| | |
|---|---|
| IN-LB | Inch-Pound Units |
| SI | International System of Units |

# Use of Silica Fume in Concrete—Guide

Reported by ACI Committee 234

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American Concrete Institute
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# ACI PRC-234-26

# Use of Silica Fume in Concrete—Guide

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Note: Special acknowledgment to T. Holland for his contribution to this guide.



*This guide describes the physical and chemical properties of silica fume; how it interacts with portland cement; its effects on the properties of fresh and hardened concrete; recent typical applications of silica fume concrete; how it is proportioned, specified, and handled in the field; how it contributes to sustainability; and areas where additional research is needed.*



**Keywords:** curing; durability; high-performance concrete (HPC); high-range water-reducing admixtures (HRWRAs); high-strength concrete; placing; plastic-shrinkage cracking; silica fume; sustainability; time of setting; water-reducing admixtures (WRAs); workability.


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# CHAPTER 1—INTRODUCTION

## 1.1—Introduction

Silica fume, a by-product of the silicon or ferrosilicon industry, is an ultrafine, highly reactive pozzolanic material used to enhance the mechanical and durability properties of concrete. It may be added directly to concrete as a supplementary cementitious material (SCM), combined with other SCMs such as slag cement or fly ash, or included as a constituent in blended cement.

Interest in using silica fume resulted from the strict enforcement of air pollution measures aimed at preventing the release of such materials into the atmosphere. The initial use of silica fume in concrete was primarily for cement replacement, in combination with water-reducing admixtures (WRAs). Eventually, the availability of high-range water-reducing admixtures (HRWRAs, often referred to as superplasticizers) allowed new possibilities for using silica fume to produce high-performance concrete (HPC).

## 1.2—Scope

This guide provides information and guidance on silica fume and its use in concrete. Topics covered include general information on silica fume; its physical and chemical properties; mechanisms by which silica fume modifies cement paste, mortar, and concrete; its performance in plastic and hardened concrete; proportioning; specifications; contributions to concrete sustainability; and examples of silica fume use in various concrete applications.

# CHAPTER 2—NOTATION AND TERMINOLOGY

## 2.1—Notation

$E_c$ = modulus of elasticity of concrete, ksi (GPa)
$f_c'$ = specified compressive strength, psi (MPa)
$f_{cr}'$ = required average strength, psi (MPa)
$f_{c\phi}'$ = load-bearing capacity, ksi (GPa)

## 2.2—Terminology

ACI provides a comprehensive list of definitions through an online resource, "ACI Concrete Terminology." Definitions provided herein complement that resource.

**abrasion-erosion of concrete**—a type of mechanical weathering where concrete is worn away by the friction and impact of particles carried by wind, water, or ice.

**autogenous drying shrinkage (autogenous volume change)**—change in volume due to the chemical process of hydration of cement, exclusive of effects of applied load and change in either thermal condition or moisture content.

**binder or binding materials**—an inorganic material or a mixture of inorganic materials that sets and develops strength by chemical reaction with water by the formation of hydrates and is capable of doing so under water—for example, portland cements and SCMs.

**binder intensity**—the amount of binder (lb/yd$^3$ [kg/m$^3$]) needed to achieve a specific mechanical strength or performance level. Binder intensity is used as an index to evaluate the environmental impact of concrete.

**chloride-ion penetration resistance**—the time-dependent resistance of concrete to penetration of chloride ions that may occur due to several mechanisms, including absorption, permeability, diffusion, and evaporative transport (wick action). It will also be affected by issues such as chloride binding.

**coefficient of permeability to water**—the rate of discharge of water under laminar flow conditions through a unit cross-sectional area of a porous medium under a unit hydraulic gradient and standard temperature conditions, usually 68°F (20°C). The hydraulic gradient or hydraulic pressure per unit thickness is the transport mechanism.

