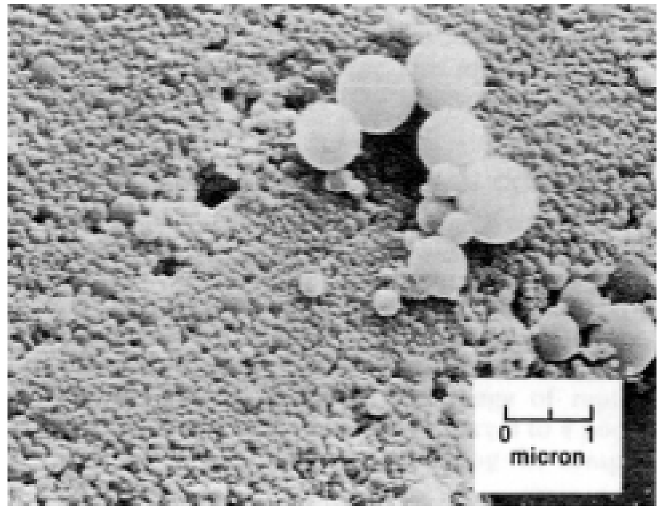
Silica fume

A pozzolan of new interest for use in some concretes

Micrograph from scanning electron microscope showing a typical silica fume. The 1-micron length in the scale is equivalent to 0.00004 inch.



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Recent research aimed at energy conservation in the cement and concrete industry has, in part, focused on the use of less energy intensive materials such as fly ash, slags and natural pozzolans. Lately some attention has been given to the use of condensed silica fume as a possible partial replacement for cement. Silica fume, a by-product in the manufacture of ferrosilicon and also of silicon metal, is a very efficient pozzolanic material, though there are some problems associated with its use in concrete. The use of silica fume in concrete should not be indiscriminate but should be limited to specialized applications that can take full advantage of its unique properties. The chief problems in using this material are associated with its extreme fineness and high water requirement when mixed with portland cement. However, the availability of superplasticizers has opened up new possibilities for its use.

Investigations of the performance of silica fume in concrete has been going on in the Scandinavian countries, particularly in Norway and Denmark, where the material has been used on a small scale since 1976. In North America, only limited data on silica fume have been reported to date.

The physical and chemical properties of silica fume are briefly reported here and possible applications of this material in concrete are given.

SILICA FUME

Electric arc furnaces used in the manufacture of ferrosilicon or silicon metal release silica fume as a by-product. The fume, which has a high content of very fine spherical particles of silicon dioxide, is collected by filtering the gases escaping from the furnaces.

Chemical composition

The fumes generally contain more than 90 percent silicon dioxide, mostly amorphous. Other constituents are carbon, sulfur and the oxides of aluminum, iron, calcium, magnesium, sodium and potassium. The loss on ignition of some Norwegian and American products runs from 0. 7 to 2.8 percent. The chemical composition of the fume varies according to the type of alloy or metal being produced. For example, the fume from a ferrosilicon furnace will generally contain more iron and magnesium oxides than that from a furnace producing silicon metal.

Fineness

Silica fume consists of very fine vitreous particles with a specific surface area in the order of 20,000 square meters per kilogram. The extreme fineness of silica fume is best illustrated by the following comparison with other fine materials.

Material	Fineness, square meters per kilogram
Silica fume	about 20,000
Tobacco smoke	about 10,000
Fly ash	400 to 700
Normal portland cement	300 to 400

Most particles of a typical silica fume are smaller than 1 micron (see photo). The high reactivity of silica fume with portland cement is primarily due to its very

FILE: Admixtures

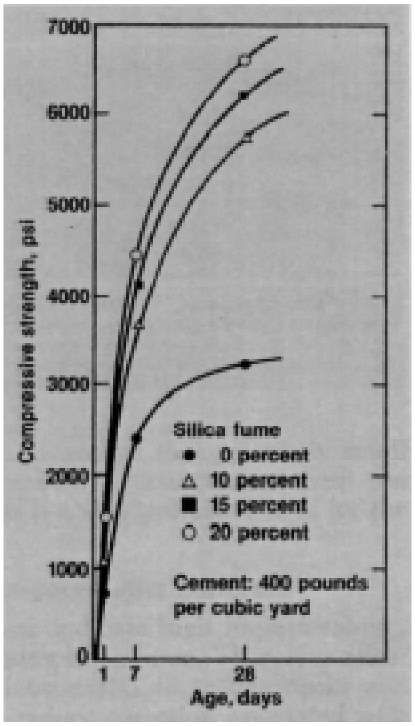

Figure 1. *Compressive strength versus age of concrete incorporating up to 20 percent silica fume as an admixture. Loss of slump with addition of silica fume compensated for by the use of a superplasticizer.*

high specific surface and its high content of amorphous silicon dioxide.

