Practical Considerations for Using Silica Fume in Field Concrete

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Ready-mixed silica-fume concrete is currently used in the United States on a regular basis. During 1986, approximately 350,000 yd^3 (270,000 m^3) of silica-fume concrete were placed. The silica fume is used as a cement replacement material or as a performance-enhancing admixture. This paper reviews the practical aspects of working with silica fume in ready-mixed concrete, with emphasis on the use of silica fume in the performance-enhancement role. Availability of silica fume and of products containing silica fume is described first. The current lack of specifications for silica fume, admixtures containing silica fume, and concrete incorporating silica fume is examined. Aspects of concrete production including measuring, adding, mixing, using high-range water-reducing admixtures, and controlling concrete temperature are discussed. Transporting, placing, finishing, and curing are reviewed to determine how silica-fume concrete differs from conventional concrete in these areas. Finally, several specific considerations for using silica fume in concrete for bridge decks are discussed.

Ready-mixed silica-fume concrete has been placed successfully in a wide variety of applications. The price for a successful placement is strict adherence to the fundamentals of good concrete practice.

Silica fume is currently used in the United States as a cement replacement material and as a performance-enhancing admixture. In the first role, silica fume is added to concrete without a specific application in mind; in the latter role, silica-fume concrete is specified for a wide variety of applications where high-strength or very durable concrete is required. Recent such projects have included 14,000-psi (97 MPa) building columns and chloride-resistant concrete for parking structures and bridge decks. During 1986 in the United States, approximately 350,0000 yd^3 (270,000 m^3) of silica-fume concrete were placed, with about 60 percent being in the replacement market. In the enhancement market, most silica fume has gone into parking structure applications.

The physical and chemical properties of silica fume, the applications for which concrete containing silica fume are suited, and the properties of hardened silica-fume concrete have been described by others (*1*, *2*). Typical current uses of silica fume in both its roles have also been described elsewhere (*3*).

This paper discusses the practical aspects of specifying, making, placing, finishing, and curing concrete containing silica fume. Additionally, some special considerations for using silica fume in concrete for bridge deck overlays are considered. In essence, the lessons learned from the major placements of silica-fume concrete to date in the United States will be reviewed.

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One area that has already been emphasized to the concrete community deserves mention again. Significant improvements in strength or durability cannot be achieved through the use of silica fume unless generally accepted good concrete practices are followed. No problem areas have been identified regarding the use of silica-fume concrete that do not exist, to some extent, with conventional concrete. Silica fume is not a cure for bad practice. If a concrete producer is not already following good practices, addition of silica fume to the concrete will probably result in better concrete, but the improvement may not be all that is expected or specified.

AVAILABILITY

Silica fume is available commercially in the United States in several forms. Figure 1 summarizes the types of products available at this time.

As-produced silica fume may be available in bulk or in bags. There is at least one area in the United States near a smelter where silica fume is being used as a cement replacement. However, elsewhere, very little silica fume in the as-produced state has been used in concrete in the United States. This reluctance to use the as-produced material results from difficulties in transporting and handling and the resulting poor economics.

When available in an as-produced state, bulk silica fume may be transported and handled generally like portland cement or fly ash. Bagged material has been used by emptying the bags directly into truck mixers, but because of the dust generated and the labor costs involved, the use of bagged silica fume has not been popular. Another deterrent to the use of the as-produced silica fume is the cost of transportation. The material typically has a unit weight of only 12–15 lb/ft^3 (192–240 kg/m^3), compared with 94 lb/ft^3 (1,500 kg/m^3) for cement, so very little will actually fit into a truck!

To overcome the difficulties associated with transporting and handling the dry material, producers have concentrated on marketing silica fume as a water-based slurry. These slurries typically have a unit weight of approximately 11 lb/gal or 82 lb/ft^3 (1,315 kg/m^3) and contain 45–50 percent silica fume by mass. Even when the weight of the water is considered, transportation of the slurry is more economical than transportation of the dry silica fume. The slurries are available with and without chemical admixtures and offer the major advantage of ease of use once the required dispensing equipment is available at the batch plant.

