Reviewed by: DCB

Donald C. Brown, P.E.
Acting Materials and
Research Engineer

CCB
Prepared By: C. C. Benda

RESEARCH UPDATE

NUMBER U89-1

EMSAC F-100 MICROSILICA ADDITIVE FOR CONCRETE

Reference:

Report No. 86-6 · Work Plan 85-C-24

Background:

Stimulated by claims of the enhanced performance of Portland Cement concrete when Silica Fume is used as an additive, testing was initiated in November of 1985 to determine if conventional Vermont Agency of Transportation concrete mixtures used in bridge deck construction could be improved with the introduction of Emsac F-100 Microsilica additive from Elkem Chemicals, Inc.

Preliminary Report No. 86-6 recommended that prolonged testing for resistance to freezing and thawing and chloride ion penetration be conducted based on the favorable initial performance of Emsac F-100. An addendum written to report 86-6 documenting resistance to chloride ion penetration and freeze-thaw durability was published in December of 1986. Favorable test results at that time resulted in recommendations to continue ponding specimens with 3% NaCl for 300 days and that Silica Fume be used on an experimental basis in the field.

This RESEARCH UPDATE concludes the planned laboratory evaluation of Emsac F-100 Microsilica additive for concrete. During the summer of 1988, 7.5% Silica Fume by weight of cement was used in the concrete mix on a bridge deck overlay placed on the Winooski MEGC M5100(8) project. As the material used in that project was not manufactured by Elkem Chemicals, Inc., results will not be presented here but will appear in future updates.

Test Results:

Given in Tables 1 and 2 are results of testing for compressive strength, resistance to chloride ion penetration and freeze-thaw durability.

Two 4" X 8" cylinders from each batch were tested for compressive strength (AASHTO T22-86) at 1, 3, 7, 14 and 28 days following standard moist curing. After 14 days of moist curing and 28 days of air drying, specimens to be used for determining resistance to chloride ion penetration were tested for base level chloride ion content. Upon completion of 100, 200 and 300 days of continuous ponding with a 3% NaCl solution, the specimens were resampled for total chloride ion content at depths of 0.25" to 1" and 1" to 2" in accordance with AASHTO T260-84. Specimens used to determine freeze-thaw durability were cycled from 40°F to 0°F and back to 40°F in a 3% NaCl solution 500 times following an initial 14 day moist curing period. The specimens were tested for weight loss and fundamental transverse frequency at 50 cycle intervals.

A complete summary of testing procedures and materials used in this evaluation along with fresh concrete test results can be found in Preliminary Report 86-6.

Summary:

Laboratory testing conducted on Emsac F-100 Microsilica based concrete additive has demonstrated that conventional Portland Cement concrete can be enhanced significantly with its use.

Results indicate that Microsilica may be a more effective pozzolan than fly ash or blast furnace slag, which demonstrate less rapid strength gain at early ages of test. Compressive strength of concrete produced with Silica Fume was substantially higher than the control concrete at all ages of test. As the percent of Microsilica in the mix increased, the cylinder strengths increased markedly. Class AA concrete with 30% Emsac F-100 (13.5% Silica Fume) by weight of cement exhibited the most dramatic increase in strength, an average of 91% higher than the control.

After subtracting baseline chloride ion levels, Emsac F-100 test batch specimens were found to be 3 to 95 times more resistant to chloride ion penetration in the top one inch of sample than the Class AA control mixture after 300 days of ponding.

Relative to the control, Class A concrete mixed with Emsac F-100 allowed approximately 2 to 5 times less chloride ion penetration in the top one inch of sample after 300 days of ponding.

After 300 days of ponding the chloride ion concentration below the one inch depth in the Class AA control specimen exceeded the threshold value of 1.3 lb/cy, the level generally reported necessary to initiate corrosion in reinforcing steel embedded in Portland cement concrete. Chloride ingress below the one inch depth was well under the threshold value in all the Emsac F-100 test batches.

Durability, as indicated by fundamental transverse frequency testing, was approximately equal for all samples. Weight loss after 500 cycles of freezing and thawing in a 3% NaCl solution decreased as the percent of Microsilica in the concrete mix increased. The high durability factors indicated a sound internal structure but the greater weight loss for the control mixtures and test batches with only 10% Emsac F-100 are indicative of moderate to severe surface scaling.

Based on the favorable results given in the Preliminary Report 86-6 and its addendum, it was recommended that condensed Silica Fume concrete be used in the field on a trial basis. Due to the extreme difficulty in finishing specimens fabricated with 30% Emsac F-100 and the less than spectacular permeability and freeze-thaw test values for the 10% addition rate, it was suggested that 15% to 20% Emsac F-100 by weight of cement be used.

Since those initial reports, use of Silica Fume has become more wide spread and its availability has grown. Handling of condensed Silica Fume has been overcome by combining the fine powder with liquid to form a slurry, as with Emsac F-100, or by shipping the Silica Fume blended with Portland Cement.

Recommendations:

Silica Fume concrete should be considered as an alternative on bare deck or overlay construction not protected by a membrane and bituminous concrete overlay system. Class AA mix should be used when the depth of concrete is 2-1/2" or less and Class A when the depth exceeds 2-1/2". The addition rate should be 7.5% Silica Fume by weight of cement and the use of high range water reducer required. (NOTE: 7.5% Silica Fume would be equivalent to approximately 16.7% Emsac F-100 by weight of cement. Emsac F-100 contains a high range water reducer in its formulation.)

In addition to overlays, it is recommended that Silica Fume concrete be used in structures where high compressive strengths and increased resistance to chloride induced corrosion of reinforcing steel are needed.

Applications in the field should include trial use in precast members and bridge curbing where abrasion and wear resistance can be monitored.

