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16. Abstract

This study consisted of a laboratory evaluation of the effect of microsilica on the physical properties of both plastic and hardened portland cement concrete. Microsilica (silica fume) is a by-product of the industrial manufacture of ferro silicon and other metallic silicones in high-temperature electric arc furnaces. Microsilica is a very fine material, pozzalanic in nature. Due to its physical and chemical characteristics, microsilica when used as an admixture has the potential of enhancing the properties of portland cement concrete.

In this study the variable selected for evaluation is the dosage rate of microsilica. Other variables included the microsilica source; the cement factor and the dosage rate of other admixtures. All experimental and control mixes contained cement and aggregate of the same type and from the same respective source. When utilized, air entraining and high-range water reducer admixtures were also of the same type and from the same respective source.

The results of this evaluation indicate that the inclusion of microsilica in a portland cement concrete mix can improve compressive and flexural strengths, increase the modulus of elasticity, improve resistance to scaling and decrease permeability. Physical properties that may be adversely affected by this admixture include freeze/thaw durability and workability. No conclusions could be drawn on the effect of microsilica on set times and length change and abrasion resistance.

A recommendation is made to further evaluate microsilica admixtures by and through the utilization of the product on selected project(s).

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EVALUATION OF MICROSILICA ADMIXTURE FOR PRODUCTION OF HIGH STRENGTH CONCRETE

BY

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RESEARCH REPORT NO. 227

RESEARCH PROJECT NO. 88-1C(B)

Conducted By

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AUGUST 1990

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A recommendation is made to further evaluate microsilica admixtures by and through the utilization of the product on selected project(s).

IMPLEMENTATION STATEMENT

The results of this study indicate that microsilica admixtures could be utilized in PCC under selected circumstances where added strength and low permeability mixes are required. Evaluation of several field installations are recommended prior to specifying its use routinely.

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INTRODUCTION

Microsilica (silica fume) is a by-product of the industrial manufacturing of ferro silicon or other metallic silicones in a high-temperature arc furnace. Microsilica particles consist of solid, glassy spheres of silicon dioxide of a fineness generally less than one micron (0.0004 inches) in diameter. The particle size of microsilica is generally from 50 to 100 times finer than the typical particle size of portland cement or flyash. Microsilica is a very fine material that is pozzalanic in nature and therefore has the ability to fill voids in the cement paste and positively react with the cement during the hydration process. Filling of voids and strengthening the mix should provide for a stronger mix that is more durable than normally achievable. Stronger and more durable mixes are needed for applications such as bridge decks and structural locations exposed to excessively corrosive conditions.

This study was undertaken to evaluate the effect of the microsilica admixture on the physical properties of plastic and hardened portland cement concrete.

PURPOSE AND SCOPE

The purpose of this study was to evaluate an admixtures (microsilica) ability to enhance portland cement concrete characteristics to such a degree that it would be beneficial in bridge decks and/or structural locations exposed to corrosive conditions.

The scope of this effort is limited to standard laboratory testing and comparison of test results concerning workability, strength and durability of pcc mixes with and without the microsilica admixture. Variables included in this study were the dosages and source of the microsilica, the cement factor and the dosages of other admixtures. Other variables that could affect the results of this study were effectively removed by utilizing the same type of cement, aggregate, air entraining admixture and water reducing admixture from their same respective sources.

METHODOLOGY

The methodology utilized during this study was established to enable acceptable comparisons of control mixes to experimental mixes. The laboratory testing program consisted of designing experimentally equivalent control and test mixes and conducting a series of standardized tests on both. One air-entrained duplicate mix at each cement factor for each microsilica source and addition rate were made for this evaluation. The following physical properties of the plastic and hardened concrete mixes were measured under the listed test conditions:

Slump	ASTM C-143	
Air content	ASTM C-148	
Unit Weight	ASTM C-148	
Set Time	ASTM C-403	
Compressive Strength	ASTM C-39	(7,28,42 DAYS)
Flexural Strength	ASTM C-78	(7,28,42 DAYS)
Static Modulus of Elasticity	ASTM C-469	(28 DAYS)
Abrasion Resistance	ASTM C-944	(38 DAYS)
Resistance To Rapid Freeze/Thaw	ASTM C-666	(PROCEDURE B)
Scaling Resistance	ASTM C-672	
Rapid Chloride Permeability	AASHTO T227	
Length Change	ASTM C-157	

The water cement ratio of all mixes was maintained at 0.40. To maintain a suitable workability, the dosage of the high-range water reducer had to be adjusted during mixing. The microsilica utilized during this study was in slurry form in one gallon cans. Each can contains approximately 50 percent microsilica, by weight. The water added to each mix was adjusted to account for the water contained in the slurry. The microsilica slurry was added to the mix at the same time as the cement.

