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TECHNOLOGY

Concrete Products begins series on the premium admixtures behind value-added, performance concretes

by Tom Kuennen

Silica fume resurges

Far from being marginalized after its highly visible target market collapsed, silica fume remains a potent force in enhancing, and adding value to, concrete.

A 1980s boom in speculative high-rise office buildings using high-strength, silica fume-modified concretes — in some instances exceeding 14,000 psi compressive strengths — led to some high-profile, highly publicized applications of silica fume. But when speculative office buildings went bust in the nervous 1990s, some of the wind came out of the sails of silica fume.

special series

Admixtures

Concrete For The 21st Century

Durability applications grow

"The market continues to grow at this time, but it seemed to skyrocket in the 1980s for a variety of reasons," said Tom Weil, P.E., of Grace Construction Products in Cambridge, Mass., a core business of W.R. Grace & Co. "The first reason was chloride protection in a salt environment, whether it be bridge decks, or marine structures or parking structures. The second reason was its use in high-strength mixes for high-rise building construction. But in the early '90s, high-rise construction came to a screeching halt. In parking structures, use of silica fume continues to grow."

"There has been a slow down in the use of fume in high-rise, high-strength construction, but no significant drop-back in durability applications, primarily parking structures," said Dr. Terry Holland, Master Builders, Inc., Cleveland. "The high-rise market gets a lot of publicity, but is a very small percentage of the market. The vast majority of the fume has gone into parking structures and bridge decks, where you're looking for durability. The parking structure market has remained a good one for silica fume."

Moreover, silica fume concrete is moving from decks into the substructure of the bridges, and this will drive further use. "There's a growing interest in the highway community on higher-strength concrete bridge beams," Holland said. "And as the state DOTs, which are very conservative organizations, start to move up to higher compressive strengths in their concrete, then we'll start to see silica fume incorporated in those mixtures."

Silica fume-enhanced concrete girders for bridges are being studied at this time, and will receive a big boost this month. At the end of March, a Federal Highway Administration-sponsored "Showcase" workshop on high-performance concrete being used in precast girders will be held in Houston. Centered around the Texas Department of Transportation's Louetta Road Overpass project, the workshop will examine the use of high-performance concrete that is incorporated into structural elements (see "DOTs, FHWA step up girder testing," *Concrete Products*, January 1996).

Furthermore, life-cycle cost analysis for federal-aid projects is written into the Intermodal Surface Transportation Efficiency Act of 1991 (ISTEA), and that dovetails nicely with silica fume's attributes. "We actively promote the concept of life-cycle cost analysis for the concrete industry," Weil said. "We feel it's in the best interest of the concrete producer to do so. You can show that the product can perform for a longer period, even though it may cost a little more to put into a structure."

The specific ISTEA words are, Section 1024:

In developing plans and programs pursuant to this section, each metropolitan planning organization shall, at a minimum, consider ... the use of life cycle costs in the design and engineering of bridges, tunnels, or pavement.

What's in a name?

There are many names and uses for silica fume, and a new publication from American Concrete Institute's (ACI) Committee 234 is attempting to standardize usage. Among the names for the product are silica dust, condensed silica fume, microsilica, and fumed silica, each burdened with its own marketing and proprietary product cachet. The most appropriate term is silica fume, the committee contends.

While the long-term mission of ACI Committee 234 simply is to study and report on silica fume, its immediate goal is to get published this spring a definitive *Guide for the Use of Silica Fume in Concrete*. And that's just a start. "We're already working on the update," Holland said.

"We'd like to beef up on case studies and practical aspects of using silica fume," said the University of Toronto's Dr. Doug Hooton, current ACI Committee 234 chairman. "Silica fume changes the properties of concrete dramatically. A danger is that you may get a ready-mix plant out there which tries to incorporate silica fume in a mix, with no knowledge of how it's going to impact the fresh concrete, the rate of hardening, all the durability properties, or the contractor doesn't protect the concrete in its early stages of hardening."

Material properties

If a little knowledge can be a dangerous thing, a lot of knowledge is required for specifiers, material suppliers, and project owners.

Silica fume is a by-product of the reduction of high-purity quartz with coal or coke and wood chips in an electric arc furnace (note photo, preceding page), during the production of silicon metal or ferrosilicon alloys, reports the ACI 234. The fume, which is condensed from gases escaping from the furnaces, has a very high content of amorphous silicon dioxide, and is made of superfine spherical particles.

