Experimental Installation of a Concrete Bridge-Deck Overlay Containing Silica Fume

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This paper summarizes the experimental installation of a concrete bridge deck overlay containing silica fume (SF). The minimum thickness of the overlay was specified as 1.25 in. The objective was to determine whether concretes containing silica fume can be successfully used in thin overlays as a cost-effective alternative to the widely used latex-modified concrete (LMC). A two-lane, four-span bridge deck was overlaid with concrete containing silica fume at 7 percent or 10 percent by weight of the portland cement as an additional cementitious material. The concrete was mixed in a truck mixer rather than a continuous mixer (which is used for LMC), but otherwise the placement procedures established for LMC were applied to concretes with SF. Concretes with 7 percent or 10 percent SF exhibited satisfactory strengths and would be rated as having very low chloride permeability as determined by AASHTO Method T 277. The resistance of these concretes to cycles of freezing and thawing were satisfactory when air content was within specification. Performance of the SF concrete will be monitored for a period of at least 5 yr to evaluate the durability of the overlay.

Laboratory investigation at the Virginia Transportation Research Council and studies by others indicate that concretes containing silica fume (SF) exhibit low permeabilities and are resistant to the intrusion of chlorides or other corrosive solutions (*1–3*). Such liquids can cause corrosion of the reinforcing bars and consequent deterioration of the concrete in bridge decks. Currently, one of the protective systems against corrosion widely used in the repair of bridge decks is latex-modified concrete. This concrete, generally used in thin overlays with a minimum thickness of 1.25 in. is effective but costly. A possible alternative to LMC is concrete containing SF (*1*). In addition to the cost savings, other benefits such as improved strength and resistance to alkali-aggregate reaction are expected from the use of concrete with SF. Savings result from a reduction in actual material costs and from the use of widely available truck mixers for concretes with SF instead of mobile mixers, which are required for LMC.

The experimental installation described in this report was initiated to investigate SF concretes under field conditions as a possible alternative to LMC.

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OBJECTIVE

The objective of the project was to determine whether concretes containing SF can be successfully used in thin overlays with a minimum thickness of 1.25 in. as a cost-effective alternative to the widely used LMC system.

PROJECT DESCRIPTION

The bridge overlaid with SF concrete was built in 1941 and is located on Route 50 over Opequon Creek near Winchester, Virginia. The deck carries westbound traffic and has two lanes and four spans; each span is 42.5 ft long and 24 ft wide. The deck is on a 5° grade and is lower at the west end. The minimum thickness of the overlay containing silica fume was specified as 1.25 in. Silica fume was added at 7 percent or 10 percent by weight of portland cement.

The degree of resistance of concretes to the penetration of chloride ion, was determined by the rapid chloride permeability test given in AASHTO T 277 and explained in detail in an FHWA report (*4*). This test measures the amount of electricity in coulombs passed through the specimen in 6 hr. The relative resistance to penetration of chloride ions is judged by the total charge passed through the specimen (Table 1). LMC produced from locally available materials is expected to yield low or sometimes moderate chloride permeability at 28 days and low or very low permeability at later ages (90 and 365 days) as indicated by this test. Such concretes have performed satisfactorily over the years (*5*). Concretes with silica fume will be considered satisfactory if low or very low permeability can be obtained at 28 and 90 days. In earlier laboratory work, concretes with 5 percent silica-fume replacement of the portland cement have yielded satisfactory results (*1*). However, because of the variabilities expected in the field and the recommendations of the marketers of the silica fume products, higher amounts (7 or 10 percent) were used in this study.

During construction, the placement procedure was observed and recorded. Samples were obtained from four of the seven truckloads of concrete and tested for air content, slump, and temperature at the fresh stage. Specimens were then prepared for tests on strength, permeability to chloride ions, and resistance to cycles of freezing and thawing. Also, a petrographic analysis of the air-void system in the hardened concrete was made (Table 2). The condition of the overlay will be monitored periodically for 5 yr.

