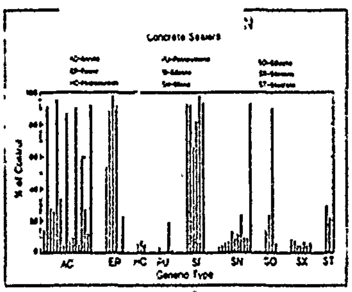
US Army Corps of Engineers

AD-A227 373



REMR RESEARCH PROGRAM

DTIC FILE COPY

(2)

REPAIR, EVALUATION, MAINTENANCE, AND REHABILITATION RESEARCH PROGRAM

TECHNICAL REPORT REMR-CS-17

SURFACE TREATMENTS TO MINIMIZE CONCRETE DETERIORATION

Report 2
LABORATORY EVALUATION OF SURFACE TREATMENT MATERIALS

by

Tony B. Husbands, Fred E. Causey

Structures Laboratory

DEPARTMENT OF THE ARMY
Waterways Experiment Station, Corps of Engineers
3909 Halls Ferry Road, Vicksburg, Mississippi 39180-6199

US ARMY ENGINEER WATERWAYS EXPERIMENT STATION

September 1990

Report 2 of a Series

Approved For Public Release; Distribution Unlimited

Prepared for DEPARTMENT OF THE ARMY
US Army Corps of Engineers
Washington, DC 20314-1000

Under Civil Works Work Unit 32302

The following two letters used as part of the number designating technical reports of research published under the Repair, Evaluation, Maintenance, and Rehabilitation (REMR) Research Program identify the problem area under which the report was prepared:

	Problem Area		Problem Area
CS	Concrete and Steel Structures	EM	Electrical and Mechanical
GT	Geotechnical	EI	Environmental Impacts
HY	Hydraulics	OM	Operations Management
CO	Coastal		

COVER PHOTOS:

TOP — Application of surface treatment material to concrete cube for water-absorption test.

MIDDLE — Water-absorption test results for concrete sealers.

BOTTOM — Application of HMWM monomer to bridge deck.

Unclassified

SECURITY CLASSIFICATION OF THIS PAGE

REPORT DOCUMENTATION PAGE

Form Approved OMB No. 0704-0188

1a. REPORT SECURITY CLASSIFICATION Unclassified	1b. RESTRICTIVE MARKINGS
2a. SECURITY CLASSIFICATION AUTHORITY	3. DISTRIBUTION/AVAILABILITY OF REPORT Approved for public release; distribution unlimited.
2b. DECLASSIFICATION/DOWNGRADING SCHEDULE	
4. PERFORMING ORGANIZATION REPORT NUMBER(S) Technical Report REMR-CS-17	5. MONITORING ORGANIZATION REPORT NUMBER(S)
6a. NAME OF PERFORMING ORGANIZATION USAEWES Structures Laboratory 6b. OFFICE SYMBOL (If applicable) WESSC	7a. NAME OF MONITORING ORGANIZATION
6c. ADDRESS (City, State, and ZIP Code) 3909 Halls Ferry Road Vicksburg, MS 39180-6199	7b. ADDRESS (City, State, and ZIP Code)
8a. NAME OF FUNDING/SPONSORING ORGANIZATION US Army Corps of Engineers 8b. OFFICE SYMBOL (If applicable)	9. PROCUREMENT INSTRUMENT IDENTIFICATION NUMBER
8c. ADDRESS (City, State, and ZIP Code) Washington, DC 20314-1000	10. SOURCE OF FUNDING NUMBERS PROGRAM ELEMENT NO. / PROJECT NO. / TASK NO. / WORK UNIT ACCESSION NO.

11. TITLE (Include Security Classification)
Surface Treatments to Minimize Concrete Deterioration; Laboratory Evaluation of Surface Treatment Materials

12. PERSONAL AUTHOR(S)
Husbands, Tony B.; Causey, Fred E.

13a. TYPE OF REPORT	13b. TIME COVERED	14. DATE OF REPORT (Year, Month, Day)	15. PAGE COUNT
Report 2 of a series	FROM Oct 1985 TO Oct 1989	September 1990	102

16. SUPPLEMENTARY NOTATION A report of the Concrete and Steel Structures Problem Area of the Repair, Evaluation, Maintenance, and Rehabilitation (REMR) Research Program. Available from National Technical Information Service, 5285 Port Royal Road, Springfield, VA 22161

17. COSATI CODES			18. SUBJECT TERMS (Continue on reverse if necessary and identify by block number)
FIELD	GROUP	SUB-GROUP	See reverse.

19. ABSTRACT (Continue on reverse if necessary and identify by block number)

The US Army Corps of Engineers initiated in 1984 a research program designated Repair, Evaluation, Maintenance, and Rehabilitation (REMR). One of the REMR work units was the evaluation of surface treatments to minimize concrete deterioration. Many of the Corps' hydraulic structures have experienced concrete surface deterioration due to (a) freezing and thawing, (b) aggressive chemical exposure, and (c) erosion. Surveys by Corps personnel have shown that freezing and thawing was the major contributing factor to concrete surface deterioration followed by erosion.

Many different types of surface treatments were evaluated under this work unit including concrete sealers, coatings, polymer systems, thin overlays, and shotcrete. Emphasis was placed on materials that could be applied to the surface to reduce or prevent damage to concrete by freezing and thawing. Polymer systems for sealing cracks by topical application

(Continued)

20. DISTRIBUTION/AVAILABILITY OF ABSTRACT ☐ UNCLASSIFIED/UNLIMITED ☐ SAME AS RPT ☐ DTIC USERS	21. ABSTRACT SECURITY CLASSIFICATION Unclassified	
22a. NAME OF RESPONSIBLE INDIVIDUAL	22b. TELEPHONE (Include Area Code)	22c. OFFICE SYMBOL

DD Form 1473, JUN 86 *Previous editions are obsolete.* SECURITY CLASSIFICATION OF THIS PAGE

Unclassified

Unclassified
SECURITY CLASSIFICATION OF THIS PAGE

10. SOURCE OF FUNDING NUMBERS (Continued).

Civil Works Work Unit 32302, "Surface Treatments to Minimize Concrete Deterioration."

18. SUBJECT TERMS (Continued).

Abrasion	Sealers
Coatings	Shotcrete
Concrete	Surface treatments
Dampproofing	Vapor transmission
Latex admixtures	Water absorption

19. ABSTRACT (Continued).

and elastomeric coatings for coating cracked concrete were evaluated. Other coatings for protecting concrete from erosion, chemical attack, and graffiti were evaluated. Latex admixtures for shotcrete and mortar for thin overlays were investigated.

Coatings and concrete sealers for protecting concrete from damage by freezing and thawing were tested for their effectiveness to seal concrete from water intrusion, ability to breath (passage of water vapor), resistance to freezing and thawing, and resistance to weathering and moisture. Latex-modified mortars and shotcrete were tested for resistance to freezing and thawing, bond to concrete, and other properties measured. Other tests for materials included bond strength to concrete, viscosity, abrasion resistance, tack free time, gel time, and resistance to weathering.

Unclassified
SECURITY CLASSIFICATION OF THIS PAGE

PREFACE

The study reported herein was authorized by Headquarters, US Army Corps of Engineers (HQUSACE), under Civil Works Work Unit 32302, "Surface Treatments to Minimize Concrete Deterioration," for which Mr. Tony B. Husbands, Concrete Technology Division (CTD), Structures Laboratory (SL), US Army Engineer Waterways Experiment Station (WES), is Principal Investigator. This work unit is part of the Concrete and Steel Structures Problem Area of the Repair, Evaluation, Maintenance, and Rehabilitation (REMR) Research Program. Mr. James E. Crews (CECW-OM) and Dr. Tony C. Liu (CECW-EG) served as the HQUSACE Overview Committee for REMR and provided overall direction. The HQUSACE Technical Monitor for this effort was Dr. Liu. Mr. Jesse A. Pfeiffer, Jr., (CERD-C), was the REMR Coordinator at the Directorate of Research and Development, HQUSACE.

This study was conducted at WES during the period October 1985 to October 1989 under the general supervision of Messrs. Bryant Mather, Chief, SL; John M. Scanlon and Kenneth L. Saucier, former and present Chiefs, respectively, CTD; and R. L. Stowe, Chief, Materials and Concrete Analysis Group, CTD. Problem Area Leader for the Concrete and Steel Structures Problem Area is Mr. James E. McDonald, CTD. Program Manager for REMR is Mr. William F. McCleese, CTD. This report was prepared by Messrs. Husbands and Fred E. Causey, CTD.

The authors wish to express their deep appreciation to the following individuals in the US Army Engineer District and Division offices who gave of their valuable time and knowledge:

Allen Bodron, Memphis District
Bob Becker, New Orleans District
Lee Lenzner, St. Louis District
Dick Huff, Kansas City District
Rick Donovan, Omaha District
Art Fleetwood, Baltimore District
William Kennedy, Norfolk District
Wallace Berry, Norfolk District
Jim McKinnery, Philadelphia District
Dick Atkinson, Rock Island District
Vick Cervasi, Rock Island District
Lee Stenerson, St. Paul District
Rosie Braatz, St. Paul District
Dave Ellison, Portland District
Seichi Konno, Portland District

Steve Tatro, Walla Walla District
Richard Kaden, Walla Walla District
Tom Hugenburg, Ohio River Division
Tim Entiline, Huntington District
Larry Brockman, Louisville District
Noah Whittle, Louisville District
Wayne Hickman, Nashville District
Joe Coletti, Pittsburgh District
Larry McElfresh, Pittsburgh District
Bobby Feldon, Mobile District
Bill Heyenbrouch, Sacramento District
Charles Deaver, Little Rock District
Johney Broko, Little Rock District
Jim Davis, Tulsa District
William Coy, Missouri River Division
Gary Miller, Baltimore District
Carolyn Flaherty, Portland District
David Campbell, Galveston District
Joseph Colucci, New England Division
Leo Cain, Mobile District
George Hunt, Vicksburg District

COL Larry B. Fulton, EN, is the Commander and Director of WES, and Dr. Robert W. Whalin is Technical Director.

CONTENTS

CONVERSION FACTORS, NON-SI TO SI (METRIC) UNITS OF MEASUREMENT

Non-SI units of measurement used in this report can be converted to SI (metric) units as follows:

Multiply	By	To Obtain
centipoises	0.001	pascal-seconds
cubic yards	0.7645549	cubic metres
Fahrenheit degrees	5/9	Celsius degrees or kelvins*
feet	0.3048	metres
gallons (US liquid)	3.785412	litres
inches	25.4	millimetres
mils	0.0254	millimetres
pounds (force) per square inch	0.006894757	megapascals
pounds (mass)	0.4535924	kilograms
pounds (mass) per cubic foot	16.01846	kilograms per cubic metre
pounds (mass) per cubic yard	0.5932764	kilograms per cubic metre
square inches	6.452	square centimetres
square feet	0.09290304	square metres
square feet per gallon	0.024542	square metres per litre
square yards	0.8361	square metres

* To obtain Celsius (C) temperature readings from Fahrenheit (F) readings, use the following formula: $C = (5/9)(F - 32)$. To obtain kelvin (K) readings, use: $K = (5/9)(F - 32) + 273.15$.

SURFACE TREATMENTS TO MINIMIZE CONCRETE DETERIORATION

LABORATORY EVALUATION OF SURFACE TREATMENT MATERIALS

PART I: INTRODUCTION

Background

1. The surfaces of many of the Corps of Engineers' concrete structures are subject to deterioration due to freezing and thawing, penetration of solutions, weathering, chemical attack, and erosion. Surface treatment of the concrete with a material more resistant to these factors than concrete is one way to slow the rate of deterioration. The Corps has used various coatings in the past, and some have been successful while others have failed. In most cases the failures resulted from the wrong choice of surface treatment material or improper application. Very little guidance is available for Corps personnel in choosing and applying these surface treatment materials.

2. Freezing and thawing has been reported to be the major cause for concrete surface deterioration in Corps structures. This type of deterioration is caused when water penetrates the concrete, produces critical saturation, and freezes. Many of the older Corps structures were constructed from nonair-entrained concrete and do not successfully withstand cycles of freezing and thawing. Cracks, allowing water to enter the concrete, have developed in many of the structures, thereby enhancing spalling or scaling of these areas as a result of freezing. Surface treatment materials, sealers, coatings, or penetrants, are available and can provide added protection against the intrusion of water. The ideal material is one that restricts the intrusion of water into the concrete yet allows the concrete to breathe (transmit water vapor).

3. Erosion has also been reported as a major reason for concrete deterioration. A report (Bean 1988) published earlier in this study and including a field survey of Corps of Engineers' projects revealed that most surface treatments used by the Corps have been for the prevention of erosion. A few projects reported deterioration due to aggressive waters (low pH and soft water) and penetrating salt solutions into concrete.

Objective

4. The objective of this study was to investigate the effectiveness of various types of surface treatments used for protecting and repairing concrete subjected to aggressive agents in the environment by laboratory testing and to develop information and guidance on the selection and application of these surface treatments.

Approach

5. Emphasis was placed on surface treatment materials that could minimize or prevent damage to concrete due to freezing and thawing. The effectiveness of these surface treatments was determined by:

- a. The ability to seal concrete from water intrusion and to transmit water vapor;
- b. The resistance to freezing and thawing and weathering; and
- c. The total solids, bond strength to concrete, and ease of application.

6. Other types of surface treatments evaluated were: coatings to minimize erosion, polymer systems for sealing cracks by topical application, elastomeric coatings for sealing surfaces containing numerous cracks, thin cementitious overlays, shotcrete containing latex admixtures, and a few graffiti-resistant coatings. Keywords: Concrete; Coatings; Sealing compounds; Freezing; Thawing; Waterproofing (RH)

PART II: MATERIALS

Types for Reporting Test Data

7. Surface treatment materials evaluated in this study were separated into types for reporting test data based on manufacturers' recommended use, viscosity, total solids, and chemical composition. The types of materials were classified as: concrete sealers, concrete coatings, special polymer systems, shotcrete, and cementitious materials for thin overlays. The American Concrete Institute (ACI) (1987a) defines coatings as materials applied to a surface by brushing, dipping, mopping, spraying, trowelling, etc. to preserve, protect, decorate, seal, or smooth the substrate. Most of the surface treatment materials evaluated would meet this description. For ease of reporting test data, the surface treatment materials were separated into the classes of coatings just mentioned. A description of the different types and generic classification of materials evaluated follows.

Concrete Sealers

8. Approximately one-half of the surface treatment materials evaluated would be classed as concrete sealers. Concrete sealers are the surface-treatment materials most often applied to the surface of concrete to minimize or prevent damage from freezing and thawing. They are also used to slow or prevent the intrusion of solutions into concrete and for reducing the penetration of water into concrete. Concrete sealers are normally low in viscosity and total solids (less than 50 percent). Some of the concrete sealers tested did have solid contents greater than 50 percent. Concrete sealers penetrate to some degree into the surface of the concrete, and the degree of penetration depends on the porosity and moisture content of the concrete, viscosity and solids content of the material, application rate, and drying time of the sealer. Some concrete sealers after drying leave a film on the surface ranging from a few mils to approximately 10 mils* in thickness. Others

---

* A table of factor for converting non-SI units of measurement to SI (metric) units is presented on page 4.

penetrate deeper into surface leaving no noticeable film on the surface. Some sealers darken or leave a sheen on the surface, whereas others cause no change in the appearance of the concrete. A report by Koltke (1987) categorized concrete sealers as coatings and penetrating sealers.

9. Over the past 25 years, there has been an ongoing investigation of numerous concrete sealers including linseed oil, petroleum distillates, epoxies, urethanes, acrylics, silicones, etc. Results varied widely for the effectiveness of these various materials. Some of the materials that appear to be effective are very expensive or are difficult to handle safely.

10. The most widely used surface treatment based on boiled linseed oil. It is composed of 50 percent boiled linseed oil and 50 percent mineral spirits or kerosene and is widely used as received. Investigators differ greatly on the effectiveness of this surface treatment.

11. The second most widely used surface treatment is epoxy resin. Epoxy resins have been used as penetrating sealants and as coatings. Solids may vary from as little as 10 percent to as much as 100 percent, and the performance has varied from effective to ineffective. Usually two coats of epoxy resin are recommended to reduce pinholing.

12. Materials that are now becoming very popular are silanes and siloxanes. Both materials are generally penetrating sealants and have low total solids (1 to 40 percent).

13. There are many varieties of synthetic resins that have also been evaluated. They include acrylics, polyurethanes, and hydrocarbon resins. These materials may be solvent or waterbase, and their effectiveness varies widely.

14. There are also a number of inorganic surface treatments that have been investigated. Generally, these materials are based on a silicate solution. The advantage of silicate solutions are that they are nontoxic, nonflammable, or nonhazardous under normal conditions, and are inexpensive compared to most.

Concrete Coatings

15. Most of the other surface treatment materials, excluding those classified as concrete sealers, were classified as concrete coatings. The

manufacturers' recommended usage of the concrete coatings obtained for evaluation included: reducing the permeability of concrete; protective coatings for erosion, chemical attack and weathering; underwater application to concrete; and graffiti resistance, as well as others. Most coatings obtained were high in total solids (greater than 50 percent), with consistency ranging from low viscosity (sprayable) to high viscosity (brushable or trowellable). Types of coatings included epoxy resins, polyester resins, acrylics, vinyls, polyurethanes, silicones, neoprenes, butyl rubbers, and cementitious coatings. The general characteristics of these coatings and sealers can be found in Appendix A of Report 1 (Bean 1988).

16. Epoxy resins have long been used by the Corps of Engineers as a coating to protect against concrete erosion. Sand is normally added to the mixed epoxy resin to produce an epoxy-resin mortar when thickness of the coating is greater than 1/16 in. Epoxy-resin coatings have been used for a few applications in protecti concrete from chemical attack and for reducing the permeability of concrete. Some guidance in selecting and applying epoxy-resin coatings is available in the ACI Manual of Concrete Practice (ACI 1987b), and the American Society for Testing and Materials (ASTM), 1989 Annual Book of ASTM Standards (1989ℓ). A large number of epoxy-resin coatings were obtained with emphasis being placed ore on the protection of concrete from chemical attack and freezing and thawing rather than erosion. Some special epoxy resins were obtained for erosion studies and underwater application. In the latter part of this study, an inquiry was made on slow curing epoxy resins that could be used to bond freshly mixed concrete to hardened concrete and to serve as a bond breaker during the early stages (first 48 hr) of hardening of the concrete. Four epoxy resins were obtained and tested.

17. An existing problem is finding coatings that can be used on concrete with numerous narrow surface cracks. Most concrete sealers are not effective for sealing cracks. Cracks will reflect through most coatings. Elastomeric coatings that might bridge these cracks were sought since the elastomeric quality would not yield under any crack movement. Most manufacturers of such concrete coatings recommend routing out wide cracks and sealing them before coating or the use of fabrics underneath the coating. Different types of the coatings, acrylics, polyurethanes, neoprenes, and one silicone were obtained for evaluation.

18. A few polyester-resin coatings were obtained for evaluation. Polyester resins are moderately priced when compared to epoxy resins. Some of these resins can be obtained for approximately $1.00 per pound, whereas, epoxy resins cost $3.00 to $5.00 per pound. Polyester resins with engineering properties similar to epoxy resins can be obtained. Polyester resins mixed with sand could be applied in thick coats as protection against erosion. One disadvantage of polyester-resin coatings is that they are more moisture sensitive than epoxy resins during curing, and they cannot be applied to damp concrete surfaces.

19. A few cementitious coatings were obtained, since the manufacturers claim that these materials can be used to "waterproof" concrete walls from the negative side. One manufacturer also stated that its cementitious coating had been used to protect concrete from damage due to freezing and thawing. One cementitious coating system that consisted of two powders and a liquid for stopping water leaks was tested in the laboratory and field tested at Gathright Dam, Virginia, to stop a leak at a construction joint.

Polymer Systems for Sealing Cracks

20. Approximately 5 years ago a manufacturer of polymers introduced a high molecular-weight methacrylate (HMWM) monomer for sealing cracks by topical application. The monomer is polymerized by the addition of a catalyst. These monomers are of low viscosity (10 to 40 cp) and can penetrate into very narrow cracks when poured on the surface of concrete. Since the introduction of this monomer, other manufacturers began marketing similar monomers. Three manufacturers of such monomers were contacted and samples obtained for testing. A low-viscosity epoxy resin (40 cp) and one polyurethane were also tested.

Shotcrete

21. The use of shotcrete for coating deteriorated concrete surfaces was investigated. Two problems may exist when using a conventional shotcrete mixture (sand, cement, water, and possibly small coarse aggregates), poor resistance to freezing and thawing and cracking of the material. Shotcrete

mixtures containing a latex admixture were evaluated to determine if the problems described could be eliminated. Two latex admixtures, an acrylic copolymer and a styrene-butadiene were obtained for evaluation. Polypropylene fibers were also added to some of the shotcrete mixtures for evaluation.

Thin Overlay Materials

22. Latex-modified mortars and concretes are presently being used by the Corps of Engineers for thin overlays on existing concrete structures. A few commercial latex-modified mortars and a number of latex admixtures for preparing latex-modified mortars were obtained for evaluation. A Repair, Evaluation, Maintenance, and Rehabilitation (REMR) report (Bean and Husbands 1986) published earlier describes some of these materials.

