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Emerging Trends in Concrete Mix Design

New materials and sustainability concerns drive innovation.

The concrete industry may change slowly, but it does change when manufacturers, designers, and contractors develop and recognize new and better ways to solve longstanding problems. It also can change in response to changes in the culture at large, such as the increasing knowledge and concern about sustainability and safety. This article examines some new products and approaches that are beginning to affect concrete mix designs and will likely grow in influence soon.

In a broad sense, sustainability is the driving force behind most current innovation in the construction industry. One overarching goal is to produce strong, durable structures that use materials efficiently. Another is to reduce the amount of nonrenewable energy resources needed to manufacture, transport, and

By Kenneth A. Hooker

assemble building products. A third is to reduce the energy consumed in inhabiting and maintaining buildings. Concrete mix designs are changing in ways that will help achieve all these goals.

A producer's insights

Kevin A. MacDonald, vice president of engineering services, Cemstone Concrete Products Co., Mendota Heights, Minn., sees a number of ways that mix designs have changed and will continue to change—many due to sustainability concerns.

"We're getting away from the idea that a particular quantity of cement or a particular water-cement ratio is the key to high-quality concrete," says MacDonald. "Adding portland cement to a mix design often ends up to be the easiest and fastest way to achieve desired results, but it's not the most sustainable. The trend now is to find other methods that are more energy-efficient and environmentally friendly."

One such method is the replacement of some portland cement with fly ash, blast furnace slag, metakaolin, and other pozzolans. As byproducts of other industrial processes, these supplementary cementitious materials (SCM) impart strength and other desirable properties to the concrete with less energy demand and carbon emissions than would be involved in manufacturing an all-portland mix.

According to MacDonald, the use of SCM is well enough established, and their beneficial effects are substantial enough to ensure their continued role in concrete mixes, even if the EPA's proposal to reclassify fly ash as a hazardous waste should pass. (See **Proposed Fly Ash Reclassification Could Curtail Its Use.**)

"I think the reclassification would be a disaster, because the proposal is based on bad science," says MacDonald. If fly ash is reclassified, leading to less fly ash in concrete, he expects the use of other pozzolans to increase.

On another front, MacDonald sees potential for greater use of recycled aggregates in concrete. "ASTM C33 [Standard Specification for Concrete Aggregates] allows the use of recycled aggregates. There is a perception that recycled aggregate results in somewhat lower quality concrete, but we need to educate the industry to combat that misperception. In fact, it's maybe a bit better because it contains some residual cementitious materials. More efforts also are needed to separate and reuse materials so they're not rejected," says MacDonald.

MacDonald sees a trend toward more customized mixture designs, as ready-mix producers work closely with the contractor clients to get the desired characteristics in the plastic mixture, using the specific cementitious materials and aggregates that are available. "Contractors are concerned about properties like set time and strength gain, and producers are developing a better understanding of how various admixtures can interact to achieve the desired results," he says. He believes that progress on this front is hampered somewhat because concrete plants often don't employ engineers who can develop effective mixtures.

Looking ahead, MacDonald expects air entrainment methods to change the most over the next 10 years. He sees a move toward methods that can achieve more stable air contents without adversely affecting concrete strength.

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Configuration of macrosynthetic fiber allows reinforcement to be used in high dosages. With earlier microsynthetic fibers, high dosages made mixing, placing, and finishing difficult. PHOTO: FORTA CORP.

Addition of polymeric beads to the mix facilitated pumping of concrete for seating tiers at Central Michigan University's Rose Event Center. PHOTO: SYNTHEON INC.

EPS beads in the mix

One innovative product that's beginning to make a difference in some concrete mixtures is an additive called Elemix. It consists of uniform polymeric spheres—expanded polystryrene beads—that are reported to reduce the variability of concrete mixtures while improving the characteristics of the concrete. Manufactured by Syntheon Inc., Moon Township, Pa., the additive was introduced at the World of Concrete in 2009.

Macrosynthetic fibers alter the texture of fresh concrete, so contractors should place and finish a prejob trial slab to gain experience with it. PHOTO: FORTA CORP.

The additive supplements or replaces other aggregates to produce a lighter weight mixture that achieves structural compressive strengths. It also enhances the concrete's thermal properties, resistance to cracking, and pumpability.

Syntheon senior sales manager Larry Chappell says one key to the additive's benefits is that it eliminates the need for conventional air entrainment. "The beads compress and act like air voids in the presence of frozen water. Non-air-entrained mixtures with the additive successfully withstood 999 cycles in the ASTM C-666 [Freeze/Thaw Resistance] Test by Methods A and B, as well as testing for UL and ULC fire ratings.

"The additive also makes concrete slightly more ductile, so it helps reduce shrinkage cracking substantially. It stops microcracks from forming beneath the surface, producing smaller and fewer cracks overall," says Chappell.

The additive was used to replace half of the lightweight aggregate in concrete to build 20 seating tiers at the Rose Event Center at Central Michigan University in Mt. Pleasant. Paul Albanelli, president of Albanelli Cement Contractors, Livonia, Mich., learned of the product at an ACI committee meeting in May 2009 and thought it could be beneficial for the project.

"It can be difficult to pump or pour concrete with lightweight aggregate, because the aggregate is porous and absorbs water. We typically would use at least a 4-inch or preferably a 5-inch hose to pump it, but we thought it would be too hard to drag a 4- or 5-inch line to place concrete for those 20 rows. With the additive, we were able to use a 290-foot pump line, the last 80 feet of which was 3-inch-diameter rubber hose. The concrete maintained its 4-inch slump through the placement, and we had none of the delamination that often happens when you try to give lightweight concrete a hard-troweled finish," says Albanelli.

