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Concrete Is Remixed With Environment in Mind

By HENRY FOUNTAIN

Soaring above the Mississippi River just east of downtown Minneapolis is one remarkable concrete job.

There on Interstate 35W, the St. Anthony Falls Bridge carries 10 lanes of traffic on box girders borne by massive arching piers, which are supported, in turn, by footings and deep pilings.

The bridge, built to replace one that collapsed in 2007, killing 13 people, is constructed almost entirely of concrete embedded with steel reinforcing bars, or rebar. But it is hardly a monolithic structure: the components are made from different concrete mixes, the recipes tweaked, as a chef would, for specific strength and durability requirements and to reduce the impact on the environment. One mix, incorporated in wavy sculptures at both ends of the bridge, is designed to stay gleaming white by scrubbing stain-causing pollutants from the air.

The project, built for more than $230 million and finished in September, three months ahead of schedule, "might have been the most demanding concrete job in the United States in 2008," said Richard D. Stehly, principal of American Engineering Testing, a Minneapolis firm that was involved in the project. It is a prime example of major changes in concrete production and use — changes that make use of basic research and are grounded, in part, in the need to reduce concrete's carbon footprint.

Concrete may seem an unlikely material for scientific advances. At its most basic, a block of concrete is something like a fruitcake, but even more leaden and often just as unloved. The fruit in the mix is coarse aggregate, usually crushed rock. Fine aggregate, usually sand, is a major component as well. Add water and something to help bind it all together — eggs in a fruitcake, Portland cement in concrete — mix well, pour into a form and let sit for decades.

Let a lot of it sit. Every year, about a cubic yard of concrete is produced for each of the six-billion-plus people on the planet.

Think of it this way. The stretch of sidewalk in front of your house? That is you and your spouse's share. That concrete truck rumbling down the street? It holds a yard for each member of the New York Yankees' starting lineup. Add the Mets and the Red Sox, and you have enough for the typical house foundation and basement floor.

But those are small projects. The St. Anthony Falls Bridge used about 50,000 yards of concrete. Hoover Dam used more than three million. And the Three Gorges project in China contains more than a yard for every man, woman and child in Canada, population 33 million.

All that concrete may seem the same. And the basic product did remain relatively unchanged since the invention of Portland cement in the early 1800s. (The ancient Romans made concrete, too, but from volcanic ash.) Producers have always tinkered with the mix to find the right proportions of concrete's basic ingredients, but the recipe never varied much.

Now the experimentation is more elaborate, designed to tailor the concrete to the need. Increasingly, that need includes the environment. Aesthetic considerations aside, concrete is environmentally ugly. The manufacturing of Portland cement is responsible for about 5 percent of human-caused emissions of the greenhouse gas carbon dioxide.

"The new twist over the last 10 years has been to try to avoid materials that generate CO_2," said Kevin A. MacDonald, vice president for engineering services of the Cemstone Products Company, the concrete supplier for the I-35W bridge.

In his mixes, Dr. MacDonald replaced much of the Portland cement with two industrial waste products — fly ash, left over from burning coal in power plants, and blast-furnace slag. Both are what are called pozzolans, reactive materials that help make the concrete stronger. Because the CO_2 emissions associated with them are accounted for in electricity generation and steel making, they also help reduce the concrete's carbon footprint. Some engineers and scientists are going further, with the goal of developing concrete that can capture and permanently sequester CO_2 from power plants or other sources, so it cannot contribute to the warming of the planet.

Given the numbers, the possibilities for carbon sequestration are enormous. The United States concrete industry's big annual trade show, held in Las Vegas each winter, is called World of Concrete, and for good reason. Concrete is made and used just about everywhere, with China responsible for half the world's production.

In the making of concrete, the Portland cement and water form a paste in which a series of reactions occur, hardening the paste and locking the aggregates within it. Those reactions use up the water — concrete doesn't "dry out" through evaporation — and produce heat. They also make the product caustic. While most of the strengthening occurs in the first few days and weeks, the process can continue for years, as long as there is a little moisture around.

