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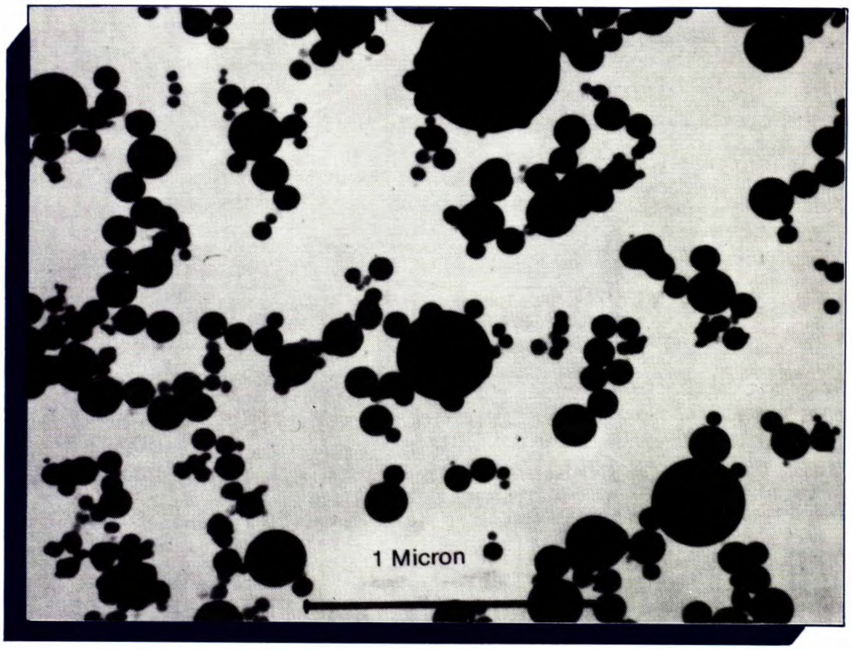
COMPILATION OF ABSTRACTS OF PAPERS FROM RECENT INTERNATIONAL CONFERENCES AND SYMPOSIA ON CONDENSED SILICA FUME IN CONCRETE

E. Douglas and V.M. Malhotra
MINERAL PROCESSING LABORATORY



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COVER PHOTO

The scanning electron micrograph on the cover shows particles of condensed silica fume that have a mean particle size of about 1.0 μm, approximately 100 times smaller than that of portland cement particles.

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COMPILATION OF ABSTRACTS OF PAPERS FROM RECENT INTERNATIONAL CONFERENCES AND SYMPOSIA ON CONDENSED SILICA FUME IN CONCRETE

E. Douglas* and V.M. Malhotra**

Synopsis

This report is a compilation of abstracts of papers from recent international conferences and symposia on the use of condensed silica fume in concrete. The conferences covered include those held in Europe and North America between 1980 and 1988. Papers for this report were selected on the basis of their direct relevance to the use of condensed silica fume in concrete. The abstracts are given in chronological order and include keywords.

COMPILATION DE RÉSUMÉS DE COMMUNICATIONS PRÉSENTÉES LORS DE CONFÉRENCES ET SYMPOSIUMS INTERNATIONAUX RÉCENTS SUR LES FUMÉES DE SILICE CONDENSÉES DANS LE BÉTON

E. Douglas* et V.M. Malhotra**

Résumé

Ce rapport est le résultat d'une compilation des résumés de communications présentées lors de conférences et de symposiums récents sur l'utilisation des fumées de silice condensées dans le béton. Les conférences couvertes comprennent celles qui ont eu lieu en Europe, en Amérique du Nord et Amérique du Sud entre 1980 et 1988. Les communications mentionnées dans ce rapport ont été choisies en fonction de leur pertinence pour ce qui est de l'utilisation des fumées de silice condensées dans le béton. Les résumés sont présentés par ordre chronologique. Les mots clés sont indiqués.

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KEYWORDS

abrasion resistance; accelerated curing; accelerating agents; admixtures; adsorption; age–strength relation; air; air–entrained concretes; air–entraining agents; air entrainment; alkali–aggregate reactions; alkali content; aluminum oxide; ashes; autoclaving; bauxite; beams (supports); bending; blast–furnace slag; bleeding (concrete); blended cements; bond (concrete to reinforcement); bonding; bond (paste to aggregate); bond stress; C–S–H; calcium hydroxide; carbonation; cement content; cement pastes; cements; chemical analysis; chemical attack; chlorides; coatings; compressive strength; concrete cores; concrete durability; concrete pipes; concretes; concrete slabs; consistency tests; conveying; corrosion; corrosion resistance; costs; creep properties; cubes; curing; cyclic loads; damage; dams; Darcy's law; deflection; deformed reinforcement; deicers; density (mass/volume); diffusivity; drying; drying shrinkage; dynamic modulus of elasticity; economics; electrical resistance; electron microscopes; erosion; evaluation; expanded clay aggregates; expanding agents; expansion; fiber reinforced concretes; flexural strength; fly ash; freeze–thaw durability; fresh concretes; grouts; hardened concretes; hardened paste structure; heat of hydration; high–strength concretes; impregnating; lateral pressure; lightweight aggregate concrete; mass concrete; materials handling; metal fibers; microhardness; microstructures; mineral admixtures; mixing; mix proportioning; modulus of elasticity; mortars; mortars (material); naphthalene sulfonate; opal; oxygen; penetration; performance; permeability; plasticizers; polymerization; polymethyl methacrylate; porosity; portland cements; pozzolans; precast concrete; prestressed concrete; prisms; pullout tests; ready–mixed concrete; reinforced concrete; reinforcing steels; repairs; resurfacing; reviews; rheological properties; sands; scaling; sealers; shotcrete; silica; silica gel; slags; slump tests; slurries; static loads; steam curing; stilling basins; strength; stresses; sulfate attack; sulfate resistance; temperature; temperature rise; tensile strength; tests; viscosity; voids; water/cement ratio; water content; water–reducing agents; weight measurement; workability; X–ray analysis; X–ray diffraction; zeta potential.

CONTENTS

INTRODUCTION

In the past seven years a number of conferences and symposia have been conducted on the use of supplementary cementing materials in portland cement concrete. The most notable have been the following:

- Seventh International Congress on the Chemistry of Cement, Paris, France, 1980.
- Fifth International Symposium on Concrete Technology, Nuevo Leon, Mexico, March 1981.
- International Conference on Slags and Blended Cements, Mons, Belgium, September 1981.
- Symposium on Fly Ash Incorporation in Hydrated Cement Systems, Materials Research Society, Boston, Massachusetts, U.S.A., November 1981.
- International Conference on Slag and Blended Cements, University of Alabama, Birmingham, Alabama, U.S.A., February 1982.
- EPRI Workshop on Research and Development Needs for Use of Fly Ash in Cement and Concrete, Palo Alto, California, U.S.A., March 3–5, 1982. (Proceedings EPRI Report, CS–2616–SR, September 1982.)
- Sixth International Symposium on Fly Ash Utilization, Reno, Nevada, U.S.A., March 1982.
- International Symposium on the Use of PFA in Concrete, University of Leeds, England, April 14–16, 1982.
- First CANMET/ACI International Conference on the Use of Fly Ash, Silica Fume, Slag and Other Mineral By–Products in Concrete, Montebello, Quebec, Canada, July 31 – August 5, 1983. (Published as ACI Special Publication SP–79, American Concrete Institute, Detroit, Michigan, U.S.A.)
- Second CANMET/ACI International Conference on the Use of Fly Ash, Silica Fume, Slag and Natural Pozzolans in Concrete, Madrid, Spain, April 21–25, 1986. (Published as ACI Special Publication SP–91, American Concrete Institute, Detroit, Michigan, U.S.A., edited by V.M. Malhotra.)
- Concrete Durability – Katharine and Bryant Mather International Conference, Atlanta, Georgia, U.S.A., April 27 – May 1, 1987. (Published as ACI Special Publication SP–100, American Concrete Institute, Detroit, Michigan, U.S.A., edited by John Scanlon.)