DISCUSSION OF RESULTS

The pcc mixes, mixed and tested in this study contained the same type of cement, aggregate and admixtures. Variations in the mixtures were derived by changing the content or dosage rates of the cement and admixtures. The as mixed design variables are presented in Table 1.

TABLE 1
PCC MIX VARIATIONS

MIX NO.	MICROSILICA SOURCE[1]	RATE[2]	WATER REDUCER RATE[3]	AIR ENTRAINING RATE[4]	CEMENT FACTOR[5]
1(C)	n/a	0	12.0	0.0	7.0
2	n/a	0	12.0	1.0	7.0
3	A	1	13.0	0.0	7.0
4	A	1	15.0	2.5	7.0
5	B	1	7.5	0.0	7.0
6	B	1	8.0	0.75	7.0
7	A	2	8.2	0.0	7.0
8	A	2	15.5	3.0	7.0
9	B	2	6.8	0.0	7.0
10	B	2	2.5	2.25	7.0
11(C)	n/a	0	11.4	0.0	7.5
12	n/a	0	9.5	2.5	7.5
13	A	1	12.0	0.0	7.5
14	A	1	9.2	2.5	7.5
15	B	1	8.5	0.0	7.5
16	B	1	7.0	1.75	7.5
17	A	2	13.5	0.0	7.5
18	A	2	14.0	2.5	7.5
19	B	2	7.2	0.0	7.5
20	B	2	5.5	1.75	7.5

TABLE 1 (Cont'd)

PCC MIX VARIATIONS

MIX NO.	MICROSILICA SOURCE[1]	RATE[2]	WATER REDUCER RATE[3]	AIR ENTRAINING RATE[4]	BAG FACTOR[5]
21(C)	n/a	0	11.0	0.0	8.0
22	n/a	0	3.7	2.2	8.0
23	A	1	11.0	0.0	8.0
24	A	1	5.0	2.2	8.0
25	B	1	4.8	0.0	8.0
26	B	1	5.5	1.5	8.0
27	A	2	12.0	0.0	8.0
28	A	2	3.0	3.0	8.0
29	B	2	6.0	0.0	8.0
30	B	2	4.1	1.5	8.0

NOTES: 1) Microsilica source; A=W.R. Grace, Force -10000
B=Elkem Chemicals, Emsack

2) Microsilica rate; Gallons per sack of cement

3) Water Reducer rate; Ounces per sack of cement

4) Air Entraining rate; Ounces per sack of cement

5) Cement factor; No. of bags or sacks of cement per cu.yd.

WORKABILITY

The workability of pcc mixes is generally judged by the slump of the mix and its set time. Factors that normally control workability include the aggregate type and gradation, the cement bag factor, and the water-cement ratio. Admixtures may be added to mixes to adjust workability to desired levels.

In this study the water-cement ratio and the aggregate type and gradation were kept constant. As expected, the workability of the mixes as judged by the slump of the mix was reduced by the addition of the microsilica admixture. The workability of pcc mixes containing microsilica was readily maintained by increasing the dosage of the high-range water reducer. All slump tests for the 30 separate mixes as listed in Table 1 were between 4 and 8 inches. Initial and final set times were measured for each mix and are listed in Table 4, Appendix A along with measured air content and unit weight. Due to the presence of chemical admixtures in the microsilica slurry and in the mix and variations in the measured slump, the true effect of microsilica on set times could not be determined. As can be seen in the listed test results in Table 4, both acceleration and retardation of set times from control mix set times were measured.

STRENGTH CHARACTERISTICS

One of the main reasons for utilizing microsilica admixtures is to increase the strength characteristics of pcc. Compressive and flexural strengths of each of the 30 mixes were measured after curing. These strength measurements are listed in the following Table.

