Working with Silica Fume in Ready-Mixed Concrete—U.S.A. Experience

by T.C. Holland

Synopsis: The first silica fume admixture aimed at the ready-mixed concrete market appeared in the United States in 1983. Since then, the use of silica fume has developed slowly. It is currently being 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 an emphasis on the use of silica fume in the property enhancement role. The forms of silica fume currently being marketed in the United States are briefly described. Then, the current state of specifications for silica fume, admixtures containing silica fume, and concrete incorporating silica fume is examined. Next, aspects of concrete production are discussed. Finally, transporting, placing, finishing, and curing practices are reviewed.

Keywords: admixtures; curing; finishing; mix proportioning; placing; ready-mixed concrete; silica fume; specifications

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INTRODUCTION

In 1983 the first large scale project using silica-fume concrete was completed in the United States (1). This particular project used silica fume in the concrete to gain a very high compressive strength to increase the abrasion resistance of the concrete. At about the time that this project was completed, the first advertisement for a silica-fume based admixture appeared in an engineering magazine (2). This advertisement also emphasized high-strength concrete as an application.

Since there was then a relatively limited market for high-strength concrete, the primary silica fume supplier at that time also began actively promoting silica-fume concrete for its reduced permeability to chlorides for use in bridge decks. However, the maze of state approvals required for bridge deck work and the limited volumes of most such placements led that supplier to look for other areas of application. The most promising market found was the use of silica-fume concrete in parking structures in those areas of the United States where there is a significant use of deicing salt in winter months. This market has been very responsive and a large number of parking structures have been constructed or repaired using silica-fume concrete. The use of silica fume to achieve either high strength or low permeability has been the primary application of the material to date in its property enhancement role in the United States.

In a few limited areas in the United States, silica fume is also currently being used as a portland cement replacement material. In this role, silica fume is being added to concrete without a specific application in mind. For silica fume to be cost effective as a portland cement replacement, the source of the silica fume must be located very close to the concrete producer and the supplier of the silica fume must be willing to sell at a price significantly below that being quoted for silica fume used in a property enhancement role.

During 1986 in the United States, approximately 270,000 m^3 of silica-fume concrete were placed, with about 60 percent being in the portland cement replacement market. In the enhancement market the vast majority of 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 (3, 4). Typical current uses of silica fume in both of its roles have also been described elsewhere (5). This paper discusses the practical aspects of specifying, making, placing, finishing, and curing concrete containing silica fume. In essence, the lessons learned from the major placements of silica-fume concrete to date in the United States will be reviewed.

AVAILABILITY

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

As-produced silica fume may be available in bulk or in bags. Other than for use as a portland cement replacement material in certain areas near smelters, 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 has resulted from difficulties in transporting and handling it 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 involved with transportation: the material typically has a unit weight of only 192 to 240 kg/m^3 (compared with 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 initially concentrated on marketing silica fume as a water-based slurry. These slurries typically have a unit weight of approximately 1,315 kg/m^3 and contain 45 to 50 percent silica fume by mass. Even when the mass 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 installed at the batch plant.

There are also now available dry, densified (also termed compacted) silica fume products with or without chemical admixtures. These products have a unit weight of 560 to 640 kg/m^3 and are cost effective to transport dry. Because of the densification, there is little dust created when using the material from bags. When used in bulk, this product is transported by tankers similarly to portland cement or fly ash. At a concrete producer, the densified silica fume is blown into a silo and dispensed like any other cementitious material. This densified material is being marketed as a substitute for as-produced dry silica fume and for small or isolated jobs where installation of dispensing equipment and use of slurry is not practical.

Depending upon 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 may have an effect on the properties of the fresh and hardened concrete. Therefore, it has been recommended that 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 and co-workers have shown that variations in silica fume from a single furnace at a given source are relatively small (6, 7). It is the author's experience that silica fume from different sources will behave differently in concrete, particularly in respect to water demand. Therefore, it appears to be 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.

The problems created by the different levels of performance that may be encountered from different sources or different forms of silica fume may be avoided by specifying desired levels of concrete performance rather than amounts of silica fume to be included per unit volume of concrete.

SPECIFICATIONS

Specifications for silica-fume concrete must be considered on three levels. First, there are the dspecifications for the silica fume itself; second, there are specifications for admixtures containing silica fume; and third, there are the project specifications for concrete incorporating silica fume as an admixture. Each of these areas is currently a source of concern and questions for specification writers in the United States.