Production of silica fume

Exact data on the annual output of silica fume in Canada and the United States are not available but estimates are that in 1981 a total of about 22,000 tons was available in Canada. The corresponding estimated figure for the United States was on the order of 200,000 to 500,000 tons.

Norway is one of the world's largest producers of silica fume with an estimated production of about 200,000 tons and this is expected to double over the next several years. Total worldwide production is estimated at about 1.1 million tons.

METHODS OF USING SILICA FUME IN CONCRETE

As an admixture

Small quantities of silica fume, 5 to 10 percent by weight of cement, can be added to concrete. The resulting loss in slump is compensated for either by the addition of more water or the use of superplasticizers. In either case, there is a marked increase in compressive strength as compared with the control mix. This is particularly so with the use of superplasticizer (Figure 1).

As a partial replacement for cement

Silica fume can be used as a partial replacement for cement. The percentage replacement may vary from 0 to 30 percent. Though this does not change the weight of the cementitious materials, there is an increase in the water demand because of the extreme fineness of silica fume. In order to maintain the same water- (cement plus silica fume) ratios, superplasticizers are used to maintain the required slump. This approach also results in an increase in compressive strength at the age of 3 days and thereafter.

EFFICIENCY OF SILICA FUME IN CONCRETE

Silica fume is a very efficient pozzolan and, like other pozzolanic materials, it is generally more efficient in concretes having high water-cement ratios. Research in Norway and Canada indicates that in concretes with a water-cement ratio of about 0.55 and higher, the silica fume has an efficiency factor of 3 to 4. This means that (within the usual 0-to-10-percent range of replacement) 1 pound of silica fume can replace 3 to 4 pounds of cement in concrete without changing the compressive strength.

POSSIBLE APPLICATIONS OF SILICA FUME IN CONCRETE

To conserve cement

Because of its very high efficiency, the judicious use of silica fume can help conserve cement, especially in concretes with a water-cement ratio around 0.55. A number of ready mixed concrete producers in Norway are using silica fume in this way. A small ready mixed concrete producer in Quebec has also started using silica fume to conserve cement.

To produce ultra-high-strength concrete

Silica fume has been used with superplasticizers to produce ultra-high-strength concrete. Compressive strengths on the order of 15,000 psi and greater have been reported (Tables 1 and 2). This of course is a very specialized area with limited applications.

To reduce alkali-aggregate reaction

Like fly ashes and natural pozzolans, silica fume can be used to counter alkali-aggregate reactions. Silica

TABLE 1. COMPRESSIVE STRENGTH OF MORTARS AND CONCRETES INCORPORATING SILICA FUME AND SUPERPLASTICIZERS

Material	Size and type of aggregate	Unit weight, pounds per cubic foot	Compressive strength, psi
Concrete	0.63-inch granite	156	18,070
Concrete	0.63-inch diabase	166	24,380
Concrete	0.39-inch calcined bauxite	180	31,550
Mortar	0.16-inch calcined bauxite	178	38,910

Data from H.H. Bache, "Densified Cement/Ultra-Fine Particle-Based Materials," Second International Conference an Superplasticizers in Concrete, Ottawa. Canada, 1981. Note: Results are based on 4x8-inch cylinder specimens tested after 4 days of moist curing at 60 to 80 degrees F.

(more)

TABLE 2. COMPRESSIVE STRENGTH AT VARIOUS AGES OF CONCRETE INCORPORATING A SILICA FUME AND SUPERPLASTICIZER-BASED ADMIXTURE

Age at test, days	Compressive strength, psi
1	9,430
7	13,730
28	16,170
90	16,700
128	18,020

Data from J. Wolsiefer, "Ultra-High-Strength Field-Placeable Concrete in the Range 10,000 to 18,000 psi," paper presented at 1982 annual convention in Atlanta, Georgia, American Concrete Institute (of Detroit), January 1982. Note: Results are based on 4x8-inch cylinder specimens. moist cured.

fume has the added advantage that relatively small quantities may be needed, by comparison with the former materials. This is a very promising area for the use of silica fume.

