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SAFETEA-LU HPC BRIDGE RESEARCH AND DEPLOYMENT PROGRAM

M. Myint Lwin, Federal Highway Administration and Shri Bhidé, National Concrete Bridge Council

On August 10, 2005, President George W. Bush signed the Safe, Accountable, Flexible, Efficient Transportation Equity Act: A Legacy for Users (SAFETEA-LU). SAFETEA-LU authorizes the federal surface transportation programs for highways, highway safety, and transit for the years 2005-2009, providing an average of about $4.3 billion per year for the Highway Bridge Program. The new legislation includes $4.125 million for each of the fiscal years 2006 through 2009 for a High Performance Concrete (HPC) Bridge Technology Research and Deployment Program to conduct research and deploy technology relating to HPC bridges.

Motivation for the HPC program in the legislation is described in the National Concrete Bridge Council (NCBC) brochure entitled "Building a New Generation of Bridges – A Strategic Perspective for the Nation."* The brochure defines the problem: 173,000 (36 percent) of America's bridges are deficient, highway usage is increasing rapidly, and motorists are 11 times more likely to drive into a fatal accident in a bridge work zone than in normal traffic. Even though annual funding has been increasing, it will still take 57 years to repair or replace our deficient bridges at the current rate.

High performance concrete contributes to solving the bridge problem by meeting the program goals to Reduce Congestion and Improve Safety; Reduce Life-Cycle Costs; and Develop Engineering Design Criteria for innovative materials, structural systems, and construction techniques. The fourth goal of the program is to Train the Workforce, which is extremely important since HPC bridge quality is highly dependent on the people actually involved in bridge design and construction. The four goals for the HPC program are closely aligned with the Federal Highway Administration's (FHWA) Highways for LIFE program.

The recommendations for HPC bridges will provide a solid return on investment for the public. Based on the specific descriptions, implementation requirements, and timelines of the four goals, the HPC plan will reduce the number of deficient bridges, ease traffic congestion, reduce bridge construction time, save maintenance expenses, and lower life-cycle costs.

To initiate the HPC program, the FHWA and the National Concrete Bridge Council are working together to identify topics for research, deployment, and education. The topics will address the entire HPC bridge system including concrete materials, design, construction, structural arrangement, speed of construction, overall performance, and long service life.

Deployment and technology transfer topics include such items as worker training in HPC construction practices and certification, prototype bridge construction and showcases, newsletters, best practice manuals, university courses on HPC, and national conferences.

Research topics will address short-term needs (i.e., before and during construction) and long-term behavior, which is related to FHWA's Long-Term Bridge Performance program. Research topics include such items as improving durability, developing maturity criteria, controlling cracking, increasing robustness of mixes under varying conditions, and validating HPC properties under field conditions.

Implementation of the HPC Bridge Technology Research and Deployment Program will allow the FHWA, State Departments of Transportation, and industry to work together in building a new generation of concrete bridges that are safe, durable, efficient, and cost effective.

Further Information

For more details or to provide comments, please contact the second author at sbhide@cement.org or 847-972-9100.

**See HPC Bridge Views Issue No. 20, March/April 2002.*

NEW JERSEY'S FIRST SEGMENTAL CONCRETE BRIDGE

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The new Victory Bridge on State Route 35, across the Raritan River between Perth Amboy and Sayreville, is New Jersey's first segmental concrete box girder bridge. The bridge consists of twin parallel structures with a main span of 440 ft (134 m) — a U. S. record for fully match-cast segments, two side spans of 330 ft (101 m) each, and approach spans that vary in length from 142 to 150 ft (43 to 46 m). The main span and side spans were erected using the balanced cantilever construction method. Concurrently, the approach spans were erected using the span-by-span method. This allowed delivery of the completed bridge on an expedited schedule.

The first 3,971-ft (1.21-km) long structure was opened to traffic in June 2004, just 15 months after notice to proceed was received. The second structure was erected nine months later and opened to traffic in September 2005 — more than two months ahead of schedule.

Superstructure

The concrete segments were cast in Virginia and barged to the site for erection. Typical superstructure precast concrete segments are 9 ft 4 in. (2.84 m) long. This length was chosen to allow for ease in transportation and erection operations. Pier segments were cast in halves, each weighing 115 tons (104 metric tons), so that the same equipment could be used in the erection process. High performance 8,000 psi (55 MPa) compressive strength concrete was utilized for the superstructure segments. The segments include an additional 1¾ in. (44 mm) of concrete integral to the slab, consisting of 1¼ in. (32 mm) for a durable wearing surface and ½ in. (13 mm) for milling to meet the rideability criteria. A final profilograph measurement of 3.47 in. per mile (55 mm per km) exceeded the owner's request of a 6 in. (95 mm) value and provides an extremely smooth riding surface. With an integral wearing surface, construction of a second course was not required; thereby shortening the construction schedule.

