

# Silica Fume, Latex-Modified Portland Cement Mortars and Concretes

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Portland cement mortars and concretes, modified by the addition of silica fume (SF) or by styrene-butadiene (S-B) latexes, have and are being used as overlays for bridge and parking-garage decks. The overlays are used both in repair of old construction and in new construction. The primary reason for the incorporation of either admixture in overlays is to improve permeability resistance of the mortar or concrete to deicing salts. The latter cause corrosion of reinforcing steel, which in turn leads to deterioration of the deck. SF is widely used to produce high compressive strength concrete. Laboratory work is described that examines the combined use of silica fume and S-B latex. The results indicate that the combined use of SF and S-B latex yields mortars and concretes that have superior properties to those using one or the other of the admixtures. This work also indicates that the two admixtures can be combined into one, which means that current equipment for placing latex-modified mortars or concretes could be used without modification.

S-B latex-modified mortars and concretes (LMCs) have been used since 1959 (1) as protective overlays for bridge and parking-garage decks. LMC is now considered a standard-type overlay for providing permeability resistance to deicing salts and satisfactory adhesion or bond to the subdeck of the construction.

SF-modified concrete (SFC) has been used since 1982 (2) for similar applications.

Although LMC has low permeability to water-soluble salts, it is significantly higher than that of SFC; also the compressive strength of LMC is significantly lower. Conversely, it is accepted that SFC has lower adhesion and flexural strength values than those of LMC, and the latter does not require extensive moist curing.

SF and S-B latex have been used together in portland cement mixtures (M. MacArthur, unpublished data), but there does not appear to have been any attempt to use the combination for deck overlays.

## EXPERIMENTAL

In this work, the following test procedures were used:

- Flow of mortars (ASTM C230), 25 drops;
- Wet densities were determined by measuring the mass in grams required to fill a 400-ml Vicat cup and dividing the value by 400;
- Compressive strength of mortars (ASTM C109);
- Flexural strength (ASTM C78);

- Permeability (AASHTO T277);
- Adhesion-tensile bond method developed by Kuhlmann (3); and
- Dry densities were determined by measuring the mass of the various test specimens and dividing by their relative and approximate volume.

The mixture proportioning of all of the mortars used a 3:1 ratio of silica sand to portland cement. Details of the gradation of the silica sand are presented in Table 1.

Except where stated otherwise, the mortars and concretes were cured for 1 day in the mold covered with wet paper toweling and plastic sheeting followed by storage in laboratory air at about 50 percent relative humidity and at 75°F until time of testing.

Four mortars were prepared, one contained no admixtures, the second had a ratio of SF to portland cement of 0.10, the third a ratio of S-B polymer to cement of 0.15, and the fourth used both admixtures with ratios of SF and S-B polymer to cement of 0.10 and 0.15, respectively. The SF (Emsac F-100, Elkem Materials, Inc., Pittsburgh, Pa.) was obtained in an aqueous dispersion with a reported activity of 50 percent. The S-B latex (Tylac 6800 9-00, Reichhold Chemicals, Inc., Dover, Del.), which was carboxylated and had an approximate S-B ratio of 65/35, had a solids or nonvolatile content (NVC) of 47 percent. The nonlatex mortars had ratios of water to cement of 0.50, whereas those containing latex had ratios of 0.34. The unhardened mortars were measured for flow. The hardened mortars were measured for adhesion and for permeability. The nonlatex mortars were cured in saturated lime water for 27 days after demolding (where applicable).

SF is available in several forms (2). Two other SFs were obtained from different suppliers, one was an aqueous dispersion (Force 10,000, W. R. Grace Co., Cambridge Mass.) with a reported activity of 60 percent, whereas the second was in powder form (MB-SF, Master Builders, Cleveland, Ohio).

