

NATIONAL COOPERATIVE
HIGHWAY RESEARCH PROGRAM REPORT

244

**CONCRETE SEALERS FOR PROTECTION
OF BRIDGE STRUCTURES**

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NATIONAL COOPERATIVE HIGHWAY RESEARCH PROGRAM
REPORT

244

CONCRETE SEALERS FOR PROTECTION OF BRIDGE STRUCTURES

D. W. PFEIFER AND M. J. SCALI
Wiss, Janney, Elstner & Associates, Inc.
Northbrook, Illinois

RESEARCH SPONSORED BY THE AMERICAN
ASSOCIATION OF STATE HIGHWAY AND
TRANSPORTATION OFFICIALS IN COOPERATION
WITH THE FEDERAL HIGHWAY ADMINISTRATION

AREAS OF INTEREST:

STRUCTURES DESIGN AND PERFORMANCE
CONSTRUCTION
MAINTENANCE
(HIGHWAY TRANSPORTATION)

TRANSPORTATION RESEARCH BOARD

NATIONAL RESEARCH COUNCIL

WASHINGTON, D.C.

DECEMBER 1981

NATIONAL COOPERATIVE HIGHWAY RESEARCH PROGRAM

Systematic, well-designed research provides the most effective approach to the solution of many problems facing highway administrators and engineers. Often, highway problems are of local interest and can best be studied by highway departments individually or in cooperation with their state universities and others. However, the accelerating growth of highway transportation develops increasingly complex problems of wide interest to highway authorities. These problems are best studied through a coordinated program of cooperative research.

In recognition of these needs, the highway administrators of the American Association of State Highway and Transportation Officials in 1962 an objective national highway research program employing modern scientific techniques. This program is supported on a continuing basis by funds from participating member states of the Association and it receives the full cooperation and support of the Federal Highway Administration, United States Department of Transportation.

The Transportation Research Board of the National Research Council was requested by the Association to administer the research program because of the Board's recognized objectivity and understanding of modern research practices. The Board is uniquely suited for this purpose as: it maintains an extensive committee structure from which authorities on any highway transportation subject may be drawn; it possesses avenues of communications and cooperation with federal, state, and local governmental agencies, universities, and industry; its relationship to its parent organization, the National Academy of Sciences, a private, nonprofit institution, is an insurance of objectivity; it maintains a full-time research correlation staff of specialists in highway transportation matters to bring the findings of research directly to those who are in a position to use them.

The program is developed on the basis of research needs identified by chief administrators of the highway and transportation departments and by committees of AASHTO. Each year, specific areas of research needs to be included in the program are proposed to the Academy and the Board by the American Association of State Highway and Transportation Officials. Research projects to fulfill these needs are defined by the Board, and qualified research agencies are selected from those that have submitted proposals. Administration and surveillance of research contracts are the responsibilities of the Academy and its Transportation Research Board.

The needs for highway research are many, and the National Cooperative Highway Research Program can make significant contributions to the solution of highway transportation problems of mutual concern to many responsible groups. The program, however, is intended to complement rather than to substitute for or duplicate other highway research programs.

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The members of the technical committee selected to monitor this project and to review this report were chosen for recognized scholarly competence and with due consideration for the balance of disciplines appropriate to the project. The opinions and conclusions expressed or implied are those of the research agency that performed the research, and, while they have been accepted as appropriate by the technical committee, they are not necessarily those of the Transportation Research Board, the National Research Council, the National Academy of Sciences, or the program sponsors.

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FOREWORD

*By Staff
Transportation
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This report will be of interest and usefulness to individuals concerned with the protection of reinforced concrete bridge elements, or other concrete structural elements, from the corrosive effect of chloride found in marine environments or deicing chemicals. Several sealers intended for use on concrete surfaces were evaluated using laboratory tests devised by the researchers. (The primary focus of the project excluded the top surface of bridge decks.) Recommendations on materials, their application, and test procedures were formulated. The report is recommended particularly to construction and maintenance engineers involved with reinforced concrete bridges or other concrete structures, materials engineers, specification writers, and the suppliers or manufacturers of "concrete sealers."

Concrete structures undergo accelerated deterioration when deleterious chemical substances penetrate the concrete and cause corrosion of the embedded reinforcing steel. Accumulated corrosion products around the reinforcing steel cause cracks to develop in the protective concrete cover, allowing intrusion of more deleterious material and thereby accelerating corrosion, causing spalling, and diminishing the structural integrity of the member. Considerable attention has been directed to deterioration of bridge decks caused by deicing salts. However, in a marine environment, chloride penetration can affect all bridge members, including piles, caps, girders, and diaphragms, as well as decks. Deterioration is also often caused by faulty bridge deck drainage that permits contamination of structural members by deicing salts.

Under NCHRP Project 12-19A, researchers from Wiss, Janney, Elstner and Associates, Inc, were assigned the objective of evaluating the efficacy of sealers used to protect reinforced concrete bridges exposed to potential chloride contamination and to provide guidance for their use on bridge members. The research concentrated on the protection of structural elements other than the top surface of the bridge deck. Several sealers were evaluated, including commonly used linseed oil, under a testing program carefully devised by the researchers. The report includes recommendations on the types of sealers and testing procedures for selecting sealers. It also provides general recommendations on sealer applications.

As with any laboratory tests, the reader must realize that the evaluations of sealers are comparative and not absolute. Although every attempt was made to replicate "real world conditions," there is always uncertainty under accelerated laboratory testing. However, the researchers have taken into account several factors in their tests not normally considered with standard available testing.

Furthermore, the reader should fully realize that although sealers are generically classified, the evaluations were done on specific formulations. Extending test results of specific formulations as representative of an entire generic classification could be extremely dangerous. For the readers' information, infrared spectra are included in Appendix F for those sealers that were considered more extensively in the study.

The identification of sealers by their trade or manufacturer's name will be supplied under separate cover to the sponsors of NCHRP, namely, the state departments of transportation or highways. However, it cannot be over emphasized that it is possible for specific formulations to vary even under proprietary labels.

Because it is not the policy nor the intent of NCHRP to endorse specific products or manufacturers (and for others to do so based on information in this report is not permitted), a decision was made not to identify proprietary labelling to other than the NCHRP sponsorship. It is firmly believed that this position does not seriously hinder the usefulness to other readers. Comments on the general nature of various sealer classifications and the testing procedures used should be worthwhile not only to NCHRP sponsors but also to engineers, in other organizations, who deal with the protection of concrete structures, as well as to suppliers and manufacturers of sealers in developing more substantive testing procedures in support of their products.

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The research reported herein was performed under NCHRP Project 12-19A by Wiss, Janney, Elstner and Associates, Inc. A portion of the experimental work was performed by Erlin, Hime Associates, Inc.

Donald W. Pfeifer, Vice President, Wiss, Janney, Elstner and Associates, Inc., was the principal investigator. The other investigators were Stella L. Marusin, Senior Chemical Engineer; and Mauro J. Scali, Petrographer, both of Wiss, Janney, Elstner and Associates, Inc.

The chloride content tests on concrete and aggregates and the infrared spectroscopical analyses of the chemical sealers were made by William G. Hime, Vice President, and James D. Connolly, Executive Director, Analytical Services, of Erlin, Hime Associates, Inc. They both also offered numerous constructive comments during the planning and the execution of the project.

The authors would like to thank others who aided in various phases of the investigation; namely David H. Berry, Jr., Concrete Technology Engineer, Illinois Department of Transportation, for his assistance in planning the project; and to William F. Perenchio, Consultant, Wiss, Janney, Elstner and Associates, Inc.; and Robert Landgren, Senior Engineer, Wiss, Janney, Elstner and Associates, Inc. for their continual assistance and counseling during the project.

CONCRETE SEALERS FOR PROTECTION OF BRIDGE STRUCTURES

SUMMARY

Concrete bridges in different regions of the United States are undergoing accelerated deterioration caused by corrosion of embedded reinforcing steel. This deterioration affects all such bridge members as the piles, walls, piers, caps, girders, diaphragms as well as the bridge deck. The corrosion is caused by the gradual intrusion of chloride into the concrete from deicing salts used in the northern climates and from saltwater exposure in the coastal regions, particularly in southern coastal regions. The development of effective surface-applied liquid sealers, coatings, or penetrants for use on these various bridge members could provide added protection against the intrusion of the salt-laden waters. This added protection would extend the life of bridge structures subjected to these various environments.

The objective of this investigation was to study the effectiveness of different chemical surface sealers when applied on concrete and cracked reinforced concrete which are subjected to different environmental conditions. Their effectiveness was established by determining if these chemical materials could minimize or prevent the intrusion of saltwater into concrete during four different laboratory test phases, including 24 weeks of accelerated northern and southern climate weathering tests. The investigation was aimed at all bridge surfaces except the top surface of the bridge deck which is subjected to tire abrasion.

The results of this project show that a wide range of generic types of chemicals are being marketed and used to seal concrete bridge surfaces. However, the laboratory performance of these numerous types of chemical materials in minimizing the intrusion of saltwaters into concrete was found to be highly variable. Many of the chemical materials were found to be ineffective in reducing the water absorption and chloride intrusion characteristics during simple saltwater soaking tests. Some materials, such as linseed oil, were variable, depending on the test procedure used. Significant performance variation was observed within a given generic type of chemical, such as within the epoxies, the polyurethanes, etc.

Although significant variations in performance exist, there are certain specific formulations of different chemical materials that exhibit very good to excellent performance. These materials are able to reduce the intrusion of chloride by 80 to 99 percent when compared with uncoated concrete. The approximate formulations and infrared spectra for these specific materials are identified in the report. Two test procedures, including limits on chloride intrusion, are suggested for use by chemical manufacturers, highway agencies, and testing laboratories to evaluate the performance of sealers.

Certain sealant materials appear to offer added corrosion protection to embedded steel when cracks are present. This observation would suggest that cracks in such members could be given multiple coats of these sealers to achieve even better corrosion performance than was exhibited in this study.

The materials tested can be sprayed, roller-applied or brush-applied. The material costs for the excellent performance materials may range from about \$0.15 to \$0.50 per sq ft. Application costs will vary significantly depending on the details

of the bridge structure. They are generally solvent-based chemicals that require safety precautions. The precautions are similar to those required for solvent-type epoxy or polyurethane paints that are apparently used on steel bridges. These sealant materials generally cause a color-darkening of the concrete. One of the best performing materials is a true penetrant that does not cause any color change. The cost of this particular material is the highest of the three materials that achieved consistently good to excellent performance.

Guidance is given in the report on proper application rates for the materials that provide good to excellent results, and on the proper amount of air drying time the concrete should be allowed, after curing or rain, prior to applying these sealers. All specimens in this investigation received a very light sandblasting to prepare the concrete surface for the sealers.

Although certain sealer materials can significantly reduce the intrusion of chloride into concrete, the use of properly consolidated and cured low water/cement ratio concrete, and deep cover over the embedded reinforcing steel is still needed for long-term protection in severe environments.

CHAPTER ONE

INTRODUCTION AND RESEARCH APPROACH

INTRODUCTION

Numerous concrete bridge structures in different regions of the United States are undergoing accelerated deterioration caused by corrosion of the embedded reinforcing steel. This deterioration can affect all such bridge members as the piles, walls, piers, caps, girders, diaphragms as well as the top and bottom surfaces of the bridge deck. The corrosion is caused primarily by the gradual intrusion of chloride ion into the concrete from deicing salts used in the northern climates and from saltwater exposure in the coastal regions, particularly in southern coastal regions. The steel corrosion is intensified when the protective concrete cover over the embedded bars is inadequate, where there are cracks in the concrete, or when other design or construction inadequacies occur in these different bridge members.

The development of effective surface-applied liquid sealers, coatings, or penetrants for use on these various bridge members could provide added protection against the intrusion of these salt-laden waters. This added protection would extend the life of bridge structures subjected to the various environments. Such protective sealer materials could be used on new bridges as well as older bridges that are not already contaminated with chloride beyond tolerable limits (36, 72). Their effectiveness presumably would arise not only from restricting the ingress of chloride ion but moisture as well. These sealer materials would be used on vertical surfaces and horizontal surfaces, including the undersides of bridge members.

Although numerous studies (1-70) have been completed on many generic types of coating materials or sealers, such as boiled linseed oil, epoxies, polyurethanes, methyl methacrylates, silicones, etc., the results of laboratory and field

tests have generally been varied or nonconclusive. This variability may be due in part to the use of different test procedures by different testing organizations because a standard test method has not been developed to evaluate the long-term performance of such sealers when applied on concrete.

RESEARCH OBJECTIVE

The objective of this investigation was to study the effectiveness of different surface sealers when applied on concrete and subjected to different environmental conditions. The effectiveness was established by determining if these sealer materials could minimize or prevent the intrusion of chloride-laden water into concrete during four different laboratory test phases, including 24 weeks of accelerated weathering tests. The investigation was aimed at all bridge surfaces except the top surface of the bridge deck which is subjected to tire abrasion.

This investigation also included some consideration of the economic feasibility of such materials, potential safety hazards associated with these chemical materials, application techniques and costs, and the esthetics of the bridge surfaces after being coated. Guidance for the use of these types of materials is provided in this report. Guidance for laboratory testing procedures that could be used by chemical companies, highway agencies, and testing laboratories is also provided.

RESEARCH APPROACH

Because previous investigations on surface sealers generally concentrated on only one type of chemical material per investigation and the present research was aimed at investi-

gating as many different chemical types of sealers as possible, the research approach included a literature search of libraries, highway departments, and chemical companies to determine appropriate chemical sealer materials. Four different laboratory investigations on different selected materials were undertaken. Thus, the research consisted of the following tasks:

1. Literature search to determine the appropriate chemical materials that should be tested in the laboratory phases.
2. Series I laboratory tests on 21 selected materials to determine their ability to reduce chloride intrusion into concrete and to select five materials exhibiting good performance for the Series II, III, and IV laboratory tests.

3. Series II laboratory tests on five selected materials to study the effect of concrete moisture content at the time of application upon chloride intrusion into concrete.

4. Series III laboratory tests on five selected materials to study the effect of different coverage rates upon chloride intrusion into concrete.

5. Series IV, 24 weeks of accelerated northern and southern climate laboratory weathering tests on five selected materials to determine their performance during simulated long-term weathering exposure conditions which included exposure to acid, saltwater, fresh water, ultraviolet light radiation, heat, freezing and thawing, and wetting and drying. Unreinforced concrete specimens and cracked reinforced concrete specimens were tested.

CHAPTER TWO

FINDINGS

LITERATURE SEARCH

During the past 20 years, numerous sealer materials have been investigated, including several types of oil and rubber, a wide variety of resins, petroleum products, silicones, and other inorganic or organic materials. Some of these materials were found to be ineffective, while others appeared to be effective but expensive.

Review of the literature indicates that boiled linseed oil is one of the most widely used materials. It is supplied and widely used as a solution of 50 percent boiled linseed oil and 50 percent mineral spirits or kerosene. Opinions of the numerous investigators (8-35) differ concerning the value of the linseed oil treatment.

Epoxyes appear to be the second most commonly used sealant material. They have been tested or routinely used as penetrating sealants and as coating materials (20, 34, 37-47). The solids content is generally in the range of 17 to 100 percent. Two coats are usually recommended to reduce pinholing. Experiences in the laboratory and the field with epoxy penetrants and coatings have been varied.

Many other varieties of synthetic resins have been evaluated, including acrylics, polyurethanes, and hydrocarbon resins. Acrylic resins are used with different solvents. Two coats are usually recommended. Review of the literature indicates that acrylic resin is one of the most effective sealant materials being used. Urethane coatings are a more recent development in the area of catalyzed systems. Experiences with urethane sealants vary widely. Coatings based on polyurethanes were proposed in Japan because of their reportedly excellent resistance to water, weathering, and cracking (59, 60).

Latex coating materials are dispersions or emulsions of pigmented and compounded organic film-forming materials in water. The film formers may be styrene butadiene, polyvinyl acetate, acrylic or blends of these with other polymers, dispersed as latices in water. One coat is usually recommended. These materials have been found to be permeable and quickly penetrated by a salt solution (34).

Two types of silicone materials have been used as surface treatments (1). One type consists of impervious coatings which seal the surface so that neither liquid water nor water vapor will penetrate. The other type consists of water repellents, which prevent the passage of liquid water but do not stop the movement of water vapor. This latter type is of primary interest to the present study. It has been shown (66) that, although silicones reduce the initial rate of absorption of water, after continued immersion the total absorption for treated and untreated concretes is similar. It also has been shown (31) that silicones do not prevent the intrusion of chlorides into concrete.

A number of inorganic coatings, anticipated to be more compatible with concrete than organic coatings, also have been investigated. They are generally based on silicate solutions. Advantages of silicate solutions during application are that they are neither toxic, flammable, nor hazardous under normal conditions.

Numerous departments of transportation are now evaluating a new silane product which is marketed as a waterproofing material. Unlike coatings, oils, and other currently used sealants, this silane material does not block the porosity of concrete. Instead, it reacts chemically with the surface of the concrete to form a hydrophobic layer which is repellent to liquid water but permeable to water vapor.

Numerous types of laboratory tests have been used to evaluate the effectiveness of sealants in protecting concrete surfaces against the penetration of moisture and chloride solution. The results of the literature search indicate that a standard test method has not been developed to evaluate water absorption, water vapor transmission qualities, and chloride ion intrusion characteristics of coated concrete specimens that must experience environmental factors, such as saltwater, acids, heat, cold, freezing, thawing, ultraviolet radiation, etc.

A survey of the 50 highway departments and 239 chemical or paint manufacturers was made to identify candidate sealers for the four laboratory testing phases and to collect

performance test data generated in their laboratories or in the field by these various organizations. A total of 41 highway departments and 69 chemical or paint companies responded to the survey letter. Thirteen of the responding highway departments apparently do not use sealants for protection of bridge surfaces. The most commonly used materials from the remaining 28 highway departments which responded are 50-50 mixtures of boiled linseed oil and mineral spirits, and epoxies. From the 69 chemical companies which responded, 57 companies suggested 103 different materials.

Only three chemical companies submitted data on water absorption and chloride ion contents for concrete specimens that were coated with their candidate materials and subjected to laboratory testing. Therefore, the selection of materials for the Series I laboratory tests was based primarily on known chemical composition coupled with either laboratory results or field trials from highway departments which merely indicated that the material showed promise in resisting the ingress of chloride-laden water. Members of the project team reviewed the submitted letters and test reports and then selected materials for the Series I screening tests. Twenty-one penetrants or coatings from 21 different chemical companies were selected which generally include all of the chemical types of materials most widely used. These are as follows:

	Test Nos.
Boiled linseed oil	2
Five epoxies with different amounts of solids	15,16,18,19,21
Two epoxies containing polysulfide	17,20
Three materials based on methacrylate	8,10,13
Silane	6
Two types of urethane	4,14
Two materials based on butadiene	7,11
Chlorinated rubber	5
Silicate	9
Siliconate	3
Siloxane	1
Material based on isobutylene and aluminum stearate	12

SERIES I TESTS

The Series I screening tests (App. B) were designed to evaluate the differences in water absorption and chloride intrusion characteristics for the 21 selected materials when applied on concrete and then soaked in a 15 percent NaCl saltwater solution. The subsequent water vapor transmission characteristics were also compared during an air drying period which followed the soaking period. The objective was to select five materials that exhibited good performance for further testing in Series II, III, and IV.

The water absorption characteristics of the 21 tested materials varied over an extremely wide range, as shown in Figure 1. Three of the materials actually exhibited water absorption values somewhat greater than uncoated concrete. Five of the materials exhibited low water absorption values ranging from 10 to 30 percent of that of uncoated concrete. The concrete treated with boiled linseed oil had a high water absorption value of 80 percent of uncoated concrete.

Four of the five materials exhibiting low water absorption

values also lost more weight by vapor transmission during an air drying period than they had gained during water soaking.

Companion specimens were pretreated with boiled linseed oil to simulate an older bridge structure previously treated with linseed oil. These were tested also, after applying the 21 materials over the linseed oil treatment. The results of this phase showed much lower water absorption values for these linseed oil pretreated concretes, with one exception. In this group of tests, 10 of the 21 materials exhibited low water absorption values, ranging from 6 to 26 percent of that of uncoated concrete.

Wide variations in performance existed between the seven epoxy formulations. Two epoxy materials having solid contents of 50 and 100 percent had very low water absorption values. Both required two coats and both had shiny, glassy-

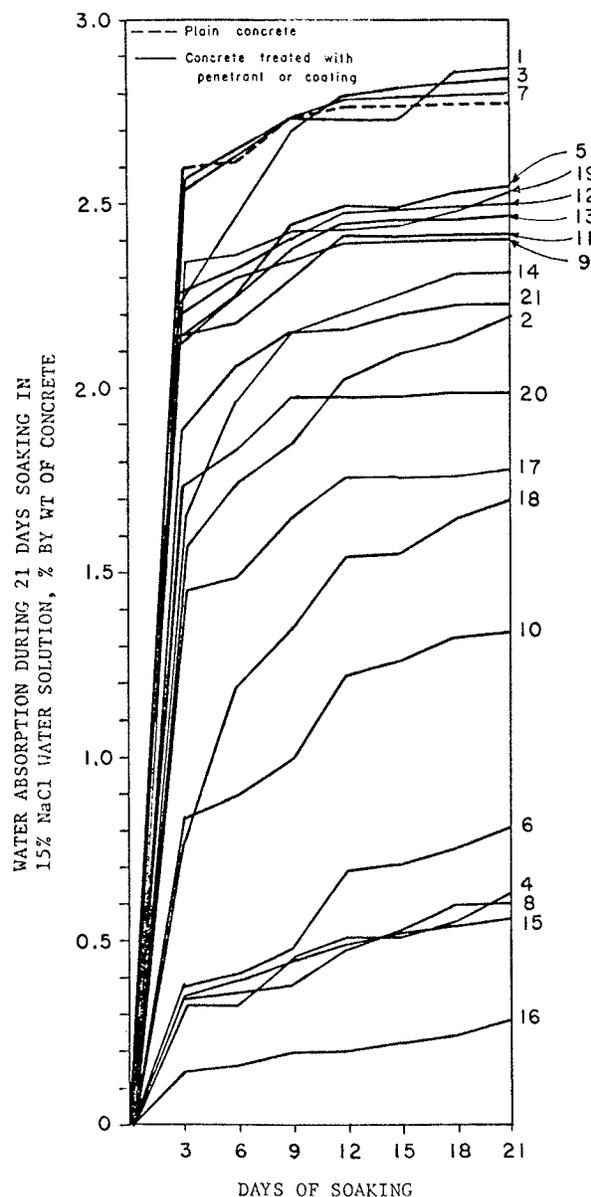


Figure 1. Water absorption characteristics of concrete coated with 21 different sealers.

appearing surfaces after treatment. The water absorption values of the other three epoxies and the two epoxies incorporating polysulfide were very high. The water absorption values were found to relate to the actual coverage rate in pounds of epoxy solids applied per sq ft of surface. The two epoxy formulations based on polysulfide polymers were much less effective, at equal coverage rates, than the straight epoxies.

The silane material exhibited a relatively low water absorption value of about 30 percent of that of uncoated concrete. When applied on linseed oil pretreated concrete, however, the water absorption value increased to 47 percent of that of uncoated concrete. The silane material was the only one of the 21 materials that exhibited higher water absorption values when applied over concrete pretreated with linseed oil as compared to untreated concrete.

The aggregates used in Series I to make the concrete test specimens contained unanticipated and relatively high chloride contents. (This observation points out the importance of

highway departments checking the chloride contents of all aggregate sources to be used for concrete containing embedded steel.) All values for chloride ion contents reported herein have been corrected for this background amount.

The data in Figure 2 show that a good relationship exists between weight gain (saltwater absorption) and the chloride content in the surface-sealed hardened concrete after the saltwater soaking tests. The line labeled 9.2 percent Cl^- represents the locus of all points if water and chloride ion were absorbed at the same rate (a 15 percent NaCl solution contains 9.2 percent chloride ion). Theoretically, if a point falls above this line, the coating acted as a "chloride screen," allowing a larger proportion of water to pass than chloride ion. Conversely, a point falling below the line indicates that the coating was more permeable to chloride ion than to water.

Five materials had very low water absorption, good water vapor transmission, and low chloride ion intrusion characteristics, compared to uncoated plain concrete, as follows:

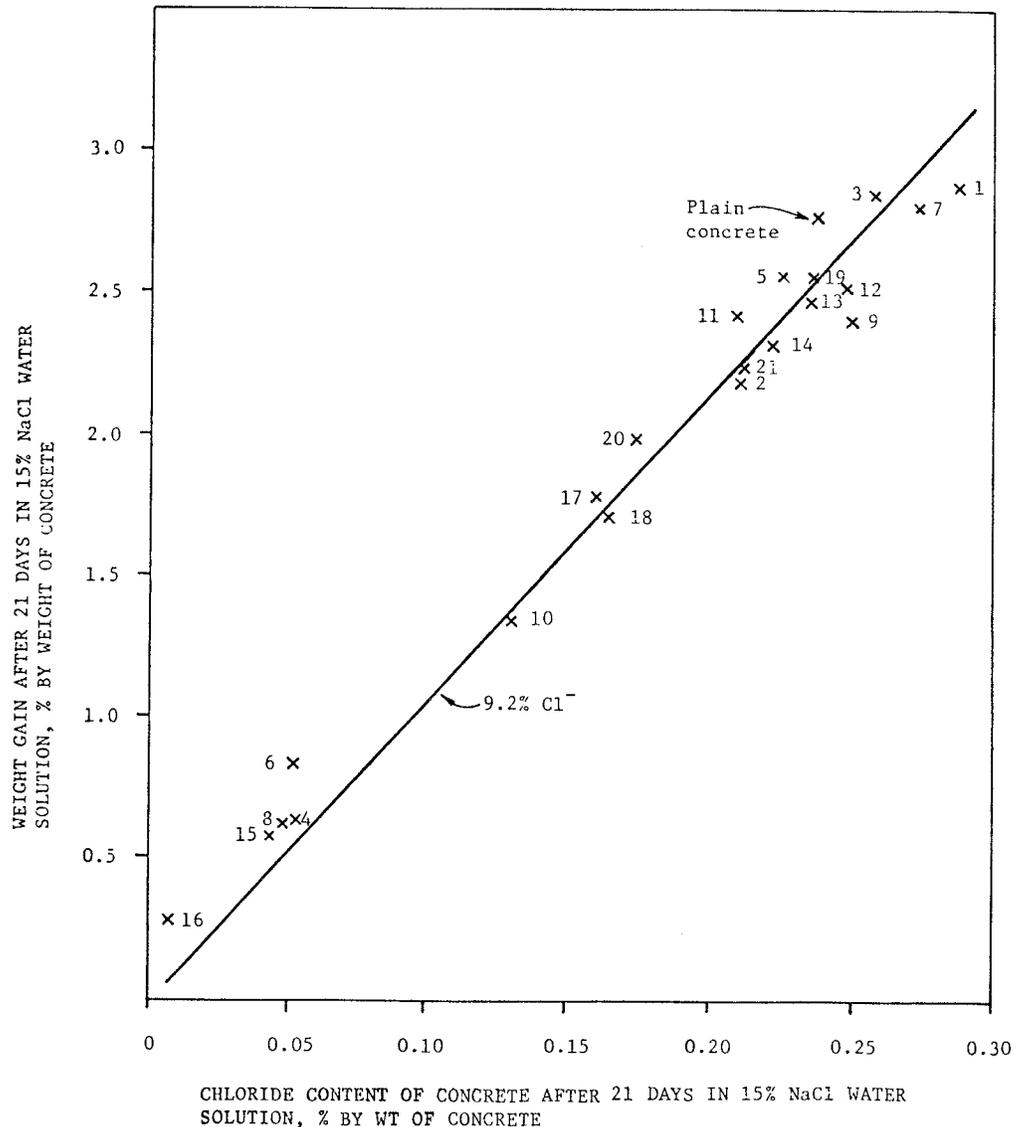


Figure 2. Relationship between water absorption and chloride content of concrete coated with 21 different sealers.

Material No.	Weight Gain % by wt.	Weight Loss	Chloride Ion Content % by wt.	Chemical Composition
		Weight Gain %		
16	0.29	100	0.008	Epoxy, 50% solids
15	0.57	60	0.044	Epoxy, 100% solids
8	0.61	120	0.047	Methyl methacrylate
4	0.63	107	0.048	Urethane, moisture-cured
6	0.83	100	0.050	Alkyl-alkoxy silane
Uncoated Concrete	2.77	66	0.236	

All five of these materials acted as chloride screens during the soaking period. One epoxy material, No. 16, reduced the chloride value to less than $\frac{1}{3}$ of the original saltwater solution strength.

The chloride content of concrete treated with linseed oil was only 11 percent less than that of uncoated concrete. The five materials previously discussed had chloride ion contents that were reduced by 79 to 97 percent when compared with uncoated concrete. These comparisons show that boiled linseed oil was much less effective compared to these five materials.

The materials based on chlorinated rubber, methyl silicate solution, siloxane, sodium silicate solution, styrene butadiene, several epoxies, vinyl toluene butadiene, a urethane, a methyl methacrylate, and a mixture of aluminum stearate and isobutylene were found to provide minimal or no protection against water absorption and chloride intrusion into concrete. It appears that many of these materials that exhibited poor performance did so because of the use of only a single coat of the material and or the use of insufficient coverage rates.

On the basis of the results of Series I, the following materials were recommended for laboratory tests in Series II, III, and IV.

Material No.	Chemical Composition
16-E	Epoxy
8-MM	Methyl methacrylate
4-U	Moisture-cured urethane
6-S	Alkyl-alkoxy silane
10-PM	Polyisobutyl methacrylate

The epoxy formulation No. 15 was not recommended, although it was consistently among the top five materials, because of its similarity in performance and composition with No. 16. Also, the use of the No. 6 silane in combination with linseed oil pretreatment was not recommended. Because of the greatly improved performance of the No. 10 polyisobutyl methacrylate material when applied over linseed oil, it was recommended that this material be substituted for the No. 6 silane material in those tests which were to include the linseed oil pretreatment. This set of recommendations was prepared with the intent of including in Series II, III, and IV laboratory tests the greatest number of generically different materials which performed best in the Series I tests.

SERIES II TESTS

The curing of the concrete in Series II (App. C) was more realistic as related to actual field curing of bridge surfaces. It consisted of 21 days inside plastic bags instead of the 6 days

of water soaking employed in Series I. The concrete was then allowed to air dry for 1, 5, and 21 days following the 21 days of initial curing. The coatings were then applied at these three different ages, which provided concretes with different moisture conditions that could occur in the field following the curing of fresh concrete or where rain must be anticipated. The remainder of the Series II tests was conducted in a similar manner to the Series I tests. The objective was to determine the influence of various lengths of air drying or concrete moisture contents prior to the time of application of the five selected materials on the subsequent saltwater absorption and chloride ion penetration characteristics of sealed concrete. Linseed oil pretreatment was not included.

The materials labeled 4-U, 6-S, 8-MM and 10-PM can be applied after 1, 5, or 21 days of air drying following moist curing without a significant decrease in water vapor transmission characteristics when compared to uncoated concrete; the 16-E material cannot.

The water absorption characteristics of concretes coated with materials 4-U, 6-S, and 8-MM are not significantly influenced by the number of days of air drying prior to coating. The 10-PM material was sensitive to coating age. The lowest water absorption was achieved when the 10-PM coating was applied after 1 day of air drying. The performance of the 16-E material was also influenced by the length of air drying time prior to coating. The lowest water absorption was achieved when the 16-E coating was applied after 1 or 5 days of air drying. The results for these latter two materials probably reflect the greater potential for absorption after longer drying periods.

These five materials provided water absorption characteristics that were moderately to significantly reduced when compared to uncoated concrete, as follows, when the best air drying time or times prior to coating are selected:

Material No.	Reduction of Water Absorption into Concrete, %
16-E	91
8-MM	82
4-U	75
6-S	74
10-PM	58

The chloride content data show a good relationship to weight gain during the saltwater soaking. The 6-S, 8-MM, and 16-E materials exhibit very low chloride contents, generally less than 0.03 percent by weight of concrete after this test. The cubes coated with the 4-U and 10-PM materials have higher chloride contents, generally ranging from 0.06 to 0.17 percent by weight of concrete.

These five materials significantly reduced chloride intrusion when compared to uncoated concrete, as follows, when the best air drying periods prior to coating are selected:

Material No.	Reduction in Chloride Content in Concrete, %
16-E	94
8-MM	91
4-U	88
6-S	87
10-PM	55

Materials 6-S and 8-MM appear to act as chloride screens since their absorbed chloride ion contents were less than the calculated 9.2 percent solution strength, irrespective of the number of days of air drying prior to coating.