Substructure

The concrete substructure consists of 22 piers and two abutments for each of the twin structures. Piers in the river have foundations consisting of footings supported on drilled shafts, while those on land have rectangular footings on steel pipe piles.

The piers were constructed from precast concrete box sections. The approach pier sections are 8 by 16 ft (2.4 by 4.9 m) and weigh about 28 tons (25 metric tons) each, while the pier sections for the main span are 9 by 16 ft (2.7 by 4.9 m) with thicker walls that resulted in weights up to 32 tons (29 metric tons) each. Overall, the piers range in height from about 21 to 101 ft (6.2 to 30.8 m). Through careful scheduling and coordination, even the tallest pier was assembled in a single day, a benefit of segmental technology. High performance concrete mixes with compressive strengths of 8,000 psi (55 MPa) were used to cast the pier sections.

HPC

For freeze-thaw durability of the HPC used in the substructure and superstructure, a relative dynamic modulus of elasticity of 80 percent after 300 cycles, when tested per AASHTO T 161 or ASTM C 666 Procedure A, was specified. A maximum chloride permeability of 1000 coulombs at 56 days per AASHTO T 277 or ASTM C 1202 was also specified. In order to achieve the desired resistance to chloride penetration, fly ash was used in the concrete. For abrasion resistance of the concrete used in the water footings, an average depth of wear of 0.04 in. (1.0 mm) maximum per ASTM C 944 was required by the owner.

Bid Documents

The bid documents were significantly more detailed than usual, enabling the contractor to work directly from them rather than creating shop drawings, thereby, saving both time and money. The bid documents included details of reinforcement bends, segment geometry, and tendon stressing sequence. For certain elements, the documents included electronic files with integrated 3D color drawings. The first segment was cast just six weeks after notice to proceed, getting the project off to a quick start.

World War I

The original Victory Bridge was dedicated to New Jersey residents who served in World War I and the new bridge fulfills this same vision. Light poles are supported on concrete pilasters that showcase bronze plaques commemorating various branches of the services in World War I. Four memorial obelisks are located at the bridge abutments; two incorporating the original bronze plaques from the 1927 structure and two featuring new plaques that rededicate this important bridge for New Jersey.

HPC was used in the foundations, piers, and superstructure of the new Victory Bridge. Photo ©FIGG.

NEW YORK STATE'S USE OF HIGH STRENGTH HIGH PERFORMANCE CONCRETE

Mathew Royce, New York State Department of Transportation

New York State's Department of Transportation (NYSDOT) first used high strength, high performance concrete (HSHPC) for bridge beams in 2001. Initial experience showed that concrete with a compressive strength of 10,150 psi (70 MPa) allowed the design of bridge beams for significantly longer spans compared to conventional strength concrete. Higher performance requirements for durability held the promise of a maintenance-free service life of 100 years or more for bridge beams even in aggressive environments. Based on the success of the initial applications during 2001, 2002, and 2003, NYSDOT began specifying HSHPC for all precast, prestressed concrete beams in 2004.

Specifications

The NYSDOT HSHPC specification is performance based using seven criteria for design efficiency and durability as follows:

Compressive strength (f'_c) at 56 days by AASHTO T 22: >10,150 psi (70 MPa)

Modulus of elasticity at the concrete age when $f'_c \geq 10,150$ psi (70 MPa) by ASTM C 469: ≥ 4350 ksi (30 GPa)

Shrinkage after 56 days of drying by AASHTO T 160: < 600 millionths

Specific creep after 56 days of loading by ASTM C 512: ≤ 0.41 millionths/psi (60 millionths/MPa)

Freeze-thaw relative dynamic modulus after 300 cycles by AASHTO T 161 Proc. A: ≥ 80%

Scaling resistance by ASTM C 672 visual rating: ≤ 3

Chloride penetration by AASHTO T 259 (modified) increase in chloride ion by weight: < 0.025% at 1 in. (25 mm)

In addition, certain requirements are established for the mixes:

1. Minimum entrained air content of 3 percent
2. Minimum silica fume content of 5 percent by weight of the cementitious materials
3. Maximum water-cementitious materials ratio of 0.40
4. Calcium nitrite corrosion inhibitor at a dosage rate of 646 fl oz/cu yd (25 l/cu m)

Eight precasters in and around New York State, including most of the precasters who produce beams for NYSDOT, have completed the mix design and pre-production testing. Most of these precasters have already used their approved mixes for producing concrete beams for NYSDOT. In addition, most of the local governments within the state, including the New York City Department of Transportation, are also using NYSDOT High Performance Concrete Specifications and NYSDOT approved concrete mixes for precast, prestressed concrete bridge beams.