Product Description

23. The products classified as concrete sealers and coatings are listed in the Key accompanying this report. The manufacturer, product name, classification, and assigned laboratory numbers are given. Seven HMWM's, an epoxy resin, and one polyurethane system were obtained for evaluation in sealing cracks in concrete by topical application. Two latex admixtures and a polypropylene fiber were used in the shotcrete mixtures. Three latex admixtures were used in mortars for thin overlays.

Health and Environmental Consequences

Health and safety with chemicals

24. This technical report discusses the use of chemical substances that, if used improperly, may have adverse health and safety impacts. Reasonable caution should guide the use of such materials. Manufacturer's directions and recommendations for the protection of occupational health and safety should be carefully followed. Material Safety Data Sheets (MSDS) should be obtained from the manufacturers of such materials. In cases where the effects of a chemical substance on occupational health and safety are

unknown, chemical substances should be treated as potentially hazardous or toxic materials.

Environmental

25. In addition to the potentially extreme a 'e worker health and safety effects, improper handling and disposal of surface treatment materials and their associated solvents may have adverse environmental effects. Reasonable caution should guide the use of surface treatment activities involving the use of potentially hazardous and toxic chemical substances. Manufacturer's directions and recommendations for the protection of environmental quality should be carefully followed. The MSDS should be consulted for detailed handling and disposal instructions. The MSDS also provides guidance on appropriate responses in the event of spills. In cases where the effects of a chemical substance on environmental quality are unknown, chemical substances should be treated as potentially hazardous or toxic materials. Residual surface treatment materials may be classified as a hazardous waste requiring special disposal considerations. The MSDS will generally recommend that Federal, state, and local regulations be consulted prior to determining disposal requirements. Improper handling and disposal of waste materials may result in civil and criminal liability.

PART III: TEST METHODS

26. Published test methods were used whenever applicable, but certain tests had to be developed to evaluate the surface treatment materials. For a surface treatment to protect concrete (nonair-entrained) from damage due to freezing and thawing, the treatment must prevent water from entering the concrete. A water-absorption test was selected to screen the materials to determine the effectiveness of surface treatments in preventing the intrusion of water into concrete. Most materials that were not effective (high early water-absorption values) were eliminated from further testing. The literature survey made earlier in the study indicated that an ideal surface treatment material prevents water from entering and is breathable (ability of material to allow water vapor to escape from the substrate). A test to determine the water-vapor transmission was developed. The resistance to freezing of nonair-entrained concrete coated with the surface treatment materials was determined by measuring the resistance to scaling and rapid freezing and thawing. Other tests used to evaluate the different surface treatment materials were: bond strength to concrete, accelerated weathering, and total solids. A few of the concrete coatings were tested for resistance to abrasion, viscosity, permeability, and dry to touch. Other tests were developed to determine the performance of the materials.

Water Absorption

27. The method used to determine the relative percent of water absorption by concrete sealed with various surface treatments based on ASTM C 642-82 (1989b) is discussed in the following paragraphs. This method is intended to apply for the testing of various types of concrete sealers and coatings regardless of the coverage rate or thickness of the treatment.

28. The concrete mixture was proportioned to have relatively high permeability. The parameters selected were: (a) water-to-cement ratio, 0.62; (b) slump, 3-1/2 ± 1/2 in.; (c) nonair-entrained; (d) durable aggregate, 12.5-mm (1/2-in.) nominal maximum size aggregate; and (e) minimum compressive strength of 3,500 psi. The mixture proportions used are shown in the following tabulation:

Material	Amount, lb/cu yd
Coarse aggregate, 12.5 mm (1/2 in.)	1,483
Sand	1,454
Cement	470
Water	291
Total	3,698

Compressive strength tests on 6- by 12-in. cylinders gave an average value of 3,700 psi.

29. Mixing of the concrete was in accordance with standard concreting practices. Four-inch cubes were cast and compacted. The cubes were cured 24 hr in the molds in the moist curing room (100-percent humidity and 73 ± 3 °F), then stripped and moist cured for a minimum of 28 days.

30. After the concrete cubes were cured, the water-absorption specimens were prepared by the following procedure. The cubes were lightly sandblasted to remove laitance and foreign debris. Next, they were dried 24 hr at 225 ± 5 °F and cooled overnight. Surface treatments were applied to the dried cubes in accordance with the manufacturer's recommendations as shown in Figure 1. Also, the manufacturer's recommended curing procedure was followed. Records were made of application, curing, and appearance of each surface treatment.

31. The following testing procedure was followed to determine the water absorption for each surface treatment. Specimens were stored in laboratory air for 7 days, then they were weighed to the nearest 0.1 g. This is the initial weight. Next, specimens including controls that had been sandblasted and dried were immersed in 73 ± 3 °F water. A minimum of a 1/2-in. cover of water was maintained over the specimens. Specimens were removed one at a time and weighed at 24, 48, 72, and 96 hr, and 7 days. A paper towel was used to blot the surface dry before weighing. Each specimen was weighed to the nearest 0.1 g and returned to the soaking tank.

32. The percent water absorbed was calculated based on the initial weight of the specimen. Surface treatments were tested in duplicate and the average reported in relative percent absorption.

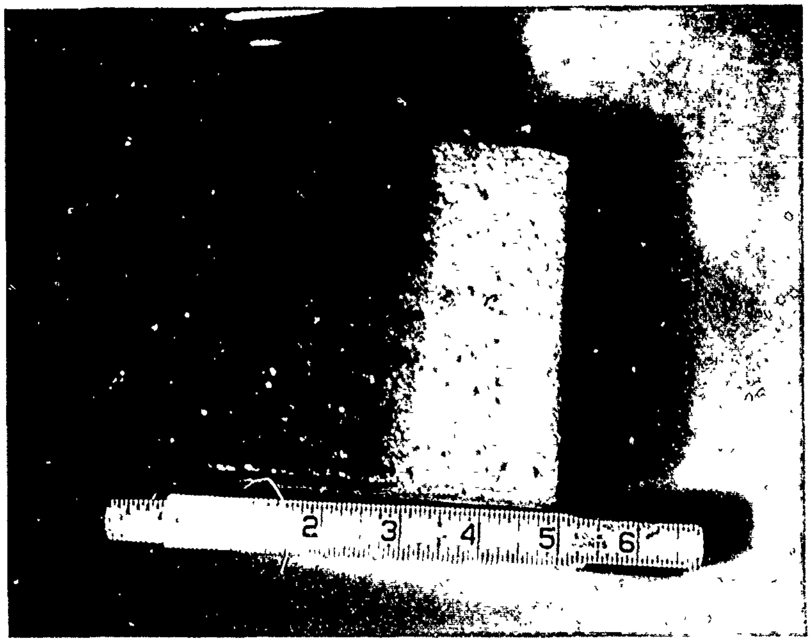


Figure 1. Application of surface treatment material to concrete cube for water-absorption test

33. Another test method for determining the effectiveness of surface treatment in preventing water from entering concrete is the inverted funnel method. A calibrated tube or buret is attached to the spout of a funnel. The funnel is placed over the treated surface of a concrete or mortar specimen. A bead of silicone caulk about 3/8 in. wide is then placed around the outer edge of the funnel. Water is poured through the funnel into the calibrated tube until the tube is filled to the zero calibration line. Care should be taken not to entrap air in the funnel containing the water. The water absorption is then measured with time by reading the volume change. This method was evaluated as a possible method to determine the effectiveness of surface treatments applied in the field. The inverted funnel testing device is shown in Figure 2.

Water-Vapor Transmission

34. As with water absorption, a water-vapor transmission test method was developed to determine the relative percent of water-vapor transfer through a concrete sealed with a surface treatment. The method used was

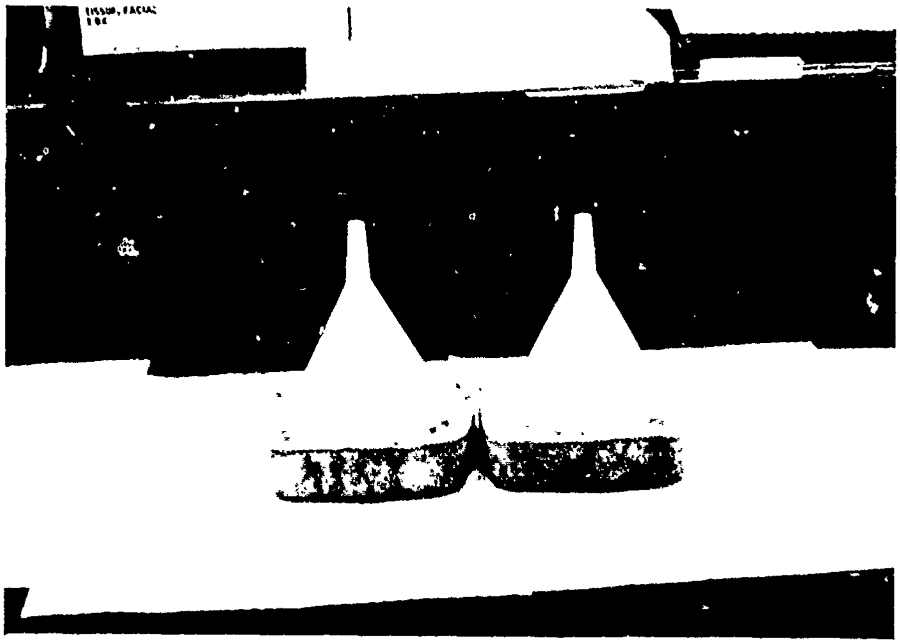


Figure 2. Inverted funnel for measuring water absorption

applied to various types of surface treatments regardless of coverage or thickness.

35. Specimens were prepared, just as the water-absorption specimen, through curing of the surface treatment. After surface treatments were cured, the cubes were drilled on one face in the middle with a 1/2-in. masonry bit. The drill hole was 2 in. deep. A test specimen with a drill hole is shown in Figure 3. Specimens were dusted and soaked in water at 73 ± 3 °F for 5 days. When the soaking period was completed, specimens were removed one at a time and the drill hole was sealed. The following procedure was used to seal the drill hole. All water in the hole was poured out. A paper towel was used to dry standing water and the hole was sealed with a size 0 rubber stopper. Hot paraffin wax was used to seal the stopper-hole interface. Petroleum jelly was used to make sure of the seal between surface treatment and the wax. A sealed test specimen is shown in Figure 4.

36. The water-vapor transmission was determined by the following procedure. As soon as specimens were sealed, they were weighed to the nearest 0.1 g, and this weight is the initial weight. Specimens were placed in an environmental room at 100 ± 4 °F and 40 ± 5 percent relative humidity. Specimens were weighed at 2, 4, and 7 days to the nearest 0.1 g. Each surface treatment was tested in duplicate and the water-vapor transmission was

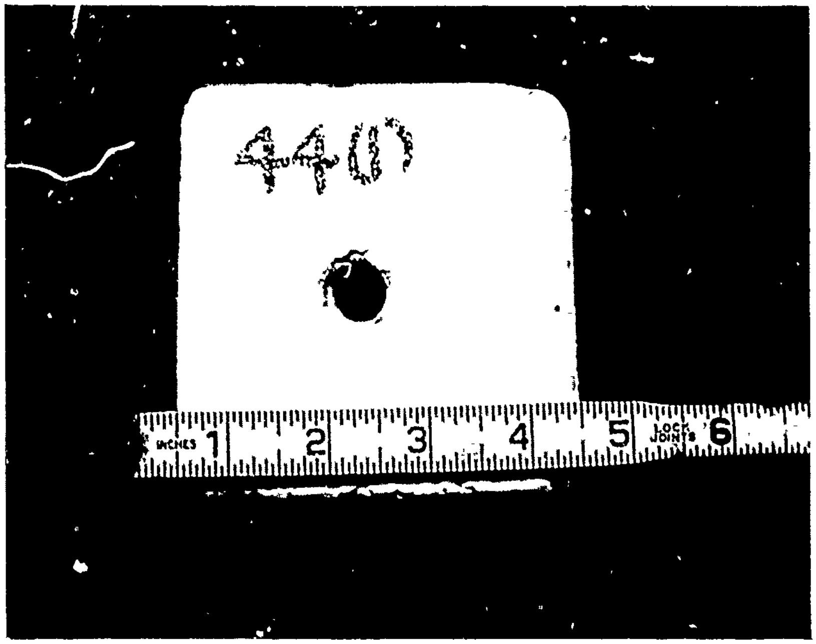


Figure 3. Water-vapor transmission test specimen showing 1/2-in. hole

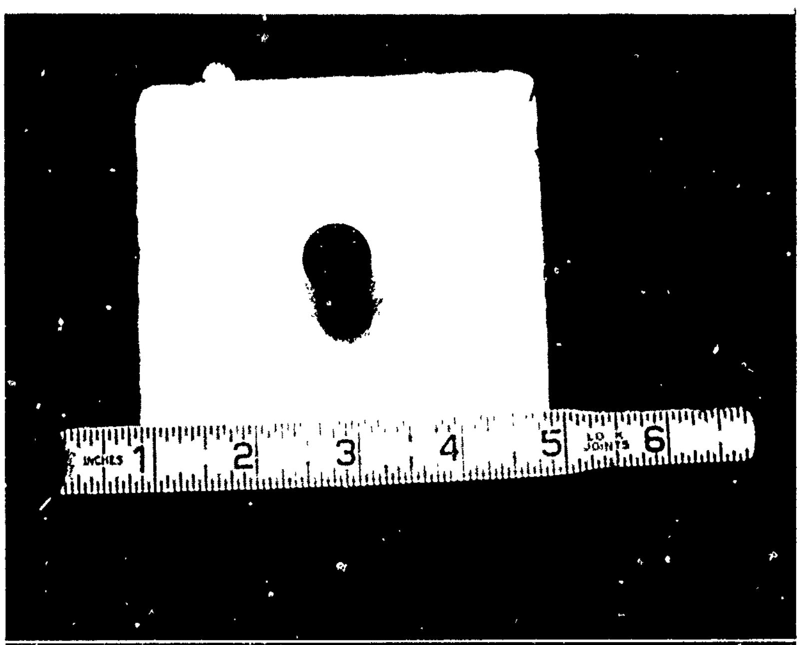


Figure 4. Water-vapor transmission specimen with hole sealed

calculated based on initial weight of specimen. The water-vapor transmission was reported as the relative average percent.

37. Another test to determine water-vapor transmission through coated mortar was evaluated. This method was used earlier in the study to determine water-vapor transmittance of thin latex-modified mortars, and is described by Bean and Husbands (1986). The 1/2- by 3-1/2-in. mortar disks were coated with concrete sealers and sealed to the metal container. The specimens were placed in an oven set at a designated temperature and the weight loss was recorded with time.

Freezing and Thawing Tests

38. Freezing and thawing and scaling tests were performed using ASTM methods as guides rather than developing other methods. The test method used for rapid freezing and thawing studies was ASTM C 666-84, Procedure A, (ASTM 1989d) and for scaling studies ASTM C 672-84 (ASTM 1989e) was used. Mixture proportions used for the first series of concrete specimens produced a poor quality concrete with a compression strength of less than 2,500 psi. This concrete mixture was used to evaluate surface treatments when applied to a poor quality concrete surface. The mixture proportions were as follows:

Materials	Amount, lb/cu yd
Cement, Type I	288.5
Fly ash, Type F	73.3
Fine aggregate (natural sand)	1,425.9
Coarse aggregate, 19.0-mm (3/4-in.) limestone	2,051.9
Water	250.0

The average compression strength for the above mixture proportions was 2,340 psi.

39. Concrete beams cast for the freezing and thawing tests were 16 by 4-1/2 by 3-1/2 in. The concrete beams were lightly sandblasted and surface treated in accordance with the manufacturer's recommendations. The test specimens were then tested following ASTM C 666-84, Procedure A, (ASTM 1989d) for resistance to freezing and thawing. All the specimens tested showed poor resistance, therefore the concrete mixture was changed to prepare a concrete

with higher strength and a lower permeability. The mixture proportions for this concrete are as follows:

Materials	Amount, lb/cu yd
Cement, Type II	564.0
Fine aggregate (natural sand)	1,379.9
Coarse limestone aggregate, size 12.5 mm (1/2 in.)	1,744.4
Water	293.3

Using these mixture proportions, five batches were cast giving the following averages values: (a) water to cement ratio (w/c) = 0.52; (b) slump, 3-1/2 in.; (c) unit weight, 147.8 pcf; (d) air, 2.5 percent; and (e) compressive strength, 5,550 psi. Specimens were moist cured a minimum of 28 days. This concrete mixture was used to prepare the concrete beams for the remainder of the tests.

40. The test procedure, ASTM C 666-84, Procedure A, (ASTM 1989d), was modified because of poor test results obtained for concrete beams treated with the concrete sealers and coatings. Another series of specimens was tested using the modified method following this pattern:

2 days of freezing and thawing cycles, 1 day drying in laboratory air,
2 days of freezing and thawing cycles, 2 days drying in laboratory air

This sequence of exposure was continued each week until failure occurred or sufficient cycles were completed.

Scaling Test

41. Scaling test specimens were cast in plastic molds about 12 by 8 by 3-1/2 in. The first set of specimens used for scaling were cast using the same mixture proportions as was used with the first set of freezing and thawing beams. This mixture had a compressive strength of less than 2,500 psi. The top surface of the concrete was lightly sandblasted and only the top surface was treated (sealed) with the surface treatments. A 1/2-in. bead of silicone caulking compound was placed around the outside edge of the slab to create a storage reservoir to hold water for freezing. One-quarter inch of water was placed in the reservoir. The specimens were placed in the freezer at -5 °F each night for 16 hr freezing of the water in the reservoir and taken out each morning for 8 hr thawing at 73 ± 3 °F for 50 cycles.

42. Upon completion of the first set of scaling tests, it was decided that the quality of concrete from these mixture proportions was too poor for the tests. Thus, a mixture was proportioned using the parameters from ASTM C 672-84 (ASTM 1989e). The parameters are as follows: (a) nonair-entrained; (b) cement content 564 ± 9.4 lb/cu yd; (c) slump, 3 ± 1/2 in.; (d) durable aggregate of 25.0-mm (1-in.) maximum size; and (e) a minimum compressive strength of 4,000 psi. From these parameters, the mixture was proportioned using 12.5-mm (1/2-in.) maximum size limestone aggregate and natural sand. The mixture proportions are the same as those shown for preparing the concrete beams. Several sets were lightly sandblasted and sealed with surface treatments in accordance with the manufacturer's recommendations. A 1/2-in. bead of silicone caulking compound was applied to the top treated and sealed surface to form a reservoir. The specimens were cycled according to the first set. On reviewing ASTM C 672-84 (ASTM 1989e) closely, it was decided that for penetrating surface treatments, the specimens should be lightly wirebrushed to remove dust and loose debris rather than sandblasted. All other handling, application of surface treatments, curing, and testing of specimens follow the previously given procedure.

43. The first tests were performed using a 4-percent calcium chloride solution instead of water. It was soon observed that spillage of the salt solution caused corrosion in the walk-in freezer, and water was used for most tests reported. A salt solution should accelerate scaling, and would have been better for comparing surface treatments. Because of the time required to complete a test and the larger number of test specimens, a maximum of 50 cycles was decided upon. A greater number of cycles, 75 to 100, would have been preferred. Later in the study it was decided that some of the surface treatments should be tested using the salt solution. The specimen size was decreased to 7 by 7 by 3 in. so that four specimens could be placed into a small freezer. A smaller test specimen used for measuring resistance to scaling is shown in Figure 5. The concrete mixture used was changed to obtain a higher porosity concrete to accelerate the testing by cycling only 25 times. The concrete mixture selected for these tests was the one used in preparing the 4-in. cubes for water absorption and is shown in paragraph 28. The scaling resistance was determined by a visual rating described in ASTM C 672-84 (ASTM 1989e), except for the later test using the smaller specimens. The

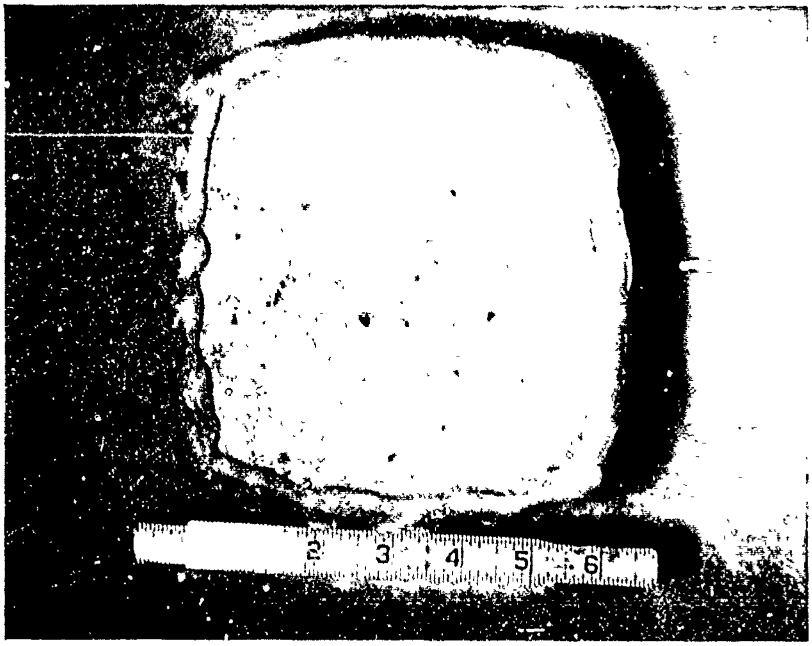


Figure 5. Smaller test specimen used for measuring resistance to scaling

weight loss (material and concrete scaled from the surface) was used for rating.

