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Effect of Micro-Silica on Mechanical Properties of Concrete

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Abstract: Global warming and environmental destruction have become manifest problems in recent years, heighten concern about global environmental issues, and a change over from the mass-production, mass-consumption, mass-waste society of the past to a zero-emission society is now viewed as important. Preventing the exhaustion of natural resources and enhancing the usage of waste materials has become a significant problem of the modern world.

To study the effect of partial replacement of cement by silica fume (micro-silica), studies have been conducted on concrete mixes for M40 grade at 0%, 3%, 6%, 9%, 12% & 15% replacement levels of micro-silica. Properties of hardened concrete such as Compressive strength, Split Tensile strength, Flexural strength, Capillary absorption (Durability) have been assessed, analyzed & represented graphically. Eventually, based on comparisons and interpretations, conclusions have been drawn.

Key words: Micro-silica, high performance concrete, pozzolana, super-plasticizer, durability, compressive strength, split Tensile strength, flexural strength, capillary absorption.

1. Introduction

Concrete is the most versatile construction material because it can be designed to withstand the harshest environments while taking on the most inspirational forms. Engineers are continually pushing the limits to improve its performance with the help of innovative chemical admixture and supplementary cementitious materials (SCMs).

In recent years significant attention has been given to the use of the pozzolan silica fume as a property-enhancing material, as a partial replacement for portland cement, or both. Silica fume has also been referred to as silica dust, condensed silica fume or micro-silica.

The initial interest in the use of silica fume was mainly caused by the strict enforcement of air-pollution control measures in various countries to stop release of the material into the atmosphere.

More recently, the availability of high range water-reducing admixtures (HRWRA) has opened up new possibilities for the use of silica fume as part of the cementing material in concrete to produce very high strengths or very high levels of durability or both. Fly ash (a waste product from coal thermal power plant), ground granulated blast furnace slag, silica fumes (a waste by-product of the manufacture of Silicon or Ferro-silicon alloys from high purity quartz and coal in a submerged-arc electric furnace), rice husk ash (waste by-product from co-generation electric power plant burning rice husk), high reactive meta-kaoline (HRM) as partial replacement for cement which are largely available in India.

To study the effect of partial replacement of cement by silica fume (micro-silica), studies have been conducted on concrete mixes for M40 grade at 0%, 3%, 6%, 9%, 12% & 15% replacement levels of micro-silica. Properties of hardened concrete such as Compressive strength, Split

Tensile strength, Flexural strength, Capillary absorption (Durability) have been assessed.

Silica fume is a byproduct in the reduction of high-purity quartz with coke in electric arc furnaces in the production of silicon and ferrosilicon alloys. Silica fume consists of fine particles with a surface area of 20,000 m²/kg when, measured by nitrogen adsorption techniques, with particles approximately one hundredth the size of the average cement Because of its extreme fineness and high silica content, silica fume is a very effective pozzolanic material particle.

Properties of Micro-Silica:

Chemical compositions of silica fume in %:

SiO_2	93
Al_2O_3	0.4
CaO	1.2
Fe_2O_3	0.2
MgO	1.2
Na_2O	0.1
K_2O	1.1
S_O3	0.3

Chemical Requirements:
As per IS-15388

SiO2 minimum %	85.0
Moisture content max %	3.0
Loss on ignition max %	4.0
Alkalies as Na_2O max %	1.5

The effect of silica fume can be explained by two mechanism i.e pozzolanic reaction and micro filler effect.
The first product is calciumsilicate-hydrate (C-S-H) gel, that is cementitious and binds the aggregate together in concrete and Ca(OH)2 The C-S-H formed by the reaction between micro-silica and the product Ca(OH)2 which comprises 25% of volume of hydration product.

Silica fume reacts with calcium hydroxide to produce more aggregate binding C-S-H gel, simultaneously reducing Ca(OH)2. The net result is increase in strength and durability. The second mechanism is through the micro filler effect. The extreme fineness of silica fume allows it to fill or pack the microscopic voids.

2. Materials used

SILICA FUME (MICRO-SILICA):
AC- GEL FILL

Test Performed	*Test Results*	*Requirement Reference*
Physical State	Silver Grey Powder	Silver Grey Powder
Dry Material Content	99.98%	100%
% Retained on 45 µ Sieve	4 µ	< 10 µ
Compatibility	Compatible	Required Compatibility With OPC & PPC

Oversize percent retained on 45 µ (No. 325) sieve = 2 % < 5% (hence, ok)
Specific Gravity = 1.4
(using gravity bottle)

AC- GEL FILL conforms to ASTM-C-1240-03, IS 15388-2003 & European standards. AC- GEL FILL is best recommended for use in Self-Compacting Concrete & High Strength Grouts.