Now dry, densified silica fume products with or without chemical admixtures are also available. These products have

1.0 **Dry Products**

1.1 As-produced silica fume. Availability depends somewhat on willingness of producers to supply for this application. Transportation and handling constraints also apply. Several possible suppliers, each of whom may have different capabilities to supply in bags or in bulk. Unit weight: 12 to 15 lb/ft^3 (192 to 240 kg/m^3).

1.2 As-produced silica fume with dry chemical admixtures. Chemical admixture dosage is high enough to provide water reduction for the concrete. One product is available in bags. Unit weight: same as as-produced silica fume.

1.3 Densified silica fume with dry chemical admixtures. Chemical admixture dosage is high enough to provide water reduction for the concrete. One product is available in bags. Unit weight: 35 to 40 lb/ft^3 (560 to 640 kg/m^3).

1.4 Densified silica fume without chemical admixtures. One product is available in bags. Unit weight: same as densified silica fume with dry chemical admixtures.

2.0 **Wet Products**

2.1 Silica fume slurry. Typically slurries are composed of 50 percent silica fume by mass. Not currently available commercially. Unit weight: 11 lb/gal (82 lb/ft^3 (1315 kg/m^3)).

2.2 Silica fume slurry with low dosages of chemical admixtures. The dosage of chemical admixtures is just enough to offset some or all of the increased water demand of the silica fume itself. There is no water reduction provided for the concrete. One product is available in drums and in bulk. Unit weight: same as silica fume slurry; silica fume content may be reduced by chemical admixture solids.

2.3 Silica fume slurry with high dosages of chemical admixtures. The dosage of chemical admixtures is high enough to offset the water demand of the silica fume and to provide water reduction for the concrete. Chemical admixtures may include retarders. Two products are available in drums and in bulk. Unit weight: same as silica fume slurry; silica fume content may be reduced by chemical admixture solids.

FIGURE 1 Forms of silica fume currently available for use in concrete in the United States.

a unit weight of 35–40 lb/ft^3 (560–640 kg/m^3) and are cost-effective to transport dry. Because of the densification, little dust is created when the material is used from bags. This densified material, marketed as a substitute for as-produced dry silica fume, is for small or isolated jobs where installation of dispensing equipment and use of slurry is not practical.

Depending on the type of material selected and the supplier, silica fume or products containing silica fume may be available in bulk, drums, or bags. The form of the material that is selected will have an impact on the handling of materials and the production of concrete. Available data and experience indicate that the form of the silica fume can affect the properties of the fresh and hardened concrete, particularly if a densified silica fume is substituted for one of the other forms. Therefore, changing products during a project should be avoided unless appropriate testing has been accomplished to verify mixture proportions and concrete performance using the alternate material.

Pistilli et al. have shown that variations in silica fume from a single furnace at a given source are relatively small (*4*, *5*). It is the author's experience that silica fume from different sources will behave differently in concrete, particularly in respect to water demand. It is, therefore, also inadvisable to change sources of silica fume during a project without conducting additional laboratory testing to verify the performance of the material from the new source.

SPECIFICATIONS

Specifications for silica-fume concrete must be considered on three levels: first, specifications for the silica fume itself; second, specifications for admixtures containing silica fume; and third, project specifications for concrete incorporating silica fume as an admixture. Each of these areas is currently a source of problems in the United States.

At present, no standard specification that covers silica fume as a material. The appropriate subcommittee of ASTM Committee C-9 is working on developing a specification for silica fume. Initially, the intent of the subcommittee was to include silica fume as an additional material in the existing standard for pozzolans (*6*). However, that intent was defeated, and work is under way on a stand-alone specification for silica fume. So far, the process has taken 4 yr and will probably require another 2 yr before a specification is approved and available.