Design Efficiency

NYSDOT bridge designers, as well as consultants working for the DOT, are achieving substantial design efficiency improvement by using HSHPC. With the use of 10,150 psi (70 MPa) concrete and 0.6-in. (15.2-mm) diameter strands, span-to-beam depth ratios have been increasing. This is helping the designers use precast, prestressed concrete beams for replacement bridges where, in the past, it was not feasible due to site limitations on maximum allowable beam depths.

Lower creep and shrinkage in HSHPC beams helps to reduce secondary stresses in indeterminate structures, such as superstructures made continuous for live load. Reduced positive moment in beams at the intermediate supports usually produces more efficient designs as well as increased durability due to the reduced potential for cracking in the closure pours between beam segments. The camber and camber growth of HSHPC beams are more predictable. Camber growth control is important in design and construction of bridges built in stages. Usually, concrete decks for the first stage of these bridges are thickened to accommodate the expected camber growth of beams to be used for the second stage. Since beams using HSHPC have lower camber growth, unnecessary increases in deck thickness can be avoided, resulting in a more efficient design.

Durability

Resistance to chloride penetration of HSHPC meeting NYSDOT specification is many times higher than the conventional concrete used for bridge beams fabricated prior to 2004. The calcium nitrite corrosion inhibitor also elevates the corrosion initiation threshold significantly. NYSDOT is confident that the combination of HSHPC and corrosion inhibitor will provide a service life of 75 to 100 years for precast, prestressed concrete beams.

Cost of High Performance Concrete

Based on the cost data for concrete bridges constructed during the last five years, there has not been any significant cost difference between bridges with HSHPC beams (cost of mix design and initial testing included) and bridges with conventional concrete beams. Use of HSHPC in precast, prestressed concrete bridge beams is very advantageous to bridge owners due to significantly reduced life-cycle costs.

High Performance Self-Consolidating Concrete (HPSCC)

Some of the precast concrete producers have started using HPSCC in products used by the Department. NYSDOT is allowing the use of HPSCC when requested by the contractor. In general, pre-production testing is similar to conventional HSHPC except that additional quality control tests are performed to ensure no segregation of aggregates during or after the placement of HPSCC. All precast concrete components produced using HPSCC for NYSDOT have shown very good results.

Conclusion

In general, the use of HSHPC and HPSCC for precast, prestressed concrete bridge beams has been a remarkable success. With no apparent increase in construction cost, NYSDOT is building bridges that are much more durable and less expensive to maintain. For a copy of the Engineering Instruction and HSHPC Specifications, go to www/dot/state/ny.us/cmb/consult/eib/files/ei03037.pdf.

Editor's Note

This article is the fifth in a series that describes how the use of HPC has progressed since it was first introduced into a State's program. Other articles appear in Issue Nos. 30, 35, 36, and 37

HPC MIXTURE DEVELOPMENT FOR MONTANA USING LOCAL MATERIALS

John Lawler and Paul Krauss, Wiss, Janney, Elstner Associates, Inc. and Craig Abernathy, Montana Department of Transportation

Concrete bridge decks in Montana are subjected to severe service conditions. Potential deterioration mechanisms include corrosion of the reinforcing steel and scaling of the concrete surface resulting from deicing salt applications, freezing and thawing distress, cracking due to thermal and humidity extremes during and after construction, and other materials-related problems. To overcome these challenges, the Montana Department of Transportation (MDT) funded research to develop high performance concrete (HPC) mixtures to optimize the durability of bridge decks. A previous article discussed a field trial of an HPC bridge in Montana.[*] A parallel investigation, conducted to identify the best combination of materials available in Montana for use in HPC, is summarized in this article.(1)

Performance objectives for durable concrete decks were used to design an experimental program focused on Montana's environmental conditions and local materials. Testing included plastic concrete properties, slump loss, setting characteristics, air-void system parameters, electrical conductivity, strength, chloride penetration resistance, freezing and thawing resistance, scaling resistance, and drying shrinkage.