TABLE 2

COMPRESSIVE AND FLEXURAL STRENGTH

MIX	COMPRESSIVE STRENGTH @			FLEXURAL STRENGTH @		
NO.	7 DAY	28 DAY	42 DAY	7 DAY	28 DAY	42 DAY
			7.0 BAG MIXES			
1(C)	6907	8512	8340	879	846	821
2	8977	9275	9581	923	912	1030
3	8360	9508	9979	854	987	1085
4	8532	10894	10967	958	1225	1167
5	7763	9707	10469	912	1288	1020
6	7650	9056	9912	870	991	1191
7	9076	10085	10815	958	1025	1322
8	8187	9959	10012	900	1099	1154
9	8944	11206	11704	992	1365	1287
10	7398	9335	9475	900	1116	1230

TABLE 2 (Cont'd)

COMPRESSIVE AND FLEXURAL STRENGTH

MIX NO.	COMPRESSIVE STRENGTH @ 7 DAY	28 DAY	42 DAY	FLEXURAL STRENGTH @ 7 DAY	28 DAY	42 DAY
			7.5 BAG MIXES			
11(C)	7079	8877	9209	900	940	901
12	5003	5951	6482	700	739	755
13	8294	10523	10390	950	1193	1151
14	6857	8718	8645	821	1026	976
15	7657	9461	9581	892	1215	1066
16	6940	8632	7929	838	1055	891
17	9899	11697	11372	920	1295	1221
18	8333	8652	10642	791	1185	1095
19	9302	11196	11206	984	1240	1347
20	8333	9893	9786	975	1112	1244
			8.0 BAG MIXES			
21(C)	7152	8542	8911	916	983	876
22	5036	5706	6336	753	898	750
23	8167	10111	10490	930	1142	1273
24	5885	7258	7577	902	1160	990
25	8167	9461	9581	1008	1004	1112
26	7252	8075	8824	939	1041	1073
27	8824	10848	10947	1155	1241	1422
28	7079	8798	8619	800	941	1079
29	9561	11180	10788	971	1270	1324
30	8320	9023	9687	951	1264	1185

NOTE: All strength data is in psi.

The cement factor and the air content of a particular mix has a substantial effect on the strength characteristics of pcc. The above listed data are for non-air-entrained mixes and mixes that had air entraining admixtures added at a rate of 0.75 oz. per sack of cement to 3.0 oz. per sack of cement. Cement factors were 7.0, 7.5 and 8.0 with measured air contents ranging from 1.1 percent to 6.9 percent. For comparative purposes the data set above has been short listed in groups according to cement factor and reflect only those mixes wherein no air-entraining admixtures were added . The short-listed compressive and flexural strength data is presented in the following Table, along with corresponding modulus of elasticity and poisson's ratio.

TABLE 3

SHORT LIST OF STRENGTH DATA
(non-air-entrained mixes)

MIX NO.	BAG FACTOR	MICROSILICA SOURCE/RATE		42-DAY COMPRESSIVE/FLEXURAL		E	POISSON'S RATIO
1(C)	7.0	n/a	0	8340	821	6.13	0.2000
2	7.0	A	1	9979	1030	6.41	0.1886
5	7.0	B	1	10469	1020	6.45	0.2339
3	7.0	A	2	10815	1085	6.62	0.1996
9	7.0	B	2	11704	1287	6.42	0.2000
11(C)	7.5	n/a	0	9209	901	5.82	0.2169
13	7.5	A	1	10390	1151	6.43	0.2291
15	7.5	B	1	9581	1066	6.31	0.2293
17	7.5	A	2	11372	1221	6.31	0.2445
19	7.5	B	2	11206	1347	6.35	0.1885
21(C)	8.0	n/a	0	8911	876	5.78	0.2218
23	8.0	A	1	10490	1273	6.32	0.2366
25	8.0	B	1	9899	1112	6.16	0.2279
27	8.0	A	2	10947	1422	6.12	0.2211
29	8.0	B	2	10788	1324	6.55	0.2466

NOTES: 1) Microsilica source and rate as indicated in Table.
2) Compressive and Flexural strength in psi.
3) (E) Modulus of Elasticity in millions (psi)

The compressive, flexural and moduli strength data in Table 3 is presented graphically in Figures 1 through 3. As can be seen in Figure 1, there is a trend evident which indicates that compressive strengths increase with increasing microsilica contents. As with compressive strengths, flexural strengths also tend to increase with increasing microsilica content. The flexural strength data is presented in graphical form in Figure 2. There is little if any evidence indicating any marked differences attributable to microsilica source.

