Bridge Views

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SLAG CEMENT ASSOCIATION

RENEWAL OF FHWA'S HPC TECHNOLOGY DELIVERY TEAM

Terry D. Halkyard, Federal Highway Administration

The Federal Highway Administration's High Performance Concrete (HPC) Technology Delivery Team (TDT), through funding in the Intermodal Surface Transportation Efficiency Act (ISTEA), produced positive results in helping state departments of transportation (DOTs) implement HPC in their highway bridges. The TDT, created in 1997, helped 13 states build HPC bridges and host or participate in technology transfer activities such as showcases and workshops. Working with the AASHTO Lead States Team for HPC Implementation, the TDT influenced many additional state DOTs to try HPC in their highway bridges.

When the ISTEA ended, about 25 states had used HPC. Though lacking a direct funding mechanism, the TDT continued to promote HPC and encouraged states to build HPC bridges through a new program created under legislation following the ISTEA. The Transportation Equity Act for the 21st Century (TEA-21) included a new program for constructing bridges utilizing innovative materials—the Innovative Bridge Research and Construction (IBRC) program.* HPC is considered an innovative material under the guidelines of the IBRC program. This is the primary source of the FHWA funding for states wanting to implement HPC today.

In 1998, the FHWA created resource centers in Baltimore, Chicago, San Francisco, and Atlanta. These centers are staffed to bring technical expertise and technology transfer agents closer to state and local highway agencies. In addition, the TDT is being renewed with a focus on field delivery of HPC technology. The TDT members represent the four Resource Centers; the Offices of Bridge Technology, Pavement Technology, and Infrastructure Research and Development; Division Bridge Offices; the Eastern Federal Lands Highway Office; and state DOTs. Recognizing that the successes of earlier HPC technology transfer efforts were the result of cooperation and coordination between the FHWA, academia, state DOTs, and industry, the new TDT includes representatives from academia and industry.

The TDT is formulating a business plan that will include statements of the team's vision, mission, and goals. The emphasis of these statements will be to provide leadership in advancing HPC technology and in implementing HPC for increased structural efficiency and durability, thereby leading to reduced life-cycle costs for bridges and pavements.

The TDT will also work to increase its presence on the World Wide Web. A new HPC web site will allow easier and more frequent updating of the web pages. A new Community of Practice web site is being developed for HPC. It will allow users to post questions, participate in discussions, share documents, and review works in progress. Users will have the option to subscribe to an e-mail notification system where they will receive a summary of postings to the Community of Practice site for the subject areas that they choose.

More Information

More information about the TDT may be obtained by contacting the author at 202-366-6765 or e-mail at terry.halkyard@fhwa.dot.gov

* *See HPC Bridge Views, Issue No. 14, March/April 2001.*

TECHNOLOGY DELIVERY TEAM

Member	Representing	Member	Representing	Member	Representing
Louis Triandafilou	Eastern Resource Center	Jon Mullarky	Pavement Technology	Barry Brecto	Washington Division
Tom Saad	Midwestern Resource Center	Joseph Hartmann	Infrastructure R&D	Hala Elgaaly	Eastern Federal Lands
Jeffrey Smith	Southern Resource Center	Marcia Simon	Infrastructure R&D	Celik Ozyildirim	VA Transportation
Myint Lwin	Western Resource Center	Douglas Edwards	Florida Division		Research Council
Terry Halkyard	Bridge Technology	Michael Praul	Maine Division	Charles Goodspeed	University of NH
Suneel Vanikar	Pavement Technology	Milo Cress	Nebraska Division	Shri Bhide	NCBC
Gary Crawford	Pavement Technology	Claude Napier	Virginia Division		

BENEFITS OF SLAG CEMENT IN HPC

Jan R. Prusinski, Slag Cement Association

Slag cement—commonly referred to as ground granulated blast-furnace slag or GGBFS—is a hydraulic cement that works synergistically with portland cement to improve concrete strength and durability.

What is Slag Cement?

