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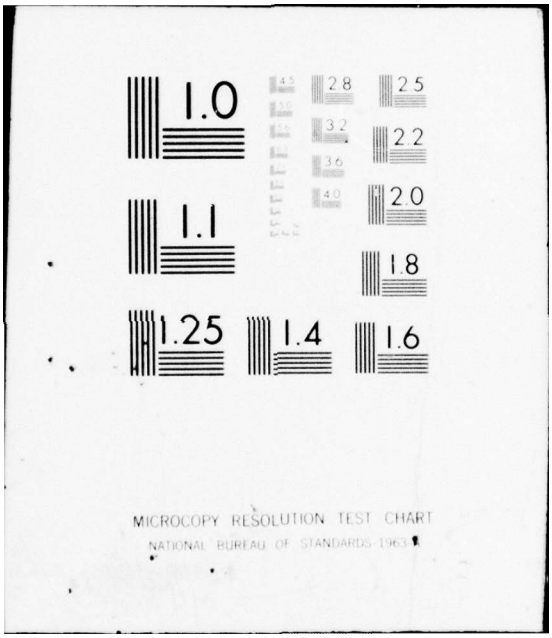
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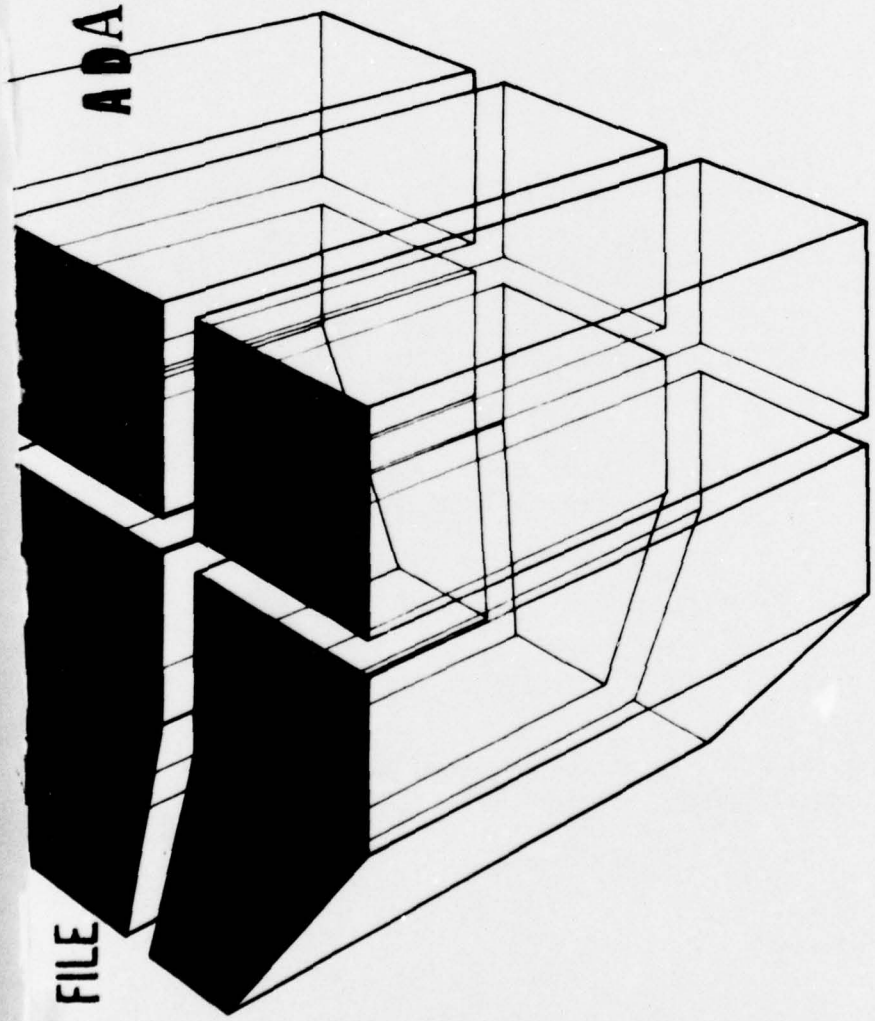
SPECIAL REPORT M-204
March 1977
Corrosion Behavior of Cracked Fibrous Concrete

INTERNAL SEALING OF FIBER-REINFORCED CONCRETE



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The effects of salt corrosion on steel-reinforced concrete can be predicted when chlorides are absorbed in amounts sufficient to reduce the pH of the concrete to the reaction threshold. In this study, concrete strength and chloride absorption were used to evaluate the effect of internal sealing on steel-fiber-reinforced concrete. Replicate concrete specimens were prepared from four mix designs: control; internally sealed; steel-fiber reinforced; and internally sealed, steel-fiber reinforced.

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Primary test specimens, 6 x 6 x 24 in. (15.2 x 15.2 x 60.8 cm) flexural beams, were prepared for four testing intervals. To obtain maximum information, secondary or gage specimens of 1.5 x 3 x 12 in. (3.8 x 7.6 x 30.4 cm) were prepared for daily inspection and frequent screening tests to detect early stages of decay and enable selection of the primary exposure periods.

The specimens were exposed to a 3 percent saline mist spray in a tent enclosure. The spray was operated 8 hours per day, 5 days per week. During the first 41 days, the tent enclosure was left in place continuously; high humidity retained by the enclosure prevented drying, and the specimens remained moist from day to day. This continuous saturation of the surface may have blocked oxygen entry and retarded corrosion. After 41 days, the sides of the enclosure were rolled up for free air circulation and drying when the spraying was not in operation.

Total testing time was 110 days. Two primary tests and two screening tests were made at exposure times of 0, 3, 41, and 110 days.

No chloride penetration of the sealed concrete was observed during the testing. Measured chloride contents of these specimens remained essentially at baseline levels, i.e., the chlorides introduced by the aggregates, cement, and mixing water.

By contrast, the nonsealed specimens rapidly absorbed the saline solution. Measured chlorides at the 0.5-in. (1.27 cm) sampling depth were ~0.1 percent after 3 days and >0.4 percent at the conclusion of testing.

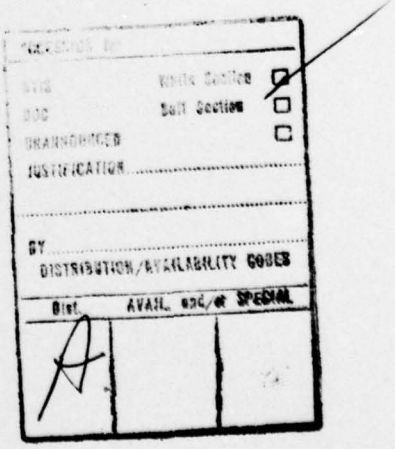
Active internal corrosion was seen only in the nonsealed specimens and, at the end of the study, had progressed to a depth of ~0.25 in. (0.63 cm). No significant effect of corrosion on the strength of the concrete specimens was observed in the flexural or compressive tests.

