Silica Fume Concrete
A Vermont Research Study

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State of Vermont
Agency of Transportation
Materials and Research

Glen Gershaneck, Secretary of Transportation
Gordon MacArthur, P.E., Director of Construction and Maintenance
Robert F. Cauley, P.E., Materials and Research Engineer

Prepared by:

Ronald I. Frascoia
Research & Development Supervisor

Reveiwed by:

Robert F. Cauley

Robert F. Cauley, P.E.
Materials and Research Engineer

Date: FEB 24 1997

Silica Fume Concrete

Introduction:

The first record of the experimental use of silica fume (also known as micro silica) as an additive to portland cement concrete occurred in the 1950's at the Norwegian Institute of Technology. Reports documenting enhanced concrete performance in the areas of increased strength, improved durability, and reduced permeability led to increased testing and use by state and provincial agencies by the mid 1980's.

Vermont's first field installation of silica fume concrete (SFC) consisted of a 3 ½ inch thick bridge deck overlay completed in 1987. The trial identified problems with workability and placement and resulted in the occurrence of craze cracking and 500+ lineal feet of longitudinal and transverse cracking in the 314 square yard deck. The problems noted forestalled further use of SFC until a decision was made to use the material in curbs and sidewalks on new structures beginning in 1992.

Further reports of field problems with the workability and placement of SFC, plus the common occurrence of craze cracking (plastic shrinkage cracking) and straight-line cracking, led to the initiation of a research study in early 1994 designed to identify the procedures, techniques and specifications required to obtain enhanced performance of the product in a variety of concrete (bridge) construction applications.

The research study was managed by David H. Sargent, a Construction Division employee, who accepted the task as a winter assignment. The major activities completed during the study include the following:

- Review of literature and reports on SFC.
- Correspondence and phone contacts with SFC specialists in all 50 states, manufacturers' technical representatives and university researchers.
- A visit to a New York project during the placement of a SFC deck rehabilitation overlay.
- Visits to two New Hampshire projects during the placement of new full depth SFC bridge decks.
- Condition surveys of Vermont bridges constructed with both SFC and standard PCC curbs and sidewalks.

- A follow-up survey of the 1988 SFC deck overlay.
- Preparation of a summary describing the status of SFC use by the 50 State Transportation Departments.
- Presentations on SFC to Agency employees.
- Recommendations on placement and curing.

Silica Fume Properties And Benefits

Silica fume, fly ash and slag are artificial pozzolans which can be added to portland cement to change calcium hydroxide, a weak by-product of the cement hydration process, into beneficial calcium silicate hydrates.

Silica fume is a by-product of the production of silicon metal and silicon alloys. It results from the reduction of quartz (SiO_2) by carbon in the electric arc furnace. Part of the partially reduced quartz evaporates as SiO and is reoxidized to SiO_2 when it comes into contact with oxygen in a cooler part of the furnace. The SiO_2 condenses in tiny microscopic spherical particles as amorphous silicon dioxide with an average grain size of 0.1 micron. The silica fume particles are thus about 100 times finer than a grain of cement.

The major benefits achieved with the addition of silica fume involve increased strengths, improved durability and reduced permeabilities. Other benefits include greater abrasion resistance, increased bond strength between concrete and steel, and weight savings.

In some cases, agencies are combining silica fume with fly ash or slag for cost savings or due to availability of materials.

Silica Fume Concrete Usage

As a part of this study, all 50 states were surveyed in early 1994 to determine the status of SFC use. Details obtained in the phone survey, including mix designs and comments, and a list of the agency personnel who were contacted are found in the appendix.