Adhesion Test

Elcometer tester

44. An Elcometer tester was used for testing the concrete coatings for bond strength to concrete. The Elcometer tester and test method is described in ASTM D 4541-85 (ASTM 1989h). The bond strengths were determined on the concrete block specimens prepared for the water-absorption test. Three sides of each block specimen were selected for testing, measuring the bond strength in the center, to obtain three bond strength values.

45. Aluminum dollies (referred to as loading fixtures in the ASTM procedure) were furnished with the Elcometer tester. Problems were encountered with this loading fixture; failure of the adhesive to the interface of the loading fixture; difficult to read low pull-off strengths; and a small area. A loading fixture was designed by the researchers to obtain more precise results. The loading fixture was prepared by cutting disks 1-1/2 in.

in diameter from rolled steel with a thickness of 3/8 in. The center of the disk was threaded to a depth of 1/4 in. so that a 1/4-in. bolt could be screwed into the disk. A small washer having an outside diameter of 5/8 in. was placed between the head of the bolt and disk to attach to the tester on the other end. The loading fixture prepared by the researchers had a surface area of 1.77 sq in., an area four times the loading fixture furnished with the Elcometer tester. The load in pounds per square inch recorded on the Elcometer tester was divided by four to obtain actual pull-off strengths in pounds per square inch. The loading fixtures supplied with the tester and a loading fixture prepared by the laboratory is shown in Figure 6.

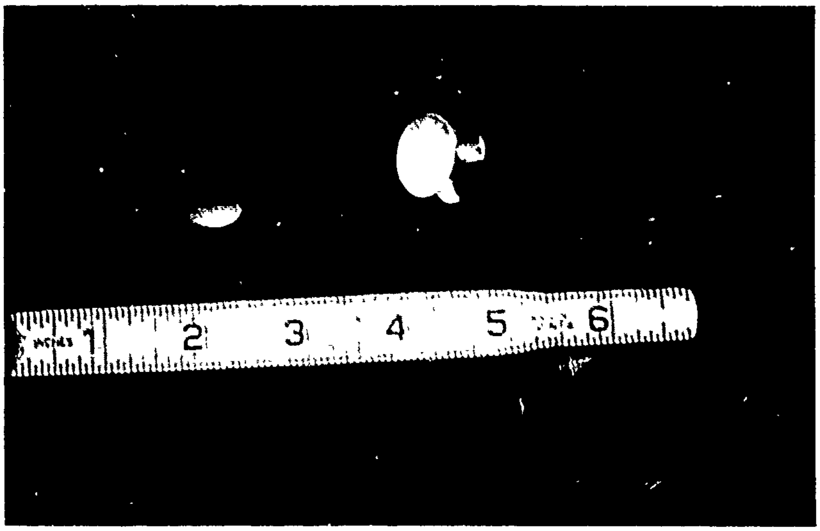


Figure 6. Loading fixtures for Elcometer tester

46. The surface of the steel loading fixture to be bonded to the coating surface was abraded slightly with an emery cloth and cleaned with a solvent (Freon). The surface of the coating was also abraded slightly with the emery cloth. The loading fixture was then bonded to the coating surface by a fast-setting epoxy resin. The following day a diamond-tipped core barrel (1-1/2 in. in diameter) was used to cut around the loading fixture through the coating. A portable coring device was made by cutting off an end of a core barrel and attaching a metal plate and rod so that the device could be used in a variable speed drill (Figure 7). The Elcometer tester and a coating being tested for bond strength was shown in Figures 8 and 9.

Slant-shear test

47. Bond strengths of the HMWM polymer systems, polyester resins, and

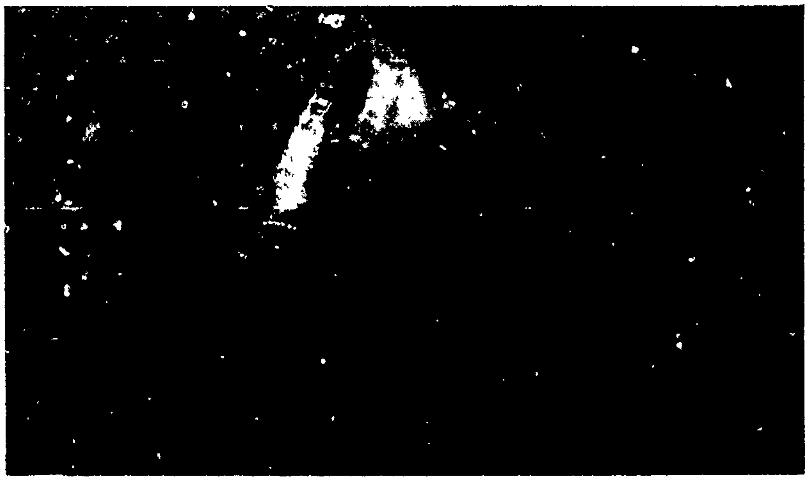


Figure 7. Apparatus for cutting around loading fixture

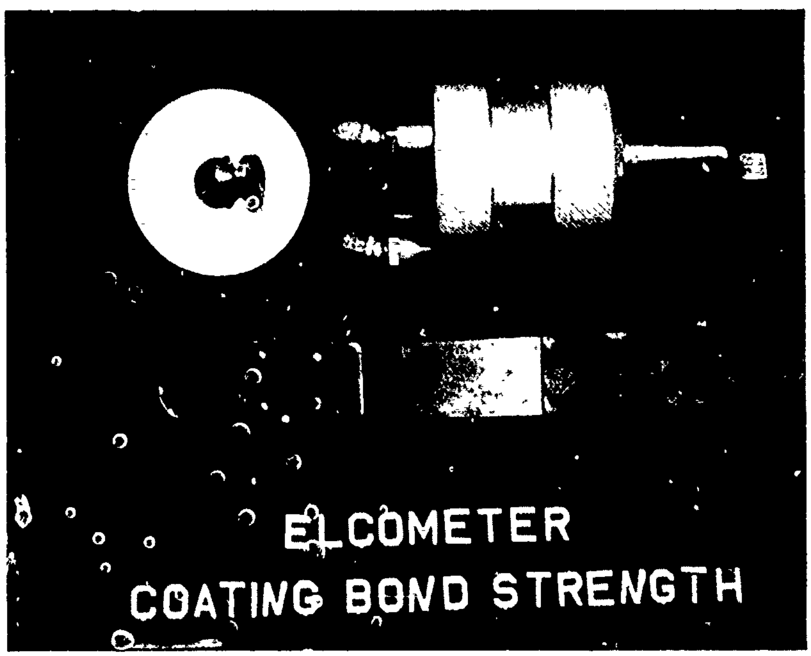


Figure 8. Elcometer tester

certain epoxy resins to concrete were determined in accordance with ASTM C 882-87 (ASTM 1989k).

Accelerated Weathering Test

48. The effect of weathering on the surface treatment materials was determined by an accelerated weathering tester using the equipment and test

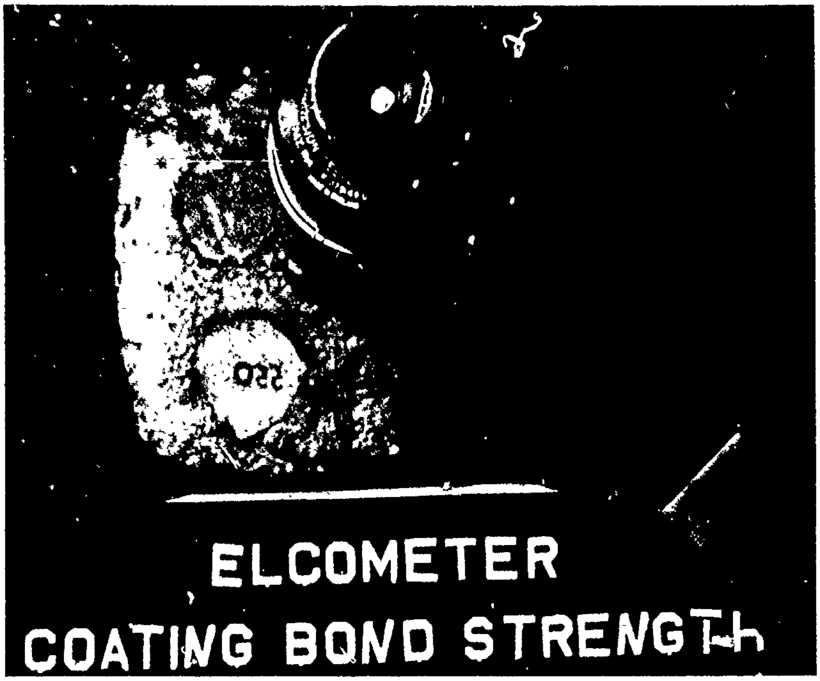


Figure 9. Elcometer testing coating for bond strength

method described in ASTM G 53-84 (ASTM 1989g). The tester contained ultraviolet (UV-B) fluorescent lamps with peak emission occurring at 313 nanometers. The time cycles used for the test were 5 hr UV and 3 hr condensation. The temperature for both UV and condensation was 50 °C.

49. Test specimens were prepared by casting 6- by 3- by 1/2-in. mortar prisms from a mortar mixture containing 1 part Type I portland cement, 2.75 parts graded Ottawa sand, and a w/c ratio of 0.47. The mortar prisms were moist cured for 28 days, then stored in a controlled chamber at 100 °F and 30-percent relative humidity for 7 days before coating with the surface treatment material. The material was applied to all sides using a 1/2-in. paint brush. After coating the prisms the materials were allowed to cure for 7 days in laboratory conditions, followed by placing the prisms in a forced-air oven at 130 °F for an additional 4 days.

50. The prisms were weighed to the nearest 0.1 g and then immersed in tap water at 73 °F. The prisms were placed in the water container with one of the narrow sides on the bottom to fully expose the wider sides to water. The prisms were removed from the container after 48 hr and the surfaces lightly

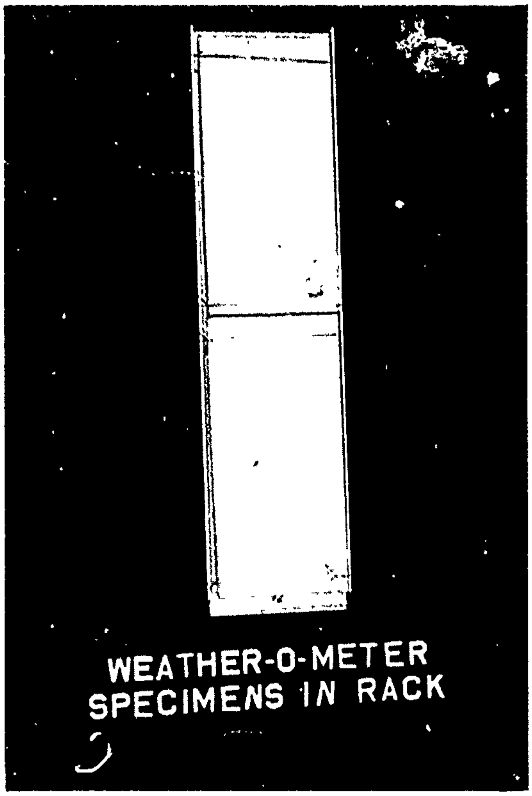


Figure 10. Test specimens in rack for accelerated weathering test

blotted with a paper towel to produce a saturated surface dried condition. The prisms were reweighed to the nearest 0.1 g to obtain water absorption before testing.

51. The prisms were placed into sample holders and held in place by tying a copper wire, small in diameter, around the top and bottom of the prism. The test specimens in the sample holders are shown in Figure 10. The sample holders were placed into the accelerated weathering tester and the prisms exposed to 1,600 hr of UV and condensation. The prisms were removed after exposure and placed into a forced-air oven at 130 °F for 4 days, then weighed to the nearest 0.1 g, and immersed in water for 48 hr. The water absorption was determined as before to obtain water absorption after testing. The coated prisms were visually examined and differences in appearance noted after exposure.

Other Tests

Total solids

52. The total solids were determined by weighing 1 to 2 g of the surface treatment material in a tared aluminum weighing dish. The dish was then placed into a forced-air oven at 220 °F. After 24 hr the dish was removed, placed into a desiccator to cool, then reweighed. The solids content was calculated as follows:

$$\frac{B}{A} \times 100 = \text{percent total solids}$$

where

B = weight of material after heating

A = weight of material before heating

Viscosity

53. The viscosity of the polymer systems and a few other materials were determined in accordance with ASTM D 1824-83 (ASTM 1989c) using a Brookfield viscometer, Model LVF.

Tensile strength and elongation

54. The tensile strengths and elongation of a few elastomeric coatings and some less flexible polymers were determined in accordance with ASTM D 638-84 (ASTM 1989f). Specimens were prepared from some of the coatings, less than 90 percent total solids, by brushing multiple coatings onto a plastic sheet. Each coat was allowed to dry overnight before application of another coat. When the desired film thickness was obtained, test specimens were cut out of the film with a die. The higher solid systems were cast by pouring the material into a teflon mold. All specimens were cured for 14 days in the laboratory before testing.

Abrasion resistance

55. A few coatings were tested for abrasion resistance using the underwater-abrasion tester described by Liu (1980). Coatings were applied to the 12- by 4-in.-concrete test specimens and were allowed to cure for 14 days before testing. All specimens were tested for 72 hr.

Testing of Shotcrete

56. Latex-modified shotcrete was evaluated by applying the shotcrete to wood and concrete panels. The dry-mix shotcrete process was used to apply the various shotcrete mixtures, and the equipment used to apply the shotcrete is shown in Figure 11. The latex admixtures were diluted with water and pumped to the nozzle using a Graco pump (Figure 12). A defoaming agent, Nopco NXZ, was added to some of the latex-water mixtures to reduce foaming from the pumping action.

57. The dry shotcrete was prepared by weighing the fine aggregate and cement on weight scales, and blending the two together in a drum mixer. The sand-cement mixture was transferred to a metal drum. A shovel was used to

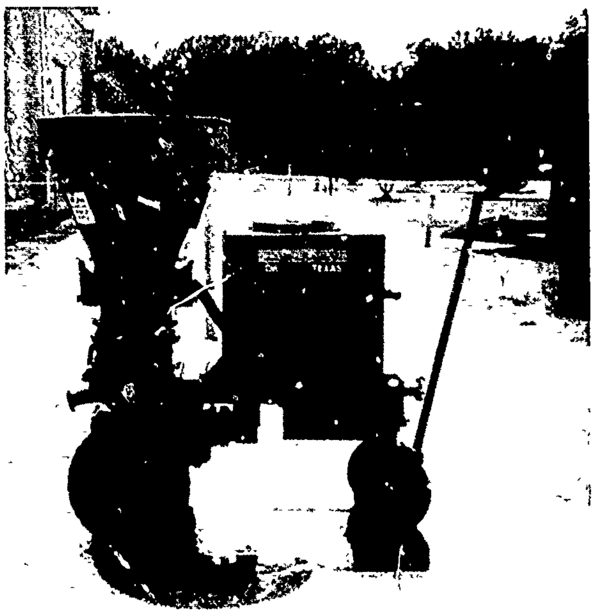


Figure 11. Dry-mix shotcrete equipment

Figure 12. Graco pump used to transfer latex-water solution to nozzle

fill the hopper with dry mixture during application. Polypropylene fibers were used in some of the mixtures, and they were blended into the sand and cement in the drum mixer.

Bond strength

58. The bond strength of the shotcrete to hardened concrete was determined by applying 2- to 3-in. coverage of the shotcrete to a concrete panel. Two sizes of panels, 20 by 20 by 4 in. and 2 ft by 4 ft by 4 in., were used for the test. The latex-modified shotcrete was moist cured for all tests by covering the shotcrete with wet burlap and plastic for 24 hr. Test specimens were obtained by removing 4-in. cores from the coated panels. An apparatus for determining the shear bond strength was made at the US Army Engineer Waterways Experiment Station (WES). The testing apparatus is shown in Figure 13. The test specimen was placed into the testing apparatus with the bond line placed along the vertical axis of the shear plane. The testing apparatus was then placed in a universal testing machine and a load applied to the testing apparatus until failure of the shotcrete or concrete. A specimen being tested is shown in Figure 14. The bond strength was calculated by dividing the load at failure by the cross-sectional area of the core.

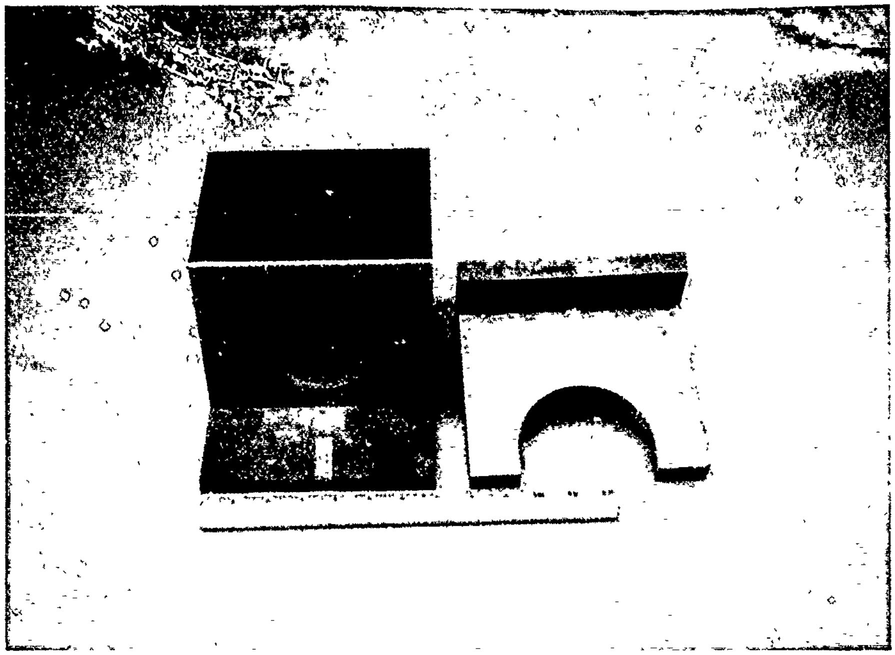


Figure 13. Apparatus for determining bond strength

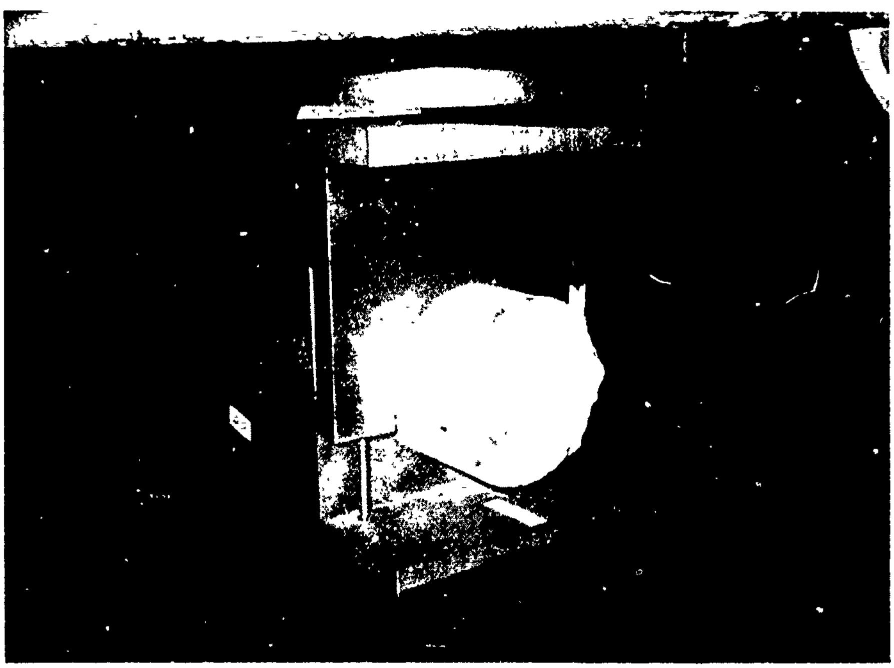


Figure 14. Latex-modified shotcrete being tested for bond strength

Water and polymer content

59. Since the water or latex-water mixture is controlled at the nozzle, there was no way to accurately measure the water or polymer content of the mixture. The water content was determined by placing approximately 500 g of the wet shotcrete in a tared pan immediately after application and weighing the pan and wet shotcrete. The pan was then placed on a hot plate to dry the mixture. The percentage of water in the mixture was calculated as follows:

$$\text{Water, \%} = \frac{\text{weight of wet shotcrete} - \text{weight of dry shotcrete}}{\text{weight of wet shotcrete}} \times 100$$

The polymer content was then determined by the amount of water in the mixture, the dilution factor (latex to water), and the polymer content of the latex admixture.

