GGBF slag in concrete helps hold up some history

Bridge pier work in St. Paul, Minn., reveals the benefit of the material's production of a lower heat of hydration

Cemstone Products Co. convinced MnDOT officials to increase the allowable per-yard slag content for pier concrete on the Wabasha Street Bridge in St. Paul, Minn. A mix using a 70% slag replacement by weight of cement easily met thermal-gradient and strength specifications.

Replacing the nearly 100-year-old Wabasha Street Bridge in St. Paul, Minn., in the early 1990s was a project not to be taken lightly. After all, four structures built there since 1859 provided a link across the Mississippi River and aided the city's growth from a fur-trading center to a cosmopolitan state capital. The fourth bridge, a steel truss structure, even made the National Register of Historic Places, although it had a sufficiency rating of only 2 on a scale of 100.

So the weight of history, not just a new bridge, would bear upon piers for a new cast-in-place concrete segmental

CEMSTONE PRODUCTS CO.

The new bridge now links downtown St. Paul to its redeveloping riverfront. The project also set a precedent for case-by-case use of high-slag-content mixes for MnDOT projects.

box girder structure. Project consultant MnDOT agreed with Kevin Nelson, project engineer for St. Paul, that replacing 70% of the portland cement by weight with ground granulated blast-furnace (GGBF) slag would control thermal cracking in the piers and meet specified concrete compressive strengths.

Uncharted waters

The design specification for the pier footings and stems (the partially submerged structures on the footings) included maximum temperature gradients of 50° F and a maximum concrete temperature of 160° F. However, an MnDOT mass concrete specification for bridges was a work in progress in 1996, when Cemstone Products Co. of Mendota Heights, Minn., was submitting mix designs.

To Nelson, the only option for slowing the hydration rate was using a high GGBF slag content, but MnDOT to that point allowed only 35% in paving mixes. That wouldn't maintain the required temperature differential using the Schmidt Model found in ACI 207.1R-99, "Mass Concrete," which measures gradients between the core and outer surfaces of a mass concrete structure. However, MnDOT was wary about increasing the slag content.

"We said, 'We'll show you what our testing shows,' " says Dave Pace, vice president of concrete sales for Cemstone, which has worked with GGBF slag mixes for several years. Gary Brenno of Cemstone's quality control department showed MnDOT test data revealing the effects of GGBF slag on heat of hydration and later strengths in concrete.

Brenno passed along the results of a Holnam test showing that a 60% slag replacement would maintain heat below the limit for Type IV cement at 7 days. He also made test cylinders from eight mixes, including ones with varying amounts of Grade 100 (moderately active) GGBF slag and projected 56-day compressive strengths. A 60% slag

How GGBF slag improves concrete

Until recently, the concrete producer has offered customers concrete that includes ground granulated blast-furnace slag in limited quantities. In unveiling its GranCem product at ConExpo-Con/Agg '99 in Las Vegas last March, Holnam Inc. noted that recent acquisitions of slag-processing facilities and stepped-up production will increase supply. Holnam and sister company St. Lawrence Cement expect to produce more than 1 million metric tons of GGBF slag by the end of this year.

Research shows that GGBF slag improves plastic and hardened concrete in several ways.

■ Improved workability/low water demand. Although finer than portland cement, GGBF slag may absorb little, if any, water during mixing, unlike portland cement. Contractors aren't as apt to retemper concrete containing GGBF slag.

■ Longer setting time. Since it takes longer for GGBF slag to absorb water, the material works as a set retarder at a concrete temperature up to 85° F.

■ Lower heat of hydration. In mass concrete placements, alternative high-cement-content mixes would create so much heat of hydration as to cause thermal cracking. GGBF slag produces much less heat in concrete than does an equal content of portland cement—and less potential for thermal cracking.

■ Higher strength. Testing shows that at a relatively fine grading of Grade 120 per ASTM C 989, "Ground Granulated Blast-Furnace Slag as a Constituent in Concrete and Mortars," the material produces less water-soluble calcium hydroxide [$Ca(OH)2$] and more "glue-like" calcium silicate hydrate (CSH) binder in fresh concrete than an equal amount of portland cement. Calcium hydroxide crystals tend to accumulate at the interface between aggregate and cement paste, weakening the concrete. Grade 80 (low activity) and Grade 100 (moderate activity) slag are shown to produce lower strengths at 28 days. GGBF slag concretes have lower early-age strengths (at 1 to 3 days) than ordinary concrete.