FOREWORD

This study was conducted for the Directorate of Military Construction, Office of the Chief of Engineers (OCE) under Project 4A762719AT41, "Design, Construction, and Operations and Maintenance for Military Facilities"; Task T7, "Materials Research and Development for Military Construction"; Work Unit 003, "Corrosion Behavior of Cracked Fibrous Concrete." The applicable QCR number is 1.03.007. Mr. S. Gillespie was the OCE Technical Monitor.

The work was performed under Contract No. DACA 88-75-M-0555 by Monsanto Research Corporation, Dayton, OH. The work was performed for the Construction Materials Branch (MSC), Materials and Science Division (MS), U. S. Army Construction Engineering Research Laboratory (CERL), Champaign, IL.

Mr. P. Howdyshell is Chief of MSC, and Dr. G. Williamson is Chief of MS. COL J. E. Hays is Commander and Director of CERL, and Dr. L. R. Shaffer is Technical Director.



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INTERNAL SEALING OF FIBER-REINFORCED CONCRETE

1 INTRODUCTION

Background

Chloride-induced steel corrosion and the resultant cracking and spalling are major problems in reinforced concrete structures. The vulnerability of steel-reinforced concrete to corrosive salt atmospheres is seen as (1) deterioration of physical properties caused by oxide-pressure-induced spalling of the concrete matrix and (2) weakened or severed reinforcing fibers. Earlier research by Monsanto Research Corporation has shown that an internally sealed concrete can be made by mixing small discrete wax particles with the normal components of Portland cement concrete. After cure, warming the structure to the fusion point of the additive transforms the continuous capillary system in the concrete to a discontinuous one so that penetration of water and corrosive chemicals is effectively blocked.

In the Monsanto tests, concrete was internally sealed by adding a blend of 25 percent montan and 75 percent paraffin wax to the initial mix and subsequently heating it. The concrete produced from this mix was completely resistant to chloride penetration after extended periods of continuous ponding in a salt solution. Under identical conditions, a typical conventional concrete without the additive absorbed large quantities of chloride and approached saturation within 7 days. Work is currently underway with the Federal Highway Administration (FHWA) to apply this technology to highway and bridge construction.[1]

New processes and fabrication techniques developed by the U. S. Army Construction Engineering Research Laboratory (CERL), Champaign, IL are establishing steel-fiber-reinforced concrete as a viable and promising construction material. One drawback is that the small-diameter steel fibers have higher surface-area-to-volume ratios than conventional reinforced rods and are therefore more vulnerable to corrosion damage; however, combining internal sealing and fiber reinforcing could eliminate the concrete's vulnerability to corrosive atmospheres and expand the areas of its application. Extending the service lives of fiber-reinforced concrete structures by internal sealing could significantly reduce their costs.

Purpose

The purpose of this report is to evaluate the effect of internal sealing

[1] G. H. Jenkins and J. M. Butler, *Internally Sealed Concrete*, Research Report FHWA-RD-75-20 (Federal Highway Administration, January 1975).

on the service life of steel-fiber reinforced concrete in highly corrosive environments.

Approach

This work compared the chloride ion resistance of plain fibrous concrete to that of fibrous concrete internally sealed with the 25 percent montan and 75 percent paraffin wax. Chloride absorption and concrete strength were used to evaluate the effects of the internal sealing. Exposure time was from 0 to 110 days.

2 DETAILS OF TESTING

Mix Design

Replicate concrete specimens were prepared from four mix designs:

1. Control: a standard concrete mix design without reinforcement or internal sealing. (This mix design was provided by CERL.)

2. Internally sealed: same as mix number 1 in cement factor, slump, etc., but modified to include sealing additive.

3. Steel-fiber reinforced: the cement factor was the same as that of mix number 1 but included approximately 1.4 volume percent of steel fibers. (This mix design was provided by CERL.)

4. Internally sealed, steel-fiber reinforced: same as mix number 3, but modified to include internal sealing.

A typical fiber-reinforced concrete mix design was a model for the four mixes:

Cement, type I, non-air-entraining	750 lb (340 kg)
Concrete sand	1500 lb (680 kg)
Coarse aggregate (3/8 in. - 1/4 in. [0.95 cm - 0.63 cm])	330 lb (150 kg)
Coarse aggregate (<1/4 in. [0.63 cm])	670 lb (304 kg)
Steel fibers minimum	175 lb (79 kg)
Water for slump--5 $^{+2\text{ in.}}_{-1\text{ in.}}$ ($12.7\ ^{+5.0\text{ cm}}_{-2.5\text{ cm}}$)	375 to 400 in. (9.5 to 10.2 m)

The mix designs (see Appendix) use a constant cement factor (8 sacks per cubic yard [10.5 sacks per cubic meter]) and are adjusted to compensate for fiber and sealing additive volumes by varying the quantities of coarse aggregate. A ratio of 1 to 2 of the large to small size coarse aggregate was maintained in all mix designs.

Materials

Aggregates

Coarse aggregates used in this study were crushed limestone from the Phillipsburg, OH, plant of American Aggregates Co. The aggregates were screened to obtain the two size categories (3/8 in.--1/4 in. [0.95 cm--

0.63 cm]) and (<1/4 in. [0.63 cm]). Concrete sand, also obtained from American Aggregates Co., had a fineness modulus of 3.16. All aggregates were air dried to a constant low moisture content and stored in sealed drums until used.

Since the proposed method of measuring the rate and amount of chloride absorbed during salt exposure reflects only the total concentration in the sample and does not distinguish between bound chlorides in the aggregates and absorbed sodium chloride, chloride tests of the aggregates and cement were necessary (Table 1).

Table 1

Chloride Content of Cement and Aggregates

Materials	Percent of Material in Category	Percent Chloride Content
Cement, Portland, type I, non-air-entraining	100	0.004
Coarse aggregate, gray, nonporous	70	0.069
Coarse aggregate, gray, porous	25	0.071
Coarse aggregate, brown, porous	5	0.083
Fine aggregate, concrete sand	100	0.030

Portland Cement

The cement used in this study was type I non-air-entraining and was taken from a single lot from the Southwestern Portland Cement Co., Fairborn, OH. To insure uniformity, the cement was thoroughly blended in a rotating drum and then packed and sealed in polyethylene-lined fiber sacks.

Admixtures

Approximately 20.0 mℓ per mix of Vinsol single-strength resin from Protex Industries was the air-entraining agent. The air-entraining efficiency of this material varied from mix to mix, but all air contents were within the desired 6 $\pm$ 2 percent designated by CERL.

Steel Fibers

Fibers used were 0.010 x 0.022 x 1.0 in. ribbons (0.025 x 0.055 x 2.54 cm) (Figure 1) produced by U. S. Steel Corp., Pittsburgh, PA.