Significant findings from the survey include the following:

- 35 states are using, or plan to use, SFC in the immediate future.
- 27 states have constructed 1 or more SFC deck overlays.
- 11 states have constructed 10 or more SFC deck overlays.
- 5 states (Illinois, Maine, New York, Ohio & Washington) have done more than 100 deck overlays.
- 64% of the respondents specify between 7 and 8% SF, while 21% (including 4 of the largest users) specify between 9 and 10%.
- Most states specify wet curing and recognize the need for its early application.
- Some bridge contractors in NH are using SFC to meet reduced permeability requirements in QC/QA specifications which can result in a 10% incentive payment.
- Some states specify combinations of silica fume and fly ash or slag to obtain the desired end result.
- A number of states allow the use of SFC as an option to low slump or latex modified concrete.
- Most states reported satisfactory performance.
- 5 states reported problems with craze cracking and/or full depth cracking of silica fume concrete overlays.
- Many states are moving towards the use of high performance concrete which includes the combination of SF, fly ash or slag as a means of reducing the admixture cost.

SFC Usage and Performance in Vermont

The quantity of SFC used in Vermont did not vary appreciably during the period of the study. Use continues to be limited to curbs and sidewalks with occasional use in exposed concrete headers on bridge joints.

The initial field condition surveys of existing projects included the 1987 SFC overlay on Rte 7, Bridge No. 151 in Winooski, 17 bridges with standard concrete curbs constructed between 1988 and 1991, and 13 bridges with SFC curbs constructed between 1992 and 1994. The 314 square yard deck overlay contained approximately 1400 lineal feet of cracking 8 years after construction. A significant, but unrecorded, amount of the cracks were present upon completion of the original 10 day cure period. Samples taken to determine chloride contamination levels revealed 763 ppm in the top inch and 120 ppm in the second inch of the SFC. In comparison, the adjacent standard PCC roadway had 2906 ppm in the top inch and 822 ppm in the second inch. The results show the SFC is significantly less permeable than the standard mix.

The switch over to SFC for curb placements led to the realization that significant cracking was occurring in spite of the construction of joints at 10 to 20 feet intervals. In addition, fine craze type cracking (also known as plastic shrinkage cracking) was noted in many of the installations. Both types of cracking were a concern and were a primary reason for undertaking the study.

The resulting field survey of standard and SFC curbs identified significant transverse cracks at average intervals of 9.3 feet in the SFC and 11.9 feet in the standard concrete. Significant craze cracking was noted only in the SFC curbs.

A review of product literature and discussions with users and experts in the field all pointed towards the need for greater care in the surface protection and curing procedure. A discussion of the cracking problems with an emphasis on the need for more immediate and better curing procedures was included in winter training sessions for all Construction Division engineers and inspectors.

Some reduction in cracking was noted in projects constructed in 1994 and further improvements were obtained in 1995. In May of 1995 the specification for finishing concrete was modified by adding the following Part 4:

> **Finishing Silica Fume Concrete.** The finishing characteristics of silica fume concrete are different from portland cement concrete. The rate of addition of silica fume specified will essentially eliminate bleeding.
>
> Plastic shrinkage cracking may be a problem and shall be guarded against by applying an evaporation retardant on the concrete surface after finishing and prior to the texturing operation. Any product used for such purpose shall be specifically marketed for such use (plain water is not acceptable) and shall be applied as per the manufacturer's recommendations. The completed surface shall receive two layers of wet burlap within fifteen (15) minutes of the completion of the finishing process and shall be kept wet for a cure period of five (5) days.

The specification was also modified by decreasing the length of cure for SFC on superstructure work from 10 to 5 days. Several contractors elected to follow the new specifications but were unable to obtain the evaporation retardant. They were equipped to provide a suitable mist/fog spray and the placements were considered successful. Later in the year several projects were completed with an evaporation retardant. There was reluctance to place the wet burlap within 15 minutes in fear of creating defects on the soft concrete surface. Delays in placement of an hour or more were noted but misting was maintained to insure the surface was kept moist.

The rate of both transverse and craze cracking was low on all projects inspected during the latter half of the 1995 construction season. The projects used both the old and new specifications; which suggests that the amount of attention paid to finishing and curing is probably more important than strict adherence to a given construction specification.

The study included a review of SF addition rates and mix requirements and recommendations. The 7 1/2% rate currently specified is typical of a majority of the 50 states surveyed. Although further improvements in concrete performance have been identified with higher SF addition rates, such increases have raised the cost of the concrete and increased the risk of problems with mixing and placement.