60. Specimens for tests for resistance to freezing and thawing were made by applying the shotcrete to wood panels, 20 by 20 in. then beams measuring 3-1/2 by 4-1/2 by 16 in. were later sawed from the hardened shotcrete. The beams were allowed to cure for 28 days and were tested according to ASTM C 666-84, Procedure A, (1989d).

61. Compressive strength tests were made by taking 2- and 4-in. cores from the shotcrete panels. The cylinders were capped and tested for compression strength in accordance with ASTM C 39-86 (1989j). The density and water absorption of the shotcrete mixtures were determined from the cores according to ASTM C 642-82 (ASTM 1989b).

PART IV: TEST RESULTS

Test Results for Concrete Sealers

Water absorption

62. The water-absorption test results for the concrete sealers are shown in Table 1. The total solids content and the application rate are also shown in this table. The control values shown in the table are the average of 12 uncoated concrete cubes cast in sets of three at different times in the study. Early tests of the control concrete cubes indicated that the concrete had nearly reached saturation after 8 hr soaking in water.

63. A wide range of water-absorption values were obtained for and within the different generic types as can be seen in Figure 15. The results

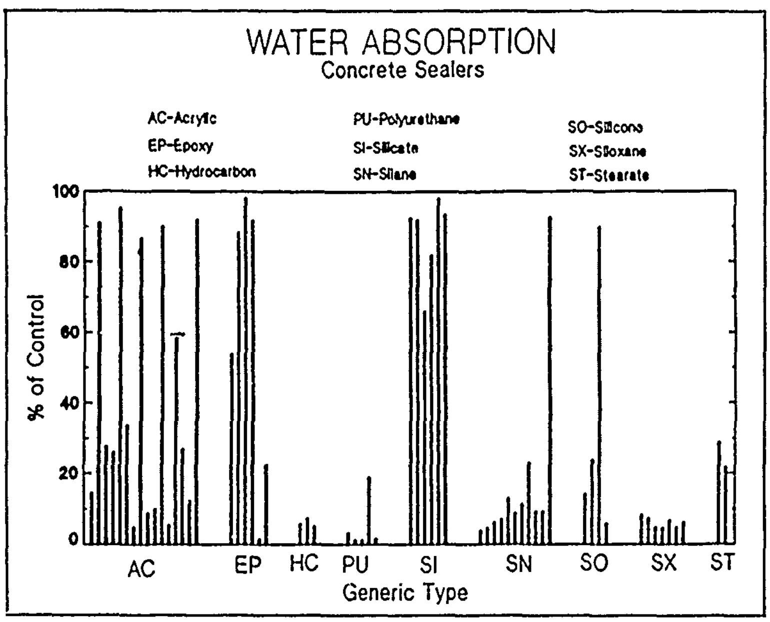


Figure 15. Water-absorption test results for concrete sealers

are reported in percent of the control after 2 days soaking in water. The difference within could be contributed to solids content of the sealer for most sealers. The solid content of the one silane and silicone that performed poorly was significantly lower than the others. Five of the six acrylic sealers that performed poorly had total solids of less than 15 percent. One acrylic sealer that had less than 15 percent total solids did perform satisfactorily indicating that the chemical composition could be a contributing factor for performance. Application rate is also a contributing factor to performance, the rate depending on the porosity and texture of the concrete. One manufacturer of a siloxane sealer recommended an application rate of 300 sq ft/gal. Concrete cubes coated with the sealer at the recommended application rate were found to have a water absorption of 3.01 percent after soaking for 48 hr. A second set of concrete cubes were coated with the sealer at an application rate of 150 sq ft/gal, and these cubes were found to have a water absorption of only 0.39 percent after soaking foι 48 hr, indicating the importance of application rate.

64. No specific type of sealer was best in preventing the intrusion of water into concrete. None of the silicates tested performed satisfactorily, while most silanes, siloxanes, polyurethanes, and hydrocarbons tested did perform satisfactorily. Only one of six epoxy-resin sealers performed acceptably, and one was marginal. A wide range of water-absorption values were noted for the acrylic sealers. A few other types of sealers were tested in limited numbers, HMWM, methyl methacrylate (MMA), butyrate, and fluorelastomer, and each type performed satisfactorily. If one used a criterion of ≤ 15 percent water absorption of the control after 7 days, 28 sealers would have met this criterion. The types of sealers, number tested, and the number meeting the criterion are presented in the following list:

Type of Sealer	No. Tested	No. of Sealers Meeting Criterion
Acrylic	16	3
Butyrate	1	1
Chlorinated rubber	1	0
Epoxy	6	1
Fluorelastomer	2	1
Hydrocarbon	3	3
Methacrylate	2	2
Linseed	1	0
Polyurethane	5	4

(Continued)

Type of Sealer	No. Tested	No. of Sealers Meeting Criterion
Silicate	6	0
Silane	10	5
Silicone	4	1
Siloxane	7	7
Stearate	2	0
Total	66	28

65. Silanes are highly volatile at low temperatures and there was concern that these types of concrete sealers could be ineffective if applied outside in warm weather. Concrete blocks were coated outside with a silane sealer, W-CS-1, and a siloxane sealer, W-CS-14, to determine their effectiveness in sealing concrete. The test results are:

Sealer	Application Ambient, °F	Temperature Surface Temperature, °F	Application Rate, sq ft/gal	Water Absorption 7 days %
Silane	86	113	140	0.44
Siloxane	86	113	140	0.28
Silane	90	124	170	0.36
Siloxane	90	124	170	0.43

66. Both sealers were found to be effective in sealing concrete outside in warm weather.

67. The water absorption of concrete and mortar coated with a few concrete sealers were tested using the inverted funnel method, and the results are shown in Table 2. The first test was made by coating portland-cement mortar disks, 1 in. thick with a diameter of 6 in. Additional tests were made by coating concrete prisms measuring 12 by 8 by 2 in. The diameters of the funnels were 4 and 5 in. for testing the coated mortar and concrete, respectively.

68. The test results correlated well with the concrete block method. Concrete sealers that performed satisfactorily when tested by the block method also performed well when tested by the inverted funnel method. This test showed that the silicate sealer W-CS-48 slowed water intrusion when compared to the control. The concrete block test did not indicate improvement after 48 hr. A more uniform application rate of the sealers could be applied using this test method, since only one surface has to be coated, instead of six. It

was noted that when coating the concrete blocks the sealer had a tendency to run down the sides. This method could also be used to measure the effectiveness of sealers applied to concrete structures in the field.

Water-vapor transmission

69. The water-vapor transmission test results for the concrete sealers are shown in Table 3. Most of the concrete sealers that performed unsatisfactorily for preventing water intrusion were not tested for water-vapor transmission. A wide range of water-vapor transmission results were obtained for and within some of the generic types of sealers, and this range of values can be seen in Figure 16. These results are reported in percent of the control after storage for 4 days at 100 °F and 30 percent relative humidity.

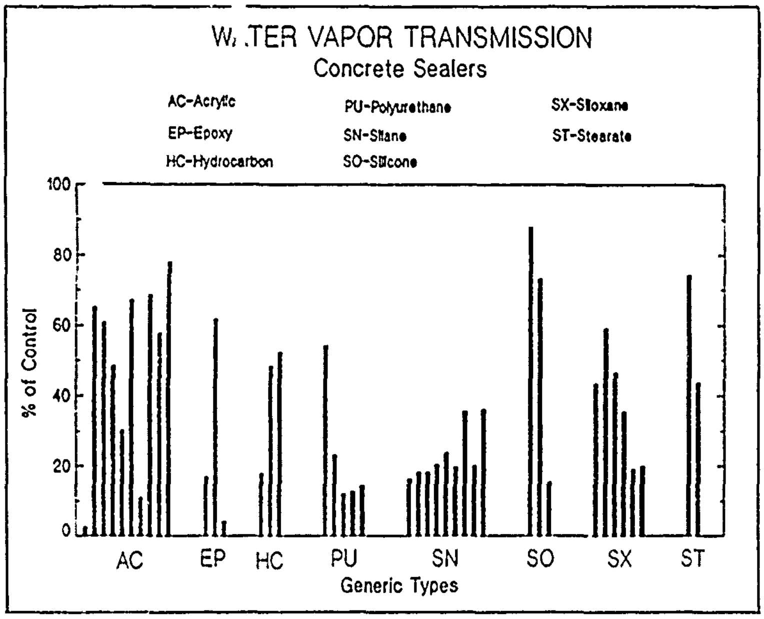


Figure 16. Water-vapor transmission test results for concrete sealers

70. Seven of the ten acrylic sealers tested had water-vapor transmission values of 50 percent or higher, indicating satisfactory performance for transmitting water vapor. Three of the acrylic sealers that performed satisfactorily for the water-absorption test also performed well for transmitting water vapor. Only one of the three epoxy-resin sealers tested transmitted water vapor satisfactorily, and this sealer was found to have a high water-absorption value. Two of the hydrocarbon sealers had satisfactory

water-vapor transmission values (50 percent of the control). These two sealers also had low water-absorption values. The polyurethanes had low water-vapor transmission values. Low values were expected, since these sealers form a thin coating on the surface of the concrete. There was one exception, but this sealer had a much higher water-absorption value than the other polyurethane sealers tested. The siloxanes performed better than silanes for transmitting water vapor. Four of the six siloxanes tested for water-vapor transmission were found to have water-vapor transmission values greater than 50 percent of the control after 7 days. Only two of the nine silanes tested had water-vapor transmission values near or above 50 percent of the control. The silicones were found to have high water-vapor transmission values, but only one of the four tested had a satisfactory water-absorption value after 7 days. The two stearates tested performed satisfactorily for transmitting water but neither performed that well when tested for water absorption.

71. A search for a criterion for water-vapor transmission in concrete was not successful. If one used a criterion of a ≥30-percent water-vapor transmission of the control after 7 days, 25 sealers of 47 tested would have met this criterion. Listed below are the types of sealers, number tested,. and the number meeting the criterion:

Type of Sealer	No. Tested	Water-Vapor Transmission ≥30 percent of Control, 7 days
Acrylic	10	8
Butyrate	1	0
Epoxy	3	1
Fluorelastomer	2	2
Hydrocarbon	3	1
Methacrylate	2	0
Polyurethane	5	1
Silane	9	3
Silicone	4	3
Siloxane	6	4
Stearate	2	2
Total	47	25

Accelerated weathering tests

72. The test results for the accelerated weathering tests are shown in Tables 4 and 5. The test results for the first set of concrete sealers are shown in Table 4 and the water absorption was measured after 800 and 1,600 hr testing. The only significant change observed was that one sealer, after 800 hr testing, indicated a need for a longer testing time. Table 5 shows test results for the second set of sealers with water absorption measured after 1,600 hr testing.

73. A large percentage of the sealers were found to be affected by the accelerated weathering test. The six acrylic sealers tested (W-CS-35, W-CS-36, W-CS-46, W-CS-55, W-CS-63, and W-CS-64) were significantly affected by the accelerated weathering test, an unexpected turn since these materials are stated to have good weatherability properties. The four silanes (W-CS-1, W-CS-10, W-CS-31, and W-CS-45), the three siloxanes (W-CS-14, W-CS-37, and W-CS-47), the two silicones (W-CS-56 and W-CS-62) all resisted additional water penetration after 1,600 hr testing. Three hydrocarbon sealers were tested and only one, W-CS-17, performed satisfactorily to water absorption after testing. The epoxy resins (W-CS-3 and W-CS-65) and the polyurethanes (W-CS-54, W-CS-60, and W-CS-62) all produced a glossy sheen on the mortar, the appearance of the two epoxy resins was significantly affected, and the polyurethanes had a motley appearance after testing. One epoxy resin performed satisfactorily in resisting additional water penetration, and the other epoxy resin and polyurethanes were considered to be marginal. The appearance of the HMWM (W-CS-43) was also affected, but the sealer performed satisfactorily for reducing water absorption. The silicate sealers were tested to determine whether or not accelerated weathering would improve the performance of these types of sealers. No improvement was observed.

74. A linseed oil treatment was included in this test. The linseed oil was a 50-percent mixture of boiled linseed oil and mineral spirits. Another linseed oil sealer (W-CS-38, a water emulsion) was also tested. Both treatments improved significantly, and there is no explanation for this improvement, except that possibly the oil continued to polymerize due to the heat and UV light.

Sealing of clay bricks

75. An inquiry was made during this study for information on sealers

for clay bricks. A few penetrating sealers that would not discolor or leave a dark sheen on the brick were tested by coating sections of a clay brick and measuring the water absorbed into the coated brick. The sections of the clay brick were cut from the brick using a masonry saw and measured 2-1/4 by 3-1/2 by 1/2 in. The coated brick section was air dried for 14 days, then weighed and immersed in water. The coated brick sections were removed after 24 and 48 hr, the surface dried with a paper towel, and weighed to determine the water absorption. The test results are shown in Table 6.

76. The two siloxane sealers, W-CS-13 and W-CS-47, were very effective in limiting the water penetration for 48 hr. The stearate sealer, W-CS-11, was not effective, and the coated brick sections showed a water absorption of 5.75 percent in 24 hr.

Resistance to freezing and thawing

77. The effectiveness of the sealers in protecting concrete from damage by freezing and thawing was determined by coating concrete with the sealers and testing the coated concrete for its resistance to scaling and damage due to rapid freezing and thawing. The test results for the rapid freezing-and-thawing tests are shown in Tables 7 and 8. None of the sealers were effective in preventing freeze-thaw damage to the concrete when tested by ASTM C 666-84, Procedure A, (ASTM 1989d) or by the modified test method. Compared to the control, a number of the sealers did slow the damage to the concrete based on the relative E (relative dynamic modulus of elasticity) value after 50 or more cycles. None of the sealers tested by the modified test method were effective in preventing freeze-thaw damage after only 100 cycles or less. After completing most of these tests, it was questionable if this test method was an appropriate method for evaluating surface treatments of concrete.

Scaling test

78. The test results for sealed concrete surfaces to resist scaling when exposed to water and deicing chemicals are shown in Tables 9 through 12. The first round of tests were made on coated concrete low in strength, 2,800 psi, and these test results are shown in Table 9. None of the penetrating sealers, silanes and siloxanes, were effective in preventing scaling. The two acrylic sealers tested performed better than the penetrating sealers but were considered ineffective in resisting scaling. The polyurethane sealer, W-CS-59, was effective in the protection of the concrete surface.

79. Because of corrosion forming in the large environmental chamber due to spillage of the deicing chemical solution, the solution used to pond on top of the test specimens was changed to tap water. The second round of tests were made on concrete that had been sandblasted lightly before applying the surface treatment, and the concrete used in preparing the test specimens had a compressive strength of 5,500 psi. The test results for the second round are shown in Table 10. The third round of tests were made on concrete that had been wirebrushed before application of the surface treatment, and the concrete mixture was the same. The test results for the round 3 are shown in Table 11.

80. Higher rating values were observed for round 3, and these ratings indicated that surface scaling had increased due to the difference in surface preparation. This difference was evident when comparing rating values of the same sealer tested in each round. Rating values of some of the sealers tested are listed and show the difference in rounds 2 and 3. It was unexpected that some of the treated test specimen surfaces showed more scaling than the controls (untreated surfaces).

	Rating of Surface Scaling	
Sealer	Round-2	Round-3
WES-CS-32	2	4
WES-CS-1	2	3
WES-CS-10	2	5
WES-CS-4	3	5
WES-CS-27	1	3
WES-CS-52	4	5

81. The sealers that formed a film on the surface, such as the epoxies, polyurethanes, and acrylics, performed best in preventing surface scaling. The five epoxy sealers had ratings of 0, indicating that no surface scaling had occurred. Three of the four polyurethane sealers tested had ratings of 0. Five of the nine acrylic sealers tested had satisfactory performance ratings of 0 and 1, and three had marginal ratings of 2. A test specimen coated with an epoxy resin before and after testing is shown in Figures 17 and 18.

82. The penetrating sealers, such as silanes, siloxanes, silicates, silicones, stearates, and hydrocarbons, did not perform as well in preventing surface scaling. Six silanes were tested and only one, W-CS-31, was effective

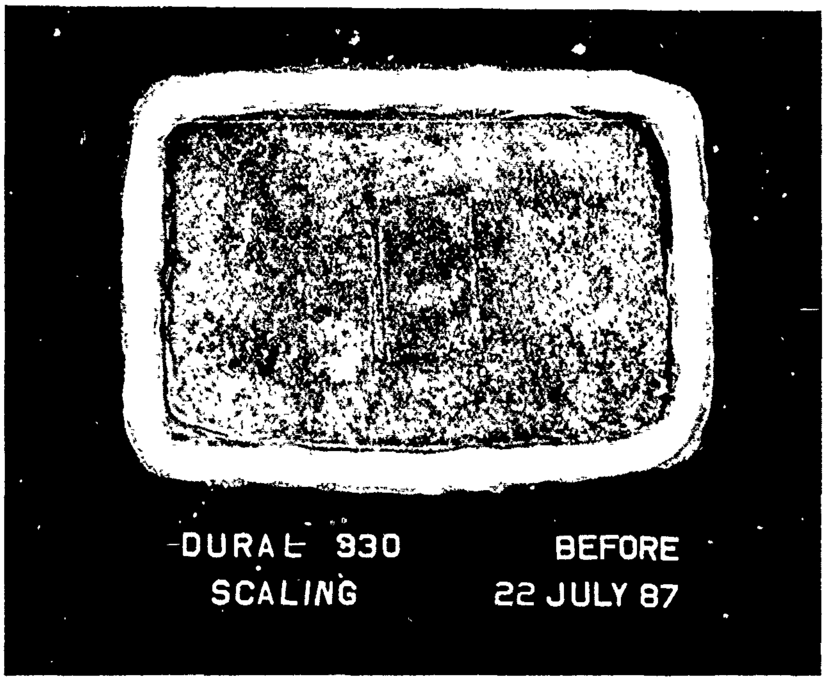


Figure 17. Epoxy-resin sealer before scaling test

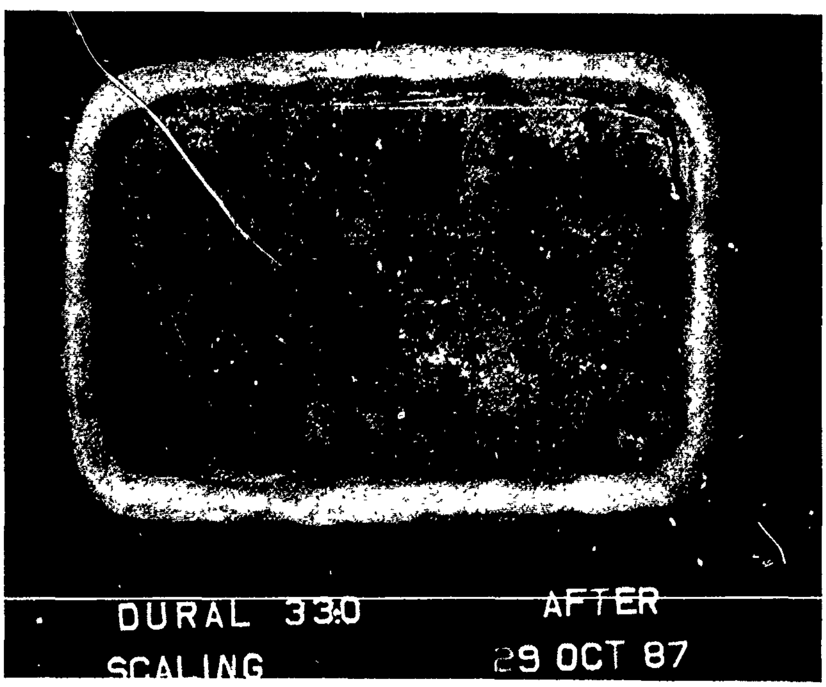


Figure 18. Epoxy-resin sealer after scaling test

in preventing surface scaling. This was a combination of sealers, silane primer, and an acrylic topping. Only one siloxane was effective in round 2, but had a rating of 3 in round 3. No scaling was observed when testing a combination of a silane and siloxane, W-CS-22 and W-CS-23. The silane sealer was applied first, followed by a coating of the siloxane. One hydrocarbon sealer, W-CS-17, performed well with only slight scaling observed. The other three hydrocarbons were marginal or unacceptable. Neither stearate tested performed satisfactorily. One of the silicates, W-CS-48, tested in the round 3 had a rating of 2, a better rating than the control. Surface scaling of a silane treated surface after testing is shown in Figure 19.