Recent compilations of abstracts of selected papers from these sources, relating to the use of fly ash and slags in concrete, have been prepared by CANMET. This document is an extension of those compilations and presents abstracts relating to the use of condensed silica fume in concrete. The abstracts have been compiled in this form because the proceedings of some of the above conferences and symposia are not easily available to the general reader.

Papers on the use of condensed silica fume were presented only at the Montebello Conference (1983), the Madrid Conference (1986) and the Concrete Durability Conference (1987). The other conferences did not include presentations on the subject. In preparing these abstracts, papers were selected on the basis of their direct relevance to concrete construction. The reader is urged to consult the original proceedings of these meetings for further consideration of the topic and to review the many papers on research and other aspects of the topic not directly applicable to concrete construction.

ABSTRACTS OF PAPERS

First CANMET/ACI International Conference on the Use of Fly Ash, Silica Fume, Slag and Other Mineral By–Products in Concrete Montebello, Quebec, Canada, July and August 1983

(Edited by V.M. Malhotra, ACI Special Publication SP–79.)

1. Jahren, P.A. "The use of silica fume in concrete," Vol. 2, pp. 625–642.

This paper presents a review of the role of silica fume in concrete, based mainly on the experience of the author and his colleagues. Statistics on silica fume production, its composition, quality and the way it is handled and proportioned for making concrete are briefly described. Various factors that influence the physical and mechanical properties of fresh and hardened concrete, such as water/cement ratio, temperature of curing and superplasticizer, are also discussed. Factors that determine the economy of using silica fume are emphasized. A brief survey of the literature pertaining to silica fume concrete is also included.

Keywords: *bleeding (concrete); concrete durability; economics; fresh concretes; hardened concretes; materials handling; mix proportioning; plasticizers; pozzolans; reviews; silica; water/cement ratio; workability.*

2. Sellevold, E.J. and Radjy, F.F. "Condensed silica fume (microsilica) in concrete: water demand and strength development," Vol. 2, pp. 677–694.

This paper reports results of a comprehensive investigation of the performance of concrete incorporating 8 and 16% of condensed silica fume (microsilica). Two types of portland cement and one blended cement with 20% fly ash were used. Two dosage levels of a normal, water–reducing agent and one superplasticizing agent were used. The water demand to produce a 12–cm slump and the compressive strength development of the concretes were measured. The main conclusions are as follows:

a. The water demand increases with microsilica content when no water–reducing agent is used. However, water–reducing agents have a greater effect on microsilica concrete than on normal concrete. Thus, the water demand for given microsilica content may be controlled to be either greater or smaller than for the reference concrete by adjusting the dosage of water–reducing agents.

b. The main pozzolanic contribution to strength develops between 3 and 28 days, at 20°C. The shape of the 28–day compressive strength versus water/cement ratio curve for a fixed microsilica content is the same as that for the reference concrete, but it shifts to a substantially higher level.

c. The "efficiency" of the microsilica in increasing the compressive strength was calculated to be between two and four times greater than that for portland cement.

Keywords: *compressive strength; concretes; silica; water/cement ratio; water–reducing agents.*

3. Gjorv, O.E. "Durability of concrete containing condensed silica fume," Vol. 2, pp. 695–708.

It has been found that the addition of 20% silica fume by weight of cement to a concrete with only 100 kg/m^3 of cement gives the same permeability as that of concrete with 250 kg/m^3 cement containing no silica fume. Frost–resistant concrete can be produced using silica fume. A 15% replacement of ordinary portland cement by silica fume shows durability similar to sulfate–resisting portland cement exposed to sulfate solutions. Silica fume binds up the alkalis of the cement and reduces the detrimental alkali–silica reactions. Addition of 10 to 20% silica fume does not reduce the pH to a level lower than that of a saturated $Ca(OH)_2$ solution. The electrical resistivity of the concrete is increased dramatically. Monitoring of existing structures containing such concrete has shown that embedded steel is well protected.

Keywords: *alkali–aggregate reactions; concrete durability; corrosion resistance; electrical resistance; freeze–thaw durability; permeability; pozzolans; reinforcing steels; silica; sulfate resistance.*

4. Sorensen, E.V. "Freezing and thawing resistance of condensed silica fume (microsilica) concrete exposed to deicing chemicals," Vol. 2, pp. 709–718.

Scaling of concrete due to freezing–and–thawing action in conjunction with the use of deicing chemicals has become a severe concrete–durability problem. This paper reports results of freezing–and–thawing experiments performed to evaluate the effect of microsilica (beneficiated condensed silica fume) addition to concrete. Tests performed using a standard and a modified method show that the drying–rewetting history of the concrete before freezing and thawing has a significant influence on conventional concrete, whereas microsilica concrete is relatively unaffected. Air entrainment has a marked beneficial effect on both conventional and microsilica concrete, although microsilica concrete with relatively low cement contents can be manufactured to be frost resistant without air entrainment.

Keywords: *air entrainment; concretes; deicers; freeze–thaw durability; scaling; silica.*

5. Vennesland, O. and Gjorv, O.E. "Silica concrete – protection against corrosion of embedded steel," Vol. 2, pp. 719–729.

The ability of concrete to protect embedded steel against corrosion is due mainly to the high alkalinity of the pore water of the concrete, which provides a passive, noncorroding state for the embedded steel. If the passivity of the steel is broken – either by carbonation or by the presence of chloride ions – the corrosion of the steel will be controlled mainly by the electrical resistivity of the concrete and the rate of oxygen transport through the concrete to the steel.

This paper describes a study of how additions of up to 20% condensed silica fume by weight of cement affect the rate of carbonation, electrical resistivity and rate of oxygen transport through water–saturated concrete. It was found that the effect of silica on the parameters studied varied within wide limits. The rate of oxygen transport was only slightly affected, and the rate of carbonation was somewhat reduced. The most pronounced effect of silica was found on the electrical resistivity, which is increased by 190 to 1600% for cement contents varying from 100 to 400 kg/m^3.

Keywords: *carbonation; corrosion resistance; electrical resistance; oxygen; porosity; reinforced concrete; reinforcing steels; silica.*

6. Burge, T.A. "High strength lightweight concrete with condensed silica fume," Vol. 2, pp. 731–745.

To reduce the density and improve the strength properties of load–bearing structural members, a new binder matrix has been investigated. The binder matrix is composed of cement, variable amounts of condensed silica fume, a high–range water reducer and air–entraining agent. The use of heavy–duty grade expanded clay as a lightweight aggregate in combination with artificially introduced air voids in the concrete was found to be advantageous. With these combinations, it was possible to attain an air content up to 4.0% of the concrete volume and density/compressive strength values ranging from 1.1 t/m^3 at 10 MPa to 1.8 t/m^3 at 60 MPa. The main properties of such lightweight concrete were investigated, including strength and density, bond of embedded steel, modulus of elasticity and length change.