SUPER-PLASTICIZER:
AC- GREEN SLUMP

AC-GREEN SLUMP is formulated to give water reduction of 20 % and above. As a guide, the rate of addition is generally in the range of 1.0 to 2.0 kg per 100 kg of cement.
AC- GREEN SLUMP-GS-02B is designed on Polycarboxylate ester polymer base.

The product has got an ability to give outstanding results for almost all grades of concrete.

Test Performed	*Test Results*	*Requirement Reference*
Ph Value	7.64	> 6
Specific Gravity	1.20	Within 0.02 % of the value stated by the manufacturer
Dry Material Content	36.54	Within 5 % of the value stated by the manufacturer
Physical State	Brown Liquid	Brown Liquid
Chloride Content	Nil	Below 0.1 %
Storage & Shelf life	Max. Storage life is 365 days	---

Other Materials:

Other materials used in the concrete mixture were Portland cement, coarse aggregate of 20 mm maximum size and sand of 5 mm maximum size as fine aggregate conforming to Indian Standards recommendations. All the prescribed material tests were performed as specified.

Mix Proportion:
Grade of Concrete: M-40

Water : Cement : F.A : C.A :-
0.35 : 1.0 : 1.812 : 3.085

Super-plasticizer: 1-2 kg /100 kg of cement

Increase in the volume of admixture is induced with increase in the proportion of silica fume as per requirement to achieve the desired slump of 75-100 mm at a constant w-c ratio.

The different proportion of silica fume were 0%, 3%, 6%, 9%, 12% and 15 %.
The different mixes are conveniently designated as SF0, SF3, SF6, SF9, SF12, and SF_{15} respectively.

The concrete specimens were tested for following

- Compressive strength for 3 days, 7 days, 28 days & 56 days curing using cube specimen.
- Flexural strength after 28 days curing using beam specimen.
- Split tensile test after 28 days curing using cylinder specimen.
- Capillary absorption test after 28 days curing using cube specimen

3. Experimental Program

Methodology:
Determination of strength for M40 grade concrete, using fly ash cement (PPC), with increasing Micro-Silica content as a part replacement of cement.

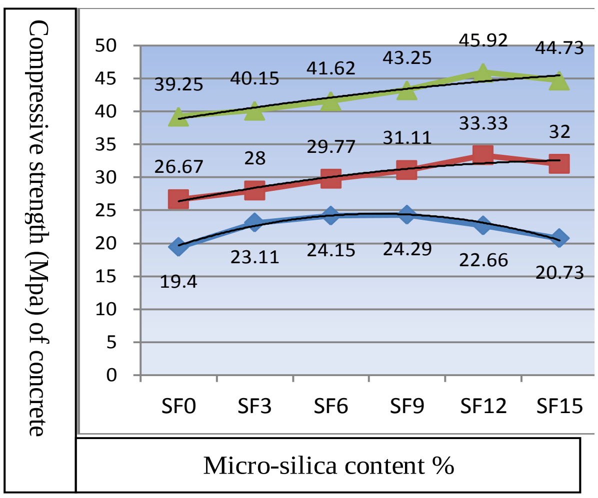
The different proportion of silica fume will be 0%, 3%, 6%, 9%, 12% and 15 %.
The different mixes are conveniently designated as SF0, SF3, SF6, SF9, SF12, and SF15 respectively.

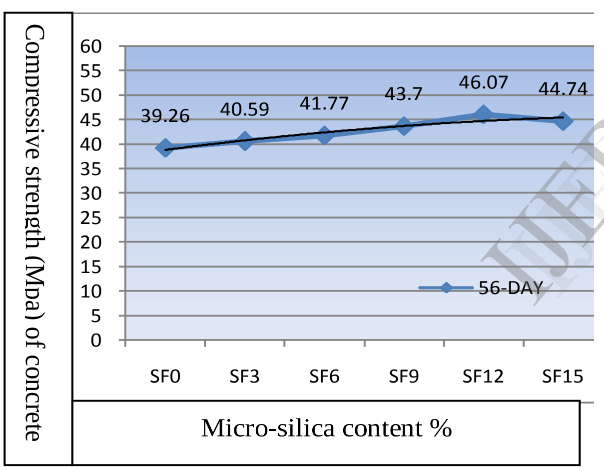
The concrete specimens will be tested for following strengths.