The three SFs were blended with the S-B latex to give a ratio of polymer to SF of 0.67. Viscosities of the blends were measured immediately and periodically over a period of 66 days. The blends were stored in closed plastic containers at about 75°F. Viscosities were measured using an RVF Brookfield viscometer at 20 rpm with a No. 3 spindle.

The three SFs were used at a 10 percent level on portland cement in a mortar with a ratio of S-B polymer to cement of 0.15. The water level was adjusted to yield a flow of 100 to 114 percent. A fourth mortar was included in the series that contained no SF. The mortars were measured for wet density, dry density, adhesion, and permeability, for set times

TABLE 1 GRADATION OF ESG SAND

SIEVE SIZE	% PASSING	% PASSING CUMULATIVE
3/8 inch	100	0
# 4	99	1
# 8	95	5
# 16	84	16
# 30	29	71
# 50	6	94
#100	2	98

FINENESS MODULUS = 2.85

using Gillmore needles (ASTM C266). Adhesion was measured 9 days after mixing, dry density 21 days after mixing, and permeability 28 days after mixing.

One of the SF dispersions was blended with the S-B latex to give a ratio of polymer to SF of 0.67. This blend was stored in a closed plastic container at about 75°F. At 0, 1, 2, 3, and 4 months after making the blend, samples were taken and

used to make portland cement mortars using a ratio of polymer to cement of 0.15, a ratio of SF to cement of 0.10, and a ratio of water to cement of 0.32. The mortars were measured for flow and wet density. A 2-in.-high, 4-in.-diameter cylinder was made with each mortar. Permeability of the specimen was measured 28 days after mixing.

Using one of the SF dispersions and the S-B latex, portland cement mortars were made using ratios of SF to portland cement of 0.00, 0.05, and 0.10. Ratios of S-B polymer to portland cement were 0.00, 0.075, and 0.15. Water levels were adjusted to a flow of 100 to 114 percent. The unhardened mortars were measured for wet density. The mortars not containing latex were cured for 1 day in the relevant mold covered with wet paper toweling and plastic sheeting, followed by storage in saturated lime-water at about 75°F. The hardened mortars were measured for density. Flexural strengths were determined 7 and 28 days after mixing, with samples measuring 5 × 1 × 1 in. Compressive strengths were measured 7 and 28 days after mixing, permeability 28 days after mixing. In all cases, three test specimens were used in measuring each property.

TABLE 2 COMPARISON OF LATEX-MODIFIED CONCRETES

Concrete Proportioning	A-5 parts by weight, as received	B-5
Portland cement Type I	100	100
ESG Sand	250	250
Pea-Gravel*	200	200
S-B Latex (47% NVC)	32	32
SF dispersion (50%)	0	12
water	19	14
Unhardened Concrete Properties		
Slump, C 143, inches	3.5	4.0
Air Content, C 231, %	6.2	6.4
Density, Lb/cu. ft	141	141
Hardened Concrete Properties		
Compressive Strength, C 39, psi		
3 days	3330	3200
7 days	3860	3830
14 days	4070	5660
28 days	5750	6850
Adhesion, Tensile Bond, psi		
3 days	205	190
7 days	250	250
14 days	300	275
28 days	310	270
Flexural Strength, C 78, psi		
28 days	1010	1100
Permeability, T 277, coulombs		
14 days	1640	590
28 days	1190	250

\* the pea-gravel had an approximate diameter of 1/4 inch, all of it passed through a 3/8 inch sieve and none passed through a No. 4 sieve.