In this paper, the main results are presented and discussed. It may be concluded that cement and condensed silica fume blends can be used for the production of low–density, high–strength, lightweight concrete for structural use.

Keywords: *air–entraining agents; bonding; compressive strength; density (mass/volume); expanded clay aggregates; high–strength concretes; lightweight aggregate concrete; reinforcing steels; silica; water–reducing agents.*

7. Lessard, S., Aitcin, P.C. and Regourd, M. "Development of a low heat of hydration blended cement," Vol. 2, pp. 747–763.

A low heat of hydration blended cement for structural applications has been developed. This cement is composed of 50% of a Canadian cement, CSA Type 20 (ASTM Type II), 35% of a slowly reactive slag and 15% of condensed silica fume. The heat of hydration measured at 20°C of this blended cement is 30% lower than that of the pure Type 20 cement, whereas the 28–day compressive strength of standard mortars is about the same. The peak temperature of an insulated mass of concrete having a 28–day compressive strength of 30 MPa is reduced from 44.4 to 34.4°C when using this composition instead of the Type 20 cement. A microstructural study has shown that when using this blended cement the C–S–H formed is very dense and amorphous–like.

Keywords: *blended cements; compressive strength; heat of hydration; mass concrete; microstructure; silica; slags; temperature rise.*

8. Carette, G.G. and Malhotra, V.M. "Early–age strength development of concrete incorporating fly ash and condensed silica fume," Vol. 2, pp. 765–784.

Early–age strength development of concrete in which part of the portland cement has been replaced by low–calcium fly ash tends to be slow because fly ash acts as a relatively inert component during this period of hydration, though at later ages it contributes significantly to strength development. It was considered that the problem of low early–age strength of portland cement fly ash concrete could be overcome by the incorporation of small amounts of condensed silica fume, a very fine and more rapidly reacting pozzolan.

This report presents the results of an investigation of the early–age strength development of concrete incorporating 30% low–calcium fly ash and small amounts of condensed silica fume. The amounts of the fume ranged from 0 to 20% by combined weight of the portland cement plus fly ash. A total of thirty 0.06–m^3 concrete mixtures with water/(cement + fly ash) ratios ranging from 0.40 to 0.80 were made; 240 cylinders were tested in compression and 180 prisms were tested in flexure. A supplementary series of six concrete mixtures was made to determine the effect of silica fume and fly ash on the long–term strength development of concrete.

Test data showed that the incorporation of condensed silica fume into concrete increased the compressive strength of the concrete at all ages as compared with the compressive strength of the control concrete (70% portland cement and 30% fly ash). At seven days, the loss of compressive strength due to the partial replacement of cement by fly ash was completely overcome by the addition of 10% condensed silica fume for concretes with water/(cement + fly ash) ratios ranging from 0.40 to 0.60; 15 to 20% was required for concretes with higher water/(cement + fly ash) ratios. At 28 days, regardless of the water/(cement + fly ash) ratio, the effect was generally achieved with the addition of less than 5% silica fume. The later–age strength development of portland cement fly ash concrete did not appear to be impaired by the use of condensed silica fume, indicating availability of sufficient lime for the fly ash pozzolanic activity.

Keywords: *age–strength relation; compressive strength; concretes; fly ash; plasticizers; pozzolans; silica.*

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9. Ramakrishnan, V. and Srinivasan, V. "Performance characteristics of fiber reinforced condensed silica fume concretes," Vol. 2, pp. 797–812.

This paper presents the results of an investigation to determine the performance characteristics of fiber reinforced concretes containing condensed silica fume. The plastic concrete properties studied are slump, air content, unit weight and Vebe–time. The hardened concrete properties investigated are compressive strength, flexural strength, toughness index, tensile strength, pulse velocity, static modulus of elasticity and absorption coefficient. These hardened concrete properties are compared at ages 3 to 90 days.

A total of 17 mixes was made using Type I cement, with the addition of condensed silica fume, steel fibers and superplasticizers. Seven cement contents varying from 160 to 560 kg/m^3 (270 to 945 lb/cu.yd.) were investigated with water/cement ratios varying from 0.28 to 1. In all mixes, condensed silica fume was added at 20% by weight of cement and steel fibers at 47.5 kg/m^3 (80 lb/cu.yd.).

The results indicate that the addition of condensed silica fume and steel fibers reduces the workability considerably; however, the workability can be restored with the addition of an appropriate amount of superplasticizer. In general, the finishability of fiber reinforced concrete is improved with the addition of condensed silica fume. The unit weight of fiber reinforced, condensed silica fume concrete is higher than that of normal concrete. The addition of condensed silica fume is beneficial for fiber reinforced concretes with low cement content. It was shown that high–strength, fiber reinforced concretes could be made with low cement contents. The moisture absorption capacity of the concrete is reduced with the addition of condensed silica fume. For the selected 20% addition of condensed silica fume, an optimum cement and water content considerably improves the performance characteristics of the steel fiber reinforced concrete.

Keywords: *compressive strength; fiber reinforced concretes; flexural strength; metal fibers; performance; plasticizers; silica; water/cement ratio; workability.*

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10. Skrastins, J.I. and Zoldners, N.G. "Ready–mixed concrete incorporating condensed silica fume," Vol. 2, pp. 813–829.

This paper describes the use of condensed silica fume in concrete mixes produced at the ready–mixed concrete plant in St. Eustache, Que. The effect of this admixture on the properties of fresh and hardened concrete is discussed. Efficiency factors for the silica fume–modified concrete are given for different strength levels. Transportation of the fume and special installations at the ready–mixed concrete plant for handling condensed silica fume are described.

Keywords: *admixtures; compressive strength; conveying; costs; mix proportioning; ready–mixed concrete; silica.*

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11. Regourd, M., Mortureux, B. and Hornain, H. "Use of condensed silica fume as filler in blended cements," Vol. 2, pp. 847–865.

At early ages, blended cement mortars with 30% hydraulic slags or active pozzolans have lower mechanical strengths than mortars incorporating 100% portland cement. The action of 5% condensed silica fume replacement for slag or pozzolan or material considered as inert has been studied from seven days to three months by measuring the mechanical strengths of mortars made according to ISO test method and by observing the microstructure of fractured samples. The action of the condensed silica fume is a function of the nature of the additive. With hydraulic slags, there is competition between slag and silica fume for the available lime. With slightly or slowly reactive pozzolans (volcanic rock, fly ash), mechanical strengths and microporosity of mortars show improvement at 28 days. With inert material (crystalline slag or quartz), the improvement is more marked. This is due to the formation of dense C–S–H, strong cement–paste–aggregate bond and 20% increase in mechanical strengths.

Keywords: *blended cements; bond (paste to aggregate); compressive strength; C–S–H; electron microscopes; fly ash; microstructure; mortars; pozzolans; silica; slags.*

Second CANMET/ACI International Conference on the Use of Fly Ash, Silica Fume, Slag and Natural Pozzolans in Concrete Madrid, Spain, April 1986

(Edited by V.M. Malhotra, ACI Special Publication SP–91.)

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12. Holland, T.C., Krysa, A., Luther, M.D. and Liu, T.C. "Use of silica fume concrete to repair abrasion–erosion damage in the kinzua dam stilling basin," Vol. 2, pp. 841–863.