The overall performance of these five coating materials can be rated, as follows, when using water absorption and chloride intrusion characteristics for the best air drying period for each material as the comparison basis:

Overall Performance Position No.	Material No.	No. of Days of Drying Prior to Coating for Best Performance
1	16-E	1 to 5
2	8-MM	1 to 5
3	6-S	5 to 21
4	4-U	21
5	10-PM	1

SERIES III TESTS

The Series III tests (App. D) were designed to use three different coverage rates of the five selected materials. The objective was to determine the influence of various application rates of these five materials on saltwater absorption, water vapor transmission, and chloride ion intrusion characteristics. Again, linseed oil pretreatment was not included, and the tests were conducted in a similar manner to Series I and II.

Materials 4-U, 6-S, 8-MM, and 10-PM did not significantly alter the water vapor transmission characteristics during the initial air drying period after the coating was applied. With these four materials applied at three different application rates, the weight loss changes due to vapor transmission ranged from 80 to 110 percent of the uncoated control cubes. The use of the 16-E material resulted in significant reductions in water vapor transmission capabilities.

The water absorption characteristics of concretes coated with materials 4-U, 6-S, and 16-E are not significantly influenced by the use of the different coverage rates used in this investigation. The 8-MM material showed low water absorption characteristics when used in the normal two-coat manner. When the 8-MM material was applied as a prime coat only or as a finish coat only, the weight gain was significantly increased when compared to when both the prime and finish coats were applied. The 10-PM material showed increase in water absorption as the coverage rate decreased.

These five materials provided water absorption characteristics that were significantly reduced when compared to uncoated control cubes, as follows, when using the maximum application of material, which always provided the best performance:

Material No.	Reduction of Water Absorption into Concrete, %
16-E	91
8-MM	83
6-S	79
4-U	75
10-PM	75

The chloride content data show a good relationship to weight gain during the saltwater soaking. The 6-S, 8-MM (normal two-coat coverage), and 16-E materials exhibited very low chloride contents, generally lower than 0.025 percent by weight of concrete. These three materials show the lowest chloride contents when the maximum amount of the materials was used. The 4-U and 10-PM materials have higher chloride contents, generally ranging from 0.05 to 0.11 percent by weight of concrete. The 4-U material was insensitive to coverage rate variation as regards chloride intrusion, whereas the chloride content of 10-PM was directly related to the amount of material applied.

Under the conditions of these tests, these five materials provide chloride intrusion characteristics that were significantly reduced when compared to uncoated concrete, as follows, when using the maximum application, which generally resulted in the lowest chloride contents:

Material No.	Reduction in Chloride Content in Concrete, %
16-E	92
8-MM	92
6-S	89
10-PM	77
4-U	70

Materials 6-S and 8-MM appear to act as chloride screens since their absorbed chloride ion contents were less than the calculated 9.2 percent solution strength, irrespective of application rate.

The overall performance of these five materials can be rated, as follows, when using water absorption and chloride intrusion characteristics for the best coverage rates as the basis for comparison:

Overall Performance Position No.	Material No.	Best Coverage Rates,* ft ² /gal
1	16-E	90/90 to 120/120
2	8-MM	100/200
3	6-S	50 to 100
4	10-PM	125/125
5	4-U	150/150 to 200/200

* 100/200 = 100 ft²/gal for first coat, 200 ft²/gal for second coat

SERIES IV TESTS

The cube specimens tested in Series I, II, and III were not exposed to different environmental conditions such as freezing, thawing, ultraviolet light radiation, acid, or repeated wetting and drying. They were only exposed to air and saltwater soaking at 70 F. The Series IV accelerated weathering tests (App. E) were undertaken to subject unreinforced concrete slabs and cracked reinforced concrete slabs to long-term weathering tests in the laboratory to simulate the environments found in southern and northern climates. Two accelerated weathering test methods were used. One test method emphasized alternate exposure of a coated slab surface at 70 F to a solution of 15 percent NaCl saltwater fol-

lowed by exposure to ultraviolet light and infrared heat at 100 F with the saltwater solution removed. This procedure simulated by accelerated test methods the alternate wet and dry environment found in southern climate coastal regions. The northern climate test method used an accelerated weathering cycle in which the coated slab surface was exposed to a wider range of environmental conditions which included acid, saltwater, infrared heat, ultraviolet light, fresh water rinse, freezing and thawing.

The objective was to determine the influence of 24 weeks of these accelerated weathering tests on the performance of these five coating materials. The performance was judged by making visual observations of the surface condition, by taking periodic copper-copper sulfate half cell corrosion potential readings on the cracked reinforced concrete slabs, and by measuring the chloride ion contents in the unreinforced concrete slabs at the end of the weathering tests. Linseed oil pretreatment was included, as outlined earlier.

Southern Climate Exposure

The chloride content of uncoated concrete was very high, at 0.547 percent by weight of concrete, at the end of the test. The use of materials 4-U, 6-S, 8-MM, 10-PM, and 16-E reduced this chloride content by 7, 97, 99, 6, and 93 percent, respectively. Thus, materials 6-S, 8-MM, and 16-E provided excellent barriers to the saltwater during this type of accelerated weathering test.

Although the 16-E and 4-U materials discolored to a brownish-yellow color, probably from the ultraviolet exposure, none of the test specimens coated with any of the five materials, or the uncoated concrete, exhibited any deterioration of the concrete surface.

The steel in the cracked, reinforced concrete slabs coated with 6-S and 8-MM exhibited average copper-copper sulfate half-cell readings less than -0.25 volts at the conclusion of the tests. These specimens also exhibited the least amount and severity of corrosion products on the embedded bars at the end of the testing. Similar concrete slabs coated with 4-U, 10-PM, and 16-E, and the uncoated control slabs, had bars that were severely corroded and that exhibited half-cell readings ranging from -0.45 to -0.55 volts during the final 12 weeks of testing.

Northern Climate Exposure

The chloride content of the uncoated concrete was relatively high, at 0.182 percent by weight of concrete at the end of this test. The use of coating materials 4-U, 6-S, 8-MM, 10-PM, and 16-E reduced this value by 43, 76, 87, 52, and 97 percent, respectively. Thus, materials 8-MM and 16-E provided excellent barriers to the saltwater during this type of accelerated weathering test.

All specimens, except those slabs coated with material 16-E, exhibited some degree of surface deterioration of the concrete. On the basis of previous tests on similar concrete with the same aggregates, water/cement ratio, and air contents, it is believed that the primary surface deterioration was caused by the acid exposure. None of the coating materials except No. 4-U exhibited any discoloration.

The only steel bars exhibiting severe corrosion were those from the uncoated, cracked, reinforced concrete slabs. The

cracked, reinforced concrete slabs coated with 4-U, 6-S, and 8-MM exhibited average copper-copper sulfate half-cell readings less than -0.30 volts at the conclusion of the tests. These same specimens also exhibited the least amount and severity of corrosion products on the bars. Similar slabs coated with 16-E had half-cell voltage readings somewhat higher than these specimens, whereas those coated with 10-PM had readings similar to the control, near -0.5 volt.

General Conclusions and Observations

The chloride contents of slabs from the southern and northern climate tests were compared with the chloride contents of cubes as tested in Series II. Both Series II and Series IV used the same coverage rates, curing procedures, and air drying period after curing and prior to coating. This comparison of chloride contents provides a reasonable correlation between these two test methods for the northern climate exposure. The correlation for the southern climate exposure was not reasonable because two materials (4-U and 10-PM) exhibited deterioration of the coating material. This lack of correlation appears to relate to the significantly greater amount of ultraviolet radiation compared to the northern climate tests. However, materials 6-S, 8-MM, and 16-E exhibited reasonable correlations between these test methods (slabs versus cubes), irrespective of the weathering test method. These same three materials also provided very good to excellent overall performance.

The control specimens coated only with boiled linseed oil and those pretreated with boiled linseed oil prior to coating with materials 10-PM and 16-E exhibited extremely low chloride contents at the end of the testing, irrespective of the exposure. This excellent performance of the linseed oil-treated concrete is in sharp contrast to the relatively poor performance of linseed oil during the Series I tests. It appears that this excellent performance in Series IV relates to the exposure of fresh linseed oil to about 5,000 watt-hours/sq meter of ultraviolet radiation immediately after the application of the two-coat linseed oil treatment. The normally coated cubes in Series I were not subjected to any ultraviolet radiation. It appears that this ultraviolet light exposure produced a durable and impervious coating when eventually subjected to the southern and northern climate tests which included extensive saltwater ponding tests and additional exposure to ultraviolet radiation.

There was significant variation in the copper-copper sulfate half-cell voltages within a given slab, which contained four bars, and also between duplicate slabs. Such variations were probably caused by variations in crack width, coating performance, pinholes in the coating, locations of anodes and cathodes relative to the half cell, and deterioration of the concrete surface. However, there was a reasonable correlation between the average measured half-cell voltage obtained from the eight bars in a duplicate pair of slabs and the amount of corrosion products found on the embedded bars at the conclusion of the tests. The corrosion activity was always more advanced on the tops of the embedded bars (which were closest to the ponded test surface), indicating that the top surfaces contained most of the anodic areas. The southern climate exposure testing was more severe than the northern climate testing in terms of chloride intrusion into the concrete and degree of corrosion on the steel bars.

INTERPRETATION, APPRAISAL, AND APPLICATIONS

INTERPRETATION

The results of this project show that a wide range of generic types of chemicals are being marketed and used to seal concrete bridge surfaces. However, the performance of these numerous types of chemical materials in minimizing the intrusion of salt waters into concrete is highly variable. Many of the chemical materials evaluated in Series I were found to be ineffective in reducing the water absorption and chloride intrusion characteristics of coated concrete specimens subjected to simple saltwater soaking tests. One of those materials showing relatively poor performance in Series I was boiled linseed oil. This observed variability in performance of different materials agrees with similar observations made by other investigators. This performance variation also exhibited itself in Series I within a given generic type of chemical, such as within the epoxies, the polyurethanes, etc.

Although significant variations in performance exist, there are certain specific formulations of different materials that exhibited very good to excellent performance in all four laboratory test series in this project. Three specific materials exhibited the following reductions in chloride intrusion and water absorption at the conclusion of these different series of tests:

Material No.	Reduction of Chloride Content in concrete, %				
	Series I	Series II	Series III	Series IV Northern	Series IV Southern
16-E	97	94	92	97	93
8-MM	80	91	92	87	99
6-S	79	87	89	76	97

Material No.	Reduction of Saltwater Absorption into Concrete, %		
	Series I	Series II	Series III
16-E	90	91	91
8-MM	78	82	83
6-S	70	74	79

These three different materials, an epoxy (16-E), a methyl methacrylate (8-MM), and a silane (6-S) provided good to excellent performance through all the tests. Other materials, such as a polyurethane (4-U) and the polyisobutyl methacrylate (10-PM), which were also tested in all four laboratory series, did not provide the same consistent good performance. These two specific materials provided good performance in the simple saltwater soaking tests in Series I, II, and III, but their performance was extremely poor in the

Series IV southern climate weathering tests that utilized significant ultraviolet exposure and alternate wetting and drying. This poor performance shows that simple saltwater soaking tests cannot be used as the sole acceptance test method.

Two of the materials, 8-MM and 16-E, that exhibited good to excellent performance required two coats, whereas the No. 6 silane required only one coat.

The materials 8-MM and 16-E exhibit good performance behavior when applied to concrete that has been allowed to air dry for 1 to 5 days after initial curing. The 6-S material exhibits good and consistent performance when applied to concrete that has been allowed to air dry for 1, 5, or 21 days. These data suggest that a 5-day air drying period prior to coating is reasonable for all three of these materials.

The 6-S and 8-MM materials apparently act as chloride screening materials since the water absorbed through these materials contained less than the 9.2 percent chloride solution strength of the original saltwater solution.

The 6-S and 8-MM materials also provided added protection for the embedded bars in the cracked reinforced concrete slabs, in both the northern and southern climate test exposures. This suggests that these two materials penetrate into existing cracks and could provide added protection against corrosion for bridge surfaces containing cracks of the width (0.010 in.) investigated in this project.

The 16-E epoxy material exhibited low water vapor transmission characteristics. Therefore, fresh concrete should be allowed a reasonable air drying period so that adequate internal water can evaporate prior to the application of this material. Once the concrete has been sealed, the 16-E material allows sufficient water vapor transmission to allow subsequently absorbed water to evaporate by vapor transmission during a reasonable drying period.

These tests have shown that many different chemical sealers can be applied effectively over linseed oil treated surfaces, as described in Appendix B, with significant improvement in their ability to minimize chloride intrusion and water absorption. Such surfaces appear much more glassy than when the same sealers are applied over normal concrete. This difference in appearance is attributed to the retention of more chemical solids on the surface because the surface had already been partially saturated with linseed oil. Also, the linseed oil may reduce the tendency towards pinhole formation due to the collapse of air bubbles beneath the coating.

The only material whose performance was not improved by the linseed oil pretreatment was the No. 6 silane. This appears to be consistent with the manufacturer's claim as to the mechanism of the protection it imparts to concrete. The linseed oil would be expected to coat some of the surfaces to which the silane would normally adhere, thereby interfering

with the establishment of an unbroken water-repellent surface.

Because this project was not concerned with the wearing surface of bridge decks, the frictional characteristic of these coatings when applied on concrete was not a factor. The 16-E epoxy material produces a glassy-appearing coating which would be dangerous to use on a driving or walking surface, but the material provides excellent performance as measured in this project. The No. 6 silane material, on the other hand, is a true penetrant which produces no color change and appears not to impart a smooth surface texture as do many of the other materials tested in this project. Thus, if surface friction were of concern, numerous materials would have been eliminated from consideration. Numerous materials would probably be slippery when applied over surfaces previously treated with linseed oil.

A factor which appears to be misleading about these materials is that the use of the word "penetrating sealer" is a misnomer for almost all the materials tested. The No. 6 silane material exhibits a measurable penetration effect. This silane material produces a non-wettable concrete surface to a depth of about 0.10 in. The other materials tested in this project, including boiled linseed oil, generally do not produce a measurable penetration or a measurable thickness of non-wettable concrete. Most of these other materials are coatings and should not be referred to in specifications as "penetrating sealers."

The specification writer should also be aware that most of the good to excellent performing sealer materials impart a moderate to significant color change to the concrete. The only effective material that did not cause a darkening of the concrete was the No. 6 silane material.

ECONOMICS

The total cost for using these materials generally includes material costs, the application costs which would involve labor, scaffolding, etc., and the surface preparation costs. The three materials that exhibited good to excellent performance in the Series IV weathering tests have material costs, for the coverage rates used, that range from \$0.16 to \$0.47 per sq ft. The material costs are lowest for the 8-MM material, intermediate for the 16-E material, and highest for the No. 6-S material. The material costs for 6-S, 8-MM, and 16-E are significantly more than the \$0.03 to \$0.04 per sq ft material costs for the two-coat, boiled, linseed oil treatment used in this project.

All three materials can be sprayed, roller-applied or brush-applied. The application costs on horizontal bridge deck or parking deck surfaces typically range from \$0.03 to \$0.10 per sq ft. Application costs on vertical or elevated bridge member surfaces would depend on numerous factors which would undoubtedly increase the cost beyond that for application on horizontal deck surfaces.

Surface preparation costs must also be considered. All of the cube and slab specimens tested in this project received a very light sandblasting to remove the portland cement surface laitance prior to coating. This same type of light sandblasting surface preparation to remove surface contaminants and to provide for a better bond or penetration is generally recommended by most manufacturers of chemical sealers for

concrete. This cost item also will depend on the bridge surface position and geometry.

Although the No. 6 silane has the highest materials cost of the three materials, it is also the only one of the three that is applied as a single coat. This factor would probably help reduce the overall cost when compared with materials that require two coats.

SAFETY

Most of the materials tested in this project are solvent-based chemicals that require safety precautions. Such precautions, if provided, are listed in the Series I technical data in Appendix B. The users of these chemicals must be aware of these precautions and should follow the manufacturer's safety instructions on how to use the materials.

The manufacturers of 6-S, 8-MM, and 16-E believe that their materials are no more flammable or dangerous than the newer type of solvent-based epoxy or polyurethane paints that have been developed in the last 10 years and that apparently are used on steel bridge structures.

SUGGESTED TESTING METHODS

Basically three different test methods were used during this project. The simple saltwater soaking tests in Series I, II, and III on 4-in. cubes required about 13 weeks to complete. However, the cubes did not receive any exposure to ultraviolet light, temperature changes, acid, freezing, or repeated wetting and drying. The 24-week, Series IV, northern climate exposure testing on slabs included the foregoing environmental exposures. The chloride content test results from the Series IV northern climate tests correlated fairly well with the simple saltwater testing of cubes from Series II. In fact, the uncoated slab specimens from Series IV contained 85 percent of the chloride that was found in the uncoated cubes from Series II.

These observations were not true for the Series IV southern climate test results. The chloride content in the uncoated slab specimens in the Series IV southern climate tests was 250 percent of that in the uncoated cubes from the Series II saltwater soaking tests. In addition, two of the five coating materials in the Series IV southern climate tests exhibited extremely poor durability and resistance to chloride intrusion even though they had exhibited good performance in Series I, II, and III.

The above observations suggest that two different test procedures could be used by chemical manufacturers, highway departments, and testing laboratories. The first procedure would be a preliminary screening test that would easily and economically eliminate materials that should not be considered for the final accelerated weathering acceptance testing. These two test procedures are as follows:

1. Preliminary screening tests could be made on 4-in. cubes using the simple saltwater soaking procedure as given in Series II, incorporating 5 days of air drying prior to coating. The upper limits on average weight gain and chloride content at the completion of this test should be limited to 25 percent of the weight gain of uncoated control cubes and 25 percent of the net chloride content of uncoated control

cubes. Materials exceeding either of these limits should not be tested further. The net chloride limit does not include any chloride that existed in the aggregates and water used to make the concrete. Chloride-free aggregates should be used, if possible, during these tests. The coating material should be applied by brush so that accurate coverage rates can be maintained.

2. Following the above screening tests, additional tests should be made with the acceptable coating materials on unreinforced concrete slab specimens that are subjected to the 24-week, Series IV, southern climate testing procedure.

It appears that the length of testing is sufficient to cause deterioration in materials susceptible to attack by ultraviolet rays. The upper limit on average chloride content at the end of this testing should be limited to 10 percent of the net chloride content of companion-tested, uncoated control slabs.

Since the chemical composition of these coating materials can be altered, the infrared spectra for the materials used in the Series IV accelerated weathering tests are given in Appendix F for identification purposes.

CHAPTER FOUR

CONCLUSIONS AND SUGGESTED RESEARCH

CONCLUSIONS

Certain specific surface-applied chemical materials, labeled Nos. 6, 8, and 16 in Appendixes B, C, D, and E, can provide excellent added protection to concrete bridge surfaces to minimize the intrusion of salt-laden water into the concrete. These specific materials are commercially available and could be used immediately on bridge surfaces to minimize the long-term corrosion potential of the structure. Prior to specifying a particular sealer material, any agency contemplating the use of a material or materials should initiate a test program to evaluate the materials as outlined in Chapter Three. This testing will allow the specific evaluation of the performance of the coating material when applied on concrete typical of the region.

These sealer materials are generally surface coatings (except for the No. 6 silane). They do not achieve any significant measurable penetration of the concrete surface. As such, their life expectancy is difficult to estimate based on this project, and they should probably be viewed as maintenance items.

Maintenance departments should realize that proper surface preparation of the concrete, generally recommended to be by light sandblasting, is essential to achieve a good penetration or bond between the concrete and the applied sealers. They must also be aware that a drying period of about 5 days generally seems appropriate after initial curing of new concrete, or after rain on old concrete, prior to applying these chemicals.

Some chemical sealers exhibit performance that is affected by application rate, whereas other materials provide good performance irrespective of variation in application rate, within the ranges studied. Materials whose performance is relatively insensitive to actual application rate are desirable because application in the field will result in a certain variability in coverage. Such insensitive materials should be used, and good performance in the field should be achieved.

Some of these materials appeared to have the ability to

penetrate into cracks in concrete surfaces and provide added protection to embedded steel against corrosion. This observation would suggest that multiple coats of these materials could be applied immediately over a crack, achieving even better protection of the embedded bars than was observed in this project.

Aggregates to be used by highway agencies in concrete containing embedded reinforcing should be analyzed for chloride content because the aggregate sources may be highly contaminated.

Although certain sealer materials can significantly reduce the intrusion of chloride into concrete, the use of properly consolidated and cured low water/cement ratio concrete, and deep cover over the embedded reinforcing steel, is still needed for long-term protection in severe environments.

SUGGESTED RESEARCH

The outstanding performance of ultraviolet light-cured linseed oil treated concrete needs to be examined further. Tests need to be undertaken to determine whether the data presented in this investigation are reproducible. If they are, additional research needs to be undertaken to determine whether a practical technique for applying linseed oil and rapidly curing it with artificial ultraviolet light can be developed to achieve the impervious coating that apparently was achieved in this project during the Series IV tests.

Because cracks in reinforced concrete are a prime source of accelerated corrosion, tests should be continued on cracked reinforced concrete specimens having different crack widths and clear cover. These tests should include the use of different chemical sealers to determine which materials can provide added protection for the embedded bars at these different crack configurations.

Tests should be undertaken using the Series IV northern climate exposure cycle without the acid exposure, or with reduced acid amount or strength. The acid exposure used in

Series IV created slight to severe etching of the portland cement concrete. This caused the removal of as much as 1/16 to 1/8 in. of surface which created long-term performance problems for certain materials, particularly the penetrating No. 6 silane material.

Chemical companies should continue their development of

potentially more economical sealers which can be evaluated by test methods proposed in this report. These chemical companies should also evaluate the use of light colored, pigmented coatings so that color darkening problems associated with the use of sealers may be eliminated.

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APPENDIX A

RESULTS OF THE LITERATURE SEARCH

Type of Penetrant or Coating Materials Recommended for Concrete

A literature search was completed in the libraries of Wiss, Janney, Elstner and Associates, Inc., the Portland Cement Association, the John Crerar library at the Illinois Institute of Technology and the U. S. Gypsum Company. The Highway Research Information Service File Search titled "Sealants and Penetrants for Concrete Surfaces", which was prepared for the Florida Department of Transportation in 1979, was also reviewed. Also reviewed were materials received from the 41 state highway departments that answered the survey letter and the 57 suppliers of coatings that answered the survey letter.

During the last 20 years, numerous penetrant and coating materials have been investigated, including several types of oil and rubber, a wide variety of resins, petroleum products, silicones and other inorganic or organic materials. Some of these products were ineffective, while others appeared to be effective but expensive.

Table A-1 presents data from Maslov (1) on the most widely used generic types of paints and coatings and describes the basic resin composition of each type, the outstanding properties, and the coverage rate.

Many studies present materials concerning protective penetrants or coatings to prevent deterioration of concrete. Several handbooks and application manuals were also published (2-7).

TABLE A-1 - GENERIC TYPES OF PAINTS SUITABLE FOR CONCRETE FROM MASLOV (1)

<u>Generic Type</u>	<u>Resin Composition</u>	<u>Outstanding Properties</u>	<u>Coverage Rate sq ft/gal</u>
Phenolic Varnish	Substituted phenol, formaldehyde, drying oil, coreacted	Moisture resistance, Weatherability	250-350
Chlorinated Rubber	Chlorinated natural rubber	Adhesion, Alkali and Water resistance	300-350
Vinyls	Polyvinyl Chloride, Polyvinyl acetate copolymerized	Durability, Chemicals and Water resistance	200-250
Bituminous (Cold Applied)	Coal - Tar or Asphalt Pitch	Asphalt-Heavy Duty Atmosphere Coal Tar-Water Immersion	60-70
Catalyzed Epoxy	Epichlorohydrin "Bisphenol A" Copolymerized	Adhesion, Chemical, Acid, Alkali resistance	200-250
Catalyzed Phenolic	Substituted Phenol, Formaldehyde Copolymerized	Abrasion resistance, Chemical, Acid, Hot Water resistance	100-150
Bitumen Epoxy	Asphalt or Coal Tar Pitch, Epoxy Resin	Heavy Duty Atmosphere and Water Immersion	100-150
Hypalon	Chlorosulfonated polyethylene	Flexibility; Weatherability, Hot Water resistance	50-100
Polyester	Organic Acid, Polyalcohol, Styrene, Copolymerized	Acid and Solvent resistance	150-300
Water Base	Styrene-butadiene, PVA, or Polyacrylic in Water	Good hiding, no odor; Nonflammable	250-350
Fire Retardant	Nonflammable Resin	Nonflammable; Foam with Heat	200-250

Linseed Oil. Review of the available literature indicates that linseed oil is one of the most widely used materials. Solutions or emulsions of linseed oil have been reported to provide good protection against salt scaling. A number of state highway departments specify the application of linseed oil solutions or emulsions on bridge decks and structures. In spite of the development of newer synthetic materials, linseed oil is still considered an effective and economical treatment.

Linseed oil is now supplied and widely used as a solution of 50 percent boiled linseed oil and 50 percent mineral spirits or kerosene. To accelerate the drying of the oil, the solution often contains driers such as cobalt, manganese, lead salts or naphthenic acids.

Many studies (8-35) included the evaluation of the effectiveness of linseed oil in preventing deterioration of concrete road pavements and bridge decks.

Opinions of the investigators differ concerning the value of the linseed oil treatment. The difference in the results of linseed oil treatment may be due to the following:

1. Various Types of Linseed Oil Preparations

- raw, boiled, oxidized, modified, etc.

2. Various Types of Solvent

- mineral spirits, kerosene

3. Factors Which Affect Depth of Penetration

- quality of the concrete, concrete moisture condition, percent mineral spirits in the mixture (9)

4. Application Conditions

- temperature, weather, coverage rate, recoat time, and number of coats

Linseed oil is a glyceride of organic acids and, more specifically, is a mixture of the triglycerides of oleic, linolic and linoleic acids. Linseed oil made with driers, commonly called boiled linseed oil, is preferred as a concrete treatment because of its tendency to undergo oxidative polymerization which forms a polymeric film on the concrete surface more readily than raw linseed oil. Investigation of different types of oils indicated that boiled linseed oil is more effective than other preparations (34).

Mineral spirits are usually used as a solvent to reduce the viscosity, thereby increasing depth of penetration of boiled linseed oil (9, 12). According to one study, a mixture of boiled linseed oil and kerosene resulted in excellent protection of non-air-entrained concrete (34). Depth of penetration of these mixtures may range from 1/16 in. to 1/4 in. (10, 19, 21, 25, 28, 29). The deepest penetration reported was made by a mixture of linseed oil and kerosene (19). Surface treatment with such mixtures had little or no effect in reducing spalling associated with corrosion of reinforcement steel (8, 12).

Linseed oil should not be applied on new concrete before the end of a minimum of 28 days of curing or to wet concrete, for optimum results. It should be applied to the concrete before exposure to deicing salts. Ambient temperature at application should not be below 40 degrees F (1) and the temperature of the concrete surface should be above 50 degrees F (29).

Two coats are usually recommended, and adequate drying time should be permitted between coats. The second coat is applied after the first coat is absorbed and the surface is dry. The application rate depends on the porosity of the concrete surface. Over-application creates a slippery surface (24, 30).

It has been shown that linseed oil treatment is effective against scaling for only a few years (1, 15) and is ineffective in resisting moisture penetration into concrete (16, 19).

Linseed oil provides a very soft film which is highly vulnerable to attack by the lime contained in concrete (1). This reaction produces a saponification of the linseed oil. This saponified film ultimately loses adhesion and ceases to protect the concrete.

A time-to-corrosion study (36) and a study on a bridge deck in Vermont (16) have shown that linseed oil treatment significantly reduced chloride penetration but did not prevent it. One of the first extensive laboratory and field studies concluded that there was no significant difference between the durability of non-air-entrained concrete panels treated with linseed oil and panels of properly air-entrained concrete (31). However, Newlon (26) reported that when insufficient entrained air is obtained in concrete, the linseed oil treatments delayed the onset of scaling but did not prevent it.

Epoxy. Epoxies appear to be the second most commonly used material. They have been commercially available for concrete applications for approximately 25 years. They have been tested or routinely used as penetrating sealants and as coating materials (20, 34, 37-47).

Catalyzed epoxy systems consist of two components, resin and hardener, which must be mixed together in accordance with the manufacturer's instructions before application. The two materials must be thoroughly mixed to provide a reactive site on one species for each reactive site on the other, the exact ratio being somewhat critical in terms of ultimate properties. A 1:1 mixing ratio by volume is usually used.

Because of the variety of basic epoxy resins available and the large numbers of suitable co-reactants, epoxy formulations are extremely versatile.

The two components react chemically to produce protective films of high chemical, solvent, moisture, and heat resistances. These systems produce high film thickness, thicknesses in excess of 3 mils per coat being entirely practical. They adhere to concrete better than any of the other coating systems reported by Maslov (1). The epoxy resins are characterized by having an average of two reactive epoxy groups per molecule. The reactivity of the epoxy groups will depend on their locations within the molecule and the nature of adjacent substituents.

Generally, the diglycidyl ether of bisphenol A is synthesized by the reaction of epichlorohydrin (epi) and bisphenol A (bis) in a caustic liquid (48).

Molecular weight of the newly formed epoxy resin will depend upon the ratio of epichlorohydrin to bisphenol A employed. The greater the excess epichlorohydrin, the lower the molecular weight of the resulting resin. The epichlorohydrin-bisphenol resins account for the majority of the epoxy resins of commercial use. They are the residue of a phenol of an aromatic amine or of a short-chain alcohol.

Depending on the specific selection of ingredients, the material may be cured at any convenient temperature from 40 degrees F upward. The finished product may range from soft and flexible to hard and rigid.

With coating materials the solids content is generally in the range of 17 to 100 percent. Two coats are usually recommended to reduce pinholing. The concrete surface must be dry and well prepared by sandblasting or acid etching before applying the first coat. The second coat should follow the first as soon as practicable to allow polymerization to occur between coats.

If this is impossible, then the first coat should be roughened before application of the second for proper bonding.

Experiences with epoxy penetrants and coatings are varied. Since epoxies are thermosetting materials, no self-healing is possible at a later date if the initial bond is unsatisfactory. A number of successful installations have been reported (37, 44). On the other hand, it has been shown that epoxy overlays on bridge decks after six years exposure were in no better condition than untreated surfaces (41), or the protection did not last more than two to three years (20). While a two component, 100 percent solids epoxy coating has been in use by the Department of Transportation of New York for over 12 years with no known failures of the coating itself or the concrete substrate, experiences with epoxy resin seal coats in Kansas over a number of years were unsatisfactory (38, 43). Laboratory studies have shown that thin epoxy seal coats were not impermeable (19). An interim report on NEEP Project 12 (48) concluded that epoxy sealants have not been satisfactory and recommended against their continued use in experimental projects. In another report (50), epoxy installations were evaluated as failures and were not recommended.

The coefficient of thermal expansion of epoxies seems to be a significant factor since it is much higher than that of concrete (51). This differential thermal expansion potential suggests that cracking may occur, permitting the ingress of water into the underlying concrete and possibly leading to breakup of the epoxy itself (52). Stanley (45) notes that penetration of epoxies into the concrete deck is comparable to that of linseed oil, but that they are more expensive than linseed oil.

Other Materials. Many other varieties of synthetic resins have been evaluated, including acrylics, polyurethanes and hydrocarbon resins. The idea of filling the voids of a hardened concrete with a monomer and polymerizing in situ originated at the United States Bureau of Reclamation in 1965. Laboratory studies have shown that impregnating concrete with a polymer is effective in improving the strength (53) and durability of the concrete (54) and in retarding the penetration of salts into the concrete (55, 56). Several studies reported that coatings consisting mainly of the methylmethacrylate or a vinyl toluene form of acrylic resins provide good protection against concrete deterioration (45, 57, 58). Proper drying, impregnation, and polymerization procedures using methylmethacrylate will produce concrete with essentially zero permeability to water and will immobilize deleterious contaminants already contained in the concrete pore system (12).

Acrylic resins are used with different types of solvents, and two coats (primer and finish) are usually recommended. These materials are classified as coatings or penetrants. Review of the literature indicates that acrylic resin is one of the most effective sealant materials routinely being used or evaluated in eight different states.