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TABLE 3 COMPARISON OF PORTLAND CEMENT MORTARS

Mortar	A-1	B-1	C-1	D-1
Proportioning	parts by weight, as received			
Portland Cement I	100	100	100	100
ESG Sand	300	300	300	300
SF dispersion (50%)	0	20	0	20
S-B Latex (47% NVC)	0	0	32	32
water	50	40	17	7
Unhardened Mortar Properties				
Flow, C 230, %	111	123	112	115
Type of Cure	Wet	Wet	Dry	Dry
Hardened Mortar Properties				
Adhesion, psi				
7 days	140	155	365	290
Permeability, coulombs				
28 days	8160	900	1980	120

Finally, two latex-modified concretes were prepared. Mixture proportioning is presented in Table 2. One contained SF at a ratio of SF to portland cement of 0.06, whereas the other did not. The unhardened concretes were measured for air content (ASTM C231), slump (ASTM C143), and wet density using a 0.5-ft<sup>3</sup> bucket. The hardened concretes were measured for flexural strength after 28 days using 22- × 6- × 6-in. beams; for compressive strength after 3, 7, 14, and 28 days using 6- × 3-in.-diameter cylinders by ASTM C39; for adhesion after 3, 7, 14, and 28 days; and for permeability after 14 and 28 days. For flexural strength, compressive strength, and adhesion measurements, three specimens were tested at each age. For permeability measurements, four test specimens were tested at each age.

## RESULTS AND DISCUSSION

Values for coefficients of variations (COV) were determined for adhesion (tensile bond), permeability, flexural strength, and compressive strength. These values obtained by dividing the standard deviation by the average value and expressing it as a percentage, were as follows:

Parameter	COV (%)
Adhesion	7.3
Permeability	11.7
Flexural strength	8.9
Compressive strength	3.2

Table 3 presents the initial comparison of unmodified; SF-modified; latex-modified; and silica fume, latex-modified mortars (SFLMC). As expected, the SFC gave a significantly lower permeability than that of the LMC, which in turn was significantly lower than that of the unmodified mortar. However, the permeability of the SFLMC was significantly lower than that of the SFC. Also as expected, the bond strength of the SFC was similar to that of the unmodified mortar, whereas that of the LMC was higher. The bond strength of the SFLMC was significantly higher than those of either of the unmodified and SF mortars, and the former approached that of the LMC. This study indicated that the combined use of SF and S-B

latex could yield a material with outstanding permeability resistance without significant loss of other advantageous properties.

Table 4 presents the viscosity of the blends of the three different types of SF with the S-B latex. The viscosity of the blend using the SF in powder form could not be obtained because an incompatible mixture was obtained. It appeared that the surfactant in the latex was unable to wet out the SF powder. With one of the SF dispersion-latex blends, the viscosity was relatively constant over the storage period of 66 days, whereas the viscosity of the other blend gradually increased. The SF dispersions probably contain water-reducing agents that would account for the various degrees of compatibility of the latex with the three silica fumes.

Table 5 presents the comparison of LMC with SFLMC using the three different sources of SF. The two SFLMC values using the dispersed SF gave virtually identical properties, but the permeability of the SFLMC using the powdered form of SF was significantly higher than that of the other mortars.

The blend of the one SF dispersion and S-B latex gave similar workability and permeability properties in a portland cement mortar despite being stored in the blended form for 4 months. Data are presented in Table 6.

Table 7 presents the data obtained from a series of mortars that contained ratios of SF and S-B latex to cement varying from 0.0 to 0.10 and 0.0 to 0.15, respectively. As expected, compressive strength increases with increasing SF level, as permeability decreases. Also as expected, flexural strength increases with increasing S-B latex level, as permeability decreases. Although the incorporation of the S-B latex causes a decrease in the compressive strength of SFC, the incorporation of SF does not cause any decrease in the flexural strength of LMC. From this work, it was judged that the optimum ratios of S-B latex and SF for overlay applications would be 0.15 and 0.07, respectively.