■ Resistance to sulfate attack. ASTM C 1012 mortar-bar testing by Holnam shows that a 50-50 blend of GGBF slag and various Type I cements outperforms Type V cement, and a 35% blend of slag with Type II or various Type I cements provides high sulfate resistance.

■ Improved ASR resistance. Another benefit to a higher amount of CSH binder production is that it decreases alkali-silica reactivity by tying up alkalis in concrete. A relatively high content of GGBF slag, 40% to 65%, virtually eliminates expansion.

replacement appeared to produce the necessary strengths and temperature gradients.

Getting the heat out

Nelson had agreed that the 4000-psi strength specified for the pier footings and stems by designer Figg Engineering was to be reached at 56 instead of 28 days because loading wouldn't occur quickly. Brenno designed a mix with 60% GGBF slag, or 354 pounds of slag and 236 pounds of Type I cement per yard. Brenno based the mix on a state mix that was to reach a 4300 psi minimum anticipated strength according to MnDOT's prescriptive approach.

Thermocouples, connected to a data collector, recorded temperature gradients at nine points on the first footing placed, for Pier No. 3, in summer 1996. The footing turned out to be a good test of the mix. Although Lunda Construction of Black River Falls, Wis., had placed the concrete at 75° F and the core would stay below 160° F, a lower heat of hydration appeared necessary for the more massive pier stems. In addition, the spreadsheet-based Schmidt Model predicted an unacceptable 57 days for the gradients to decrease to where a cofferdam could reopen around the stems and construction could continue.

So Brenno designed a mix with 413 pounds of GGBF slag or a 70% replacement of cement weight based on a MnDOT mix with the next lower minimum anticipated 28-day strength, 3900 psi. The new mix also used 177 pounds of Type II cement, 3% air entrainment, and a low-range water-reducer for pumpability.

The pier stem, designed to withstand a barge impact force of 3.2 million pounds and support the weight of the superstructure, was poured in 5-foot lifts. After concrete temperature spiked at 72 hours and then leveled off at 162° F after 9 days, workers raised the pump intakes to flood the cofferdam, first to 1 foot above the footing, then every 3 feet up to 15. During this controlled cooling process, no thermal cracking was visible. Fifteen days after pier stem concrete placement, workers refilled the cofferdam so superstructure construction could begin.

Heat of hydration testing on partially hydrated GGBF/portland cement samples

	Slag replacement %			
	0 (control)	35	60	85
7-day heat of hydration (cal/gm)	77.0	62.0	49.9	34.2

Results of heat of hydration testing conducted by Holnam on ground granulated blast-furnace slag/portland cement samples showed that higher percentages kept 7-day heat below the 60 cal/gm limit for Type IV cement per ASTM C 150, "Standard Specification for Portland Cement."

Cemstone strength testing of concrete mixes with GGBF slag (4000 psi specified)

	Slag replacement %			
	0	35	60	85
56-day psi				
projected	8287	8091	6894	3758
actual	7740	7660	6290	3060

Thermal gradients between some points reached a high of about 60° F around the 13-day mark, but the concrete had reached 4000 psi. "We decided that once we reached strength and the core temperature was dropping, we'd waive the differential spec," Nelson says. Cylinder testing on the footing revealed 28-day strengths of 4680 to 5090 psi, 28-day strengths of 4010 to 4630 for the stem, and 56-day strengths of 4770 to 5550 psi for the stem. Construction of Piers 2 and 3 would continue the following autumn and spring with similar strength and temperature differentials.

A mass-concrete model

When it opened in summer 1998, the new bridge, noted for its curved twin traffic lanes and accompanying pedestrian paths, linked downtown St. Paul to the city's redeveloping riverfront. And the piers supporting the main structure are a product of careful study of the benefits of GGBF slag when used as a high percentage of the total cementitious material for concrete in massive structures.

For Doug Schwartz, concrete engineer for MnDOT, "It's another tool to solve various problems. We've had shrinkage cracks in bridges that had to be repaired no matter what we've done. This (70%) wouldn't be the normal (GGBF slag) content used, but on a case-by-case basis we'll allow a higher content."

That's good news to Nelson, who feels that MnDOT's calculated risk-taking has opened some new doors for similar future work on state projects. "Using a high slag content is really something that hadn't been tried in Minnesota mass concrete before," he says. "These mixes wouldn't have worked without the slag."

—Don Talend

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