- Compressive strength for 3 days, 7 days, 28 days & 56 days curing using standard cube specimen.
- Flexural strength after 28 days curing using standard beam specimen.
- Split tensile test after 28 days curing using standard cylinder specimen.
- Capillary absorption test after 28 days curing using standard cube specimen.

4. Results and Discussions

4.1 Compressive Strength Test:
3-day, 7-day, 28-day & 56-day Compressive Strengths





From the graphs, we can conclude that 7 days strength and 28 days strength increases with increase in percentage of replacement by silica fume.

The increase in strength from 3 to 7 days curing is varying in the range of 27% to 35%. The increase in strength from 7 to 28 days curing is varying in the range of 27% to 32%. The increase in strength from 28 to 56 days curing is not much significant but it is on slightly higher side.
The maximum increase in characteristic strength is observed for 12% replacement.

For this dose, the relative increase in compressive strength is found to be up to 14.5%

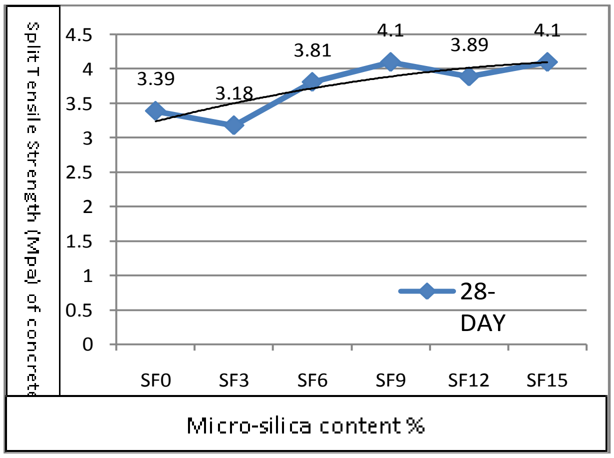
The reason for gain of strength in fly ash cement (PPC) could be fast reaction between fly ash and silica-fume particles due to fine nature.

It is observed that up to 12% replacement of cement with silica fume the Compressive strength increases with increasing dose of silica Fume and then reduces slightly.

The gain in strength can be attributed to the formation of calcium silicate hydrate (C-S-H) gel which is stronger than the normal C-H gel. This silica-fume gel C-S-H forms in the voids of the C-S-H produced by cement hydration, thus producing a very dense structure.

Silica fume increases the strength of concrete largely because it increases the strength of the bond between the cement paste and the aggregate particles.
In hardened concrete, silica-fume particles increase the packing of the solid materials by filling the spaces between the cement grains in much the same way as cement fills the spaces between the fine-aggregate particles, and fine-aggregate fills the spaces between coarse-aggregate particles in concrete.

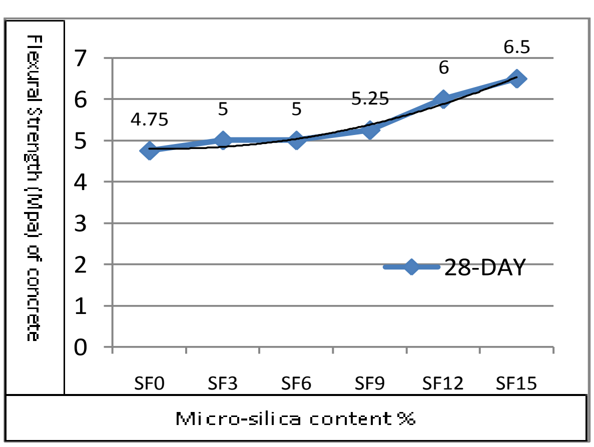
4.2 Split Tensile Test:
28-day Tensile Strengths



From the graphs it can be concluded that inclusion of micro-silica as a replacement of cement shows slight increase in the split tensile strength though not in a definitive manner. However, there is no loss or any significant reduction in strength with increase in the micro-silica content.

It is observed that the split tensile strength of concrete increases with increase in silica content up to 9% replacement of cement. The maximum increase in characteristic strength is observed for 9%. For this dose the relative increase in split tensile strength is found to be up to 17%.

4.3 Flexural Test:
28-day Flexural strength



It is observed that inclusion of micro-silica as a replacement of cement shows slight increase in the flexural strength.
The 28 days strength increases with increase in percentage of replacement of cement by silica fume.