TABLE 1

COMPRESSIVE STRENGTH, FREEZE-THAW, AND CHLORIDE ION CONCENTRATION TEST RESULTS CONCRETE CLASS A

	Control Batches		EMSAC F-100 Test Batches				
Laboratory Batch #	Batch 1	Batch 2	Batch 3	Batch 4	Batch 5	Batch 6	Batch 7
Cement Content, lbs/cy	660	660	660	660	660	660	660
Percent EMSAC F-100 (Percent Silica Fume) by weight of cement	N.A.	N.A.	10(4.5)	10(4.5)	30(13.5)	30(13.5)	30(13.5)
Compressive Strength, PSI: 1 day	2834	2944	3401	3282	4525	4823	4416
3 days	4038	4495	5231	5131	7319	7628	7290
7 days	4644	4963	5808	5997	8145	8592	8304
14 days	5441	5500	6813	6962	9767	10,264	10,085
28 days	5887	6136	7399	7409	10,084	11,028	10,998
Resistance to Freezing and Thawing: Weight loss, percent 500 cycles	5.0	6.4	3.3	2.3	1.2	0.7	0.6
Durability Factor 500 cycles	103.7	100.7	103.7	104.5	101.5	102.9	102.2
Chloride Ion Penetration, PPM (lbs/cy) of concrete Base Level Cl		53(0.2)		53(0.2)			83(0.3)
100 Day Ponding ¼" to 1" depth		160(0.6)		86(0.3)			110(0.4)
1" to 2" depth		62(0.2)		53(0.2)			89(0.4)
200 Day Ponding ¼" to 1" depth		466(1.9)		153(0.6)			198(0.8)
1" to 2" depth		62(0.2)		53(0.2)			92(0.4)
300 Day Ponding ¼" to 1" depth		824(3.3)		379(1.5)			243(1.0)
1" to 2" depth		83(0.3)		71(0.3)			83(0.3)

TABLE 2

COMPRESSIVE STRENGTH, FREEZE-THAW, AND CHLORIDE ION CONCENTRATION TEST RESULTS CONCRETE CLASS AA

	Control Batches		EMSAC F-100 Test Batches					
Laboratory Batch #	Batch 8	Batch 9	Batch 10	Batch 11	Batch 12	Batch 13	Batch 14	Batch 15
Cement Content, lbs/cy	705	705	705	705	705	705	705	705
Percent EMSAC F-100 (Percent Silica Fume) by weight of cement	N.A.	N.A.	10(4.5)	10(4.5)	20(9)	20(9)	30(13.5)	30(13.5)
Compressive Strength PSI: 1 day	2854	2596	3411	3530	4087	4256	5042	5141
3 days	3938	3709	5390	5002	5748	6513	7260	7578
7 days	4624	3998	6514	6017	7409	7687	8851	9397
14 days	5300	5002	7518	7180	8234	8980	10,054	10,223
28 days	6126	5798	8373	7707	9736	10,293	11,088	11,715
Resistance to Freezing and Thawing: Weight Loss, percent 500 cycles	6.7	5.7	7.5	6.7	3.0	1.9	1.5	1.4
Durability Factor 500 cycles	103.7	105.2	105.2	103.7	107.5	104.4	103.7	103.7
Chloride Ion Penetration, PPM (lbs/cy) of concrete Base Level Cl		47(0.2)		65(0.3)		65(0.3)		100(0.4)
100 Day Ponding ¼" to 1" depth		918(3.7)		317(1.3)		98(0.4)		154(0.6)
1" to 2" depth		110(0.4)		83(0.3)		80(0.3)		95(0.4)
200 Day Ponding ¼" to 1" depth		2907(11.6)		634(2.5)		142(0.6)		136(0.5)
1" to 2" depth		121(0.5)		74(0.3)		80(0.3)		98(0.4)
300 Day Ponding ¼" to 1" depth		4621(18.0)		1408(5.6)		218(0.9)		148(0.6)
1" to 2" depth		497(2.0)		77(0.3)		81(0.3)		109(0.4)

PRELIMINARY REPORT
ON EMSAC F-100, MICROSILICA
ADDITIVE FOR CONCRETE

REPORT 86-6

APRIL 1986

Reporting On Work Plan 85-C-24

STATE OF VERMONT
AGENCY OF TRANSPORTATION
MATERIALS & RESEARCH DIVISION

Susan C. Crampton, Secretary
Frank E. Aldrich, P.E., Chief Engineer
R. F. Nicholson, P.E., Materials & Research Engineer

Prepared By:

C. C. Benda, P.E., Structural Concrete Engineer

Reviewed By:

R. F. Nicholson

R. F. Nicholson, P.E.
Materials & Research Engineer

Date: 05-06-'86

"The information contained in this report was compiled for the use of the Vermont Agency of Transportation. Conclusions and recommendations contained herein are based upon the research data obtained and the expertise of the researchers, and are not necessarily to be construed as Agency policy. This report does not constitute a standard, specification, or regulation. The Vermont Agency of Transportation assumes no liability for its contents or the use thereof."

TABLE OF CONTENTS

ABSTRACT

Microsilica, frequently called silica fume, is a by-product of the ferrosilicon and silicon metal manufacturing process.

Stimulated by claims of the enhanced performance of Portland Cement Concrete when microsilica is used as an additive, testing was initiated to determine if conventional Vermont Agency of Transportation concrete mixtures used in bridge deck construction could be improved with the introduction of EMSAC F-100 microsilica additive manufactured by Elkem Chemicals, Inc.

Given in this preliminary report are strength test results, short-term freeze-thaw characteristics and setting times for laboratory mixed concrete containing 10 to 30 percent microsilica by weight of cement.

Initial indications are that concrete with substantially higher compressive strengths and improved durability can be produced with microsilica. The EMSAC F-100 additive accelerated setting times at the lower addition rate while retarding the setting times at the upper addition rate relative to the control mixtures.

Continued research to determine resistance to prolonged freezing and thawing and Chloride Ion penetration is recommended.

INTRODUCTION

With the ever present need to construct more durable highway structures, conserve energy and use our natural resources more wisely, pozzolans including fly ash and slags have played an increasingly popular role in the production of Portland Cement Concrete. Recently, a greater awareness has been placed on the use of another pozzolanic material, condensed silica fume, or microsilica, as an additive to concrete.