Depending on the degree of sophistication of the specifier or specifying agency, the lack of a national standard has usually been addressed by developing job-specific specifications for silica fume. Users of silica fume have generally relied on product suppliers for guidance in preparing these specifications. Basically, these specifications have been patterned after ASTM C 618 and have usually included requirements for silicon dioxide content, loss on ignition, moisture content, and surface area. Most frequently, the common wisdom has been to specify a high silicon dioxide content and a high surface area.

This last property is particularly troublesome because there is not a consensus regarding the appropriate technique for determining the surface area of silica fume. It appears that the air permeability methods used for portland cement and other pozzolans are not appropriate for silica fume. A method such as nitrogen adsorption, that is well suited for such a fine material, is limited by availability of the apparatus within the concrete industry. The current draft document being worked on by the ASTM subcommittee sidesteps the fineness issue by specifying washing over a 45-micrometer (no. 325) sieve.

Standard specifications for admixtures containing silica fume or silica fume and chemical admixtures are also nonexistent. At present, there is no activity regarding the development of such a standard. This situation is complicated by the variety of types of admixtures containing silica fume plus chemical admixtures that are available. Again, users have generally relied on materials suppliers for assistance and have specified such elements as total solids and silica-fume content and that any chemical admixtures meet the requirements of ASTM C 494 (*7*). This area is further complicated for public agencies because their specifications usually must not include brand names and because different products contain different combinations of silica fume and chemical admixtures. Preparing a clear specification that does not eliminate any prospective bidders has become an extremely complex process.

Standard (guide) specifications and general guidance for projects actually employing silica fume in concrete are also lacking. There is a recently published ACI state-of-the-art document (*1*), but it deals more with suitable uses of silica-fume concrete than with how to make and place it.

Project specifications have included prescriptive and performance elements and have been based on extensive input from materials suppliers. Usually, silica-fume concrete has been treated as a separate class of concrete. The specifications then detail exceptions to normal practice or special requirements for the silica-fume concrete. A very common item in the specifications for many projects has been a requirement for test placements outside the area of the actual structure. Such placements have been particularly beneficial in flatwork construction by allowing finishers to become familiar with the concrete before they attempt to finish concrete in the structure.

Because most silica fume being used for performance enhancement is going into concrete for parking structures, performance specifications structured to include measures of the impermeability of the in-place concrete are becoming popular. The test most often specified is the Rapid Chloride Permeability Test (*8*), which has been adopted by AASHTO (*9*) and is under review by ASTM. Unfortunately, while the test has become popular among specifiers, there is little information available regarding the variability of the test method and the correlation between the results obtained and the rate of chloride penetration. Contractors have responded by bidding conservatively.

Overall, the specification issue is certainly unclear at present. Limited relief in terms of an ASTM specification for silica fume is on the horizon. The immediate outcome of this situation will continue to be uncertainty on the part of specifiers, extensive dependence upon suppliers for assistance, and increased costs for owners.

CONCRETE PRODUCTION

Five critical areas must be considered when producing concrete containing silica fume: measuring, adding, mixing, using a high-range water-reducing admixture (HRWRA), and controlling concrete temperature. Each of these areas is discussed below. In addition to these areas, extra care must be given to the routine aspects of concrete production. For example, the amount of wash water in the truck should be accounted for in mixture calculations; and drivers should be cautioned not to add additional water to the drum when washing dust off a truck after loading. It has been difficult, in most instances, to convince ready-mixed-concrete producers of the importance of paying attention to these details. Production of silica-fume concrete for a demanding application requires an educational effort followed by careful inspection.

Measuring

The first critical area is measuring; the correct amount of silica fume must be added. Although this point seems simplistic, measuring is complicated by the variety of forms of silica fume being marketed. The concrete supplier must understand the specifications and the mixture proportions. In some specifications, the silica fume will be shown as an addition to the portland cement; while in other specifications, it may be shown as a replacement for portland cement. The concrete producer also must understand what is being specified and what is being measured—the silica fume itself or the commercial product containing silica fume. For example, the slurried products contain about 50 percent silica fume by mass while the dry products could be 100 percent silica fume.