The stilling basin of Kinzua Dam on the Allegheny River in western Pennsylvania has experienced severe abrasion–erosion damage since the structure was put into operation in 1967. The basin was repaired in 1973–74 using a steel fiber reinforced concrete overlay. Deterioration continued to the extent that repairs were again necessary in 1983. A laboratory program was undertaken to evaluate the abrasion–erosion resistance of several concrete mixtures proposed for the 1983 repairs. This program showed that high–strength concrete made with silica fume and limestone aggregates available near the project site would provide suitable abrasion–erosion resistance at a reasonable price. The Corps of Engineers, owner of the structure, required potential suppliers of silica fume to conduct full–sized placements to demonstrate that this concrete could be made and placed outside the laboratory. Based upon these demonstrations and the laboratory program, the repair concrete was specified with a compressive strength of 86 MPa (12 500 psi) at 28 days as a means of obtaining the required abrasion–erosion resistance. Approximately 1500 m^3 (2000 yd^3) of 250–mm (9¾–in.) slump concrete were placed using silica fume delivered as a slurry that included water–reducing admixtures. The average 28–day compressive strength was more than 90 MPa (13 000 psi). Diver inspection of the concrete after one year in service, including a period with a very large volume of debris in the stilling basin, indicated that the silica fume concrete is performing as intended.

Keywords: *abrasion resistance; admixtures; damage; dams; erosion; high–strength concretes; repairs; silica; stilling basins.*

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13. Jahren, P.A. "Performance of concrete incorporating condensed silica fume and super–plasticizers," Vol. 2, pp. 865–892.

This paper reports results from an ongoing research program on the use of condensed silica fume and superplasticizers in concrete. The program is being performed at different laboratories, and variations caused by the local conditions are reported. The major objective of the research program has been to establish influence charts for variable dosage rates of mineral and chemical admixtures under conditions that are as close to the field conditions as possible. The relative increases in compressive and bending strengths of concrete for various dosage rates of condensed silica fume and superplasticizer are presented. It is concluded that important admixtures such as silica fume and superplasticizers do not influence strength at a constant or linear ratio; the influence is more complex, and is governed by the variables involved.

Keywords: *admixtures; bending; compressive strength; concretes; performance; plasticizers; silica.*

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14. Sandvik, M. and Gjorv, O.E. "Effect of condensed silica fume on the strength development of concrete," Vol. 2, pp. 893–901.

The effect of condensed silica fume on the strength development in concrete was studied by replacement of 0, 5, 10 and 20% cement by silica fume. No admixtures were used. For all the mixes, about the same strength was obtained up to seven days. From then on, the mixes with silica fume produced an increased strength development compared to that of pure cement. At a partial replacement of cement by 20%, the compressive strength at 28 and 90 days was increased by 43 and 55%, respectively, over the strength at seven days.

Keywords: *age–strength relation; cement content; compressive strength; concretes; silica.*

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15. Tazawa, E. and Yonekura, A. "Drying shrinkage and creep of concrete with condensed silica fume," Vol. 2, pp. 903–921.

Drying shrinkage and creep of concrete with condensed silica fume are experimentally analyzed and compared with those of concrete without condensed silica fume. Specimens for drying–shrinkage and creep tests are manufactured by two kinds of curing methods, namely, standard and autoclave curing, and are measured in air at 20°C and 50% relative humidity. Some specimens are measured in water at 20°C. Measurements for volume change and weight change are continued for 800 days.

Within the scope of this research, the following conclusions may be drawn:

a. Drying shrinkage of concrete with condensed silica fume is lower than that of concrete without condensed silica fume at the same water/cement ratio. In the case of standard curing, the values of drying shrinkage per unit cement paste volume are roughly the same for both concretes with and without condensed silica fume at the same compressive strength; however, in the case of autoclave curing, the values are higher for concrete with condensed silica fume at the same compressive strength.

b. Creep in air is high for concrete with condensed silica fume in both cases of standard curing and autoclave curing. Creep in water is high for concrete with condensed silica fume in the case of standard curing, but low in the case of autoclave curing.

Keywords: *autoclaving; concretes; creep properties; curing; drying shrinkage; high–strength concretes; silica.*

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16. Maage, M. "Strength and heat development in concrete: influence of fly ash and condensed silica fume," Vol. 2, pp. 923–940.

To reduce energy, save raw materials and improve mechanical properties, different pozzolans are now commonly used in cement and concrete production. A comprehensive research program was undertaken to study the influence of different combinations of fly ash and condensed silica fume on cement and concrete properties. This paper presents their influence on strength and heat development. The program included an ordinary portland cement and two blended cements containing 10 and 25% fly ash. The three cements were combined with 0, 5 and 10% condensed silica fume. Curing temperatures were 5, 20 and 35°C.

Condensed silica fume is very finely graded and the content of amorphous SiO_2 is very high. Therefore, the pozzolana reaction started early, after about seven days at 20°C and two days at 35°C. At 5°C, no pozzolana reaction was observed for the first 28 days. The pozzolana reaction from fly ash was found to be slower than that from condensed silica fume, probably because of the coarser grinding and lower SiO_2 content of fly ash. The compressive strength results indicated that the pozzolana reaction was more sensitive to the temperature than the reaction involving cement hydration alone. The slow strength development of concrete when using fly ash in blended cements can be avoided by grinding the cements to a higher fineness. The effect on strength development when using condensed silica fume was approximately the same in all three types of cement investigated. The heat development was higher in pure portland cement than in blended cements. However, the heat development increased when adding condensed silica fume. Maturity functions were found to be valid up to maturities corresponding to curing in 20°C for approximately two days.

Keywords: *age–strength relation; blended cements; compressive strength; concretes; curing; fly ash; heat of hydration; silica; temperature.*

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17. Robins, P.J. and Austin, S.A. "Bond of lightweight aggregate concrete incorporating condensed silica fume," Vol. 2, pp. 941–958.

Condensed silica fume at up to 30% by weight was used as a partial cement replacement in lightweight aggregate concrete. The results of round and deformed bar cube pullout tests, with and without applied lateral stress, show that condensed silica fume increases ultimate bond strength and affects the mechanism of failure.. The influence of condensed silica fume on bond stress of round bars was similar at all lateral stresses, producing a 50% increase at 20% by weight replacement of cement. For deformed bars the increase in bond strength was more pronounced at higher levels of lateral stress, producing increases approaching 70% at 20% silica fume content. The improvements in ultimate bond strength with condensed silica fume are shown to be only partially a result of associated increases in compressive strength, and more a result of the modified properties of the concrete matrix.

Keywords: *bond (concrete to reinforcement); bond stress; cement content; deformed reinforcement; lateral pressure; lightweight aggregate concrete; plasticizers; pullout tests; reinforcing steels; silica; stresses.*

18. Buil, M., Witier, P., de Larrard, F., Detrez, M. and Paillere, A.M. "Physicochemical mechanism of the action of the naphthalene sulfonate based superplasticizers on silica fume concretes," Vol. 2, pp. 959–971.

The adsorption of a naphthalene–sulfonate–formaldehyde superplasticizer on the surface of a silica fume has been studied by adsorption isotherms and zeta potential measurements. A model is proposed for the fixation of naphthalene sulfonate formaldehyde on a silica fume surface in the presence of cement, which can explain the high efficiency of this type of superplasticizer on the portland cement, silica fume, water system. The rheological efficiencies of several silica fumes have been evaluated by the determination of the water content of one fresh silica fume mortar composition at a constant workability. A hypothesis is suggested for explaining the higher water demands by the five silicon or ferro–silicon silica fumes tested in this study, compared to a zirconia silica fume.