Early research on silica fume in Europe has come from Scandinavian countries, primarily Norway, and in North America, from Quebec (note Milestones box, page 73). Like fly ash, development of silica fume as a cementitious material was spurred by a desire to find a use for an industrial waste product. Because abundant hydroelectric power is available in Norway and Quebec, coal-derived fly ash never established a foothold. Furthermore, cheap electric power drives the silicon reduction process, so development of end uses for condensed silica fume

Silica fume decks an Illinois bridge

Real-life test shows silica fume concrete cuts bridge deck chloride penetration by half, compared to dense concrete

New research findings to be presented this month give advocates of silica fume admixtures the ammunition they need to prove long-term durability benefits when the material is used in concrete bridge decks.

The research, on a two-lane Illinois Department of Transportation bridge in central Illinois, was conducted by Construction Technology Laboratories, Inc., of Skokie, Ill., for Pittsburgh-based Elkem Materials. A presentation is scheduled at the 1996 spring convention of the American Concrete Institute in Denver, by Tony Kojundic of Elkem U.S., Per Fidjestol of Elkem Norway and Rachel Detwiler of CTL.

The bridge, Illinois Route 4 over I-55 south of Staunton in Madison County, represents the first use of silica fume concrete on a bridge deck by IDOT. The silica fume-enhanced concrete deck was placed on S.R. 4's northbound lane side-by-side with a low-slump dense concrete deck in the southbound lane, providing an apples-to-apples comparison of performance of premium concretes. The lanes were placed in spring of 1987 during a deck rehabilitation.

"Not only are the concretes under similar environments, but they were also very good jobs," said Elkem's Kojundic. "A visual site inspection shows an excellent bond between both concretes, good air void structure, good frost resistance, no scaling, no delamination, very little abrasion. We're fortunate that the dense concrete is a good job, as good as you would expect."

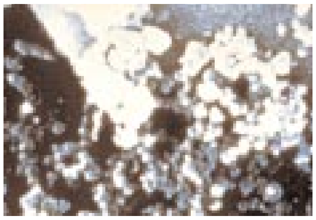
Tests were run on cores from both sides of the deck. Chloride profile tests — in which chloride content is measured from a very thin section ground off the core — found that the silica fume concrete contained many fewer chlorides. Consecutive 1 mm sections cut deeper from the core found consistent results, until a chloride baseline content was reached at 25 mm of depth, meaning no chloride had penetrated beyond an inch into the concrete, Kojundic said.

"In the case of the dense concrete, we had to go down 35 to 40 mm in depth in order to find baseline chloride content," Kojundic said. Plots made of the chloride content profiles indicated about half the level of chloride in the silica fume samples, across four cores from each side of the deck, compared to the dense concrete sample, at virtually every depth.

In addition to periodic vehicle counts — at 2,200 vpd in 1987, to 3,600 vpd in 1995 — IDOT kept good records on how much salt was placed on the deck, estimating that the bridge received 10 times as much salt as adjacent highways over the period of time. The silica fume was added at a rate of 11 percent by weight of cement, and the concrete had a 0.35 water-to-cementitious materials ratio. The dense concrete, with 823 lb.of cement per cubic yard, had a 0.32 w-c ratio.

"What was originally said about silica fume is true," Kojundic said. "Now we're looking at real-life projects and saying it does what it's supposed to do. There's not a drop-off in performance going from research to real life."

In January 1996, Elkem introduced to North America new product, white microsilica, which does not discolor concrete as does conventional gray silica fume (see page 28 of NEWS & DEVELOPMENTS).



A view under scanning electron microscope reveals how silica fume can "pack" between the cement particles and provide a finer pore structure.

was a likely outcome in those countries.

What are the functions of silica fume in portland cement concrete? They are twofold, both physical and chemical in nature. Also, there are three major physical attributes for silica fume.

Because the silica fume particles are much, much smaller than the cement particles — with a surface area in the neighborhood of 20,000 sq m/kg — they can "pack" between the cement particles and provide a finer pore structure.

In the early stages of hydration, silica fume can help accelerate the hydration process, because its tiny particles provide nucleation sites for hydration, much the same way microfine dust particles, or cloud seeding, induce formation of rain droplets.