Urethane coatings are a more recent development in the catalyzed systems. The following table of ASTM D-16 Classifications of Polyurethane Coatings (1) provides a detailed description of the characteristics of both one and two-component systems:

ASTM Classification of Polyurethane Coatings

Description	One-Package			Two-Package	
	ASTM-1 air cured	ASTM-2 moisture cured	ASTM-3 heat cured	ASTM-4 catalysed prepolymer	ASTM-5 polyol cured
Curing mechanism	uralkyd oxidation	moisture	unblocking with heat	catalysis	hydroxyl groups of polyol pigment in polyol
Pigmentation	conventional	difficult	conventional	difficult	
Air-dry or cure, hrs.	0.4-4	0.2-8*	depends on temperature	0.1-2	2-16
Sward hardness	20-40	20-60	40-85	25-70	30-60
Chemical resistance	poor to good	fair to very good	excellent	fair to very good	good to excellent
Weatherability	good to very good	poor to very good	excellent	poor to very good	good to outstanding
Overall rating	good	very good	excellent	excellent	excellent

Of the five ASTM types, the ones most commonly used as floor coatings and general chemical-resistant coatings are Type 1, Type 2 and Type 5. Type 2 is an oil-modified urethane similar to an epoxy ester or an alkyd. The solids content is in the range of 20 to 40 percent, the solvent being mineral spirits. These coatings exhibit excellent abrasion and chemical resistance with excellent durability, toughness and flexibility. This material is far superior to the epoxy ester system but is more expensive. Drying is rapid, and when more than one coat is applied, no more than four hours should elapse between applications. Type 2 cures by exposure to atmospheric moisture. This system offers most of the benefits of the two-part urethane system (1). Since moisture acts as a catalyst, the curing rate depends upon the amount of moisture or humidity present. These coatings offer outstanding abrasion resistance properties, even greater than two component epoxy systems. They are based on aromatic solvents, such as xylol or xylene. Two coats are usually recommended.

Experiences with urethane sealants vary widely. Generally, urethane materials have low penetration and adhesion and tend to peel (34). Some types

of urethane sealant are reported as having good crack resistance (34). One type of urethane was rated as a failure in test installations while another type was rated as fully successful (42). Polyurethane overlays on bridge decks did not last more than two to three years (20).

Several types of coatings based on polyurethanes were proposed in Japan because of their reportedly excellent resistance to water, weathering and cracking (59-60).

Latex coatings are dispersions or emulsions of pigmented and compounded organic film-forming materials in water. The film formers may be styrene butadiene, polyvinyl acetate, acrylic or blends of these with other polymers, dispersed as latices in water. This type of coating is sometimes identified as "rubber-base latex" (1). One coat is recommended.

Many studies evaluated the ability of latex to prevent scaling of concrete surfaces (19, 21, 25, 28, 29). These materials penetrated into the concrete but were found to be permeable and were quickly penetrated by a salt solution (34).

Chlorinated rubber has low corrosive resistance. A deck treated with chlorinated rubber was recognized as being 40 percent damaged, when a survey was made (38). A laboratory and field evaluation concluded that chlorinated rubber and latex imparted little or no additional durability or scaling resistance to concrete (33).

Two classes of silicone materials have been used as surface treatments for concrete (1). One class consists of waterproofers, impervious coatings which seal the surface so that neither liquid water nor water vapor will penetrate. The other class consists of water repellents, which prevent the penetration of liquid water but do not stop the movement of water vapor. This is the class which is of primary interest to the present study. Several forms

of silicones are used for water repellents. In the form of resins, silicones are commonly used in an organic solvent solution, but are sometimes supplied in the form of water solutions of sodium methyl silicate. The solutions contain 3 to 5 percent silicone resin in a solvent such as mineral spirits. One coat with an average coverage of 100 ft²/gallon is recommended. Several studies reported the influence of silicone treatments on concrete durability (20, 31, 62-67). It was shown (66) that although silicones reduce the initial rate of absorption of water, after continued immersion for periods ranging from 7 to 14 days, the total absorption for treated and untreated concretes was similar. Surface silicone treatments resulted in lower resistance to freezing and thawing in water and to deicer scaling. Other investigations (20) also indicated that silicone treatments did not improve long-term durability of non-air-entrained concrete. Ryell (31) has shown that silicones do not prevent the migration of chlorides through concrete and they are ineffective in improving concrete durability.

A number of inorganic coatings or treatments, which were expected to be more compatible with the concrete than organic coatings, were also investigated. They are generally based on silicate solutions. Tests evaluating the effect of sodium silicate solutions on the resistance of concrete to deicer scaling were not encouraging (34). Advantages of silicate solutions during application are that they are neither toxic, flammable nor hazardous under normal conditions.

About ten departments of transportation recently evaluated or now routinely use a silane product which is marketed as a waterproofing material with a 40 percent active ingredient alkyl-alkoxy-silane of a given composition. Unlike coatings, oils and other currently used sealants, the silane does not block the porosity of concrete. Instead, it reacts chemically with the

surface of the concrete to form a hydrophobic layer repellent to liquid water but permeable to water vapor. By chemical reaction, a water repellent hydrocarbon group is bonded to the substrate. The treated surface becomes water repellent through the elimination of water between the silanols in the organosilane and those in the concrete surface with a resultant bonding of the hydrocarbon group to the concrete.

Review of Test Methods

Several types of tests have been used to evaluate the effectiveness of sealants in protecting concrete surfaces against the penetration of moisture and chloride solution.

Since the properties of some sealant treatments depend on the depth of their penetration, investigators have tried to determine the relationship between this depth of penetration and spalling due to corrosion of rebars and to chloride or moisture penetration into the concrete (9, 12, 19, 69). It was reported that shallow penetration of linseed oil treatment had little or no effect in reducing corrosion-induced spalling (9, 12). Impregnation of a bridge deck to a depth of 1 in. with methyl-methacrylate was shown to be sufficient to prevent chloride penetration into the concrete (56).

In another study, fluorescent material was mixed with sealants before application and the depth of penetration measured by linear traverse equipment using ultraviolet light (69).

The penetration of moisture (19, 70) and chloride (71-76) has been tested by several different methods. Measurements of "half cell" or "standard reference electrode" potentials were found unsuitable as detectors of water penetration (70).

Corrosion activity of embedded steel can be nondestructively detected by electrical measurement (77-80). Half cell potential measurements have been successfully used to study the condition of steel in (77, 39) bridge deck concrete, and in laboratory investigations (12). Freeze-thaw and deicer scaling tests have been performed by many agencies (26, 33, 34, 62, 68, 69, 81-83). It is not possible to compare the results of the laboratory and field tests because the test conditions are so different. Even in standard laboratory tests, the number of freeze-thaw cycles varies from 50 to 300 and the total time for one cycle varies from 5 to 66 hours (34).

Other weathering tests (84-86) are also made under different laboratory or field conditions, making comparisons between them very difficult.

The bond between the concrete and sealant has also been studied (69). The tests evaluated either direct tensile or shear bond strengths.

The results of this portion of the literature search indicate that a standard test method to evaluate water absorption, water vapor transmission qualities and chloride ion intrusion characteristics of coated concrete specimens that must experience environmental factors such as saltwater, acids, heat, cold, freezing, thawing, ultraviolet radiation, etc., has not been developed.

APPENDIX B

SERIES I LABORATORY SCREENING TESTS

Selection of Candidate Materials

Prior to the laboratory screening tests, a survey of highway departments, chemical companies and paint manufacturers was made to identify candidate sealers or penetrants for laboratory testing and to collect appropriate test data generated in their laboratories or in the field by these various organizations on such candidate materials.

A letter was sent to two hundred and thirty-nine (239) different chemical and paint companies to request their assistance in identifying appropriate candidate sealers. A similar letter addressed to the materials engineers was sent to the 50 state highway departments. A total of 69 chemical companies responded. Of these, 12 were from companies which did not manufacture a material which they would consider as a potential candidate. The remaining 57 companies suggested 103 different candidate materials.

A total of 41 highway departments responded. Thirteen of these apparently do not use sealants for protection of bridge surfaces. The most commonly used materials from the other 28 states are 50-50 mixtures of boiled linseed oil and mineral spirits, and epoxies.

Members of the project team reviewed the submitted letters and test reports and then selected materials for the Series I screening tests. Twenty-one penetrants or coatings from 21 different companies were selected. The selection process was hindered by the lack of submitted technical information on the performance of the 103 suggested candidate materials. Only three chemical companies submitted data on water absorption and chloride ion

contents for concrete test specimens that were coated with their candidate materials and subjected to laboratory testing. Therefore, the selection was based primarily on known chemical composition coupled with either laboratory results or field trials from highway departments which indicated that the material showed promise in resisting the ingress of chloride-laden water.

The selected materials generally include all of the chemical types of coatings most widely used or tested. These are as follows:

- Boiled linseed oil with mineral spirits
- Five epoxies with different amounts of solids
- Two epoxies containing polysulfide
- Three materials based on methacrylate
- Silane
- Two types of urethane
- Two materials based on butadiene
- Chlorinated rubber
- Silicate
- Siliconate
- Siloxane
- Material based on isobutylene and aluminum stearate

Table B-1 identifies the materials and their assigned test number. Verification of the chemical composition of each material, as listed in Table B-1, was made by infrared spectroscopy, when possible.

A list of technical data, manufacturer's application data and the actual application data of each material is shown in Tables B-2 to B-22. Where two coats were required, coverage is given, for example, by 360/600 ft²/gallon. This indicates that the first coat was applied at 360, the second at

TABLE B-1 - MATERIALS SELECTED FOR SERIES I SCREENING TEST

Test No.	Chemical composition	Penetrant or coating	Notes	Test No.	Epoxies	Penetrant or coating	% of solius
1	Siloxane mixture	P		15	A = Epoxy resin B = Polyamine + Bisphenol A	P/C	100
2	Boiled linseed oil with mineral spirit	P	Uniformly blended mixture	16	A = Epoxy (Epichlorohydrin/Bisphenol A) B = Polyamine + Bisphenol A	P	50
3	Sodium methyl silicate	P	Water soluble	17	A = Epoxy (Epichlorohydrin/Bisphenol A) B = Polysulfide	P	25-30
4	Urethane (Isocyanate-polyether)	P	Moisture cured	18	A = Epoxy resin (Epichlorohydrin/Bisphenol A + amide) B = Polyamide + Bisphenol A	P	17
5	Chlorinated rubber	P	Solution in xylene	19	A = Epoxy resin (Epichlorohydrin/Bisphenol A) B = Polyamide	P	20-25
6	Alkyl-Alkoxy silane	P		20	A = Epoxy resin (Bisphenol A) B = Polysulfide	P	50
7	Styrene-butadiene	C		21	A = Epoxy resin (Epichlorohydrin / Bisphenol A) B = Polyamide + phenolic	P	30
8	Primer: Methyl siloxane Finish: Methyl methacrylate-ethylacrylate	C					
9	Sodium silicate	P					
10	Primer and finish—polyisobutyl methacrylate	P					
11	Vinyl toluene butadiene copolymer	C					
12	Isobutylene and aluminum stearate mixture	P					
13	Methyl methacrylate-ethylacrylate copolymer	P	Emulsion				
14	Aliphatic urethane	C	Chemically cured				

B-3

TABLE B-2 - TECHNICAL DATA AND APPLICATION DATA - MATERIAL NO. 1

TEST NO: 1		
CHEMICAL COMPOSITION:	Siloxane mixture	
Technical Data	Manufacturers Application Data	Actual Application Data
<p>Solids (Minimum % by Weight) 6.5 ± 0.5 Specific Gravity: 0.86 Viscosity: 1 cps pH: <7 Color: Slightly Cloudy Solution Boiling Point: 250°F Flash Point: 120°F</p> <p><u>Precautions</u> - Do not fog or mist. Penetrant is supplied in a hydrocarbon solvent which is combustible.</p>	<p>Weight (lb per gallon): 8 Number of Coats : 1 Primer Required : 0 Recoat Time (hrs) : 0 Coverage (ft²/gallon) : Up to 500 Drying Time To Touch : Not Given To Set : Not Given</p> <p><u>Limits of Application</u> - New concrete and masonry walls should be cured a minimum of 7 days. Freeze Temperature - 80°F</p> <p><u>Limitations</u> - It is not recommended for below grade waterproofing or for application on painted surfaces; is not intended to seal visible cracks and crevices or as a substitute for tuckpointing defective mortar joints. Do not apply heavily enough to cause excessive run down. Surface must be dry, free of chemical film, paint or oil.</p>	<p>Number of Coats: 1 Recoat Time: 0 Coverage -ft²/gallon: 500</p> <p><u>Notes:</u></p> <p><u>General Comments:</u> Concrete surface treated with penetrant; Uniform - color unchanged - dull. Concrete surface treated with linseed oil and penetrant; Uniform - slightly darker - dull.</p>

TABLE B-3 - TECHNICAL DATA AND APPLICATION DATA - MATERIAL NO. 2

TEST NO: 2		
CHEMICAL COMPOSITION:	A uniformly blended mixture of mineral spirits and boiled linseed oil (50/50) containing sufficient metallic driers for proper drying and penetration.	
Technical Data	Manufacturers Application Data	Actual Application Data
<p>Solids (Minimum % by Weight) 50</p> <p>Specific Gravity: 0.8569</p> <p>Viscosity: A-5 Gardner-Holdt</p> <p>pH: Not Given</p> <p>Color: Clear, Light Amber in Color</p> <p>Boiling Point: 318 - 338°F</p> <p>Flash Point: Open Cup - 109°F</p>	<p>Weight (lb per gallon): 7.125</p> <p>Number of Coats : 2</p> <p>Primer Required : 0</p> <p>Recoat Time (hrs) : 4 hrs</p> <p>Coverage (ft²/gallon) : 360/600</p> <p>Drying Time To Touch : 70°F > Few Hours</p> <p>To Set : Not Given</p> <p><u>Limits of Application</u> - It should only be applied to concrete which has cured for a minimum of 28 days; should not be used on concrete less than 28 days old where curing compounds are still present to inhibit penetration.</p> <p><u>Limitations</u> - Not recommended for densely troweled concrete as adequate penetration might not be obtained. Not recommended for use in poorly ventilated interior spaces due to hazard of solvent evaporation.</p>	<p>Number of Coats: 2</p> <p>Recoat Time: Overnight</p> <p>Coverage -ft²/gallon: 360/600</p> <p><u>Notes:</u></p> <p><u>General Comments</u> -</p> <p>Concrete surface treated with penetrant; Uniform - much darker - dull.</p> <p>Concrete surface treated with linseed oil and penetrant; Non-uniform - slightly and much darker - dull.</p>
<p><u>Precautions</u> - It is a combustible mixture and should not be used near open lights or flames. Do not heat.</p>		

TABLE B-4 - TECHNICAL DATA AND APPLICATION DATA - MATERIAL NO. 3

TEST NO: 3		
CHEMICAL COMPOSITION:	Water soluble sodium methylsiliconate solution	
Technical Data	Manufacturers Application Data	Actual Application Data
<p>Solids (Minimum % by Weight) 30</p> <p>Specific Gravity: 1.24</p> <p>Viscosity: Not Given</p> <p>pH: 12</p> <p>Color: Clear, Colorless</p> <p>Boiling Point: Not Given</p> <p>Flash Point: None</p>	<p>Weight (lb per gallon): 10</p> <p>Number of Coats : 1</p> <p>Primer Required : 0</p> <p>Recoat Time (hrs) : 0</p> <p>Coverage (ft²/gallon) : 80</p> <p>Drying Time To Touch : 24 hours</p> <p>To Set : Not Given</p> <p><u>Limits of Application</u> - Do not use concentration higher than 3 percent solids unless prior testing indicates a necessity.</p>	<p>Number of Coats: 1</p> <p>Recoat Time: 0</p> <p>Coverage -ft²/gallon: 80</p> <p><u>Notes:</u></p> <p>Diluted in water to a concentration of 3% before applied.</p> <p><u>General Comments</u> -</p> <p>Concrete surface treated with penetrant; Uniform - color unchanged - dull.</p> <p>Concrete surface treated with linseed oil and penetrant; Uniform - color unchanged - dull.</p>
<p><u>Precautions</u> - Do not allow to contact glass or aluminum. It is an alkaline material and should be handled with the same care as solutions of caustic soda. Nonflammable.</p>		

TABLE B-5 - TECHNICAL DATA AND APPLICATION DATA - MATERIAL NO. 4

TEST NO: 4		
CHEMICAL COMPOSITION:	A uniquely formulated moisture cured polyurethane resin. (Isocyanate-polyether)	
Technical Data	Manufacturers Application Data	Actual Application Data
<p>Solids (Minimum % by Weight) 60 Specific Gravity: 1.018 Viscosity: Zahn # 4 - 16 sec. pH: 4 - 7 Color: Clear, Dark Amber Boiling Point: 311°F Flash Point: Tap Closed Cup 108°F</p>	<p>Weight (lb per gallon): 8.5 Number of Coats : 2 Primer Required : 0 Recoat Time (hrs) : 2-4 hrs - Must be recoated within 24-36 hours Coverage (ft²/gallon) : 200/200-400 Drying Time To Touch : 1 hour To Set : Not Given</p> <p><u>Limits of Application</u> - Dilute with an equal volume of solvent such as Xylene (xylol) or Solvesso 100. May be applied all year around at temperatures as low as 18°F provided surface is free of frost and moisture.</p>	<p>Number of Coats: 2 Recoat Time: Overnight Coverage -ft²/gallon: 200/200</p> <p><u>Notes:</u> Diluted by xylol - 50%</p> <p><u>General Comments:</u> Concrete surface treated with penetrant: Non-Uniform - much darker - dull and glassy. Concrete surface treated with linseed oil and penetrant: Uniform - much darker - glassy.</p>
<p><u>Precautions</u> - Product Flammable.</p>	<p><u>Limitations</u> - Do not apply to wet or damp surfaces or under high humidity conditions, should not be used on exterior surfaces where ambering is undesirable.</p>	

TABLE B-6 - TECHNICAL DATA AND APPLICATION DATA - MATERIAL NO. 5

TEST NO: 5		
CHEMICAL COMPOSITION:	A chlorinated rubber solution in xylene	
Technical Data	Manufacturers Application Data	Actual Application Data
<p>Solids (Minimum % by Weight) 20</p> <p>Specific Gravity: 0.92</p> <p>Viscosity:</p> <p>pH: ~6.5</p> <p>Color: Clear, Yellow</p> <p>Boiling Point: Not Given</p> <p>Flash Point: Not Given</p>	<p>Weight (lb per gallon): 7.7</p> <p>Number of Coats : 1</p> <p>Primer Required : 0</p> <p>Recoat Time (hrs) : 0</p> <p>Coverage (ft²/gallon) : New Work: 200-350</p> <p>Drying Time To Touch : Old Work 400-600</p> <p>To Set : Not Given</p> <p><u>Limits of Application</u> - Can be applied to freshly placed concrete immediately after final troweling or as soon as concrete can be walked upon.</p>	<p>Number of Coats: 1</p> <p>Recoat Time: 0</p> <p>Coverage -ft²/gallon: 350</p> <p><u>Notes:</u></p> <p><u>General Comments:</u></p> <p>Concrete surface treated with penetrant: Uniform - color unchanged - dull.</p> <p>Concrete surface treated with linseed oil and penetrant: Uniform - slightly darker - shiny.</p>
<p><u>Precautions</u> - Product Flammable</p>	<p><u>Limitations</u> - DeKote may yellow with sunlight exposure and should not be used on white cement concrete, exposed aggregate, or wherever yellowing will be objectionable.</p>	

TABLE B-7 - TECHNICAL DATA AND APPLICATION DATA - MATERIAL NO. 6

TEST NO: 6		
CHEMICAL COMPOSITION:	Alkyl-Alkoxy Silane	
Technical Data	Manufacturers Application Data	Actual Application Data
<p>Solids (Minimum % by Weight) 40 Specific Gravity: 0.8 Viscosity: 0.98 mPA-s (68°F) pH: ~6.5 Color: Clear, Colorless Boiling Point: 174°F Flash Point: 54°F</p>	<p>Weight (lb per gallon): 6.7 Number of Coats : 1 Primer Required : 0 Recoat Time (hrs) : 0 Coverage (ft²/gallon) : 100-400 (Based on surface texture and absorption) Drying Time To Touch : Not Given To Set : Not Given</p> <p><u>Limits of Application</u> - For new and old concrete and masonry; should not be applied at temperatures below 32°F, or when the temperature is expected to fall below 32°F within 12 hours of application.</p>	<p>Number of Coats: 1 Recoat Time: 0 Coverage -ft²/gallon: 100</p> <p><u>Notes:</u></p> <p><u>General Comments:</u></p> <p>Concrete surface treated with penetrant; Uniform - color unchanged - dull.</p> <p>Concrete surface treated with linseed oil and penetrant; Uniform - color unchanged - dull.</p>
<p><u>Precautions</u> - Product flammable, contains ethyl alcohol; do not store or use near heat, sparks or an open flame; do not store in a glass container.</p>	<p><u>Limitations:</u> It is not intended for waterproofing under hydrostatic pressure but may be applied prior to applying asphalt or paint. Surfaces need not be completely dry before application; must be clean, and standing water be removed, but residual moisture does not affect the treatment.</p>	

TABLE B-9 - TECHNICAL DATA AND APPLICATION DATA - MATERIAL NO. 8

TEST NO: 8		
CHEMICAL COMPOSITION:	Primer: Methyl siloxane Finish: Methyl methacrylate-ethylacrylate	
Technical Data	Manufacturers Application Data	Actual Application Data
<p>Solids (Minimum X by Weight) Primer: 6 Finish: 20</p> <p>Specific Gravity: Not Given</p> <p>Viscosity: Primer: Ford B Cup 70-80 Sec. Finish: Ford B Cup 150-160 Sec.</p> <p>pH: Not Given</p> <p>Color: Clear, Colorless</p> <p>Boiling Point: Not Given</p> <p>Flash Point: Not Given</p>	<p>Weight (lb per gallon): 7.2/9.1</p> <p>Number of Coats : 1</p> <p>Primer Required : 1</p> <p>Recoat Time (hrs) : 2 hours @ 75°F</p> <p>Coverage (ft²/gallon) : 100/200</p> <p>Drying Time To Touch : Not Given To Set : Not Given</p> <p><u>Limits of Application</u> - Not Given</p>	<p>Number of Coats: 2</p> <p>Recoat Time: Overnight</p> <p>Coverage -ft²/gallon: 100/200</p> <p><u>Notes:</u></p> <p><u>General Comments</u> -</p> <p>Concrete surface treated with penetrant: Uniform - color unchanged - shiny.</p> <p>Concrete surface treated with linseed oil and penetrant: Uniform - slightly darker - shiny.</p>
<u>Precautions</u> - Not Given	<u>Limitations</u> - Surface must be dry, free of grease, oil and laitance.	

TABLE B-10 - TECHNICAL DATA AND APPLICATION DATA - MATERIAL NO. 9

TEST NO: 9		
CHEMICAL COMPOSITION:	Sodium silicate	
Technical Data	Manufacturers Application Data	Actual Application Data
<p>Solids (Minimum % by Weight) 31.4 Specific Gravity: 1.200 Viscosity: 100° CST pH: 2.16 11 Color: Clear, Colorless Boiling Point: 214°F Flash Point: None</p>	<p>Weight (lb per gallon): 10.5 Number of Coats : 1 or 2 Primer Required : 0 Recoat Time (hrs) : 0 Coverage (ft²/gallon) : 200-300 Drying Time To Touch : Not Given To Set : Not Given</p> <p><u>Limits of Application</u> - Dilution of any kind will negate results. Do not apply if temperature is below 40°F.</p>	<p>Number of Coats: 1 Recoat Time: 0 Coverage -ft²/gallon; 200</p> <p><u>Notes:</u> Was flushed with water twice, according to directions.-</p> <p><u>General Comments</u> -</p> <p>Concrete surface treated with penetrant; Uniform - color unchanged - dull. Concrete surface treated with linseed oil and penetrant; Non-uniform - slightly darker - dull.</p>
<p><u>Precautions</u> - Do not apply to glass, glazed tile. #7 is nontoxic, noncaustic and nonflammable.</p>	<p><u>Limitations</u> - Do not apply during rain or to wet surface. Concrete surface must be free of petroleum and dirt; remove rust stains prior to application. Remove all pooled or standing water.</p>	

TABLE B-12 - TECHNICAL DATA AND APPLICATION DATA - MATERIAL NO. 11

TEST NO: 11		
CHEMICAL COMPOSITION:	Vinyl toluene butadiene copolymer	
Technical Data	Manufacturers Application Data	Actual Application Data
<p>Solids (Minimum % by Weight) 64</p> <p>Specific Gravity: 0.975</p> <p>Viscosity: 93 Poises</p> <p>pH: Not Given</p> <p>Color: Milky-white/gray</p> <p>Boiling Point: Not Given</p> <p>Flash Point: 100°F</p>	<p>Weight (lb per gallon): 9.75</p> <p>Number of Coats : 1 to 3 (one for cast-in-place concrete)</p> <p>Primer Required : 0</p> <p>Recoat Time (hrs) : 0</p> <p>Coverage (ft²/gallon) : 30 - 50</p> <p>Drying Time To Touch : 20-30 Minutes</p> <p>To Set : 24 - 36 hours</p> <p><u>Limits of Application</u> - Coating may be applied at 35°F or above.</p>	<p>Number of Coats: 1</p> <p>Recoat Time: 0</p> <p>Coverage -ft²/gallon: 30</p> <p><u>Notes:</u></p> <p><u>General Comments</u> -</p> <p>Concrete surface treated with penetrant; Uniform - milky-white - dull. Heavy bodied coating.</p> <p>Concrete surface treated with linseed oil and penetrant; Uniform - milky-white - dull. Material did not fill pores and holes on the surface due to high viscosity.</p>
<p><u>Precautions</u> - Not Given</p>	<p><u>Limitations</u> - Not for use on roof or floor surface, over tar or asphalt coated areas; not recommended for application over conventional drywall systems. Not for use over moving cracks, hairline or larger. May be applied to a damp (not wet) surface.</p>	

TABLE B-13 - TECHNICAL DATA AND APPLICATION DATA - MATERIAL NO. 12

TEST NO: 12		
CHEMICAL COMPOSITION:	Aluminum stearate and isobutylene mixture	
Technical Data		Manufacturers Application Data
Solids (Minimum % by Weight)	9.97	Weight (lb per gallon): 6.77
Specific Gravity:	0.8144 @ 68°F	Number of Coats : 2
Viscosity:	ASTM D7824 (75°F) = 2.5 cps	Primer Required : 0
pH:	6.8	Recoat Time (hrs) : 12 hours
Color: Clear, Colorless		Coverage (ft ² /gallon) : 150-200/300-400
Boiling Point:	212°F	Drying Time To Touch : 24 - 48 hours
Flash Point:	ASTM D92 128°F	To Set :
		<u>Limits of Application</u> - Application should be made in a dry atmosphere with ambient temperature of product and surface being treated above 40°F at time of application.
<u>Precautions</u> - Nontoxic Material		<u>Limitations</u> - Surface must be sound, clean, dry and free from oil, grease, tar, dirt or loose mortar. Efflorescence must be removed.
		<u>Actual Application Data</u>
		Number of Coats: 2
		Recoat Time: Overnight
		Coverage -ft ² /gallon, 200/200
		<u>Notes:</u>
		<u>General Comments</u> -
		Concrete surface treated with penetrant; Uniform - color unchanged - dull.
		Concrete surface treated with linseed oil and penetrant; Non-Uniform - slightly darker - dull.

TABLE B-14 - TECHNICAL DATA AND APPLICATION DATA - MATERIAL NO. 13

TEST NO: 13		
CHEMICAL COMPOSITION:	Methyl methacrylate-ethylacrylate copolymer	
Technical Data	Manufacturers Application Data	Actual Application Data
<p>Solids (Minimum X by Weight) 15 Specific Gravity: 1.00 Viscosity: 10 cps pH: 9.5 Color: Milky-White Boiling Point: 212°F Flash Point: None</p>	<p>Weight (lb per gallon): 8.4 Number of Coats : 2 Primer Required : 0 Recoat Time (hrs) : 2 Hours Coverage (ft²/gallon) : 100-400/100-400 Drying Time To Touch : Not Given To Set : Not Given</p> <p><u>Limits of Application</u> - Do not apply when temperature is below 50°F or on frozen or frost-filled surfaces.</p>	<p>Number of Coats: 2 Recoat Time: Overnight Coverage -ft²/gallon; 200/200</p> <p><u>Notes:</u></p> <p><u>General Comments:</u></p> <p>Concrete surface treated with penetrant Uniform - Color unchanged - shiny.</p> <p>Concrete surface treated with linseed oil and penetrant Uniform - slightly darker - dull.</p>
<u>Precautions</u> - Not Given	<u>Limitations</u> - Surface must be dry, free of any dirt, wax, foreign materials, defective paints or coatings (it is not enough for just the visible surface to be dry - it must be dry throughout). It is not recommended for sealing heavy duty floors. Do not use to seal floors exposed to underground water or new slate or quarry tile floors. Do not use on glazed tile, very dense surfaces or over ceramic	

TABLE B-15 - TECHNICAL DATA AND APPLICATION DATA - MATERIAL NO. 14

TEST NO: 14		
CHEMICAL COMPOSITION:	One component chemically curing aliphatic urethane	
Technical Data	Manufacturers Application Data	Actual Application Data
<p>Solids (Minimum % by Weight) 20 ± 2 Specific Gravity: 0.9346 Viscosity: 10 cps ± 0.2 pH: Not Given Color: Clear, Light Straw Boiling Point: Not Given Flash Point: 86°F Seta Flash</p>	<p>Weight (lb per gallon): 8.1 ± 0.2 Number of Coats : 1 Primer Required : 0 Recoat Time (hrs) : 0 Coverage (ft²/gallon) : 200 Drying Time To Touch : Not Given To Set : 10 Hours at 70°F</p> <p><u>Limits of Application</u> - Can be applied in the temperature range of 40°F - 100°F.</p>	<p>Number of Coats: 1 Recoat Time: 0 Coverage -ft²/gallon: 200</p> <p><u>Notes:</u></p> <p><u>General Comments -</u> Concrete surface treated with penetrant: Non-Uniform - slightly and much darker - dull. Concrete surface treated with linseed oil and penetrant: Non-uniform - much darker - dull and shiny.</p>
<p><u>Precautions</u> - Flammable, vapor harmful; contains 2 - ethoxyethylacetate and isocyanate.</p>	<p><u>Limitations</u> - Concrete surface must be swept clean and all loose material removed; must be free of oil, paints, anti freeze.</p>	

TABLE B-16 - TECHNICAL DATA AND APPLICATION DATA - MATERIAL NO. 15

TEST NO: 15		
CHEMICAL COMPOSITION:	Two-component epoxy A - Epoxy resin B - Polyamine + Bisphenol A	
Technical Data		Manufacturers Application Data
Solids (Minimum % by Weight) 100 Specific Gravity: 1.064 Viscosity: 40°F = 500 cps 77°F = 140 cps pH: 11+ (contains an amine) Color: A - Clear, Light Stray B - Black Boiling Point: Above 302°F Flash Point: Cleveland Open Cup 280°F		Weight (lb per gallon): 8.1 Number of Coats : 2 Primer Required : 0 Recoat Time (hrs) : 3 hours Coverage (ft ² /gallon) : 100/100 Drying Time To Touch : Not Given To Sat : Not Given <u>Limits of Application</u> - As low as 32°F, but should be used at higher ambient temperatures for sealing concrete due to lower viscosity.
<u>Precautions</u> - Product Flammable <u>Mixing Information</u> - Mixing Ratio: 2:1 by volume add Part A to B Induction Time: 20-30 Minutes Note: Mix thoroughly using a mechanical mixer; proper mixing will take approximately 2 minutes.		Actual Application Data Number of Coats: 2 Recoat Time: Overnight Coverage -ft ² /gallon: 450/450 <u>Notes:</u> Added Part A to B (2:1 by volume). Mixed by hand 5 minutes. <u>General Comments</u> - Concrete surface treated with penetrant: Uniform - very dark - glassy heavy bodied coating. Concrete surface treated with linseed oil and penetrant: Uniform - very dark - glassy.

