certification, **www.nrmca.org/certifications/employee-certifications**.

Concrete Design Center, Free Concrete Project Design and Technical Assistance, **www.buildwithstrength.com/design-center.**

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BUILD WITH STRENGTH

National Ready Mixed Concrete Association

Founded in 1930, the National Ready Mixed Concrete Association (NRMCA) is the leading industry advocate. Our mission is to provide exceptional value for our members by responsibly representing and serving the entire ready mixed concrete industry through leadership, promotion, education and partnering to ensure ready mixed concrete is the building material of choice.

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Build With Strength

Build with Strength, an initiative of the National Ready Mixed Concrete Association, educates the building and design communities and policymakers on the benefits of ready mixed concrete, and encourages its use as the building material of choice. No other material can replicate concrete's advantages in terms of strength, durability, safety and ease of use.

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