Microsilica is produced by condensing the hot gases generated in the manufacturing of ferrosilcon and silicon metal. The liquid silicon or ferrosilicon is drawn off the bottom of the electric arc furnace as the rising vapor condenses in air and is collected in baghouses [1, 2].

The condensed silica fume contains in excess of 90 percent amorphorus silicon dioxide in the form of fine powder. The submicron sized spherical particles are 50 times as fine as the average cement or fly ash particle making microsilica extremely light and not easily handled [3].

By marketing EMSAC F-100 microsilica additive for concrete in a slurry form, Elkem Chemicals, Inc. claims to have overcome handling and water demand problems. The microsilica is dispersed in water and combined with chemical admixtures which include a high range water reducer.

This preliminary report discusses the laboratory batching and testing of conventional Vermont Agency of Transportation Class A and Class AA concrete control mixes and collates them to Class A and Class AA concrete mixed with EMSAC F-100. Class A mixes containing 10 and 30 percent by weight of cement EMSAC

F-100 and Class AA mixes with 10, 20, and 30 percent by weight of cement EMSAC F-100 are evaluated.

MATERIALS

The materials used in this investigation are as follows:

A. Aggregates

1. Fine Aggregate

Washed Natural Sand

A. G. Anderson, Highgate, Vermont

TABLE 1

FINE AGGREGATE TEST DATA

Fine Aggregate

	Date Sampled 12/10/85	Date Sampled 12/10/85	VAOT Specification Requirements
Sieve Size	% Passing	% Passing	% Passing
3/8"	100	100	100
# 4	99	99	95-100
# 8	89	89	-
# 16	75	73	50-80
# 30	49	48	25-60
# 50	20	18	10-30
#100	4	4	2-10
Fineness Modulus	2.66	2.69	2.60-3.10
Color		1	2 Max.

2. Coarse Aggregate

Crushed Igneous Stone

Cooley, Websterville, Vermont

TABLE 2

<u>COARSE AGGREGATE TEST DATA</u>

	3/8" Crushed Igneous Stone Date Sampled 12/4/85	VAOT Specification Requirements	3/4" Crushed Igneous Stone Date Sampled 12/4/85	VAOT Specification Requirements
Sieve Size	% Passing	% Passing	% Passing	% Passing
1"			100	100
3/4"			96	90-100
1/2"	100	100		
3/8"	94	85-100	39	20-55
# 4	29	10-30	8	0-10
# 8	7	0-10	5	0-5
#16	3	0-5		
L.A. Abrasion, % loss	36.2	"C" Grading 50 Maximum	32.8	"B" Grading 50 Maximum
Thin & Elong. Pieces, percent	1.3	10 Maximum	2.4	10 Maximum
Frac. Faces, percent	100		100	

B. <u>Cement</u>

Type II Cement

Glens Falls Portland Cement Company, Glens Falls, New York

TABLE 3

CEMENT TEST DATA

	Glens Falls Type II Date Sampled 12/23/85	AASHTO M85-84I Specification Requirements
Air content of mortar percent by volume	7.7	12 Maximum
Fineness - specific surface sq. cm. per gram	3967	2800 Minimum 4000 Maximum
Soundness - autoclave expansion, percent	0.02	0.80 Maximum
Normal consistency - Vicat needle	23.5	
Time of setting - Gillmore needle		
Initial - hrs:min	2.50	1:00 Minimum
Final - hrs:min	4:00	10:00 Maximum
Compressive strength, psi 3 days Cube No. 1	2960	
Cube No. 2	3040	
Cube No. 3	3010	
Average	3000	1500 Minimum
7 days Cube No. 1	3650	
Cube No. 2	3680	
Cube No. 3	3650	
Average	3660	2500 Minimum

C. Air-Entraining Admixture

Daravair

W. R. Grace & Company, Cambridge, Massachusetts

D. Microsilica Concrete Additive

EMSAC F-100

Elkem Chemicals, Inc., Pittsburgh, Pennsylvania

E. Water Reducing Admixture

WRDA W/HYCOL

W. R. Grace & Company, Cambridge, Massachusetts

PROCEDURES

Control concrete mixtures batched in this investigation were typical of Class A concrete used in Agency bridge deck construction and Class AA concrete used in overlay and patch work. Four control batches were prepared, two each of Class A concrete and Class AA concrete.

The conventional Class A and Class AA mix designs for the control batches were modified according to the microsilica manufacturer's recommendations for the introduction of EMSAC F-100. Test batches included five Class A batches and six Class AA batches. Two of the Class A microsilica concrete batches contained 10% EMSAC F-100 by weight of cement and three were mixed with 30% EMSAC F-100 by weight of cement. Class AA microsilica concrete mixtures contained 10%, 20%, and 30% EMSAC F-100 by weight of cement. Two batches at each addition rate were prepared.

Batches 1½ cu. ft. in volume were mixed in a Sears 3½ cu. ft. rotary drum mixer. The EMSAC F-100 was homogenized in the five gallon delivery containers with a paint stirring paddle and industrial sized electric drill just prior to weighing. After all other materials were added to the mixer, the microsilica additive was introduced into the batching sequence. Mixing time was increased by two to three minutes over the reference batches to ensure complete blending of materials.

Tests were performed on the fresh concrete to determine slump (AASHTO T 119-82), air content (AASHTO T 152-82), unit weight (AASHTO T 121-82), time of setting (AASHTO T 197-82) and temperature. Ten 4" X 8" test cylinders, and one 3" w X 3" d X 16" l freeze-thaw specimen were cast from each batch. Two cylinders from each batch were tested for compressive strength (AASHTO T 22-82) at 1, 3, 7, 14, and 28 days of age following standard moist curing. The freeze-thaw specimens were moist cured for 14 days and are presently being subjected to freezing and thawing in 3% NaCl solution.

In addition to compressive strength testing, one cylinder from each pair was tested for static modulus of elasticity using ASTM C469-83 as a guide. As a compressometer for 4" X 8" cylinders was not available at the time of testing, a stand mounted dial indicator was set against the upper bearing plate of the compression testing apparatus to obtain deformation measurements at various loading intervals.