Slag cement is a value-added material that results from a tightly controlled production process that ensures consistent physical and chemical properties. Molten slag—the non-metallic mineral constituent of iron ore—is tapped from an iron blast furnace, then rapidly quenched with water in a granulator. The resulting glassy granules are then dried and either ground to a fine powder to make slag cement or interground with portland cement to produce blended cement. Slag cement is different from slag aggregates, which are either air-cooled or expanded blast-furnace slag and possess no cementitious value. Available for many years in the United States, slag cement use has doubled over the last five years.

Cementitious Reaction

Slag cement is a hydraulic binder that reacts with water to form a cementitious material (calcium-silicate hydrate or CSH). Similar to a pozzolan, it also reacts with the calcium hydroxide formed during the hydration of portland cement to form additional CSH. The resulting cement paste is stronger and denser, thereby improving the properties of concrete.

High Strength and Modulus of Elasticity

Slag cement provides a higher compressive strength in concrete at later ages than is achieved by using portland cement alone. Concrete strength is usually optimized when slag cement replaces 40 to 50 percent of the portland cement. Additionally, concrete made with slag cement commonly exhibits higher ratios of flexural to compressive strength. The relationship between modulus of elasticity and concrete compressive strength for slag cement concrete is the same as that for portland cement concrete.

Permeability and Corrosion Resistance

HPC mixtures are often proportioned to achieve low permeability. The additional CSH created with slag cement forms a denser cement paste, reducing pore size and lowering concrete permeability, as illustrated in the figure. Lower permeability significantly enhances the corrosion protection offered by concrete to the reinforcing steel by reducing the rates of chloride ion diffusion and carbonation.

Resistance to Alkali-Silica Reaction and Sulfate Attack

The low permeability of slag cement concrete reduces available moisture necessary for alkali-silica reaction (ASR) and sulfate attack. In the case of sulfate attack, the low permeability keeps sulfates from migrating into the concrete. For ASR mitigation, slag cement consumes some of the alkalis produced from the portland cement during hydration, leaving them unavailable for reaction with the aggregates. For mitigation of sulfate attack, slag cement lowers the total amount of tricalcium aluminate available for reaction with the sulfates. Proper proportioning of slag cement can eliminate the need to use low alkali or sulfate-resistant portland cements.

Early Age Properties

Slag cement improves the workability, placeability, and consolidation of concrete. This results in easier and better finishing, and helps ensure proper consolidation of the placed material.

In mass concrete applications, it is often necessary to limit the temperature differential between the surface and center of the concrete to guard against thermal cracking. Dosage rates of 50 to 80 percent of slag cement normally enable mass concrete to meet low heat of hydration requirements.

When slag cement is used, the time of initial set is generally extended by 1 to 3 hours at 73°F (23°C) but generally becomes unnoticeable above 85°F (29°C). Lower temperatures can extend time of set significantly, but conventional accelerators can offset this effect.

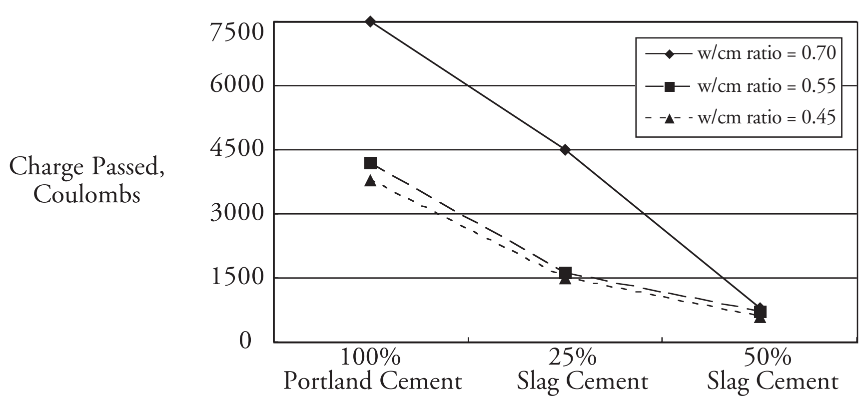
For the first 3 to 7 days, slag cement concrete exhibits lower strengths compared to portland cement concrete. By a concrete age of 28 days, slag cement concrete strengths are normally higher. Steam curing in precast, prestressed concrete operations can virtually eliminate early age strength differences and still maintain later age benefits.