It is observed that the flexural strength of concrete increases with increase in silica content up to 15% replacement of cement.

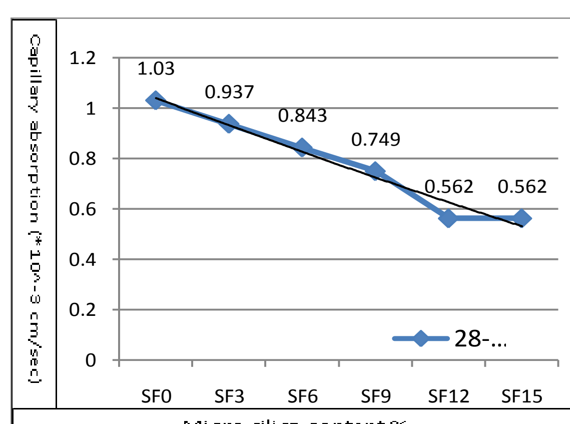
The maximum increase in characteristic strength is observed for 15%. For this dose the relative increase in flexural strength is found to be nearly 27%.

The ratio of tensile to compressive strength or flexural to compressive strength is strongly affected by the properties of the materials used. A unique relationship among the various types of strengths does not exist. If tensile/flexural strength is important for design, it must be tested for individual concretes.

The split tensile strength is found to be 8-10% of the compressive strength for 28 days of curing. The flexural strength is found to be 12-15% of the compressive strength for 28 days of curing.

4.4 Capillary Absorption Test:

Coefficients of capillary absorption of different mixes after 28 days of curing



We can conclude that capillary absorption decreases with increase in percentage of replacement by silica fume.

The reason could be the inclusion of silica fume to the concrete actually forms denser matrices thereby improve resistance of the matrices against water ingress which is one of the most important reasons that increases the deterioration of concrete.

So, by using micro-silica, the concrete matrix gets a denser composition filling even the micro-voids thus enhancing the impermeability of concrete. Better impermeability ensures better crack-resistance and corrosion resistance as well as less prone to chemical attack.

Capillary absorption coefficient decreases with increasing % of silica fume up to 15% replacement. This shows that there is a reduction in the size of capillary pores as stated theoretically. Hence, silica fume concrete is less susceptible to deterioration and hence more durable. Its low permeability, shall offer possible benefits by reducing the rate of penetration of chloride ions.

The main effect on the pore structure is the reduction of large pores by blocking them with hydration products. The transformation of continuous pores into discontinuous pores has a profound effect on the permeability of silica-fume concretes.

The increase in the rate of concrete per cubic meter is significant. It should be included as a replacement only when certain desirable properties have to be achieved. The properties shown by micro-silica concrete are much better than plain cement concrete. It is desirable to use micro-silica in high performance and high grade concretes in spite of the increased cost keeping in mind the increased strength and enhanced durability that micro-silica concrete has to offer.

5. Conclusions

Water requirement or normal consistency of a mix increases with increment in percentage of Micro-Silica replacement.

With the use of super-plasticizer, it is possible to get a mix with desired slump at a low water to cement ratio.

Thorough mixing is required to ensure maximum dispersion of Micro-silica within the concrete.

The increase in strength from 3 to 7 days curing is varying in the range of 27% to 35%.

The increase in strength from 7 to 28 days curing is varying in the range of 27% to 32%.

The increase in strength from 28 to 56 days curing is not much significant but it is on slightly higher side.

The maximum increase in characteristic strength is observed for 12% replacement. For this dose, the relative increase in compressive strength is found to be up to 14.5%.

The reason for gain of strength in fly ash cement (PPC) could be fast reaction between fly ash and silica-fume particles due to fine nature.

It is observed that up to 12% replacement of cement with silica fume the Compressive strength increases with increasing dose of silica Fume and then reduces slightly.

The gain in strength can be attributed to the formation of calcium silicate hydrate (C-S-H) gel which is stronger than the normal C-H gel. This silica-fume gel C-S-H forms in the voids of the C-S-H produced by cement hydration, thus producing a very dense structure.

Silica fume increases the strength of concrete largely because it increases the strength of the bond between the cement paste and the aggregate particles.

It is observed that the split tensile strength of concrete increases with increase in silica content up to 9% replacement of cement.

Inclusion of micro-silica as a replacement of cement shows slight increase in the split tensile strength though not in a definitive manner. However, there is no loss or any significant reduction in strength with increase in the micro-silica content.