A related laboratory study by the Agency's Structural Concrete Unit included the following conclusions and recommendations with regard to the use of densified (compacted) SF products:

- Increase mixing periods to a minimum of 150 revoluations of the drum at mixing speed when transit mixers are used.
- Increase mixing times a minimum of 50% when central mixers are used.
- Limit the maximum load size to 80% of rated mixing capacity.
- Retain the current 7 1/2% addition rate when SFC is specified.

Complete details of the laboratory study are available in Report 94-4 completed in May 1994 by William L. Meyer.

Summary

The benefits of adding silica fume to portland cement have been well documented in a number of laboratories and field studies.

The Agency's current silica fume addition rate of 7 1/2% is considered appropriate.

Immediate and proper curing is required to prevent or reduce the occurrence of surface and full depth cracking.

Increased attention to finishing and curing has reduced the level of cracking on recent projects.

Recommendation

A few new projects should be inspected on an annual basis to insure that problems with cracking do not recur.

VT AOT PHONE (802)828-2561
FAX (802)828-2792

STATUS OF SILICA FUME CONCRETE USE

May 1996

STATE	1ST USE	FULL DEPTH DECKS	DECK OVERLAYS	OTHER	POUNDS SF PER CY	% SILICA FUME	TYPE SILICA FUME*	W/C RATIO	CEMENT TYPE	POUNDS CEMENT	CURE TIME	CURE TYPE	COMMENTS
ALABAMA	1991			x		10			II		Same as std. conc.		Salt water environment
ALASKA	1993		6	x	52	8	C	0.33	II	658	3 DAY	H2O	Mixed results but not being closely monitored
ARIZONA	1992		1										Visual inspec. & chain drag after several weeks. V.G. cond. then & now
ARKANSAS	1995												Specified as an overlay but no bids received
CALIFORNIA			1			5-10	C,S		II				Specify polyester concrete overlays
COLORADO	1993		4			7.5	C,S	0.35	I & II	660	5 DAY	Compound,H2O	Satisfactory results to date, 15% flyash
CONNECTICUT													No use to date
DELAWARE	1993		1		50	7.5	C	0.4	I	705	7 DAY	H2O	Performing fine
FLORIDA	1992			x		8	S, C	0.33	II	752(-1 sf)	7 DAY	Compound,H2O	8% SF 20% FA of 752 (use FA for overlays)
GEORGIA	1989		1		49.5	6.66	S	0.39	III	750			Deck has been replaced, no projects planned.
HAWAII													Not using in 1995, didn't contact in 1996
IDAHO	1990		6			7.5	C	0.38	I & II	658	7 DAY	H2O	Satisfactory results to date.
ILLINOIS	1987		100+		55	9	C,S&R	0.36-39	I	600	7 DAY	Compound,H2O	Some cracking & balling in mixer, popouts.
INDIANA	1990		3	x	30-50		C	0.36-0.41	II		7 DAY	H2O	Barrier railing also, satisfactory results with all uses