Internal Sealing Additive

A mixture of 25 percent montan crude grade ester wax and 75 percent paraffin (melting point--148°F [63°C]) was sprayed in the mixture to

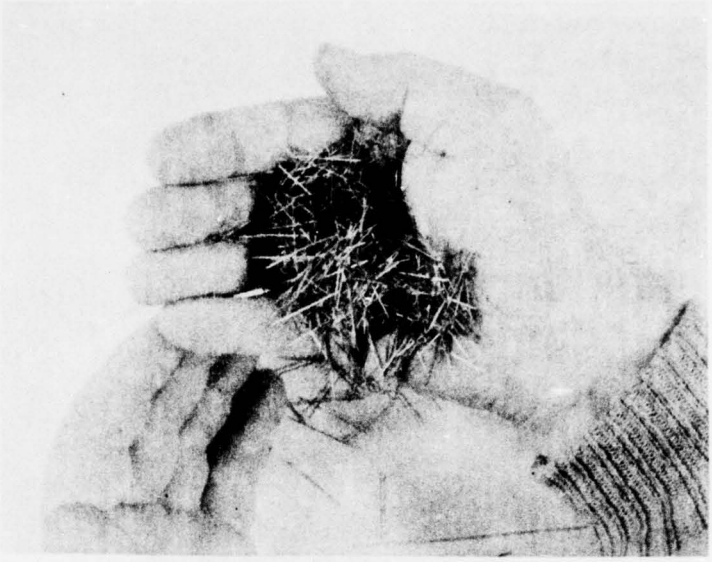

Figure 1. 0.010 x 0.022 x 1.0 in. (0.025 x 0.055 x 2.54 cm) steel ribbon reinforcement.

produce the additive spheres (Figure 2). All particles were spherical and ranged from 20 to 80 mesh, with 70 percent between 30 and 40 mesh. An FHWA publication provides a detailed description of the additive's manufacturing process.[2]

Sample Preparation

Mixing

Concrete used in this study was mixed in a 3 cu ft (0.08 m^3) rotary drum mixer. Each mix design used two separate 3 cu ft (0.08 m^3) batches.

The mixing time, temperature, and relative humidity were approximately constant for all mixes. The sealing additive was distributed rapidly and uniformly in either a dry mix form or after addition of the water. The steel fibers tended to agglomerate into tight tangles or balls unless carefully sifted through a screen to separate the fibers entering the rotating dry mix. The time required to add the fibers to the reinforced mixes was compensated for in the sealed and control mixes, so that the actual dry mix time for all formulations was equal.

Wet mixing times varied slightly by sample. After 6 minutes of wet mixing, samples were taken for air content and slump. Air content did not deviate from the desired 6 ± 2 percent, but several mixes required additional water to develop the 6^{+2}_{-1} in. ($15.2^{+5.0}_{-2.5}$ cm) slump required. These mixes then received an additional 2 minutes of mixing.

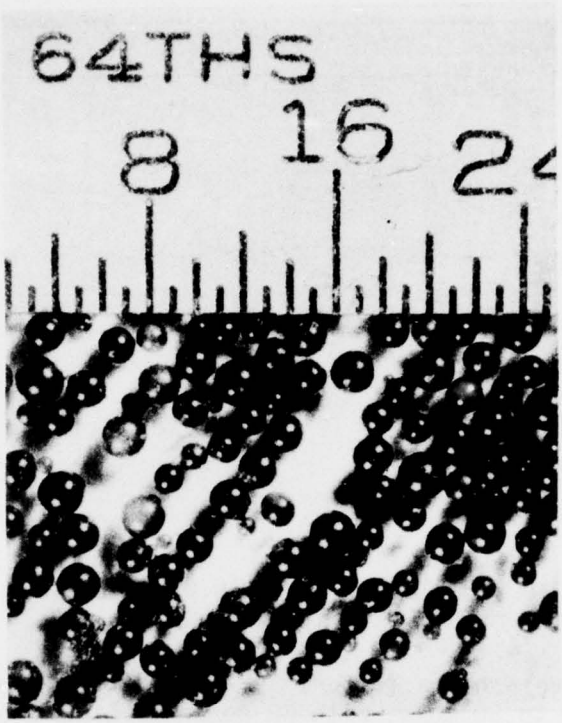

Figure 2. Typical sealing additive sphere size distribution obtained from spray process.

Figure 3 shows the average cement factors (ratio of cement to total mix volumes). Cement factors varied with the water used to produce the required slump range of 6^{+2}_{-1} in. ($15.2^{+5.0}_{-2.5}$ cm).

Steel fibers significantly reduced the slump and "workability" of these mixes (Figure 4). The control mix, which had the highest cement factor and slump, had the lowest ratios of water to cement (Figure 5) and water to total mix volume (Figure 6).

The sealing additive spheres tended to reduce the mix's slump but not its workability. With a constant water-to-mix volume, the measured slump of sealed concrete was lower, but working and finishing characteristics were approximately equal to a similar, higher-slump, nonsealed concrete. This effect was not considered in this study. Water addition for all mixes was based on slump.

[2]G. H. Jenkins and J. M. Butler, *Internally Sealed Concrete*, Research Report No. FHWA-RD-75-20 (Federal Highway Administration, January 1975).

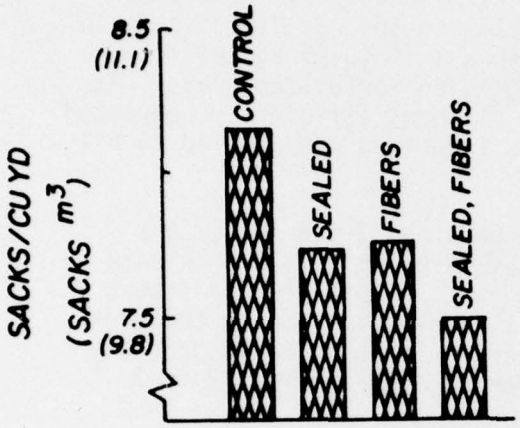

Figure 3. Average ratio of cement to mix volume (cement factor) for four mix designs.

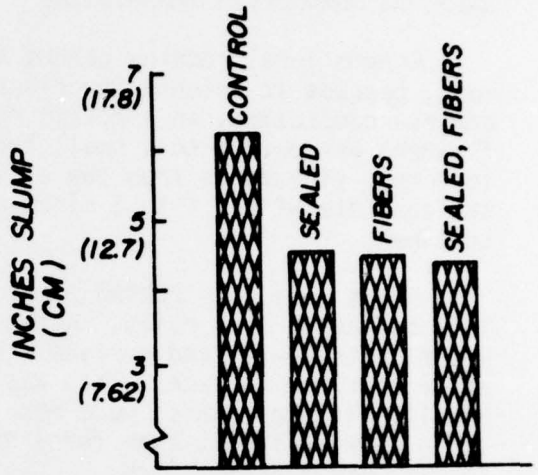

Figure 4. Average slump (in.) for four mix designs.

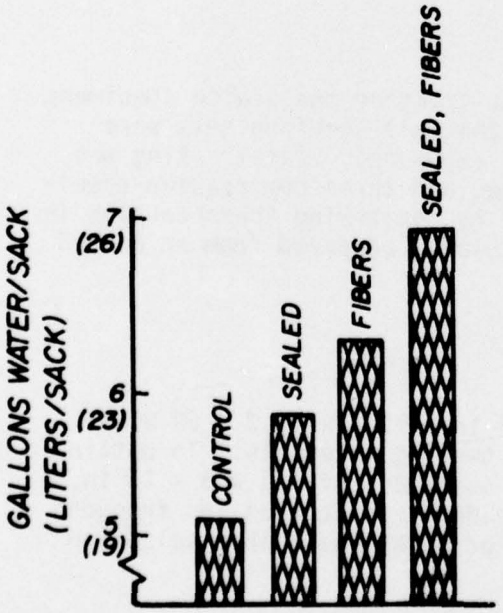

Figure 5. Average ratio of water (gal) to Portland cement (sacks) in four mix designs.