Specimens used to determine resistance to Chloride Ion penetration were fabricated and cured in accordance with AASHTO T 259-80. Following 14 days of moist curing and 28 days of air drying, the specimens were sampled and tested for base Chloride Ion levels (AASHTO T 260-84I). Upon completion of 100 days of continuous ponding with a 3% NaCl solution, the specimens will be resampled and tested for total Chloride Ion content at depths of 0.25" to 1" and 1" to 2".

Chloride Ion penetration and time of set specimens were fabricated on alternate batches due to limited material and equipment resources.

Mix design quantities for the Class A and Class AA control batches and the test batches with various percentages of microsilica additive are given in Tables 4 & 5.

TABLE 4

BATCH QUANTITIES PER CUBIC YARD
CONCRETE CLASS A

	Control Batches		EMSAC F-100 Test Batches				
Laboratory Batch #	Batch 1	Batch 2	Batch 3	Batch 4	Batch 5	Batch 6	Batch 7
Percent EMSAC F-100 by wgt. of cement	N.A.	N.A.	10	10	30	30	30
*3/4" Crushed Stone, lbs.	1592	1592	1592	1592	1592	1592	1592
*Fine Aggregate, lbs	1255	1255	1245	1245	1300	1300	1300
Cement, Type II, lbs	660	660	660	660	660	660	660
EMSAC F-100, lbs.	N.A.	N.A.	66	66	198	198	198
WRDA With HYCOL, oz.	19.8	19.8	N.A.	N.A.	N.A.	N.A.	N.A.
Daravair, oz.	7.0	7.0	9.1	9.1	12.2	9.1	9.1
Net Water, gal.	31.52	31.28	30.00	30.00	23.72	24.35	24.48

* Weights are saturated - surface - dry.

TABLE 5

BATCH QUANTITIES PER CUBIC YARD
CONCRETE CLASS AA

	Control Batches		EMSAC F-100 Test Batches					
Laboratory Batch #	Batch 8	Batch 9	Batch 10	Batch 11	Batch 12	Batch 13	Batch 14	Batch 15
Percent EMSAC F-100 by wgt. of cement	N.A.	N.A.	10	10	20	20	30	30
*3/8" Crushed Stone, lbs.	1182	1182	1182	1182	1182	1182	1182	1182
*Fine Aggregate, lbs	1601	1601	1593	1593	1626	1626	1654	1654
Cement, Type II, lbs	705	705	705	705	705	705	705	705
EMSAC F-100, lbs.	N.A.	N.A.	71	71	141	141	212	212
WRDA With HYCOL, oz.	21.2	21.2	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.
Daravair, oz.	8.0	7.0	3.5	4.0	6.0	3.5	8.75	7.0
Net Water, gal.	33.79	33.91	32.14	32.14	28.87	28.87	25.54	25.54

* Weights are saturated surface-dry.

RESULTS

Results of tests on fresh concrete are shown in Tables 6 and 7. Technical personnel representing the manufacturer indicated the volume of air-entraining admixture required to entrain air in concrete containing EMSAC F-100 comparable to air contents in concrete without EMSAC F-100 would be substantially greater. The representative suggested using 30%, 60%, and 100% more air-entraining admixture than required in the control batches for the concrete mixtures containing 10%, 20%, and 30%, respectively, EMSAC F-100. Air content testing of freshly mixed concrete, however, revealed that no increase in air-entraining admixture was necessary and, in fact, the EMSAC F-100 mixtures required up to 50% less air-entraining admixture to maintain air contents equal to the control batches.

Results of compressive strength testing at 1, 3, 7, 14, and 28 days, resistance to freezing and thawing after 150 cycles and total Chloride Ion concentrations prior to ponding are presented in Tables 8 and 9.

Data generated in testing for static modulus of elasticity is under evaluation and results will be given in a future report.

TABLE 6

FRESH CONCRETE TEST RESULTS
CONCRETE CLASS A

	Control Batches		EMSAC F-100 Test Batches				
Laboratory Batch #	Batch 1	Batch 2	Batch 3	Batch 4	Batch 5	Batch 6	Batch 7
Percent EMSAC F-100 by wgt. of cement	N.A.	N.A.	10	10	30	30	30
Slump, inches	3 1/2	3 1/4	4 3/4	4	2 1/4	3	3 1/4
Air Content, percent	7.3	6.6	8.5	8.5	10	7.6	7.5
Unit Weight, lbs/ft^3	141.01	142.93	139.64	139.72	139.56	141.73	141.69
Temperature, °F	72	72	74	74	76	78	77
Time Of Setting:							
Initial Set, Hrs:Min	7:06		6:15		8:48	8:48	
Final Set, Hrs:Min	8:30		7:36		10:18	10:18	

TABLE 7

FRESH CONCRETE TEST RESULTS
CONCRETE CLASS AA

	Control Batches		EMSAC F-100 Test Batches					
Laboratory Batch #	Batch 8	Batch 9	Batch 10	Batch 11	Batch 12	Batch 13	Batch 14	Batch 15
Percent EMSAC F-100 by wgt. of cement	N.A.	N.A.	10	10	20	20	30	30
Slump, inches	2 1/2	3	2 3/4	3 1/2	4 1/4	3 1/4	1 3/4	2
Air Content, percent	8.3	8.1	6.6	7.5	10.5	8.2	10.3	9.0
Unit Weight, lbs/ft^3	138.82	137.59	141.93	140.44	136.79	140.69	138.24	139.48
Temperature, °F	75	75	74	75	76	76	76	76
Time Of Setting:								
Initial Set, Hrs:Min	7:00		5:24		7:15		8:51	
Final Set, Hrs:Min	8:39		6:24		8:33		10:54	