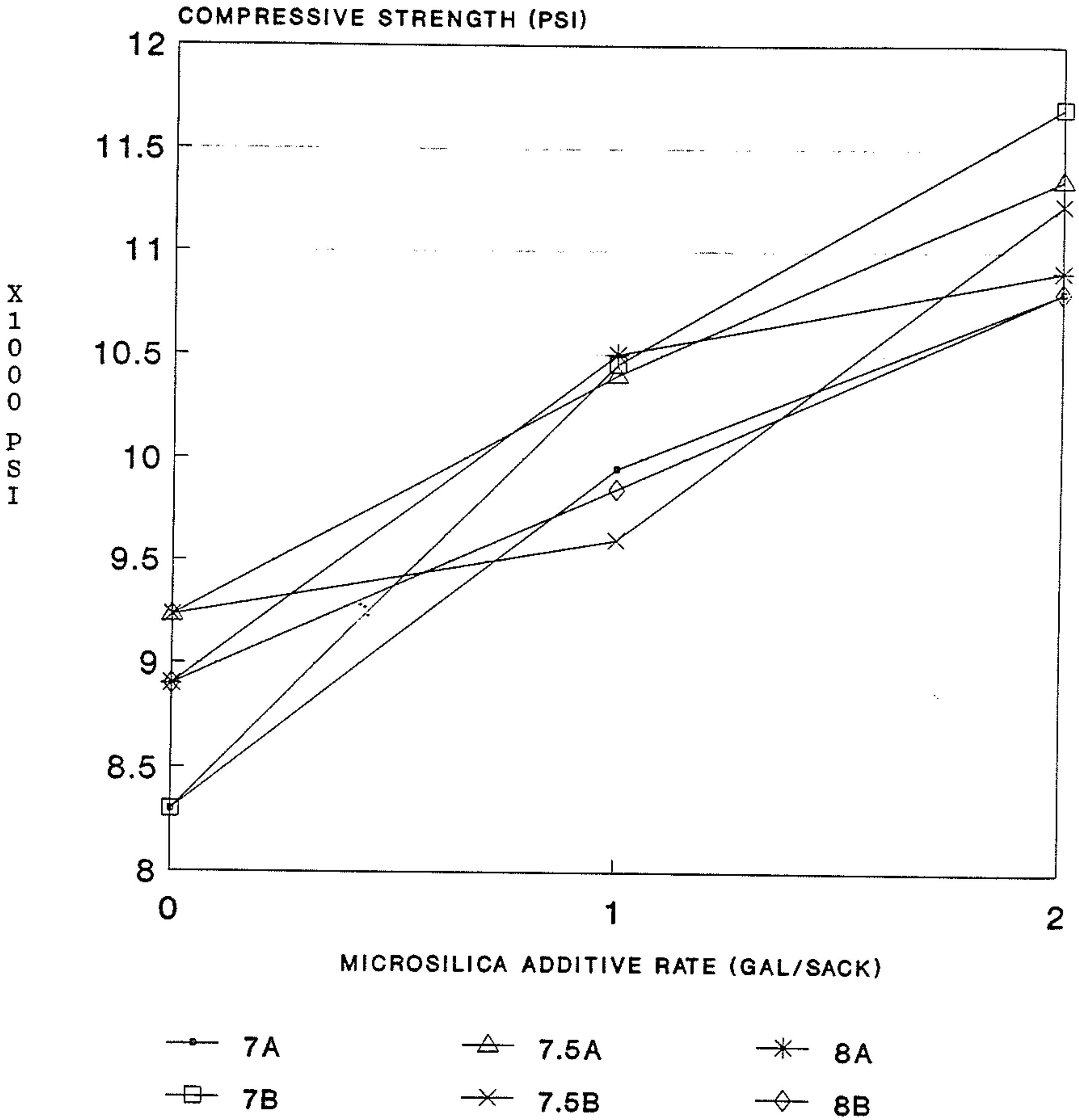

Figure 1

Compressive strength of microsilica/pcc mixes

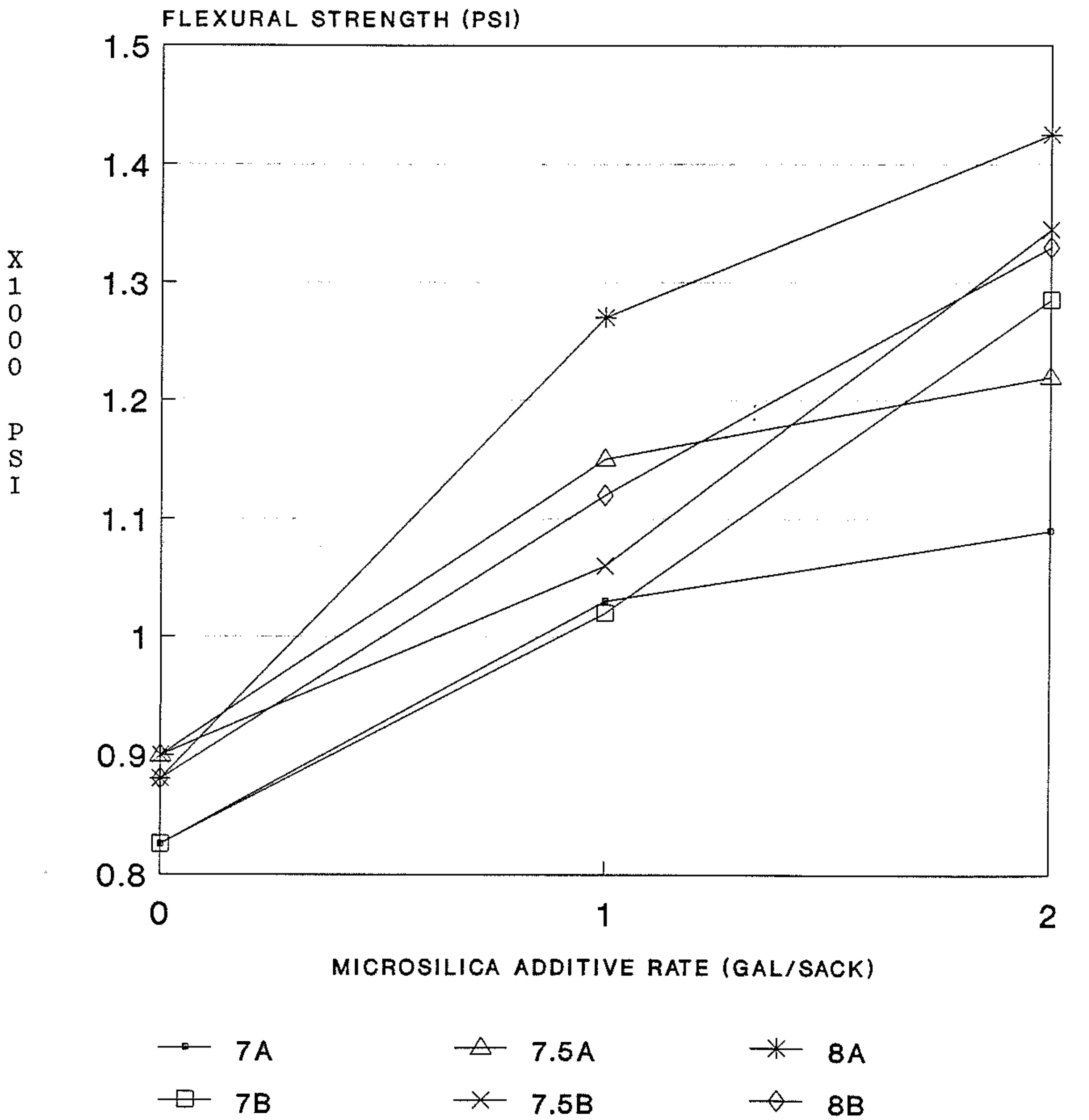

Figure 2

Flexural strength of microsilica/pcc mixes

Figure 3 presents the measured moduli of the pcc mixes as listed in Table 3. Moduli data indicates an increase in strength when the microsilica admixture rate is increased from 0.0 to 1.0 gallons per sack of cement. A somewhat less and in some cases a negative increase in moduli is indicated when the microsilica additive rate is increased from 1.0 to 2.0 gallons per sack of cement.

Of note, in the data sets for compressive and flexural strength and moduli are unexpected relative values for both the "control mixes" and the experimental mixes containing microsilica. For example, the compressive strength of the 7.5 bag "control" mix is higher than that measured for the 8.0 bag "control" mix. Another example is that at the microsilica additive rate of 2.0 gallons per sack of cement, a 7.0-sack mix obtained the highest compressive strength of all mixes tested, when one would expect the 8.0 sack mixes to obtain the higher compressive strengths. Likewise, the relativity in measured values of flexural strength and moduli are not always as expected. The reason for the unexpected relativity in measured strength indicators is not known.