In the nucleation process, a silica fume particle provides a site on which material in solution can "nucleate" or "center," which helps the material precipitate sooner than it might otherwise do. And once it precipitates, the concentration of that material in solution is reduced, which tends to get more material into solution from elsewhere, speeding the process.

And it also can dramatically reduce bleeding, because the silica fume introduces a lot of surface area into the mix, which in turn helps hold the water in place.

Chemically, if time and moisture are allowed to do their job, silica fume has a very strong pozzolanic reaction, so that when the cement grains hydrate and generate calcium hydroxide, the silica fume will react to that and create more calcium silicate hydrate.

In that instance, more space is filled up within the concrete, which gives much more strength, and improves resistance to intrusion from a number of factors. These benefits include radically reduced permeability to water, and reduced diffusivity to chloride ions. This impacts the migration of dissolved chloride ions (from road deicing salt or marine spray) through the concrete and onto imbedded reinforcing steel; the presence of chloride ions will accelerate oxidation (rusting) of the steel, and concomitant expansion of the steel within the concrete, which ultimately causes cracking and spalling.

Does use of silica fume mean engineers may design structures, in which chloride intrusion is a consideration, without specifying epoxy-coated rebar, or corrosion inhibitors? Perhaps, but a conservative "belt-and-suspenders" design would include both. But the exclusion of silica fume in favor of epoxy-coated rebar, or vice versa, in engineering plans has led to dueling engineering reports, in which the ability of concrete to adhere to epoxy coating has been called into question, as well as the ability of silica fume to resist chloride intrusion.

"Part of the slowdown [in use of silica fume in recent years] has been the controversy over the coulomb test. Several people have questioned whether it is a correct measure of the permeability of the concrete," Weil said. "In fact, it is a test of the resistivity of the concrete. When you look at long-term chloride ponding studies, it is clear that silica fume reduces the permeability of the concrete, and the more you put in, the more significant it is. We just have to get that message out."

At low doses of 3 percent or less, silica fume actually serves to liquefy the concrete. People can be really puzzled as to how one can take a dry mix, and add a little bit of dry powder, and make the mix "wetter." The silica particles are so fine, and fit in between the cement grains, that they displace water, which becomes free to help with the flowability of the concrete. In effect, it becomes its own water reducer.

But when you add more and more silica fume, up to the neighborhood of 5 percent of cementitious material, the surface area of the silica fume begins to outweigh its water displacement function, and surface forces begin to have a strong effect, and water reducer, or superplasticizer, or both must be added to overcome the need for more water.

One of the considerations that has slowed silica fume shipments is that it requires more attention on the part of the contractor than conventional concrete. As dosages are increased, the bleed water that comes to the surface is reduced. If the surface is not protected, plastic shrinkage cracks may appear.

"You need to provide assistance to the contractor," Weil said. "Once you understand it, it's not difficult to work with. But it does require product education and training. When we supply materials, we require a pre-construction meeting with all the people involved. We request that test pours be made before the job starts, so you know how to finish it, how to cure it."

Supply is centralized

Silica fume is marketed by a variety of admixture suppliers in the U.S. Master Builders and Grace Construction Products are prominent suppliers, followed by Euclid and Sika. A third tier includes regional suppliers which repackage silica fume for their customers.

All of the silica fume comes from two primary manufacturers, Elkem and Norchem, who sell to all of the suppliers. (Elkem retailed the material until 1991.) There tends to be little differentiation among the products; instead, most often the sale goes to the supplier who has been the long-term supplier to the concrete producer.

The pricing strategy for silica fume is different in Europe than in America, and it may impact the utility of European research when

continued on page 89

Silica Fume Concrete Milestones

1948 Researchers in Norway identify potential for silica fume as concrete admixture

1952 First field experiment using silica fume involves the Blindtarmen Tunnel in downtown Oslo

1971 First experiment on use of condensed silica fume in concrete takes place at University of Sherbrooke in Quebec

1976 First standard on use of condensed silica fume, with the addition of 10 percent by weight of cement, is permitted in Norway

1976 Naphalene sulfonate-based Type F and Type G high-range water reducers are commercialized in North America by Grace Construction Products; they become critical in making high-strength or high-performance concretes containing silica fume or other admixtures commercially available; subsequently they are added to ASTM 494 admixtures. Melamine-based water reducers appear earlier

1977 Norchem begins selling silica fume in North America

1980 Using technology from Norchem, Pittsburgh-based Elkem Materials begins building staff, and introduces silica fume for commercial concrete use in the U.S. in 1981