TABLE 1 RAPID CHLORIDE PERMEABILITY TEST

Charged Passed, coulombs	Chloride Permeability
>4000	High
2000 to 4000	Moderate
1000 to 2000	Low
100 to 1000	Very low
<100	Negligible

Materials and Mixture Proportions

A type 2 cement and a commercially available silica-fume slurry were used. The materials, including silica fume, were required to meet the special provisions attached in Appendix A. The silica fume used has a specific gravity of 2.25. The cement factor was 658 lb/yd^3. The maximum water-to-cementitious (cement plus SF) ratio (w/c) was 0.40. The fine aggregate was a siliceous sand with a fineness modulus of 2.90 and a specific gravity of 2.61. The coarse aggregate was gravel with a specific gravity of 2.66 and a unit weight of 104.0 lb/ft^3, and the nominal maximum size was 0.5 in. The concrete mixture proportions are summarized in Table 3.

All of the batches contained a commercially available neutralized vinsol resin for air entrainment and a sulfonated napthalene formaldehyde condensate as a high-range water reducer (HRWR), both of which were added at the plant. However, to achieve the desired workability while maintaining the w/c, more HRWR was added at the job site in two of the seven batches.

Placement Procedure

The traffic lane and the passing lane were overlaid on May 13, 1987, and June 5, 1987, respectively, with concrete containing 7 percent or 10 percent silica fume by weight of portland cement (Figure 1). A total of 29.5 yd^3 of concrete was placed: 17 yd^3 with 10 percent silica fume and 12.5 yd^3 with 7 percent silica fume. The actual w/c was 0.39 rather than 0.40 because a gallon of water per cubic yard was withheld at the plant and not added in the field. To minimize the time between batching and placement, the concrete was furnished in four trucks, each carrying about 4 yd^3 for the traffic lane, and three additional trucks, each with 4.5 yd^3 for the passing lane. The travel time for the truck mixers was about 20 min, and the average time from batching to discharge was about 35 min. The decks had previously been overlaid with an asphalt mixture that was completely removed by scarifying and milling.

TABLE 2 NUMBER OF SPECIMENS AND TESTS FROM EACH BATCH

Tests	Specimens No.	Specimens Size	Test Method	Age (days) Tested
Comp. strength	12	4" x 8"	AASHTO T23	1,7,28
Flexural strength	3	3" x 3" x 11¼"	ASTM C78	28
Bond	3	4" in dia.	a	28
Chloride perm.	4	4" x 2"	AASHTO T277	28
Freeze-thaw	3	3" x 4" x 16"	ASTM C666[b]	21
Petrography	1	4" x 8"	ASTM C457	28

[a] 2-in thick overlays on base concrete were sheared at the interface.

[b] Cured 2 weeks moist, 1 week dry and tested in 2% NaCl.

TABLE 3 MIXTURE PROPORTIONS

	Silica Fume, 7%	Silica Fume, 10%
Portland cement	658 lb/yd^3	658 lb/yd^3
Silica fume	46 lb/yd^3	66 lb/yd^3
Maximum w/c	0.40	0.40
Fine aggregate	1,269	1,225
Coarse aggregate	1,516	1,516
Air content	7 ± 2%	7 ± 2%

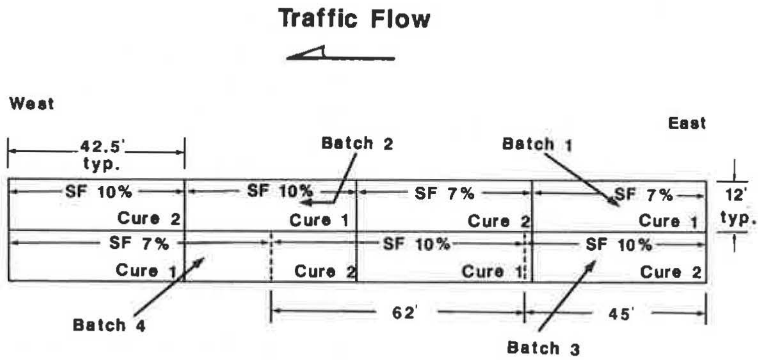

FIGURE 1 Westbound lanes. Cure 1: wet burlap and polyethylene sheet followed by a curing compound; cure 2: curing compound.

On the day before the placement of the overlay, the concrete surface was sandblasted, wetted, and covered with a plastic sheet to achieve a saturated surface dry condition. The placement of the overlay started from the higher east end. The plastic cover on the deck was removed, and the concrete surface was wetted if it was dry. To ensure a good bond between the base concrete and the overlay, the mortar fraction of the mixture from the truck mixer was scrubbed on the surface with coarse bristle brooms. All coarse aggregate from the concrete was brushed aside and discarded. As soon as possible after the scrubbing, the concrete from the trucks was placed on the deck surface. It was consolidated using a vibratory roller screed. The concrete along the joints and the edge of parapets was vibrated using immersion-type vibrators. Behind the screed, the surface levelness was checked and hand floats were used to eliminate the surface defects. Along the edge of the parapet and at the longitudinal joint, the surface was screeded with hand floats. The deck surface was textured using metal tines and subsequently subjected to curing.