"The seating tiers used 120 yards of 3000-psi concrete in three placements. With a 50% replacement factor, the beads added $5/cubic yard over typical lightweight aggregate, but the time and effort we saved made up the difference on a job of this size. If a similar opportunity and economics came up on another project, I'd be glad to use it again," says Albanelli.

Macrofiber reinforcement

A new generation of synthetic fiber reinforcement products is helping to realize the promise long felt but seldom achieved by earlier versions of the material. Microsynthetic fibers—i.e., very fine single-filament polypropylene and nylon fibers and deformed, net-shaped polypropylene fibers—have been available for decades. These were designed to reduce plastic shrinkage and help control thermal cracking when added to a concrete mixture. Their effectiveness was limited, however, by the fact that the fibers made mixing and placing difficult when used in dosages high enough to reduce cracking substantially.

In 1999, Forta Corp., Grove City, Pa., introduced a macrosynthetic fiber reinforcement product with characteristics that address the challenges of mixing, placing, and finishing concrete with high-dosage fiber reinforcement. The newer product has a twisted-bundle shape to prevent balling, a revised chemical composition and longer lengths to increase strength, and concrete-gray color and a special fiber shape to enhance finishability.

The ability to incorporate high dosages of synthetic fiber reinforcement into a concrete floor slab allows the slab a degree of ductility that prevents it from cracking, while still maintaining a hard, durable surface and the strength to withstand heavy loading. Project experience has shown that joint spacing in a fiber-reinforced slab can be widened considerably without detrimental effects on performance.

Beginning in early 2009, Concrete Construction sponsored a field test in Bartlett, Ill., to document how variables such as mix design, aggregate size and proportioning, admixtures, finishing methods, and synthetic fiber reinforcement affect slab shrinkage and curling. A 60,000-square-foot warehouse floor slab was divided into 5000- and 10,000-square-feet sections. In the test section with the highest dosage of macrosynthetic fibers (7½ pounds/cubic yard), joints were sawcut to form 38 x42½-foot panels. This section exhibited no significant elevation changes over its first year in service. You can read senior editor Joe Nasvik's detailed reports on CC's Field Test research in the February 2009, May 2009, September 2009, and March 2010 issues at www.concreteconstruction.net.

Forta vice president of sales Dan Biddle says the company makes it easy for designers to select the right fiber reinforcement product for a particular job by devising and publishing a "4-C formula" that specifies its configuration, chemistry, contents (dosage rate), and correct length. Although this formula gives the material characteristics, it doesn't specify the workability, mixing, and finishing characteristics.

"The steps needed to achieve workability will vary with fiber dosage," says Biddle. "At 3 to 5 pounds of fibers/cubic yard, mixes don't need to be altered—you can use the same aggregate gradation and admixtures that you would without the fibers. For a 5- to 7½-pound dosage, you'd want to look closely at the mixture design and maybe alter the aggregate gradation and water-cement ratio to ensure workability. Above 7½ pounds/cubic yard, you might need to add a mid-range water reducer or polycarboxylate superplasticizer to the mix to maintain proper flowability. We recommend that contractors do a preplacement trial to get used to the differences in handling the fiber-reinforced material."

According to Biddle, the cost of adding a pound of macrosynthetic fiber reinforcement to a cubic yard of concrete is approximately 1.5¢/square foot/inch of slab thickness. Some of this cost can be offset by eliminating steel reinforcement; the need for fewer sawcut joints also reduces labor costs. However, the potential improvements in slab performance, durability, and customer satisfaction may be the most important benefits. CC

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Proposed Fly Ash Reclassification Could Curtail Its Use

The U.S. Environmental Protection Agency (EPA) is currently considering a proposal to regulate coal combustion residuals (CCRs), such as fly ash generated at power plants across the country. The proposal was prompted in part by the disastrous 2008 failure of a fly ash impoundment at a Tennessee Valley Authority plant in Kingston, Tenn., which released coal ash slurry into the Emory and Clinch Rivers, covered 300 acres of land, and damaged nearby homes.

Two options are under consideration: The first would reclassify CCRs as "special" or hazardous wastes when they're being sent to landfills or impoundments for disposal; the second would leave the current classification intact but impose more stringent conditions on disposal. Either option would move oversight responsibility from the states to the federal level.

EPA's intention is to exempt fly ash from the regulations when it is to be reused in concrete or other beneficial products, but there is concern that reclassification as a "special" waste would carry a stigma likely to curtail fly ash use anyway. In a white paper published last December, Orville "Bud" Werner, president of CTL|Thompson's commercial testing laboratories wrote: "Power companies and concrete industry officials claim that the stigma … will deter shipment and use of fly ash for production of concrete. The power companies have suggested that the liability of shipping fly ash, plus any incidental 'disposal' of fly ash at a concrete plant, make it a liability that is greater than its economic good. It is rumored that specifications are being revised to exclude fly ash in portland cement concrete, and that plans are being made to stop shipping fly ash to concrete production facilities."

It's hard to tell what the real consequences of reclassification might be. If fly ash were no longer available for use in concrete, though, it would affect the industry significantly, because there is no real substitute for it. Using portland cement instead would greatly increase the cost and environmental impact of concrete production. Other natural pozzolans require fuel to process, and still don't duplicate all of the beneficial effects of fly ash. Furthermore, if fly ash is not reused, the power industry will have that much more to stockpile and dispose.

A decision on the proposed regulation is expected sometime this year, and Concrete Construction will continue to report on developments.