**cradle-to-gate**—corresponding to life cycle modules A1 through A3 according to ISO 21930.

**diffusion coefficient or diffusivity**—the rate at which a diffusing substance is transported between opposite faces of a unit cross section and depth of a porous medium when there is a unit concentration difference between them. Commonly, chloride diffusion rates in saturated concretes are reported. In practice, the chloride gradient occurs between one surface and the interior of the concrete.

**drying shrinkage**—shrinkage resulting from loss of moisture.

**durability**—the ability of a material to resist weathering action, chemical attack, abrasion, and other conditions of service.

**embodied energy**—the total amount of energy required to produce a product or service, including the energy used in extracting and processing raw materials, manufacturing construction materials, transportation and distribution, assembly and construction, and demolition and waste management.

**environmental product declaration (EPD)**—declaration providing environmental data using predetermined parameters meeting the requirements of ISO 21930.

**gas permeability**—the gas pressure gradient across the porous medium.

**global warming potential**—index is used to determine the energy absorption caused by the emissions of different gases associated with a product, normalized to an equivalent mass of carbon dioxide over 100 years.

**life cycle assessment**—compilation and evaluation of a product's input, output, and potential environmental impact throughout its life cycle.

**mineral addition**—inorganic materials, both natural minerals and industrial by-products, that are used in quantities of 5% or more by mass of the cement. Mineral additions may be blended or interground with portland cement or added directly to the concrete before or during mixing (RILEM Technical Committee 73-SBC 1988).

**oversize**—larger non-silica particles or silica fume agglomerates that remain after a silica fume sample is washed through a No. 325 (45 µm) sieve.

**product category rule (PCR)**—set of specific rules, requirements, and guidelines for developing EPDs for one or more product categories.

**resilience**—in a social or ecological system, resilience may include the ability to absorb disturbances while

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retaining the same basic structure and ways of functioning, as well as the capacity to adapt to stress and change.

**robustness**—the ability of a structure to withstand events such as fire, explosions, impact, or the consequences of human error without collapsing or being damaged or distressed to an extent disproportionate to the original cause/local damage.

**vapor permeability**—a material's ability to allow water vapor, which is water in its gas form, to pass through it. Also referred to as "vapor diffusivity".

**water absorption**—the process by which a liquid is drawn into and tends to fill permeable pores in a porous solid. It occurs only in unsaturated concrete, and the rate and magnitude of absorption decrease as the permeable pores become saturated.

## CHAPTER 3—SILICA FUME MATERIALS

### 3.1—General

Silica fume is defined in ASTM C125 as "very fine pozzolanic material, composed mostly of amorphous silica produced by electric arc furnaces as a by-product of the production of elemental silicon or ferro-silicon alloys."

Silica fume, which condenses from the gases escaping from the furnaces, consists of spherical particles (Fig. 3.1a and 3.1b) typically averaging $4.0 \times 10^{-6}$ in. to $8.0 \times 10^{-6}$ in. (0.1 to 0.2 μm) in diameter. Often, several individual spheres may fuse to form small silica-fume agglomerates.