TABLE B-17 - TECHNICAL DATA AND APPLICATION DATA - MATERIAL NO. 16

TEST NO: 16		
CHEMICAL COMPOSITION:	Two-component epoxy A = Epoxy resin (Epichlorohydrin/Bisphenol A) B = Polyamine + Bisphenol A	
Technical Data	Manufacturers Application Data	Actual Application Data
<p>Solids (Minimum % by Weight) 50 Specific Gravity: A = 1.030 B = 0.923 Viscosity: 15 - 40 cps pH: Not Given Color: A - Clear, Light Straw B - Clear, Light Straw Boiling Point: Not Given Flash Point: 45°F</p>	<p>Weight (lb per gallon): A = 8.6 B = 7.7 Number of Coats : 1 for Penetrating Sealer : 2 for Protective Coating Primer Required : 0 Recoat Time (hrs) : Not Given Coverage (ft²/gallon) : 120/120 Drying Time To Touch : 4 Hours Max. To Set : Not Given <u>Limits of Application</u> - Apply at ambient temperature above 50°F.</p>	<p>Number of Coats: 2 Recoat Time: Overnight Coverage -ft²/gallon: 120/120 <u>Notes:</u> 1:1 by volume was mixed by hand for 5 minutes.</p> <p><u>General Comments</u> - Concrete surface treated with penetrant: Non-Uniform - very dark - dull and glassy. Concrete surface treated with linseed oil and penetrant: Uniform - very dark - glassy.</p>
<p><u>Precautions</u> - Contains an alkaline amine.</p> <p><u>Mixing Information</u> - Mixing Ratio: 1:1 by volume Induction Time: 0 Note: Mix Thoroughly</p>	<p><u>Limitations</u>: - Coating and sealer for nonwearing surfaces, such as curbing, handrails, piers, pier caps. Surface must be free of loose dirt, loose particles, weak sections, oil and asphalt.</p>	

TABLE B-18 - TECHNICAL DATA AND APPLICATION DATA - MATERIAL NO. 17

TEST NO: 17		
CHEMICAL COMPOSITION:	Two-component epoxy A = Epoxy resin (Epichlorohydrin/Bisphenol A) B = Polysulfide	
Technical Data	Manufacturers Application Data	Actual Application Data
<p>Solids (Minimum % by Weight) 25 - 30 Specific Gravity: 0.921 Viscosity: @ 77°F = 10 cps pH: 6.29 Color: A - Clear, Colorless B - Clear, Light Amber Boiling Point: 90°F Flash Point: 76°F</p>	<p>Weight (lb per gallon): A = B = 7.85 Number of Coats : 2 Primer Required : 0 Recoat Time (hrs) : Not Given Coverage (ft²/gallon) : 100-150/200-300 Drying Time To Touch : Not Given To Set : @ 77°F, 150 sq ft gal = 3-4 hours</p> <p><u>Limits of Application</u> - Do not apply at temperatures below 45°F or if rain is expected within 6 hours.</p>	<p>Number of Coats: 2 Recoat Time: Overnight Coverage -ft²/gallon: 100/100</p> <p><u>Notes:</u> 1:1 by volume, mixed by hand for 5 minutes; induction time was 30 minutes.</p> <p><u>General Comments -</u> Concrete surface treated with penetrant: Non-Uniform - slightly and much darker - shiny. Concrete surface treated with linseed oil and penetrant: Non-uniform - slightly and much darker-dull and glassy.</p>
<p><u>Precautions</u> - Product flammable contains xylene.</p> <p><u>Mixing Information</u> - Mixing Ratio: 1:1 by volume Induction Time: 20-30 Minutes</p>	<p><u>Limitations</u> - Surface must be free of dust, oil, grease, wax, previous sealer and coating.</p>	

TABLE B-20 - TECHNICAL DATA AND APPLICATION DATA - MATERIAL NO. 19

TEST NO: 19		
CHEMICAL COMPOSITION:	Two-component epoxy A - Epoxy resin (Epichlorohydrin/Bisphenol A) B - Polyamide	
Technical Data	Manufacturers Application Data	Actual Application Data
<p>Solids (Minimum % by Weight) 20-25 Specific Gravity: 0.949 + 0.01 Viscosity: (Mix) 30 ± 15 cps pH: 10.5 ± 2 A - Clear, Light Straw Color: B - Clear, Straw Boiling Point: Not Given Flash Point: 106°F</p>	<p>Weight (lb per gallon): A B = 7.9 Number of Coats : 2 Primer Required : 0 Recoat Time (hrs) : 2 hrs Coverage (ft²/gallon) : 200-400/200-400 Drying Time To Touch : Not Given To Set : Not Given <u>Limits of Application</u> - Not Given</p>	<p>Number of Coats: 2 Recoat Time: Overnight Coverage -ft²/gallon: 300/300 <u>Notes:</u> Each component was stirred for 2 minutes by hand. 1:1 by volume mixed by hand-for</p> <p><u>General Comments</u> - Concrete surface treated with penetrant: Uniform - color unchanged - dull. Concrete surface treated with linseed oil and penetrant: Uniform - slightly darker - shiny.</p>
<p><u>Precautions</u> - Flammable</p> <p><u>Mixing Information</u> - Mixing Ratio: 1:1 by volume Induction Time: 0</p> <p><u>Note</u> - Stir each component thoroughly. Combine equal parts of Component A and B in a clean pail and mix with spark proof electric equipment until blend is uniform in color.</p>		

TABLE B-21 - TECHNICAL DATA AND APPLICATION DATA - MATERIAL NO. 20

TEST NO: 20		
CHEMICAL COMPOSITION:	Two-component epoxy A - Epoxy resin (Bisphenol A) B - Polyamide	
Technical Data	Manufacturers Application Data	Actual Application Data
<p>Solids (Minimum % by Weight) : 50 Specific Gravity: A - 0.972 B - 1.016 Viscosity:(Mix) : 25 cps @ 120°F pH: Not Given A - Clear, Straw Color: B - Clear, Light Amber Boiling Point: 230°F Flash Point: Tag Closed Cup - 45°F</p>	<p>Weight (lb per gallon): A - 8.10 B - 8.42 Number of Coats : 1 Primer Required : 0 Recoat Time (hrs) : 0 Coverage (ft²/gallon) : 80 Drying Time To Touch : Not Given To Set : 4 Hours Maximum <u>Limits of Application</u> - Not Given</p>	<p>Number of Coats: 1 Recoat Time: 0 Coverage -ft²/gallon: 80 <u>Notes:</u> 1:1 by volume mixed by hand for 5 minutes. Induction time was 45 minutes, then samples were remixed 1 minute.</p>
<p><u>Precautions</u> - Flammable, vapor harmful; must not be ingested.</p> <p><u>Mixing Information</u> - Mixing Ratio: 1:1 by volume Induction Time: 30-60 Minutes</p> <p><u>Note</u> - Stir thoroughly for 3 to 5 minutes; restir before application.</p>	<p><u>Limitations</u> - Surface must be free of oil, grease, dirt or bituminous materials.</p>	<p><u>General Comments:</u> Concrete surface treated with penetrant; Non-Uniform - slightly and much darker - dull and shiny. Concrete surface treated with linseed oil and penetrant; Almost uniform - much darker - glassy.</p>

TABLE B-22 - TECHNICAL DATA AND APPLICATION DATA - MATERIAL NO. 21

TEST NO: 21		
CHEMICAL COMPOSITION:	Two-component epoxy A - Epoxy resin (Epichlorohydrin/Bisphenol A) B - Polyamide + phenolic	
Technical Data		Manufacturers Application Data
Solids (Minimum % by Weight) 30 Specific Gravity: 0.97 - 1.07 Viscosity: 50-100 cps pH: 6.0 Color: A - Clear, Light Straw B - Clear, Straw Boiling Point: 395°F Flash Point: 120°F		Weight (lb per gallon): A - 9.1 B - 8.1 Number of Coats : 2 Primer Required : 0 Recoat Time (hrs) : 2 Hours Coverage (ft ² /gallon) : 300/300 new concrete 400/400 old concrete Drying Time To Touch : Not Given To Set : Not Given <u>Limits of Application</u> - New concrete - should be applied immediately after final trowel in two applications of 300 ft ² per gallon.
<u>Precautions</u> - Flammable <u>Mixing Information</u> - Mixing Ratio: 1:1 by volume Induction Time: 120 Minutes <u>Note</u> - Mixing thoroughly for 4-5 minutes by hand.		Actual Application Data Number of Coats: 2 Recoat Time: Overnight Coverage -ft ² /gallon: 300/300 <u>Notes:</u> 1:1 mixed by hand for 5 minutes Induction time was 120 minutes <u>General Comments</u> - Concrete surface treated with penetrant; Uniform - much darker - glassy. Concrete surface treated with linseed oil and penetrant; Uniform - much darker - glassy.

600 ft²/gallon. Technical data for all materials are summarized in Table B-23.

Test Objectives

The objective of Series I was to evaluate the differences in water and chloride ion absorptions for concretes coated with these 21 materials and then soaked in a saltwater solution, and the subsequent water vapor permeability characteristics of such coated concrete specimens during an air drying period. As such, this series evaluated the following parameters:

1. Water absorption - desorption characteristics of surface-coated concretes
2. Chloride ion penetration into surface-coated concretes
3. Influence of pretreatment of the concrete with linseed oil on the effectiveness of the sealer on the subsequent water absorption, water vapor transmission and chloride penetration characteristics. This phase simulated the coating of older bridge surfaces which had been previously treated with boiled linseed oil.

Test Materials and Procedures

Concrete Characteristics. Nominal 4 in. concrete cubes were made using the following materials:

Sand: Natural sand from Bensenville, Illinois

Coarse aggregate: No. 67 crushed limestone from Thornton, Illinois

Portland cement: Type I

Air-entraining agent: Neutralized Vinsol resin

TABLE B-23 - SUMMARY OF TECHNICAL DATA FOR MATERIALS TESTED DURING SCREENING TESTS

Test No.	Chemical composition	Minimum solids % by wt.	Specific gravity	Viscosity	pH	Boiling point (°F)	Flash point (°F)
1	Siloxane mixture	6.5±0.5	0.86	1 cps	<7	250	120
2	Linseed oil	50	0.8569	A-5 Gardner-Holdt	Not given	318-338	Open cup 109
3	Methylsiliconate	30	1.24	Not given	12	Not given	None
4	Moisture-cured polyurethane	60	1.018	Zahn #4 16 sec	4-7	311	Closed cup 108
5	Chlorinated rubber	20	0.92	Not given	~6.5	Not given	Not given
6	Alkyl-Alkoxy Silane	40	0.8	0.98mPA-S (68°F)	~6.5	174	54
7	Styrene butadiene	41	0.996	#2sp@20cps 500 max.	7.5-8.5	Not given	180
8	Methylmethacrylate-ethylacrylate	20	Not given	Ford B cup 70-80/150-160	Not given	Not given	Not given
9	Sodium silicate	31.4	1.200	100°CST 2.16	11	214	None
10	Polyisobutyl methacrylate	12/36	0.86	#4 Ford cup 12 sec/68 sec	~7	230/313-389	ASTM D56 105
11	Vinyl toluene butadiene	64	0.975	93 poises	Not given	Not given	100

TABLE B-23 - SUMMARY OF TECHNICAL DATA FOR MATERIALS TESTED DURING SCREENING TESTS (Contd)

Test No.	Chemical composition	Minimum solids % by wt.	Specific gravity @68°F	Viscosity (75°F)=2.5cps	pH	Boiling point (°F)	Flash point (°F)
12	Al stearate and isobutylene	9.97	0.8144	ASTM D7824 (75°F)=2.5cps	6.8	212	ASTM D92 128
13	Methyl methacrylate 15 ethylacrylate	15	1.00	10 cps	9.5	212	None
14	Chemically cured urethane	20+2	0.9346	10cps+0.2	Not given	Not given	86°F Seta flash
15	Epoxy	100	1.064	60°F=500cps 77°F=140cps	11+ (amine)	<302	Open cup 280
16	Epoxy	50	A=1.030 B=0.923	15-40cps	Not given	Not given	45
17	Epoxy polysulfide	25-30	0.921	@77°F=10cps	6.29	90	76
18	Epoxy	17	0.90	3.1±0.5cps	A=7.7	124	77
19	Epoxy	20-25	0.949	30±15cps	10.5±2	Not given	106
20	Epoxy polysulfide	50	A=0.979 B=1.016	25cps@120°F	Not given	230	Closed cup 45
21	Epoxy	30	0.97- -1.07	50-100cps	6.0	395	120

B-27

Both aggregates meet the requirements of ASTM C33. Preliminary trial batches were made to cover the w/c ratio range from 0.44 to 0.59. These concretes had 28 day strengths from 4400 psi to 6100 psi. From these trial concretes, the test concrete was designed to have a 28 day compressive strength of 4500 to 5000 psi with a w/c ratio of 0.53, an air content of 4 to 5 percent, and a slump of approximately 3 in.

The forms for the 4 in. cubes were constructed of special resin-coated plywood to preclude the need for any chemical release agent which might chemically contaminate the concrete surfaces during casting.

The wooden gang forms were table-vibrated using two lifts of concrete. Each 2 in. lift was vibrated for 30 seconds. The top surfaces were then floated with a wooden float and covered with polyethylene film for overnight curing. Specimens were stripped at the age of 1 day and then cured in lime-saturated water for 6 days at 73 degrees F.

The significant properties of the fresh and hardened concrete from the two batches were as follows:

S.S.D. quantities/yd ³	Batch No.	
	1	2
Cement content, lb	496	497
Sand content, lb	1593	1595
Coarse aggregate content, lb	1580	1582
Water content, lb	261	262
Plastic unit weight, pcf	145.6	145.8
Air content, %	4.3	4.6
W/C (S.S.D), by weight	0.526	0.527
Slump, in.	3	2-3/4
Average 28 day compressive strength, psi	4660	5050

B-28

Some significant properties of the two aggregates are as follows:

	Crushed Stone	Sand
Specific gravity @ S.S.D.	2.67	2.67
Absorption @ S.S.D., %	1.83	1.67

Test Procedures. The cubes were lightly sandblasted after the water curing at an age of 7 days to remove the portland cement skin which would normally wear off by natural weathering. Following sandblasting, the cubes were labeled with an attached tag and weighed to the nearest 0.1 gram. They were then allowed to air dry in a controlled climate room for 21 days at 73 + 3 degrees F and 50 + 4 percent R.H. on steel racks which provided air circulation on all six sides. The cubes were periodically moved within the rack so that the influence of variations in air circulation would be minimized. During this air drying period, the cubes were weighed to the nearest 0.1 gram after 7, 14 and 21 days of air drying to determine weight loss from the saturated condition at age 7 days.

It had been estimated that 21 days of air drying at 73 degrees F and 50 percent R.H. should cause a weight loss of about 2.5 to 3.0 percent of the total weight of the concrete. The actual average weight losses and range in weight losses for the 104 cubes is shown on Fig. B-1. Weight losses within a batch of 52 cubes varied about +7 percent from the average values. The actual average weight loss percentages at 14, 21 and 28 days of age are as follows:

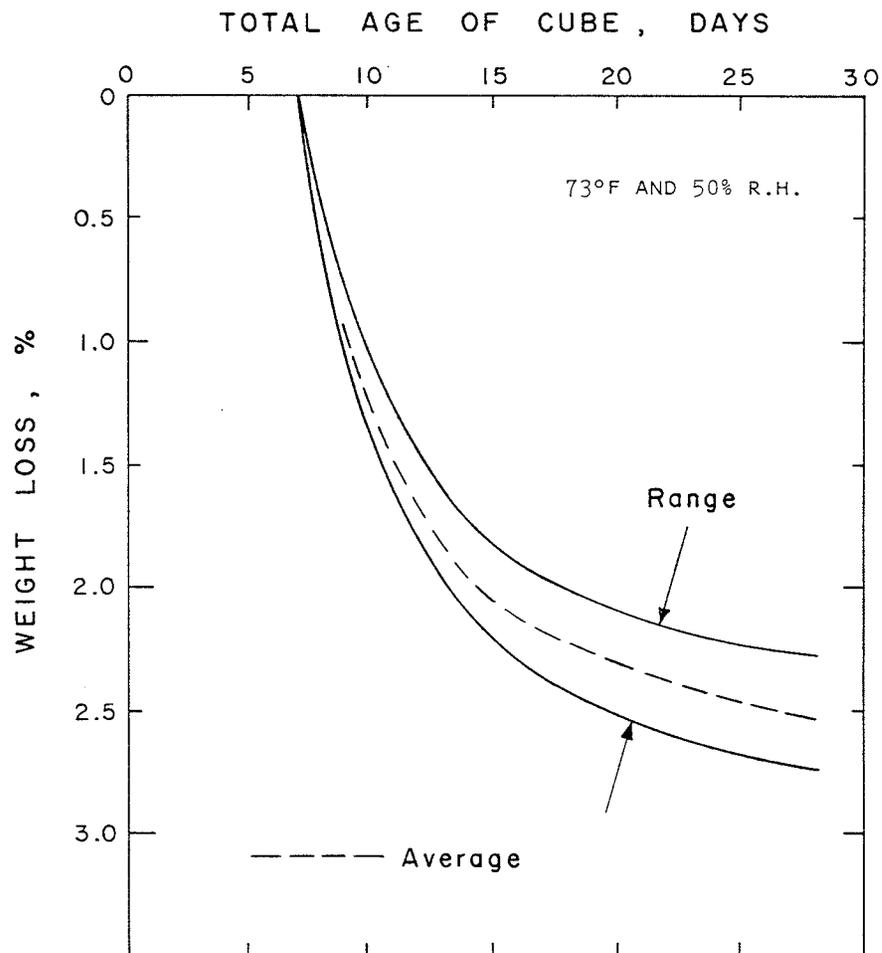


Fig. B-1 - Weight Loss Characteristics of Specimens During Initial Air Drying Period

<u>Total Age, days</u>	<u>Average Weight Loss from Saturated Condition, %</u>		
	<u>Batch 1</u>	<u>Batch 2</u>	<u>Avg. 1 and 2</u>
14	1.95	2.06	2.01
21	2.29	2.40	2.34
28	2.49	2.61	2.55

These data show that the anticipated weight losses were achieved.

After the 21 days of initial air drying, the cubes were separated into two groups of 42 samples from each concrete batch. One cube from Batch 1 and one cube from Batch 2 were used to produce each two-cube sample. The 42 cubes (21 pairs) of the first group were coated at age 28 days with the materials. All coatings were applied using the manufacturer's recommendations.

The amount of material for each cube was calculated using the weight of material in lb per gallon, the recommended coverage rate and the surface area of the cube. The calculated amount of each material was weighed to the nearest 0.1 gram and applied by brush in a room temperature of about 65 degrees F. The second coat, when required, was applied after 24 hours. The coated cubes were then stored in the controlled climate room for 14 days. After this 14 day curing period for the coatings, the cubes were weighed and immersed in a 15 percent NaCl solution.

The second group of 42 cubes was coated with the recommended two coats of the boiled linseed oil/mineral spirits solution on two successive days at age 28 and 29 days. After exposure to ultraviolet light for aging purposes (one day on each cube face), the cubes were again lightly sandblasted and then coated at age 35 days as described above with the 21 penetrants or coatings. After a 14 day period for the curing of the penetrants, in the controlled climate room, these cubes were also immersed in the 15 percent NaCl water solution.

Six cubes were placed in a covered plastic container with three gallons of 15 percent NaCl solution. The tops of the cubes were covered with about 1 in. of solution. During the soaking period, the gain in the S.S.D. cube weight after 3, 6, 9, 12, 15, 18 and 21 days of soaking was determined to the nearest 0.1 gram. Immediately after each weighing, the cubes were returned to the solution. The salt solution was stirred two times each day. After 21 days of water soaking, all cubes were removed from the water bath and moved back into the controlled climate room. They were again stored in air on the steel racks and periodically moved to reduce the effect of variations in air circulation. During the following 24 day air drying period, the loss in cube weight at 3, 6, 9, 12, 15, 18, 21, 22, 23 and 24 days was determined by weighing to the nearest 0.1 gram. During the last 3 days, each cube was placed within three closed, heavy-duty plastic bags. Three porous paper bags containing a total of 100 grams of magnesium perchlorate were placed around the cube to produce a very low relative humidity within the bag.

The program included two types of uncoated control specimens. One pair remained in the air in the controlled climate room during the entire 13 week test period during which time their weights were monitored. The other control cubes were subjected to the same air drying and saltwater soaking tests as the coated cubes.

Results of the average weight gain and loss of water are given in Tables B-24 and B-25 and are depicted graphically in Figs. B-2 to B-22.

After the final air drying period, each cube was mechanically split in half. One-half was crushed, and the total chloride ion content was determined using an acid digestion potentiometric titration procedure. The total chloride ion test results are listed in Table B-26.

TABLE B-24 - AVERAGE WEIGHT CHANGE DURING SOAKING AND DRYING PERIODS

Concrete Treated with Penetrant or Coating Only

Test No.	Chemical composition	Soaking period								Drying period									
		Weight change after days, %								Weight change after days, %									
		3	6	9	12	15	18	21	21 (Range)*	3	6	9	12	15	18	21	22	23	24
1	Siloxane misture	2.54	2.63	2.73	2.73	2.73	2.86	2.87	(0.01)	1.86	1.52	1.35	1.23	1.16	1.07	1.01	0.91	0.84	0.72
2	Linseed oil	1.57	1.75	1.86	2.03	2.10	2.13	2.19	(0.26)	1.52	1.30	1.21	1.10	1.03	0.95	0.89	0.81	0.79	0.50
3	Siliconate	2.25	2.47	2.71	2.80	2.82	2.83	2.84	(0.16)	1.81	1.48	1.33	1.20	1.12	1.04	0.97	0.86	0.79	0.66
4	Urethane	0.33	0.33	0.46	0.52	0.52	0.56	0.63	(0.27)	0.33	0.18	0.12	0.06	0.04	0.01	-0.05	-0.07	-0.11	-0.14
5	Chlorinated rubber	2.13	2.26	2.45	2.50	2.50	2.53	2.54	(0.09)	1.80	1.48	1.31	1.20	1.09	1.00	0.94	0.86	0.78	0.50
6	Alkyl-Alkoxy Silane	0.38	0.42	0.49	0.70	0.72	0.76	0.82	(0.02)	0.34	0.20	0.14	0.11	0.07	0.05	0.00	-0.07	-0.12	-0.20
7	Styrene butadiene	2.57	2.65	2.73	2.79	2.79	2.80	2.80	(0.01)	1.99	1.68	1.50	1.38	1.27	1.20	1.11	1.04	0.99	0.64
8	Methylmethacrylate	0.36	0.40	0.46	0.50	0.53	0.61	0.61	(0.07)	0.24	0.09	0.03	-0.01	-0.04	-0.08	-0.12	-0.18	-0.20	-0.28
9	Sodium silicate	2.21	2.31	2.36	2.40	2.41	2.41	2.41	(0.10)	1.55	1.26	1.11	1.00	0.91	0.83	0.78	0.69	0.60	0.49
10	Polyisobutyl methacrylate	0.84	0.91	1.00	1.23	1.27	1.33	1.34	(0.32)	0.93	0.65	0.58	0.49	0.43	0.37	0.30	0.27	0.22	0.18
11	Vinyl toluene butadiene	2.15	2.18	2.30	2.42	2.42	2.42	2.42	(0.04)	1.77	1.47	1.28	1.17	1.06	0.98	0.91	0.84	0.77	0.71

* Range in weight gain after 21 days of soaking of duplicate specimens

TABLE B-24 - AVERAGE WEIGHT CHANGE DURING SOAKING AND DRYING PERIODS (Cont'd)

Concrete Treated with Penetrant or Coating Only

Test No.	Chemical composition	Soaking period								Drying period									
		Weight change after days, %								Weight change after days, %									
		3	6	9	12	15	18	21	21 (Range)*	3	6	9	12	15	18	21	22	23	24
12	Aluminum stearate and polyisobutylene	2.27	2.33	2.42	2.48	2.49	2.50	2.50	(0.07)	1.71	1.39	1.22	1.11	0.99	0.92	0.87	0.76	0.69	0.62
13	Methylmethacrylate	2.14	2.26	2.38	2.45	2.46	2.47	2.47	(0.14)	1.79	1.46	1.32	1.24	1.11	1.04	0.96	0.90	0.81	0.77
14	Urethane	1.66	1.97	2.15	2.21	2.26	2.32	2.32	(0.14)	1.51	1.28	1.13	1.02	0.94	0.87	0.83	0.73	0.67	0.59
15	Epoxy	0.35	0.37	0.39	0.48	0.53	0.55	0.57	(0.48)	0.37	0.35	0.31	0.29	0.26	0.24	0.23	0.14	0.08	-0.01
16	Epoxy	0.15	0.17	0.21	0.21	0.23	0.25	0.29	(0.00)	0.11	0.08	0.05	0.05	0.02	0.01	0.00	-0.02	-0.04	-0.13
17	Epoxy Polysulfide	1.46	1.50	1.66	1.77	1.77	1.77	1.78	(0.20)	1.29	1.15	1.05	0.97	0.89	0.82	0.78	0.71	0.68	0.63
18	Epoxy	0.79	1.12	1.36	1.55	1.56	1.65	1.70	(0.56)	1.13	0.94	0.82	0.74	0.66	0.60	0.56	0.49	0.41	0.36
19	Epoxy	2.35	2.37	2.43	2.44	2.44	2.48	2.53	(0.05)	1.73	1.48	1.32	1.20	1.09	1.02	0.95	0.85	0.78	0.72
20	Epoxy Polysulfide	1.74	1.84	1.93	1.98	1.98	1.99	1.99	(0.48)	1.46	1.32	1.19	1.10	1.02	0.96	0.87	0.84	0.79	0.75
21	Epoxy	1.90	2.07	2.16	2.17	2.21	2.23	2.23	(0.12)	1.74	1.54	1.34	1.27	1.17	1.09	1.01	0.97	0.91	0.86
23	Plain concrete	2.60	2.62	2.73	2.77	2.77	2.77	2.77	(0.09)	1.72	1.45	1.29	1.18	1.08	1.01	0.93	0.81	0.76	0.69

*Range in weight gain after 21 days of soaking of duplicate specimens

TABLE B-25 - AVERAGE WEIGHT CHANGE DURING SOAKING AND DRYING PERIODS
Concrete Treated with Linseed Oil Followed by Treatment with Penetrant or Coating

Test No.	Chemical composition	Soaking period								Drying period									
		Weight change after days, %								Weight change after days, %									
		3	6	9	12	15	18	21	21 (Range)*	3	6	9	12	15	18	21	22	23	24
1	Siloxane mixture	1.82	2.49	2.59	2.64	2.73	2.73	2.74	(0.30)	1.96	1.78	1.63	1.52	1.43	1.33	1.25	1.20	1.12	1.08
2	Linseed Oil	0.29	0.86	0.99	1.08	1.21	1.22	1.34	(0.01)	1.01	0.95	0.90	0.87	0.84	0.80	0.79	0.76	0.74	0.72
3	Siliconate	1.24	1.79	1.99	2.17	2.26	2.36	2.39	(0.01)	1.68	1.52	1.38	1.29	1.19	1.09	1.02	0.96	0.90	0.85
4	Urethane	0.13	0.18	0.18	0.18	0.19	0.24	0.24	(0.16)	0.05	0.03	0.00	0.00	-0.01	-0.04	-0.05	-0.06	-0.08	-0.08
5	Chlorinated rubber	0.99	1.28	1.40	1.55	1.62	1.69	1.72	(0.10)	1.29	1.20	1.10	1.06	0.99	0.94	0.89	0.85	0.81	0.77
6	Alkyl-Alkoxy Silane	0.77	0.97	1.01	1.18	1.24	1.31	1.31	(0.03)	0.72	0.61	0.54	0.48	0.43	0.37	0.34	0.32	0.23	0.21
7	Styrene butadiene	1.76	2.08	2.19	2.32	2.37	2.44	2.47	(0.49)	1.86	1.71	1.60	1.52	1.44	1.36	1.33	1.28	1.21	1.16
8	Methyl Methacrylate	0.33	0.40	0.45	0.53	0.57	0.58	0.60	(0.04)	0.31	0.27	0.20	0.17	0.14	0.08	0.07	0.04	0.01-0.01	
9	Sodium Silicate	1.33	1.58	1.69	1.82	1.89	1.94	1.97	(0.16)	1.40	1.26	1.14	1.06	0.99	0.89	0.85	0.79	0.72	0.67
10	Polyisobutyl methacrylate	0.29	0.43	0.47	0.59	0.59	0.68	0.72	(0.03)	0.48	0.45	0.40	0.36	0.34	0.28	0.27	0.26	0.23	0.21
11	Vinyl toluene butadiene	0.78	1.07	1.17	1.37	1.46	1.57	1.68	(0.36)	1.24	1.14	1.07	1.02	0.97	0.90	0.86	0.84	0.79	0.76

*Range in weight gain after 21 days of soaking of duplicate specimens

TABLE B-25 - AVERAGE WEIGHT CHANGE DURING SOAKING AND DRYING PERIODS (Cont'd)
 Concrete Treated with Linseed Oil Followed by Treatment with Penetrant or Coating

Test No.	Chemical composition	Soaking period								Drying period									
		Weight change after days, %								Weight change after days, %									
		3	6	9	12	15	18	21	21 (Range)*	3	6	9	12	15	18	21	22	23	24
12	Aluminum stearate & polyisobutylene	0.57	0.86	1.02	1.22	1.24	1.28	1.29	(0.22)	0.88	0.82	0.75	0.69	0.63	0.59	0.54	0.51	0.45	0.43
13	Methyl methacrylate	0.70	0.82	0.96	1.13	1.13	1.20	1.20	(0.06)	0.84	0.75	0.70	0.65	0.59	0.55	0.51	0.48	0.45	0.42
14	Urethane	0.42	0.48	0.54	0.63	0.64	0.69	0.69	(0.29)	0.43	0.40	0.34	0.33	0.29	0.26	0.25	0.24	0.19	0.17
15	Epoxy	0.29	0.31	0.32	0.36	0.36	0.36	0.36	(0.16)	0.20	0.19	0.17	0.15	0.14	0.13	0.12	0.11	0.08	0.07
16	Epoxy	0.11	0.13	0.14	0.18	0.18	0.18	0.18	(0.06)	0.03	0.02	0.00	-0.01	-0.01	-0.02	-0.03	-0.03	-0.04	-0.06
17	Epoxy-polysulfide	0.51	0.67	0.75	0.86	0.86	0.92	0.92	(0.11)	0.68	0.67	0.62	0.59	0.58	0.54	0.53	0.52	0.48	0.47
18	Epoxy	0.01	0.32	0.45	0.58	0.61	0.66	0.66	(0.14)	0.53	0.50	0.46	0.44	0.42	0.38	0.37	0.37	0.34	0.33
19	Epoxy	0.19	0.37	0.41	0.53	0.53	0.53	0.53	(0.10)	0.36	0.33	0.29	0.27	0.25	0.20	0.20	0.20	0.17	0.16
20	Epoxy-polysulfide	0.38	0.43	0.51	0.59	0.59	0.61	0.69	(0.18)	0.45	0.42	0.39	0.38	0.36	0.33	0.32	0.31	0.28	0.28
21	Epoxy	0.23	0.27	0.27	0.31	0.31	0.31	0.31	(0.14)	0.12	0.12	0.09	0.07	0.06	0.04	0.04	0.03	0.00	-0.01

* Range in weight gain after 21 days of soaking of duplicate specimens

TEST NO. 1

CHEMICAL COMPOSITION: Siloxane mixture
 Coverage (ft²/gal): 500

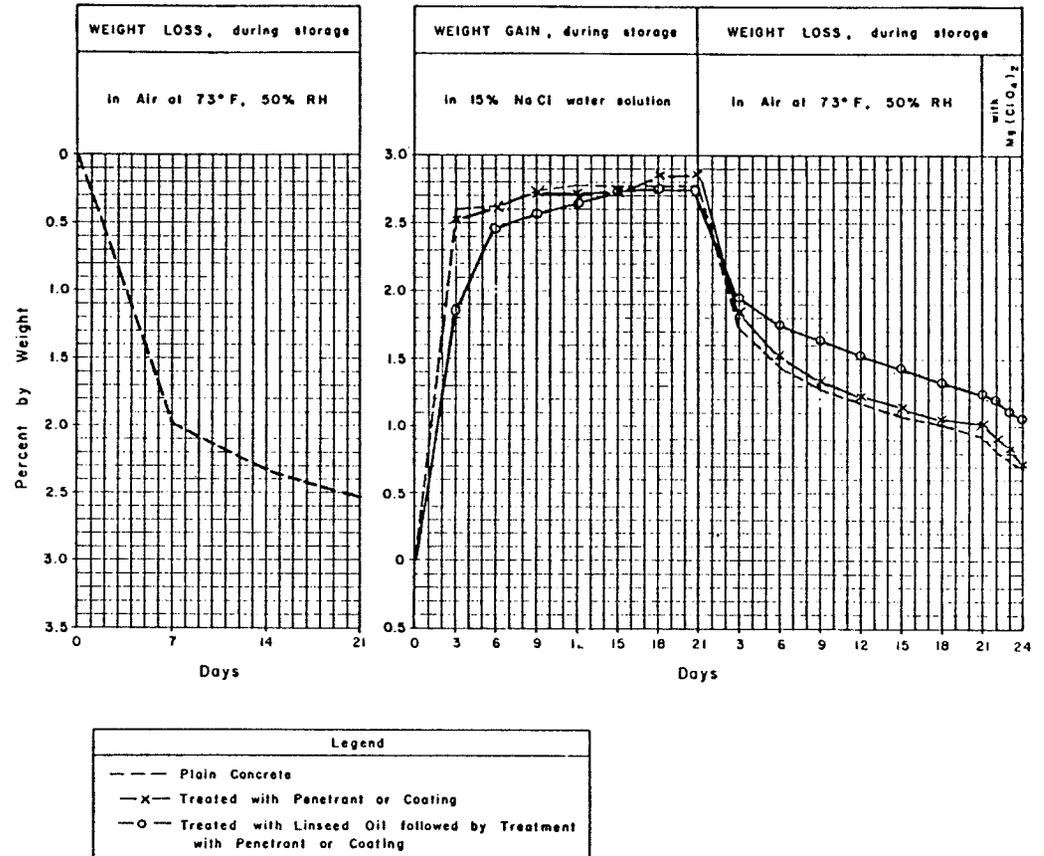


Fig. B-2 - Weight Loss and Gain Data - Material No. 1

CHEMICAL COMPOSITION: An uniformly blended mixture of mineral spirits and
boiled linseed oil (50/50)
Coverage (ft²/gal): 360/600