The silica fume should be measured with the same degree of accuracy as other concrete ingredients. Typically, accuracies of plus or minus 1 percent by mass or volume have been specified. The dispensing equipment being provided to concrete producers can meet these accuracies. If slurried silica fume is used, the amount of water in the slurry must also be accounted for in the mixture proportions; an appropriate reduction in the amount of batch water must be made.

Because of the thixotropic nature of most of the slurries and because the quantities used per cubic yard of concrete are greater, the dispensing equipment is larger and more complex than that used for chemical admixtures. For example, a typical water-reducing admixture may require only 12 fl oz/yd^3 (465 mL/m^3); a typical HRWRA, 135 fl oz/yd^3 (5.2 L/m^3); and a silica fume slurry, 11 gal/yd^3 (55 L/m^3). Clearly, the concrete supplier must be aware of the significant increase in the volume of admixture being dispensed.

Silica fume suppliers in the United States have addressed the dispensing equipment situation from two basic positions. One approach has been to develop a number of mobile dispensers that are towed to a batch plant, set up, and used for the duration of a project. This approach has the disadvantages of high capital cost for the equipment and the repeated relocation costs. Relocation costs make the use of such units uneconomical for small placements. Another approach has been to supply permanent dispensing equipment in customer batch plants. This latter approach has the disadvantage that equipment may be idle between projects because, so far, there is little economic incentive for the concrete supplier to use the silica fume admixture in day-to-day concrete.

Adding

The second critical point concerning production is determining when to add the silica-fume product. The deciding factor here is the type of material being used. Dry silica fume can usually be added at any time during the production process, particularly if the batch plant can handle the dry material in bulk. Slurried products are best added to a truck mixer first because these products will contain a portion of the batch mixing water. (For high dosages of silica fume, slurried products may contain most of the batch water.) Adding slurried products to a truck last may result in "head pack" or in poor distribution of the silica fume throughout the load. Whenever possible, concrete producers have been encouraged to make a few trial batches of the silica-fume concrete before the actual project begins to establish the appropriate batching sequence.

Mixing

The third critical area is the actual mixing; the silica fume must be uniformly distributed throughout the concrete. Compressive strength variations of 3,000 psi (21 MPa) within a single load resulting from poor mixing have been seen during mixer uniformity testing. This requirement for adequate mixing has also been difficult to get across to many producers.

Use of silica fume in central-mixed concrete has worked well and has generally caused less concern than has use in truck-mixed concrete. In this case, the only problem that has been encountered has been one of timing. The measurement of mixing time must begin after all ingredients, including the silica fume, are in the drum. On one project, no adjustment in the mixing time was made to account for the length of time required to pump the silica fume slurry into a central mixer. As a consequence, the slurry was, in some instances, passing directly through the mixer without any mixing at all.

Use of silica fume in truck-mixed concrete requires strict adherence to the requirements of ASTM C 94 (*10*). In particular, the rated mixing capacity of the truck must not be exceeded. As might be expected, this area is also one in which there have been difficulties in dealing with producers. As defined by ASTM C 94, the volume of mixed concrete should not exceed 63 percent of the total volume of the drum. This requirement has been hard to enforce because it conflicts directly with the desires of many concrete producers. On one project on which there were difficulties in obtaining satisfactory compressive strength of the silica-fume concrete, concrete was observed spilling from the truck mixers when they went up a hill between the plant and the job site. The amount of mixing achieved under such circumstances is open to question.