Proportioning and Use with Admixtures and Pozzolans

The use of slag cement in a concrete mixture will necessitate minor adjustments in the mix proportions. Slag cement should conform to AASHTO M 302 (ASTM C 989) or, if used in blended cement, AASHTO M 240 (ASTM C 595) or ASTM C 1157. Slag cement is compatible with chemical admixtures in a manner similar to portland cement. Also, slag cement is frequently used in HPC ternary blends with fly ash or silica fume.

Further Information

Further information on the use of slag cement in high performance concrete can be obtained from the Slag Cement Association (SCA) at phone: 281-494-0782 or e-mail: info@slagcement.org



Reduction of chloride ion permeability with slag cement

Editor's Note

This article is the fourth in a series that addresses the benefits of specific materials used in HPC. The benefits of silica fume, lightweight aggregate, and different cements were discussed in previous issues of HPC Bridge Views.

HPC FOR CHICAGO'S WACKER DRIVE

Stan L. Kaderbek, Chicago Department of Transportation and Sharon L. Tracy and Paul D. Krauss, Wiss, Janney, Elstner Associates

Wacker Drive is a major two-level viaduct bordering the north and west sides of Chicago's downtown "Loop." The existing 75-year old structure is being replaced due to severe corrosion of the embedded reinforcing steel and spalling of the concrete cover. The columns and deck of the new structure are being built using cast-in-place high performance concrete (HPC). The deck is post-tensioned HPC with a latex-modified concrete overlay.

Reconstruction of Wacker Drive is a joint project by the Chicago Department of Transportation, the Illinois Department of Transportation (IDOT), and the Federal Highway Administration. A lengthy process for prequalification of concrete materials and suppliers began in 1999, when a plan was initiated requiring testing and evidence that raw materials and HPC mixes would exhibit properties to ensure long-term durability, quality, and performance in the field. These requirements provided the groundwork for the HPC specifications.

The requirements for the HPC focused on durability, not strength. The minimum and maximum specified concrete compressive strengths at 28 days were 6000 and 9500 psi (41 and 66 MPa), respectively. The water-cementitious materials ratio was specified as 0.36 to 0.38. The upper strength limit and the moderately low water-cementitious materials ratio were specified to reduce the risk of cracking or placement problems that often accompany very high strength concrete. Durability requirements included testing for freezing and thawing resistance, chloride permeability, chloride ion penetration, deicer scaling resistance, and shrinkage. The HPC was also proportioned to be easily placed using conventional concreting practices. Two mix designs were suggested in the specifications, with a contractor-designed mix as a third option. Tables 1 and 2 on page 4 list the HPC mix performance and durability criteria.

The HPC specification also included high performance raw materials. The portland cement had to be an ASTM C 150 Type I or I/II and IDOT approved, meeting requirements for total and water-soluble sulfate contents, total alkali content, fineness, and early stiffening behavior. The coarse and fine aggregates were required to be IDOT approved, Class A, alkali-silica nonreactive, and with water-soluble chloride contents less than 0.04 percent. Class F fly ash, silica fume, and ground granulated blast-furnace slag (GGBFS) were included in the preferred mix design.

A prequalification process was followed whereby interested concrete suppliers submitted their raw materials for testing. In total, ten cements, five coarse aggregates, six fine aggregates, five fly ashes, one GGBFS, and three silica fumes were tested. Concurrently, a total of 14 HPC mixes were batched and samples were cast at the plants for durability testing.

Many potentially harmful issues were brought to light by the testing. For example, many of the fine aggregates were found to be potentially alkali-silica reactive, containing moderately high amounts of potentially deleterious chert. Many local cements and some fly ashes were found to have high alkali contents. The HPC mix testing emphasized the importance of having good air void systems in the hardened concrete for freeze-thaw durability. Some suppliers' concrete exhibited poor performance in the chloride ponding and chloride permeability tests, had high shrinkage, or did not meet the strength requirements. It was clear that specifying "high performance" concrete alone was not adequate to achieve the performance goals. Verification testing of concrete cast in plant conditions using job materials was required.