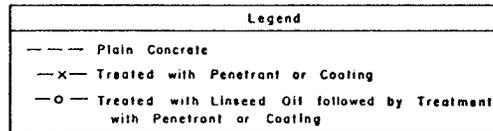
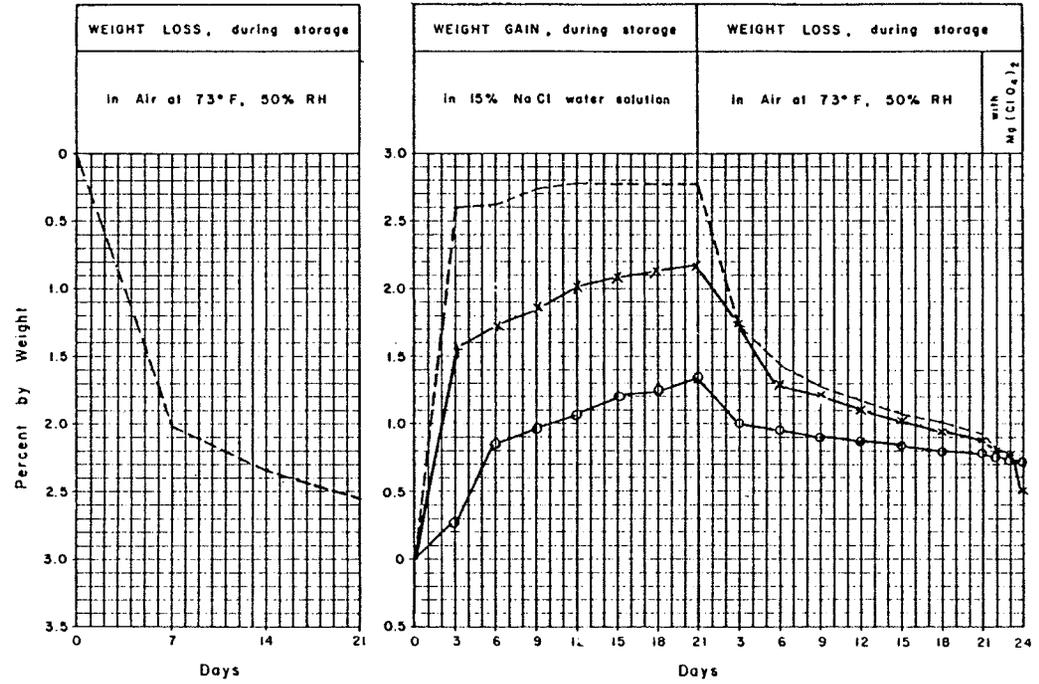


Fig. B-3 - Weight Loss and Gain Data - Material No. 2

TEST NO. 3

CHEMICAL COMPOSITION: Water soluble sodium methyl silicate solution
 Coverage (ft²/gal): 80

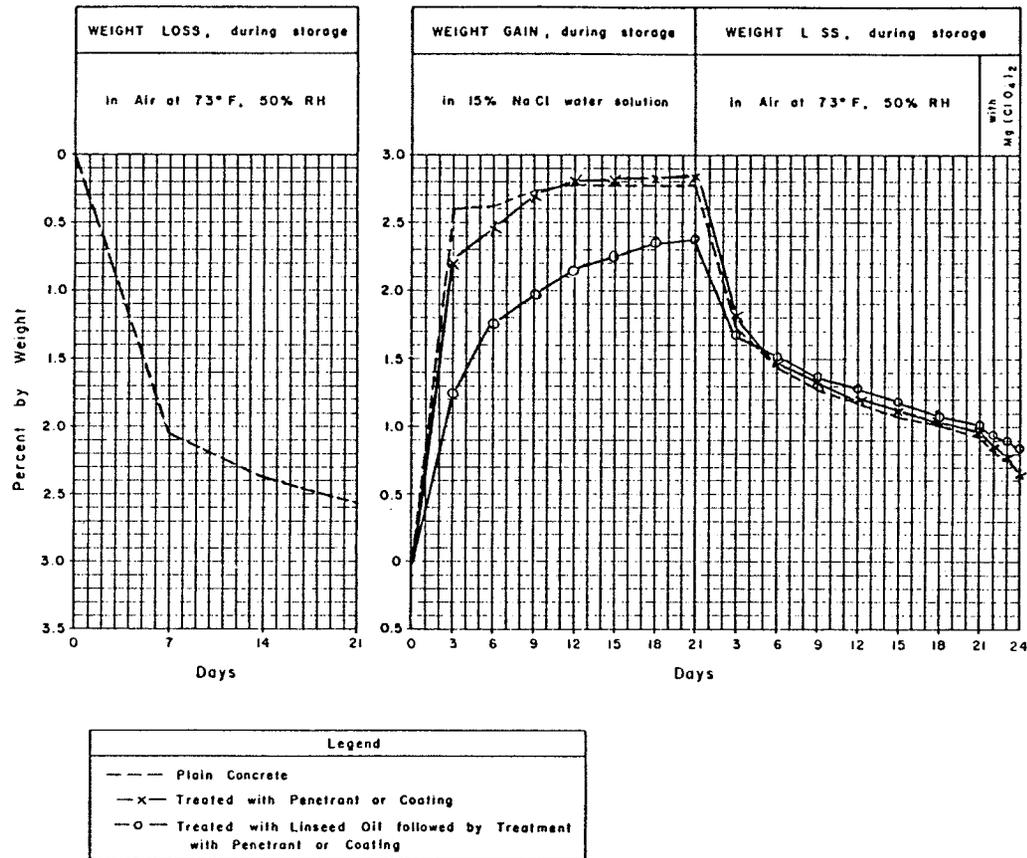


Fig. B-4 - Weight Loss and Gain Data - Material No. 3

CHEMICAL COMPOSITION: An uniquely formulated moisture cured polyurethane resin (isocyanate-polyether)
 Coverage (ft²/gal): 200/200

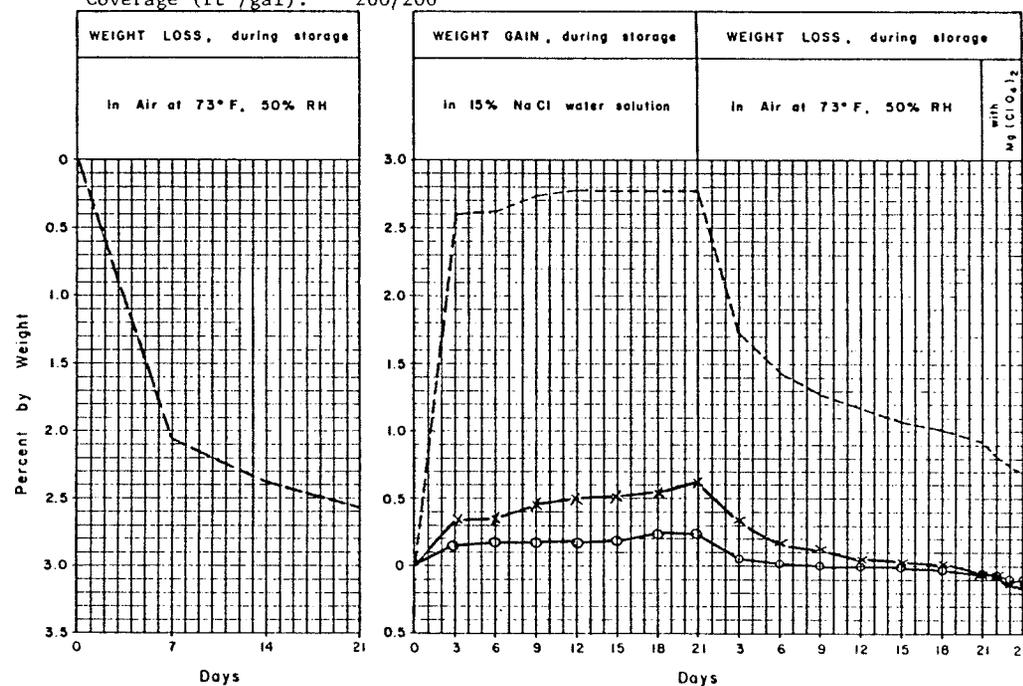


Fig. B-5 - Weight Loss and Gain Data - Material No. 4

CHEMICAL COMPOSITION: A chlorinated rubber solution in xylene
 Coverage (ft²/gal): 350

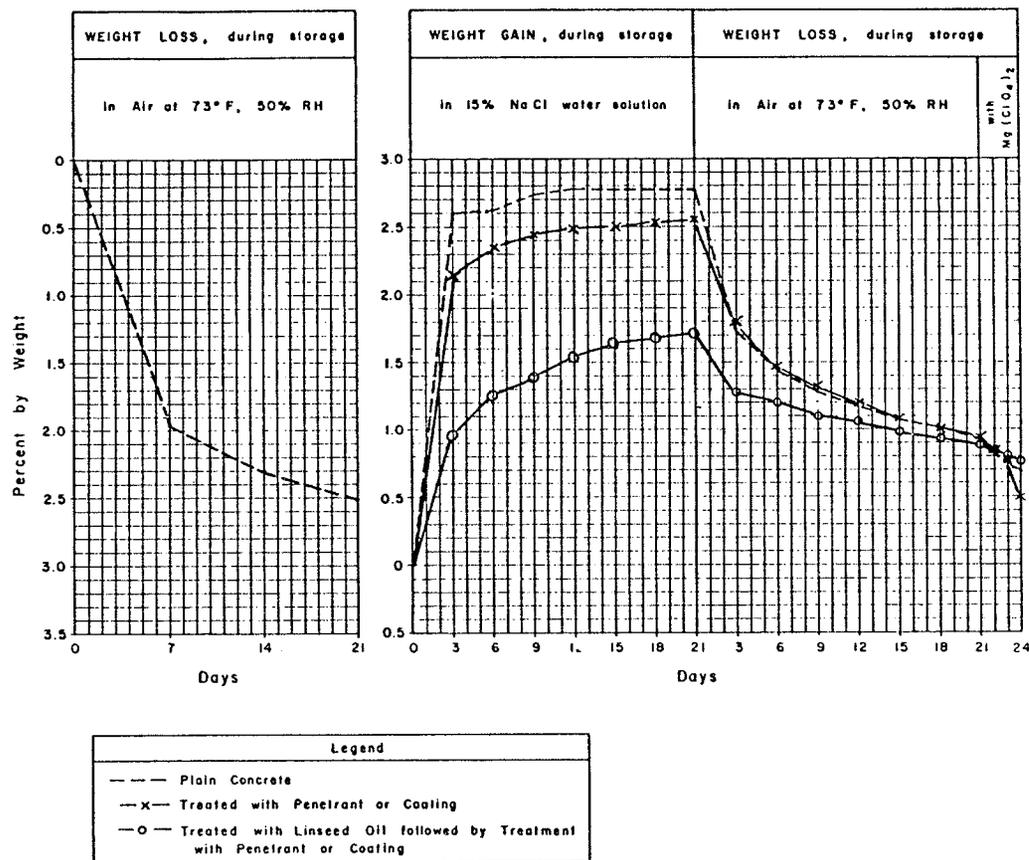
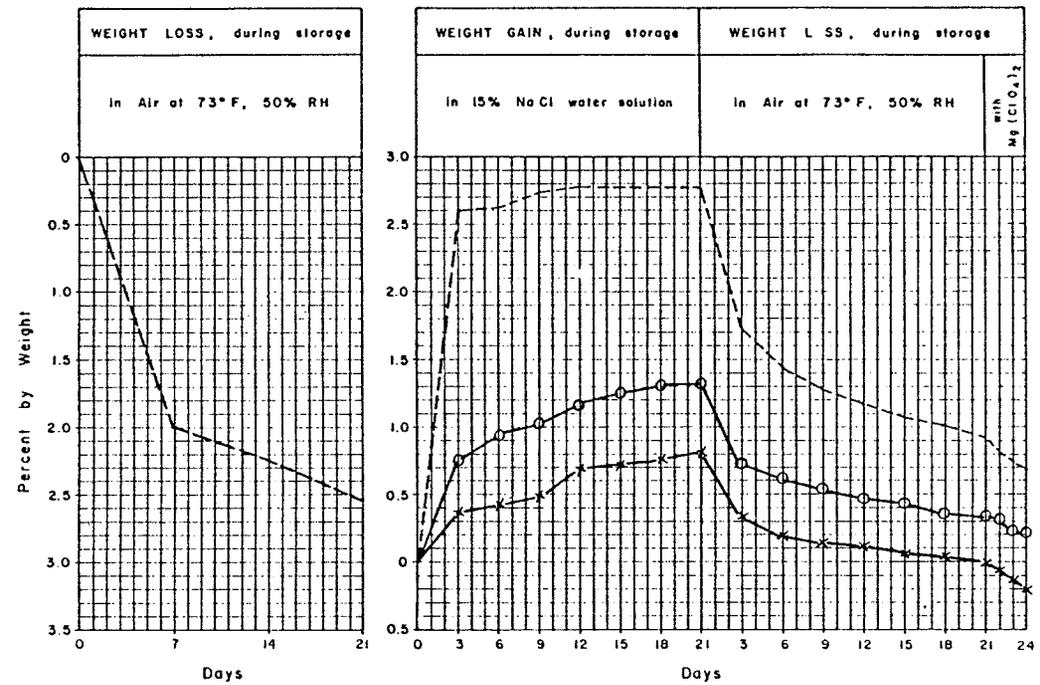


Fig. B-6 - Weight Loss and Gain Data - Material No. 5

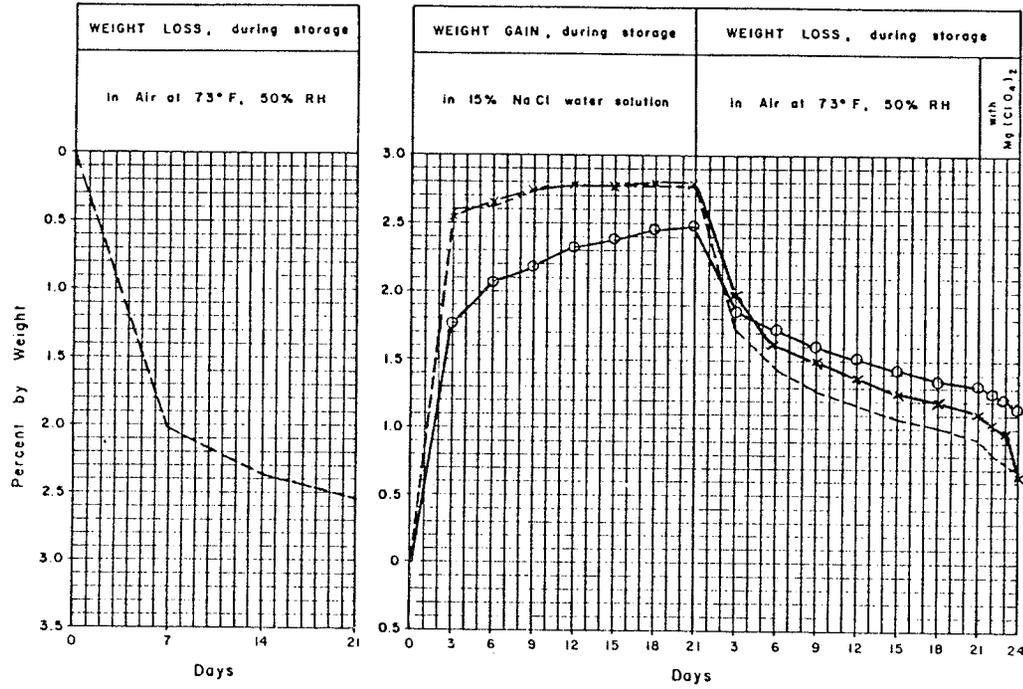
CHEMICAL COMPOSITION: Alkyl-alkoxy silane
 Coverage (ft²/gal): 100



Legend	
---	Plain Concrete
-x-	Treated with Penetrant or Coaling
-o-	Treated with Linseed Oil followed by Treatment with Penetrant or Coaling

Fig. B-7 - Weight Loss and Gain Data - Material No. 6

CHEMICAL COMPOSITION: Styrene-butadiene polymer
 Coverage (ft²/gal): 600



Legend	
---	Plain Concrete
-x-	Treated with Penetrant or Coating
-o-	Treated with Linseed Oil followed by Treatment with Penetrant or Coating

Fig. B-8 - Weight Loss and Gain Data - Material No. 7

CHEMICAL COMPOSITION: Primer - Methyl siloxane
 Finish - Methyl methacrylate-ethylacrylate
 Coverage (ft²/gal): 100/200

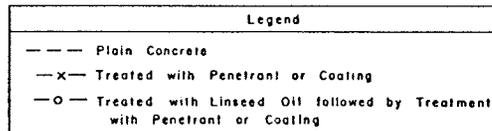
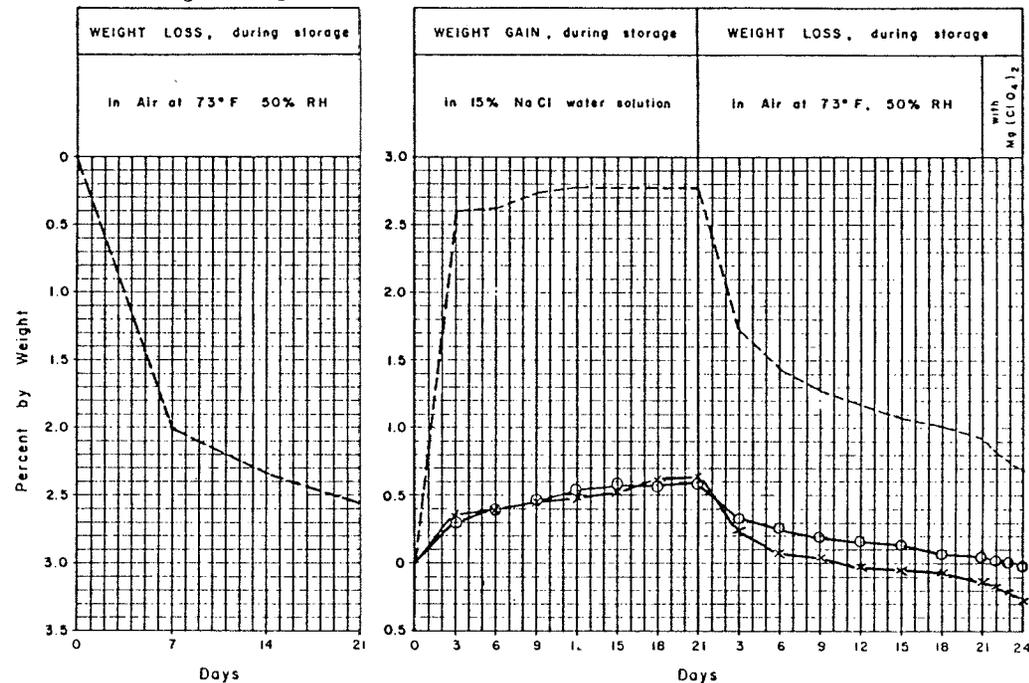


Fig. B-9 - Weight Loss and Gain Data - Material No. 8

CHEMICAL COMPOSITION: Sodium silicate
 Coverage (ft²/gal): 200

TEST NO. 9

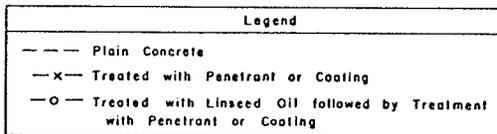
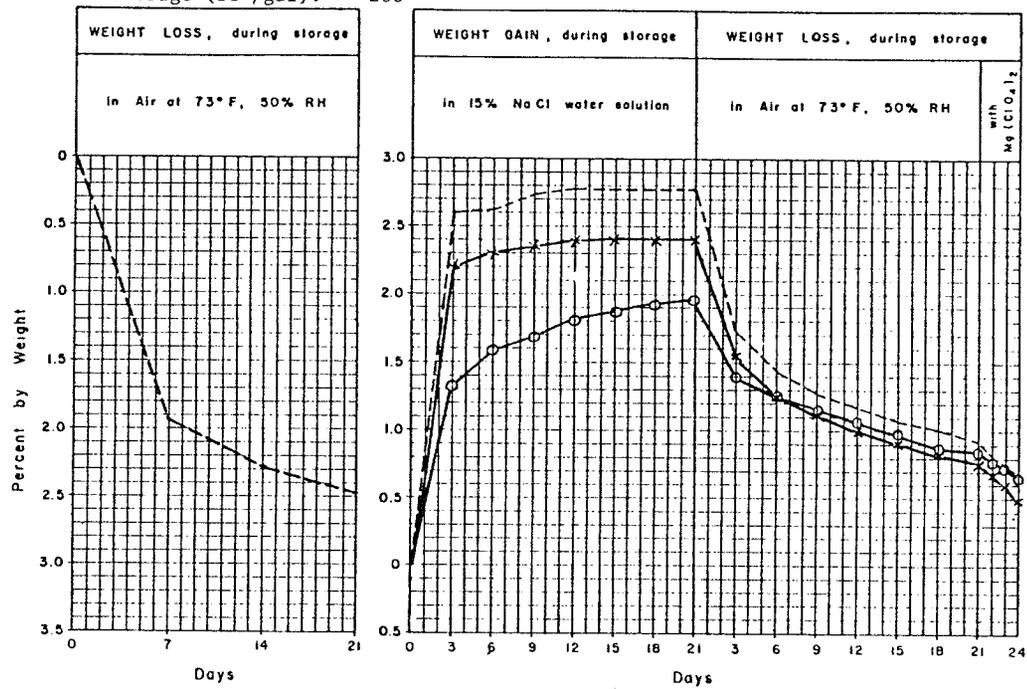


Fig. B-10 - Weight Loss and Gain Data - Material No. 9

CHEMICAL COMPOSITION: Primer and finish - Polyisobutyl methacrylate
 Coverage (ft²/gal): 250/250

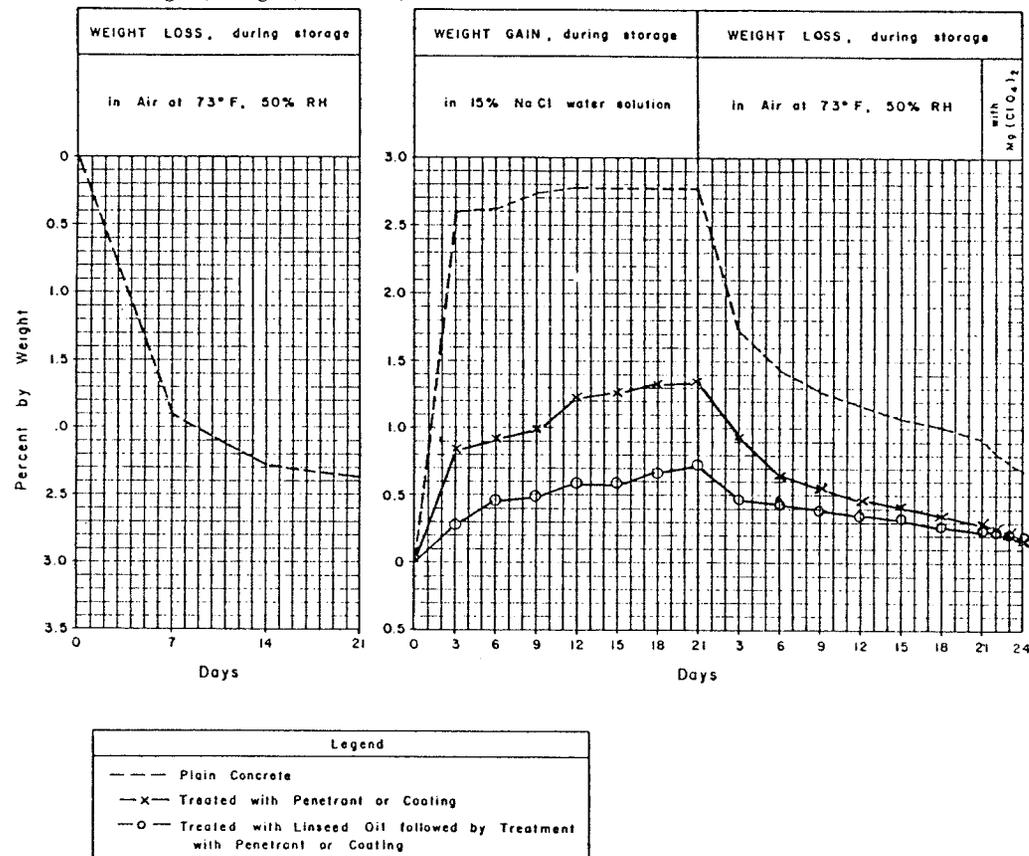


Fig. B-11 - Weight Loss and Gain Data - Material No. 10

CHEMICAL COMPOSITION: Vinyl toluene butadiene
 Coverage (ft²/gal): 30

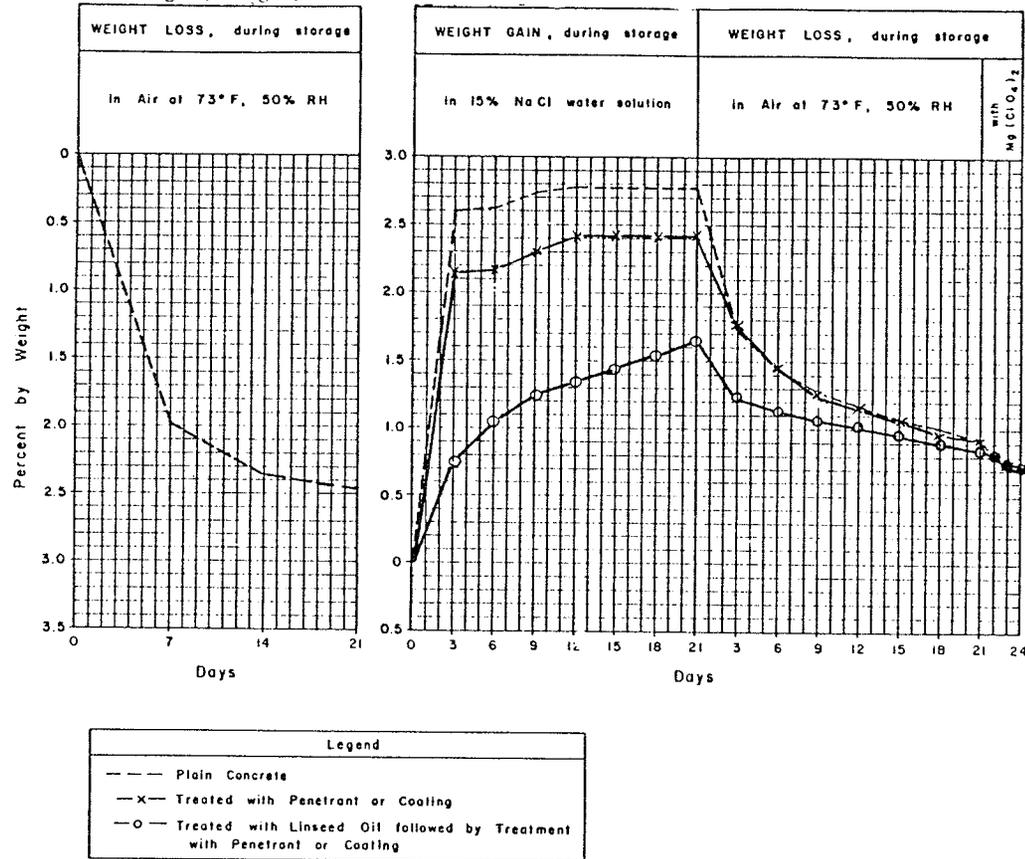


Fig. B-12 - Weight Loss and Gain Data - Material No. 11

CHEMICAL COMPOSITION: Mixture of Aluminum stearate and isobutylene
 Coverage (ft²/gal): 200/200

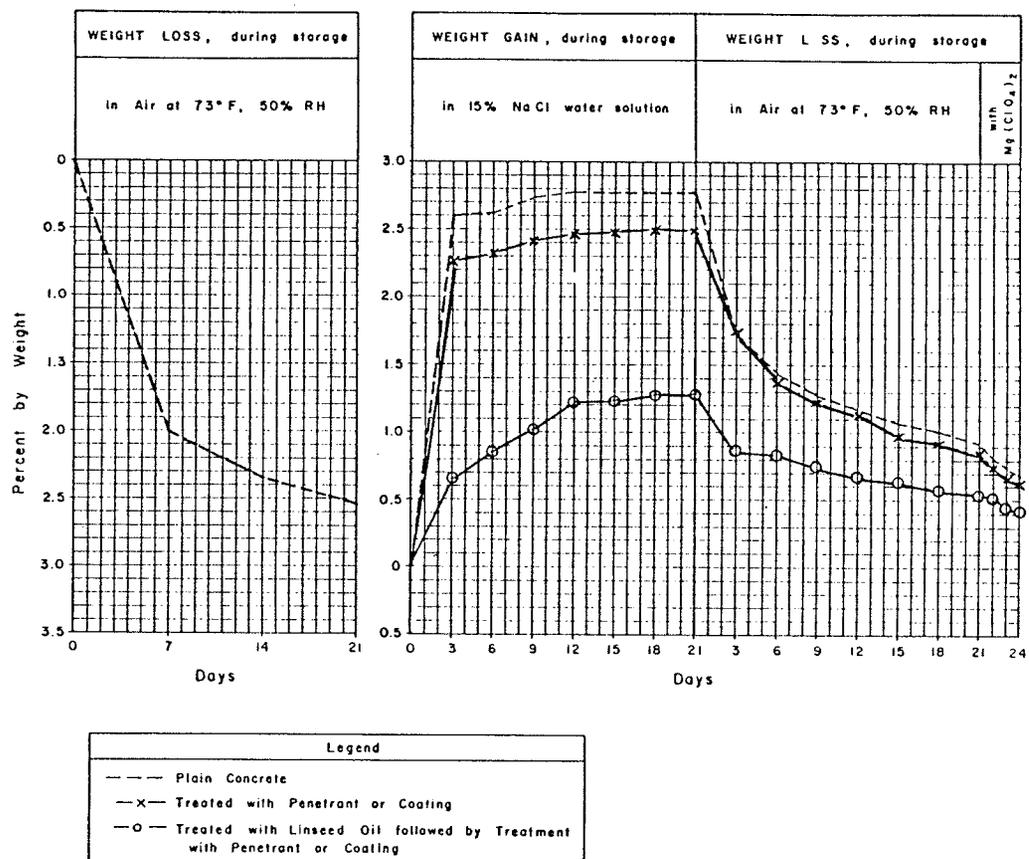


Fig. B-13 - Weight Loss and Gain Data - Material No. 12

TEST NO. 13

CHEMICAL COMPOSITION: Methyl methacrylate-ethylacrylate
 Coverage (ft²/gal): 200/200