1982 Demonstration slabs of 20,000 psi concrete are placed at site of Dashields Lock & Dam on Ohio River in Pennsylvania

1982 First use of shotcrete containing silica fume, attaining 13,000 psi, at Lake Lynn Testing Facility, southwestern Pennsylvania, Bureau of Mines

1983 In two important applications, both involving abrasion resistant concrete, U.S. Army Corps of Engineers specifies silica fume for Kinsua Dam Stilling Basin Rehabilitation, Warren, Pa. (10,000 psi in seven days, and 12,500 psi in 28 days), and Los Angeles River Low-Flow Channel Liner

1984 First U.S. bridge deck using silica fume is placed on Oct. 18 in northeastern Ohio by Chapin & Chapin, Norwalk, Ohio

First use of silica fume specified for commercial building in U.S., Nashville's 28-story Third National Bank and Finance Center. Concrete is supplied by Metro Ready Mix

1985 First use of silica fume in a parking garage, for repair work in Horne's Garage, Pittsburgh, using 10 percent by weight of cementitious material. Concrete was provided by Frank Bryan, Inc., Southside, Pa.

1986 First use of silica fume in a new parking deck, the Manor Parking Structure in Pittsburgh, featuring cast-in-place slabs, post-tensioned two ways, and precast architectural parapets. By 1990 over 15 parking garages in Pittsburgh will have incorporated silica fume

First state to issue a proposal note, permitting contractors to propose use of silica fume in DOT projects, is Ohio

Effective finishing and curing techniques for silica fume concrete flatwork are developed, including the use of fresno trowels, fog misting, and immediate application of wet curing techniques, such as wet burlap

Canadian National Standard for silica fume is published (Canadian Standards Association Standard CAN/CSA A23.5-M86 Supplementary Cementitious Materials)

Scotia Plaza is constructed in Toronto with a composite concrete/steel system, using 10,000 psi (70 MPa) silica fume mixes

1988 Two early ultra-high-strength concrete Seattle towers are constructed, Two Union Square, and Pacific First Center, with silica fume supplied by W.R. Grace. Both are designed by Skilling Ward Magnusson Barkshire. 14,000 psi concrete is specified for 62-

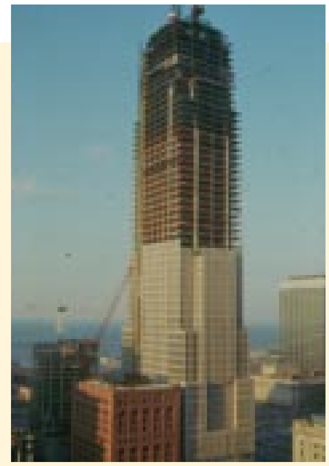
All U.S. states have used silica fume at least once in bridge deck applications.

story Two Union Square, but at times reaches compressive strengths of 19,000 psi, and is supplied by Lonestar Northwest. Nominal 14,000 psi concrete for the 45-story Pacific First Center is supplied by Stoneway Concrete of Seattle

1989 High-strength, 9,000 to 10,000 psi prestressed girders using silica fume are incorporated into Perdido Pass marine structure, Gulf Shores, Ala.

1989-1992 Silica fume concretes are specified for reinforced concrete columns or composite concrete/steel structures in a wave of high-rise buildings that close the 1980s binge of speculative construction. These include: Chicago's 311 South Wacker Drive, 12,000 psi mixes supplied by Prairie Materials; Atlanta's One Peachtree Center, 12,000 psi mixes supplied by Blue Circle Williams, Marietta, Ga.; Minneapolis' Dain Bosworth Tower, 14,000 psi mixes supplied by AVR Inc., Apple Valley, Minn.; Cleveland's Society Tower, 12,000 psi mixes supplied by Cuyahoga Concrete, Cleveland; and New York City's Trump Palace, 12,000 psi mixes

1990 Phase I of Concrete Canada is launched, through 1994, with Phase II from 1994 through 1998. A consortium of research centers — the Network of Centres of Excellence on High-Performance Concrete — encompasses 12 research projects, six bridges in Ontario and Quebec, and a number of repair projects incorporating silica fume



When construction of speculative office buildings slowed in the early 1990s, use of high-strength silica fume mixes dwindled as well.