TABLE 8

COMPRESSIVE STRENGTH, FREEZE-THAW, AND BASE LEVEL CHLORIDE ION CONCENTRATION TEST RESULTS CONCRETE CLASS A

	Control Batches		EMSAC F-100 Test Batches				
Laboratory Batch #	Batch 1	Batch 2	Batch 3	Batch 4	Batch 5	Batch 6	Batch 7
Percent EMSAC F-100 by wgt. of cement	N.A.	N.A.	10	10	30	30	30
Compressive Strength, PSI:							
1 day	2834	2944	3401	3282	4525	4823	4416
3 days	4038	4495	5231	5131	7319	7628	7290
7 days	4644	4963	5808	5997	8145	8592	8304
14 days	5441	5500	6813	6962	9767	10,264	10,085
28 days	5887	6136	7399	7409	10,084	11,028	10,998
Resistance To Freezing & Thawing: Weight Loss, percent							
50 cycles	0.5	0.8	0.2	0.0	0.1	(-)0.3*	(-)0.3
100 cycles	0.5	1.5	0.7	0.4	0.2	0.1	(-)0.2
150 cycles	0.3	1.6	1.0	0.5	0.2	0.0	(-)0.3
Durability Factor							
50 cycles	100.0	100.0	100.0	100.0	100.0	100.0	100.0
100 cycles	103.0	100.7	100.7	100.7	100.0	100.0	100.0
150 cycles	102.2	100.7	100.7	100.7	99.3	99.3	99.3
Chloride Ion Content: Base Level Cl-, PPM (lbs/cy) of concrete		53(0.2)		53(0.2)			83(0.3)

* (-) Indicates Weight Gain

TABLE 9

COMPRESSIVE STRENGTH, FREEZE-THAW, AND BASE LEVEL CHLORIDE ION CONCENTRATION TEST RESULTS CONCRETE CLASS AA

	Control Batches		EMSAC F-100 Test Batches					
Laboratory Batch #	Batch 8	Batch 9	Batch 10	Batch 11	Batch 12	Batch 13	Batch 14	Batch #15
Percent EMSAC F-100 by wgt. of cement	N.A.	N.A.	10	10	20	20	30	30
Compressive Strength, PSI:								
1 day	2854	2596	3411	3530	4087	4256	5042	5141
3 days	3938	3709	5390	5002	5748	6513	7260	7578
7 days	4624	3998	6514	6017	7409	7687	8851	9397
14 days	5300	5002	7518	7180	8234	8980	10,054	10,223
28 days	6126	5798	8373	7707	9736	10,293	11,088	11,715
Resistance To Freezing & Thawing: Weight Loss, percent								
50 cycles	0.7	2.0	0.4	0.3	0.4	0.0	0.5	0.0
100 cycles	1.2	2.1	0.7	1.7	0.8	0.2	0.5	0.1
150 cycles	1.9	2.1	2.4	2.8	1.2	1.1	0.5	0.2
Durability Factor								
50 cycles	100.7	100.0	100.0	100.0	100.0	100.0	100.0	100.0
100 cycles	103.0	100.7	100.2	97.8	102.9	100.0	102.1	100.0
150 cycles	103.0	102.2	100.7	98.5	101.4	100.7	99.3	100.0
Chloride Ion Content: Base Level Cl-, PPM (lbs/cy) of concrete		47(0.2)		65(0.3)		65(0.3)		100(0.4)

DISCUSSION OF RESULTS

Water demand decreased at almost a linear rate as the microsilica content was increased. This was probably due to the greater percentage of superplasticizer in the mix at higher EMSAC F-100 dosages. At relatively constant slumps, workability of the fresh concrete, as determined by ease of handling, became more difficult as the amount of silica fume was increased due primarily to its cohesive nature. Further discussion with the manufacturer indicated that limiting the EMSAC F-100 addition rate to 20% by weight of cement or increasing slumps by one to two inches would solve most of the handling problems. Increasing the water-cement ratio or limiting the maximum microsilica content would likely mean some sacrifice in the performance obtained with 30% EMSAC F-100 as presented here.

As the microsilica content of the mixes increased, mixing times had to be extended to assure complete blending of materials. Total mixing time for the control batches was five minutes while the Class AA mixes with 30% EMSAC F-100 required eight minutes for total dispersion. Prolonged mixing times were noted in earlier work done on high range water reducers as well [5]. The reduced water content combined with the overall sticky consistency of microsilica concrete required that test specimens be vibrated more intensely to reach complete consolidation.

Setting times for concrete with the microsilica additive were less than the control mixtures at the 10% addition rate and greater at the 30% addition rate while they were approximately equal to the setting times of the control batches at 20%. For example, the initial and final setting times of batch 10 with 10% microsilica additive were 23% and 26% earlier, respectively, than the Class AA control batches. The initial and final setting times of batch 14 mixed with 30% microsilica were 26% later than the corresponding setting times of the control mixtures. The initial and final times of set for batch 12 with 20% EMSAC F-100 were 3% later and 1% earlier than the respective setting times of the control concrete. As the quantity of EMSAC F-100 was increased, the volume of chemical admixture in the solution per weight of cement increased effectively accelerating setting times at the low dosages and retarding setting times at the high, a common quality of water reducing admixtures.

Entraining air in the microsilica concrete was not nearly as difficult as the manufacturer had initially indicated. The manufacturer as well as other sources [4] reported requiring AEA (air-entraining admixture) dosages of two or more times the control quantity to achieve air contents equivalent to the control. Fresh concrete testing demonstrated, for example, that when approximately equal AEA dosages were used in the Class AA control batches and batch numbers 14 and 15 made with 30% EMSAC F-100, air contents were 17% higher in the microsilica concrete. This contradiction in expected behavior is unexplained at this time.

Compressive strength of concrete produced with silica fume was substantially higher than the control concrete at all ages of test. As the percent of microsilica in the mix increased the cylinder strengths increased markedly. Class AA concrete with 30% EMSAC F-100 by weight of cement exhibited the most dramatic increase in strength, an average of 97% higher than the control. These results indicate that microsilica may be more effective as a pozzolin than fly ash or blast furnace slag which demonstrate less rapid strength gain at early ages of cure. It is not known, however, exactly how much of an effect the superplacticizer in EMSAC F-100 contributes to early strength development, but based on earlier work [5] it is assumed to be significant.