IOWA	1988		2			5	S	0.32-0.39	I	624	3 DAY	H2O	Still prefer Iowa low slump
KANSAS	1990		72	x	30	5, 7.5	S,C	0.40	II	595	7 DAY	H2O	Started with 7½ %, currently using 5%
KENTUCKY	1986		3			7	C,S	0.37	I	658	4 DAY	H2O	Satisfactory, learning curve
LOUISIANA	1990			x	95								Used on superstructure(beams) and substructures
MAINE	1986	1	100+	x	40	6.5	C	0.38	II	635, 611	7 DAY	H2O	Extensive program. Considering QC/QA deck program.
MARYLAND	1995	2			46	7.5	S	0.43	II	615	7 DAY	H2O	Starting new program
MASSACHUSETTS	1994	1		x	50	7.5	S, B	0.40	II	660	7 DAY	H2O	Experimental use prior to 1994. Inverset panels
MICHIGAN	1985		7	x	50	8	C	0.40	I	610	7 DAY	H2O	Satisfactory results with expanded use planned.
MINNESOTA													No use to date
MISSISSIPPI													No use to date
MISSOURI	1991		12		69	10	C,S	0.39	I	686	7 DAY	H2O	Sensitive. No problems when applied properly
MONTANA	1992		2										Just starting program no information on performance.
NEBRASKA	1994		5		50		C	0.38	I	658	4 DAY	H2O	Still evaluating results
NEVADA	1992			x		10	S	0.42	II	658			Not using SF at this time., Conc. Polymer overlays
NEW HAMPSHIRE	1992	20	1	x	50	8	C,S,B	0.38	II	658	3 DAY	H2O	QC/QA program. S.F. or Slag being used
NEW JERSEY	1995	3			45	7	C,S	0.40	II	610	4 DAY	H2O	1 Project, 8" decks
NEW MEXICO													No use to date
NEW YORK		1	200+		60	9.1	C,S,R	0.40	II	658	4 DAY	H2O	Lots of experience. Switching to H.P. conc.
N. CAROLINA	1995		2	x									Allowed but contractors choosing latex.
N. DAKOTA													No use to date
OHIO	1986	10	500+		70	10	C,S	0.36	I, IA	700	3 DAY	H2O	100 decks in the H.P. program then eval. w/c 0.36 of cementitious materials
OKLAHOMA		1											INVERSET deck panels
OREGON	1989		70		50	7.5	C	0.36	I, II	658	7 DAY	H2O	Great results, holdingup well.
PENNSYLVANIA	1985	1											No current use
RHODE ISLAND													No use to date
SO. CAROLINA	1995	1 & 1					C	0.32	I	600	7 DAY	H2O	Very pleased, hard to place, foggers required
S. DAKOTA													No use to date
TENNESSEE	1989		3	x			S		I				Presently used in prestressed girders
TEXAS													No use to date, research at Texas University
UTAH													No use to date
VERMONT	1988		1	x	49.5	7.5	C	0.40	II	658	3 DAY	H2O	Superstructure curbs and sidewalks
VIRGINIA	1987		50+		50	7	C	0.40	II	635	3 DAY	H2O	Going to H.P. conc.
WASHINGTON	1987		81	x	52	7.5	S		I & II		42 HRS	H2O	Good alternative to latex modified concrete
WEST VIRGINIA	1992		12+		50+	7.5-10	C	0.40	I	658	4 DAY	H2O	Performance doing quite well, more projects planned.
WISCONSIN													No use to date
WYOMING	1988		80			7.5	C,S	0.4	II	658	4 DAY	Compound,H2O	Trying METAKALIN, S.F. with F.A. this summer.