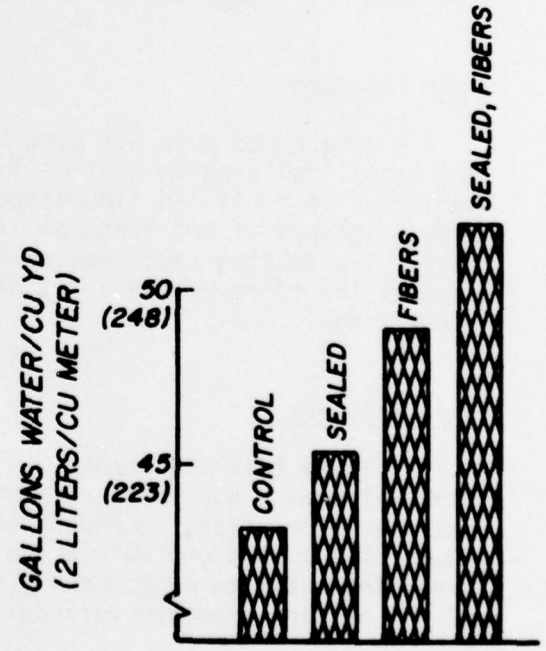

Figure 6. Average ratio of water (gal) to mix volume for four mix designs.

Specimen Compaction and Molding

Conventional rodding cannot be used with short-fiber reinforcement, because it orients the fibers parallel to the rod direction. To achieve compaction, an electric motor with a 1 lb (0.45 kg) elliptical flywheel was bolted to a small table mounted on spring foot pads. At 1600 rpm, vibrations from the elliptical flywheel efficiently compacted the concrete within 1 to 2 minutes. This technique was applied to all specimens.

Molds were constructed of a plywood base and 3 x 6 in. (7.6 x 15.2 cm) angle iron rails. A thin film of motor oil was the release agent. Strike-off and surface finishings were complicated by fibers at or near the surface. This was largely compensated for by the high mobility (slump), which made repair easier. Finishing would probably be no more difficult than for a nonreinforced concrete with 2 to 3 in. (5.0 to 7.6 cm) slump.

Curing

Specimens were cured in the molds at 75°F (23.6°C), 50 percent relative humidity (RH) for 48 hours. After this initial cure, they were immersed in a saturated calcium oxide solution for 14 days, followed by 14 days at 75°F (23.6°C), 50 percent RH.

Heat-Treating

A programmed oven was used for heat-treating the sealed specimens. The mechanical program control insured that all specimen sets were subjected to duplicate time/temperature exposure. Heat-treating was done in groups of two flexural, ten gage, and three compression specimens. The heating cycle was determined by monitoring thermocouples in several locations within a set of test blocks prepared from an unused control mix.

Salt Exposure

Primary test specimens, 6 x 6 x 24 in. (15.2 x 15.2 x 60.8 cm) flexural beams, were prepared for four testing intervals. To obtain maximum information, secondary or gage specimens of 1.5 x 3 x 12 in. (3.8 x 7.6 x 30.4 cm) were prepared for daily inspection and frequent screening tests to detect early stages of decay and enable selection of the primary exposure periods.

The specimens were exposed to a 3 percent saline mist spray in a tent enclosure. The spray was operated 8 hours per day, 5 days per

week. During the first 41 days, the tent enclosure was left in place continuously; high humidity retained by the enclosure prevented drying, and the specimens remained moist from day to day. This continuous saturation of the surface may have blocked oxygen entry and retarded corrosion. After 41 days, the sides of the enclosure were rolled up for free air circulation and drying when the spraying was not in operation.

Total testing time was 110 days. Two primary tests and two screening tests were made at exposure times of 0, 3, 41, and 110 days.

The specimens were supported over a 2 x 4 x 8 ft (0.6 x 1.2 x 2.4 m) brine storage tank with 2 in. (5.0 cm) clearance between each, as shown in Figure 7. The saline solution was pumped from the storage tank to a reservoir 4 ft (1.2 m) above the specimens and then gravity fed to ten spray heads constructed of glass tubing jets (Figure 8) located to cover all areas of the chamber. The saline solution was fed through the center of the jets and atomized by two converging air jets. These spray heads provided a corrosion- and maintenance-free system which filled the chamber with a finely divided mist and maintained constant spraying conditions. All areas within the chamber were uniformly wetted during the 8-hour operation cycle. Figure 9 shows one end of the spray chamber, the gravity reservoir, and the pump. Figure 10 shows some flexural (gage) and compression specimens during mist exposure.

Testing

The rate and extent of chloride penetration, flexural strength, and compressive strength were monitored at selected intervals. Visible corrosion progress was observed daily.

1. Baseline: After completion of 30-day cure and heat treatment and before salt mist exposure
2. 72 hours: Significant oxide staining had occurred, and surface-exposed fibers were embrittled by corrosion
3. 41 days: Oxide stains from interior fibers of the non-sealed specimens were bleeding to the surface
4. 110 days: First spall, apparently due to oxide build-up on interior fiber.

Compressive strengths were determined using 3 x 6 in. (7.6 x 15.2 cm) molded cylinders with asbestos/sulfur caps for uniform load distribution. Flexural strength was determined by four-point loading of the 6 x 6 in. x 2 ft (15.2 x 15.2 cm x 0.6 m) beams. These tests, conducted by the Bowser-Moerner Co., an independent testing laboratory in Dayton, OH, followed standard ASTM methods.

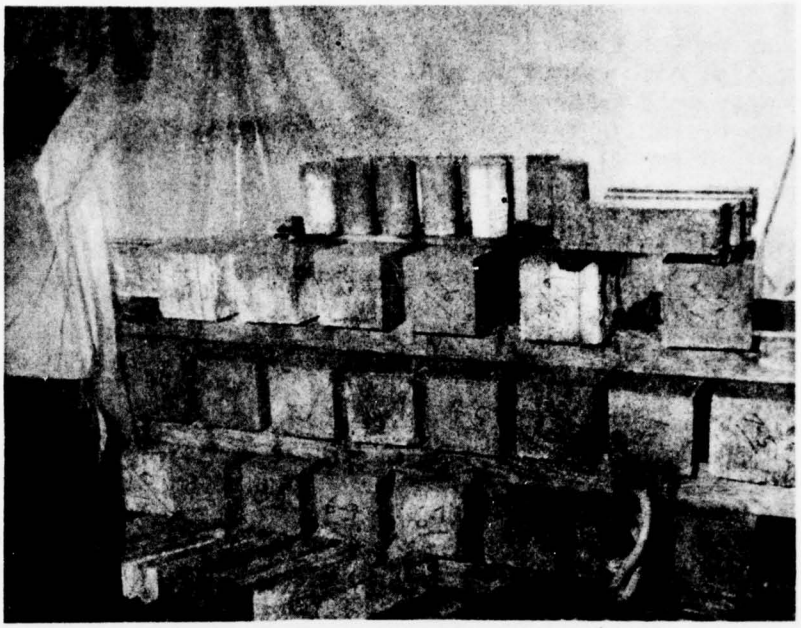

Figure 7. Test specimens in salt spray chamber.