The surface of the concrete was required to be covered immediately after plastic texturing.

A list of acceptable raw materials and suppliers was generated from the prequalification program. After the contract award, the contractor was required to place a large trial slab using concrete pumps and other bridge-finishing equipment to gain experience placing the HPC mix. Deck curing required 7 days exposure to water-soaked cotton mats covered with plastic sheeting.

Finally, a quality control and quality assurance plan specific to the HPC was developed. It specified that the contractor was responsible for much of the quality control testing. Representatives of the City of Chicago performed quality assurance tests. Job-site testing included frequent monitoring of the plastic concrete properties. Hardened concrete specimens were routinely tested for compressive strength, coulomb values, and air void parameters. Control charts and limits were maintained on water-cementitious materials ratio, aggregate gradation, air content of plastic concrete, and strength.

The placement of the HPC columns and decks at Wacker Drive has been very successful. The mix, as given in Table 3, has proved to be very workable, easily consolidated, and lacking early age cracks. Laboratory data indicate the HPC has the long-term durability characteristics for which it was designed. The success has been due to careful planning, testing, and a commitment to high performance. This commitment should result in durability and a lifetime of 75 years. High performance cannot be achieved solely by specification. Prequalification testing of raw materials, testing of HPC mixes, and thorough quality control and quality assurance programs are necessary.

(Continued on pg. 4)

Table 1. HPC Mix Performance Criteria

Property	Required Value	AASHTO or ASTM Test Method
Plastic Concrete Properties		
Total Air Content of Plastic Concrete	7 ± 1.5%(1)	T 152
Maximum Slump After HRWR Addition	8 in.	T 119
Slump, minimum after 45 minutes	4 in.	T 119
Initial Set Time, minimum	3 hours	T 197
Hardened Concrete Properties		
Post-Tensioning Strength, minimum	4200 psi	T 22
28-day Compressive Strength, minimum	6000 psi	T 22
28-day Compressive Strength, maximum	9500 psi	T 22
Total Air of Hardened Concrete	7 ± 1.5%	C 457
Air Void Spacing Factor, maximum	0.010 in	C 457
Air Void Specific Surface, minimum	500 $in.^2/in.^3$	C 457

(1) Or as required to meet the total air content in the hardened concrete.

Table 2. Testing of Durability and Material Properties of HPC

Property	Required Value	AASHTO or ASTM Test Method
Freezing and Thawing Resistance	DF > 90% at 300 cycles DF > 85% at 500 cycles	T 161
Chloride Ion Permeability Resistance	< 2000 coulombs at 28 days	T 277
Chloride Ion Penetration Resistance	1/2 to 1 in., < 0.03% Cl^- by weight of concrete at 90 days 1/2 to 1 in., < 0.07% Cl^- by weight of concrete at 6 months	T 259 and T 260
Deicer Scaling Resistance	Rating of 0-1 at 50 cycles	C 672
Shrinkage	< 600×10^{-6} at 90 days	T 160

Table 3. Concrete Mix Proportions

Material	Quantities per yd^3	Quantities per m^3
Portland Cement(1)	525 lb	311 kg
Fly Ash, Class F	53 lb	31 kg
Silica Fume	27 lb	16 kg
GGBFS	79 lb	47 kg
Fine Aggregate(2)	1140 lb	676 kg
Course Aggregate(3)	1800 lb	1068 kg
Water	254 lb	151 kg
Water Reducer	41 fl oz	1.59 l
HRWR	55-110 fl oz	2.1-4.3 l
Air Entrainment	As needed	
Water/Cementitious Materials Ratio	0.27	

(1) Type I/II
(2) Natural siliceous sand
(3) 3/4-in. (19-mm) maximum size limestone

Further Information

Further information on the project may be obtained by contacting Sharon Tracy at 847-272-7400 or e-mail at stracy@wje.com.

HPC BRIDGE CALENDAR

October 19-22, 2003
Third International Symposium on High Performance Concrete, Orlando, FL. Jointly sponsored by FHWA and PCI. Contact Paul Johal, Precast/Prestressed Concrete Institute at 312-786-0300, info@pci.org or www.pci.org

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