Michelle L. Wilson, director of concrete knowledge for the Portland Cement Association, a trade group, described a hydrating cement particle this way: "It's not a piece of popcorn, it's not popping from the inside out. It's more like a jawbreaker — as the water hits it, the hydration is in layers from the outside in. You can continue to hydrate that jawbreaker down."

Just as a dose of brandy or other extra ingredient can improve a fruitcake, concrete can be modified by adding other materials and chemicals. The recipes have become much more sophisticated, said Jay Shilstone, a concrete consultant in Plano, Tex.

"It used to be that the chemicals added to concrete were soaps or sugars — very simple," Mr. Shilstone said. "Now we're doing designer chemicals to work on specific components."

Some chemicals make wet concrete flow better into a form's nooks and crannies without separating. Others prevent the cement particles from flocking together, so the amount of water can be reduced — which means that less cement is needed as well. Chemicals can be added to slow the reactions to give contractors more time to work with the wet concrete. Isocyanates and other catalysts can speed the reactions up, if the concrete needs to reach a certain strength in a short time.

Increasingly engineers are also paying attention to the internal structure of the concrete to improve strength and reduce permeability. "There's been a major push to look at the particle size distribution," Mr. Shilstone said.

Although powdery, on a microscopic scale cement actually consists of relatively large grains. So researchers are looking at even smaller particles, "microproducts that can go in and do magical things with the cement matrix," Mr. Shilstone said.

Dr. MacDonald added a small percentage of silica fume, another industrial waste material, to the mix for the bridge's box girders, to make the concrete more impermeable to road salt, which corrodes rebar, eventually destroying concrete from within.

One large cement producer, the Italcementi Group, adds titanium dioxide particles to one of its products. The cement makes the concrete white by acting as a catalyst under sunlight to break down organic pollutants in the air. "It speeds up the natural oxidation process," said Dan Schaffer, a product manager for an Italcementi subsidiary, Essroc, which supplied the cement for the I-35W bridge sculptures.

Some researchers want to eventually eliminate Portland cement entirely and replace it with other cements to produce zero-carbon, or even carbon-negative, concrete.

Portland cement is at the heart of concrete's environmental problems. About a ton of CO_2 is emitted for every ton of cement produced. The basic manufacturing process involves burning limestone and other minerals at about 2,700 degrees Fahrenheit to create an intermediate product called clinker.

"Essentially, we're trying to make the same minerals that they did in 1825," said Mr. Stehly, who is head of a committee addressing sustainability issues at the American Concrete Institute.

The cement industry, particularly in the United States and Europe, has reduced CO_2 emissions through the use of more efficient kilns and processes, and is now allowed to add some ground unburned limestone to the clinker, reducing the actual cement in the mix. But about half of the CO_2 from cement cannot be eliminated — it is produced in the reaction, called calcination, that occurs as the limestone (which consists of calcium carbonate) is being burned.

So to reduce concrete's carbon footprint to near zero or less, different approaches are needed. Novacem, a British startup, is developing a cement that does not use carbonates and can make concrete that absorbs carbon dioxide. Carbon Sense Solutions, in Halifax, Nova Scotia, wants to bubble CO_2 through wet cement, sequestering the gas through carbonation (a process that occurs naturally, though very slowly, under normal conditions).

At a site adjacent to a gas-fired electricity generation plant in Moss Landing, Calif., the Calera Corporation is developing a process to bubble power plant flue gases through seawater or other brackish water, using the CO_2 in the gases to precipitate carbonate minerals for use as cement or aggregates in concrete. The process mimics, to some extent, what corals and other calcifying marine organisms do.

Calera calculates that producing a ton of these minerals consumes half a ton of CO_2, so the resulting concrete could potentially be carbon negative — sequestering carbon dioxide permanently.

Brent R. Constantz, the company's founder, has a background in cements, having made specialty products for use in orthopedic surgery. But he does not describe Calera as a cement company. "We're primarily driven by the need to capture large amounts of CO_2 and sequester it," he said.

The company probably will begin by making aggregate, because the barriers to making a commercially acceptable product are lower than with cement. Even with aggregate, any new product must meet standards and must be accepted by the concrete industry, which can be conservative. "Any time you introduce anything new," Dr. Constantz said, "it's a challenge."

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