Early freeze-thaw test results indicate that as the percentage of microsilica was increased, the durability was moderately improved. After 150 freeze-thaw cycles in a 3% NaCl solution there was an average of 0.9% less weight loss in the Class A with 30% EMSAC F-100 and 1.7% less weight loss in the Class AA with 30% EMSAC F-100 compared to the control mixtures. As a result of the higher than normal air contents, durability of the control and the test concrete is expected to be excellent.

CONCLUSIONS

Laboratory testing conducted on EMSAC F-100 microsilica based concrete additive has demonstrated that conventional Portland Cement concrete can be enhanced significantly with its use.

Compressive strengths are increased 75 to 90 percent at the 30 percent EMSAC F-100 addition rate and preliminary indications are that freeze-thaw resistance relative to the conventional Vermont Agency of Transportation Class A and Class AA control mixtures is improved.

Although workability was reduced at the higher dosages of EMSAC F-100, the manufacturer indicated water content could be increased above that used in this study to improve handling characteristics. To what extent this action will effect other desirable properties is still questioned.

The finer pore structure of the concrete containing microsilica is expected to significantly retard deterioration as a result of reinforcing steel corrosion. If, in addition to reducing Chloride Ion penetration, the electrical resistivity is increased and the rate of oxygen transport remains constant as indicated by one source [6], microsilica should be considered in addition to, or as an alternate to, other bridge deck protection systems.

Cost figures quoted by the manufacturer in April of 1986 were $0.15 per pound F.O.B. Pittsburg, Pennsylvania. The resulting cost per cubic yard is estimated to increase by $50.00 at the 20% addition rate when shipping and handling is included.

RECOMMENDATIONS

Based on the favorable test results given in this report, it is recommended that testing for resistance to Chloride Ion penetration and freeze-thaw durability be continued. In order to more effectively evaluate EMSAC F-100, freezing and thawing should be extended to 500 cycles and 3% NaCl solution should be ponded for 300 days.

Long-term research should include studies on rate of slump loss and the electrical resistivity of microsilica concrete and the effect this has on protection of embedded reinforcement. These goals should be accomplished through continued literature review and laboratory and eventual field testing.

REFERENCES

[1] Pistilli, M. F., Rau, G., Cechner, R. "The Variability of Condensed Silica Fume From a Canadian Source and Its Influence on the Properties of Portland Cement Concrete", Cement, Concrete, and Aggregates, ASTM, Summer 1984, Vol. 6, No. 1, p. 33.

[2] "How Microsilica Improves Concrete", Concrete Construction, April 1985, pp. 327-331.

[3] Malhotra, V. M. and Carette, G. G., "Silica Fume", Concrete Construction, May 1982, p. 443.

[4] Carrette, G. G. and Malhotra, V. M., "Mechanical Properties, Durability, and Drying Shrinkage of Portland Cement Concrete Incorporating Silica Fume", Cement, Concrete, and Aggregates, ASTM, Summer 1983, Vol. 5, No. 1, pp. 3-13.

[5] Meyer, W. L., "Laboratory Evaluation of High Range Water Reducing Admixtures", Report 84-8, Vermont Agency of Transportation Materials & Research Division, October 1984.

[6] Fly Ash, Silica Fume, Slag & Other Mineral Products in Concrete, ACI Publication, SP-79, 1983, p. 719.

MATERIAL SAFE HANDLING DATA SHEET

ELKEM CHEMICALS, INC.
412-788-6490
Emergency Telephone Number:
Chemtrec: 800-424-9300

SECTION 1

EFFECTIVE DATE: May 1984

PRODUCT FAMILY OR NAME:	
EMSAC™ MICROSILICA ADDITIVES FOR CONCRETE.	**FORMULA:** Microsilica Slurry + Chemical Additive(s)
	SYNONYMS: EMSAC™
	PRODUCTS COVERED: EMSAC™ Family

SECTION 2

APPEARANCE AND ODOR:	MELTING POINT RANGE: (Approx.):	SOLUBILITY:	OTHER:
Gray, aqueous suspension of Amorphous Silica. No odor.	Not applicable **SPECIFIC GRAVITY (Approx.)** 1.25 to 1.35	Not applicable **REACTIVITY IN WATER:** Not applicable	Viscosity: <1000 centipose Approx. 50% solids pH: 6 ± 1

SECTION 3 TLV DATA ON PRINCIPAL ALLOY INGREDIENTS

SIGNIFICANT INGREDIENTS:	QUANTITY:	TLV (mg/M³): Silica (Amorphous) Dry Basis
Slurry of Amorphous Silica	88% - 100%	OSHA - 15 mg/m³ Total Dust, 5 mg/m³ Respirable Dust ACGIH* - 10 mg/m³ Total Dust, 5 mg/m³ Respirable Dust *ACGIH - American Conference of Governmental Industrial Hygienists Recommendation.
Chemical Additive(s)	Balance	

SECTION 4 FIRE AND EXPLOSION HAZARD DATA

COMBUSTIBILITY: The EMSAC ™ family is not combustible.
EXTINGUISHING MEDIA: Not applicable.

SECTION 5 HEALTH-HAZARD DATA

FIRST AID PROCEDURES:
SKIN CONTACT - Thoroughly wash exposed areas with soap and water.
EYE CONTACT - Flush with water to ensure that no particles remain in the eye.
INGESTION - EMSAC™ is of low toxicity. Avoid ingestion whenever possible.

EFFECTS OF OVEREXPOSURE:
EMSAC™ is of low toxicity. In the dried state, exposure to remaining solids may cause some irritation to the eyes, nose, and throat. No residual injury is expected.

ELKEM CHEMICALS, INC. • PITTSBURGH, PENNSYLVANIA 15275

SECTION 6 REACTIVITY DATA

STABILITY:
EMSAC™ is stable.