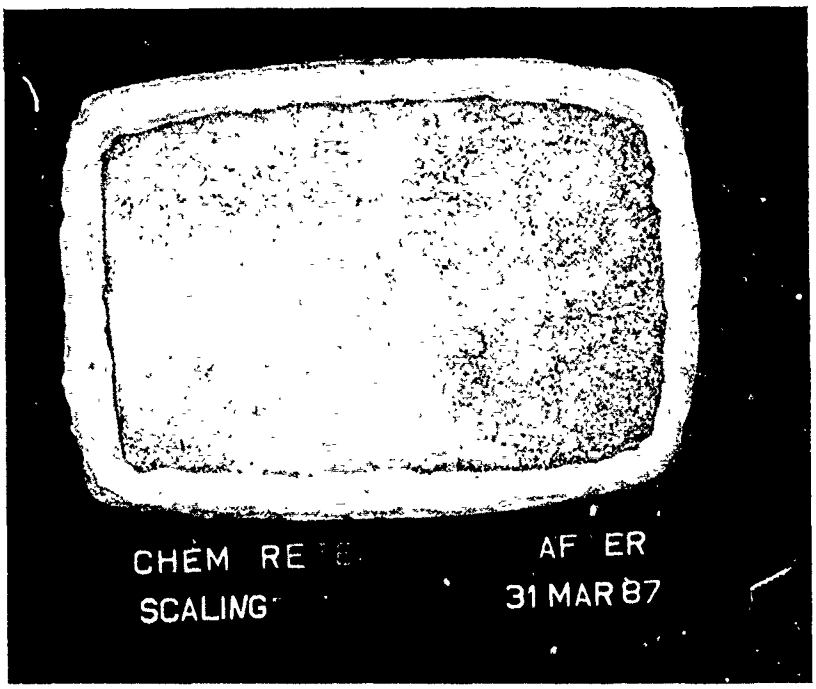


Figure 19. Silane sealer after scaling test

83. It was more difficult to visually rate the surface scaling for round 2 because of the sandblasted surface. A better comparison between test specimens could have been made if the loose material from scaling had been weighed. Additional tests were made using test specimens with a smaller surface area. A concrete with a higher permeability and a compressive strength of 3,800 psi was used for these tests. The surface was prepared by sandblasting before treatment with the sealer. The scaled material was

removed during testing and weighed. The results of the modified test are shown in Table 12.

84. The penetrating sealers, silanes, siloxanes, and hydrocarbon, performed better for these tests than in round 2. The only explanation that can be given is that the sealers were applied in two applications with approximately 10 min between applications, and a greater depth of penetration was obtained because of the more permeable concrete. After 25 cycles, the concrete surfaces treated with the two siloxanes and a silane showed no weight loss. A slight amount of scaling (0.4 g) was measured from the surface treated with W-CS-45, a water-based silane. One silane and two siloxanes, W-CS-1 and W-CS-47, were tested for 50 cycles. No scaling was observed after the 50 cycles and the visual rating was 0. W-CS-1 had a visual rating of 2 when tested in round 2. The hydrocarbon sealer, W-CS-17, performed well with no scaling observed. The stearate, silicate, and one of the hydrocarbons did not protect the surfaces from scaling. The hydrocarbon did offer protection through the first 15 cycles before the surface began scaling. A slight amount of scaling was noted (2.1 g) for the surface treated with the epoxy sealer. A mixture of boiled linseed oil and mineral spirits was tested and no scaling was noted after 25 cycles of testing.

Acceptance criterion for sealers

85. A search for a performance specification for concrete sealers was unsuccessful. Most departments of transportation use a water-absorption test or salt-penetration test for acceptability. If one established a criterion using the water absorption, water-vapor transmission, accelerated weathering, and the scaling resistance tests, the criteria might be as follows:

Test	Requirement
Water absorption, percent of control 7 days	≤15
Water-vapor transmission, percent of control 7 days	≥25
Accelerated weathering, percent difference in water absorption after 1,200 hr testing	≤0.50
Scaling resistance (ASTM C 672-84 (ASTM 1989e)) 50 cycles, 4% $CaCl_2$ solution	Must have a visual rating of 1 or less

86. Very few of the sealers tested would meet the criteria. Only one hydrocarbon and possibly two siloxanes and two silanes sealers would have met the criteria.

87. If sealers are used for bridge decks or other areas subjected to abrasion, an abrasion test followed by a water-absorption test would be beneficial in the selection of sealers. Alberta Transportation and Utilities (Koltke 1987) requires such a test and require that the reduction in water absorption be not less than 75 percent compared to controls after removal of a 1-mm thickness from the concrete surface.

Test Results for Polymer Systems

88. The 10 polymer systems evaluated for sealing cracks by topical application were tested for viscosity, bond strength to concrete, and gel time. The test results are shown in Table 13. The flash points of three HMWM's, W-CC-57, W-CC-58, and W-CC-60, were determined, and the flash points for all three monomers were greater than 200 °F.

89. The viscosity for the seven HMWM's ranged from 9.8 to 33 cp. The monomer, W-CC-56, with the highest viscosity was recommended by the manufacturer to be used as a binder for polymer concrete and not necessarily for sealing cracks. The bond strengths for the HMWM's ranged from 900 to 2,910 psi. A bond strength (slant shear) of 1,500 psi would be considered satisfactory. W-CC-56 was the only HMWM polymer system that had a bond strength less than 1,500 psi, and the low bond strength was contributed to the lower modulus of elasticity of this polymer system. The gel times ranged from 17 to 90 min. Only one of the HMWM polymer systems, W-CC-61, had a gel time less than 30 min, and a gel time of 30 min is recommended so that the mixed polymer system will have time to penetrate into the cracks.

90. The polyurethane system, W-CC-52, had a gel time of only 3 min, a time too low for topical application. The epoxy resin showed promise based on the high gel time and bond strength. The viscosity of this polymer system was low, 40 cp, but the system did not appear to penetrate small hairline cracks as well as the HMWM.

Field Application of HMWM

91. The US Army Engineer District, Kansas City, contacted WES in 1987 in regard to the HMWM for sealing cracks in a bridge deck. Information

regarding material specifications, application guidance, and manufacturers was given to the Kansas City District.

92. During September 1987, a contract was awarded to seal cracks in a bridge deck on the Woods Chapel Road Bridge, Blue Spring Lake, Missouri. Members of the staff of WES inspected the sealing of the bridge deck. HMWM, W-CC-55, was used for this application. The application procedure used follows:

a. Five gallons of the monomer were measured and the appropriate amounts of the two catalysts, cobalt naphthenate, and cumene hydroperoxide were added and mixed into the monomer, mixing one in thoroughly before adding the other.

b. The mixed polymer system was poured onto the bridge deck and spread with a squeegee.

c. A broom was then used, after squeegeeing, to remove excess polymer left in the grooves and low areas.

d. After brooming, a graded sand was spread over the treated area for skid resistance.

93. The bridge deck was open to traffic the day after application. The polymer penetration showed through a few cracks when observing the bottom of the bridge deck. All cracks appeared to be filled with the cured polymer system. Application of the HMWM is shown in Figure 20.

Figure 20. Application of HMWM monomer to bridge deck

94. The US Air Force Engineering and Services Center (AFESC) contacted WES in the Summer of 1988 in regard to overseeing applications of HMWM for

sealing cracked concrete pavement at Seymour Johnson AFB, North Carolina. During September 1988, three areas of airfield pavement containing cracks were coated with two different HMWM's, W-CC-59 and W-CC-60.

95. The pavement slabs in these areas contained numerous cracks, and some small spalls were evident along many of the cracks. The reason for the topical application using HMWM was to determine if sealing of the cracks would reduce the spalling until the pavement slabs were replaced. The manufacturer of W-CC-59 furnished 9 gal of the material and the Civil Engineering Squadron obtained one drum of W-CC-60 for the test. The 9 gal of W-CC-59 completely covered one slab and two-thirds of another slab, approximately 1,040 sq ft, for an application rate of 115 sq ft/gal. Seven pavement slabs were treated with W-CC-60, four slabs in one area and three in another area. The application rate ranged from 6 to 7 gal per slab or 90 to 150 sq ft/gal.

96. Before treating the surfaces with the HMWM, small spalled areas were filled with sand. The mixed polymer system was poured onto the slabs and spread with squeegees, making at least two passes over the cracks. An 18-in. paint roller was used to remove excess polymer left in the grooves and low areas. Sand was spread over the treated area for skid resistance.

97. In April 1989, 7 months after the application, the three test sections were inspected by AFESC. They reported that the areas appeared to be in a satisfactory condition. The appearance of the area treated with W-CC-59 was reported to be somewhat better than the two areas treated with W-CC-60. Some light areas were noticeable in the W-CC-60 coating. All cracks appeared to be sealed in the three test sections.

Test Results for Concrete Coatings

Water absorption

98. The water-absorption test results for the coatings are shown in Table 14. There was not as wide a range in values for the coatings tested as with the sealers. All of the epoxy-resin, hypalon, polyester, and polyurethane coatings were effective in preventing high absorptivity of water into the concrete, except for one polyurethane coating, W-CC-33. Pinholes were observed in this coating after application, a contributing factor to the high water absorption.

99. The acrylic coatings were not as effective in preventing water intrusion into the concrete as were the other coatings tested. Pinholes were observed in some of these coatings after application, especially the water-based mastic type. It was difficult to obtain a uniform coating on the edges of the concrete cubes when applying the thicker mastic coatings, and this could have contributed to some variation in water absorption. The water absorption ranged from a low of 5.5 percent to a high of 36.2 percent of the control after soaking in water for 48 hr.

100. The water-absorption test method was modified for cementitious coatings containing silicates, because water is necessary to begin the crystallization process of the silicates. Coating W-CC-16 was tested 14 days after coating the concrete cubes and a water absorption of 2.80 percent was obtained after 48 hr soaking in water. The cubes were then allowed to dry at 100 °F and 30 percent relative humidity for 7 days, then soaked in water for 48 hr. The water absorption decreased to 2.07 percent. The wetting and drying cycles were continued for three more cycles, and the water absorption after the fourth cycle was only 0.27 percent. The three cementitious coatings containing silicates, W-CC-16, W-CC-43, and W-CC-51, were tested using this method.

101. Two of the silicate-cement coatings, W-CC-16 and W-CC-43, were tested on concrete masonry units using the inverted funnel method. A concrete masonry unit was cut with a saw to obtain sections for coatings measuring approximately 8 by 8 by 1-1/2 in. Masonry units were selected for this test since they are highly porous and would give a good indication of the coatings' resistance to water passage. Two coatings were applied to one side of the masonry unit section and were allowed to cure in laboratory air for 28 days. The absorptivity of water was measured every 24 hr and the results are shown in Figure 21.

102. The water absorptivity began to significantly decrease after 2 to 4 days, indicating that crystallization of the silicates had occurred. The water absorptivity (L/m^2/hr) of the two coatings measured after the first 24 hr and again after 7 days are shown:

	Age of Test	
Coating	0-24 hr	7-9 day
Control	2.600	

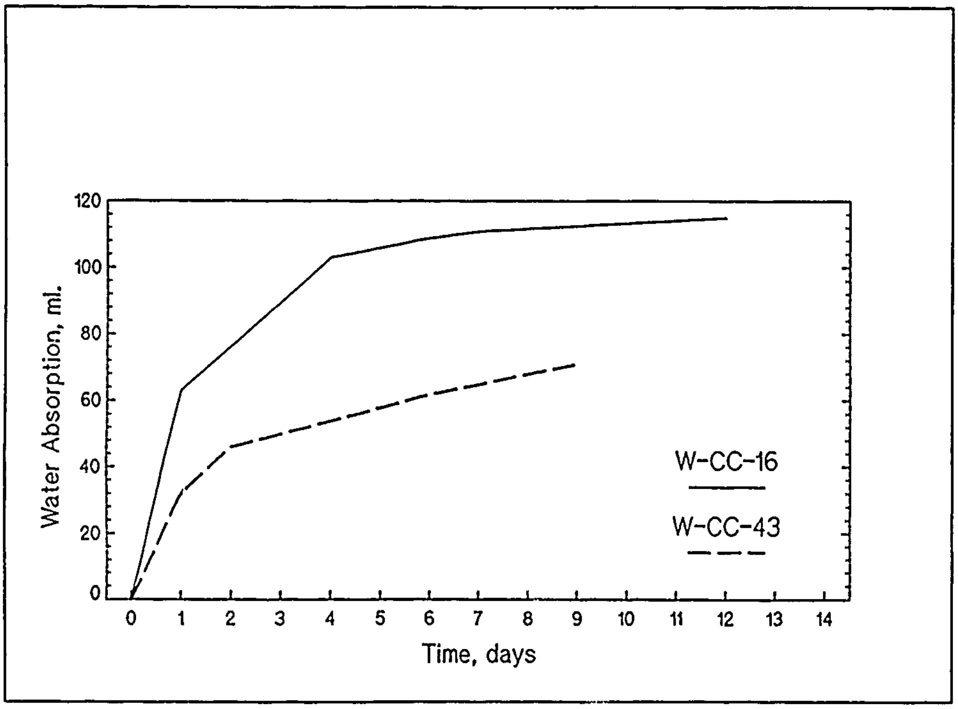


Figure 21. Water absorptivity of silicate-cement coatings

Coating	Age of Test 0-24 hr	7-9 day
W-CC-16	0.207	0.003
W-CC-43	0.105	0.010

Water-vapor transmission

103. The water-vapor transmission test results for the concrete coatings are shown in Table 15. Most of the coatings were tested for water-vapor transmission. A wide range of water-vapor transmission test results was observed for the different types of coatings. The acrylic, cementitious, and the one silicone tested were found to satisfactorily transmit water vapor. The water-vapor transmission values were low for most epoxy, polyurethane, hypalon, and the one neoprene tested. Two of the polyurethane coatings (W-CC-33 and W-CC-34), both high water-vapor transmission values, were less effective in preventing water intrusion into the concrete.

104. The acrylic coatings had higher water-vapor transmission values than the other polymeric type of coatings except for the one silicone coating. The silicone coating, a water-base coating, had a water-vapor transmission of 2.76 percent or 78.2 percent of the control after 7 days. Seven of the nine

acrylic coatings tested had water-vapor transmission values greater than 33 percent of the control after 7 days.

105. The cementitious coatings were also satisfactory in transmitting water vapor. The water-vapor transmission values ranged from 29 to 65 percent of the control. The cementitious coating, W-CC-16, the most effective coating of this type for reducing water intrusion, also had the higher water-vapor transmission.

Accelerated weathering test

106. A few of the coatings were tested for accelerated weathering. The water absorption before and after testing was not measured; the coatings were examined for discoloration, blistering, or loss of bond. The accelerated weathering test results are given in Table 16.

107. Two of the acrylic coatings, W-CC-46 and W-CC-49, and the silicone coating were not affected by the accelerating weathering test. No blistering nor loss of bond was observed for the coatings tested. The two-component polyurethane coatings were not affected as much as the one-component polyurethane coatings.

Bond strength to concrete

108. The bond strength to concrete test results are shown in Table 17. Bond strengths (pulloff test) of 200 psi or higher would be considered a satisfactory bond. The type of bond failure for 15 of the coatings tested was within the concrete, and these bond strengths ranged from 290 to 380 psi, an indication of the tensile strength of the concrete. Failure of the concrete occurred when six of the seven epoxy resins were tested. The only epoxy coating, W-CC-20, that failed bond at the concrete interface was a coal-tar that was a flexible epoxy resin.

109. The coatings that were highly flexible with lower tensile strengths had the lower bond strengths. W-CC-7, a silicone rubber coating, had the lowest bond strength, a tensile elongation of 550 percent, and a tensile strength of 400 psi. The neoprene coating, W-CC-18, and the acrylic coating, W-CC-19, were also flexible coatings with low tensile strength.

110. Most polyurethane coatings had satisfactory bond strengths. A few of these coatings were not highly flexible, and a few required prime coats were a contributing factor to the higher bond strengths. W-CC-11 was a flexible polyurethane coating with a low tensile strength (600 percent

elongation and 750 psi tensile strength), and this coating had one of the lower bond strengths. Two of the polyurethane coatings, W-CC-35 and W-CC-36, were reported by the manufacturer to be moisture insensitive. These coatings were applied to concrete that had been soaked underwater for 24 hr. Test results indicated that they would bond to damp concrete.

Elastomeric properties

111. Flexible coatings were obtained for this study since this type would be needed when coating cracked concrete surfaces. Some manufacturers reported that cracks greater than 1/32 in. in width should not be covered unless the crack was routed out and a sealant applied. A flexible acrylic or polyurethane sealant is recommended when coating with the acrylic and polyurethane coatings, respectively. A polyester fabric and a concrete primer was supplied with the flexible acrylic coating, W-CC-2.

112. The tensile elongation, strength, and hardness for the flexible coatings are shown in Table 18. Most of the values reported were taken from the manufacturer's technical bulletins. Four of the coatings, W-CC-7, W-CC-16, W-CC-35, and W-CC-46, were tested by WES. The values obtained for W-CC-7 and W-CC-16 were very near the manufacturer's test data. WES test results for coating W-CC-35 were 180 percent elongation and 2,610 psi tensile strength, and for coating W-CC-46 the percent elongation was 160 percent and the tensile strength was 320 psi.

Resistance to freezing and thawing

113. The effectiveness of the coatings for protecting concrete from damage due to freezing and thawing was determined by testing the coated concrete for its resistance to scaling and damage due to rapid freezing and thawing. The test results for the rapid freezing and thawing test are shown in Tables 19 and 20. Only one coating, W-CC-1, was effective in preventing damage due to freezing and thawing to concrete when tested by ASTM C 666-84 (ASTM 1989d) or by the modified test method. This coating was a 100-percent solid epoxy-resin coating. All coatings tested improved the resistance of the concrete to freezing and thawing when comparing the test results with the controls (uncoated nonair-entrained concrete). Most of the coatings were not tested by this test method due to the poor results obtained early in the study.

114. The test results for coated concrete surfaces to resist scaling when exposed to water and deicing chemicals are shown on Table 21. Only 2 of the 15 coatings tested performed unsatisfactorily in preventing surface scaling. Coating W-CC-49 came unbonded from the concrete, and light to moderate scaling of the concrete surface was observed after the 50 cycles of freezing and thawing. The cementitious coating, W-CC-51, began unbonding from the surface of the concrete early, and the testing was discontinued after eight cycles of freezing and thawing. Two of the coatings, W-CC-18 and W-CC-42, developed blisters in the coating during the testing.

Preventing water seepage from the inside

115. A number of manufacturers were contacted regarding coatings that could be applied to concrete from the inside to prevent or reduce water seepage into the structure. Most polymeric coatings will not perform satisfactorily because of poor bond to damp concrete, slow curing times, and loss of bond due to water pressure. Some of the manufacturers of cementitious coatings stated that their products could be used from the inside. One of these coating systems, W-CC-17, was obtained for evaluations. The system consisted of two cementitious powders and a liquid.

116. The system was evaluated by sealing cracks that were created in cored concrete cylinders. A 3-in.-diam core was removed from the inside of a 6- by 12-in. cylinder. A crack was then created into one side using a universal testing machine. The bottom 1 in of the hollow cylinder was filled with a polymer concrete. A tube was connected to a faucet to keep the hollow cylinder filled with water. The crack was treated with the coating system to determine if the water coming through the crack could be stopped. The coating system was successful in stopping the water.

117. Two of the cementitious coatings, W-CC-16 and W-CC-43, were applied to the topside of 4- by 8-in. concrete cylinders. The coatings were allowed to cure for 14 days in laboratory air followed by 14 days in a moist curing room. After 4 days underwater, the cylinders were then placed in Hassler Cells with pressure and water on the uncoated end of the cylinder to measure permeability. The test results follow:

Coating	Permeability, μdarcies
Control	0.094
W-CC-16	0.005
W-CC-43	0.004

Both cementitious coatings significantly reduced the rate of flow of water through the concrete cylinders under pressure of 400-ft head of water.

118. Different urethane and epoxy-resin grouts were field tested at Gathright Dam, under another study to determine if these materials would stop water leakage through cracks in the control tower. Since WES was applying these materials, the manufacturer of the coating system, W-CC-17, was contacted regarding field testing of the coating system.

119. During July 1988 the coating system, W-CC-17, was applied at Gathright Dam. The material is not suitable for stopping water from a moving crack. A construction joint experiencing water seepage was selected for the field test. The surface around the construction joint was first cleaned with a bushhammer. The cleaned surface was dampened with water and coated using the coating system. The coating stopped the water leakage. An inspection of the application was made in February 1989, 7 months after the application and during cold weather. The coating was performing satisfactorily at the time of inspection.

Abrasion resistance

120. Four of the coatings were tested for abrasion resistance using the underwater abrasion tester described by Liu (1980). Very few coatings were tested for abrasion resistance since these types of evaluations fall under other REMR work units. The two polyester resins, W-CC-31 and W-CC-40, were selected for testing since polyester resins were never tested using this test method, and polyester resins are less expensive than most types of polymeric coatings used to protect concrete from erosion. The two polyurethane coatings, W-CC-35 and W-CC-36, were tested since they were moisture insensitive and were reported to have high abrasion resistance.

121. Graded Ottawa sand was added to each of the coating systems to make a polymer mortar. Three parts sand to one part polyester resin by volume was used in preparing the polyester mortar. Two parts sand to one part polyurethane by volume was used in preparing the polyurethane mortar. The top

surface of the 12-in.-diam concrete cylinder was first primed with the coating system or the manufacturer's recommended primer. The surface was then coated with a 1/8-in.-thick coating of the polymer mortar. The coatings were allowed to cure for 7 days in the laboratory before being tested. The test results are shown in Table 22.