Keywords: *adsorption; mortars (material); naphthalene sulfonate; plasticizers; silica; workability; zeta potential.*

19. Feldman, R.F. "Influence of condensed silica fume and sand/cement ratio on pore structure and frost resistance of portland cement mortars," Vol. 2, pp. 973–989.

Pore–structure changes in silica fume portland cement blend mortars fabricated with 0, 10 and 30% silica fume at a water/binder ratio of 0.60 and a sand/cement ratio of 2.25 have been monitored by mercury porosimetry while being cured for 1 to 180 days. The threshold value for pore intrusion increases with pore size and becomes less abrupt with silica fume addition; it is in the 0.5 to 20 by 10^3 nm region.

Mortars were also made with and without 10% silica fume at a water/cement ratio of 0.60 and sand/cement ratios of 0, 1.0, 1.5, 1.8, 2.0, 2.25 and 3.0; the sand passed ASTM C 109. Mercury intrusion measurements were carried out after 14 days of curing. In the presence of silica fume, pore volume in the 0.5 to 20 by 10^3 nm pore diameter range increased with sand/cement ratio. Mortar prisms were subjected to freezing–and–thawing cycles (two cycles in 24 h) according to ASTM standard test method C 666, Procedure B. Freezing–and–thawing resistance was monitored by measuring changes in residual length and weight. Results indicate that if the sand/cement ratio is 2.25 or more, expansion is less than 0.02% after 500 cycles. At lower sand/cement ratios, 10% silica fume gives little protection.

Keywords: *cements; freeze–thaw durability; mortars (material); porosity; portland cements; sands; silica.*

20. Gautefall, O. "Effect of condensed silica fume on the diffusion of chlorides through hardened cement paste," Vol. 2, pp. 991–997.

This report presents the results of the diffusivity of chloride ions in hardened cement paste. The experiments were carried out at 20°C and both ordinary portland cement and blended cement with 10% fly ash were investigated. Other experimental variables were water/(cement + silica fume) ratios of 0.5, 0.7 and 0.9. The condensed silica fume was used as a cement replacement, the replacement levels being 5, 10 and 15% by weight of cement.

Keywords: *cement content; cement pastes; chlorides; diffusivity; fly ash; hardened paste structure; silica; water/cement ratio.*

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21. Kawamura, M., Takemoto, K. and Hasaba, S. "Effect of silica fume on alkali–silica expansion in mortars," Vol. 2, pp. 999–1012.

The expansion of mortars containing up to 10% silica fume by weight of cement was about three times as great as that of the additive–free mortar. Concentrations of calcium and alkalis within opal grains in the silica fume mortars were determined by energy dispersive X–ray analysis (EDXA). The intrusion of smaller amounts of calcium into opal grains in the mortars at early ages seems to show that the conversion of alkali–silica gels into sols was delayed by the presence of silica fume. The delay of this conversion was also confirmed by microhardness measurements.

Keywords: *alkali content; expansion; microhardness; mortars (material); opal; silica; silica gel; X–ray analysis.*

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22. Carlsson, M., Hope, R. and Pedersen, J. "Use of condensed silica fume (CSF) in concrete," Vol. 2, pp. 1013–1030.

Although condensed silica fume is used mostly for increasing concrete strength, it also confers other advantages, such as improved durability–related properties. In the manufacture of concrete pipes, the addition of condensed silica fume is shown to increase the external load–bearing capacity of the pipes by 40%. The resistance of the pipes against chemical attack is also increased considerably. Concrete pipes containing only about 5% condensed silica fume have two to three times longer service life, when exposed to sulfates, than ordinary pipes.

Concrete containing condensed silica fume is known to have improved resistance to freezing–thawing attack, chloride penetration and deicer scaling, making it useful for road construction. The addition of condensed silica fume, especially at higher dosages, also increases the abrasion resistance of concrete. For instance, a 20% dosage of Corrocem, a proprietary admixture with condensed silica fume as a key component, shows 30 to 35% higher abrasion resistance, compared to a good quality concrete.

Because of the reduced permeability and lower free lime content in the cement paste, the condensed silica fume concrete is considered to have a high resistance to chemicals. For Corrocem concrete, a considerably increased service life is obtained in aggressive environments. Such concrete exposed to saturated ammonium nitrate solution shows a weight loss of about 0.5% after 150 weeks exposure compared with a loss of 15% after 100 weeks for a plain concrete. The strength of the admixtured concrete is about 70 to 75 MPa after 163 weeks and about 30 MPa after 21 weeks for the plain concrete after exposure to nitrate solutions. A similar trend was obtained for specimens exposed to saturated calcium nitrate.

Keywords: *abrasion resistance; admixtures; chemical attack; concrete durability; concrete pipes; flexural strength; resurfacing; silica.*

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23. Skjolsvold, O. "Carbonation depths of concrete with and without condensed silica fume," Vol. 2, pp. 1031–1048.

Cores were drilled from 16 structures of concrete with silica fume and 11 structures of concrete without silica fume (ordinary portland cement concrete). The nominal strength of the concretes was 25 MPa. Testing was done at different periods. Carbonation depths were corrected to 60 months and 33 MPa. The mean corrected carbonation depth for all structures of silica fume concrete was 11.6 mm. The corresponding value was 8.8 mm for ordinary portland cement. However, the dispersion in the results was too high to make conclusions. The standard deviations were 5.9 mm and 2.4 mm for silica fume concrete and ordinary portland cement concrete, respectively. Considering statistical variations in carbonation depths and concrete cover over the reinforcement, the observed carbonation depths indicate an initiation period for corrosion as short as two to three years for both types of concrete at the stated strength level. This initiation period is very short.

Carbonation depths were also measured on beams and slabs that were cured under different curing conditions. Curing conditions had a significant effect. The rate of carbonation was proportional to the water/cement ratio. Therefore the compressive strength is an unreliable parameter by which to judge the quality of concrete containing condensed silica fume.

Keywords: *beams (supports); carbonation; concrete cores; concrete slabs; permeability; reinforced concrete; silica; strength; water/cement ratio.*

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24. Nagataki, S. and Ujike, I. "Air permeability of concretes mixed with fly ash and condensed silica fume," Vol. 2, pp. 1049–1068.

The objective of this study was to investigate the behavior of air flow through concrete and to clarify the effects of fly ash and condensed silica fume on the air permeability of concrete. The air permeability of concrete was estimated by means of the coefficient of air permeability, and the difference in this coefficient among concretes with fly ash, without fly ash and with condensed silica fume was investigated. Furthermore, the improvement of the airtightness of concretes with fly ash and condensed silica fume was discussed from the view point of the internal structure of concrete such as porosity.

The results of this study confirmed that the flow of air through concrete obeyed Darcy's law. It is possible to apply the coefficient of air permeability as the index of air permeability of concrete. The coefficient of air permeability of concrete with fly ash, cured in water for a period of 28 days, was almost the same as that of concrete without fly ash, when compared at the same level of compressive strength. However, the concrete with fly ash, cured in water for a period of 91 days, is more airtight than concrete without fly ash. The coefficient of air permeability of concrete with condensed silica fume decreased with the increase of replacement ratio of condensed silica fume, and did not depend on the period of curing in water. These results can be quantitatively understood by means of the internal structure of concrete.