CONDITIONS TO AVOID:
(1) Generation of airborne dusts from dried EMSAC™ (2) Contact with hydrofluoric acid or fluorides may generate silicon tetrofluoride, a toxic substance (3) Mixing EMSAC™ with other products may alter toxicological properties.

MATERIALS TO AVOID:
Hydrofluoric acid (HF), fluorides.

HAZARDOUS DECOMPOSITION PRODUCTS:
Does not decompose.

SECTION 7 SPILL, LEAK OR DISPOSAL INFORMATION

STEPS TO BE TAKEN IN CASE OF SPILLS:
Contain all spills and leaks. Transfer spilled material to an appropriate container. Do not use compressed air to maneuver dried material.

WASTE DISPOSAL OR REPACK INFORMATION:
Dispose of according to applicable federal, state, and local regulations.

No special precautions are necessary for repacking.

SECTION 8 EMPLOYEE PROTECTION INFORMATION

RESPIRATORY PROTECTION:
Not applicable for handling EMSAC™

EYE PROTECTION:
Subject to safety rules; recommend wearing safety goggles.

VENTILATION:
Not applicable for EMSAC™

OTHER PROTECTION:
Clothes contaminated with EMSAC™ should be laundered before reuse. If dusts of dried material is present, use a United States Bureau of Mines Schedule 21B respirator.

SECTION 9 ADDITIONAL INFORMATION

HANDLING/STORAGE: Exposure to freeze — thaw cycles and boiling temperatures degrades EMSAC™ effectiveness. Continuous exposure to temperatures near or below 0° C (32° F) and near or above 100° C (212° F) may cause the EMSAC™ container to rupture due to internal pressure build-up.

LABELING: No Department of Transportation hazardous materials labels required.

APPENDIX B

Prepared By: C. Benda
Date: 11-22-85
Sheet 1 of 1

STATE OF VERMONT
AGENCY OF TRANSPORTATION
MATERIALS & RESEARCH DIVISION

PRODUCT EVALUATION

Work Plan No. 85-C-24

Product Emsac F-100 Microsilica Additive for Concrete

Manufacturer Elkem Chemicals Inc.
Parkwest Office Center
Cliff Mine Road
Pittsburgh, PA 15275

Distributor or Representative Buckeye Industries
P.O. Box 870
Scituate, MA 02066

Evaluation Requested By Structures Division **Date** November 7, 1985

Date Evaluation Required ASAP **Date Product Information Received** Nov.4, 1985

Date and Quantity of Samples Received Material to be shipped by distributor when quantity required for testing is known.

Purpose of Evaluation To determine if durability and impermeability of Vt. A.O.T. Standard Class A and Class AA concrete can be improved with the addition of Microsilica.

Proposed Tests Class A and Class AA test batches containing EMSAC at addition rates from 10 to 30 percent by weight of cement will be compared to standard reference mixes without Emsac Microsilica.

Testing to include Slump, Air Content, Unit Weight, Time of Setting, Freeze-Thaw Durability, Resistance to Chloride Ion Penetration and Compressive Strength @ 1, 3, 7, 14, and 28 days will be performed on 10 test batches and 4 reference batches. Initial report will document all test results up to and including 90 day Chloride ponding. Final report will include results of extended periods of Chloride ponding.

Proposal Discussed With DCB, NRD **Projected Manpower Requirements** 25 man-days

Evaluation To Be Conducted By Structural Concrete Subdivision

Proposed Starting Date Nov. 25, 1985 **Estimated Completion Date** Preliminary Report - 3/14/86, Final Report 11/21/86

Approval/Disapproval by Materials Engineer R. F. Nicholson 11-25-85

Comments by Materials Engineer

Materials & Research Division
Agency of Transportation
Date Typed: ~~11/22/85~~

STATE OF VERMONT
AGENCY OF TRANSPORTATION
MATERIALS & RESEARCH DIVISION

Addendum To Report 86-6

Preliminary Report On Emsac F-100
Microsilica Additive For Concrete
(Work Plan No. 85-C-24)

Background

Stimulated by claims of the enhanced performance of Portland Cement Concrete when Silica Fume is used as an additive, testing was initiated in November of 1985 to determine if conventional Vermont Agency of Transportation concrete mixtures used in bridge deck construction could be improved with the introduction of Emsac F-100 Microsilca additive from Elkem Chemicals, Inc..

Preliminary Report No. 86-6 recommended that prolonged testing for resistance to freezing and thawing and Chloride Ion penetration be conducted based on the favorable initial performance of Emsac F-100. This Update presents the results of continued testing and recommends a dosage for experimental use in the field.

It should be noted that Preliminary Report 86-6 indicated laboratory mixed concrete containing 10 to 30 percent condensed Silica Fume (Microsilica) by weight of cement was evaluated. This should be revised to read 4.5 to 13.5 percent condensed Silica Fume by weight of cement as Emsac F-100 is only 45 percent condensed Silica Fume by weight. 55 percent of Emsac F-100 is water and chemical admixtures.

Test Results

Given in Tables 1 and 2 are results of testing for compressive strength, resistance to Chloride Ion penetration and freeze-thaw durability.

Two 4" x 8" cylinders from each batch were tested for compressive strength (AASHTO T22-82) at 1, 3, 7, 14, and 28 days following standard moist curing. After 14 days of moist curing and 28 days of air drying, specimens to be used for determining resistance to Chloride Ion penetration were tested for base level Chloride Ion content. Upon completion of 100 and 200 days of continuous ponding with a 3% NaCl solution, the specimens were resampled for total Chloride Ion content at depths of 0.25" to 1" and 1" to 2" in accordance with AASHTO T260-84I. Specimens used to determine freeze-thaw durability were cycled from 40°F to 0°F and back to 40°F in a 3% NaCl solution 500 times following an initial 14 day moist curing period. The specimens were tested for weight loss and fundamental transverse frequency at 50 cycle intervals.

A complete summary of testing procedures and materials used in this evaluation along with fresh concrete test results can be found in Preliminary Report 86-6.

Summary

Laboratory testing conducted on Emsac F-100 Microsilica based concrete additive has demonstrated that conventional Portland Cement concrete can be enhanced significantly with its use.