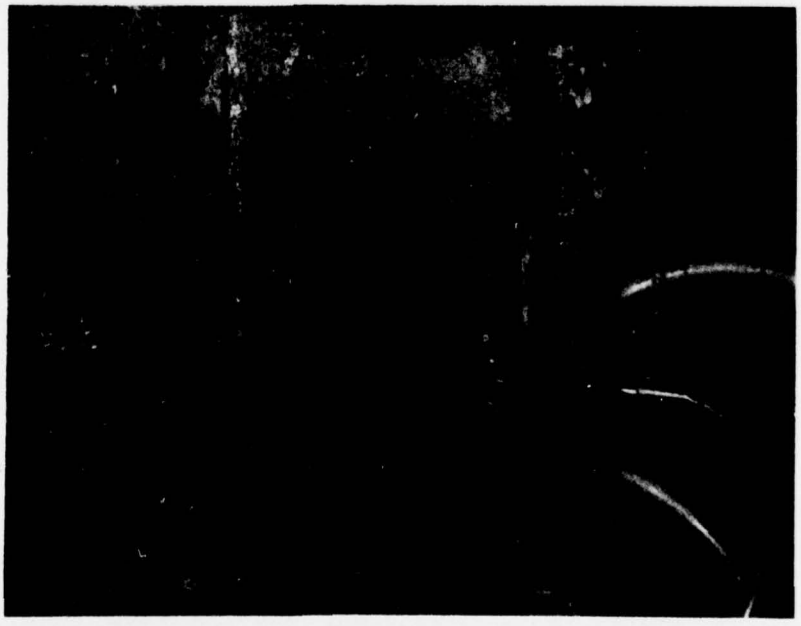

Figure 8. Glass jets provide corrosion-free spray system.

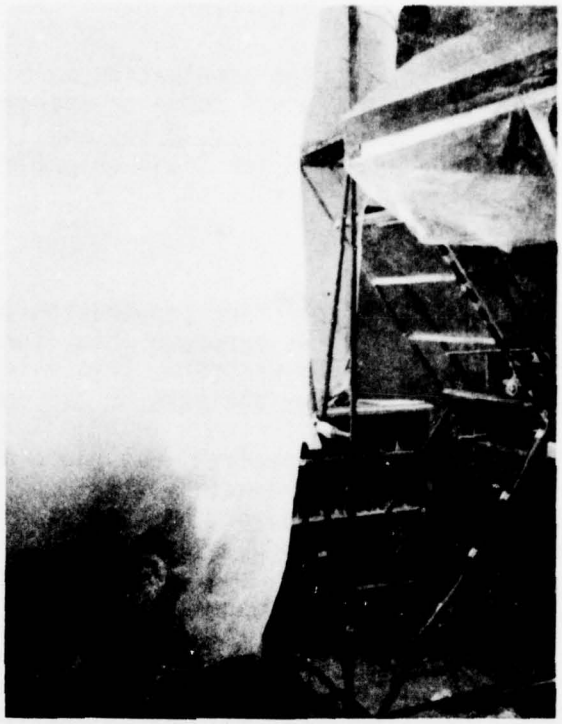

Figure 9. Spray chamber with elevated reservoir and pump.

Figure 10. Specimens during exposure to saline mist.

The rate and extent of chloride penetration were determined by removing core samples from the exposed concrete and sectioning them at depths of 0.5, 1.0, and 1.5 in. (1.27, 2.54, and 3.81 cm). These sections were powdered and analyzed for total chloride content by the method described in an FHWA staff research study.[3]

Chloride Penetration

Table 2 provides data from chloride penetration tests. Measured chloride contents before salt spray exposure (baseline) range from 0.033 to 0.053 percent and average 0.039 percent. This value agrees closely with the 0.037 percent predicted by analysis of the component materials.

Absorption by the nonsealed specimens was rapid and probably exceeded the corrosion reaction threshold at the 0.5 in. (1.27 cm) sampling depth within the first 3 days. At this sampling depth, measured chlorides were ∿0.1 percent after 3 days and >0.4 percent at the conclusion of testing. After 110 days, measured chloride contents ranged from 0.346 to 0.516 percent for the gage specimens and were consistently higher in the fiber-reinforced mixes than in the controls.

With one exception, all sealed specimens remained essentially at baseline levels throughout the exposure, which indicated no chloride penetration of these specimens. No difference was observed between the reinforced and nonreinforced sealed specimens.

One fiber-reinforced sealed gage specimen tested at 41 days had a 0.074 percent chloride content. While this value is 0.011 percent higher than the baseline range, it is believed to reflect aggregate rather than absorbed chloride. Tests of the same mix after 110 days were all within the baseline chloride range for both gage and flexural specimens. Figure 11 shows absorbed chloride data for the 0.5 in. (1.27 cm) samplings of the gage specimens. This graphically shows two consistently observed phenomena: (1) the rapid absorption of chloride by nonsealed specimens rapidly results in free chloride levels in excess of the corrosion reaction threshold; and (2) chloride absorption is more rapid and more extensive in steel-fiber-reinforced concrete than in nonreinforced concrete, probably because the fiber/concrete interface provides additional entries.

Figure 12 shows the relationship between absorbed chloride content and sampling depth after 110 days exposure. The figure shows that chloride content decreases with sampling depth. At all levels, chlorides were present in the nonsealed steel fiber concrete in amounts sufficient to

[3]H. A. Berman, *Determination of Chloride in Hardened Portland Cement Paste, Mortar and Concrete*, Report No. FHWA-RO-72-12 (Federal Highway Administration, September 1972).

Table 2

Chloride Absorption of Four Mix Designs

Exposure Period (days)	Specimen Type	Sample Depth (in.)	Control			Fibers			Sealed			Sealed/Fibers		
			% Cl^-	Avg	% Cl^- Abs	% Cl^-	Avg	% Cl^- Abs	% Cl^-	Avg	% Cl^- Abs	% Cl^-	Avg	% Cl^- Abs
Baseline	flex	1.0 (2.54 cm)	0.041	0.042	0	0.048	0.040	0	0.038	0.036	0	0.042	0.037	0
			0.037			0.041			0.033			0.033		
			0.053			0.037			0.037			0.037		
			0.039			0.033			0.036			0.037		
3	gage	0.5 (1.27 cm)	0.117	0.135	0.085	0.167	0.153	0.103	0.036	0.036	0	0.041	0.039	0
			0.152			0.139			0.035			0.037		
41	gage	0.5 (1.27 cm)	0.214	0.187	0.137	0.299	0.351	0.301	0.039	0.038	0	0.048	0.061	0.011
			0.160			0.402			0.037			0.074		
110	gage	0.05 (0.127 cm)	0.396	0.396	0.346	0.511	0.514	0.464	0.033	0.038	0	0.043	0.042	0
						0.516			0.038			0.040		
									0.044					
	flex	0.5 (1.27 cm)	0.515	0.457	0.407	0.564	0.669	0.619	0.039	0.050	0	0.052	0.054	0.004
			0.357			0.648			0.061			0.048		
			0.500			0.796			0.050			0.062		
		1.0 (2.54 cm)	0.144	0.192	0.142	0.309	0.271	0.221	0.022	0.035	0	0.040	0.035	0
			0.211			0.254			0.041			0.037		
			0.220			0.251			0.041			0.027		
			0.076	0.092	0.042	0.124	0.101	0.051	0.034	0.037	0	0.035	0.035	0
			0.088			0.042			0.034			0.037		
			0.111			0.137			0.042			0.033		