Although a relatively simple procedure defined in ASTM C 94 allows determination of the adequacy of mixing and the qualification of truck mixers, very few producers are interested in performing the test. The author is aware of only one silica-fume concrete project for which this testing was done. Instead, on most projects the appearance of the concrete as it has been discharged has been carefully monitored. The most common symptom of inadequate mixing has been slump variations during discharge of the concrete. For example, if during a continuous discharge the slump changes by several inches from the front to the back of the load, it is highly probable that the concrete was not properly mixed and that a uniform slump never existed in the drum. Another common symptom has been the appearance of "concrete balls" in the discharge. Usually, additional mixing or reducing the size of the load has eliminated this problem. On some projects it has been possible to determine that a specific truck mixer was more prone to producing the concrete balls (probably because of worn fins). In such a case, the truck has been disqualified from the silica-fume concrete project only to supply concrete for another, less particular user!

Adding High-Range Water-Reducing Admixtures

The fourth critical area is the use of an HRWRA. The successful use of silica fume as a performance-enhancing admixture requires the use of an HRWRA. The amount of HRWRA required and the appropriate time to add it are a function of the dosage of silica fume being used and of the nature of the silica fume product itself. For high-strength concretes with high dosages of silica fume and low water-to-powder (cement plus silica fume) ratios, it is usually necessary to add the HRWRA at the batch plant to ensure that the concrete is adequately mixed. This requirement to add HRWRA at the plant causes the usual problems and concerns regarding loss of slump between initial mixing and discharge. For some concrete applications, it may be necessary to add some or all of the chemical admixtures at the batch plant to allow initial mixing and to redose at the discharge site to achieve the workability desired for placing.

On one project, the addition of too much HRWRA too soon in the mixing cycle caused problems because the concrete became so fluid that concrete balls were formed that would not break up. Reducing the initial dose of admixture reduced the fluidity of the concrete and seemed to improve the mixing action of the truck.

Controlling Concrete Temperature

The final critical area concerning production is the control of concrete temperature during either hot- or cold-weather concreting conditions. Again, the difficulties that arise are a function of the amount of silica fume being added and of the nature of the product. The greatest problems arise from high dosages of products that are provided as a slurry. In such applications, a major portion of the batch water is typically being supplied as part of the slurry and is unavailable for use in heating or cooling the concrete. On two projects that had very strict maximum temperature requirements, liquid nitrogen was injected into the truck mixers to achieve the degree of cooling required. On another project, concrete temperature was reduced by cooling the slurry product itself by air conditioning the trailer containing the dispensing equipment.

TRANSPORTING, PLACING, AND CONSOLIDATING

In these three areas concerned with getting the concrete from the batch plant and satisfactorily into the forms, concrete containing silica fume behaves very much like conventional concrete, and there have been very few problems reported. However, several points should be mentioned, based on the nature of the silica-fume concrete itself. The fresh concrete, depending on the dosage of silica fume, will usually be more cohesive and less prone to bleeding and segregation during handling than conventional concrete. Because of the variety of silica-fume admixtures available, it is very risky to generalize further concerning the performance of fresh silica-fume concrete. Questions of slump or air stability should be addressed only by testing with project specific materials.

Silica-fume concrete has been transported in most of the equipment used to transport conventional concrete. Some difficulties in cleaning high-strength concrete from equipment have been reported.

Concrete containing silica fume has been successfully placed using all types of placement devices: buckets, pumps, tremies, etc. Because of the increased cohesiveness of the concrete, using a slump 1–2 in. (25–50 mm) higher than normally used for the same type of placement is recommended. For overall ease of placing and finishing, as high a slump as is practical should be used. Specification writers must be flexible, bearing in mind the lower tendency for segregation, and allow these higher slumps if successful placements are to be achieved.

High-slump flowing concretes containing silica fume are somewhat deceptive when it comes to consolidation. Although the concrete will flow into place well and appear to be ready for further working, it will still require thorough consolidation. The increased cohesiveness caused by the silica fume will entrap air that must be removed by vibration, even in concretes with slumps of 8–10 in. (200–225 mm).

FINISHING

The greatest differences between conventional concrete and silica-fume concrete have shown up during finishing. Up to an addition level of about 5-percent silica fume by mass of cement, there will be little difference. Above that level, the differences will become greater with increasing dosages of silica fume because of the reduced bleeding of silica-fume concrete. At low dosages of silica fume, the concrete will bleed much less than conventional concrete; at higher dosages, bleeding will be essentially eliminated.