To produce highly impermeable concrete

Some published data indicate high impermeability of concrete incorporating silica fume. Therefore silica-fume concrete could be useful in bridge decks and parking structures to reduce corrosion associated with chlorides.

PROBLEMS WITH THE USE OF SILICA FUME

Availability

In some areas silica fume is still regarded as a waste product and is not actively marketed for use in concrete. Some users have found it practical to send a cement-hauling truck to a plant that has furnaces making silicon or ferrosilicon, and haul loads of fume to their own silos.

Handling problem

Because of its extreme fineness, silica fume is very light (about 20 pounds per cubic foot) and does present handling problems. In Norway, the problems have been overcome to a degree by transporting and using silica fume in slurry form. In Canada, patents have been taken out on a process to densify the fume for transportation purposes. The densification would be done at the plant where the fume is produced. The process increases the bulk density by a factor of about 3 and makes the particles slightly coarser than cement or fly ash but, it is claimed, without any sacrifice of its beneficial properties. Some ready-mixed concrete producers are currently using the fume as produced, without densification.

Health hazards

Silica fume may pose a health hazard though some data published in Norway (Reference 1) indicate otherwise. Further research is needed in this area.

Difficulty in entraining air

Investigations at the Canada Center for Mineral and Energy Technology (CANMET, Reference 2) have indicated some difficulty in entraining 5 to 7 percent air in concretes with high cement contents and 20 to 30 percent of silica fume. At lower percentage replacements, no such problems were encountered, although the dosage of air-entraining agent required to entrain a

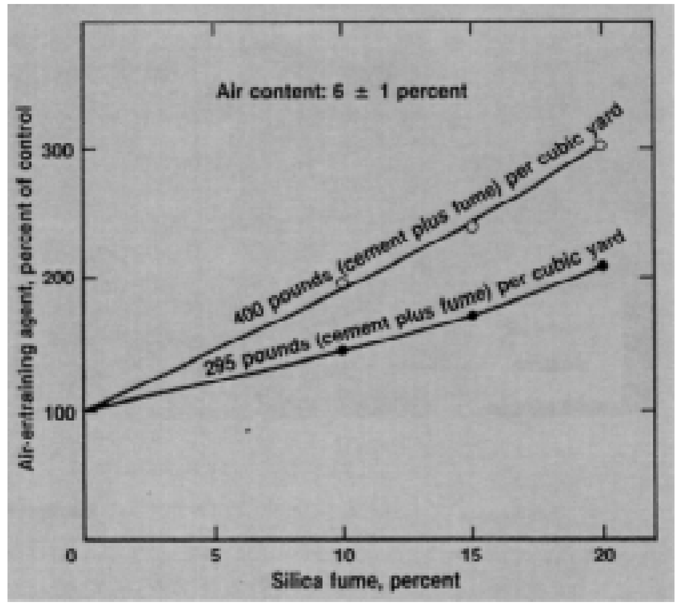

Figure 2. *Effect of silica fume on the dosage requirement of an air-entraining agent in air-entrained concrete.*

given percentage of air did increase markedly as compared with the control concrete (Figure 2).

Cost

In the past two years, people have begun to recognize the value of silica fume. Consequently the price has skyrocketed. It was only a waste product a few years ago. Now the price of fume varies from half to twice the price of normal portland cement. Further increases in the price may limit the use of fume to specialized applications.

CONCLUSIONS

Silica fume is a highly efficient pozzolanic material and has a considerable potential for use in concrete. Because of the relatively limited supplies of the material, it is recommended that it be used judiciously to solve specific problems and to make specialized products. Its indiscriminate use in concrete is not recommended.

References

1. Jahr, J. "Possible Health Hazards from Different Types of Amorphous Silicas— Suggested Threshold Limit Values," Institute of Occupational Health, Oslo, Norway, 1980.

2. Carette, G. G. and Malhotra, V. M. "Preliminary Investigations into the Use of Silica Fume in Concrete," CANMET Report 82-6 (R), CANMET, Energy, Mines and Resources Canada, 1982.

For information about the process for densifying silica fume circle **105** on the reader service card.