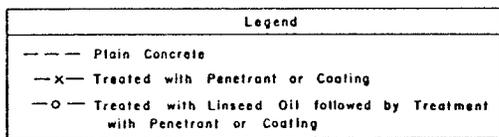
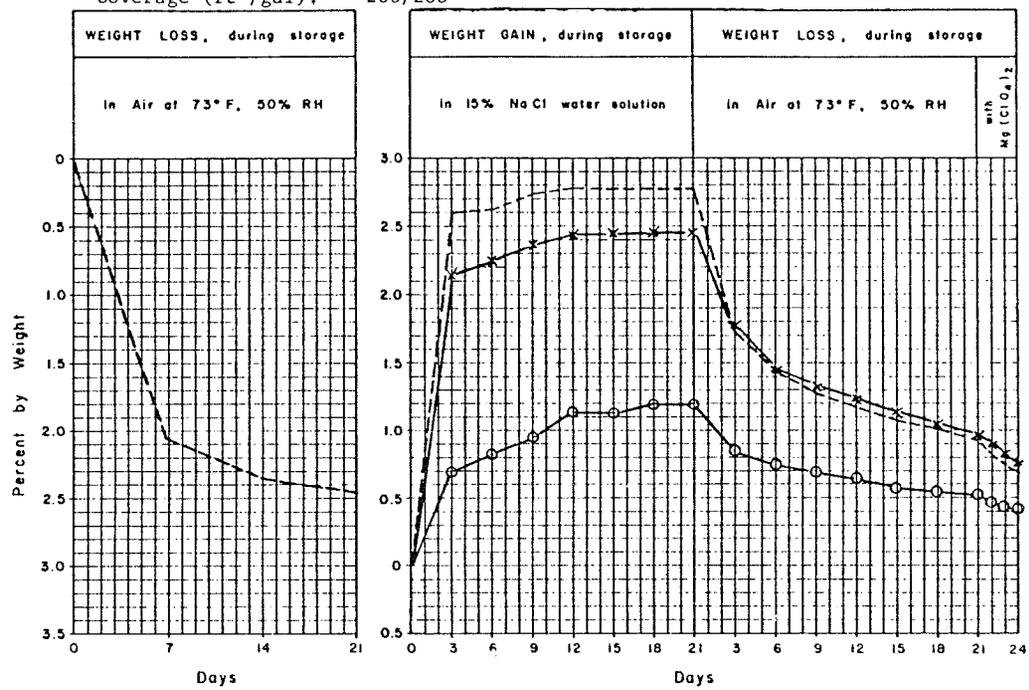


Fig. B-14 - Weight Loss and Gain Data - Material No. 13

CHEMICAL COMPOSITION: One component chemically curing aliphatic urethane
 Coverage (ft²/gal): 200

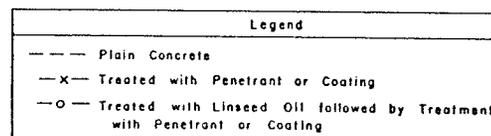
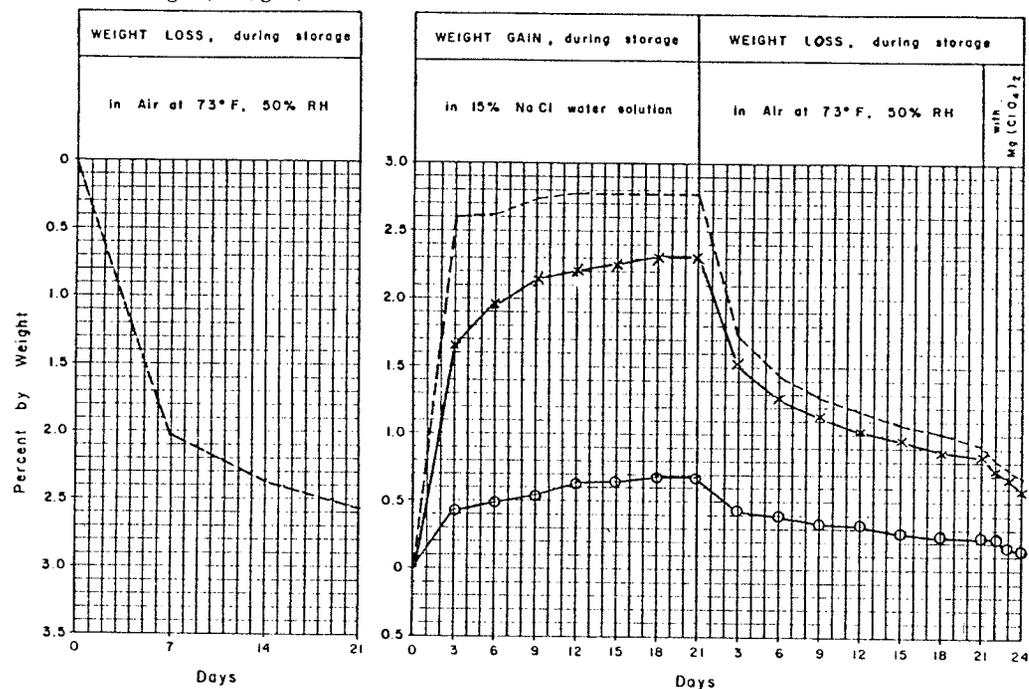


Fig. B-15 - Weight Loss and Gain Data - Material No. 14

CHEMICAL COMPOSITION: Two-component epoxy
 Coverage (ft²/gal): 450/450

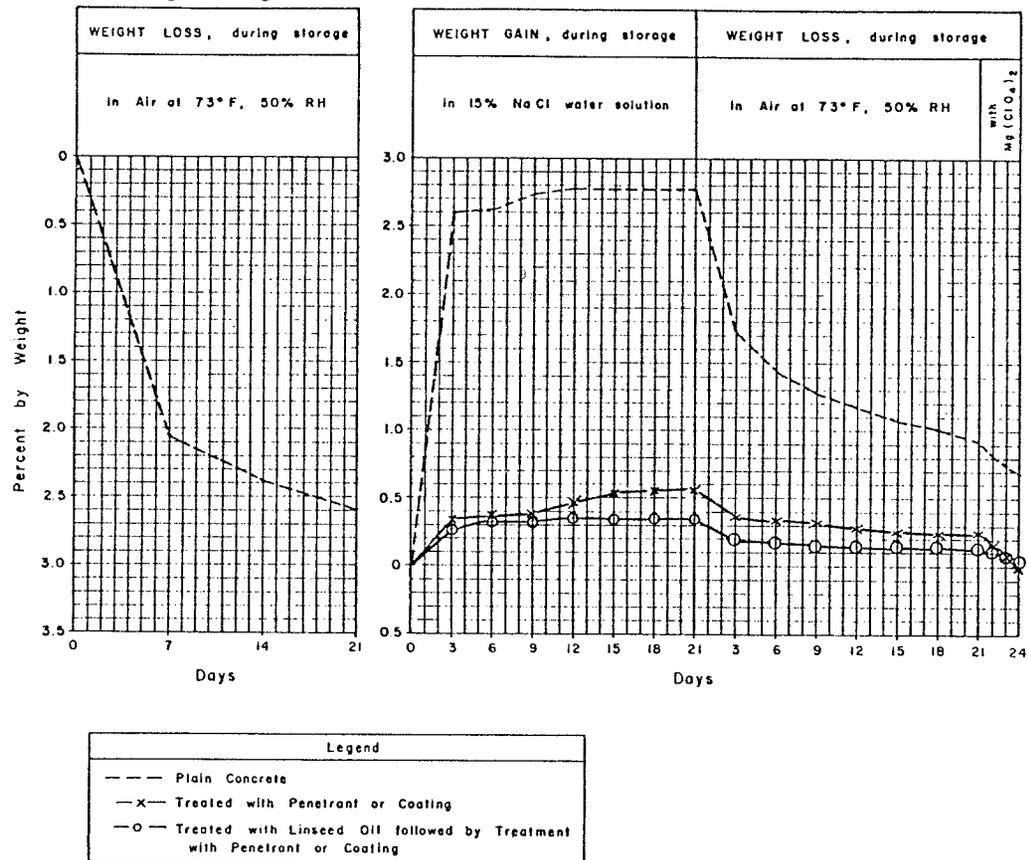
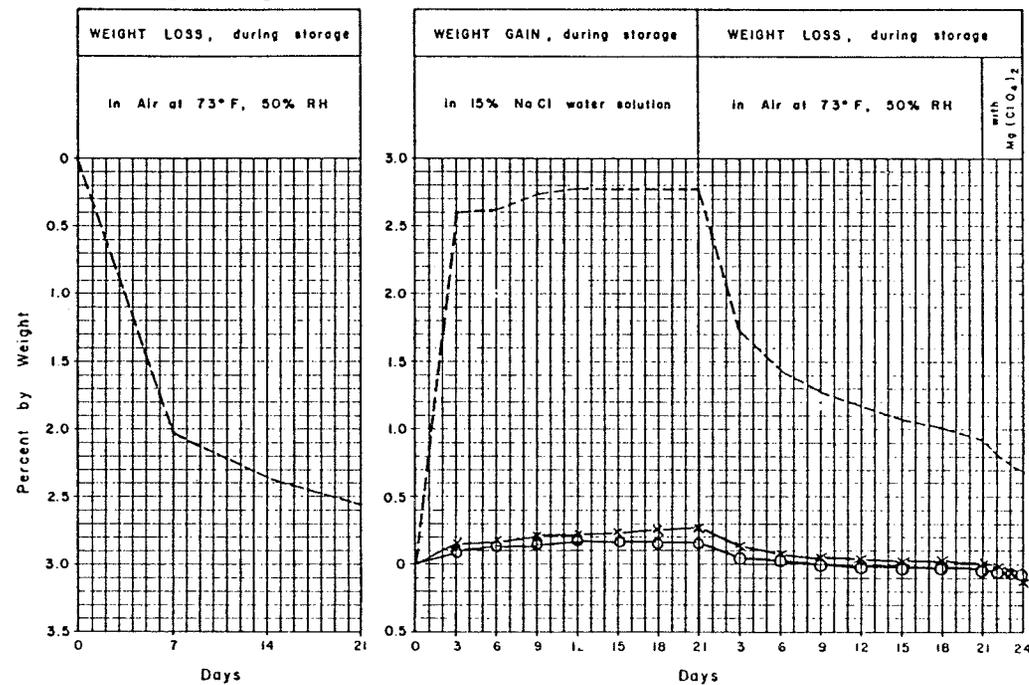


Fig. B-16 - Weight Loss and Gain Data - Material No. 15

CHEMICAL COMPOSITION: Two-component epoxy
 Coverage (ft²/gal): 120/120



Legend	
---	Plain Concrete
-x-	Treated with Penetrant or Coating
-o-	Treated with Linseed Oil followed by Treatment with Penetrant or Coating

Fig. B-17 - Weight Loss and Gain Data - Material No. 16

CHEMICAL COMPOSITION: Two-component epoxy based on polysulfide polymer
 Coverage (ft²/gal): 100/100

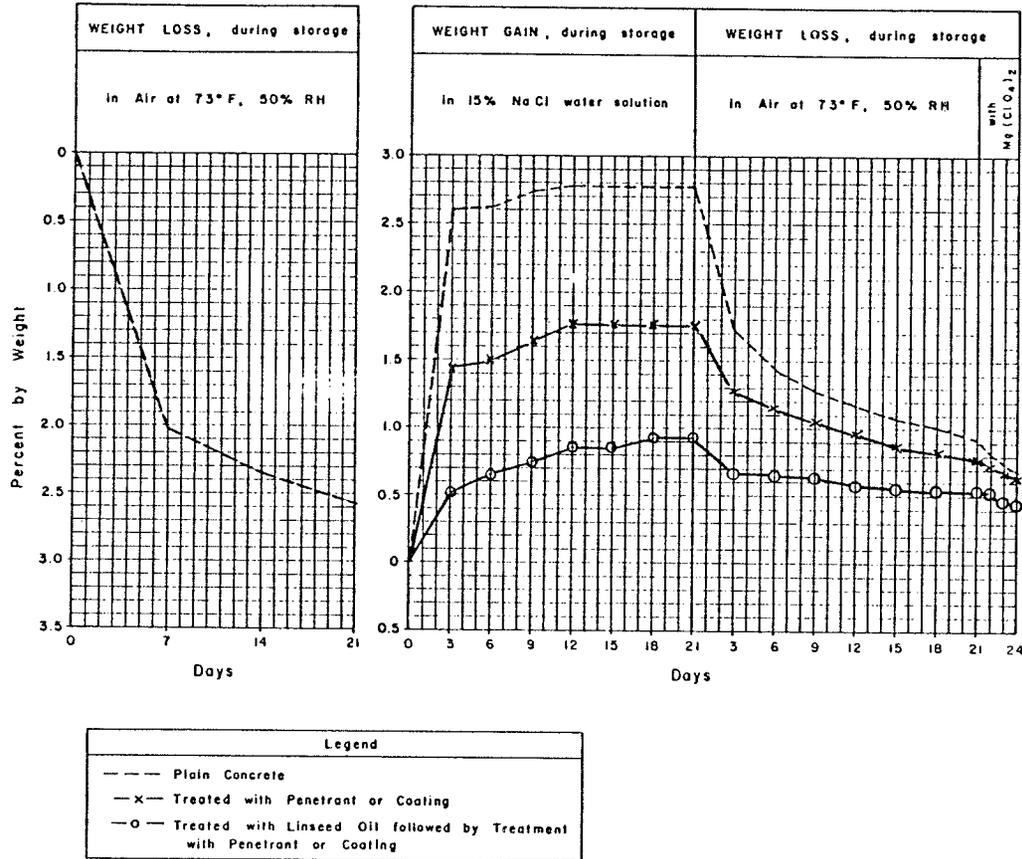
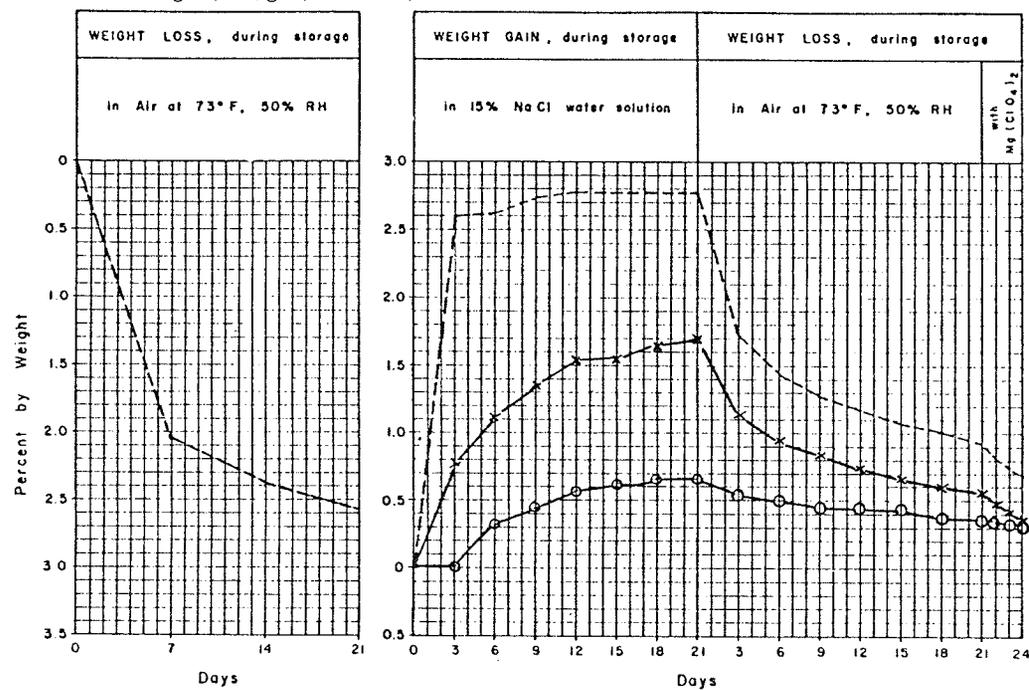


Fig. B-18 - Weight Loss and Gain Data - Material No. 17

CHEMICAL COMPOSITION: Two-component epoxy
 Coverage (ft²/gal): 200/200



Legend	
---	Plain Concrete
-x-	Treated with Penetrant or Coating
-o-	Treated with Linseed Oil followed by Treatment with Penetrant or Coating

Fig. B-19 - Weight Loss and Gain Data - Material No. 18

CHEMICAL COMPOSITION: Two-component epoxy
 Coverage (ft²/gal): 300/300

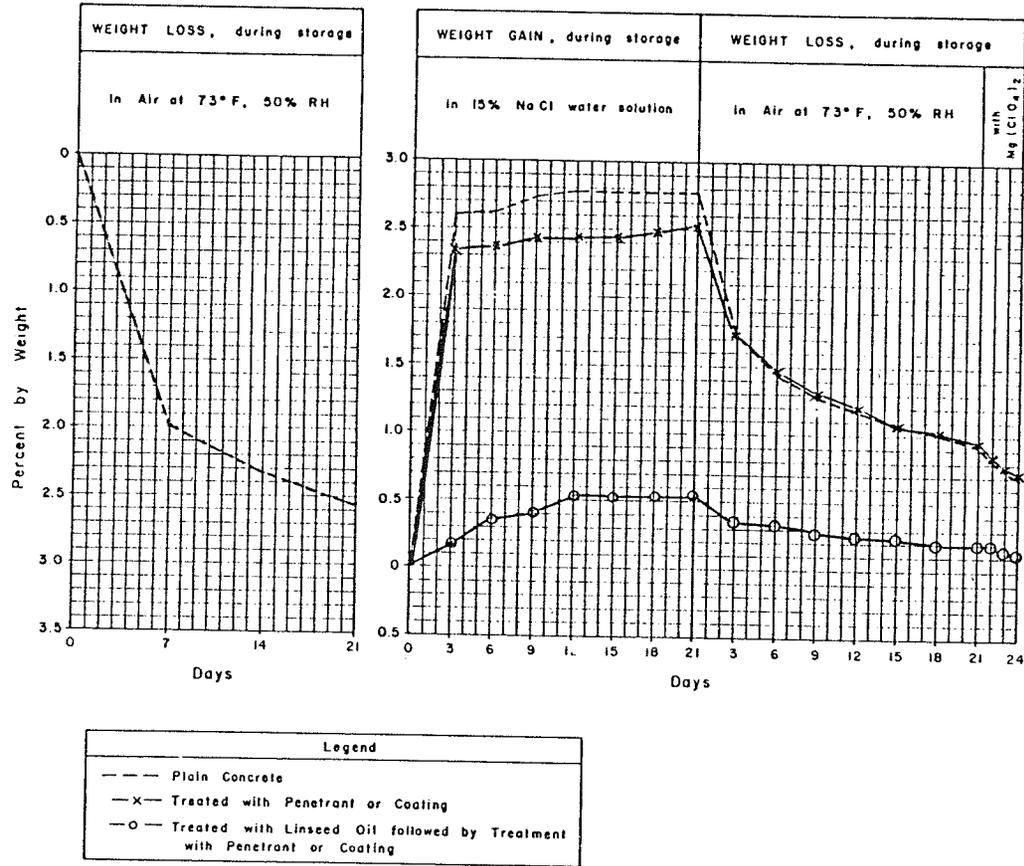


Fig. 20 - Weight Loss and Gain Data - Material No. 19

CHEMICAL COMPOSITION: Two-component epoxy system based on polysulfide polymer.
 Coverage (ft²/gal): 80

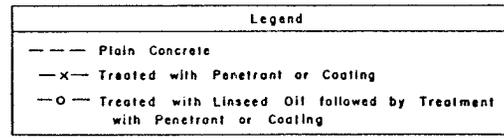
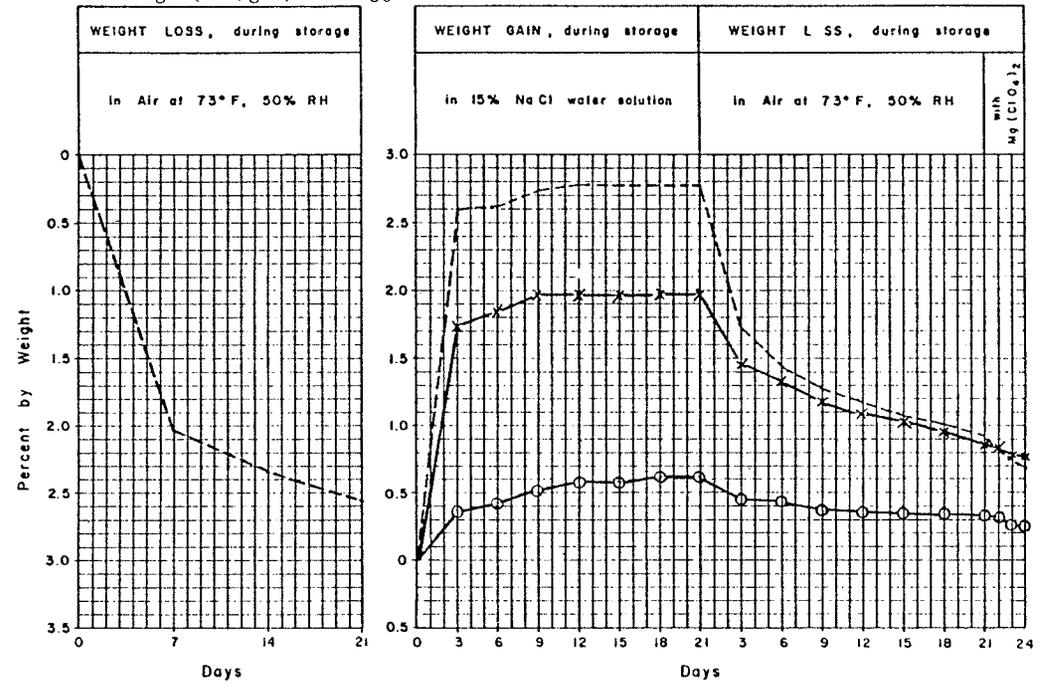


Fig. B-21 - Weight Loss and Gain Data - Material No. 20

CHEMICAL COMPOSITION: Two-component epoxy
 Coverage (ft²/gal): 300/300

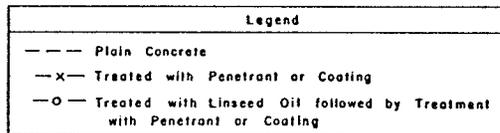
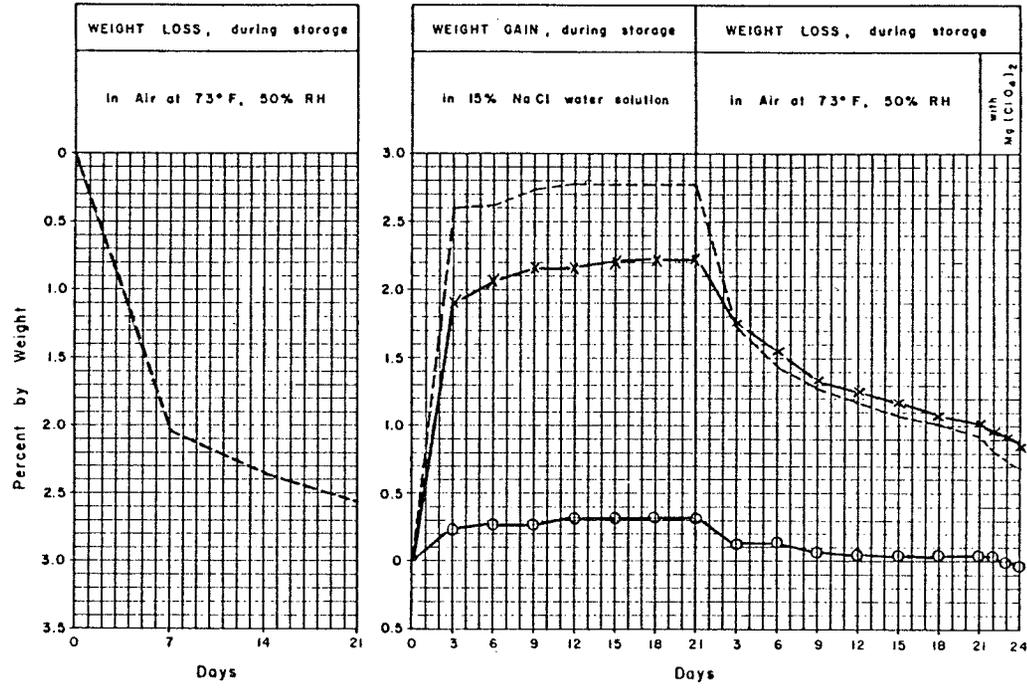


Fig. B-22 - Weight Loss and Gain Data - Material No. 21

TABLE B-26 - CHLORIDE ION CONTENT IN CONCRETE AFTER SCREENING TESTS

Test No.	Chemical composition	Concrete treated with penetrant or coating	Concrete treated with linseed oil followed by treatment with penetrant or coating
		Percent by weight of concrete	
1	Siloxane	0.367* (0.002) ⁺	0.313* (0.007) ⁺
2	Linseed oil	0.289 (0.027)	0.174 (0.012)
3	Siliconate	0.338 (0.025)	0.271 (0.036)
4	Urethane	0.128 (0.022)	0.079 (0.012)
5	Chlorinated rubber	0.303 (0.001)	0.200 (0.026)
6	Silane	0.130 (0.030)	0.185 (0.020)
7	Styrene butadiene	0.351 (0.015)	0.261 (0.031)
8	Methyl methacrylate	0.127 (0.019)	0.105 (0.023)
9	Sodium silicate	0.327 (0.067)	0.268 (0.012)
10	Polyisobutyl-methacrylate	0.206 (0.008)	0.095 (0.014)
11	Vinyl toluene butadiene	0.289 (0.012)	0.191 (0.021)
12	Al stearate and isobutylene	0.326 (0.020)	0.194 (0.005)
13	Methyl methacrylate-ethylacrylate	0.313 (0.022)	0.174 (0.065)
14	Urethane	0.300 (0.046)	0.118 (0.013)
15	Epoxy	0.124 (0.056)	0.105 (0.030)
16	Epoxy	0.088 (0.016)	0.086 (0.009)
17	Epoxy-polysulfide	0.238 (0.015)	0.155 (0.037)
18	Epoxy	0.241 (0.050)	0.139 (0.029)
19	Epoxy	0.313 (0.007)	0.131 (0.016)
20	Epoxy-polysulfide	0.252 (0.029)	0.128 (0.006)
21	Epoxy	0.281 (0.001)	0.092 (0.008)
22	Plain concrete TESTED	0.316 (0.015)	—
23	Plain concrete UNTESTED	0.080	—

Test No. 22 = Plain concrete exposed to 15% NaCl water solution
 Test No. 23 = Plain concrete - (control samples stored in air at 73°F and 50% RH only)

* Average values of chloride ion from two tests

⁺ Range of chloride ion content from two tests

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Discussion of Test Results

The weight change results at the conclusion of the soaking and drying tests for all 22 samples (including the uncoated concrete control specimens), with and without the linseed oil pretreatment, are given in Tables B-27 and B-28. Because of the large amount of data presented, the results for specimens which were not pretreated with linseed oil will be discussed first, followed by those that were pretreated with linseed oil.

Weight Change for Specimens without Linseed Oil Pretreatment. The final weight gain data shown in Table B-27 and Fig. B-23 can be separated, for convenience, into the following three groups:

Group No.	Final Weight Gain, %	No. of Materials
1A	< 1.0	5
2A	> 1.0; < 2.77	13
3A	> 2.77	3

The five materials in Group 1A were coated with two epoxy formulations, a methyl methacrylate, a urethane, and a silane. All of these materials, with the exception of the silane, required two coats.

The 13 materials in Group 2A exhibited weight gains between 1.0 percent and 2.77 percent, which was the amount gained by the uncoated concrete control specimens. These 13 specimens were coated with the polyisobutyl methacrylate, five epoxy formulations, the linseed oil, a urethane, the sodium silicate, the vinyl-toluene-butadiene, a methyl methacrylate, a mixture of

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TABLE B-27 - AVERAGE WEIGHT GAIN AFTER 21 DAYS IN 15 PERCENT NaCl WATER SOLUTION

Average weight gain % by wt	Concrete treated with penetrant or coating		Concrete treated with linseed oil followed by treatment with penetrant or coating		Group No.
	Test No.	Chemical composition	Test No.	Chemical composition	
0.18	16	Epoxy	16	Epoxy	1A
0.24			4	Urethane	
0.29			21	Epoxy	
0.31			15	Epoxy	
0.36			19	Epoxy	
0.53	15	Epoxy	8	Methyl methacrylate-ethylacrylate	
0.57			8	Methyl methacrylate-ethylacrylate	
0.60			4	Urethane	
0.61	8	Methyl methacrylate-ethylacrylate	18	Epoxy	
0.63	4	Urethane	14	Urethane	
0.66			10	Polyisobutyl methacrylate	
0.69	6	Silane	17	Epoxy (polysulfide)	
0.72			13	Methyl methacrylate-ethylacrylate	
0.83			12	Al stearate and isobutylene	
0.92			6	Silane	
1.20			2	Linseed oil	
1.29			11	Vinyl toluene butadiene	
1.31	10	Polyisobutyl methacrylate	5	Chlorinated rubber	
1.34			9	Sodium silicate	
1.68	17	Epoxy	2	Linseed oil	
1.70			20	Epoxy (polysulfide)	
1.72			2	Linseed oil	
1.78			21	Epoxy	
1.97			14	Urethane	
1.99			9	Sodium silicate	
2.19			11	Vinyl toluene butadiene	
2.23			13	Methyl methacrylate-ethylacrylate	
2.32			12	Al stearate and isobutylene	
2.39			19	Epoxy	
2.41	9	Sodium silicate	3	Siliconate	
2.42			7	Styrene-butadiene	
2.47	13	Methyl methacrylate-ethylacrylate	1	Siloxane	
2.50			12	Al stearate and isobutylene	
2.53			19	Epoxy	
2.54	5	Chlorinated rubber			
2.74					
2.77	PLAIN CONCRETE				
2.80	7	Styrene butadiene			3A
2.84	3	Siliconate			
2.87	1	Siloxane			

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TABLE B-28 - AVERAGE RESIDUAL WEIGHT CHANGE AFTER 21 DAYS IN AIR AT 73°F, 50 PERCENT R.H., AND 3 DAYS IN MAGNESIUM PERCHLORATE ATMOSPHERE

Average residual weight change % by weight	Concrete treated with penetrant or coating		Concrete treated with linseed oil followed by treatment with penetrant or coating		Group No.
	Test No.	Chemical composition	Test No.	Chemical composition	
-0.28	8	Methyl methacrylate			1B
-0.20			6	Silane	
-0.14			4	Urethane	
-0.13			16	Epoxy	
-0.08			4	Urethane	
-0.06	15	Epoxy	16	Epoxy	
-0.01			8	Methyl methacrylate	
-0.01			21	Epoxy	
-0.07	10	Polyisobutyl methacrylate	15	Epoxy	
+0.16			19	Epoxy	
+0.17			14	Urethane	
+0.18			6	Silane	
+0.21			10	Polyisobutyl methacrylate	
+0.21			20	Epoxy (polysulfide)	
+0.28			18	Epoxy	
+0.33			13	Methyl methacrylate-ethylacrylate	
+0.36			12	Al stearate and isobutylene	
+0.42			17	Epoxy (polysulfide)	
+0.43	5	Chlorinated rubber	12	Al stearate and isobutylene	
+0.45			17	Epoxy	
+0.47			9	Sodium silicate	
+0.49			2	Linseed oil	
+0.50			14	Urethane	
+0.59			12	Al stearate and isobutylene	
+0.62			17	Epoxy	
+0.63			7	Styrene butadiene	
+0.64			3	Siliconate	
+0.66					
+0.67					
+0.69	PLAIN CONCRETE				
+0.71	11	Vinyl toluene butadiene			3B
+0.72	19	Epoxy	2	Linseed oil	
+0.72	1	Siloxane	11	Vinyl toluene butadiene	
+0.76	13	Methyl methacrylate-ethylacrylate	5	Chlorinated rubber	
+0.77	20	Epoxy (polysulfide)	3	Siliconate	
+0.79	21	Epoxy	1	Siloxane	
+0.85			7	Styrene butadiene	
+0.86					
+1.08					
+1.16					

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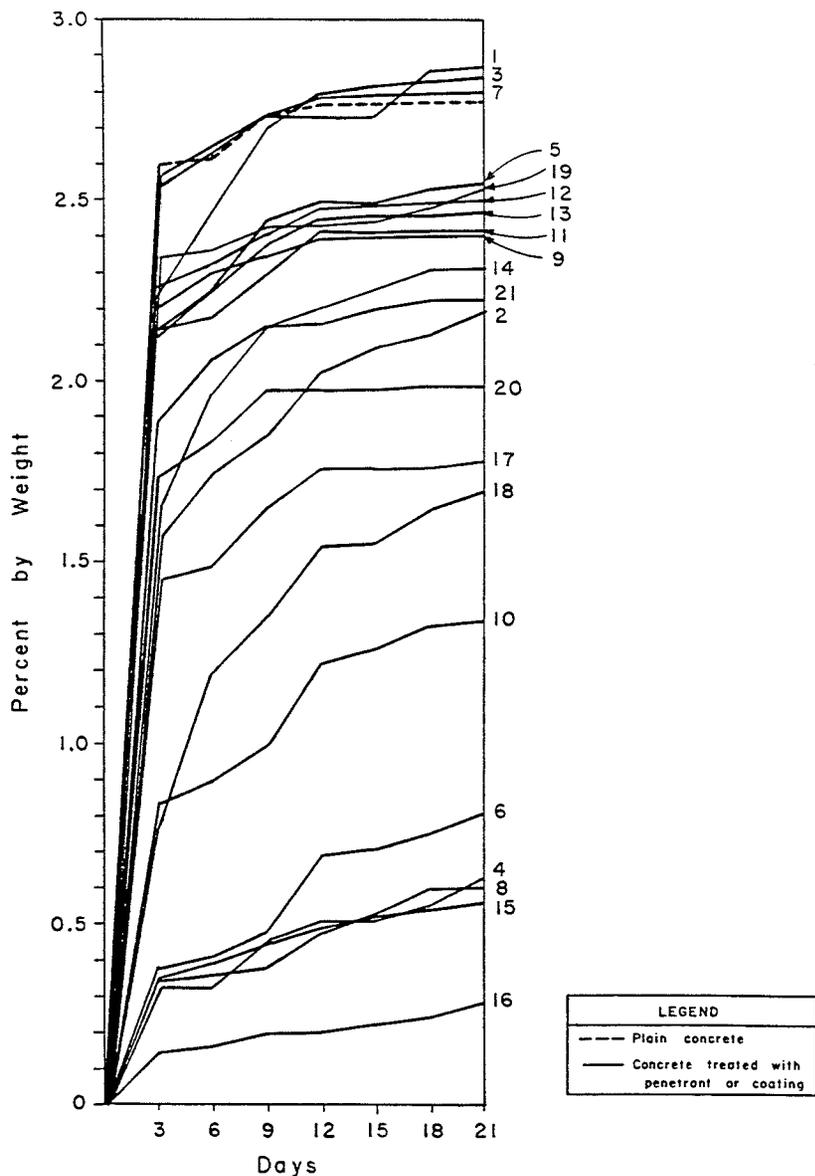


Fig. B-23 - Weight Gain During Storage in 15% NaCl Solution for 21 Days

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aluminum stearate and isobutylene, and chlorinated rubber. The urethane, sodium silicate, vinyl-toluene butadiene and one of the polysulfide-based epoxy formulations required one coat. All of the remaining nine materials required two coats.