Plastic Shrinkage Cracking

Plastic shrinkage cracking has been singled out for special attention because it has been the most common source of difficulty and complaints associated with the use of silica-fume concrete. Plastic shrinkage cracking can affect concrete, with or without silica fume, at two points: first, during the period after the initial finishing operations of screeding and bull floating but before final finishing; and second, after final finishing and before initiation of curing or final setting. Silica-fume concrete has been seen to be susceptible to problems during both of these periods.

Contractors have been urged to refer to and use the chart presented as Figure 2.1.5 in ACI 305 (*11*), or as Figure 1 in ACI 308 (*12*), that allows predictions regarding rate of evaporation to be made. For higher dosages of silica fume, the general recommendation has been to reduce the threshold for concern over potential plastic shrinkage to approximately onehalf of that recommended for conventional concrete. For applications in which the chart predicts that plastic shrinkage cracking is likely, contractors have also been referred to the preventive steps included in ACI 305 and 308.

In some situations, although plastic shrinkage cracks have not occurred, the surface of the silica-fume concrete has dried and started to stiffen before the underlying concrete. This process gives the fresh concrete a spongy consistency and makes it difficult to finish. The same procedures used to prevent plastic shrinkage cracking have been effective in preventing surface drying and hardening.

A great deal of attention has been given to the tendency of silica-fume concrete to dry and suffer plastic shrinkage cracking. The problem is now well known, and all parties involved with a placement are usually made aware of the tendency beforehand. While there is no way to eliminate the tendency, the problem can be managed and it has not hindered the development of applications for silica-fume concrete. Successful preventive measures have included applying curing compound immediately after screeding, using evaporation retarding materials, the more traditional approaches of fogging and covering the concrete between finishing operations, and, when possible, waiting for a more suitable day for placing exposed slabs.

Finishing Practices

With regard to specific finishing practices of silica-fume concrete, the same tools and procedures that are normally used have been found to be satisfactory. Generalizations regarding particular types of tools are difficult to make; this decision is best left to the finishers. There may be a difference in the timing of the finishing operations because of the chemical admixtures that may be used with the silica fume and because of the lack of bleeding. The chemical admixtures will generally include retarders that will delay setting while the lack of bleeding has caused some finishers difficulty in determining when to get on the concrete.

Two general recommendations have been made to ease problems with finishing: First, silica-fume concrete should be "underfinished." Underfinishing has been advocated to mean that a greater degree of finishing than is actually necessary for the intended use of the concrete should not be specified. This concept has not always been attractive to owners and architects, particularly if a finishing technique has been selected on the basis of aesthetics rather than performance. Second, a trial placement should be conducted to allow the finishing crews to practice and get the bugs out of their approach to the silica-fume concrete. Such a trial is particularly important for finishers used to working on wetter concrete surfaces and should be mandatory for silica-fume concretes requiring a high degree of finishing.

If the concrete application requires a dosage of more than about 10-percent silica fume, a one-pass finishing procedure of screeding, bull floating, and brooming or other texturing followed immediately by curing has usually been recommended. On one parking structure the contractor used a paving train approach to placing and finishing the silica-fume concrete. According to information presented by the contractor at a 1987 World of Concrete seminar, this approach speeded placements and resulted in significant savings.

High quality, steel trowel finishes have been achieved on high-strength, high-durability silica-fume concrete flatwork. These finishes usually have been achieved by specialty contractors who were used to dealing with specialty concretes in their day-to-day placements.

CURING

Silica-fume concrete will not perform well unless it is properly cured, and proper curing is particularly important for concretes containing high dosages of silica fume in conjunction with low water contents. The general recommendation for curing has been to "overcure" the concrete. Overcuring has been emphasized to mean that to get the maximum benefit from silica fume, more curing than would be done for conventional concrete in the same placement will be required. As might be expected, this recommendation as well has not always met with an overwhelming response from contractors. Silica-fume concrete has been successfully cured using most of the generally accepted practices—wet burlap, sheets of plastic, and curing compound. As an absolute minimum, curing equivalent to 7 days of wet curing has been recommended.