There is, at present, no standard specification that covers silica fume as a material. The appropriate subcommittee of ASTM Committee C-9 is currently 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, ASTM C 618, "Standard Specification for Fly Ash and Raw or Calcined Natural Pozzolan for Use as a Mineral Admixture in Portland Cement Concrete" (8). However, that intent was defeated and work is currently under way on a stand-alone specification for silica fume. To date, the subcommittee has agreed upon what characteristics should be included in the specification; however, agreement on what values to assign for each specified characteristic has not been achieved. So far, the process has taken four years and will probably require at least another two or three years before a specification is approved and available.

Depending upon 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 frequently relied upon 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.

Specifying this last property is particularly troublesome since 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, has been limited by the lack of the necessary equipment in the concrete industry. The current draft document being worked on by the ASTM subcommittee does include a requirement for measuring fineness that will force the silica fume suppliers to provide this information.

Standard specifications for admixtures containing silica fume or silica fume and chemical admixtures in combination are also non-existent. At present, there is no activity regarding the development of such a standard (although the first indications of interest in such a specification have appeared). This situation is complicated by the variety of types of admixtures containing silica fume plus chemical admixtures that are available. Again, users have frequently relied on materials suppliers for assistance and have specified such elements as total solids, silica-fume content, and that any chemical admixtures meet the requirements of ASTM C 494, "Standard Specification for Chemical Admixtures for Concrete" (9). This area is further complicated for public agencies since their specifications usually must not include brand names and since different products contain different combinations of silica fume and chemical admixtures. Attempting to prepare 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. The American Institute of Architects has expressed an interest in developing a silica-fume concrete section for its Masterspec. There is a recently published ACI state-of-the-art document (3), but it deals more with suitable uses of silica-fume concrete than with how to make and place it.

Project specifications that have been prepared have included prescriptive and performance elements and have been based upon extensive input from materials suppliers. Usually, silica-fume concrete has been treated as a separate class of concrete. The specifications have then detailed 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.

Since the majority of silica fume being used for performance enhancement is currently going into concrete for parking structures, performance specifications structured to include measures of the permeability of the in-place concrete are becoming popular. The test most often specified has been the Rapid Chloride Permeability Test (10), which has been adopted by AASHTO (11) and is under development 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 to the uncertainty regarding this test method 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

Several aspects have been identified as critical when producing concrete containing silica fume. These aspects include measuring and adding silica fume, mixing silica-fume concrete, using a high-range water-reducing admixture (HRWRA), and controlling concrete temperature. Each of these areas is discussed below. In addition to these critical 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 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.

Most project specifications to date have required that the silica fume should be measured with the same degree of accuracy as other concrete ingredients. Typically, accuracies of plus or minus one percent by mass or volume have been specified. The dispensing equipment being provided to concrete producers is capable of meeting these accuracies. If slurried silica fume is being 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 is necessary.

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 465 mL/m^3, a typical HRWRA may require 5.2 L/m^3, while a silica fume slurry may require 55 L/m^3. Clearly, the concrete supplier must be aware of the significant increase in the volume of admixture being dispensed.

Suppliers of slurried silica fume 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 dis-advantages 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 the equipment may be idle between projects since, so far, there has been little economic incentive for the concrete supplier to use the silica fume admixture in day-to-day concrete.

The problem of accurately measuring the silica fume has made use of silica-fume concrete on small jobs such as bridge decks more difficult. Because of the low volumes of concrete involved, the silica fume suppliers have been reluctant to set up a mobile dispenser for slurried silica fume at a concrete supplier for a deck placement. Therefore, slurried silica fume products 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 transportation agency was very reluctant to enter into such an arrangement. The current availability of a dry, densified silica fume in bags makes it much easier to accomplish small projects by adding a fixed number of bags per unit volume of concrete.

Adding

There has been some uncertainty regarding the appropriate time to add silica fume during the concrete production cycle. The deciding factor here appears to be 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 is capable of handling the dry material in bulk. Slurried products are best added to a truck mixer first since these products will contain a portion of the batch mixing water. (For high dosages of silica fume, slurried products may contain the majority of the batch water.) Adding slurried products to a truck last has resulted in "head pack" or in poor distribution of the silica fume throughout the load.

Concrete producers have been encouraged to make a few trial batches of the silica-fume concrete before the actual project begins in order to establish the appropriate batching sequence.

Mixing

The silica fume must be uniformly distributed throughout the concrete. Compressive strength variations of 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 for 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, "Standard Specification for Ready-Mixed Concrete" (12). 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 since it is directly in contrast to the economic interests 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 that was being achieved under such circumstances is open to question.

Although there is a relatively simple procedure defined in ASTM C 94 to allow for determination of the adequacy of mixing and the qualification of truck mixers, very few producers have been 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.