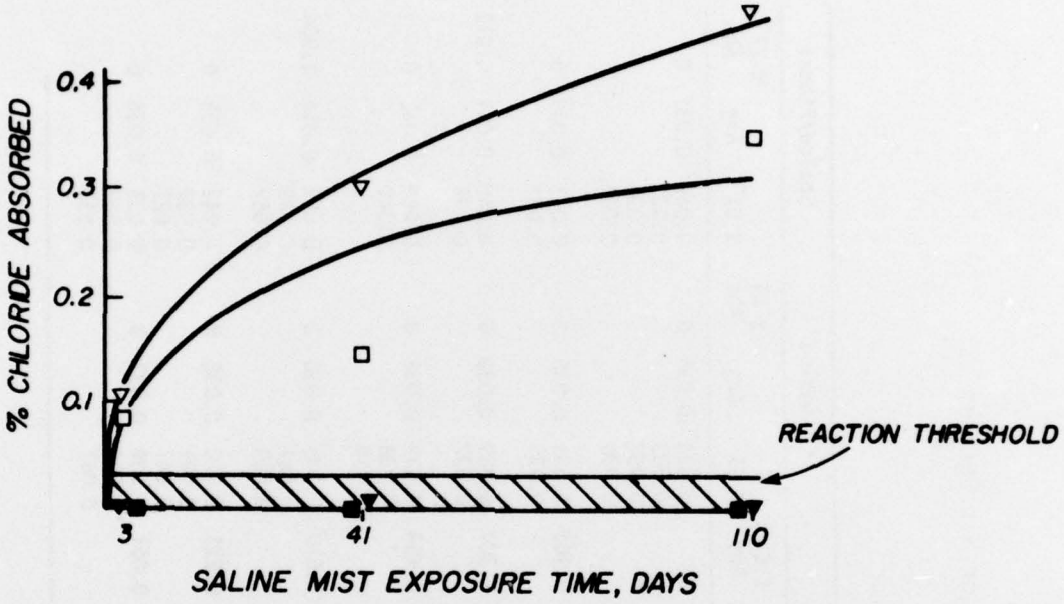

Figure 11. Absorbed chloride at 0.5 in. (1.27 cm) depth vs. exposure time for gage specimens.

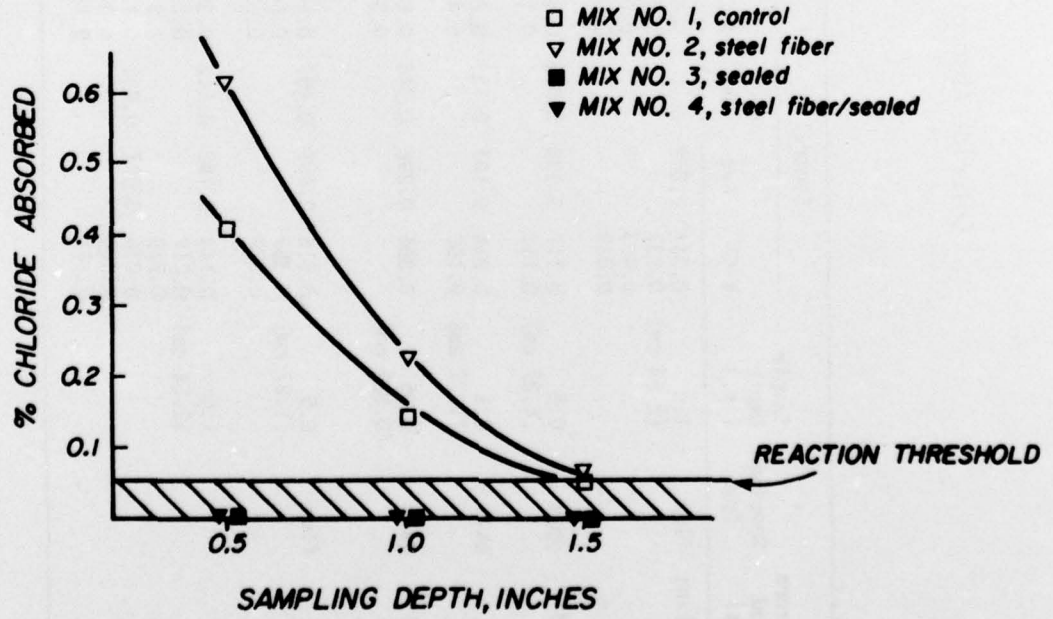

Figure 12. Absorbed chloride vs. sampling depth for flexural specimens exposed 110 days.

initiate corrosion. Again it was apparent that absorption levels are higher for the steel-fiber-reinforced concrete than for the control. At all levels, the sealed mixes remained essentially at baseline, showing no penetration by the saline solution.

Specimens broken in flexural testing were carefully examined for internal corrosion. No internal corrosion was observed in any of the sealed specimens, but in the nonsealed specimens, internal corrosion progressed much more slowly than had been predicted after examining chloride concentrations. Through the 41-day tests, corrosion seemed to progress only a short distance into the concrete and only along fibers which extended to the surface. After 110 days, nonsurface fibers generally indicated corrosion, but only to a depth of 0.2 to 0.3 in. (0.50 to 0.75 cm).

Two factors may have limited oxygen ingress and thereby retarded corrosion. First, the samples were compacted by an eccentric fly-wheel vibration table. This technique was effective in removing entrapped air and produced high-intensity, low-porosity concrete. The low porosity may have limited oxygen access. Second, during the first 41 days of exposure, the polyethylene tent was not opened during the 16 hours per day that the spray was not operating. High humidity within the chamber prevented evaporative drying. Since samples remained damp from day to day, the retained moisture probably limited oxygen entry. After 41 days, the procedure was changed so that the tent was open and a fan circulated dry air over the specimens.

Compression and Flexural Strength Tests

Tables 3 and 4 provide compressive and flexural strength test data. These tests were proposed as screening methods to monitor concrete damage induced by corrosion progress. The actual active corrosion rate observed was much lower than what was predicted and had just begun when this work was concluded. Corrosion had progressed only 0.2 to 0.3 in. (0.50 to 0.75 cm) into the specimens, and only one minor spall could be attributed to oxide formation. No significant degradation of compressive or flexural strength could be seen in these data. However, visible active corrosion was occurring in the non-sealed specimens, and it must be concluded that with continued exposure, corrosion damage would degrade the concrete strength.