The maximum increase in characteristic strength is observed for 9%. For this dose the relative increase in split tensile strength is found to be up to 17%.

It is observed that the flexural strength of concrete increases with increase in silica content up to 15% replacement of cement.

The maximum increase in characteristic strength is observed for 15%. For this dose the relative increase in flexural strength is found to be nearly 27%.

The split tensile strength is found to be 8-10% of the compressive strength for 28 days of curing. The flexural strength is found to be 12-15% of the compressive strength for 28 days of curing.

Capillary absorption coefficient decreases with increasing % of silica fume up to 15% replacement. This shows that there is a reduction in the size of capillary pores as stated theoretically. Hence, silica fume concrete is less susceptible to deterioration and hence more durable.

It would be reasonable to say that inclusion of silica fume to the concrete actually forms denser matrices thereby improving resistance of the matrices against water ingress which is one of the most important reasons that increases the deterioration of concrete

So, by using micro-silica, the concrete matrix gets a denser composition filling even the micro-voids thus enhancing the impermeability of concrete. Better impermeability may ensure better crack-resistance and corrosion resistance as well as less prone to chemical attack.

The properties shown by micro-silica concrete are much better than plain cement concrete. It is desirable to use micro-silica in high performance and high grade concretes in spite of the increased cost (nearly 1000 Rs/cubic meter) keeping in mind the increased strength and enhanced durability that micro-silica concrete has to offer.

Sufficient trial mixes and various tests should be carried out with the on-site concrete ingredients to get the desired properties for a particular constructional application. The percent of micro-silica to be replaced should be assessed on the basis of the property of concrete to be enhanced in particular.

6. References

Jagadish Mallick , “EFFECT OF SILICA FUME ON STEEL SLAG CONCRETE”, NIT, Rourkela, May 2010. (JAGADISH_MALLICK.pdf)

Ashish kumar, “EFFECT OF POZZOLANAS ON FIBER REINFORCED CONCRETE”, NIT, Rourkela,2010. (FINAL_PROJECT_OF_M_TECH.pdf)

Srinivas Gutha, “COMPARATIVE STUDY OF PROPERTIES OF DIFFERENT TYPES OF BINDER MIXES MODIFIED WITH SILICA FUME”, NIT, Rourkela, May 2010. (btech_10601025.pdf)

IS-15388 (2003) SILICA FUME — SPECIFICATION.

ACI 234R-96 (Reapproved 2000)- Guide for the Use of Silica Fume in Concrete.

Gary M. Gapinski and John Scanlon, “Silica Fume” (technical-papers-articles-gapinksi-scanlon.pdf)

IS 10262:2009- CONCRETE MIX PROPORTIONING- GUIDELINES.

Silica fume-users-manual by Federal Highway Administration, United States.

ASTM C 1240 – 05 Standard Specification for Silica Fume Used in Cementitious Mixtures.

High performance admixture for micro-silica concrete, INDIA/0148/D

K. C. Biswal and Suresh Chandra Sadangi, “Effect of super-plasticizer and silica fume on properties of concrete”, Presented in conference at Trivandrum, Kerela, March 16th, 2011 (Effect of superplasticizer and silica fume on properties of concrete.pdf)

Praveen Kumar and S.K. Kaushik, “Some trends in the use of concrete : Indian scenario”, December 2003 * The Indian Concrete Journal (Some trends in the use of concrete Indian scenario.pdf)

Silica Fume Association, “MAKING SILICA-FUME CONCRETE IN THE LABORATORY” (SFA), 11/03.

S.C. Maiti and Raj K. Agarwal, “Concrete and its quality by, The Indian Concrete Journal”, SEPTEMBER 2009 (POV_Maiti_Agarwal.pdf)

Safwan A. Khedr, “CHARACTERISTICS OF SILICA-FUME CONCRETE”, ~ Member, ASCE, 18 Aug 2011-ASCE library (silica fume concrete.pdf)

ASHISH KUMAR DASH, MAHABIR PANDA AND KISHORE CHANDRA BISWAL, “EFFECT OF SILICA FUME ON ENGINEERING PROPERTIES OF FIBER REINFORCED CONCRETE”, S3-M042, February 8, 2011 (S3-M042-16+03+11.pdf)

Silica fume by Dept. of Civil Engineering, JNNCE (sili.doc)

Andrew Dunster, “Silica fume in concrete”, IP 5/09 (2c7d946881.pdf)

