Reducing Embodied Carbon in Structural Concrete

By David Diedrick and Cecile Roman

Anyone remotely involved in the building sector cannot help but notice the industry's monumental shift in acknowledging the intensity of the climate crisis and in formulating strategies focused on meeting the urgent need to achieve net-zero carbon goals by midcentury. The heightened awareness and sustainability-driven activity will continue to gain momentum as highly influential players in the field, such as the Structural Engineering Institute of the American Society of Civil Engineers (SEI) and the American Institute of Architects (AIA) lead the charge.

For centuries, concrete has been used to build infrastructure. While well regarded for its durability and strength, concrete is also known as a CO_2-intensive building material. Most of the embodied CO_2 in concrete originates from the hydraulic cement used in the mix. As cement and concrete producers introduce new products and technologies, structural engineers need to be aware of the latest and emerging tools that impact the industry's ability to tackle the challenges of embodied carbon. These tools will be critical to reducing the global warming potential (GWP) of projects and meeting SE 2050 and Architecture 2030 commitments.

The high-strength concrete used in the One World Trade Center was designed with fly ash, silica fume, and slag cement SCMs.

SCMs and Blended Cements

Supplementary Cementitious Materials (SCMs) impart a wide range of exceptional performance properties to concrete. SCMs can be natural pozzolans, or they can be byproducts of industrial processes. The most common are blast-furnace slag (byproduct of iron manufacturing), fly ash (byproduct of coal combustion in power plants), and silica fume (byproduct of silicon manufacturing).

SCMs are utilized in concrete as a separate component or as a constituent of blended cement. The amount used depends on performance needs and/or application. For example, a binary combination of Portland cement and slag can improve strength and reduce permeability. A ternary blend of Portland cement, silica fume, and slag can dramatically densify concrete and minimize permeability.

The partial replacement of Portland cement with SCMs results in stronger, more durable, and longer-lasting concrete, reduces greenhouse gas emissions, and diverts the disposal of industrial byproducts from landfills. The beneficial reuse of SCMs in concrete also contributes credits in a wide variety of LEED® categories.

ASTM C595 (Standard Specification for Blended Hydraulic Cements) specifies four types of blended cements. Type IL contains up to 15 percent limestone; Type IP contains up to 40 percent pozzolan; Type IS contains up to 95 percent slag cement; and Type IT contains either two different pozzolans, slag and a pozzolan, a pozzolan and a limestone, or a slag and a limestone.

PLC

Portland Limestone Cement (PLC, Type IL) is an effective alternative to ordinary Portland cement for reducing CO_2 emissions. As allowed by ASTM C595, PLC can be manufactured with up to 15 percent of high-quality limestone. It can provide equivalent or better performance than Type I/II cements and has been rigorously tested to verify concrete strength development, durability, and other desired performance properties.

With Type IL cement, similar percentages of SCMs can be used in concrete mixes while also replacing up to 15 percent of the Portland cement with limestone. This results in the potential of an additional 10 percent reduction in greenhouse gas emissions associated with the production of Portland cement clinker. When combined with typical SCM replacement, the effective reduction in the CO_2 footprint of concrete is highly significant.

Low-Carbon Concrete

To meet growing demands for sustainable construction solutions, multiple concrete producers in the U.S. have developed low-carbon concretes to reduce embodied carbon. Available in various strength classes and compliant with industry standards, low-carbon concrete can be used in all types of structural applications, regardless of performance requirements.

One example, produced with low clinker content, is a low-carbon concrete called ECOPact, which was developed by Holcim to provide 30 to 100 percent fewer carbon emissions than standard concrete. Up to 80 percent less carbon is achieved primarily with lower CO_2-intensive materials. The last 20 percent can be reached through offsets with certified carbon projects for fully carbon-neutral solutions. Lastly, regarding contributions to a circular economy, the concrete can integrate upcycled construction and demolition materials where regulatory conditions allow.

Following sustainability targets, the engineer can either specify the desired percentage of GWP reduction compared to a regional baseline or indicate a maximum GWP value per class of concrete mix. It is recommended that the specifier works with local concrete producers to determine the most practical limits to apply to mixes since the availability of cements and SCMs varies by geographical location.

Relevant ASTM Specifications

ASTM C 989	Standard Specification for Ground Granulated Blast-Furnace Slag for Use in Concrete and Mortars
ASTM C 618	Standard Specification for Coal Fly Ash and Raw or Calcined Natural Pozzolan for Use in Concrete
ASTM C 1240	Standard Specification for Silica Fume Used in Cementitious Mixtures
ASTM C 150	Standard Specification for Portland Cement
ASTM C 595	Standard Specification for Blended Hydraulic Cements
ASTM C 1157	Standard Performance Specification for Hydraulic Cement

EPDs

Life-cycle assessment (LCA) is a leading tool for assessing environmental performance, defined by ISO14040-14044 standards. Manufacturers support the LCA process with Environmental Product Declarations (EPD), an important tool for providing data and transparency on materials and supporting complex integrated design processes.

EPDs offer a substantive characterization of the environmental impacts for cement and concrete, and they provide a standard way to communicate the GWP of products. Based on the level of transparency, project teams can earn credits within the Materials and Resources category of LEED v4 for products that have verified EPDs.

The Path Ahead

The building sector needs to act immediately if it is to decarbonize by midcentury. Reliance must shift to building materials that offer the lowest amount of embodied carbon possible without sacrificing performance to curb global warming and meet the SE 2050 Challenge.

Various organizations, including the National Ready Mixed Concrete Association, the American Concrete Institute, and the Slag Cement Association, offer recommendations on specifying alternative cementitious materials to lower embodied carbon. Product manufacturers can also provide technical assistance to help develop specifications, and most offer detailed test results, quality-control records, and EPDs.▪

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