Keywords: *air; concretes; Darcy's law; drying; fly ash; permeability; porosity; silica.*

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25. Malhotra, V.M. "Mechanical properties, and freezing-and-thawing resistance of non-air-entrained and air-entrained condensed silica-fume concrete using ASTM Test C 666, procedures A and B," Vol. 2, pp. 1069–1094.

This report presents the results of a study dealing with the resistance to repeated cycles of freezing and thawing of non-air-entrained and air-entrained condensed silica fume concrete when tested in accordance with ASTM C 666, Procedures A and B. A total of 22 air-entrained and non-air-entrained concrete mixtures, 0.06 m^3 in size, were made. The water/(cement + silica fume) ratio of the mixtures ranged from 0.40 to 0.60, and the percentages of cement replacement by condensed silica fume were 0, 5, 10, 15 and 30% by weight. Any loss in slump due to the use of condensed silica fume was compensated for by the use of a superplasticizer.

A number of test cylinders were made for testing in compression at various ages. Test prisms were cast to determine their resistance to repeated cycles of freezing and thawing in accordance with ASTM C 666, Procedures A and B. Sawn sections of the test prisms were used for determining the air-void parameters of the hardened concrete.

Based upon the analysis of the test data, it is concluded that the use of non-air-entrained condensed silica fume concrete is not recommended when it is to be subjected to repeated cycles of freezing and thawing. Furthermore, the users of condensed silica fume are cautioned against using high percentages of the material as a replacement for portland cement in concretes with a water/(cement + silica fume) ratio of about 0.40 if these concretes are to be exposed to repeated cycles of freezing and thawing.

Keywords: *air-entrained concretes; air entrainment; concretes; freeze-thaw durability; plasticizers; silica; water/cement ratio.*

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26. Yamato, T., Emoto, Y. and Soeda, M. "Strength and freezing-and-thawing resistance of concrete incorporating condensed silica fume," Vol. 2, pp. 1095–1117.

This report gives results of laboratory investigations to determine the strength characteristics and the pore size distributions of mortar and concrete incorporating condensed silica fume from a Japanese source. This report also gives results for the shrinkage, permeability and freezing-and-thawing resistance of concrete incorporating silica fume.

A series of mortar mixes was made with a water/(cement + silica fume) ratio of 0.65, and with the percentage of silica fume used as partial replacement for normal portland cement being 0, 5, 10, 20 and 30% by weight. A total of 23 concrete mixes were made with the water/(cement + silica fume) ratio ranging from 0.25 to 0.55, and with the percentage of silica fume used as partial replacement for cement being 0, 5, 10, 20 and 30% by weight. None of the mixes were air-entrained except the mix with a water/(cement + silica fume) ratio of 0.55, which was air-entrained. A superplasticizer was used for all the mixes incorporating condensed silica fume.

Condensed silica fume improved the compressive strength of the mortar and the concrete at 28 and 91 days as well as the impermeability of the concrete. The drying shrinkage of the condensed silica fume concrete was comparable to that of the control concrete without silica fume. Non-air-entrained silica fume concretes with water/(cement + silica fume) ratios of 0.35, 0.45 and 0.55 showed low durability factors, although the air-entrained concrete with a water/(cement + silica fume) ratio of 0.25 performed satisfactorily under repeated cycles of freezing and thawing. The air–entrained concrete incorporating 20 and 30% silica fume with a water/(cement + silica fume) ratio of 0.55 showed very poor durability as compared with the control concrete.

Keywords: *air entrainment; compressive strength; concretes; drying shrinkage; flexural strength; freeze–thaw durability; mortars (material); permeability; porosity; pozzolans; silica.*

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27. Marusin, S.L. "Chloride ion penetration in conventional concrete and concrete containing silica fume," Vol. 2, pp. 1119–1133.

The purpose of this work was to determine the chloride ion content distribution profile through 10–cm concrete cubes made from conventional portland cement concrete and concretes containing condensed silica fume. The conventional portland cement concrete and four concretes containing condensed silica fume were prepared and tested using a test procedure developed at Wiss, Janney, Elstner Associates, Inc. The chloride ion penetration characteristics were studied on 10–cm concrete cubes, which were immersed in 15% NaCl solution for 21 days. Following the 21–day soaking period and a subsequent 21–day air–drying period, concrete powder samples were removed by drilling at depth intervals of 0 to 12 mm, 12 to 25 mm, 25 to 37 mm and 37 to 50 mm, and tested for acid–soluble chloride ion content using a potentiometric titration procedure.

The test results showed that both weight gain and chloride ion penetration are reduced by concretes containing condensed silica fume. The best performance for both reductions, at all tested depths, was shown by concrete containing 10% condensed silica fume. The chloride ion content at a depth of 12 to 25 mm reached the acid–soluble corrosion threshold level of about 0.03% by weight of concrete (as normally assumed for reinforced concrete) and was lower than this criterion below the depth of 25 mm.

Keywords: *chlorides; concretes; cubes; penetration; portland cements; silica; tests; weight measurement.*

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28. Radjy, F.F., Bogen, T., Sellevold, E.J. and Loeland, K.E. "A review of experiences with condensed silica–fume concretes and products," Vol. 2, pp. 1135–1152.

Extensive technical work has established that high–performance concrete and cementitious materials can be proportioned practically and economically by using condensed silica fume additives. These hybrid chemical/mineral admixtures can be utilized for applications ranging from bridge overlays, concrete roof tiles and fiber reinforced cements to structural uses, both on land and offshore.

The first significant applications of condensed silica fume additives began some 10 years ago in Norway, with cement replacement as the main benefit. Although cement replacement continues to be the main end use in the Scandinavian markets, performance enhancement of cementitious and concrete applications is the dominant attraction for users outside Scandinavia.

After a brief consideration of the history, a range of durability and high–strength applications is reviewed. It is shown that this range of varied applications is generally driven by particular features of performance enhancement.

Keywords: *admixtures; cement content; concrete durability; performance; precast concrete; prestressed concrete; reinforced concrete; reviews; silica.*

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29. Burge, T.A. "Fiber reinforced high–strength shotcrete with condensed silica fume," Vol. 2, pp. 1153–1170.

Today's advanced techniques in tunnelling and gallery engineering call for high–quality shotcrete, i.e., a material that develops accelerated set and high early strength to suit the safety requirements in the heading phase, and also final strength requirements for the preliminary concrete lining (New Austrian Tunnelling Method, NATM).

High early strength can be obtained with the addition of an accelerator to the shotcrete mixture. Many materials are known to accelerate the setting time of shotcrete, including strongly alkaline reacting materials such as alkali metal hydroxides, alkali metal carbonates, alkali metal aluminates and alkaline earth chlorides. The adverse effects of these admixtures are also known. With the development of an efficient alkali–free shotcrete accelerator, it has become possible to produce high early strength without undesirable effects on the final strength.

There is a long history of attempts to influence positively the fracture characteristics of cement mortars or concrete using fibers. Although organic fibers were soon discarded, great efforts are still being undertaken with glass and steel fibers. Problems in the processing of steel fiber reinforced shotcrete led to the introduction of a new type of fiber.

The addition of condensed silica fume increased the strengths and sharply reduced the permeability. The resistance to freezing and thawing was also greatly improved. No long–term strength loss was obtained owing to the use of a new alkali–free setting accelerator.