Arnon Chaipanich, “Silica Fume: Its Role in Cement and Concrete Technology”, Department of Physics, Faculty of Science, Chiang Mai University, Chiang Mai 50200, Thailand (silica fume its role in cement.pdf)

Preeti P Patel, Elizabeth George and Deepa A Sinha, ISTE, “EFFECT OF SILICA FUME ON PROPERTIES OF CONCRETE”. (EFFECT OF SILICA FUME ON PROPERTIES OF CONCRETE.pdf)

Concrete Technology - Theory and practice by M.S.Shetty

Silica Fume in Hardened Concrete- Advanced Cement Technologies, LLC. Blaine WA 98231, USA

ACI Committee 226, “Silicafume in concrete”, ACI material journal ,March /april 87, Pg 158-166.

Dr.K.Sukumaran, “application of silica fume concrete in construction”, special concrete issue.

Prof. Ashok Tiwari, “Indian silica-fume for durable structures”, Concrete journal.

S C Maiti and N K jain, “Use of silica fume in concrete”, National Council for cement and Building Materials, India.

IS 1489 (part 1): 1991 - PORTLAND-POZZOLANA CEMENT SPECIFICATION:- (PART 1) FLY ASH BASED

IS 383 (1997) — Specification for course and fine aggregates from Natural Sources for Concrete.

IS-516 (1959) — METHODS OF TESTS FOR STRENGTH OF CONCRETE

IS-5816 (1999) — Splitting tensile strength of concrete- Method of test.

Citations: In (ACI) 234R-96 (Reapproved 2000) - Guide for the Use of Silica Fume in Concrete

Malhotra, V. M., and Carette, G. G., 1983, “Silica Fume Concrete — Properties, Applications, and Limitations,” Concrete International: Design & Construction, V. 5, No. 5, pp. 40-46.

Nebesar, B., and Carette, G. G., 1986, “Variations in the Chemical Composition, Specific Surface Area, Fineness and Pozzolanic Activity of a Condensed Silica Fume,” Cement, Concrete, and Aggregates, V. 8, No. 1, pp. 42-45.

Elkem, 1980, Elkem Silica Technical Bulletin.

Pistilli, M. F., Rau, G., and Cechner, R., 1984, “The Variability of Condensed Silica Fume From a

Canadian Source and Its Influences on the Properties of Portland Cement Concrete," Cement, Concrete, and Aggregates, V. 6, No. 1, pp. 33-37.

Monteiro, P. J. M., Maso, J. C., and Ollivier, J. P., 1985, "The Aggregate-Mortar Interface," Cement and Concrete Research, V. 15, No. 6, pp. 953-958.

Cohen, M., Olek, J., and Mather, B., 1991, "Silica Fume Improves Engineering Properties of Expansive-Cement Concrete," Concrete International: Design and Construction, V. 13, No. 3, pp. 31-37.

Detwiler, R. J., 1988, "Chemical and Physical Effects of Silica Fume on the Microstructure and Mechanical Properties of Concrete," Ph.D. dissertation, Department of Civil Engineering, University of California at Berkeley.

Scali, M. J., Chin, D., and Berke, N. S., 1987, "Effect of Microsilica and Fly Ash upon the Microstructure and Permeability of Concrete," Proceedings, 9th International Conference on Cement Microscopy, Reno, International Cement Microscopy Association, Duncanville, Texas, pp. 375-387.

Grutzeck, M. W., Roy, D. M., and Wolfe-Confer, D., 1982, "Mechanism of Hydration of Portland Cement Composites Containing Ferrosilicon Dust," Proceedings, 4th International Conference on Cement Microscopy, Las Vegas, International Cement Microscopy Association, Duncanville, Texas, pp. 193-202.

Aïtcin, P. C., Pinsonneault, P., and Rau, G., 1981, "The Use of Condensed Silica Fume in Concrete," Proceedings, Symposium N on Effects of Fly Ash Incorporation in Cement and Concrete, Boston, ed. S. Diamond, Materials Research Society, Pittsburgh, pp. 316-325.

Warren, D., 1987, "Hydrogen Effects on Steel," Materials Performance, V. 26, No. 1, pp. 38-48.

Winslow, D., and Liu, D., 1990, "The Pore Structure of Paste in Concrete," Cement and Concrete Research, V. 20, No. 2, pp. 227-235.

Whiting, D., and Kuhlman, L., 1987, "Curing and Chloride Permeability," Concrete International: Design & Construction, V. 9, No. 4, pp. 18-21.