122. The four coatings had good resistance to abrasion. The two polyester-resin coatings lost 0.2 lb after 72 hr testing. The two polyurethane coatings showed no signs of abrasion after 72 hr testing.

Graffiti-resistant coatings

123. During the study, a number of inquiries on graffiti-resistant coatings from field personnel were received at WES. Manufacturers were contacted and four coatings, W-CC-3, W-CC-28, W-CC-34, and W-CC-35, were obtained for evaluations. The four coatings were polyurethanes and two of the manufacturers supplied cleaners (solvents) for removing graffiti. The coatings were tested for effectiveness to seal concrete, durability to accelerated weathering, ease of removing graffiti, and durability of the coatings to the cleaners.

124. Concrete blocks measuring 12 by 8 by 2 in. were coated with the graffiti-resistant coatings and the coatings were allowed to cure for 14 days in laboratory air. An enamel paint was then sprayed on the topside (Figure 22). The paint was allowed to dry for 2 days and removed with paint cleaners and cloth rags (Figure 23). The paint was applied and removed three times.

125. The coatings were effective sealers and graffiti (enamel paint) was removed with ease. The coatings were not affected after three applications and removal of the graffiti. The two-component coatings performed better under accelerated weathering testing than the one-component coating.

Test Results for Shotcrete

126. The dry shotcrete mixture used for these evaluations consisted of sand and a Type I portland cement. The ratio of sand to cement for most mixtures was 3.75:1 by weight. Two latexes were evaluated as admixtures for the shotcrete, an acrylic, and a styrene butadiene. Both latexes contained 47 percent polymer by weight. The latexes were diluted with water to vary the

Figure 22. Graffiti (enamel paint) sprayed on coating

Figure 23. Removal of graffiti using commercial cleaners

polymer content. The dilutions used and the polymer content of each dilution follow:

Volume of Latex	Volume of Water	Polymer Content, % by Weight
1	1	23.5
1	2	15.7
1	3	11.8

127. The performance of the different shotcrete mixtures was determined by the equipment operator (nozzleman) along with test results. The nozzleman judged the mixtures during applications, noting if the shotcrete sagged excessively or if sand pockets were visible. The test results obtained from the various shotcrete mixtures are shown in Table 23. The mixtures designated by "SB" are mixtures containing the styrene-butadiene latex and the ones designated by "A" are mixtures containing the acrylic latex. The water-absorption values reported are the percent of the control after soaking in water for 7 days.

128. Only four mixtures containing the styrene-butadiene latex were evaluated. The nozzleman reported that mixtures containing this latex were more difficult to place than mixtures containing the acrylic latex. Based on the experience during application, the evaluations were limited to the acrylic-latex admixture.

129. The first five shotcrete mixtures containing the acrylic latex, A-1 through A-5, were applied using latex-water dilutions containing higher amounts of the latex. The nozzleman reported problems in placement when using only the latex or the 1:1 dilution. Satisfactory strengths and bond to the hardened concrete were obtained with these mixtures, but it was more difficult to adjust the liquid at the nozzle to obtain a satisfactory coating. The 1:2 dilution was less difficult to adjust at the nozzle, and this dilution should be satisfactory for applications. One of the mixtures, A-5, was too wet as indicated by the 0.50 w/c, and shrinkage cracks occurred. Satisfactory test results were obtained for mixture A-4, which was slightly on the dry side (w/c 0.29).

130. Most of the latex-modified shotcrete evaluations were made using a dilution of 1:3. Laboratory test results for six shotcrete mixtures containing the 1:3 dilution, A-6 through A-11, are shown. No defoamer was added to

the latex-water solution for mixture A-11 and the placement was found to be difficult. The bond strength for this mixture (210 psi) was lower than the others tested, indicating the need for the defoamer. The compressive strengths of the shotcrete increased when reducing the polymer content of the latex-water solution. The average compressive strength for four mixtures was 6,460 psi.

131. Polypropylene fibers were added to two of the mixtures, A-12 and A-13. For the fiber latex-modified shotcrete, a 3/4-in. long polypropylene fiber was blended into the dry mixture at 1 lb per 1,000 lb of sand-cement mix. It was anticipated that there would be a large percentage of the fibers lost during placement. Tests were made by washing a known mass of the freshly applied shotcrete over a No. 8 mesh sieve to determine the amount of fibers present after application. Tests showed that the fiber loss was less than 5 percent. No placement problems were encountered when shooting the fiber latex-modified shotcrete. Satisfactory bond and compressive strength values were obtained.

Freeze-thaw durability

132. Two shotcrete mixtures, an acrylic latex diluted 1:2 for one mixture (A-17) and 1:3 for the other mixture (A-16), were applied to wood panels. Two beams were cut from each panel after curing for 28 days and tested for freeze-thaw durability. A control mixture (shotcrete containing only water) was also tested. The results are shown in Figure 24.

133. The shotcrete mixture containing the latex were found to have satisfactory resistance to freezing and thawing. After 300 cycles of testing, shotcrete mixture A-17 had a relative E value of 79 percent (average of two test specimens), and shotcrete mixture A-16 had a relative E value of 64 percent. The controls did not perform satisfactorily and the relative E value was less than 50 percent after 150 cycles.

134. Three beams were prepared from three shotcrete mixtures containing an acrylic latex diluted 1:3. Polypropylene fibers were added to mixture A-18. The other two mixtures (A-19 and A-20) did not contain polypropylene fibers. The beams were tested for freeze-thaw durability and the results are shown in Figure 25.

135. The shotcrete mixture containing the polypropylene fiber did not perform as well as the mixtures without the fibers. Beams prepared from

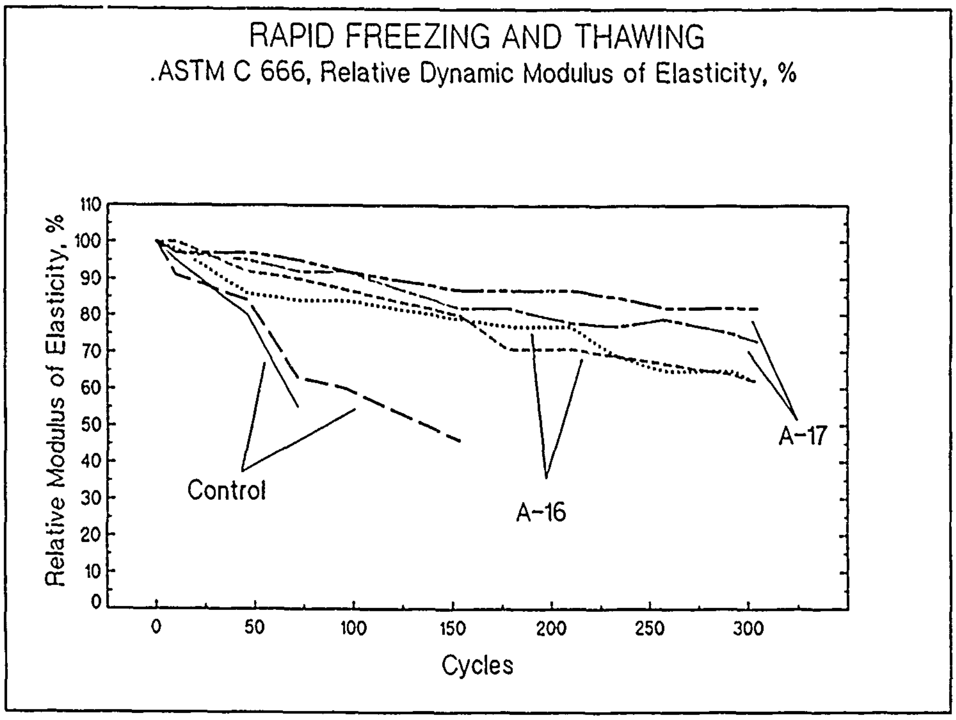


Figure 24. Freeze-thaw durability of latex-modified shotcrete (ASTM C 666-84 (ASTM 1989d))

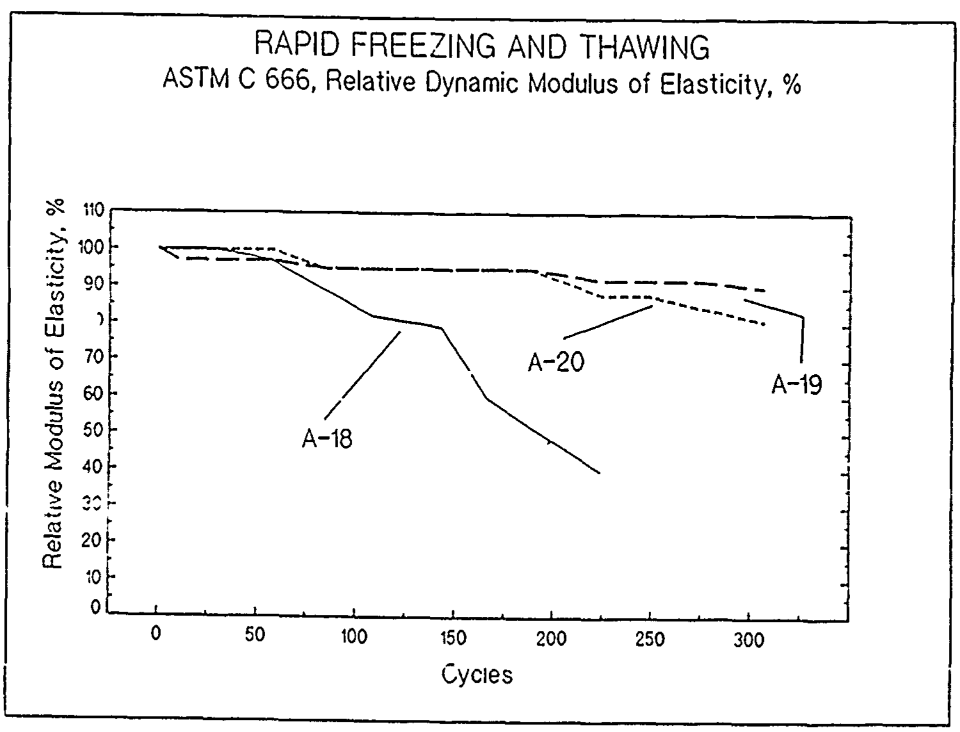


Figure 25. Freeze-thaw durability of latex-modified shotcrete containing fibers (ASTM C 666-84 (ASTM 1989d))

mixtures A-19 and A-20 had relative E values of 90 and 81, respectively, after 300 cycles of testing. The shotcrete beam containing fibers, A-18, had a relative E value of 50 after 200 cycles of testing. The reason for the poorer performance of the beam containing the fibers is not known. Additional testing of fiber latex-modified shotcrete would be necessary to confirm the effects of fibers when subjected to freezing and thawing.

Air content of shotcrete mixtures

136. Four hardened samples of shotcrete from four different mixtures were examined to determine air content in accordance with ASTM C 457-82 (ASTM 1989a). One of the mixtures was applied using an acrylic latex not diluted with water. Two of the mixtures were applied using an acrylic-water dilution of 1:3, one with a defoamer added, and one without a defoamer. The fourth mixture was considered a control and was applied using only water.

137. The results of the examination is shown in Table 24. The addition of defoamer to the latex reduced the entrapped air as expected. The addition of latex increased the entrained air content of the shotcrete.

Test Results for Latex-Modified Mortars

138. Two commercial prepackaged latex-modified mortars, W-LM-1 and W-LM-2, and mortar prepared using the latex admixtures, W-A-1, W-A-2, and W-A-3, were evaluated for use as thin overlays for concrete. The commercial latex-modified mortars were mixed and applied using the manufacturer's recommendations. Mortars using the latex admixtures were prepared by adding a 1:1 mixture of latex and water to the sand-cement mixture that consisted of three parts sand to one part cement by weight. A defoamer was added to the latex-water mixture before mixing. A Type I portland cement and a sand meeting the requirements of ASTM C 33-86 (ASTM 1989i) were used for the mortar mixtures. The amount of liquid (latex and water) added was approximately 55 percent by weight of cement. The water to cement ratio was 0.42 and the polymer to cement ratio was 0.13.

139. The latex-modified mortars were tested as thin overlays (1/2 in.) by placing the mortars on top of a 42-in.-long concrete panel, 18 in. in width. Plyboard strips were used as screed rails and a wooden board was used as a screed to consolidate and spread the mortar. The thin overlays were

observed the following day and 28 days after placement for drying shrinkage cracks or loss of bond (by sounding with a metal rod). All latex-modified mortars applied to the panels were judged to be satisfactory based on the observations. The mortars were applied inside and were not moist cured for 24 to 48 hr, the requirement for outdoor applications.

140. The two commercial latex-modified mortars were tested for compressive, flexural, and bond strengths and resistance to scaling. The results are shown in Table 25. The two latex-modified mortars had satisfactory compressive and flexural strengths and bonded exceptionally well to the concrete. They also resisted surface scaling.

141. Since some of these latex-modified mortars, shotcrete and thin overlays, could be subjected to long-term immersion in water, two latex-modified mortars prepared from the latexes, W-A-1 (acrylate copolymer) and W-A-3 (styrene-butadiene), were tested for durability to water immersion. Test specimens were prepared and air cured in the laboratory for 28 days. One-half of the specimens for each mortar were placed underwater and the remaining specimens stored in laboratory air. After 6 months, the specimens were tested and the results are shown in Table 26.

142. The durability of the latex-modified mortar prepared from the styrene-butadiene was better than mortar prepared from the acrylic copolymer. The properties of the mortar containing the acrylic copolymer were satisfactory after the 6-month water immersion.

PART V: SUMMARY

Materials Evaluated

143. Surface treatment materials evaluated in this study were separated into types based on the manufacturer's recommended use, viscosity, total solids, and chemical composition. The materials were classified as: concrete sealers, concrete coatings, special polymer systems, shotcrete, and cementitious materials for thin overlays.

Test Methods

144. Published test methods were used when applicable, but some test methods were developed to evaluate the surface treatment materials. A water-absorption test was selected to screen the materials for use in surface treatments. A test was developed to determine water-vapor transmission. Standard test methods were used to measure the resistance of coated concrete to damage due to freezing and thawing. Other tests used to evaluate the different surface treatment materials were: bond strength to concrete, accelerated weathering test, and total solids. A few of the concrete coatings were tested for resistance to abrasion, viscosity, permeability, and dry to touch.

Concrete sealers

145. Sixty-eight concrete sealers were obtained for evaluation. Different generic types were tested to determine the best and to note differences within a specific type. The types of concrete sealers included acrylics, epoxies, polyurethanes, silicates, silanes, silicones, siloxanes, stearates, and a few classified as hydrocarbons (gum resins, drying oils, and petroleum distillates).

146. A wide range of water-absorption values were obtained for and within the different types. For most sealers, the difference within could be contributed to solids content of the sealer. The only other explanation that could be given for poor performance within was the chemical composition and application rate. The solid content of the one silane and one silicone that performed poorly was significantly lower than the others. Most of the acrylic sealers with low solid contents also performed poorly. Application rate is a

contributing factor to performance, the rate depending on the porosity and texture of the concrete. Some sealers did not perform satisfactorily when applied at the recommended application rate, but were found to be satisfactory when applied at a higher application rate. All of the siloxanes, silanes, silicones, and hydrocarbons performed satisfactorily except for the one silicone and one silane that were low in solids. A wide variation in performance was noted for the acrylics and epoxies. None of the silicates tested performed satisfactorily.

147. Clay bricks were coated with 11 penetrating concrete sealers that would not discolor the bricks, and the water absorption of the coated bricks was measured. The siloxane sealers performed best for sealing the bricks.

148. Most of the sealers that performed unsatisfactorily for preventing water intrusion were not tested for water-vapor transmission. The 10 acrylic sealers tested, with the exception of 3, had high water-vapor transmission values. The siloxanes performed better than silanes for transmitting water vapor. A search for a criterion for water-vapor transmission in concrete was not successful. If one used the criterion, water absorption ≤15 percent of the control, 24 of the concrete sealers would meet the criterion. If one used the ≤15 percent of the control water-absorption criterion, and a water-vapor transmission criterion of ≤25 percent of the control, only 10 of the 68 sealers tested would meet the criterion.

149. Some of the better concrete sealers based on the water-absorption test were selected for accelerated weathering test. Linseed oil was included since it is probably the most widely used concrete sealer. The six acrylic sealers tested were significantly affected by the accelerated weathering test, an unexpected turn since these materials are stated to have good weatherability properties. The silanes, siloxanes, and the two silicones resisted water penetration after 1,600 hr testing. Only one hydrocarbon of the three tested was not affected by the accelerated weathering test. The epoxies and polyurethanes tested were considered marginal. The two linseed oil treatments improved.

150. The resistance to scaling of coated concreted surfaces was determined using three different concrete mixtures and a solution of deicing salts and tap water. The concrete sealers with high water-absorption values were not expected to perform satisfactorily for scaling resistance, however this

was not the case. All epoxy-resin sealers were effective in preventing or significantly reducing the amount of scaling. The silanes and siloxanes did not perform as expected. This could be contributed to the difference in concrete mixtures used and surface preparation before application of the sealers. Most sealers that prevented scaling formed a thin coating over the surface. A combination of sealers, a silane applied first and followed by a second application of a siloxane, performed satisfactorily. Rating scaling by visual examination was difficult if the surface had been sandblasted or wirebrushed. During the latter part of the study, the weight loss was used in evaluating the sealers and is recommended for further testing of sealers.

Concrete coatings

151. Concrete coatings were tested for water absorption and water-vapor transmission using the same test methods. Most of the coatings were effective in preventing water from entering into concrete, except for some of the acrylic, cementitious, and one polyurethane. It was difficult to obtain a uniform coating on some of the small cubes, especially over the edges, when applying some of the thicker cementitious and acrylic coatings. A few pinholes were also observed in some of the thicker water-based and a few polyurethane coatings. This contributed to the higher water absorption.

152. Two cementitious coatings were tested to determine if the coatings could prevent water intrusion from both the positive and negative sides. Both coatings significantly reduced the rate of flow of water through concrete cylinders coated on the negative side under pressure of a 400-ft head of water. One cementitious coating for stopping water leakage was tested in the laboratory and in the field at Gathright Dam. The coating showed promise based on the laboratory and field tests.

153. The acrylic coatings had the highest water-vapor transmission values of any generic type coating tested. Two of the cementitious coatings showed promise based on low water-absorption values and high water-vapor transmission values. The epoxy-resin coatings and most of the polyurethanes had low water-vapor transmissions. A water-based silicone coating had good breathability characteristics.

154. Most coatings had good adhesion to concrete. The lower bond strength values were found for the soft-elastomeric coatings, such as certain acrylics and silicone coatings. These coatings would not be satisfactory

where wheeled traffic is expected. The Elcometer tester shows promise as a field test to determine bond strengths of thin coatings.

155. Sixteen of the coatings were tested for resistance to scaling. All coatings performed satisfactorily except one cementitious coating that began peeling off the surface after eight cycles and an acrylic coating that lost bond to the concrete surface. Concrete beams coated with 10 coatings were tested for rapid freezing and thawing. All coatings improved the durability of the nonair-entrained concrete, but only three coatings significantly improved the durability.

156. Four polyurethane graffiti-resistant coatings were tested for effectiveness to seal concrete, durability to accelerated weathering, ease of removing graffiti, and durability of the coatings to the cleaners. The coatings were effective sealers and graffiti (enamel paint) was removed with ease. The coatings were not affected after three applications and removal of the graffiti. The two-component coating performed better under accelerated weathering testing than the one-component coatings.

157. Four coatings, two polyester resins and two polyurethanes, were tested for abrasion resistance using the underwater abrasion test. The polyester resins were chosen for testing since the cost of these materials is relatively low compared to epoxies. The two polyurethanes were chosen since they were reported to be moisture insensitive. All four coatings showed good resistance to abrasion, and the polyurethane coatings bonded to a damp surface.

158. Eight HMWM monomers, and one low-viscosity epoxy resin were evaluated for sealing cracks by topical application. The viscosity of the HMWM systems ranged from 9 to 33 cp and the epoxy resin had a viscosity of 40 cp. High bond strengths were obtained for all materials. The epoxy did not penetrate as well as the HMWM into narrow cracks. WES worked with the US Army Engineer District, Kansas City, in preparing specifications and guidance in application of a HMWM for sealing cracks in a bridge deck, and assisted US Air Force staff members in sealing pavements that contained numerous cracks.

<u>Shotcrete</u>

159. Beams cut from test panels prepared from latex-modified shotcrete were tested for freeze-thaw durability. The addition of latex to the shotcrete improved the resistance of the shotcrete to freezing and thawing.

Dilutions of latex to water ranging from 1:2 to 1:4 were found best for applications. A defoamer was found necessary for the acrylic latex. A petrographic examination indicated that the latex actually entrained some air into the shotcrete mixtures. Satisfactory bond and compressive strengths were obtained from latex-modified shotcrete. Polypropylene fibers were added to some of the mixtures, very little loss of fibers was observed during application, and the fibers reduced cracking.