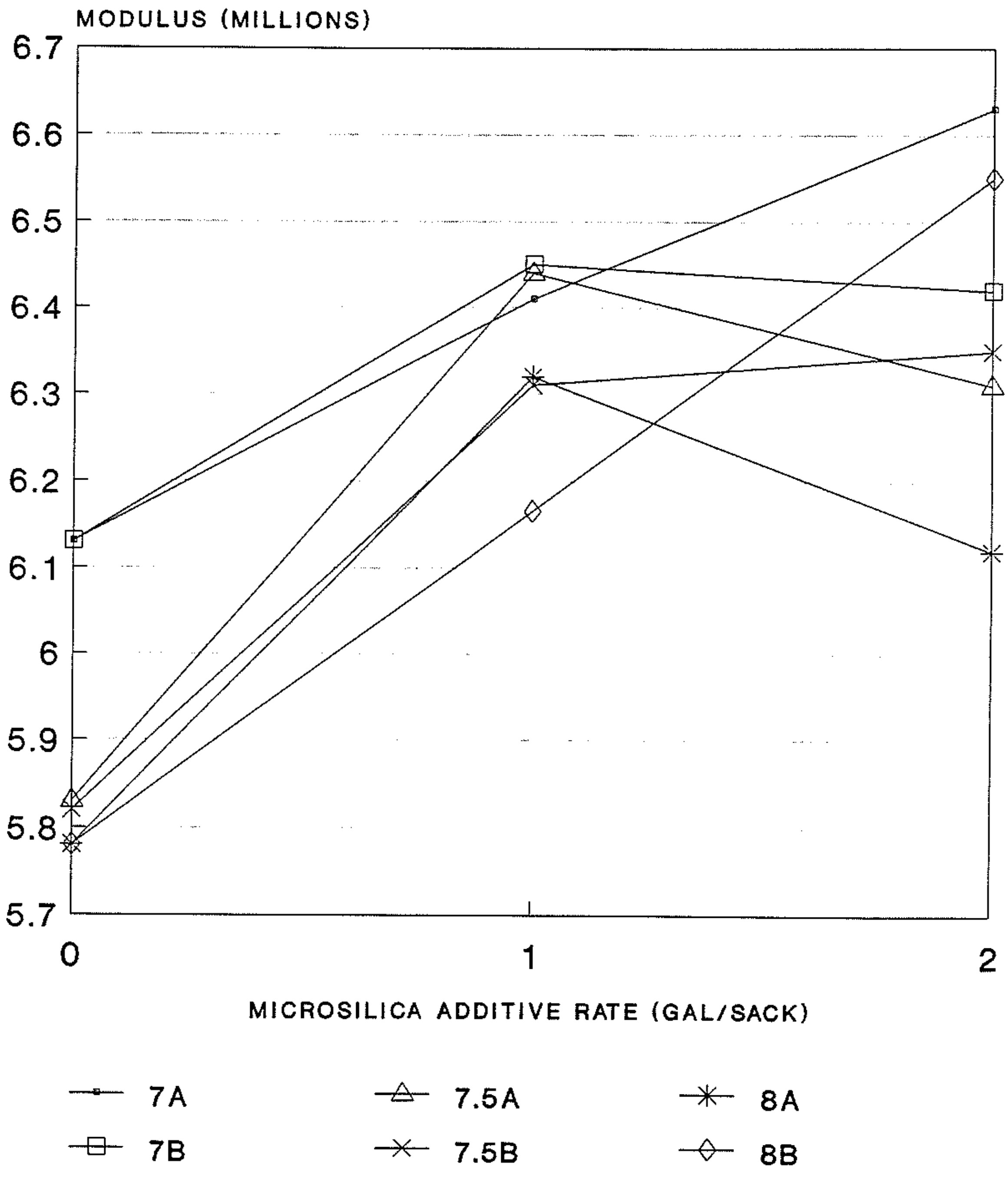

Figure 3
Modulus of elasticity of microsilica/pcc mixes

DURABILITY, PERMEABILITY, ABRASION AND SCALING TESTS

The durability of the pcc mixes in this study were characterized by conducting freeze/thaw, rapid chloride permeability, abrasion and scaling resistance tests. The results of this portion of the testing program are listed in Table 5 in Appendix B.

Air entraining admixtures are principally used to increase the void content of pcc paste and thereby increase the resistance of pcc to freeze/thaw degradation. Due to the very fine particle size of microsilica, the microsilica tends to fill the voids created in the paste. The void filling action of the microsilica tends to fill and thereby counteract the voids created through normal dosages of air entraining admixtures. To maintain freeze/thaw durability in pcc mixes utilizing microsilica, normal dosage rate of air entraining admixtures must be increased.