Table 3

Compressive Strength Tests of Four Mix Designs

	Control		Fibers		Sealed		Sealed/Fibers	
Period	Values	Avg	Values	Avg	Values	Avg	Values	Avg
Baseline	6140		4250		5070		4090	
	5940	6120	4070	4230	5610	5530	3810	3950
	6280		4380		5900		3960	
110 days	7040		5610		5610		4110	
	6980	6910	6450	5960	5660	5750	4740	4416
	6720		5820		5970		4400	

Table 4

Flexural Strength Tests of Four Mix Designs

	Control		Fibers		Sealed		Sealed/Fibers	
Period	Values	Avg	Values	Avg	Values	Avg	Values	Avg
Baseline	580	600	970	870	690	660	780	770
	620		775		630		770	
110 days	770		1050		840		820	
	780	850	1070	1080	800	820	820	870
	1000		1150		825		900	

3 CONCLUSIONS AND RECOMMENDATIONS

Conclusions

Both the rate and the extent of chloride penetration were greater with steel-fiber-reinforced concrete than with the control. This suggests that fibers extending to the surface may create entryways for the chloride in addition to the normal capillary system and make fiber reinforcement more vulnerable to corrosion damage than conventional rod reinforcement.

Internal sealing completely blocked salt penetration in all test specimens. Both the ordinary capillary network and the steel fiber interfaces were successfully sealed.

Although these tests were concluded before measurable structural damage to the nonsealed fiber concrete occurred, active corrosion, probably limited by lack of available oxygen, was in progress and with additional time would have degraded the reinforcing system and weakened the concrete.

Recommendations

Testing should be continued for a period sufficient to produce severe corrosion and a significant degradation of the concrete's physical properties. While this program has qualitatively demonstrated the applicability of internal sealing to steel-fiber-reinforced concrete, extended testing to the point of corrosion failure of the nonsealed material would provide a quantitive measure of the benefits to be attained.

APPENDIX:

MIX PROPORTIONING DATA

The data sheets in this appendix provide information about the mix designs used in this study. Two batches of each design were used to prepare the test specimens, and the run preparation sequence was randomized.

Mix Design No. 1
Run No. 1 Control
Cement Content: 8
Water Content: ~5
Admixture - Air Content: Vinsol, 6%±2%

Specimens Prepared:

Flex (6 in. x 6 in. x 24 in.)	4
Gage	20
Compression	3

Item	Specific Gravity	Wt/Cu Ft Solid	
Cement	3.15	196.6	Type 1
Fine Aggregate	2.65	165.4	F.M. 3.16
Coarse Aggregate	2.68	167.2	Wt. D.R. 107 lb

Item	Solid Volume of Materials Required/Cu Yd	Cu Ft Solid	Batch Wts. Dry/3 Cu Ft. Batch, lb
Cement	753	3.83	83.7
Polymer	-	-	-
Water	376	6.03	41.8
Fine Aggregate	1540	9.31	171.1
Coarse Aggregate	1038	6.21	115.3
Air	-	1.62	-
Fibers	-	-	-
Total	3707	27.0	411.9

Item	Batch Wts (wet), lb		Concrete Determinations		
Cement	(.890)	83.7	Slump	6.0	in.
Polymer	-	-	Meas. air	5.9	%
Concrete Sand		171.0	Wt.	138.5	lb/cu ft
C.A. No. 4		38.3	W/C	0.474	
C.A. No. 5		76.5		43.48	gal/cu yd
Water	(4.757)	39.7		5.34	gal/sk
				8.14	sk/cu yd
Total Batch Weight		409.2			
Admixture		20 ml			

Remarks: V_T=1.094 cu yd

Mix Design No. 1
Run No. 4 Control
Cement Content: 8
Water Content: ∿5
Admixture - Air Content: Vinsol, 6%±2%

Specimens Prepared:

Flex	5
Gage	5
Compression	3

Item	Specific Gravity	Wt/Cu Ft Solid	
Cement	3.15	196.6	Type 1
Fine Aggregate	2.65	165.4	F.M. 3.16
Coarse Aggregate	2.68	167.2	Wt. D.R. 107 lb

Item	Solid Volume of Materials Required/Cu Yd	Cu Ft Solid	Batch Wts. Dry/3 Cu Ft. Batch, lb
Cement	753	3.83	83.7
Polymer	-	-	-
Water	376	6.03	41.8
Fine Aggregate	1540	9.31	171.1
Coarse Aggregate	1038	6.21	115.3
Air	-	1.62	-
Fibers	-	-	-
Total	3707	27.0	411.9

Item	Batch Wts (wet), lb		Concrete Determinations		
Cement		83.7	Slump	6.5	in.
Polymer		-	Meas. air	7.7	%
Concrete Sand		168.0	Wt.	138.2	lb/cu yd
C.A. No. 4		38.3	W/C	0.466	
C.A. No. 5		76.6		42.99	gal/cu yd
Water	(4.673)	39.0		5.250	gal/sk
				8.19	sk/cu yd
Total Batch Weight		405.6			
Admixture Vinsol		20 ml			

Remarks: V_T=.1087 cu yds

Mix Design No. 2
Run No. 3 Sealed
Cement Content: 8
Water Content: ∿5
Admixture - Air Content: None

Specimens Prepared:

Flex	4
Gage	20
Compression	3

Item	Specific Gravity	Wt/Cu Ft Solid	
Cement	3.15	196.6	Type 1
Fine Aggregate	2.65	165.4	F.M. 3.16
Coarse Aggregate	2.68	167.2	Wt. D.R. 107 lb

Item	Solid Volume of Materials Required/Cu Yd	Cu Ft Solid	Batch Wts. Dry/3 Cu Ft. Batch, lb
Cement	753	3.83	83.7
Polymer	116	1.89	12.9
Water	376	6.03	41.8
Fine Aggregate	1485	8.98	165.0
Coarse Aggregate	1003	6.00	111.4
Air	-	0.27	-
Fibers	-	-	-
Total	3733	27.0	414.8

Item	Batch Wts (wet), lb		Concrete Determinations		
Cement		83.7	Slump	4.3	in
Polymer		12.9	Meas. air	4.2	%
Concrete Sand		168.3	Wt.	134.5	lb/cu ft
C.A. No. 4		37.1	W/C	0.523	
C.A. No. 5		74.3		45.37	gal/cu yd
Water	(5.249)	43.8		5.90	gal/sk
				7.69	sk/cu yd
Total Batch Weight		420.1			

Admixture: None

Remarks: V_T=.1157 cu yds

Mix Design No. 2
Run No. 7 Sealed
Cement Content: 8
Water Content: ~5
Admixture - Air Content: None

Specimens Prepared:

Flex	5
Gage	10
Compression	3

Item	Specific Gravity	Wt/Cu Ft Solid	
Cement	3.15	196.6	Type I
Fine Aggregate	2.65	165.4	F.M. 3.16
Coarse Aggregate	2.68	167.2	Wt. D.R. 107 lb