The specimens coated with the materials in Group 3A, consisting of the styrene butadiene, the siliconate, and the siloxane gained slightly more weight than the uncoated concrete control specimens. These materials all required only one coat.

The final residual weight change data shown in Table B-28 and Fig. B-24 also can be separated conveniently into three groups as follows:

Group No.	Final Residual Weight Change, %	No. of Materials
1B	-0.28 to -0.01	5
2B	+0.07 to +0.67	10
3B	+0.71 to +1.16	6

The five materials in Group 1B all lost more weight by vapor transmission during the drying period than they had gained during the soaking period. These are the same five materials from Group 1A which gained the least amount of weight during soaking.

The ten materials in Group 2B all gained more weight during the soaking period than they lost during drying, but they performed better than the uncoated concrete, which had a residual weight change of +0.69 percent.

The six materials of Group 3B all had residual weight changes greater than that of plain concrete.

The same test results are presented in Table B-29, ranked according to their weight loss as a percentage of weight gain. Groups are separated here

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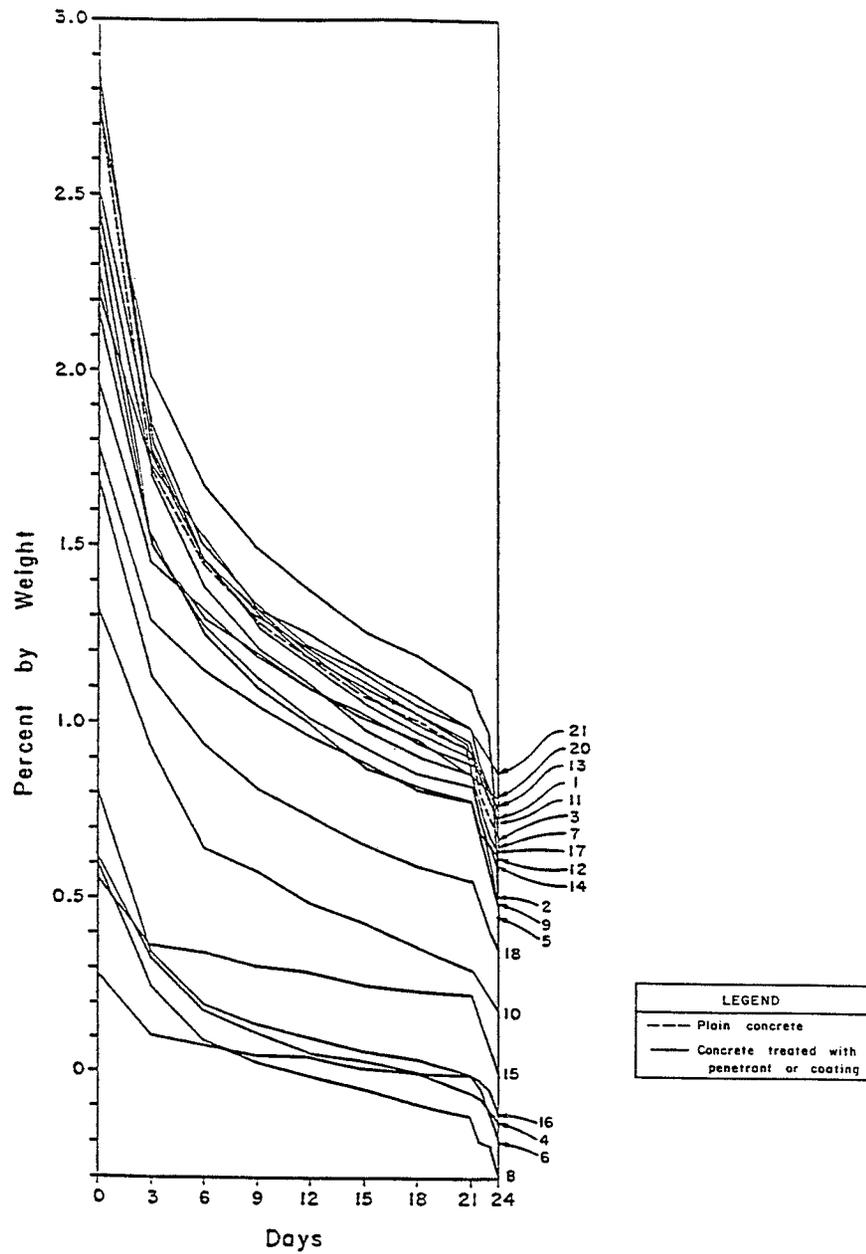


Fig. B-24 - Weight Loss During Storage in Air at 73°F, 50% R. H. for 21 Days Plus 3 Days in the Presence of $Mg(ClO_4)_2$

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TABLE B-29 - AVERAGE WEIGHT LOSS AFTER ALL DRYING AS A PERCENTAGE OF WEIGHT GAIN CAUSED BY SOAKING

Average weight loss %	Concrete treated with penetrant or coating		Concrete treated with linseed oil followed by treatment with penetrant or coating		Group No.
	Test No.	Chemical composition	Test No.	Chemical composition	
145.9	8	Methyl methacrylate-ethylacrylate			1C
144.8	16	Epoxy	4	Urethane	
133.3			16	Epoxy	
133.3	6	Silane	21	Epoxy	
124.4	4	Urethane			
122.2	15	Epoxy	8	Methyl methacrylate-ethylacrylate	
103.2					
101.8					
101.7					
86.6	10	Polyisobutyl methacrylate			
84.0			6	Silane	
82.3	5	Chlorinated rubber	15	Epoxy	
80.6					
79.6	9	Sodium silicate			
78.8	18	Epoxy			
77.2	2	Linseed oil	14	Urethane	
77.1	7	Styrene butadiene			
76.7	3	Siliconate			
75.4	12	Al stearate and isobutylene			
75.2					
75.0 PLAIN CONCRETE					
74.9	1	Siloxane			3C
74.6	14	Urethane	10	Polyisobutyl methacrylate	
71.5	19	Epoxy	19	Epoxy	
70.8					
70.7	11	Vinyl toluene butadiene	12	Al stearate and isobutylene	
69.8			9	Sodium silicate	
68.8	13	Methyl methacrylate-ethylacrylate	13	Methyl methacrylate-ethylacrylate	
66.7			3	Siliconate	
66.0	17	Epoxy (polysulfide)	1	Siloxane	
65.0	21	Epoxy	5	Chlorinated rubber	
64.6			11	Vinyl toluene butadiene	
64.4			20	Epoxy (polysulfide)	
61.4			7	Styrene butadiene	
60.6			18	Epoxy	
60.3	20	Epoxy (polysulfide)	17	Epoxy (polysulfide)	
55.2			2	Linseed oil	
54.8					
54.1					
53.0					
50.0					
48.9					
46.3					

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also into those which lost more than they gained and those which were better or worse than uncoated concrete.

Weight Change for Specimens With Linseed Oil Pretreatment. The three groups shown in Table B-27 contain the following number of materials:

<u>Group No.</u>	<u>Final Residual Weight Change, %</u>	<u>No. of Materials</u>
1A	< 1.0	11
2A	> 1.0; < 2.77	10
3A	> 2.77	0

The 11 materials in Group 1A exhibited weight gains less than 1.0 percent. These specimens were coated with seven epoxy formulations, both types of urethane, and two types of methyl methacrylate. All of these materials, with the exception of one epoxy based on polysulfide polymer and one urethane, required two coats.

The remaining 10 materials are in Group 2A, which exhibited weight gains between 1.0 percent and 2.77 percent, which was the amount gained by the uncoated concrete control specimens.

None of the specimens pretreated with linseed oil gained more weight than the uncoated concrete specimens.

The final residual weight change data shown in Table B-28 can also be separated into three groups:

<u>Group No.</u>	<u>Final Residual Weight Change, %</u>	<u>No. of Samples</u>
1B	-0.28 to -0.01	4
2B	+0.07 to +0.67	11
3B	+0.71 to +1.16	6

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The four materials in Group 1B all lost more weight during the drying period than they had gained during the soaking period. These specimens were coated with two of the epoxy formulations, a urethane and methyl methacrylate, and all required two coats.

The 11 materials in Group 2B gained more weight during the soaking period than they lost during drying but performed better than the plain concrete. These specimens were coated with five epoxy formulations, a urethane, the silane, the two types of methacrylate, a mixture of aluminum stearate and isobutylene and the sodium silicate. One of the polysulfide based epoxy formulations, the silane and the sodium silicate required one coat. All of the remaining materials required two coats.

The specimens coated with the materials in Group 3B, consisting of the linseed oil, the vinyl-toluene-butadiene, the chlorinated rubber, the silicone, the siloxane and the styrene butadiene, had residual weight changes greater than that of plain concrete. Figs. B-25 and B-26 show the weight gain during water immersion and subsequent weight loss during drying for all specimens pretreated with linseed oil prior to application of the sealants.

Discussion of Individual Absorption and Desorption Characteristics. In the following subsections, the different materials are reviewed with regard to the water absorption characteristics, the water vapor transmission characteristics, and the effect that pretreatment with linseed oil has upon these characteristics.

Linseed Oil. Normal treatment with two coats of boiled linseed oil, Test No. 2, resulted in absorption data that was improved over that of plain uncoated concrete, but which was only average

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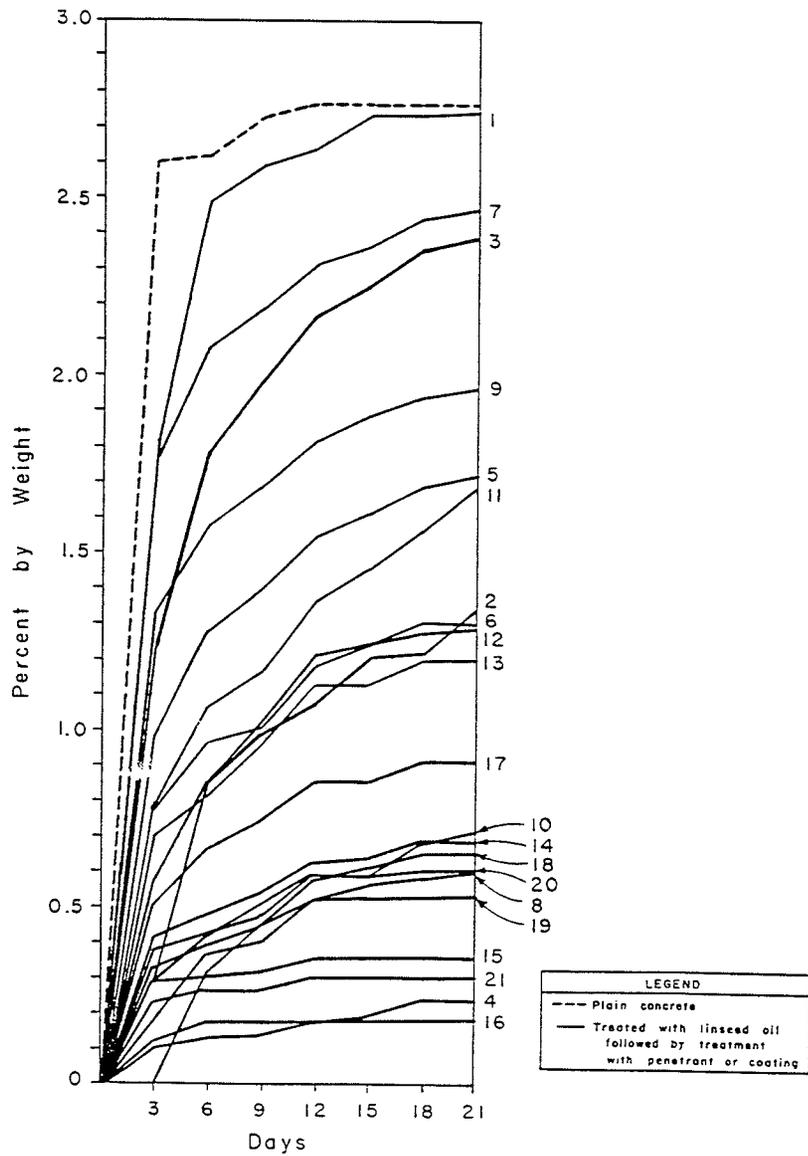


Fig. B-25 - Weight Gain During Storage in 15% NaCl Solution for 21 Days - Pretreated With Boiled Linseed Oil

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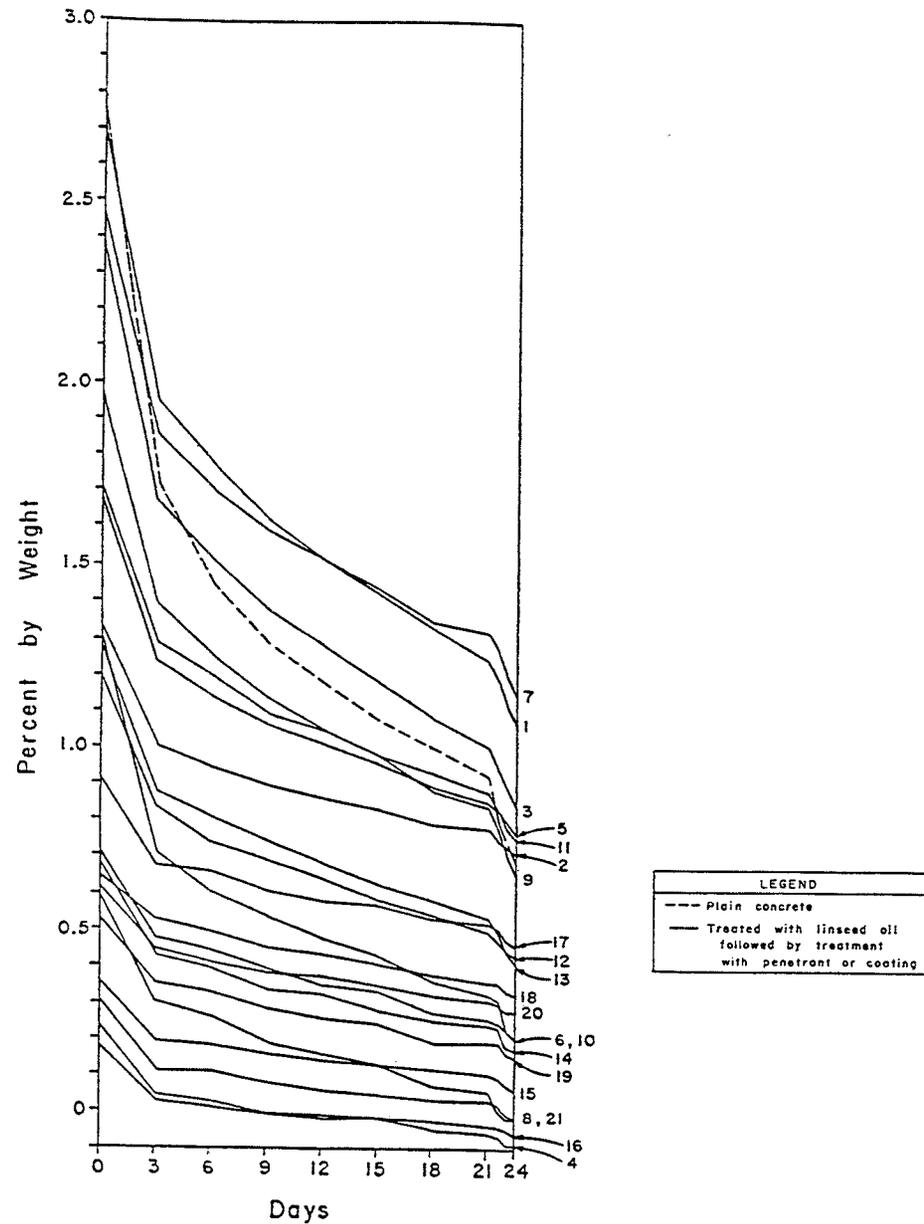


Fig. B-26 - Weight Loss During Storage in Air at 73°F, 50% R.H. for 21 Days plus 3 Days in the Presence of $Mg(ClO_4)_2$ - Pretreated With Boiled Linseed Oil

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when compared with the other tested materials. When pretreatment with linseed oil was used, the specimens eventually had four coats of linseed oil with short ultraviolet exposure between the middle two coatings. This pretreatment significantly reduced the water absorption characteristics.

The use of two or four coats of linseed oil reduced the desorption characteristics in comparison to plain uncoated concrete. In fact, as shown in Table B-29, the use of four coats of linseed oil produced the lowest (46.3 percent) weight loss percentage of all materials tested. This data suggests that multiple applications of boiled linseed oil may reduce the water vapor transmission characteristics significantly more than it reduces the water absorption characteristics.

Epoxies. The weight gain and loss characteristics of the seven epoxy formulations are generally found in all of the groupings shown in Tables B-27 and B-28, thus indicating wide variations in performance between the various epoxy formulations. Several factors appear to be significant:

1. Chemical composition
2. Solids content
3. Application rate
4. Number of coats
5. Pretreatment with linseed oil

The data appear to differentiate between the five straight epoxies and the two epoxies incorporating polysulfide polymers. The data also show that the epoxy coated specimens with low absorption are little influenced by pretreatment with linseed oil, while the epoxy coated specimens with high absorption characteristics are greatly improved by pretreatment with linseed oil.

Two epoxies, labeled Nos. 15 and 16, allowed less than 0.6 percent water absorption and subsequently allowed weight loss by water vapor transmission which was greater than the weight gain due to water absorption. These two materials had solids contents of 50 and 100 percent. Both required two coats. These test specimens both had shiny, glassy-appearing surfaces after treatment.

The weight gain characteristics of the other three straight epoxies, labeled Nos. 18, 19 and 21, are quite high. Their subsequent water vapor transmission curves are similar in shape to that of the control concrete. These three epoxies were much improved when applied over the linseed oil pretreated concrete. In fact, the pretreated No. 19 specimens had a water absorption of only 20 percent of the untreated No. 19 specimens.

When applied on untreated concrete, the water absorption characteristics for the two epoxies based upon polysulfide are relatively high. When applied to linseed oil pretreated concrete, their water absorption characteristics are significantly improved.

Fig. B-27 shows the relationship between weight gain (water absorption) and the coverage rate (in lb of epoxy solids per ft² of surface) calculated from percent solids, actual application rates and number of coats for the seven tested epoxy formulations. Smooth

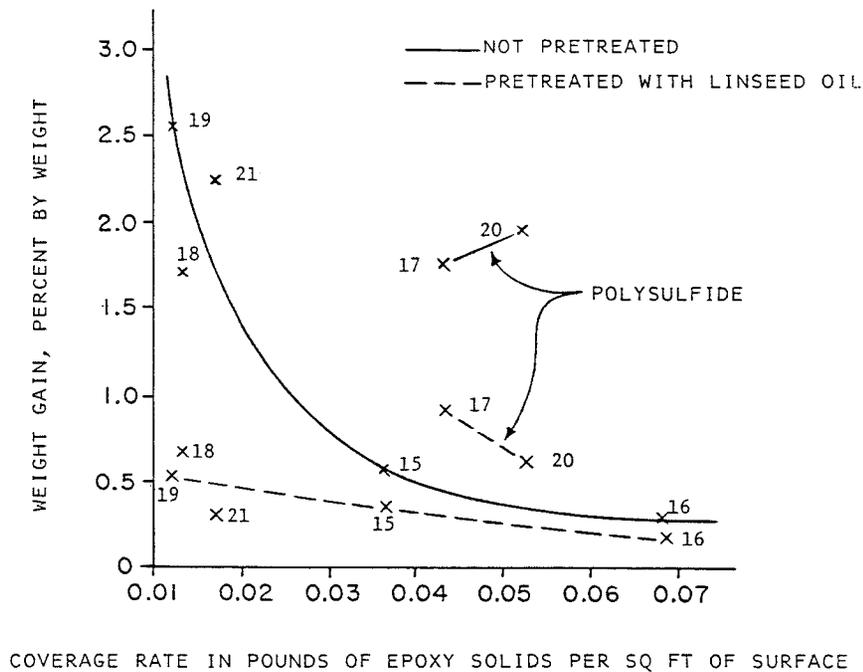


Fig. B-27 - Weight Gain vs Epoxy Solids Coverage Rate

curves have been drawn to represent the data for the five straight epoxies with and without pretreatment with linseed oil. Similar straight-line curves were drawn for the two epoxies based upon polysulfides.

These data show the dramatic influence that linseed oil pretreatment and actual epoxy coverage rate can have on water absorption. They also show that the two epoxies using polysulfides are less effective when based upon the same coverage rate.

Methyl Methacrylate. The material labeled No. 8 is described as a coating. Two coats were required. The primer was determined to be methyl siloxane and the finish coat a mixture of methyl methacrylate and ethylacrylate. It was among the most effective materials when tested on unpretreated concrete and, although it allowed somewhat more absorption than the two best epoxy formulations, it had the highest ratio of weight loss to weight gain of all of the materials. Linseed oil pretreatment significantly reduced this ratio for this material.

The second material, labeled No. 13, was found to be methyl methacrylate ethylacrylate copolymer. It also required two coats. The absorption of unpretreated concrete coated with this material was very high. The residual weight change after drying was similar to that of the control concrete. Linseed oil pretreatment greatly improved the performance of this material in both respects.

Polyisobutyl Methacrylate. This material, labeled No. 10, is based upon methacrylate and is classified as a penetrant. It was applied in two coats, one primer and one finish, both with the same

chemical composition. Its performance on untreated concrete was the best of the second group (2A) in Table B-27 in terms of low initial and residual weight gains. Pretreatment with linseed oil significantly reduced initial weight gain but slightly increased residual weight gain.

Silane. This material, labeled No. 6, is classified as a penetrant. It is described as an alkyl alkoxy silane and was applied in one coat. It greatly reduced both initial and residual weight gains. This material is the only material whose performance suffered when used with linseed oil pretreatment, enough to drop from the first group into the second group as shown in Table B-27. This apparent anomaly lends credence to the manufacturer's explanation of the mechanism by which it derives its water repellency. Briefly, it is that one portion of the molecule attaches to a silica surface, orienting the hydrophobic portion towards the center of capillary voids, thereby imparting hydrophobic properties to the capillary walls. Presumably, coating the capillary walls with linseed oil reduced this effect.

Silicate. This material, labeled No. 9, is classified as a penetrant, is described as sodium silicate and was applied in one coat. It reduced initial weight gain somewhat and reduced residual weight gain significantly. Pretreatment with linseed oil significantly reduced initial weight gain but increased residual weight gain to approximately that of the control.

Siliconate. This material, labeled No. 3, is classified as a penetrant and is described as a solution of sodium methyl silicate in water. It was diluted to a concentration of 3 percent and applied in one coat. The performance of specimens treated with this material was not significantly different from that of uncoated concrete. Pretreatment with linseed oil reduced initial weight gain somewhat but increased residual weight gain.

Urethane Resins. The range in performance between the two urethane materials is similar to that previously discussed concerning the two methyl methacrylates. The material labeled No. 4 is described as a uniquely formulated moisture-cured polyurethane resin penetrant and was among the most effective materials tested. It was applied in two coats. Linseed oil pretreatment significantly reduced both weight gain and loss characteristics. In both cases, the specimens lost more weight than they had gained.

The second material, labeled No. 14, is classified as a coating and described as a one-component chemically curing aliphatic urethane polymer solution. One coat was required. The water absorption of untreated specimens coated with the material was very high. The residual weight change after drying was similar to that of the control concrete. Linseed oil pretreatment greatly reduced initial weight gain and significantly reduced residual weight change after drying.

Butadiene Polymers. Both materials were classified as coatings and required only one coat. The material, labeled No. 7, is

described as a styrene-butadiene polymer. It had no beneficial effect on weight gain and although the rate of weight loss was slower, the residual weight gain was similar to that of uncoated concrete. Linseed oil pretreatment reduced initial weight gain somewhat but significantly increased the residual weight gain.

The second material, labeled No. 11, was determined to be a vinyl-toluene-butadiene copolymer. Initial weight gain was reduced somewhat, but residual weight gain was nearly identical to that of the uncoated concrete. Pretreatment with linseed oil significantly reduced the rate and amount of initial gain but had essentially no effect on residual weight gain.

Chlorinated Rubber. This material, labeled No. 5, is classified as a penetrant and was applied in one coat. Initial weight gain was reduced somewhat in comparison to the control concrete and residual weight gain was reduced. Linseed oil pretreatment significantly reduced the rate and amount of initial weight gain but increased residual weight gain somewhat.

Siloxane. This material, labeled No. 1, is classified as a penetrant and is described as a mixture of siloxane and was applied in one coat. It allowed the greatest initial weight gain, surpassing the uncoated concrete. Residual weight gain was also slightly higher than the control concrete. Pretreatment with linseed oil reduced initial weight gain to essentially that of the control but significantly increased residual weight gain.

Aluminum Stearate. The chemical composition of this material, labeled No. 12, was determined to be a mixture of aluminum stearate and isobutylene. It allowed a slight reduction in both initial and residual weight gain when compared with the control concrete. Pretreatment with linseed oil greatly reduced initial weight gain and significantly reduced residual weight gain.

Results of Chloride Ion Content Analyses. The chloride contents in all specimens were determined by an acid digestion potentiometric titration procedure which is routinely used by the firm of Erlin, Hime Associates. The results of these tests are given in Table B-26.

These data show that the untested control concrete samples (cubes stored continuously in air in 73 degrees F and 50 percent R.H.), labeled Test No. 23, contained a significant amount of chloride (0.08 percent). Subsequently, chloride analyses were made on unused portions of the cement and aggregates. The results of these tests were as follows:

<u>Material</u>	<u>Source</u>	<u>Chloride Ion Content (% by wt)</u>
Portland cement Type I	Huron Cement Company	< 0.007
Natural sand	Bensenville, Illinois pit	0.040
No. 67 (3/4 in.) crushed limestone coarse aggregate	Thornton, Illinois quarry	0.144

By using these data, the Series I concrete mix, containing about 500 lb of cement, 1580 lb of coarse aggregate and 1595 lb of sand was calculated to initially contain approximately 0.075 percent of chloride ion by weight of

concrete prior to the tests. Thus, the experimental results on the materials confirmed the chloride test results on the untested control specimen No. 23.

The actual chloride ion contents caused by the exposure to water containing 15 percent NaCl have been obtained by subtracting this background 0.08 percent chloride ion from the totals given in Table B-26. These adjusted (net) chloride ion values are listed in Table B-30.

The values of adjusted chloride ion content content given in Table B-30 for the unpretreated concretes can be separated into the following three groups:

Group No.	Adjusted Chloride Ion Content, %	No. of Samples
1D	0.000 to 0.050	5
2D	0.051 to 0.236	11
3D	0.236 to 0.287	6

Five materials had values less than 0.050 percent by weight. These five materials (two epoxies, one methyl methacrylate, the moisture-cured urethane and the silane) also showed the smallest weight gains after 21 days in the 15 percent NaCl water solution.

The eleven materials in the second group, labeled 2D, had values greater than 0.50 percent but less than 0.236 percent, the amount absorbed by the uncoated concrete specimens. They are polyisobutyl methacrylate, five epoxies, linseed oil, vinyl-toluene-butadiene, chemically cured urethane, chlorinated rubber and emulsion of methyl methacrylate. The five samples in Group 3D had higher values than the plain control concrete. They are the

TABLE B-30 - ADJUSTED CHLORIDE ION CONTENT IN CONCRETE AFTER SCREENING TESTS

Chloride ion content % by weight	Concrete treated with penetrant or coating		Concrete treated with linseed oil followed by treatment with penetrant or coating		Group No.
	Test No.	Chemical composition	Test No.	Chemical composition	
0.000	16	Epoxy	4	Urethane	1D
0.006			16	Epoxy	
0.008			21	Epoxy	
0.012			10	Polyisobutyl methacrylate	
0.015			8	Methyl methacrylate	
0.025	15	Epoxy			
0.025	14	Urethane			
0.038	15	Epoxy	20	Epoxy (polysulfide)	
0.044			8	Methyl methacrylate	
0.047			4	Urethane	
0.048			6	Silane	
0.050	6	Silane			
0.051	10	Polyisobutyl methacrylate	19	Epoxy	2D
0.059			18	Epoxy	
0.075			17	Epoxy (polysulfide)	
0.094			2	Linseed oil	
0.094			13	Methyl methacrylate-ethylacrylate	
0.105			6	Silane	
0.111			11	Vinyl toluene butadiene	
0.114			12	Al stearate and isobutylene	
0.120			5	Chlorinated rubber	
0.126			7	Styrene butadiene	
0.158			9	Sodium silicate	
0.161	3	Siliconate			
0.172	21	Epoxy	24	No surface treatment	
0.181			1	Siloxane	
0.188			13	Methyl methacrylate-ethylacrylate	
0.191	2	Linseed oil	19	Epoxy	
0.201			11	Vinyl toluene butadiene	
0.209			14	Urethane	
0.209			5	Chlorinated rubber	
0.220			13	Methyl methacrylate-ethylacrylate	
0.223	19	Epoxy	1	Siloxane	
0.229			13	Methyl methacrylate-ethylacrylate	
0.233	19	Epoxy			
0.233	19	Epoxy			
0.236	PLAIN CONCRETE				
0.246	12	Al stearate and isobutylene			3D
0.247	9	Sodium silicate			
0.258	3	Siliconate			
0.271	7	Styrene butadiene			
0.287	1	Siloxane			

TABLE B-31 - RELATIONSHIP BETWEEN WATER ABSORPTION AND CHLORIDE ION CONTENT

Concrete Treated With Penetrant or Coating Only

Test No.	Chloride ion content		Weight gain after 21 days in 15% NaCl		Calculated % Chloride in solution absorbed	Chemical composition
	% by weight	Order No.	% by weight	Order No.		
16	0.008	1	0.29	1	2.8	Epoxy
15	0.044	2	0.57	2	7.7	Epoxy
8	0.047	3	0.61	3	7.7	Methylmethacrylate
4	0.048	4	0.63	4	7.6	Moisture cured urethane
6	0.050	5	0.82	5	6.1	Alkyl Alkoxy Silane
10	0.126	6	1.34	6	9.4	Polyisobutyl methacrylate
17	0.158	7	1.78	8	8.9	Epoxy (Polysulfide)
18	0.161	8	1.70	7	9.5	Epoxy
20	0.172	9	1.99	9	8.6	Epoxy (Polysulfide)
21	0.201	10	2.23	11	9.0	Epoxy
2	0.209	11	2.19	10	9.5	Linseed oil
11	0.209	12	2.42	14	8.6	Vinyl toluene butadiene
14	0.220	13	2.32	12	9.5	Chemically cured urethane
5	0.223	14	2.54	18	8.8	Chlorinated rubber
13	0.233	15	2.47	15	9.4	Methylmethacrylate (emulsion)
19	0.233	16	2.53	17	9.2	Epoxy
	0.236	12	2.77	19	8.5	P L A I N C O N C R E T E
12	0.246	18	2.50	16	9.8	Al stearate and isobutylene
9	0.247	19	2.41	13	10.3	Sodium silicate
3	0.258	20	2.84	21	9.1	Siliconate
7	0.271	21	2.80	20	9.7	Styrene butadiene
1	0.287	22	2.87	22	10.0	Siloxane

mixture of aluminum stearate and isobutylene, sodium silicate, silicone, styrene butadiene polymer and siloxane.