In the opposite sense that filled voids decrease freeze/thaw durability, filled voids improve the permeability resistance of pcc. The permeability data in Table 5, Appendix B indicates substantial decreases in permeability when utilizing microsilica as a pcc admixture.

Abrasion resistance data is included in Table 5, Appendix B. General indications from an examination of this abrasion test data are that resistance to abrasion generally increases as the dosage rate of microsilica increases from 0.0 to 1.0 gallons per sack and then generally decrease when the dosage rate is increased from 1.0 to 2.0 gallons per sack. This data indicates that decreases and/or little or no increases in resistance to abrasion can be attributable to the microsilica admixture.

Scaling test is another indicator of pcc durability. Testing of the pcc mixes to determine their scaling resistance to deicing chemicals was also conducted during this study. General trends evident from this test data indicate scaling resistance increases with increasing microsilica content and that mixes with air entraining admixtures generally had better resistance than mixes without air entraining admixtures. The test data for scaling resistance is included in Table 5, Appendix B.

OTHER TEST RESULTS

One additional test was conducted on the pcc mixes in this study. This test involved determining the length change of the hardened pcc. Excessive length change can result in crack formation and can effect both the strength and durability characteristics of a mix depending upon the intended use of the mix. Percent length change data is presented in Table 5, Appendix B.

Due to the variation in the data, no trends as to the affect of microsilica on length change are evident. For most applications, the test data indicate that the percent length change would not be excessive.

CONCLUSIONS

The conclusions that can be drawn from the observations and test results obtained during this study can be summarized as follows:

1. Microsilica as a pcc admixture has the potential for increasing the strength and durability of pcc mixes. The addition of microsilica tends to increase compressive, flexural strength and modulus of elasticity. The most pronounced effect of microsilica was observed by a marked increase in permeability resistance.

2. The addition of microsilica reduces the freeze/thaw durability of pcc; however, with increased dosage of air-entraining agents, satisfactory durability could be obtained.

3. Scaling resistance of pcc is increased by the addition of microsilica admixtures.

4. Test results regarding abrasion resistance, set time and length change are inadequate and it is recommended that no conclusions be drawn from this data.

5. The workability of pcc mixes which utilize a microsilica admixture is lower than the same mix without the microsilica but can be easily increased by the utilization of water reducers and is additionally benefited by air-entraining.

6. Microsilica admixture source did not appear to have any marked effect on test results.

7. The highest potential for benefit from microsilica admixtures would be for pcc mixes not exposed to freeze/thaw degradation yet where an increase in strength and a decrease in permeability are needed, such as bridge decks and structures subject to corrosive conditions.

RECOMMENDATIONS

It is recommended that a well-designed PCC mix containing a microsilica admixture be utilized experimentally for construction of a substructure or bridge deck in a coastal location in south Louisiana and be cost effective. If microsilica is found to be of benefit after a suitable evaluation period, the utilization of this admixture should be extended to other select locations and uses. Microsilica could be cost effective in that smaller columns girders, etc. could be designed because of miscrosilica concrete's higher strength.

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APPENDIX A

TEST DATA ON PCC MIXES; PLASTIC

TABLE 4
TEST DATA ON PCC MIXES; PLASTIC

MIX NO.	SET TIME[1] INITIAL	/ FINAL	AIR CONTENT[2]	UNIT WEIGHT[3]	SLUMP[4]
			7.0 BAG MIXES		
1(C)	5.92	7.42	1.2	151.2	6.00
2	6.85	8.35	4.2	149.6	4.50
3	4.35	5.70	2.0	148.8	4.00
4	7.55	8.83	3.7	148.8	5.75
5	7.40	8.50	1.2	149.2	7.00
6	6.25	7.45	4.8	142.0	7.00
7	5.80	7.00	2.0	148.8	4.50
8	6.80	8.10	5.0	143.2	5.25
9	7.35	8.70	1.1	148.8	5.50
10	8.80	9.95	6.9	139.2	7.00
			7.5 BAG MIXES		
11(C)	5.17	6.42	1.2	148.0	7.00
12	5.35	6.83	5.9	135.6	7.50
13	5.10	6.33	1.4	149.2	5.75
14	5.50	6.75	5.2	141.2	6.00
15	7.40	8.50	1.3	147.6	6.00
16	6.15	7.22	5.9	140.0	7.00
17	5.67	6.83	1.2	148.8	6.00
18	6.68	7.95	4.1	143.2	8.00
19	8.25	9.30	1.4	148.0	6.75
20	8.60	9.75	5.9	140.0	6.50
			8.0 BAG MIXES		
21(C)	4.55	5.95	1.7	148.0	7.00
22	5.30	7.10	6.0	138.0	7.00
23	5.65	7.00	1.1	148.0	7.00
24	4.50	5.50	6.0	137.2	7.25
25	5.70	6.80	1.2	146.8	6.25
26	6.50	7.50	5.8	140.8	6.75
27	5.67	6.78	1.1	148.0	6.25
28	4.95	6.00	5.8	140.8	5.00