Item	Solid Volume of Materials Required/Cu Yd	Cu Ft Solid	Batch Wts. Dry/3 Cu Ft. Batch, lb
Cement	753	3.83	83.7
Polymer	116	1.89	12.9
Water	376	6.03	41.8
Fine Aggregate	1485	8.89	165.0
Coarse Aggregate	1003	6.00	111.4
Air	-	0.27	-
Fibers	-	-	-
Total	3733	27.0	414.8

Item	Batch Wts. (wet), lb		Concrete Determinations		
Cement		83.7	Slump	4.8	in.
Polymer	-	12.9	Meas. air	3.8	%
Concrete Sand		168.3	Wt.	135.1	lb/cu ft
C.A. No. 4		37.1	W/C	520	
C.A. No. 5		74.3		45.29	gal/cu yd
Water	(5.213)	43.5		5.86	gal/sk
Total Batch Weight		419.8		7.73	sk/cu yd

Admixture: None

Remarks: V_T=.1151 cu yds

Mix Design No. 3
Run No. 2 Fibers
Cement Content: 8
Water Content: ∿5
Admixture - Air Content: Vinsol, 6%±2%

Specimens Prepared:

Flex (6 in. x 6 in. x 24 in.)	4
Gage	20
Compression	3

Item	Specific Gravity	Wt/Cu Ft Solid	
Cement	3.15	196.6	Type 1
Fine Aggregate	2.65	165.4	F.M. 3.16
Coarse Aggregate	2.68	167.2	Wt. D.R. 107 lb

Item	Solid Volume of Materials Required/Cu Yd	Cu Ft Solid	Batch Wts. Dry/3 Cu Ft. Batch, lb
Cement	753	3.83	83.7
Polymer	-	-	-
Water	376	6.03	41.8
Fine Aggregate	1505	9.10	167.2
Coarse Aggregate	1005	6.01	111.7
Air	-	-	-
Fibers	199	0.41	22.1
Total	3838	27.0	426.5

Item	Batch Wts. (wet), lb		Concrete Determinations		
Cement		83.7	Slump	4.0	in.
Polymer		-	Meas. air	6.5	%
Concrete Sand		167.2	Wt.	139.7	lb/cu ft
C.A. No. 4		37.2	W/C	0.567	
C.A. No. 5		74.5		49.67	gal/cu yd
Steel Fibers		22.1		6.40	gal/sk
Water	(5.692)	47.5		7.77	sk/cu yd
Total Batch Weight		432.2			
Admixture		20 ml			

Remarks: V_T=.1146 cu yds
Slump increased from initial 1.0" by addition of 9.5 lb water. Fibers shaken into mix through #8 screen to prevent agglomeration and "balling." This process will be used in future fiber mixes.

Mix Design No. 3
Run No. 8 Fibers
Cement Content: 8
Water Content: ∿5
Admixture - Air Content: Vinsol, 6%±2%

Specimens Prepared:

Flex (6 in. x 6 in. x 24 in.)	5
Gage	6
Compression	3

Item	Specific Gravity	Wt/Cu Ft Solid	
Cement	3.15	196.6	Type 1
Fine Aggregate	2.65	165.4	F.M. 3.16
Coarse Aggregate	2.68	167.2	Wt. D.R. 107 lb

Item	Solid Volume of Materials Required/Cu Yd	Cu Ft Solid	Batch Wts. Dry/3 Cu Ft. Batch, lb
Cement	753	3.83	83.7
Polymer	-	-	-
Water	376	6.03	41.8
Fine Aggregate	1505	9.10	167.2
Coarse Aggregate	1005	6.01	111.7
Air	-	1.62	-
Fibers	199.0	0.41	22.1
Total	3838	27.00	426.5

Item	Batch Wts. (wet), lb		Concrete Determinations	
Cement		83.7	Slump	5.0 in.
Polymer	-	-	Meas. air	5.9 %
Concrete Sand		170.8	Wt.	139.7 lb/cu ft
C.A. No. 4		37.2	W/C	.550
C.A. No. 5		74.5		47.89 gal/cu yd
Steel Fibers		22.1		6.19 gal/sk
Water	(5.512)	46.0		7.73 sk/cu yd
Total Batch Weight		434.3		
Admixture: Vinsol		20 ml		

Remarks: V_T=.1151 cu yds

Mix Design No. 4
Run No. 5 Sealed/Fibers
Cement Content: 8
Water Content: ~5
Admixture - Air Content: None

Specimens Prepared:

Flex	4
Gage	20
Compression	2

Item	Specific Gravity	Wt/Cu Ft Solid	
Cement	3.15	196.6	Type 1
Fine Aggregate	2.65	165.4	F.M. 3.16
Coarse Aggregate	2.68	167.2	Wt. D.R. 107 lb

Item	Solid Volume of Materials Required/Cu Yd	Cu Ft Solid	Batch Wts. Dry/3 Cu Ft. Batch, lb
Cement	753	3.83	83.7
Polymer	116	1.89	12.9
Water	376	6.03	41.8
Fine Aggregate	1446	8.74	160.7
Coarse Aggregate	975	5.83	108.3
Air	-	0.27	-
Fibers	198.6	0.41	22.1
Total	3864.6	27.00	429.5

Item		Batch Wts (wet), lb
Cement		83.7
Polymer		12.9
Concrete Sand		162.7
C.A. No. 4		36.1
C.A. No. 5		72.2
Steel Fibers		22.1
Water	(6.171)	51.5
Total Batch Weight		441.2

Admixture: None

Remarks: V_T=.1193 cu yds

Concrete Determinations		
Slump	4.0	in.
Meas. air	4.0	%
Wt.	137.0	lb/cu ft
W/C	.615	
	51.73	gal/cu yd
	6.93	gal/sk
	7.46	sk/cu yd

Mix Design No. 4
Run No. 6 Sealed/Fibers
Cement Content: 8
Water Content: ∿5
Admixture - Air Content: None

Specimens Prepared:

Flex	5
Gage	10
Compression	4

Item	Specific Gravity	Wt/Cu Ft Solid	
Cement	3.15	196.6	Type 1
Fine Aggregate	2.65	165.4	F.M. 3.16
Coarse Aggregate	2.68	167.2	Wt. D.R. 107 lb

Item	Solid Volume of Materials Required/Cu Yd	Cu Ft Solid	Batch Wts. Dry/3 Cu Ft. Batch, lb
Cement	753	3.83	83.7
Polymer	116	1.89	12.9
Water	376	6.03	41.8
Fine Aggregate	1446	8.74	160.7
Coarse Aggregate	975	5.83	108.3
Air	-	0.27	-
Fibers	198.6	0.41	22.1
Total	3864.6	27.00	429.5

Item		Batch Wts. (wet), lb
Cement		83.7
Polymer		12.9
Concrete Sand		162.7
C.A. No. 4		36.1
C.A. No. 5		72.2
Steel Fibers		22.1
Water	(6.171)	51.5
Total Batch Weight		441.2

Admixture: None

Concrete Determinations

Slump	4.8	in.
Meas. air	3.5	%
Wt.	137.3 lb/cu ft	
W/C	.615	
	51.86 gal/cu yd	
	6.93 gal/sk	
	7.48 sk/cu yd	

Remarks: V_T=.1190 cu yds

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