Three important concepts were recognized at the initiation of this project: 1) supplementary cementitious materials (SCMs) and other concrete raw materials vary significantly depending on geographic location, 2) consideration of the raw materials themselves is important since they may impact durability, and 3) concrete production capabilities vary widely with producers or location.

Optimizing HPC for durability typically involves the use of SCMs because they improve workability and deterioration resistance. However, since some of these supplementary materials are byproducts of other industries, the SCM properties can be inherently variable. Therefore, generalizations about the best combination of SCMs and aggregates cannot be made. Rather, the most effective solution must be determined by testing with locally available materials.

The raw materials investigated included four aggregate sources, a Type I/II portland cement, and a range of SCMs, including Class C and Class F fly ashes, ground granulated blast-furnace slag (slag), high-reactivity metakaolin, and silica fume, from Montana or a neighboring state. To ensure that the aggregates do not limit the concrete durability, aggregates from four sources throughout the State were evaluated for alkali-silica reactivity. The aggregate test program, conducted using ASTM C 1260 and C 1293 procedures and petrographic examinations, suggested that three of the four aggregate sources are susceptible to potentially deleterious alkali-silica reaction (ASR), and the fourth may also be marginally at risk. However, combining the most reactive of these aggregate sources with SCMs produced concretes that experienced little or no expansion in modified C 1293 testing. This suggests that while ASR is a potential limiting factor on service life, it may be mitigated effectively in the HPC mixtures.

Concrete testing was conducted in three rounds, each targeted at a slightly different type of HPC. The first round examined mixture combinations that have historically demonstrated good performance as reported in the literature and based on the experience of the investigators. Since the mixes that performed best in the first round were complex containing fly ash, slag, and silica fume, the second round quantified the performance of pre-combined blended cements that enabled similar combinations. These portland cement blends included a slag blend, a Class C fly ash blend, and a calcined-clay blend. The third round examined easy-to-produce mixtures that have statewide application. The first two rounds were conducted using an aggregate from the Yellowstone River Valley (YRV), while the third used an aggregate source from Western Montana (WM).

Best-performing HPC mixtures

Material	Quantity, lb/cu yd			
Aggregate Source	YRV	YRV	WM	WM
Portland Cement	—	—	685	526
Slag Blend	575*	—	—	—
Calcined-Clay Blend	—	654**	—	—
Fly Ash (Class F)	54	—	—	—
Slag	—	—	—	133
Silica Fume	28	20	25	35
Water	252	252	252	252

**Slag at 22% by weight   ** Calcined clay at 17.5% by weight*

In evaluating the best performer, judgments must be made about the relative importance of the desired properties. The greatest cause of deterioration in Montana bridge decks is expected to be corrosion of reinforcing steel initiated by chloride ions from deicing salts. Therefore, given acceptable performance in the other tested properties, the highest emphasis was placed on chloride penetration resistance. However, some material combinations having very good chloride resistance resulted in concrete with high scaling or shrinkage making them less desirable. Based on the 14 specific mixtures evaluated, the combinations of tested SCMs that produced the best overall performance are listed in the table.

In this test program, concretes produced using the Western Montana aggregate (mainly quartzite and sandstone) demonstrated better performance in terms of strength, resistance to chloride penetration, and scaling resistance than that measured with the Yellowstone River Valley aggregate (mainly basalt and granite). However, the shrinkage tended to be higher. The influence of the raw materials and the importance of testing each mix containing specific materials were clearly demonstrated since changing the aggregate source had a greater effect on performance than modifications to the cementitious materials. The best mix combination was different for each aggregate source. This implies that the character of the paste-aggregate interfacial transition zone, as affected by aggregate type, is of utmost importance.

Reference

1. Lawler, J. S., Krauss, P. D., and Abernathy, C., "Development of High-Performance Concrete Mixtures for Durable Bridge Decks in Montana Using Locally Available Materials," Publication SP-288, American Concrete Institute, 2005, pp. 883-902.