TABLE 4 (Cont'd)

TEST DATA ON PCC MIXES; PLASTIC

MIX NO.	SET TIME INITIAL	/ FINAL	AIR CONTENT	UNIT WEIGHT	SLUMP
29	8.53	9.58	1.3	146.8	7.25
30	7.80	8.75	5.1	141.2	7.50

NOTES: 1) HOURS

2) PERCENT BY VOLUME

3) POUNDS PER CUBIC FOOT

4) INCHES

APPENDIX B

DURABILITY, PERMEABILITY, SCALING
SCALING AND LENGTH CHANGE TEST RESULTS

TABLE 5

PHYSICAL TEST RESULTS

MIX NO.	FREEZE/THAW DURABILITY (cycles)[1]	(df)[2]	CHLORIDE PERMEABILITY (value)[3]/(rating)[4]	RESISTANCE TO ABRASION (loss)[5]	SCALING (rating)[6]	LENGTH CHANGE (%)
			7.0 BAG MIXES			
1(C)	94	19	2391/ MOD.	0.008	5.0	0.020
2	71	14	1986/ LOW	0.007	5.0	0.020
3	22	4	559/V.LOW	0.008	3.0	0.016
4	44	9	428/V.LOW	0.008	2.0	0.018
5	30	6	1049/ LOW	0.004	1.5	0.018
6	232	46	701/V.LOW	0.006	1.0	0.019
7	31	6	253/V.LOW	0.004	3.5	0.012
8	300	65	317/V.LOW	0.005	1.0	0.016
9	40	8	426/V.LOW	0.002	1.0	0.018
10	71	300	350/V.LOW	0.006	1.0	0.020
			7.5 BAG MIXES			
11(C)	51	10	2815/ MOD.	0.008	5.0	0.023
12	300	91	2920/ MOD.	0.004	1.0	0.027
13	30	6	749/V.LOW	0.005	4.0	0.025
14	241	48	744/V.LOW	0.011	2.0	0.024
15	36	7	827/V.LOW	0.008	4.5	0.020
16	300	82	777/V.LOW	0.006	1.5	0.021
17	24	5	302/V.LOW	0.005	3.0	0.018
18	165	33	340/V.LOW	0.004	0.5	0.020
19	37	7	346/V.LOW	0.005	1.0	0.015
20	300	74	390/V.LOW	0.006	1.0	0.026
			8.0 BAG MIXES			
21(C)	47	9	3370/ MOD.	0.003	5.0	0.023
22	300	88	4156/ HIGH	0.007	3.5	0.027
23	22	4	743/V.LOW	0.004	5.0	0.018
24	300	82	660/V.LOW	0.007	1.5	0.026
25	44	9	880/V.LOW	0.006	5.0	0.020
26	300	90	748/V.LOW	0.011	1.5	0.028
27	30	6	373/V.LOW	0.006	4.5	0.018
28	287	62	458/V.LOW	0.006	1.0	0.018

TABLE 5 (Cont'd)

PHYSICAL TEST RESULTS

MIX NO.	FREEZE/THAW DURABILITY (cycles)[1]	(df)[2]	CHLORIDE PERMEABILITY (value)[3]/(rating)[4]	RESISTANCE TO ABRASION (loss)[5]	SCALING (rating)[6]	LENGTH CHANGE (%)
29	25	5	376/V.LOW	0.003	3.0	0.022
30	164	33	322/V.LOW	0.006	1.0	0.020

NOTES:

1. Freeze/Thaw: Number of cycles at test termination
2. Durability factor
3. Coulombs
4. Relative descriptive rating
5. Grams per square centimeter
6. Relative descriptive rating, 0=no scaling to 5=sever scaling