Keywords: *accelerating agents; deflection; fiber reinforced concretes; freeze–thaw durability; high–strength concretes; metal fibers; modulus of elasticity; permeability; shotcrete; silica.*

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30. Ohama, Y. and Demura, K. "Process technology and properties of super–high–strength concrete made by polymer impregnation of silica–fume concrete," Vol. 2, pp. 1171–1184.

This paper deals with a basic investigation of the process technology and properties of super–high–strength concrete, which is made by applying a polymer impregnation technique to silica fume concrete. The main purpose of this investigation is to find appropriate process conditions for developing the super–high–strength concrete. Silica fume concrete is prepared using fine aggregates, such as river sand and calcined bauxite, and a polyalkylaryl–sulfonate–type water–reducing agent, and curing in an autoclave. The cured silica fume concrete is dried at various temperatures, and impregnated with polymethyl methacrylate by thermal polymerization in hot water. The strength properties and pore size distribution of the super–high–strength concrete and the silica–fume concrete are tested. The effects of drying temperature and pore size distribution of the silica fume concrete on the compressive strength of the super–high–strength concrete are discussed. It is concluded from the test results that a super–high–strength concrete having a compressive strength of 225 to 255 MPa is obtained by the above process.

Keywords: *autoclaving; bauxite; compressive strength; high–strength concretes; impregnating; polymerization; polymethyl methacrylate; porosity; silica; voids; water–reducing agents.*

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31. Kakizaki, M., Okamoto, K. and Takano, T. "Study of cast-in-place high-strength concrete made with silica fume, alumina-type mineral, and fly ash," Vol. 2, pp. 1185–1214.

Three kinds of inorganic mineral admixtures (silica fume, alumina-type mineral and fly ash) were mixed with cement and aggregates, having a low water/(cement + condensed admixture) ratio, using a high-range water-reducing agent. This study clarified both the properties of fresh concrete and adequate concrete mix proportions. This test was made by dividing eight factors and three levels among the orthogonal array of L_{27} based on test plan method. The main conclusions are as follows:

a. The flowability of fly ash concrete and alumina-type mineral concrete is increased with the increase in dosage of admixture, whereas that of silica fume concrete is decreased.

b. So that concrete slump with various admixtures may obtain the same flowability as a slump of 18 cm (for concrete without admixture), at a certain dosage of admixture (X1.6), the slump value is about 21 cm with silica fume concrete, about 6 cm with fly ash concrete and about 16 cm with alumina-type mineral concrete.

c. Fly ash concrete and alumina-type mineral concrete show more segregation of aggregates, whereas silica fume concrete shows less, with the passage of time.

d. Unit water content for all cements and aggregates can be determined by ordinary mix proportioning.

e. Air-entraining agent content required to get a particular air content increases with the increase in the amount of mineral admixture and superplasticizer.

Keywords: *admixtures; air-entraining agents; aluminum oxide; concretes; consistency tests; fly ash; high-strength concretes; mineral admixtures; mix proportioning; plasticizers; silica; slump tests; temperature; water content; workability.*

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32. Balaguru, P. and Kendzulak, J. "Flexural behaviour of slurry infiltrated fiber concrete (SIFCON) made using condensed silica fume," Vol. 2, pp. 1215–1229.

This paper presents the results of an experimental investigation on the behaviour of slurry infiltrated fiber concrete (SIFCON) prisms (beams) subjected to static and cyclic flexural loading. A total of 60 prism specimens were tested. The main objective of this investigation was to study the influence of fiber length, fiber volume and silica fume on the strength and ductility of SIFCON under static and cyclic flexural loading. The fibers used were steel fibers with hooked ends. The volume content of fibers varied from 4 to 12%. The fiber lengths were 30, 40, 50 and 60 mm. The slurry was made with and without silica fume. A high-range water reducing admixture (superplasticizer) was used to obtain a flowing slurry. The water/cement ratio was maintained at 0.30. The cube strength of slurry with silica fume averaged 10.36 ksi (71.43 MPa). The slurry without silica fume had an average cube strength of 7.86 ksi (54.20 MPa). The results of this investigation indicate that a very high flexural strength, about 10 ksi (69 MPa), can be obtained using SIFCON. The prisms are extremely ductile, both under static and cyclic loading. The addition of silica fume increases the flexural strength. The percentage (magnitude) increase is the same as the increase in the compressive strength of the slurry. Silica fume has no noticeable effect on the ductility of the beams.

Keywords: *cyclic loads; fiber reinforced concretes; flexural strength; metal fibers; plasticizers; prisms; silica; slurries; static loads.*

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33. Domone, P.L. and Tank, S.B. "Use of condensed silica fume in portland cement grouts," Vol. 2, pp. 1231–1260.

The effects of the partial replacement of portland cement in grouts with condensed silica fume were studied. Initial experiments examined the fluid properties of fresh grouts, using concentric cylinder viscometry. An effective mixing procedure using a high–shear mixer was developed. Replacements of up to 20% of the cement by silica fume, using water/solids ratios ranging from 0.3 to 0.6, were examined. Two commercially available superplasticizers were used: a sulfonated melamine and a sulfonated naphthalene formaldehyde. To maintain fluidity the admixture dosage must be increased in approximately the same proportion as the silica fume content.

The grouts are thixotropic and more stable than plain ordinary portland cement grouts. The silica fume leads to an enhanced alite peak in the rate of heat output during hydration, but the use of the superplasticizer leads to a masking of changes of the time to the peak.

Compressive strength at one day and from three days onwards is increased by incorporating condensed silica fume, with greater proportional effects being obtained at higher water/solids ratios. Dynamic elastic modulus values do not show the same increase, and for equal strengths, grouts containing condensed silica fume are less stiff.

Keywords: *cement content; compressive strength; dynamic modulus of elasticity; grouts; heat of hydration; mixing; plasticizers; rheological properties; silica; viscosity; water/cement ratio.*

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34. Wakeley, L.D. and Buck, A.D. "Effects of different fly ashes and silica fume on selected properties of an expansive grout," Vol. 2, pp. 1261–1278.

An expansive grout, based on Class H cement, an expansive admixture consisting essentially of plaster of paris (calcium sulfate hemihydrate), and a Class C fly ash, was proportioned for use underground. Specimens of this grout and of five modified versions of it were tested to determine the effects of using two other fly ashes, with and without silica fume, on compressive strength, volume change, phase composition and microstructure. Properties were monitored to 960–days age.

Up to 365–days age, specimens of the mixture modified with Class F fly ash had lower compressive strengths and generally more expansion than did those of the original composition. At ages of 90 days and greater, the same was true of samples prepared with a second Class C fly ash. Substitution of silica fume for 5 or 10% of the cement gave higher early strengths, and the combination of the second Class C fly ash and 10% silica fume gave the lowest strengths at ages of 90 days and greater. Despite the substitutions, properties were markedly similar: compressive strength from all modifications exceeded 90 MPa at 365 days, and phase composition and microstructures became more similar with time.

Keywords: *compressive strength; expanding agents; expansion; fly ash; grouts; microstructure; permeability; silica; X–ray diffraction.*

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35. Kohno, K. and Komatsu, H. "Use of ground bottom ash and silica fume in mortar and concrete", Vol. 2, pp. 1279–1292.

This paper describes an investigation of the use of industrial by–products, such as bottom ash and silica fume with high silica content, as the admixture for mortar and concrete. The bottom ash used for this investigation was ground in a ball mill. At first, basic tests using mortars were conducted. Subsequently, the concretes containing different proportions of the two by–products were tested for strength development, under accelerated curing conditions, as well as for drying shrinkage and water permeability.