* B = BLENDED, C = DENSIFIED, R = RAW, S = SLURRY, S.F. = SILICA FUME, F.A. = FLY ASH, SLAG = BLAST FURNACE SLAG, H.P. = HIGH PERFORMANCE CONCRETE (COMBINATION OF S.F. W/ F.A. OR SLAG.)

STATES	SILICA FUME - CONTACT SHEET - MARCH 1996			
	Name & Organization	**Address**	**City/State/ZIP**	**Telephone**
ALABAMA	Mark Strickland Alabama D.O.T.	1409 Coliseum Rd. Room G 101	Montgomery, AL 36130-3050	(334)242-6219
ALASKA	Robert Lewis Alaska D.O.T.	Central Materials Laboratory 5750 East Tudor Rd.	Anchorage, AK 99507	(907)269-6214
ARIZONA	Donald P. Rushton, Struct. Materials Engineer Arizona D.O.T.	Materials Group 1221 N. 21st Avenue	Phoenix, AZ 85009	(602)255-8205
ARKANSAS	Alan Meadors, Staff Research Engineer Arkansas Highway & Tranportation Dept.	P.O. Box 2261	Little Rock, AR 72203-2261	(501)569-2380
CALIFORNIA	Doran Glauz Department of Transportation	Engineering Service Center 5900 Folsom Blvd.	Sacramento, CA 95819	(916)227-7272
COLORADO	Dick Hines, Concrete Engineer Colorado D.O.T.	4340 E. Louisiana Ave.	Denver, CO 80222	(303)757-9430
CONNECTICUT	Steve Gage or John O'Brian Connecticut D.O.T.	Office of Materials & Testing 280 West St.	Rocky Hill, CT 06067	(860)258-0327
DELAWARE	Jim Pappas or Tom Craft Dept. of Highways & Transportation	Materials & Research P.O. Box 778	Dover, DE 19903	(302)739-4852
FLORIDA	Dr. Jamshid Armaghani Florida D.O.T.	Materials Office 2006 NE Waldo Rd.	Gainesville, FL 32609	(352)337-3200
GEORGIA	Lamar Caylor, Chief of Research & Development Georgia D.O.T.	15 Kennedy Drive	Forest Park, GA 30050	(404)363-7569
HAWAII	Walter A Kuroiwa Hawaii D.O.T.	869 Punchbowl St.	Honolulu, HI 96813	(808)587-2150
IDAHO	Matt Farrar Idaho Transportation Dept.	P.O. Box 7129	Boise, ID 83702-1129	(208)334-8538
ILLINOIS	Don Armstrong, Concrete Technolgy Engineer Doug Dirks, Eng. Mixture Controls, Soils. Matt Mueller, Concrete Engineer Illinois D.O.T.	126 E. Ash St.	Springfield, IL 62704-4766	(217)782-7912 (217)782-7208 (217)785-1386

STATES	SILICA FUME - CONTACT SHEET - MARCH 1996			
	Name & Organization	**Address**	**City/State/ZIP**	**Telephone**
INDIANA	Youlanda Belew Indiana D.O.T.	Materials & Testing 120 South Shortridge Rd.	Indianapolis, IN 46219	(317)232-5280
IOWA	Jim Grove, P.C. Concrete Engineer Iowa D.O.T.	Office of Materials 800 Lincoln Way	Ames, IA 50010	(515)239-1226
KANSAS	John Witchakowski Kansas D.O.T.	2300 Van Buren	Topeka , KS 66611	(913)296-7410
KENUCKY	Jim Stone Kentucky Transportation Cabinet	Division of Materials 1227 Wilkinson Blvd	Frankfort, KY 40601- 1226	(502)546-3164
LOUSIANA	Nick Rabalais Lousiana D.O.T.	Transportation Research Center 4101 Courrier	Baton Rouge, LA 70808	(504)767-9104
MASSACHUSETTS	Clement Fung Technical Services Engineer Massachusetts Highway Dept.	400 D Street	So. Boston, MA 02210-1953	(617)526-8686
MAINE	Guy D. Berthiaume Maine D.O.T.	State House Station 16	Augusta, ME 04333	(207)287-2152
MARYLAND	Vicky Reier Maryland State Highway Dept.	2323 W. Joppa Rd.	Brooklandville, MD 21022	(416)321-3410
MICHIGAN	Tom Hohm, Concrete Engineer Michigan D.O.T.	P.O. Box 30049	Lansing, MI 48909	(517)322-1223
MINNESOTA	Doug Schwartz, Concrete Engineer Minnesota D.O.T.	1400 Gervais	Maplewood, MN 55109	(612)779-5576
MISSISSIPPI	Jimmy W. Brumfield, Assistant Materials Eng. Mississippi D.O.T.	Materials Division P.O. Box 1850	Jackson, MS 39215-1850	(601)944-9132
MISSOURI	W.L. Trimm, Division of Engineering & Materials MO Highway & Transportation Department.	P.O. Box 270	Jefferson City, MO 65102	(314)751-3759
MONTANA	Mike Lynch Montana D.O.T.	Materials Bureau 2710 Prospect Ave.	Helena, MT 59620	(402) 479-4755