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[*] *See HPC Bridge Views Issue No. 35, September/October 2004.*

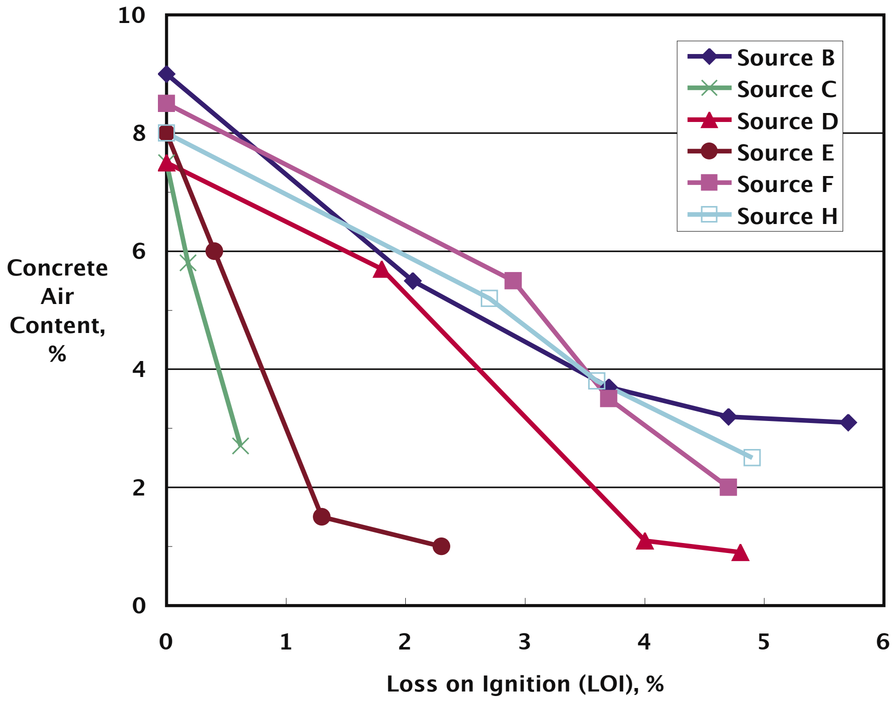
THE IMPACT OF FLY ASH ON AIR-ENTRAINED CONCRETE

Russell L. Hill, Boral Material Technologies and Kevin J. Folliard, University of Texas

The use of fly ash to produce more durable concrete is a well-established practice. The judicious use of fly ash results in reduced heat of hydration, increased later age concrete strengths, and reduced permeability. The use of appropriate dosages of fly ash enhances durability by providing mitigation of alkali-silica reactions, resistance to sulfate attack, and reduced ingress of potentially deleterious materials such as chloride and water. The widespread use of fly ash in high performance concrete (HPC) was confirmed in a survey of state highway agencies conducted by the FHWA.[*] The survey indicated that 70 percent of the respondents incorporated fly ash in HPC mixtures exposed to aggressive environments.

Perhaps one of the most significant issues that must be considered when utilizing fly ash in concrete is the potential impact this material can have on air entrainment. Special chemical air-entraining admixtures (AEAs), which are based on surfactant chemistry, are used to entrain the correct air-void system in plastic concrete. These chemicals are very effective and only small dosages are generally required; however, the system represents a rather delicate balance of many factors. The Manual on Control of Air Content in Concrete(1) lists over 40 parameters that can influence concrete air entrainment. Fly ash is one item listed; but depending on the nature of the ash, it can have a major influence on air entrainment.

The reason fly ash has such a critical role regarding air entrainment is not due to the ash itself but is related to a potential contaminant that exists in much of the ash produced today. As a by-product of coal combustion, fly ash often contains a small proportion of unburned, residual carbon. This carbon is typically measured by performing a loss on ignition (LOI) test. The carbon component of fly ash can act as an adsorbent of organic material (just as activated carbon is often used to purify water). Fly ash carbon has a strong tendency to interact with the surfactants used as air-entraining admixtures. As the LOI value of fly ash increases, the dosage of air-entrainment chemical required to produce a given air content will generally increase as well. Furthermore, fluctuations in fly ash LOI (carbon) result in fluctuations in concrete air content. This situation requires careful quality control by the concrete producer and frequent adjustments to admixture dosages.



Influence of fly ash LOI value on air entrainment of concrete.

Because of the negative influence of fly ash carbon on air entrainment, AASHTO M 295 – Coal Fly Ash and Raw or Calcined Natural Pozzolan for Use in Concrete stipulates a maximum LOI value of 6 percent for fly ash to be used in concrete without further qualification. Many specifying agencies and fly ash suppliers will impose more restrictive LOI limits in an attempt to improve quality.