The results of the mortar strength tests indicate that the optimum amount of ground bottom ash is about 5% if used to replace cement and 10% if used in addition to cement, and the optimum amount of silica fume is about 5 to 10% if used to replace cement and 10 to 15% if used in addition to cement. When steam curing and autoclave curing are used, the concretes containing ground bottom ash and silica fume have higher early compressive strengths than concrete without these materials. The coefficients of water permeability of the concretes using ground bottom ash and silica fume are lower than those of concrete without these materials. The watertightness of silica fume concrete improved remarkably, although the concrete has a slightly higher drying shrinkage in comparison with concrete without silica fume. The use of these materials in amounts of 5 to 10% to replace cement improves concrete properties.

Keywords: *accelerated curing; ashes; autoclaving; compressive strength; curing; drying shrinkage; flexural strength; mix proportioning; permeability; silica; steam curing; tensile strength.*

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(Edited by J.M. Scanlon, ACI Special Publication SP–100.)

36. Roberts–Seymour, M. "The effect of high range water reducing admixtures on some durability parameters of silica fume portland cement concretes," Vol. 1, pp. 577–585.

The author presents three experimental programs employing high–range, water–reducing admixtures to modify durability performance in portland cement silica fume concrete. Resistivity and chloride permeability are shown to be significantly improved where fume–replaced concrete utilizes a superplasticizer. Superplasticizing has some demonstrated drawbacks where silica fume is introduced to reduce alkali–aggregate reactions.

Keywords: *alkali–aggregate reactions; chlorides; concrete durability; corrosion; electrical resistance; permeability; plasticizers; silica; water–reducing agents.*

37. Marusin, S.L. "Improvement of concrete durability against intrusion of chloride–laden water by using sealers, coatings and various admixtures," Vol. 1, pp. 599–619.

This paper summarizes the research that has been undertaken by Wiss, Janney, Elstner Associates, Inc. since 1979 on sealers, coatings and concrete containing admixtures. The research used a test procedure developed during the National Cooperative Highway Research Program (NCHRP) Project 12–19A, "Concrete Sealers for Protection of Bridge Structures," which was reported in 1981 in the NCHRP Report No. 244. This test method uses 10–cm cube specimens and water absorption; chloride ion penetration is determined after 21 days exposure to 15% NaCl solution. The study focusses on the minimization of the ingress of chloride–laden water into concrete, the influence of water/cement ratio, the relationship between water absorption and chloride ion content in concrete, and the comparison of the chloride distribution profiles through the conventional portland cement concrete and concrete containing various admixtures (superplasticizers, polymer emulsions, condensed silica fume).

Keywords: *admixtures; chlorides; coatings; concrete durability; plasticizers; sealers; silica; tests.*

38. Pigeon, M., Perraton, D. and Pleau, R. "Scaling tests of silica fume concrete and the critical spacing factor concept," Vol. 2, pp. 1155–1182.

ASTM C 672 scaling tests were carried out on concretes containing 0, 5 and 10% silica fume, and with air–void spacing factors in the 100 to 200–μm range. Two methods of curing were compared: seven days in water and the use of a curing compound. Water containing 2.5% sodium chloride was used for the scaling tests, as well as pure water. Results indicate that although scaling tends to increase with the silica fume content, silica fume concrete can have a fair scaling resistance. Results also show that specimens cured in water, regardless of the silica fume content, have a lower resistance to scaling than specimens cured with a membrane. Considering previously published data by two of the authors, results further show that the critical air–void spacing factors obtained from ASTM C 666 (Procedure A) freeze–thaw cycle tests are not applicable to scaling. Spacing factors required for good scaling resistance are generally lower than those required for freeze–thaw durability, and total protection against scaling does not seem possible. A short review of the literature confirms that critical spacing factors are usually higher than 200 μm.

Keywords: *air–entrained concretes; concrete durability; curing; deicers; freeze–thaw durability; scaling; silica; tests.*

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39. Johnston, C. "Effects of microsilica and class C fly ash on resistance of concrete to rapid freezing and thawing and scaling in the presence of deicing agents," Vol. 2, pp. 1183–1204.

The freeze–thaw durability of concretes containing up to 42% Class C fly ash or 15% microsilica by weight of cement with ratios of water to cementitious material of 0.53 to 0.88 is examined to establish the extent to which such relatively lean mixtures can yield good durability along with the satisfactory levels of strength already known to be achievable, particularly with microsilica. The results show that while the inclusion of fly ash or microsilica does not detract from performance in rapid freezing and thawing (Procedure A of ASTM C 666), performance with respect to scaling (ASTM C 672) may not be satisfactory, even with an apparently adequate air–void spacing factor. When spacing factors are adequate, the 300–cycle durability factors consistently exceed 85%, even for the leanest mixtures, while scaling of some of the mixtures with fly ash or microsilica is severe. Concretes with microsilica can be durable in both ASTM C 666 and C 672 at water/(cement + silica fume) ratios up to a limit of 0.70, where strengths of 25 MPa at 28 days can be reached with as little as 225 kg/m^3 of cement. For concretes with Class C fly ash, the corresponding limit for water/(cement + fly ash) ratios appears to be no higher than the 0.45 recommended for normal concrete when exposed to deicing agents.

Keywords: *air–entrained concretes; concrete durability; deicers; fly ash; freeze–thaw durability; reviews; scaling; silica; tests.*

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40. Kawamura, M., Takemoto, K. and Hasaba, S. "Effectiveness of various silica fumes in preventing alkali–silica expansion," Vol. 2, pp. 1809–1819.

The effect of various silica fumes on expansion of mortars containing Beltane opal was investigated, with a view to using silica fume as a pozzolanic material for inhibiting alkali–silica expansion. Different silica fumes were found to vary widely in their effect on the expansion of mortars. The properties of silica fume affecting alkali–silica expansion were explored. Pozzolanic activity of silica fumes was evaluated by measuring the amounts of calcium hydroxide consumed by pozzolanic reaction in silica fume–bearing cement pastes. The amounts of calcium hydroxide in portland cement silica fume mixtures were determined by DSC–TG analysis. Pore solutions obtained from mortars containing three different silica fumes were also analyzed. The silica fume with the highest pozzolanic activity was the most effective in reducing alkali–silica expansion of mortars. However, it was found that reduction in expansion by the addition of silica fume was not necessarily in line with the amount of calcium hydroxide consumed as a whole. Although the concentrations of alkalis and OH^- ions in the pore solutions in mortars were reduced to the same level by the addition of three different silica fumes, the reductions in expansions of the three silica fume-bearing mortars were greatly different from one another.

Keywords: *alkali–aggregate reactions; calcium hydroxide; chemical analysis; expansion; mortars (material); pozzolans; silica; tests.*

41. Buck, A.D. "Use of cementitious materials other than portland cement," Vol. 2, pp. 1863–1881.

Different amounts of fly ash, silica fume, or ground granulated iron blast–furnace slag have been used with portland cement in an effort to prevent excessive expansion due to alkali–silica reaction or sulfate attack or both. The test methods used to establish optimum proportions were ASTM C 441 and ASTM C 1012. Once the optimum proportions were known, concrete mixtures were made and tested.

Keywords: *alkali–aggregate reactions; blast–furnace slag; concretes; evaluation; expansion; fly ash; mortars (material); portland cements; silica; sulfate attack; tests.*

AUTHOR INDEX

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