There have been several attempts to produce silica-fume concrete using a volumetric measuring continuous mixing (VMCM) system. The units were 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 slurried silica fume admixture and that concrete strength is reduced, probably because of inadequate mixing. Trial batches along with appropriate testing of hardened concrete are certainly recommended. Obviously, this recommendation implies beginning testing well before actual placements are to take place.

Adding High-Range Water-Reducing Admixtures (HRWRA)

Another critical area has been the use of a HRWRA. The successful use of silica fume as a performance-enhancing admixture requires the use of a HRWRA. The amount of HRWRA required and the appropriate time to add it are a function of the dosage of silica fume being used, the nature of the silica fume product itself, and the characteristics of the particular HRWRA being used. 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 insure that the concrete is adequately mixed. This requirement to add HRWRA at the plant raises the usual 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 early 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 mixers.

Controlling Concrete Temperature

The final critical area concerning concrete production has been the control of temperature during either hot or cold weather concreting conditions. The difficulties that have been seen have been a function of the amount of silica fume being added and of the nature of the product. The greatest problems have occurred with 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

One thought that has been emphasized to the concrete community in the United States has been the following: significant improvements in strength or durability cannot be achieved through the use of silica fume unless generally accepted good concrete practices are followed. This statement is particularly applicable in the areas of transporting, placing, and consolidating.

In these three areas that are concerned with getting the concrete from the batch plant and satisfactorily into the forms, concrete containing silica fume has been found to behave very much like conventional concrete, and there have been very few problems reported. Those problems that have been seen have stemmed from the nature of the silica-fume concrete itself. The fresh concrete, depending upon the dosage of silica fume, has typically been more cohesive and less prone to bleeding and segregation during handling than conventional concrete. The reduced tendency for segregation has allowed for the use of concretes with slightly higher slumps, which in turn has helped to overcome the problems of excessive cohesiveness or stickiness.

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, probably caused by the increased cohesiveness.

Concrete containing silica fume has been successfully placed using all types of placement devices such as buckets, pumps, tremies, etc. Because of the increased cohesiveness of the concrete, using a slump that is 25 to 50 mm higher than normally used for the same type of placement has been recommended. As silica fume dosage has increased, higher slumps have resulted in greater overall ease in placing and finishing. Specification writers have been urged to be flexible, bearing in mind the lower tendency for segregation, and to allow higher slumps.

High-slump flowing concretes containing silica fume have been 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 200 to 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 five percent silica fume by mass of portland 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 since 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 times. The first is during the period after the initial finishing operations of screeding and bull floating but before final finishing. The second period is 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 Fig. 2.1.5 in ACI 305, "Hot Weather Concreting" (13), or as Fig. 1 in ACI 308, "Standard Practice for Curing Concrete" (14), 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 one-half 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 preventative 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 occurrence has given the fresh concrete a "spongy" consistency and made it difficult to finish. The same procedures used to prevent plastic shrinkage cracking have been effective in preventing surface drying and hardening.

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 is a decision that is best left to the finishers. A difference in the timing of the finishing operations has been seen because of the chemical admixtures that may be used with the silica fume and because of the lack of bleeding. The chemical admixtures frequently have included retarders that have delayed setting while the lack of bleeding has caused some finishers difficulty in determining when to get on the concrete.

There are two general recommendations regarding finishing that have been made and that have eased problems with finishing: first, silica-fume concrete should be "under finished." Under finishing 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 esthetics 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.

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 have been very valuable. Projects that require only a small volume of concrete such as a bridge deck have been troublesome. One or two truck loads 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.

If the concrete application has required a dosage of more than about 10 percent silica fume by mass of portland cement, a one pass finishing procedure of screeding, bull floating, and brooming or other texturing followed immediately by curing has frequently 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 done by speciality contractors who were used to dealing with speciality 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 "over cure" the concrete. Over curing 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 should be done. As might be expected, this recommendation as well has not always met with overwhelmingly positive 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. Since high dosages of silica fume produce concrete that does not bleed, there is no requirement to wait for the concrete 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. Since these chemical admixtures frequently include retarders, it has been 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.

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 has been successfully manufactured and placed on a wide variety of projects. However, the author's experience to date is that many producers, contractors, and owners 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.

Silica fume is not a cure for bad practice. If a concrete contractor 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 or is being paid for by the owner.

There are no difficulties that 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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Table 1. Forms of Silica Fume Currently Available for Use in Concrete in the United States.

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: 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: 560 to 640 kg/m^3.

1.4 Densified silica fume without chemical admixtures. One product is available in bags and bulk. 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. Unit weight: 1,315 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.