The past decade has seen changes in the utility industry that have further complicated the use of fly ash for air-entrained concrete. Environmental regulations designed to reduce the quantity of acid rain promoting air pollutants that utilities generate have been broadly implemented. As a result, many utilities are retrofitting plant equipment to operate under new combustion regimes. Unfortunately, the combustion conditions that lead to reduced air emissions can result in increased fly ash carbon contents. For instance, the retrofitting of a utility's combustion units to reduce NOx emissions will often cause the LOI of a given fly ash produced by the facility to more than double.

To further complicate this issue, the modified combustion systems not only impact the amount of carbon available in the ash, but the activity of the carbon as well. The adsorptive capacity of fly ash carbon for air-entraining admixtures is a function of carbon mass and other carbon characteristics such as carbon surface area, carbon pore size distribution, and carbon surface chemistry. Modification of any of these parameters can impact the adsorptive capacity of the fly ash carbon.

In practical terms, this means that certain changes made by a utility to combustion conditions can result in minimal impact on carbon mass or LOI but will still significantly modify the influence that a fly ash has on air entrainment. This occurs because changes in the carbon's surface area or surface chemistry lead to a change in the carbon's adsorptive capacity. Data presented in the figure depicts

(continued on pg. 6)

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[*] *See HPC Bridge Views Issue No. 32, March/April 2004.*

(continued from pg. 5)

the influence of LOI (carbon content) on air entrainment for a number of fly ashes collected from different utility sources. It is readily apparent that fly ash from Sources C and E will be the most problematic for air entrainment even though these ashes possess the lowest LOI value of any tested.

The impact that various pollution control technologies will have on fly ash quality varies based on the specific modifications made at a plant, the fuels being fired, the combustion regime already in existence, and the compliance requirements mandated for a particular source. In many situations, the impact may be minimal, but in other cases the quality of the ash will be changed drastically. As future air quality emission standards become more restrictive, it is probable that more fly ash sources will be impacted by these types of combustion modifications.

In order to better manage fly ash quality with respect to air entrainment, many suppliers no longer rely strictly on LOI value as a measure of quality. Performance-based testing such as the foam index test (referenced in ACI 232.2) and mortar air testing (AASHTO T 137) are often used to determine product acceptance. Measuring the surface area of fly ashes, using methods such as BET absorption,** can generate useful data for those ashes in which the surface area of the carbon has been increased through modified burning processes, but this testing regime is not feasible as a quality control test in most cases. The most direct means for determining a fly ash's potential to impact air entrainment is to perform laboratory or field trial mixtures in concrete with the job specific materials.

Additional advances in the fly ash industry include the development of new beneficiation technologies designed to minimize the impact that carbon has on concrete performance. Carbon burn out is one such technology that is in commercial operation. In this system, the carbon-contaminated fly ash is processed through a fluidized bed combustion unit to remove the residual carbon content to an acceptably low level. The processed, reduced-carbon fly ash will have little impact on air entrainment. Another method of reducing carbon in fly ash is the use of electrostatic separators that selectively remove the carbon from the fly ash and subsequently use this removed carbon as a fuel for the combustion process.

Another commercially available technology is based on fly ash carbon treatment (FACT). In this technology, a proprietary chemical formulation is applied to the ash that acts as a sacrificial agent. The sacrificial agent has no influence on concrete air entrainment other than its strong tendency to interact with fly ash carbon and thus reduce its adsorptive capacity for AEAs. By "sacrificing" to the carbon, the FACT chemicals effectively reduce fluctuations in air entrainment that would normally be associated with changes in carbon mass or activity.

Research is being conducted by a number of universities, agencies, and suppliers to better understand the interactions between fly ash carbon and chemical surfactants. Results from these studies will be used to allow for better utilization of fly ash to produce durable concrete for all environments.

Reference

1. Whiting, D. A. and Nagi, M. A., "Manual on Control of Air Content in Concrete," Bulletin EB116, Portland Cement Association, Skokie, IL, 1998, 48 pp.

***A theory for measuring surface areas established by Brunauer, Emmett, and Teller*

HPC BRIDGE CALENDAR

May 7-10, 2006
2006 Concrete Bridge Conference on HPC: Build Fast, Build to Last, Reno, NV. Sponsored by FHWA, NCBC, NVDOT, and ACI. See www.nationalconcretebridge.org/cbc.

October 23-25, 2006
PCI National Bridge Conference—Bridges for Life,® Accelerated Construction: Getting In and Getting Out Fast, Grapevine, TX. Cosponsored by FHWA. See www.pci.org.

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