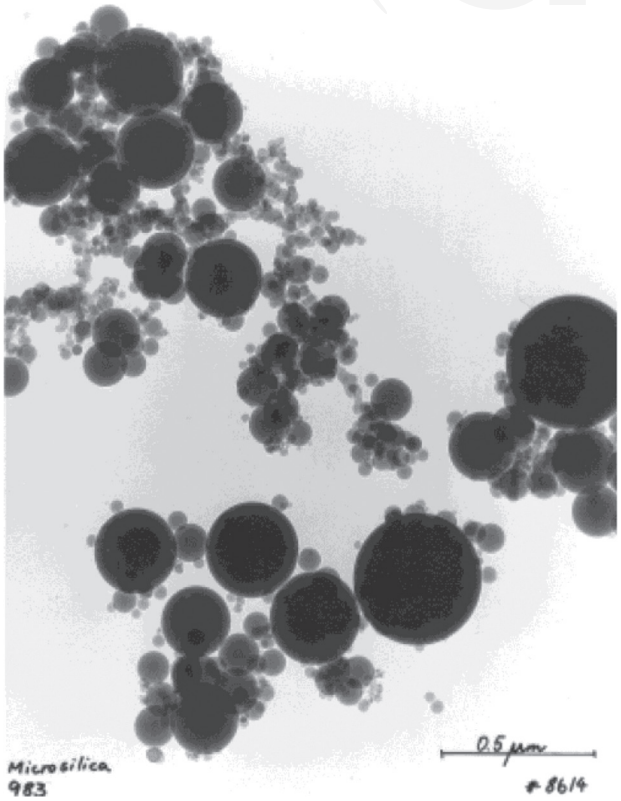


*Fig. 3.1a—Transmission electron microscope micrograph of silica fume (courtesy of Elkem ASA materials).*

The first mention of silica fume for use in concrete and mortar is in a 1946 U.S. patent (Sharp 1946), which claims that silica fume improves the properties of fresh mortar.

Silica fume was first collected in Kristiansand, Norway, in 1947. Investigations into the material's properties and uses began promptly, with the first paper published by Bernhardt (1952). Investigations into the performance of silica fume in concrete have also been conducted in other Nordic countries, including Iceland, Denmark, and Sweden. Additional early Scandinavian papers included those by Fiskaa et al. (1971), documenting improved sulfate resistance; Jahr (1981), reporting low potential health hazards; Asgeirsson and Gudmundsson (1979), noting the increased pozzolanic activity and its benefits; Løland (1981), reviewing the range of performance improvements when using silica fume in concrete; and Gjørv and Løland (1982), showing the enhanced performance of silica fume concrete.

In 1978, Norwegian Standards NS 3420-A and NS 3474 were amended to permit the addition of silica fume into concrete.

Oberholster and Westra (1981) published research results from South Africa on the use of silica fume to control the alkali-aggregate reaction.

In North America, the first paper was published in 1981 by Buck and Burkes of the United States (U.S.) Army Corps of Engineers Waterways Experiment Station (WES). Other early research was conducted by CANMET (Malhotra and Carette 1983; Carette and Malhotra 1983a), University of Sherbrooke (Aïtcin 1983), Norchem (Wolsiefer 1984), and the U.S. Army Corps of Engineers WES (Holland 1983). In 1978, the first significant use of ready mixed silica fume concrete in the United States was for a chemical-attack-resistant application (Bühler 2007). In late 1983, the U.S. Army Corps of Engineers did the first publicly bid project in the United States using silica fume concrete (Holland 1986a,b). Many thousands of papers have since been published detailing research on silica fume and silica fume concrete. From the 1990s to the present, much of the focus has been

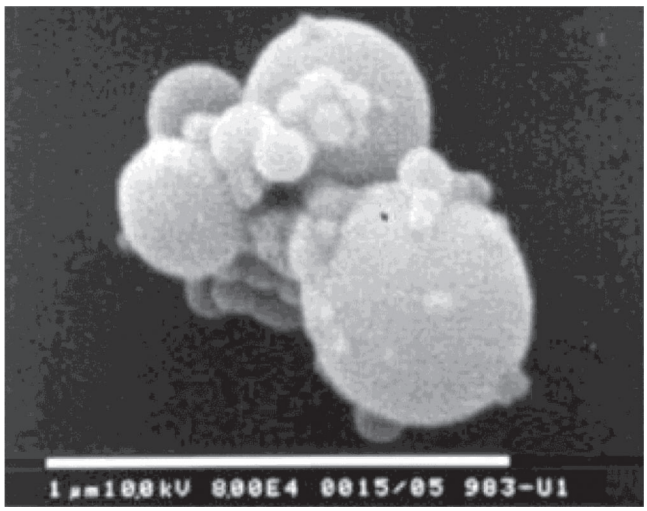


*Fig. 3.1b—Scanning electron microscope micrograph of silica fume (courtesy of Elkem ASA materials).*

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