Table 2 presents the comparison of a standard latex-modified concrete overlay with one modified by the addition of SF at a level to yield a ratio of SF to cement of 0.7. No significant differences were observed in the properties of the unhardened concretes. But the SFLMC gave significantly lower (better) permeability values and higher compressive strengths,

TABLE 4 COMPATIBILITY OF LATEX AND SILICA FUME

Mixture	A-2	B-2	C-2
	parts by weight, as received		
S-B Latex (47% NVC)	100	100	100
SF dispersion (60% active)	52.2	0	0
SF dispersion (50% active)	0	62.5	0
SF powder	0	0	31.5
Viscosity, Brookfield, RVF, 20 rpm			
initial, cps	460	220	ic
7 days, cps	480	500	ic
14 days, cps	500	800	ic
28 days, cps	420	1060	ic
66 days, cps	500	1240	ic

ic = incompatible mixture obtained.

TABLE 5 LATEX-MODIFIED MORTARS WITH DIFFERENT SILICA FUMES

Mortar	A-3	B-3	C-3	D-3
Mixture Proportioning				
	parts by weight, as received			
Portland Cement, I	100	100	100	100
ESG Sand	300	300	300	300
S-B latex (47% NVC)	32	32	32	32
SF dispersion (60%)	0	16.7	0	0
SF dispersion (50%)	0	0	20	0
SF powder	0	0	0	10
water	15	7.6	4.5	20
Unhardened Mortar Properties				
Flow, C 230, %	112	111	111	111
Set Times, Gillmore				
initial, min	95	80	55	75
final, min	210	140	100	200
Wet Density, g/ml	2.24	2.27	2.27	2.21
Hardened Mortar Properties				
Dry Density, g/ml	2.08	2.12	2.09	2.05
Adhesion, psi	360	310	310	365
Permeability, coulombs	930	140	100	520

TABLE 6 STORAGE OF LATEX AND SILICA FUME BLEND

Time of Storage months	0	1	2	3	4
Flow, %	106	107	106	106	107
Wet Density g/ml	2.26	2.27	2.26	2.28	2.27
Permeability coulombs	130	180	140	140	130

TABLE 7 MORTARS WITH VARYING LEVELS OF LATEX AND SILICA FUME

Mortar Proportioning	A-4	B-4	C-4	D-4	E-4	F-4	G-4	H-4	I-4
	parts by weight as received								
P. Cement I	100	100	100	100	100	100	100	100	100
ESG Sand	300	300	300	300	300	300	300	300	300
SF (50%)	0	10	20	0	10	20	0	10	20
S-B Latex (47%)	0	0	0	16	16	16	32	32	32
water	45	44	35	30	25	20	15	10	8
Unhardened Mortar Properties									
Flow, %	111	113	111	111	111	111	110	111	111
Density, g/ml	2.30	2.30	2.03	2.28	2.21	2.24	2.21	2.22	2.24
Type of Cure	Wet	Wet	Wet	Dry	Dry	Dry	Dry	Dry	Dry
Hardened Mortar Properties									
Density, g/ml	2.12	2.23	2.19	2.12	2.11	2.15	2.12	2.17	2.16
Compressive Strength, psi									
7 days	5180	5970	6710	5320	5520	6380	5410	5770	5540
28 days	6750	8000	8830	6900	7040	8100	6650	6950	6750
Flexural Strength, psi									
7 days	440	560	640	890	930	940	1410	1370	1240
28 days	720	690	800	1330	1520	1410	1800	1830	1820
Permeability, 28 days									
coulombs	6890	2150	610	3590	460	350	2010	270	140

whereas bond and flexural strengths were similar to that of the LMC.

## CONCLUSIONS

The combined use of silica fume and S-B latex dispersions can yield a concrete that is suitable for overlay applications. Such a concrete has excellent permeability resistance and acceptable compressive strength, while maintaining the good adhesion and flexural strength properties of latex-modified concrete.

Because acceptable blends of SF and S-B latex can be made and stored for reasonable periods of time, normal equipment and practices used for LMC should also be suitable for SFLMC.

## RECOMMENDATIONS

It is recommended that further work be carried out using SF and S-B latex blends, particularly to (a) determine if the blends are cost effective, (b) determine resistance of SFLMC to freezing and thawing, and (c) examine the use of such blends in mobile mixers and in field placements.

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