Two curing procedures were used: (a) The concrete was covered with wet burlap and a polyethylene sheet. These were removed the next day and the concrete was then sprayed with a curing compound, and (b) a curing compound was applied only after finishing and texturing. Water curing by the use of wet burlap is a very effective curing method and is commonly used the first day for LMC. In SF concretes, additional curing may be necessary and is accomplished by using curing compound. The second procedure was used to determine whether it provides adequate curing in concretes containing silica fume, which would provide additional savings and convenience.

At each span, different amounts of silica fume in the concrete and different curing method were alternated to minimize differences in external factors, such as traffic, geometry, and weather. When burlap was used, care was taken not to disturb the grooves. Special attention was given to prompt curing to eliminate plastic shrinkage cracks.

Placement of the overlay was completed with no major problems.

Test Data

Concrete samples for testing were obtained from the middle third of the truck load. Four batches were tested individually for slump, air content, and temperature at the freshly mixed stage; and from the same batches, specimens were prepared for tests on the hardened concrete (Table 2). In the first batch of concrete, slump was intentionally held low because of concerns about placement of high-slump concretes on a grade. At the job site, two additional doses of HRWR were added to this concrete for workability. In the other three batches, higher initial slump than in the first batch was attained, and no additional HRWR was used at the job site, even though some slump loss occurred.

When the first two batches were placed, the weather was cloudy with high temperatures in the 70s (F); when the next two batches were placed, it was a sunny day with high temperatures in the 80s (F). Test specimens were covered by wet burlap and plastic and left at the job site for a day before they were transferred to the laboratory.

Freshly Mixed Concrete

The results of tests on slump (ASTM C 143) and air content (ASTM C 231) and the measurements of temperature of the air and concrete from the sample obtained in the middle third of the truck load are summarized in Table 4. One of the four batches had a lower slump than the specified 6 ± 2 in. However, slumps were within specification when tested for acceptance as the loads arrived at the job site. As time passed, slump loss occurred. If the addition of the HRWR at the job site is not desired, slumps at the plant should be adjusted for the upper limit. The air content was low, and two of the four batches did not meet the specified 7 ± 2 percent. Air content should be adjusted to yield values near the center of the acceptable range.

Hardened Concrete

The tests conducted on the hardened concretes are listed in Table 2 and are explained in detail in the following sections.

Compressive Strength The compressive strengths were determined in accordance with AASHTO T 22 using 4-in. × 8-in. cylinders; neoprene pads in steel end caps were used for capping. The results of tests at 1, 7, and 28 are summarized in Table 5. The 1-day compressive strengths exceeded 3,000

TABLE 4 CHARACTERISTICS OF FRESHLY MIXED CONCRETE

Batch	Lane	Silica Fume, %	Slump, in	Air, %	Temp., °F Air	Temp., °F Concrete
1	Traffic	7	7.5	3.7	62	80
2	Traffic	10	2.5	4.5	62	78
3	Passing	10	7.5	5.2	68	80
4	Passing	7	7.0	6.0	79	82

psi in concretes with either 7 or 10 percent silica fume. This strength is accepted as sufficient for opening to traffic. All concretes had strengths at 7 days that were significantly above the specified strength of 4,500 psi. The minimum value was 6,090 psi.

Flexural Strength The flexural strengths were determined at 28 days in accordance with ASTM C 78 using a simple beam measuring 3 in. × 3 in. × 11.25 in. The test results ranged from 763 psi to 957 psi (Table 5) indicating that either addition rate of silica fume provides satisfactory values.