Curing of silica-fume concrete can usually begin immediately after finishing, whatever the finishing process may be. Because high dosages of silica fume produce concrete that does not bleed, there is no requirement to wait for the cement to set so that the bleeding will stop before initiating curing. On projects where finishing after setting was not required, curing compound has been applied within a few minutes of the pass of a vibrating screed.

The final thought regarding curing concerns use of silica fume in concrete subjected to accelerated curing. Problems relating to strength gain have been reported in some precast operations. The problem has usually been traced to the chemical admixtures incorporated in a silica fume product rather than the silica fume itself. Because these chemical admixtures may include retarders, it may be necessary to modify the curing cycle. After the silica-fume concrete was allowed to reach an initial set before beginning the accelerated curing, strength problems were resolved.

TESTING

Testing of concrete containing silica fume, particularly for high-strength concrete, has been covered elsewhere (*13*). For the purposes of this paper, it is sufficient to note that difficulties with testing procedures have certainly been encountered. The same attention to detail required for making and placing silica-fume concrete is absolutely required for its testing.

SPECIAL CONSIDERATIONS FOR BRIDGE DECKS

Because of its impermeability, silica-fume concrete has attracted a great deal of interest for its possible application in bridge decks. Several points concerned with the use of silica fume in concrete for bridge decks deserve special mention.

First, bridge deck placements (overlays) tend to require relatively small amounts of concrete. Because of the low volumes, the silica fume suppliers have been reluctant to set up a mobile dispenser at a local ready-mixed concrete supplier for a deck placement. Therefore, until recently, when the dry, densified silica-fume products became available, a slurried silica-fume product would have been supplied in drums. Using drummed material requires pumping and drum-handling equipment and, possibly, additional inspectors to verify that the correct amount of silica-fume product has been used. One state DOT was very reluctant to enter into such an arrangement.

Second, at least one deck has been placed with silica-fume concrete produced in a volumetric measuring continuous mixing (VMCM) system. The unit was modified to use silica-fume slurry rather than latex. It has been the author's experience that it is difficult to obtain a satisfactory air-void system in VMCM units in conjunction with a silica-fume admixture. Trial batches along with appropriate testing of hardened concrete are certainly recommended. Obviously, this recommendation implies testing well before actual placements are to take place.

Third, finishing machines used for other types of concrete overlays have been successfully used for silica-fume concrete. As with any piece of equipment using a new material, test placements are desirable. Because of the small volumes of concrete involved in an overlay, one or two truckloads of concrete used to calibrate the finishing machine may very well complete a major portion of the deck. One agency currently involved in a full-depth deck replacement using silica-fume concrete has overcome this problem by requiring test placements in a toll plaza area away from the actual deck.

Finally, bridge deck overlays have usually used high silica fume contents and low water contents: an ideal combination for increasing the potential for plastic shrinkage cracking. The precautions usually taken for placing latex-modified concrete, such as placing in the evenings, have also worked well for silica-fume concrete.

CONCLUSIONS

Silica fume is a material that offers significant potential for improvements in some properties of concrete. It is not a cure-all for bad practices, and it is not a laboratory curiosity that cannot be placed in the field under field conditions. Silica-fume concrete is being successfully manufactured and placed on a wide variety of projects. However, the author's experience to date is that many producers and contractors generally want to obtain the benefits of high strength or high durability without paying any price other than that of the silica fume itself. The additional price that must be paid is strict attention to detail and careful adherence to good practices.

No difficulties have been identified in the use of silica fume in field concrete that cannot be overcome by proper planning before the problems occur. The one difference that cannot be overcome is that silica-fume concrete will be less forgiving than conventional concrete of any attempts to cut corners.

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