Thin overlays

160. A number of commercial prepackaged latex-modified mortars were tested for bond strength to concrete, freeze-thaw durability, and flexural and compressive strengths. Mortars made by the addition of an acrylic and a styrene-butadiene latex were also tested. These mortars were tested on thin overlays (1/2 in.) to cover 42-in. long concrete panels. The materials tested showed promise based on satisfactory test results and observations during and after application. Durability to 6-month water immersion of mortar mixtures, containing an acrylic and a styrene-butadiene latex, was investigated with the styrene-butadiene latex mixture testing slightly better for water immersion.

PART VI: CONCLUSIONS AND RECOMMENDATIONS

161. The test data for surface treatment materials indicate that there is a wide difference in the performance of these materials for protecting or minimizing concrete deterioration. Criteria can be established based on these test results and others found in literature for guidance in the selection of these materials. Limits could be established for the effectiveness of materials to prevent or significantly reduce water intrusion into concrete, breathability of the surface treatment, resistance to freezing and thawing, accelerated weathering test, and other tests for specific applications, such as abrasion resistance, chemical resistance (to specific chemicals), bond strength, tensile strength, elongation, viscosity, solid content, and gel time.

162. The siloxanes showed promise as a generic type of sealer for concrete and clay bricks based on all tests, except for resistance to freezing and thawing. Additional tests near the end of the study showed that proper application and rate of coverage of penetrating sealers, such as silanes and siloxanes, is important to improve their resistance to freezing and thawing. A two-coat application of 100 to 150 sq ft/gal was used, waiting 5 to 10 min between applications, and is recommended for field applications. The application rate of concrete sealers depends on the porosity and texture of the concrete surface. Some of the application rates recommended by the manufacturer were unsatisfactory, and one should not choose a coating based on recommended application rates unless tests results are available or a field test performed. A field test could be made by coating approximately 1 sq yd of the concrete surface with a sealer and measuring the water absorption of the coated and uncoated concrete using a funnel as described in the report. Linseed oil may be a better sealer than first expected based on the scaling test and the accelerated weathering test.

163. Some of the elastomeric acrylic coatings can be used for coating cracked concrete if the cracks are narrow (hairline), based on good weatherability, elastomeric properties, and breathability of these coatings. Wide cracks must be sealed first with a sealant compatible with the coating. Polyurethane coatings must be used if the surfaces are subjected to traffic or abrasion, but these materials have low water-vapor transmission rates. Some

polyester-resin coatings (moderate in cost compared to epoxies) could be used as an abrasion-resistant coating if applied to dry concrete. Two moisture-insensitive polyurethane coatings tested showed promise as abrasion-resistant coatings, and can be mixed with fine graded sand. Two cementitious coatings tested can be used to waterproof concrete, from both positive and negative sides, and may minimize concrete deterioration due to freezing and thawing. One cement coating was effective in stopping water seepage through concrete based on limited laboratory testing in a field test at Gathright Dam. This coating is not recommended for active cracks since it is cementitious, and an active crack will propagate through the coating.

164. HMWM monomers are presently being used to seal cracks by topical application, and guidance in the selection and application is available from this study. A few epoxy resins were introduced near the end of this study, and the manufacturers claim they can be used to seal cracks by topical application. A limited amount of information is available for these epoxies.

165. The addition of latex admixtures to shotcrete improves the freeze-thaw durability of the material. Polypropylene fibers appear to reduce drying cracking of latex-modified shotcrete. More information on proper mixture proportions and application techniques are needed for latex-modified mortars when used as thin overlays. Addition of small fibers may be beneficial in reducing shrinkage cracking of thin latex-modified mortar overlays when placed outside.

166. Additional testing is needed to determine the effects on surface treatments when applied to damp concrete at different temperatures and to different quality concrete and concrete surfaces. Outgassing can cause blistering and pinholes in coatings, and further studies are needed to determine which coatings might resist this phenomenon and the best times for surface applications.

REFERENCES

American Concrete Institute. 1987a. "A Guide to the Use of Waterproofing, Dampproofing, Protective, and Decorative Barrier Systems for Concrete," ACI Manual of Concrete Practice, ACI Report No. 515.1R-41.

__________. 1987b. "Use of Epoxy Compound with Concrete," ACI Manual of Concrete Practice, ACI Report No. 503R-80.

American Society for Testing and Materials. 1989. 1989 Annual Book of ASTM Standards, Philadelphia, PA.

a. Designation C 457-82, "Standard Practice for Microscopical Determination of Air-Void Content and Parameters of the Air-Void System in Hardened Concrete."

b. Designation C 642-82, "Standard Test Method for Specific Gravity, Absorption, and Voids in Hardened Concrete."

c. Designation D 1824-83, "Standard Test Method for Apparent Viscosity of Plastisols and Organosols at Low Shear Rates by Brookfield Viscometer."

d. Designation C 666-84, "Standard Test Method for Resistance of Concrete to Rapid Freezing and Thawing;" also published as CRD-C 20-87, 1 Mar 1987, Handbook for Concrete and Cement, US Army Engineer Waterways Experiment Station, Vicksburg, MS.

e. Designation C 672-84, "Standard Test Method for Scaling Resistance of Concrete Surfaces Exposed to Deicing Chemicals."

f. Designation D 638-84, "Standard Test Method for Tensile Properties of Plastics."

g. Designation G 53-84, "Standard Practice for Operating Light- and Water-Exposure Apparatus (Fluorescent UV-Condensation Type) for Exposure of Nonmetallic Materials."

h. Designation D 4541-85, "Standard Method for Pull-Off Strength of Coatings Using Portable Adhesion Testers."

i. Designation C 33-86, "Standard Specification of Concrete Aggregates."

j. Designation C 39-86, "Standard Test Method for Compressive Strength of Cylindrical Concrete Specimens."

k. Designation C 882-87, "Standard Test Method for Bond Strength of Epoxy-Resin Systems Used with Concrete;" also published as CRD-C 596-78, 1 Dec 1978, Handbook for Concrete and Cement, US Army Engineer Waterways Experiment Station, Vicksburg, MS.

l. Designation C 881-87, "Standard Specification for Epoxy-Resin-Base Bonding Systems for Concrete."

Bean, D. L. 1988 (Apr). "Surface Treatments to Minimize Concrete Deterioration; Survey of Field and Laboratory Application and Available Products," Technical Report REMR-CS-17, Report 1, US Army Engineer Waterways Experiment Station, Vicksburg, MS.

Bean, D. L., and Husbands, T. B. 1986 (Jul). "Latex Admixtures for Portland Cement Concrete and Mortar," Technical Report REMR-CS-3, US Army Engineer Waterways Experiment Station, Vicksburg, MS.

Koltke, E. 1987 (Aug). "Evaluation of Sealers for Concrete Bridge Elements," Alberta Transportation and Utilities, Alberta, Canada.

Liu, T. C. 1980 (Jul). "Maintenance and Preservations of Concrete Structures; Abrasion-Erosion Resistance of Concrete," Technical Report C-78-4, Report 3, US Army Engineer Waterways Experiment Station, Vicksburg, MS.

Table 1

Water Absorption, Concrete Sealers

Concrete Sealer	Generic Type	Water Absorption, % 24 hr	48 hr	3 day	7 day	Total Solids, %	Application Rate, sq ft/gal
Control		4.66	4.69	4.72	4.79		
W-CS-12	Acrylic	0.44	0.68	0.94	1.66	18.4	140
-28	Acrylic	3.20	4.27	4.42	4.58	25.4	125
-29	Acrylic	0.74	1.30	1.56	2.44	24.7	125
-30	Acrylic	0.74	1.22	1.56	2.50	24.9	125
-33	Acrylic	2.90	4.46	4.50	4.58	12.9	120
-35	Acrylic	1.04	1.58	2.00	3.38	9.5	100
-36	Acrylic	0.16	0.23	0.32	0.62	15.1	100
-41	Acrylic	2.42	4.06	4.26	4.36	11.8	120
-42	Acrylic	0.24	0.42	0.52	1.12	33.5	130
-46	Acrylic	0.35	0.47	0.58	0.88	25.4	130
-49	Acrylic	4.22	--	--	4.48	3.5	100
-50	Acrylic	0.20	0.26	0.28	0.58	17.8	120
-51	Acrylic	1.62	2.74	3.39	4.40	11.6	180
-55	Acrylic	0.77	1.26	--	4.23	23.3	125
-63	Acrylic	0.34	0.58	0.82	1.31	12.5	125
-68	Acrylic	4.15	4.32	4.33	4.40	7.9	125
W-CS-2	Butyrate	0.16	0.23	0.30	0.51	39.2	130
W-CS-34	Chlorinated rubber	0.66	1.08	1.30	2.18	--	150
W-CS-3	Epoxy	1.51	2.53	2.86	3.76	41.0	100
-6	Epoxy	4.10	4.14	--	4.24	23.3	90
-9	Epoxy	4.60	--	4.90	4.96	29.9	110
-26	Epoxy	3.83	4.30	4.36	4.52	15.0	100
-27	Epoxy	0.04	0.07	0.07	0.12	48.7	100
-65	Epoxy	0.78	--	1.32	1.78	18.6	150
W-CS-18	Fluorelastomer	0.43	0.72	1.06	1.68	12.0	100
-19	Fluorelastomer	0.22	0.32	0.40	0.53	18.9	110
W-CS-17	Hydrocarbon	0.17	0.27	0.34	0.60	29.7	120
-32	Hydrocarbon	0.26	0.35	0.41	0.60	10.6	100
-52	Hydrocarbon	0.21	0.24	0.27	0.52	8.2	100
W-CS-43	HMWM	0.08	0.08	0.09	0.14	98.0	150
W-CS-38	Linseed emulsion	2.29	3.16	3.70	4.70	50.1	130
W-CS-58	MMA	0.18	0.29	0.40	0.61	--	120
W-CS-59	Polyurethane	0.07	0.15	0.18	0.28	44.5	130
-60	Polyurethane	0.04	0.06	0.07	0.14	40.3	130
-61	Polyurethane	0.04	0.06	0.07	0.15	40.8	130
-53	Polyurethane	0.66	0.88	1.02	1.62	39.6	150
-54	Polyurethane	0.06	0.08	0.12	0.18	20.1	100
W-CS-7	Silicate	4.34	--	--	4.51	11.1	150
-8	Silicate	4.31	--	--	4.46	15.7	100
-20	Silicate	3.06	3.10	--	3.27	--	100

(Continued)

Note: Results are reported as the average of three test specimens.

Table 1 (Concluded)

Concrete Sealer	Generic Type	Water Absorption, % 24 hr	48 hr	3 day	7 day	Total Solids, %	Application Rate, sq ft/gal
W-CS-21	Silicate	3.78	3.83	--	3.91	--	100
-39	Silicate	4.60	--	--	4.70	32.8	100
-48	Silicate	4.38	--	--	4.53	14.9	100
W-CS-1	Silane	0.14	0.18	0.22	0.31	--	120
-10	Silane	0.15	0.22	0.26	0.42	--	100
-15	Silane	0.22	0.29	0.37	0.58	--	125
-16	Silane	0.26	0.34	0.43	0.65	--	125
-22	Silane	0.29	0.60	0.93	2.02	--	100
-24	Silane	0.25	0.42	0.53	1.00	--	100
-31	Silane	0.38	0.53	0.62	0.82	--	120
-44	Silane	0.24	0.44	0.53	0.66	--	120
-45	Silane	0.34	0.44	0.52	1.19	--	160
-66	Silane	3.00	4.36	--	4.41	--	100
W-CS-46	Silicone	0.28	0.66	1.32	2.62	--	125
-56	Silicone	0.43	1.12	1.98	4.78	7.5	120
-57	Silicone	3.46	4.22	4.28	4.36	5.1	110
-62	Silicone	0.24	0.28	0.33	0.42	90.7	100
W-CS-4	Siloxane	0.25	0.39	0.47	0.78	7.0	150
-13	Siloxane	0.24	0.35	0.44	0.71	7.3	100
-14	Siloxane	0.16	0.22	0.27	0.51	14.6	100
-23	Siloxane	0.16	0.22	0.26	0.49	6.1	100
-25	Siloxane	0.18	0.32	--	0.77	11.7	110
-37	Siloxane	0.17	0.23	0.27	0.45	12.6	120
-47	Siloxane	0.15	0.29	0.42	0.82	9.7	100
W-CS-11	Stearate	0.84	--	1.85	2.86	9.8	120
-5	Stearate	0.59	1.02	1.32	2.14	--	100

Table 2

Water Absorption by Inverted Funnel Method

		Water Absorption, ml					
Concrete Sealer	Substrate	1 hr	2 hr	8 hr	1 day	2 day	7 day
Control (1)	Mortar	8.8	14.2				
Control (2)	Mortar	8.4	13.8				
W-CS-4	Mortar	0.4	0.6				
W-CS-39	Mortar	7.9	13.0				
W-CS-47	Mortar	0.2	0.3				
Control (3)	Concrete	8.9	15.4	28.9	56.4	79.7	
W-CS-48	Concrete	5.1	8.9	18.3	34.6	45.9	
W-CS-14	Concrete	0.3	0.4	1.2	2.3	3.5	5.5

Table 3

Water-Vapor Transmission, Concrete Sealers

Concrete Sealer	Generic Type	Water-Vapor Transmission, % 2 day	4 day	7 day
Control		2.69	3.21	3.53
W-CS-12	Acrylic	0.08	0.13	0.20
-29	Acrylic	1.05	2.10	2.90
-30	Acrylic	1.10	1.95	2.62
-36	Acrylic	0.77	1.55	2.37
-42	Acrylic	0.54	0.97	1.36
-46	Acrylic	1.55	2.15	2.78
-50	Acrylic	0.16	0.35	0.60
-51	Acrylic	1.61	2.20	2.53
-55	Acrylic	1.15	1.86	2.57
-63	Acrylic	1.70	2.50	3.07
W-CS-2	Butyrate	0.28	0.62	1.01
W-CS-26	Epoxy	1.42	1.98	2.43
-27	Epoxy	0.04	0.08	0.12
-65	Epoxy	0.30	0.54	0.88
W-CS-18	Fluorelastomer	0.99	1.76	2.57
-19	Fluorelastomer	0.40	0.67	1.08
W-CS-17	Hydrocarbon	0.33	0.57	0.86
-32	Hydrocarbon	0.92	1.55	2.18
-52	Hydrocarbon	0.98	1.68	2.31
W-CS-43	HMWM	0.08	0.12	0.16
W-CS-58	MMA	0.10	0.18	0.31
W-CS-53	Polyurethane	1.08	1.74	2.41
-54	Polyurethane	0.48	0.74	0.98
-59	Polyurethane	0.17	0.39	0.68
-60	Polyurethane	0.24	0.41	0.64
-61	Polyurethane	0.36	0.46	0.72
W-CS-1	Silane	0.32	0.52	0.74
-10	Silane	0.40	0.58	0.80
-15	Silane	0.42	0.58	0.56
-16	Silane	0.50	0.65	0.68
-22	Silane	0.46	0.76	1.10
-24	Silane	0.38	0.63	0.92
-31	Silane	0.64	1.14	2.08
-44	Silane	0.36	0.64	0.96
-45	Silane	0.70	1.16	1.73
W-CS-46	Silicone	1.70	2.82	3.20
-56	Silicone	1.70	2.35	3.00
-57	Silicone	1.87	2.39	2.93
-62	Silicone	0.36	0.49	0.69
W-CS-4	Siloxane	1.07	1.39	1.83
-13	Siloxane	1.12	1.90	2.49
-14	Siloxane	0.82	1.49	2.15

(Continued)

Table 3 (Concluded)

Concrete Sealer	Generic Type	Water-Vapor Transmission, %		
		2 day	4 day	7 day
W-CS-23	Siloxane	0.62	1.14	1.84
-37	Siloxane	0.38	0.61	0.97
-47	Siloxane	0.38	0.64	0.95
W-CS-11	Stearate	1.60	2.38	3.04
-5	Stearate	0.98	1.40	1.86

Table 4

Accelerated Weathering Test (Two Test Periods), Concrete Sealers

Concrete Sealer	Water Absorption, % Before Test	800 hr	1,600 hr	Difference in %, Before Test and After 1,600 hr
W-CS-1	0.56	0.60	0.70	0.14
W-CS-3	0.43	0.44	0.66	0.23
W-CS-5	0.67	0.74	1.00	0.33
W-CS-10	0.60	0.60	0.80	0.20
W-CS-11	0.93	1.12	1.67	0.74
W-CS-14	0.55	0.61	0.61	0.06
W-CS-17	0.47	0.50	0.54	0.07
W-CS-37	0.59	0.57	0.59	0.00
W-CS-43	0.05	0.14	0.25	0.20
W-CS-45	0.52	0.55	0.60	0.08
W-CS-47	0.54	0.53	0.57	0.03
W-CS-52	0.64	2.16	3.57	2.93
W-CS-54	0.33	0.29	0.74	0.41
W-CS-55	0.61	0.62	3.12	2.51
W-CS-56	0.63	0.66	0.72	0.09
W-CS-62	0.44	0.45	0.47	0.03
W-CS-63	0.81	1.08	4.50	3.69
W-CS-65	0.63	0.68	1.15	0.52
Control	4.90		4.68	-0.22

Table 5

Accelerated Weathering Test (One Test Period), Concrete Sealers

Concrete Sealer	Water Absorption, % Before Test	Water Absorption, % 1,600 hr	Difference in %, Before Test and After 1,600 hr
W-CS-2	0.91	3.21	2.30
W-CS-7	5.49	5.21	-0.28
W-CS-18	1.30	4.21	2.91
W-CS-20	5.40	5.10	-0.30
W-CS-21	5.35	5.18	-0.17
W-CS-31	0.44	0.57	0.13
W-CS-32	0.87	3.92	3.05
W-CS-35	2.10	3.44	1.34
W-CS-36	0.55	2.56	2.01
W-CS-38	3.23	0.58	-2.65
W-CS-44	0.55	0.59	0.04
W-CS-46	0.87	3.94	3.07
W-CS-48	5.57	5.23	-0.34
W-CS-60	0.22	0.87	0.65
W-CS-61	0.53	1.44	0.91
W-CS-64	1.05	4.21	3.16
Linseed Oil*	1.58	0.78	-0.80
Control	5.34	5.38	0.04

* Mixture of 50 percent linseed oil and 50 percent mineral spirits.

Table 6

Water Absorption--Coated Clay Bricks

Concrete Sealer	Water Absorption, % 24 hr	Water Absorption, % 48 hr	Application Rate sq ft/gal
W-CS-13	0.13	0.18	150
W-CS-11	5.75	6.10	170
W-CS-1	0.89	1.08	150
W-CS-17	0.58	1.08	160
W-CS-52	3.82	4.37	170
Siloxane*	0.62	0.75	160
W-CS-35	3.92	5.29	170
W-CS-62	0.50	0.90	150
Linseed Oil	5.66	6.21	150
W-CS-12	6.26	6.62	175
W-CS-47	0.09	0.14	180
Control	6.34	6.76	

Note: Results reported are average of three test specimens.
* Sealer received late in study and no designated laboratory number.

Table 7

Rapid Freezing-and-Thawing Test Results, Concrete Sealers

(ASTM C 666-84 (ASTM 1989d*))

Concrete Sealer	Relative Modulus of Elasticity, %, No. of Cycles			
	10	38	64	94
Control	84	56	18	
W-CS-1	93	69	28	
W-CS-2	97	68	41	
W-CS-4	90	68	35	
W-CS-10	94	88	45	
W-CS-17	95	92	80	55
W-CS-30	92	68	69	
W-CS-36	92	78	40	
W-CS-37	93	85	29	
W-CS-39	89	65	34	
W-CS-50	95	81	32	
W-CS-58	95	86	52	20
W-CS-63	94	81	41	
W-CS-65	95	84	38	

Note: Results reported are the average of two test specimens.
* References cited in the tables are listed following the text of this report.

Table 8

Modified Rapid Freezing-and-Thawing Test Results, Concrete Sealers

(ASTM C 666-84 (ASTM 1989d))

Concrete Sealer	Relative Modulus of Elasticity, %, No. of Cycles 24	48	72	96	120
Control	64	56	42		
W-CS-4	57	44			
W-CS-10	79	65	36		
W-CS-11	66	50			
W-CS-24	86	73	51	38	
W-CS-59	95	93	81	61	30
W-CS-63	62	48			

Note: Results reported are the average of two test specimens.

Table 9

Scaling Tests, Concrete Sealers, Round 1*

Surface-Treatment Material**	Generic Type	Scaling† Rating	Comments
W-CS-1	Silane	4	
4	Siloxane	4	
10	Silane	4	
12	Acrylic	3	At 27 cycles the sealer began flaking around the edges; concrete soft where flaking had occurred.
37	Siloxane	4	
59	Polyurethane	0	
63	Acrylic	3	At 40 cycles the sealer began flaking around the edges; concrete soft where sealer flaked off.

* A 4-percent $CaCl_2$ solution was used for 23 cycles but discontinued because of corrosion caused to freezer.

** Concrete was of low strength, about 2,800 psi. It was sandblasted and dried before treatment was applied. No control was tested in Round 1.

† No scaling - 0; slight scaling - 1; slight to moderate - 2; moderate - 3; moderate to severe - 4; and severe - 5.