Bond Strength To determine bond strengths, specimens were prepared by overlaying slabs cut from 4-in. diameter cylinders and subjecting the interface to shear after 28-day moist-curing of the overlay. The slabs used as the base concrete were made from a typical bridge-deck concrete prepared in the laboratory where they were moist cured for at least a month. Prior to placing overlays, the base concrete surface was allowed to dry for at least 1 day. This condition differs from that at the bridge deck where a mortar layer was scrubbed on the saturated-surface dry-base concrete. As shown in Table 5, the minimum bond strength was 383 psi. This is well above the 200 psi reported as being satisfactory by the Portland Cement Association (*6*). The lowest and the highest values were obtained in concretes with 10 percent silica fume. The satisfactory bond strengths obtained by the laboratory procedures indicate that a mortar layer is not necessary for proper bonding. In fact, wetting prior to scrubbing is a questionable practice. If puddles of water are left, they could significantly weaken the bond. Specifications for the placement procedure did not require the application of the mortar layer for bonding, but the contractor chose to apply this layer, which is a routine procedure with the LMC overlays.

Chloride Permeability The resistance to intrusion of chloride ions was determined using AASHTO T 277. The specimens were 2-in.-thick slabs cut from the top of 4-in. × 8-in. cylinders. The specimens were moist cured for 2 weeks and then air dried until the time of the test. In the test, 60 v are applied across the specimen, and the current passing through the specimen in 6 hr is determined in coulombs. The results show that concretes containing 10 percent silica fume exhibited lower coulomb values than did those with 7 percent silica fume, however, all the concretes exhibit values below 1,000 coulombs, which indicates very low chloride permeability (Table 6).

Resistance to Freezing and Thawing The resistance of concretes to damage from cycles of freezing and thawing was

TABLE 5 STRENGTH DATA

Batch	Lane	Silica Fume, %	Compressive Str. 1 day	Compressive Str. 7 days	Compressive Str. 28 days	Flexural Str. 28 day	Bond Str. 28 days
1	Traffic	7	4340[a]	6850	9180	957	387
2	Traffic	10	3730[a]	6090	7890	903	383
3	Passing	10	5880[b]	6770	7800	860	697
4	Passing	7	5370[b]	6100	6950	763	603

NOTE: Values are psi for the average of three specimens.

[a] 28 hours

[b] 29 hours

TABLE 6 CHLORIDE PERMEABILITY DATA

Batch	Lane	Silica Fume, %	28-Day
1	Traffic	7	648
2	Traffic	10	354
3	Passing	10	437
4	Passing	7	716

NOTE: Average of two specimens.

determined using Procedure A of ASTM C 666 except that (a) the specimens were air-dried for a week following the 2 weeks of moist-curing and (b) the test water contained 2 percent NaCl. The acceptance criteria required that for satisfactory performance at 300 cycles the average weight loss (WL) be 7 percent or less, the durability factor (DF) be 60 or more, and the surface rating (SR) be 3 or less. The SR was determined in accordance with ASTM C 672. The top and molded surfaces were rated separately and averaged. The WL, DF, and SR values are summarized in Table 7. The results indicate that the resistance to cycles of freezing and thawing is low or marginal when the air content was below the specified limit. Concretes with air content within the specification exhibited satisfactory resistance to cycles of freezing and thawing.

Petrographic Examination The petrographic examination involved the determination of the characteristics of the air-void system in the hardened concrete using the linear traverse method of ASTM C 457. The specimens were moist-cured for at least a month and cut vertically; then one side was lapped for the linear traverse analysis. Voids were separated into two groups: small (<1 mm) and large (>1 mm). Small voids are considered to result from air entrainment; large ones, from a lack of consolidation or from extra water in the mixture. The amount of coarse voids is generally 2 percent or less in properly prepared concretes. For adequate protection of critically saturated concrete from extreme exposures, specific surface values of 600 in.$^{-1}$ or more and spacing factors of 0.008 in. or less have been recommended by Mielenz et al., and these values are generally accepted for satisfactory performance (7).

The data on small, large, and total voids, specific surface and the spacing factor are summarized in Table 8. The total air-void content was in the lower half of the specified range. One of the specimens exhibited a high amount of large voids. The slump for that batch was low, and the large voids could have resulted from difficulties in consolidation.

TABLE 7 FREEZE-THAW DATA AT 300 CYCLES

Batch	Lane	Silica Fume	Wt. Loss, %	D.F.	S.R.
1	Traffic	7	5.8%[a]	33	2.5
2	Traffic	10	7.8%	60	1.9
3	Passing	10	0.5	80[b]	1.1
4	Passing	7	0.4	79	0.8

NOTE: Average of three specimens.

[a] Test terminated at 200 cycles when relative dynamic modulus values fell below 60%.

[b] One beam exhibited a DF of 63.