STATES	SILICA FUME - CONTACT SHEET - MARCH 1996			
	Name & Organization	**Address**	**City/State/ZIP**	**Telephone**
NEBRASKA	Claudette Wagne, Concrete Engineer Nebraska Dept. of Roads	P.O. Box 94759	Lincoln, NE 68509	(402)479-4755
NEVADA	Peter Booth, Concrete Specialist Nevada D.O.T.	126 S. Stewart St.	Carson City, NV 89712	(702)687-5178
NEW HAMPSHIRE	Alan D. Perkins, P.E. New Hampshire D.O.T.	P.O. Box 483 Stickney Ave.	Concord, N H 03302	(603)271-1660
NEW JERSEY	Angelo Mendola, Senior Engineer, Materials New Jersey D.O.T.	Bureau of Materials 1035 Parkway Ave.	Trenton, N J 08625	(609)530-4347
NEW MEXICO	Jim Stokes, Material & Testing Engineer New Mexico Highway Dept.	P.O. Box 1149	Santa Fe, N M 87503	(505)827-5541
NEW YORK	Don Streeter , P.E. New York D.O.T.	1220 Washington, Ave.	Albany, N Y 12232	(518)457-5956
NORTH CAROLINA	Richard Reaves, State Materials Engineer North Carolina D.O.T.	Materials & Testing Unit P.O. Box 25201	Raleigh, N C 2761	(919)733- 7086
NORTH DAKOTA	Ron Horner, Materials & Research Engineer North Dakota D.O.T.	300 Airport Drive	Bismark, N D 58504	(701)328-4377
OHIO	Kieth Keeran, Rigid Pavement Engineer Ohio D.O.T.	25 S. Front St. P.O.Box 899	Columbus, OH 43216	(614)644-6622
OKLAHOMA`	Jack Telford Oklahoma D.O.T.	200 NE 21st Street	Oklahoma City, OK 73105	(405)521-2677
OREGON	Bruce Patterson Oregon D.O.T.	800 Airport Rd. SE	Salem, OR 97310	(503)986-3787
PENNSYLVANIA	David Reidenver, Chief of Concrete Pennsylvania D.O.T.	Materials & Testing Divison 1118 State St.	Harrisburg, PA 17120	(717)787-2489
RHODE ISLAND	Hoza Lima Rhode Island Dept. of Transportation	Two Central Hill (Rm 018)	Providence, R I 02903	(401)277-2481
SOUTH CAROLINA	Richard Stewart, Concrete Supervisor Research & Materials Lab.	South Carolina Highway Public Trans. P.O.Box 191	Columbia, S C 29202	(803)737-6689

STATES	SILICA FUME - CONTACT SHEET - MARCH 1996			
	Name & Organization	**Address**	**City/State/ZIP**	**Telephone**
SOUTH DAKOTA	Ron McMahon South Dakota D.O.T.	700 Broadway Ave. East	Pierre, S D 57501	(605)773-34034
TENNESSEE	Winston Gaffdon, Assistant Director Tennessee D.O.T.	Materials Divsion 6601 Centennial Blvd.	Nashville, Tenn 37209	(615)350-4100
TEXAS	Tommy Etheredge Texas D.O.T.	Materials & Testing Division 125 East 11th Street	Austin, Tx 78701-2483	(512)465-7615
UTAH	John Butterfield Utah D.O.T.	Materials Division 4501 S. 2700 West	Salt Lake City, UT 84119	(801)964-4468
VIRGINA	Celik Ozyildirm, Research Scientist Virgina Transportation Research Council	530 Edgemont Rd.	Charlottesville, VA 22903	(804)293-1970 Fax(804)293-1990
WASHINGTON	Dwaine Wilson Washington State D.O.T.	Bridge & Structures Office P.O. Box 47340	Olympia, WA 98504-7340	(360)705-7214
WEST VIRGINA	Gary Robson, Director of Materials Testing West Virgina D.O.T.	312 Michgan Ave.	Charleston, WV 25301	(304)558-3160
WISCONSIN	Jim Perry Wisconsin D.O.T.	P.O. Box 7916	Madison, WI 53707	(608)246-7939
WYOMING	Bob Rothwell Wyoming D.O.T.	5300 Bishop Blvd.	Cheyenne, WY 82002-1708	(307)777-4476