Results indicate that Microsilica may be a more effective pozzolan than fly ash or blast furnace slag which demonstrate less rapid strength gain at early ages of test. Compressive strength of concrete produced with Silica Fume was substantially higher than the control concrete at all ages of test. As the per cent of Microsilica in the mix increased, the cylinder strengths increased markedly. Class AA concrete with 30% Emsac F-100 (13.5% Microsilica) by weight of cement exhibited the most dramatic increase in strength, an average of 91% higher than the control.

After subtracting baseline Chloride Ion levels, Emsac F-100 test batch specimens were found to be 5 to 80 times more resistant to Chloride Ion penetration in the top one inch of sample than the Class AA control mixture after 200 days of ponding.

Relative to the control, Class A concrete mixed with Emsac F-100 allowed approximately four times less Chloride Ion penetration in the top one inch of sample after 200 days of ponding.

None of the samples permitted Chloride ingress below the one inch depth greater than the threshold level of 1.3 lbs/cy, the level generally reported necessary to initiate corrosion.

Durability, as indicated by fundamental transverse frequency testing, was approximately equal for all samples. Weight loss after 500 cycles of freezing and thawing in a 3% NaCl solution decreased as the percent of Microsilica in the concrete mix increased. The high durability factors indicate a sound internal structure but the greater weight loss for the control mixtures and test batches with 10% Emsac F-100 are indicative of moderate to severe surface sealing.

Recommendations

Based on the favorable results given in this Update and Preliminary Report 86-6, it is recommended that condensed Silica Fume concrete be used in the field on a trial basis. Due to the extreme difficulty in finishing specimens fabricated with 30% Emsac F-100 and the less than spectacular permeability and freeze-thaw test values for the 10% addition rate, it is suggested that 15 to 20% Emsac F-100 by weight of cement be used.

Microsilica concrete should be considered as an alternative on bare deck or overlay construction not protected by a membrane and bituminous concrete overlay system. Class AA mix should be used when the depth of concrete is 2½" or less and Class A when the depth exceeds 2½".

Ponding of specimens with 3% NaCl should be continued for the 300 day period outlined in Preliminary Report 86-6 and a Final Report should be written documenting the results upon completion.

Reviewed By:

R. F. Nicholson

R. F. Nicholson, P.E.
Materials & Research Engineer

Date: Dec. 31, 1986

TABLE 1

COMPRESSIVE STRENGTH, FREEZE-THAW, AND CHLORIDE ION CONCENTRATION TEST RESULTS CONCRETE CLASS A

	Control Batches		EMSAC F-100 Test Batches				
Laboratory Batch #	Batch 1	Batch 2	Batch 3	Batch 4	Batch 5	Batch 6	Batch 7
Cement Content, lbs/cy	660	660	660	660	660	660	660
Percent EMSAC F-100 (Percent Silica Fume) by wgt. of cement	N.A.	N.A.	10(4.5)	10(4.5)	30(13.5)	30(13.5)	30(13.5)
Compressive Strength, PSI: 1 day	2834	2944	3401	3282	4525	4823	4416
3 days	4038	4495	5231	5131	7319	7628	7290
7 days	4644	4963	5808	5997	8145	8592	8304
14 days	5441	5500	6813	6962	9767	10,264	10,085
28 days	5887	6136	7399	7409	10,084	11,028	10,998
Resistance To Freezing & Thawing: Weight Loss, percent 500 cycles	5.0	6.4	3.3	2.3	1.2	0.7	0.6
Durability Factor 500 cycles	103.7	100.7	103.7	104.5	101.5	102.9	102.2
Chloride Ion Penetration, PPM (lbs/cy) of concrete							
Base Level Cl^-		53(0.2)		53(0.2)			83(0.3)
100 Day Ponding							
¼" to 1" depth		160(0.6)		86(0.3)			110(0.4)
1" to 2" depth		62(0.2)		53(0.2)			89(0.4)
200 Day Ponding							
¼" to 1" depth		466(1.9)		153(0.6)			198(0.8)
1" to 2" depth		62(0.2)		53(0.2)			92(0.4)

TABLE 2

COMPRESSIVE STRENGTH, FREEZE-THAW, AND CHLORIDE ION CONCENTRATION TEST RESULTS CONCRETE CLASS AA

	Control Batches		EMSAC F-100 Test Batches					
Laboratory Batch #	Batch 8	Batch 9	Batch 10	Batch 11	Batch 12	Batch 13	Batch 14	Batch #15
Cement Content, lbs/cy	705	705	705	705	705	705	705	705
Percent EMSAC F-100 (Percent Silica Fume) by wgt. of cement	N.A.	N.A.	10(4.5)	10(4.5)	20(9)	20(9)	30(13.5)	30(13.5)
Compressive Strength, PSI:								
1 day	2854	2596	3411	3530	4087	4256	5042	5141
3 days	3938	3709	5390	5002	5748	6513	7260	7578
7 days	4624	3998	6514	6017	7409	7687	8851	9397
14 days	5300	5002	7518	7180	8234	8980	10,054	10,223
28 days	6126	5798	8373	7707	9736	10,293	11,088	11,715
Resistance To Freezing & Thawing: Weight Loss, percent								
500 cycles	6.7	5.7	7.5	6.7	3.0	1.9	1.5	1.4
Durability Factor								
500 cycles	103.7	105.2	105.2	103.7	107.5	104.4	103.7	103.7
Chloride Ion Penetration, PPM (lbs/cy) of concrete								
Base Level Cl^-		47(0.2)		65(0.3)		65(0.3)		100(0.4)
100 Day Ponding								
¼" to 1" depth		918(3.7)		317(1.3)		98(0.4)		154(0.6)
1" to 2" depth		110(0.4)		83(0.3)		80(0.3)		95(0.4)
200 Day Ponding								
¼" to 1" depth		2907(11.6)		634(2.5)		142(0.6)		136(0.5)
1" to 2" depth		121 (0.5)		74(0.3)		80(0.3)		98(0.4)