TABLE 8 AIR-VOID SYSTEM OF HARDENED CONCRETE

Batch	Lane	Silica Fume, %	Void Content <1mm	Void Content >1mm	Void Content Total	Specific Surface in^{-1}	Spacing Factor in.
1	Traffic	7	4.2	1.0	5.2	539	0.0088
2	Traffic	10	3.5	3.0	6.5	489	0.0085
3	Passing	10	4.5	1.3	5.8	582	0.0077
4	Passing	7	5.1	2.1	7.2	455	0.0082

The specific surface values were low, indicating a coarse air-void system, which is expected in concretes containing HRWR (*8*). Spacing factors in three of the four concretes were above the maximum 0.008 in. recommended for satisfactory performance. However, one of the three had a value of 0.0082 in., which is very close to the limit. The concretes that had the two highest spacing factors had the smallest amount of small voids and exhibited low or marginal performance in the freezing and thawing tests.

It should be recognized that concretes used on bridge decks are not normally critically saturated and those with low w/c and low permeabilities, such as the SF concretes are expected to resist cycles of freezing and thawing in service better than the specimens subjected to ASTM C 666 Procedure A. Similarly, specimens of LMC sometimes exhibit poor performance when tested with ASTM C 666 (*5*), but their field performance has been satisfactory. Thus, these borderline characteristics will not necessarily lead to poor field performance of the experimental overlays.

INITIAL DECK SURVEY

To observe the condition of the decks and to obtain initial background data, the bridge was inspected on June 9, 1987. At that time, the passing lane was still closed, and the traffic lane had been opened to traffic for only 2 weeks. The only visible crack in the deck was about a foot long at the east end of the passing lane; it extended through the thickness of the overlay slab. The lack of cracks suggests that curing without wet burlap would be acceptable. Chain drag soundings revealed some delaminated areas along the longitudinal joint in the first three spans, mainly in the passing lane. The delaminations are attributed to poor consolidation, which occurred in areas that could not be consolidated by the roller screed and were supposed to be consolidated by an immersion-type vibrator. The contractor has made repairs to eliminate the delaminated areas to the extent possible.

SUMMARY AND CONCLUSIONS

- Concretes containing SF can be a cost-effective alternative to LMC for use as thin overlays on bridge decks. Similar placement procedures can be followed for the two materials. However, truck mixers can be used for the SF concrete, and a curing compound can be used instead of the wet burlap and the plastic sheeting. Thus it appears that cost savings in addition to those realized from the lower cost of materials could be achieved.
- Concretes containing 7 or 10 percent SF exhibited satisfactory strengths and very low chloride permeabilities.
- The resistance of concretes to cycles of freezing and thawing was satisfactory when air content was within the specification.
- Addition of more HRWR at the job site does not appear to affect the strength and chloride permeability of the concretes.

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REFERENCES

1. O. Celik. Laboratory Investigation of Concrete Containing Silica Fume for Use in Overlays. *ACI Materials Journal*, Vol. 84, No. 1, Jan.-Feb. 1987, pp. 3–7.
2. P. K. Mehta and O. E. Gjorv. Properties of Portland Cement Concrete Containing Fly Ash and Condensed Silica Fume. *Cement and Concrete Research*, Vol. 12, No. 5, Sept. 1982, pp. 587–595.
3. ACI Committee 226. Silica Fume in Concrete. *ACI Materials Journal*, Vol. 84, No. 2, March-April 1987, pp. 158–166.
4. D. Whiting. *Rapid Determination of the Chloride Permeability of Concrete*. Report FHWA/RD-81/119. FHWA, U.S. Department of Transportation, 1981.
5. M. M. Sprinkel. *Overview of Latex Modified Concrete Overlays*. VHTRC Report No. 85-RI, Virginia Transportation Research Council, Charlottesville, 1984, 43 pp.
6. E. J. Felt. Resurfacing and Patching Concrete Pavements with Bonded Concrete. *HRB Proc.*, Vol. 35, 1956.
7. R. C. Mielenz, V. E. Wolkodoff, J. E. Backstrom, and R. W. Burrows. Origin, Evolution, and Effects of the Air Void System in Concrete, Part 4: The Air Void System in Job Concrete. *ACI Journal*, Vol. 55, No. 4, October 1958, pp. 507–517.
8. M. M. Sprinkel. Super-Water Reduced Concrete Pavements and Bridge Deck Overlays. In *Transportation Research Record 720*, TRB, National Research Council, Washington, D.C., 1979, pp. 19–28.

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