1991 In a first for Canadian prestressed concrete, Vancouver, B.C.-based Con-Force Structures Ltd. fabricates I-girders, cast from 9,000 psi silica fume mixes, for the spliced 171-ft-long Esker Overhead Bridge in British Columbia

1992 With the assistance of the Federal Highway Administration, the Louisiana Transportation Research Center begins an investigation of high-strength concrete in design and construction of highway bridges. Tests involve prestressed girder and pile specimens cast from silica fume mixes with design strengths of 10,000 psi, fabricated by Sherman Prestress, Mobile, Ala. Study suggests bridge designs can be economized by potentially lowering the number of girders required to carry comparable weight, and higher-strength concrete piles are suited to extra loads and forces when being driven

1996 All states have used silica fume at least once in bridge decks. Also, despite having used silica fume in over 550 bridge decks in 12 years, Ohio — a forerunner in applying the mix technology — has yet to put silica fume into standard specs for bridge decks applied to U.S.-style applications. In America, silica fume is a premium material sold at a premium price, which tends to limit its end uses to situations deemed by the customer to be worth spending the money on. Mixes are designed accordingly, with silica fume applied only in certain cases.

One Canadian felt that, all things being equal, the price in America may be as much as double that of silica fume in Canada. Also, blended cements premixed with silica fume are readily available from a variety of producers in Canada, but they are seldom seen in the U.S. However, silica fume-modified concrete is a totally different product than conventional concrete, and concrete suppliers and contractors can make fatal mistakes without the quality control and technical support that the U.S. silica fume distributors provide. One distributor posed the rhetorical question: "If silica fume is so much less expensive in Canada, why aren't the Canadians selling more of it?"

In Europe, the economics are such that people use it in different dosages in different applications. As a result, the European experience may not be directly applicable to the U.S., where more long-term research is needed. Also, mix designs in Europe are less conservative than in America. The Norwegians have a code which attempts to state how much silica fume may replace how much cement, but the actual amount varies according to application. If strength is the primary goal, the factor is one number; if durability is the primary goal, with transport of water or chloride ions the criteria, the factor is a different number.

Domestically, the Illinois Department of Transportation has recently completed major research on silica fume concrete; findings from a field investigation begun in 1987 will be presented at this month's semi-annual meeting of the American Concrete Institute in Denver (note Illinois bridge box, page 68).

Concrete suppliers pivotal

The possibility exists that advancing technology can put the squeeze on silica fume. "There were a couple of projects in which we used 10,000 psi concrete," said Roy Keck, director of quality assurance for Blue Circle Williams, a ready mix supplier in Marietta, Ga. "We developed the technology to make 10,000 psi concrete without silica fume. So that had an immediate impact on silica fume sales."

In his southern locale, bridge deck deicing is not a concern, and so silica fume is not used by the Georgia DOT for decks. "We had one test project in Atlanta about five years ago," Keck adds. "The DOT evaluated a number of deck overlay systems and elected not to use silica fume. We don't have much of a market for silica fume in bridge decks because durability is not a major problem. There is a potential along coastal areas, and we have supplied silica fume concretes for specialty floors."

As a ready-mix supplier, it's up to Blue Circle Williams and Keck to drum up business for the value-added product that silica fume-enhanced concrete represents. "I make architectural and engineering calls," Keck told *Concrete Products*. "We do about 25 to 50 programs a year. We have a one-hour program that we show during lunch. We go through all our value-added products, and have a fairly large catalog of our products, including the microsilica and the superplasticizers, which we leave with participants. We have a whole range of products that we're promoting. We're doing architectural masonry and high-performance concretes and specialty cements.

"When an engineer gets involved in a project, and sees the potential use of our value-added product as the solution to a problem, he will call us and we will work with the engineer and owner to figure out how to solve the problem with our products," Keck said. "I don't know of any other ready-mix company that does it. We're promoting a whole range of products. You have to have materials on hand. You and your operations people have to be committed to the concept. For the typical ready-mix producer, it's a bit of a stretch. It takes him well out of his comfort zone."

Few ready-mix producers, though, pursue sales of the value-added product. Instead, nearly all simply respond to specs, which may or may not require silica fume. At another level, they see themselves simply as haulers of a commodity, rather than producers of a value-added material. As one expert complained, "When they get around a table, they all talk about the new trucks they've bought, not the new mix designs they're utilizing."

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