Table 10

Scaling Tests, Concrete Sealer, Round 2

Surface Treatment Material*	Generic Type	Scaling Rating**	Comments
Control		3	Moderate scaling
W-CS-1	Silane	2	Slight to moderate
W-CS-2	Butyrate	0	No scaling
W-CS-4	Siloxane	3	Moderate scaling, very slightly less than the control
W-CS-8	Silicate	3	Moderate scaling, about the same as the control
W-CS-10	Silane	2	Slight to moderate
W-CS-11	Stearate	3	Moderate scaling, about the same as the control
W-CS-12	Acrylic	0	No scaling of concrete, sealer surface slightly deteriorated
W-CS-17	Hydrocarbon	1-	Very slight scaling
W-CS-24	Silane	4	Moderate to severe scaling
W-CS-27	Epoxy	0	No scaling, the sealer discolored
W-CS-31	Silane†	0	No scaling
W-CS-32	Hydrocarbon	2+	Slightly moderate scaling
W-CS-36	Acrylic	1	Started flaking at 40 cycles, severe flaking of sealer at 50 cycles, slight scaling of concrete at 50 cycles
W-CS-37	Siloxane	1	Slight scaling
W-CS-46	Acrylic	1	A little flaking of sealer and slight scaling of concrete where sealer flaked off

(Continued)

* Test solution for Round 2 was WES tap water. Concrete was of high quality, 5,500 psi compressive strength. The concrete was sandblasted and dried before treatment was applied.

** No scaling - 0; slight scaling - 1; slight to moderate scaling - 2; moderate scaling - 3; moderate to severe scaling - 4; and severe scaling - 5.

† Sealer has an acrylic top coat.

Table 10 (Concluded)

Surface Treatment Material	Generic Type	Scaling Rating	Comments
W-CS-50	Acrylic	1	Slight flaking of the sealer; no detected scaling of the concrete
W-CS-52	Hydrocarbon	4	Moderate to severe scaling
W-CS-58	Methyl methacrylate	0+	No scaling--sealer's color changed from clear to cloudy white
W-CS-59	Polyurethane	0+	No scaling--sealer shows a very slight deterioration
W-CS-65	Epoxy	0	No scaling

Table 11

Scaling Tests, Concrete Sealers, Round 3

Surface Treatment Material*	Generic Type	Scaling Rating**	Comments
Control		3	Moderate scaling
W-CS-1	Silane	2	Slight to moderate scaling
W-CS-3	Epoxy	0	No scaling
W-CS-4	Siloxane	5	Severe scaling
W-CS-5	Stearate	5	Severe scaling
W-CS-6	Epoxy	0	No scaling
W-CS-8	Silicate	3	Moderate scaling
W-CS-9	Epoxy	0	No scaling
W-CS-10	Silane	5	Severe scaling
W-CS-13	Siloxane	4	Moderate to severe scaling
W-CS-14	Siloxane	3	Moderate scaling
W-CS-19	Fluorelastomer	1	Very slight scaling
W-CS-22† 23†	Silane Siloxane	0	No scaling
W-CS-25	Siloxane	3	Moderate scaling
W-CS-32	Hydrocarbon	4	Moderate to severe scaling
W-CS-33	Acrylic	2	Slight to moderate scaling
W-CS-34	Chlorinated rubber	1	75% of sealer flaked off, slight scaling of concrete
W-CS-37	Siloxane	3	Moderate scaling
W-CS-38	Linseed oil emulsion	2	Slight to moderate scaling
W-CS-40	Silicone	4	Moderate to severe scaling
W-CS-44	Silane	3	Moderate scaling

(Continued)

* Test solution was WES tap water. Concrete was wire-brushed to remove loose debris and dried before treatment was applied. The concrete was high quality, 5,500 psi compressive strength.

** No scaling - 0; slight scaling - 1; slight to moderate scaling - 2; moderate scaling - 3; moderate to severe scaling - 4; and severe scaling - 5.

† The first coat of the concrete sealer was silane and the second coat was siloxane. The materials were tested as a system in the scaling tests and not individually.

Table 11 (Concluded)

Surface Treatment Material	Generic Type	Scaling Rating	Comments
W-CS-47	Siloxane	2	Slight to moderate scaling
W-CS-48	Silicate	2	Slight to moderate scaling
W-CS-49	Acrylic	2	Slight to moderate scaling
W-CS-51	Acrylic	4	Moderate to severe scaling
W-CS-52	Hydrocarbon	5	Severe scaling
W-CS-53	Polyurethane	0††	Sealer blistered and peeled off. Test stopped at 40 cycles because of leaking of the reservoir
W-CS-54	Polyurethane	0	No scaling, sealer slightly discolored
W-CS-55	Acrylic	0††	Very slight scaling
W-CS-56	Silicone	4	Moderate to severe scaling
W-CS-57	Silicone	4	Moderate to severe scaling
W-CS-58	Methyl metacrylate	0	Slight discoloration of sealer
W-CS-59	Polyurethane	0	No scaling
W-CS-62	Silicone	2	Slight to moderate scaling
W-CS-66	Silane	3	Moderate scaling
W-CS-67	Polyurethane	5	Severe scaling
W-CS-68	Acrylic	2	Slight to moderate scaling

†† No scaling of the concrete was observed after 40 cycles.

Table 12

Modified Scaling Tests, Concrete Sealers*

Surface Treatment Material**	Generic Type	Application Rate, sq ft/gal	Weight loss, g, No. of cycles 10	15	20	25	50
Control			10.0	12.8	15.1	18.7	
W-CS-1	Silane	100	0.0				0.0
W-CS-11	Stearate	100	5.2	9.6	12.7	14.9	
W-CS-14	Siloxane	100	0.0				0.0
W-CS-17	Hydrocarbon	170	0.0			0.0	
W-CS-45	Silane	100	0.0	0.2		0.4	
W-CS-47	Siloxane	100	0.0			0.0	
W-CS-48	Silicate	130	9.2			15.9	
W-CS-52	Hydrocarbon	160	0.0	0.5	3.5	16.8	
W-CS-62	Silicone	170	0.0			0.0	
W-CS-65	Epoxy	160	0.0	0.3		2.1	
Linseed oil†		155	0.0			0.0	

* A 4-percent $CaCl_2$ solution was used.

** Concrete used was a nonair-entrained concrete having a strength of 3,800 psi and a W/C of 0.62.

† Linseed oil was a 50-percent mixture of boiled linseed oil and mineral spirits.

Table 13

Test Results for Polymer Systems

Polymer System	Viscosity, cp	Bond Strength to Concrete, psi	Gel Time min
W-CC-52	--	--	3
W-CC-53	40.5	>3,500*	60
W-CC-54	22.0	2,800	45
W-CC-55	23.0	2,910	45
W-CC-56	33.0	900	34
W-CC-57	9.2	2,300	90
W-CC-58	18.0	1,890	50
W-CC-59	20.4	2,100	35
W-CC-60	20.0	2,300	50
W-CC-61	9.8		17

* The mortar failed, all other material failures were at the bond.

Table 14

Water Absorption, Concrete Coatings

Concrete Coating	Generic Type	Water Absorption, % 24 hr	48 hr	3 day	7 day	Total Solids, %	Application Rate, sq ft/gal
Control		4.66	4.69	4.72	4.79		
W-CC-2	Acrylic	0.30	0.44	0.58	0.72	--	80
-5	Acrylic	0.60	0.92	1.12	1.84	36.8	110
-9	Acrylic	1.04	1.55	1.90	2.96	73.3	75
-10	Acrylic	0.79	1.16	1.53	3.08	59.3	75
-13	Acrylic	1.42	1.70	1.82	2.20	73.7	100
-19	Acrylic	0.29	0.40	0.50	0.66	73.5	60
-39	Acrylic	0.17	0.26	0.32	0.50	68.9	100
-46	Acrylic	0.61	0.91	1.13	1.76	--	80
-49	Acrylic	0.58	0.96	1.53	2.00	62.0	75
W-CC-8	Cementitious	2.90	2.95	2.97	3.10	100	--
-16	Cementitious	0.20	0.27	0.33	0.49	100	--
-41	Cementitious	4.44	4.48	4.50	4.56	100	--
-43	Cementitious	1.45	1.85	2.19	2.65	100	--
-51	Cementitious	2.56	2.82	2.91	2.94	100	--
W-CC-1	Epoxy	0.06	0.08	0.11	0.16	81	70
-6	Epoxy	0.07	0.08	0.10	0.15	100	80
-20	Epoxy	0.02	0.04	0.04	0.05	91.3	60
-25	Epoxy	0.16	0.21	0.25	0.37	--	60
-26	Epoxy	0.02	0.04	0.04	0.06	--	--
-29	Epoxy	0.13	0.21	0.28	0.41	96.1	75
-44	Epoxy	0.40	0.53	0.66	0.99	48.1	125
W-CC-14	Hypalon	0.06	0.11	0.18	0.42	47.8	95
-15	Hypalon	0.04	0.06	0.14	0.29	44.6	75
W-CC-8	Neoprene	0.41	0.68	--	1.06	--	70
-3*	Polyurethane	0.02	0.03	0.03	0.04	73.6	150
-3**	Polyurethane	0.04	0.06	0.07	0.12	--	100
W-CC-4	Polyurethane	0.06	0.08	0.10	0.14	62.4	175
-11	Polyurethane	0.08	0.10	0.11	0.20	95.2	100

(Continued)

Note: Results reported are the average of three test specimen.
* Coating was pigmented (tan color).
** Coating was clear.

Table 14 (Concluded)

Concrete Coating	Generic Type	Water Absorption, % 24 hr	48 hr	3 day	7 day	Total Solids, %	Application Rate, sq ft/gal
W-CC-12	Polyurethane	0.07	0.10	0.11	0.24	90.8	100
-21	Polyurethane	0.06	0.08	0.09	0.14	52.0	120
-22	Polyurethane	0.03	0.06	0.07	0.11	43.0	80
-23	Polyurethane	0.06	0.11	0.14	0.20	78.8	100
-24	Polyurethane	0.04	0.06	0.07	0.12	--	--
-27	Polyurethane	0.22	0.25	0.28	0.49	35.5	100
-28	Polyurethane	0.19	0.24	0.31	0.50	--	150
-30	Polyurethane	0.17	0.24	0.27	0.41	76.5	75
-33	Polyurethane	1.51	2.08	--	3.79	40.0	150
-34	Polyurethane	0.38	0.71	--	1.76	40.0	150
-45	Polyurethane	0.11	0.21	0.30	0.53	--	100
-48	Polyurethane	0.04	0.05	0.06	0.10	67.4	110
W-CC-32	Polyester	0.04	0.08	0.08	0.12	96.1	90
W-CC-7	Silicone	0.36	0.54	0.72	1.76	48.1	80

Table 15

Water-Vapor Transmission, Concrete Coatings

Concrete Coating	Generic Type	Water-Vapor Transmission, %		
		2 day	4 day	7 day
Control		2.69	3.21	3.53
W-CC-5	Acrylic	0.46	0.84	1.29
-9	Acrylic	0.60	0.96	1.47
-10	Acrylic	0.81	1.10	1.28
-13	Acrylic	0.82	1.23	1.78
-19	Acrylic	0.68	1.19	1.78
-39	Acrylic	0.34	0.57	0.83
-46	Acrylic	0.44	0.68	0.92
-47	Acrylic	0.68	1.20	1.88
-49	Acrylic	1.65	2.40	2.81
W-CC-16	Cementitious	1.00	1.64	2.28
-41	Cementitious	0.62	1.16	1.74
-43	Cementitious	0.57	0.77	1.02
-51	Cementitious	1.60	1.92	2.18
W-CC-1	Epoxy	0.04	0.08	0.09
-6	Epoxy	0.05	0.08	0.10
-20	Epoxy	0.03	0.05	0.06
-25	Epoxy	0.25	0.36	0.46
-26	Epoxy	0.08	0.14	0.23
-29	Epoxy	0.07	0.13	0.21
-44	Epoxy	0.11	0.18	0.26
W-CC-14	Hypalon	0.12	0.18	0.28
-15	Hypalon	0.09	0.12	0.18
W-CC-16	Neoprene	0.25	0.30	0.37
W-CC-3	Polyurethane	0.06	0.12	0.21
-4	Polyurethane	0.03	0.09	0.15
-11	Polyurethane	0.10	0.16	0.26
-12	Polyurethane	0.21	0.39	0.65

(Continued)

Note: Results reported are average of three test specimens.

Table 15 (Concluded)

Concrete Coating	Generic Type	Water-Vapor Transmission, %		
		2 day	4 day	7 day
W-CC-21	Polyurethane	0.22	0.42	0.73
-22	Polyurethane	0.18	0.34	0.54
-23	Polyurethane	0.39	0.73	1.19
-27	Polyurethane	0.07	0.12	0.20
-30	Polyurethane	0.12	0.20	0.30
-33	Polyurethane	0.62	1.06	1.54
-34	Polyurethane	0.42	0.77	1.18
-45	Polyurethane	0.20	0.36	0.56
-48	Polyurethane	0.12	0.14	0.28
W-CC-32	Polyester	0.08	0.12	0.17
-7	Silicone	1.15	2.15	2.76

Table 16

Accelerated Weathering Test Results, Concrete Coating

Coating	Generic Type	Appearance After 1,600 hr Testing
W-CC-19	Acrylic	Slight yellowing of coating
W-CC-46	Acrylic	No effect from weathering
W-CC-49	Acrylic	No effect from weathering
W-CC-3	Polyurethane	Slight yellowing of coating
W-CC-11	Polyurethane	Slight discoloration
W-CC-24	Polyurethane	Slight discoloration
W-CC-28	Polyurethane	Some chalking and loss of glossy finish
W-CC-34	Polyurethane	Some chalking and loss of glossy finish
W-CC-45	Polyurethane	Slight discoloration
W-CC-7	Silicone	No effect from weathering

Table 17

Bond Strength of Concrete Coatings to Concrete

Concrete Coating**	Generic Type	Bond Strength psi	Concrete Coating	Generic Type	Bond Strength psi
W-CC-5	Acrylic	250	W-CC-9	Epoxy	370*
-9	Acrylic	160	W-CC-44	Epoxy	290*
-10	Acrylic	110	W-CC-14	Hypalon	250
-13	Acrylic	280	-15	Hypalon	230
-19	Acrylic	140	-18	Neoprene	120
-39	Acrylic	200	-3	Polyurethane	290*
W-CC-1	Epoxy	360*	-4	Polyurethane	380*
-6	Epoxy	370*	-11	Polyurethane	190
-20	Epoxy	280	-12	Polyurethane	200
-25	Epoxy	320*	-21	Polyurethane	330*
-26	Epoxy	380*	-22	Polyurethane	330*
W-CC-23	Polyurethane	170			
-27	Polyurethane	280*			
-30	Polyurethane	270*			
-33	Polyurethane	330*			
-34	Polyurethane	250			
-35	Polyurethane	320*			
W-CC-35**	Polyurethane	200			
W-CC-36	Polyurethane	260			
W-C-36**	Polyurethane	180			
W-CC-32	Polyester	290*			
W-CC-7	Silicone	110			

Note: Results reported are average of three tests.
* Concrete failure, all other failures at the coating-concrete interface.
** Applied to a damp concrete surface.

Table 18

Elastomeric Properties of Coatings

Concrete Coating	Tensile Elongation, %	Tensile Strength, psi	Shore Hardness
W-CC-5	200	1,000	--
W-CC-7	550	400	35A
W-CC-11	600	750	60A
W-CC-12	400	1,240	85A
W-CC-14	400	800	--
W-CC-16	230	270	--
W-CC-22	500	5,000	--
W-CC-24	300	--	--
W-CC-35	300	4,800	60D
W-CC-36	450	1,600	--
W-CC-46	360	150	--

Table 19

Rapid Freezing-and-Thawing Test Results, Concrete Coatings

Concrete Coating	Relative Modulus of Elasticity, % No. of Cycles						
	10	38	64	94	109	158	178
Control	84	56	18	--	--	--	--
W-CC-1	97	97	97	--	94	90	89
W-CC-16	96	93	47	--	--	--	--
W-CC-19	94	93	66	35	--	--	--
W-CC-20	98	97	97	95	42	--	--
W-CC-29	96	92	66	37	--	--	--
W-CC-43	97	95	93	--	--	70	47
W-CC-56	86	73	31	--	--	--	--

Table 20

Modified Rapid Freezing-and-Thawing Test Results, Concrete Coatings

Concrete Coating	Relative Modulus of Elasticity, %, No. of Cycles					
	24	48	72	96	120	168
Control	64	56	42	--	--	--
W-CC-11	95	93	85	80	69	56
W-CC-12	95	94	95	89	81	64
W-CC-21	91	91	91	76	51	

Table 21

Scaling Test Results, Concrete Coatings

Surface Treatment Material	Generic Type	Rating	Comments
W-CC-4	Polyurethane	0	No scaling
W-CC-11	Polyurethane	0	No scaling, slight discoloration
W-CC-12	Polyurethane	0	No scaling, slight dulling of color
W-CC-16	Cementitious	0	No scaling
W-CC-18	Neoprene	0	Coating developed blisters
W-CC-19	Acrylic	0	No scaling, slight discoloration
W-CC-20	Epoxy	0	No scaling, slight discoloration
W-CC-21	Polyurethane	0	Slight loss of gloss
W-CC-22	Polyurethane	0	No scaling, slight discoloration
W-CC-27	Polyurethane	0	No scaling
W-CC-30	Polyurethane	0	No scaling
W-CC-42	Bituminous	0	Membrane had many large blisters
W-CC-43	Cementitious	0	No scaling
W-CC-44	Epoxy	0	No scaling
W-CC-49	Acrylic	3	Coating flaked off, concrete showed light to moderate scaling
W-CC-51	Cementitious	*	Coating began flaking off after 8 cycles, and the test was discontinued

* Test was discontinued after coating began unbonding from the concrete surface.

Table 22

Underwater Abrasion Test Results

	Weight of Specimen, lb			
Coating	Initial	24 hr	48 hr	72 hr
W-CC-31	37.6	37.4	37.4	37.4
W-CC-35	39.1	39.1	39.1	39.1
W-CC-36	43.2	43.2	43.2	43.2
W-CC-40	40.2	40.1	40.0	40.0

Table 23

Test Results for Latex-Modified Shotcrete

Shotcrete Mixture No.	Latex Dilution	Water/ Cement W/C	Water/ Cement P/C	Compressive Strength psi	Bond Strength psi	Density lb/ft^3	Water Absorption, %
Control		0.52		5,830	500	146	100
Control		0.40		7,000			
SB-1	1:1	0.33			480	140	
-2	1:3	0.38			470	143	190
-3	1:7	0.38			340	146	197
A-1	None	0.31	0.27	4,090	490	139	130
-2	1:1	0.25	0.075	4,920	690	143	84
-3	1:1*	0.32	0.097	4,830			
-4	1:2	0.29	0.054	4,800	500	130	99
-5**	1:2	0.50	0.071				
-6	1:3	0.35	0.047	6,520	630	142	77
-7	1:3	0.41	0.055	7,350	360	143	93
-8†	1:3	0.66	0.089				
-9	1:3	0.28	0.037	5,840	610		
-10	1:3	0.43	0.058	6,140	590	142	
-11	1:3*	0.33	0.044		210	140	65
-12††	1:3	0.39	0.052	6,700	610	142	91
-13††	1:3	0.37	0.049	6,480	580	141	
-14‡	1:3	0.44	0.059	4,590	470		
-15‡	1:3				470		

* No defoamer added, difficult to apply.
** Shrinkage cracks developed, too wet.
† Too wet, difficult to apply, and sagging.
†† Polypropylene fibers added to mixture.
‡ Sand to cement ratio changed to 4.5:1.

Table 24

Air Content and Composition of Latex-Modified Shotcrete

Composition and Bond Strength	Latex Admixture			No Latex Regular Shotcrete
	No Dilution*	1:3 Dilution	1:3 Dilution, No Anti-Foam	
Aggregate	48.2	53.5	50.1	56.5
Paste	41.7	36.8	34.9	38.4
Air				
Entrained	3.1	7.5	7.7	4.0
Entrapped	7.0	2.2	7.3	1.1
Total Air	10.1	9.7	15.0	5.1
W/C	0.31	0.35	0.33	0.52
Polymer/C	0.27	0.047	0.044	
Bond Strength, PSI (by shear)	550 420	640 670	230 150	640 410 450

* 47 percent acrylic polymer suspended in water.

Table 25

Test Results for Latex-Modified Mortar

Test	Test Results	
	W-LM-1	W-LM-2
Compressive strength, psi	6,200	5,810
Flexural strength, psi	1,430	1,280
Bond strength to concrete, psi	2,600	2,960
Resistance to scaling, 50 cycles of freezing and thawing, visual rating	1	1

Table 26

Effect of Water on Latex-Modified Mortar

Test	W-A-1		W-A-3	
	Air Storage	Water Storage	Air Storage	Water Storage
Compressive strength, psi	5,690	5,120	6,430	7,100
Flexural strength, psi	1,450	1,140	1,430	1,270
Bond strength to concrete, psi	2,330	2,020	2,540	2,590

Note: Results reported are average of three test specimens.