The values of adjusted chloride ion content given in Table B-30 for specimens pretreated with linseed oil can also be separated into the same three groups as follows:

Group No.	Adjusted Chloride Ion Content, %	No. of Samples
1D	0.000 to 0.050	8
2D	0.051 to 0.236	13
3D	0.236 to 0.287	0

These data show that pretreatment with linseed oil was beneficial in improving the general performance of most of the materials with respect to chloride ion intrusion, and when the specimens were pretreated with linseed oil, all samples absorbed less chloride than the plain concrete, as shown in Table B-30.

Of the entire 21 materials, only the silane lost effectiveness due to the pretreatment with linseed oil, allowing a doubling of the chloride ion intrusion over that of the untreated silane concrete specimen. Also of interest are the materials which exhibited greatly improved performance when used in conjunction with the linseed oil pretreatment, particularly those which moved from Group 2D to 1D, namely Nos. 10, 14, 20 and 21.

Values for chloride ion content and weight gain for all of the materials are summarized in Tables B-31 and B-32 and are depicted graphically in Figs. B-28 and B-29.

Also shown in Tables B-31 and B-32 are the calculated values for the apparent strength of the chloride solution which penetrated the specimens.

CONCRETE TREATED WITH PENETRANTS

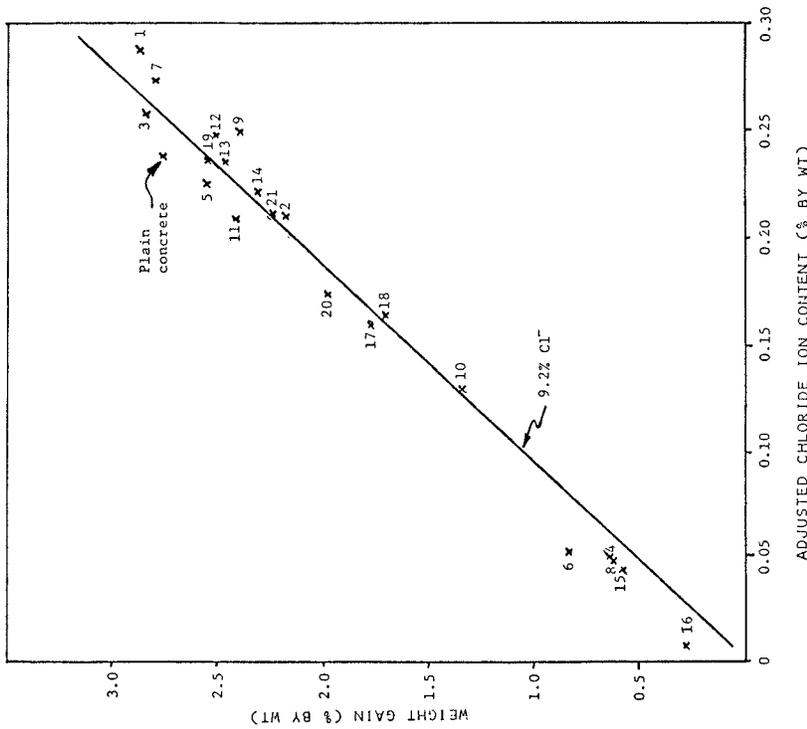


Fig. B-28 - Relationship between weight gain and adjusted chloride ion content

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TABLE B-32 - RELATIONSHIP BETWEEN WATER ABSORPTION AND CHLORIDE ION CONTENT

Concrete Treated With Linseed Oil Followed By Treatment With Penetrant or Coating

Test No.	Chloride ion content		Weight gain after 21 days in 15% NaCl		Calculated % Chloride in solution absorbed	Chemical composition
	% by weight	Order No.	% by weight	Order No.		
4	0.000	1	0.24	2	0.0	Moisture cured urethane
16	0.006	2	0.18	1	3.4	Epoxy
21	0.012	3	0.31	3	3.9	Epoxy
10	0.015	4	0.72	10	2.1	Polyisobutyl methacrylate
8	0.025	5	0.60	6	4.2	Methylmethacrylate
15	0.025	6	0.36	4	6.9	Epoxy
14	0.038	7	0.69	9	5.5	Chemically cured urethane
20	0.048	8	0.61	7	7.9	Epoxy (polysulfide)
19	0.051	9	0.53	5	9.6	Epoxy
18	0.059	10	0.66	8	8.9	Epoxy
17	0.075	11	0.92	11	8.2	Epoxy (polysulfide)
2	0.094	12	1.34	15	7.0	Linseed oil
13	0.094	13	1.20	12	7.8	Methylmethacrylate (emulsion)
6	0.105	14	1.31	14	8.0	Alkyl-Alkoxy Silane
11	0.111	15	1.68	16	6.6	Vinyl toluene butadiene
12	0.114	16	1.29	13	8.8	Al stearate
5	0.120	17	1.72	17	7.0	Chlorinated rubber
7	0.181	18	2.47	21	7.3	Styrene butadiene
9	0.188	19	1.97	18	9.5	Sodium silicate
3	0.191	20	2.39	20	8.0	Siliconate
24	0.229	21	2.37	19	9.7	Initial linseed oil treatment only (control)
1	0.233	22	2.74	22	8.5	Siloxane

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CONCRETE TREATED WITH LINSEED OIL FOLLOWED BY PENETRANTS

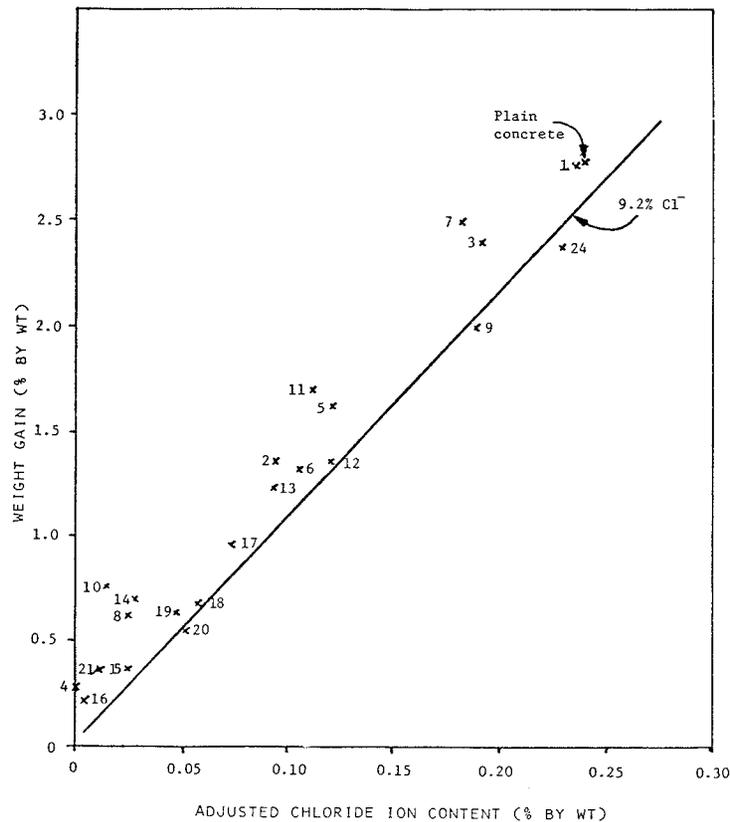


Fig. B-29 - Relationship between weight gain and adjusted chloride ion content

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Simple calculation shows that the weight percent of chloride ion in the original 15 percent NaCl water solution was 9.2 percent. The calculated chloride strength values given in Table B-31 for untreated concretes average 8.92 percent when the control specimen and the specimen coated with material No. 16 are not included. This 8.92 percent average compares with the 8.5 percent value measured on the uncoated concrete. The No. 16 specimen appeared to have performed as an excellent chloride ion screen and allowed a calculated chloride ion penetration of 2.8 percent, only 30 percent of the original 9.2 percent saltwater solution concentration.

The calculated values given in Table B-32 for linseed oil pretreated specimens show that five of these materials are substantially improved with respect to chloride ion penetration by linseed oil pretreatment. In fact, the specimen coated with the No. 4 material was found to contain no measurable chloride ion. The four other materials in the top five positions were found to contain an average of 3.4 percent chloride ion, or 37 percent of the original solution concentration. The average of the remaining 16 specimens was 7.84 percent chloride ion, or 85 percent of the original solution concentration (excluding the control specimen).

The data in Tables B-31 and B-32 and Figs. B-28 and B-29 show that there was an excellent correlation between saltwater weight gain and chloride ion concentration within the hardened concrete at the end of the Series I tests.

Conclusions

A library literature search in combination with a survey of 239 chemical companies and the 50 state highway departments was completed. These three searches concentrated on identifying penetrants or coatings for concrete

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which would minimize absorption of chloride-laden water, and maximize the water vapor transmission characteristics when applied on concrete.

While responses were received from 57 interested chemical companies and 41 state highway departments, these 98 responses contained little technical or experimental data concerning the effectiveness of materials commonly being used as penetrants or coatings for surfaces on concrete bridges.

These three searches, however, did identify the chemical compositions generally recommended, being used, or experimented with by the state highway departments. The two chemicals reported as most commonly used were a boiled linseed oil/mineral spirits formulation and epoxies. A most recent development has been the use of a silane material by an increasing number of states. A total of 103 different materials were suggested by these 57 chemical companies as candidates for this study. The project team selected 21 different materials from these for the Series I screening tests. These materials generally fall into 12 different chemical categories, but were selected from 21 different companies. Sixteen are classed as penetrants, four are classed as coatings and one is classed as a combination penetrant/coating by their manufacturers.

These 12 chemical types were selected because each has been used on bridge structures. The three searches also suggested that these particular chemicals may provide the required type of protection, i.e., reduction in liquid absorption combined with good water vapor transmission. Complete technical and application data for all 21 materials are included in the report.

The 21 samples of penetrants and coatings were then tested in the screening test. After identical moist curing and air drying, the concrete cubes

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were separated into two groups. In the first group, the coating materials were applied to plain, lightly sandblasted concrete cubes representative of previously untreated, but somewhat aged concrete. The second group was treated with an application of linseed oil, exposed to ultraviolet light, followed by light sandblasting again and then an application of the coating materials. The second group was representative of old concrete which had been previously treated with boiled linseed oil. Following an appropriate curing period for the chemicals, the cubes were immersed in a 15 percent NaCl solution. During this 21-day soaking period in saltwater, the gain in weight after 3, 6, 9, 12, 15, 18 and 21 days of soaking was determined for each cube. The cubes were then removed from the water bath and stored in air at 73 degrees F, 50 percent R.H. for 21 days, followed by three days in the presence of $Mg (CO_4)_2$ to determine relative water vapor transmission characteristics. During this air drying period, the weight loss of each cube was determined after 3, 6, 9, 12, 15, 18, 21, 22, 23 and 24 days of drying. After drying, one-half of each cube was crushed and the chloride ion content determined using an acid digestion potentiometric titration procedure. The following conclusions can be made from the results of these tests:

1. When applied to new concrete, five of these materials had very low water absorption, good water vapor transmission and low chloride ion intrusion characteristics as follows:

Test No.	Weight Gain % by wt.	Weight Loss* Weight Gain %	Chloride Ion Content % by wt.	Chemical Composition
16	0.29	100	0.008	Epoxy, 50% solids
15	0.57	60	0.044	Epoxy, 100% solids
8	0.61	120	0.047	Methyl methacrylate
4	0.63	107	0.048	Urethane, moisture-cured
6	0.83	100	0.050	Alkyl-alkoxy silane
Uncoated Concrete	2.77	66	0.236	

*After 21 days of air drying only.

- All five of the above materials acted as chloride screens during the soaking period, in that the calculated chloride content of the solution absorbed was less than that of the original 15 percent NaCl water solution. One epoxy material, No. 16, reduced this chloride value to less than 1/3 of the original solution.
- When applied to concrete pretreated with linseed oil, the water absorption characteristics and the chloride ion intrusion characteristics of 20 materials were improved, in some cases dramatically. The most significant improvements were found with the epoxies, polyisobutyl methacrylate, and the chemically cured polyurethane resin. However, the water vapor transmission characteristics of 18 of the materials were worse when used on linseed oil pretreated specimens.
- Pretreatment with linseed oil reduced water absorption and chloride ion intrusion of all materials except the silane

material, Test No. 6. The water absorption in this case was increased by 110 percent with the linseed oil pretreatment as compared to its performance when applied to plain concrete. In addition, the water vapor transmission was reduced substantially.

- The weight gain of concrete treated only with linseed oil was only 21 percent less than that of the uncoated concrete. The amount of absorbed chloride ion was reduced by only 11 percent when compared with uncoated concrete. The five materials previously discussed had weight gains that were 90 to 70 percent less than uncoated concrete and chloride ion contents that were reduced by 97 to 79 percent when compared with uncoated concrete. These comparisons show that the performance of the boiled linseed oil was much less effective when compared to that of the five materials previously discussed.
- The effectiveness of the five straight epoxy formulations in reducing weight gain during soaking was found to be directly related to the coverage rate, in terms of pounds of epoxy solids applied per square foot of surface. The two epoxy formulations based on polysulfide polymers were much less effective, at equal coverage rates, than the straight epoxies.
- The coating consisting of methyl methacrylate solution was effective in protecting concrete against the absorption of saltwater solution and intrusion of chloride into the concrete. Another methyl methacrylate, supplied as an emulsion, was much less effective.

8. The penetrant consisting of polyisobutyl methacrylate significantly reduced water absorption and chloride ion intrusion. Pretreatment with linseed oil significantly improved the performance of this material.
9. A moisture-cured urethane resin was effective in a manner similar to that of the methyl methacrylate solution, while the chemically cured urethane polymer was much less effective.
10. A material based on styrene butadiene was ineffective against absorption of water and intrusion of chloride ion.
11. The penetrants based on chlorinated rubber, methyl silicate solution, siloxane, sodium silicate solutions, and a mixture of aluminum stearate and isobutylene were found to provide little or no protection against water absorption and chloride intrusion into concrete.

Based on the results of Series I, the following materials were recommended for the Series II, III and IV laboratory tests.

<u>Material No.</u>	<u>Chemical Composition</u>
16	Epoxy
8	Methyl methacrylate
4	Moisture cured urethane
6	Alkyl-alkoxy silane
10	Polyisobutyl methacrylate

The No. 15 epoxy formulation was not recommended, although it was consistently among the top five materials, because of the similarity in composition and performance with No. 16. Also, the use of the silane in combination with

linseed oil pretreatment was not recommended. Because of the greatly improved performance of the No. 10 polyisobutyl methacrylate material when applied over linseed oil, it was recommended that this No. 10 material be substituted for the No. 6 silane material in those tests which were to include the linseed oil. This set of recommendations was prepared with the intent of including in Series II, III and IV laboratory tests the greatest number of generically different coating materials which performed best in the Series I screening tests.

APPENDIX C

SERIES II LABORATORY TESTS - EFFECT OF CONCRETE MOISTURE CONTENT WHEN COATED UPON WATER ABSORPTION, WATER VAPOR TRANSMISSION AND CHLORIDE ION INTRUSION CHARACTERISTICS

Introduction

During the Series I laboratory screening tests, the cube specimens were moist cured under water for 6 days and then allowed to air dry at 73 degrees F and 50 percent R.H. for 21 days prior to the application of the coating or penetrant. This procedure provided relatively dry concrete at the coating age since 21 days of air drying was allowed.

The Series II tests were undertaken to be essentially the same as the Series I tests with the following exceptions:

1. The moist curing for the concrete cubes was provided by 21 days of storage inside plastic bags stored in a room at 73 degrees F. This change eliminated the saturated concrete condition which occurred in Series I after the 6 days of curing in water. The Series II curing was considered to be more realistic as related to actual field curing of concrete bridge elements.
2. The cubes were allowed to air dry at 73 degrees F and 50 percent R.H. for 1, 5 and 21 days following their removal from the plastic curing bags. The coatings were then applied at these three different times which provided concretes with different moisture contents when the coatings were applied. This procedural change provided a range of concrete moisture conditions that could occur in the field where rain must be anticipated.

3. Aggregates from Eau Claire, Wisconsin were used. These aggregates have a very low chloride content.

Only five coating or penetrant materials were evaluated during the Series II tests. These five coating materials were selected based upon their good to excellent performance from Series I. These materials are as follows:

<u>Test No.</u>	<u>Chemical Composition</u>	<u>Symbol in Tables</u>
4	Moisture-cured polyurethane	4-U
6	Alkyl-Alkoxy Silane	6-S
8	Methyl Methacrylate-Ethylacrylate	8-MM
10	Polyisobutyl Methacrylate	10-PM
16	Epoxy	16-E
0	Control Concrete	0-PC

The objective of Series II was to determine the influence of various lengths of air drying or concrete moisture content prior to the time of application of these five materials on the subsequent water absorption and chloride ion penetration characteristics of protected concrete. The coating application rate used was that defined by the manufacturers as normal.

Test Materials and Procedures

Concrete Characteristics. The nominal 4 in. cubes were made using the following materials:

Sand: Natural river sand

Coarse aggregate: Natural, rounded river gravel

Both of these aggregates were obtained from the American Materials Corporation, Eau Claire, Wisconsin

Portland cement: Type I

Air-entraining agent: Neutralized Vinsol resin

The concrete was designed to have a 28-day compressive strength of approximately 4500 psi, a w/c ratio of about 0.50, air content of 4 to 6 percent, and a slump of approximately 3 in. The significant properties of the fresh and hardened concrete were as follows:

<u>S.S.D. quantities/yd³</u>	
Cement content, lb	439
Sand content, lb	1477
Coarse aggregate content, lb	1684
Water content, lb	220
Plastic unit weight, pcf	141.52
Air content, %	6.2
W/C (S.S.D) by weight	0.501
Slump, in.	3
Average 28 day compressive strength, psi	4130

All of the cubes were cast using the same procedures and forms as described in Series I. As with Series I, duplicate cube specimens were used to produce a test sample.

Test Procedures. The test specimen layout and application rates are provided in Table C-1.

After stripping at age 1 day, the cubes were placed within sealed heavy-duty plastic bags for moist curing in the controlled climate room. At age 7 days, the cubes were lightly sandblasted, labeled and weighed to the nearest

TABLE C-1 - TEST SPECIMEN LAYOUT FOR SERIES II TESTS CONCERNING CONCRETE MOISTURE CONTENT AT APPLICATION TIME

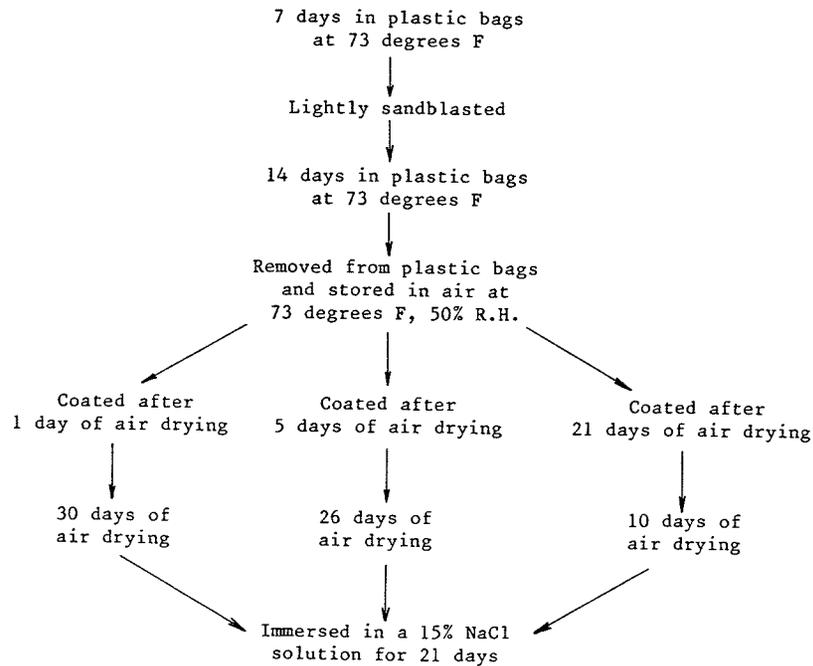
Material No.	Application rate (ft ² /gal)	Time of air drying ⁺ prior to coating (Days)		
		1	5	21
4	200/200	2*	2*	2*
6	100	2*	2*	2*
8	100/200	2*	2*	2*
10	250/250	2*	2*	2*
16	120/120	2*	2*	2*
Control	—	—	—	4

⁺After initial 21 day cure in plastic bags

*Two cubes each, brushed application

0.1 gram. Immediately after this initial weighing, the cubes were returned to the plastic bags and placed in the controlled climate room for 14 more days of moist curing. At age 21 days, the cubes were removed from the plastic bags and stored in the controlled room on steel racks for air drying.

The materials were applied to the cubes after they were air dried for periods of 1, 5 and 21 days. After coating, the cubes were returned to the controlled climate room for continued air drying. During air drying (before and after coating), the cubes were weighed to the nearest 0.1 gram at intervals of approximately 7 days. All cubes were then immersed in a 15 percent NaCl solution at an age of 54 days, as illustrated in the following diagram.



The test program included two types of uncoated control specimens. One pair remained in the controlled climate room during the entire test period. Their weight losses were periodically monitored. The other pair of control cubes were subjected to the air drying and saltwater soaking tests in the same manner as the coated cubes.

All cubes were immersed in a 15 percent NaCl water solution for 21 days. During this soaking period, the gain in weight at 3, 6, 9, 12, 15, 18 and 21 days was determined to the nearest 0.1 gram. After the 21 day S.S.D. wet weight was determined, the cubes were returned to the air in the controlled climate room to observe weight loss, or water vapor transmission characteristics. During this 21 day final air drying period, the loss in weight at 3, 6, 9, 12, 15, 18 and 21 days was determined to the nearest 0.1 gram. After the final 21 day air drying period, each cube was mechanically split in half. One half was crushed and the total chloride ion content of the crushed concrete determined using an acid digestion, potentiometric titration procedure. The second half of each cube was retained.

Test Results and Discussion

The change of weight during the initial air drying, coating, and subsequent air drying periods are given in Table C-2. The weight gain and weight losses during the following saltwater soaking and final air drying periods are given in Table C-3 and are depicted graphically in Figs. C-1 to C-5. Results of the chloride content tests are given in Table C-4.

Vapor Transmission Characteristics Following Coating. The data in Table C-2 indicate that the application of four of these materials, labeled 4-U, 6-S, 8-MM and 10-PM did not significantly alter the water vapor

TABLE C-2 - AVERAGE WEIGHT LOSS IN AIR AT 73°F, 50% R.H.
BEFORE AND AFTER COATING

Test No.	Days of air drying before coating	Weight loss, percent by weight					
		Before coating	After coating				
			1 day	7 days	14 days	21 days	30 days
4-U	1	-0.48	-0.32	-0.63	-0.89	-1.04	-1.20
6-S	1	-0.43	-0.40	-0.77	-0.99	-1.11	-1.22
8-MM	1	-0.43	-0.38	-0.52	-0.74	-0.89	-1.05
10-PM	1	-0.46	-0.32	-0.57	-0.79	-0.93	-1.10
16-E	1	-0.45	-0.20	-0.22	-0.30	-0.36	-0.42
0-PC	1	-0.45	-0.55	-0.88	-1.08	-1.24	-1.36
			1 day	7 days	14 days	26 days	
4-U	5	-0.78	-0.68	-0.83	-0.96	-1.10	
6-S	5	-0.81	-0.78	-1.02	-1.13	-1.28	
8-MM	5	-0.73	-0.62	-0.76	-0.88	-1.01	
10-PM	5	-0.81	-0.70	-0.85	-0.98	-1.10	
16-E	5	-0.74	-0.60	-0.66	-0.68	-0.74	
0-PC	5	-0.80	-0.87	-0.91	-1.25	-1.37	
			1 day	10 days			
4-U	21	-1.12	-1.08	-1.20			
6-S	21	-1.16	-1.12	-1.29			
8-MM	21	-1.23	-1.07	-1.10			
10-PM	21	-1.09	-1.10	-1.05			
16-E	21	-1.15	-0.90	-0.86			
0-PC	21	-1.24	-1.26	-1.35			

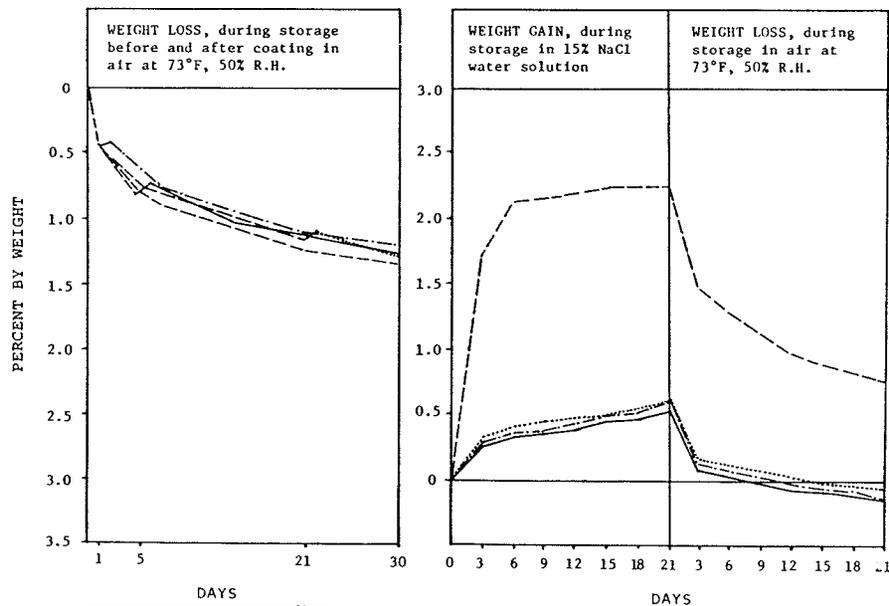
TABLE C-3 AVERAGE WEIGHT CHANGE DURING SOAKING AND DRYING PERIODS

Test No.	Days of drying before coating	Weight change after days of soaking (%)								Net weight change after days of drying (%)						
		3	6	9	12	15	18	21	21 (Range)*	3	6	9	12	15	18	21
4-U	1	0.31	0.44	0.46	0.48	0.56	0.57	0.61	(0.03)	0.21	0.12	0.06	0.01	-0.05	-0.07	-0.12
	5	0.33	0.36	0.44	0.47	0.48	0.55	0.62	(0.04)	0.17	0.11	0.05	-0.01	-0.05	-0.09	-0.12
	21	0.31	0.35	0.42	0.43	0.47	0.49	0.55	(0.06)	0.20	0.14	0.08	0.03	-0.01	-0.04	-0.08
6-S	1	0.29	0.37	0.39	0.44	0.50	0.52	0.60	(0.00)	0.12	0.07	0.02	-0.02	-0.05	-0.08	-0.12
	5	0.27	0.33	0.36	0.39	0.45	0.46	0.52	(0.03)	0.08	0.03	-0.01	-0.06	-0.09	-0.11	-0.15
	21	0.34	0.41	0.46	0.48	0.50	0.55	0.60	(0.02)	0.15	0.11	0.06	0.03	-0.01	-0.03	-0.07
8-MM	1	0.23	0.25	0.30	0.32	0.35	0.36	0.40	(0.05)	0.07	0.00	-0.06	-0.12	-0.15	-0.19	-0.23
	5	0.25	0.27	0.28	0.32	0.35	0.37	0.39	(0.01)	0.06	0.01	-0.04	-0.09	-0.14	-0.19	-0.21
	21	0.23	0.29	0.34	0.35	0.40	0.42	0.46	(0.01)	0.13	0.06	0.01	-0.04	-0.08	-0.12	-0.16
10-PM	1	0.45	0.59	0.78	0.80	0.89	0.92	0.95	(0.22)	0.54	0.43	0.34	0.27	0.21	0.17	0.12
	5	0.52	0.64	0.84	0.93	1.07	1.14	1.14	(0.10)	0.77	0.64	0.54	0.45	0.39	0.34	0.28
	21	1.01	1.23	1.42	1.45	1.50	1.52	1.55	(0.00)	1.03	0.89	0.77	0.66	0.58	0.51	0.43
16-E	1	0.11	0.12	0.13	0.15	0.15	0.16	0.18	(0.00)	-0.03	-0.06	-0.09	-0.13	-0.16	-0.19	-0.21
	5	0.12	0.14	0.15	0.17	0.17	0.18	0.20	(0.03)	0.03	-0.01	-0.03	-0.06	-0.08	-0.10	-0.13
	21	0.17	0.24	0.27	0.29	0.32	0.33	0.33	(0.05)	0.18	0.15	0.14	0.11	0.09	0.07	0.05
0-PC		1.71	2.12	2.16	2.20	2.23	2.24	2.24	(0.11)	1.48	1.28	1.12	0.99	0.90	0.83	0.76

*Range in weight gain after 21 days of soaking of duplicate specimens

MATERIAL 6-5

COVERAGE (ft²/gal) 100



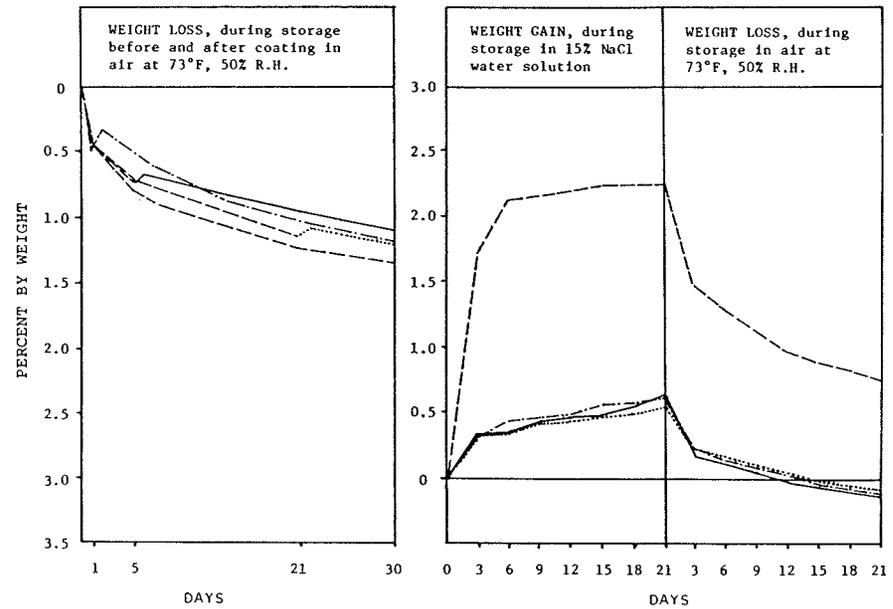
LEGEND:
 Air Drying Time
 - - - 1 day
 - - - 5 days
 21 days
 - - - Plain Concrete

Fig. C-2 - Weight loss and gain data; coated after 1, 5 and 21 days of drying

C-10

MATERIAL 4-U

COVERAGE (ft²/gal) 200/200



LEGEND:
 Air Drying Time
 - - - 1 day
 - - - 5 days
 21 days
 - - - Plain Concrete

Fig. C-1 - Weight loss and gain data; coated after 1, 5 and 21 days of drying

C-9

MATERIAL 10-PM

COVERAGE (ft²/gal) 250/250

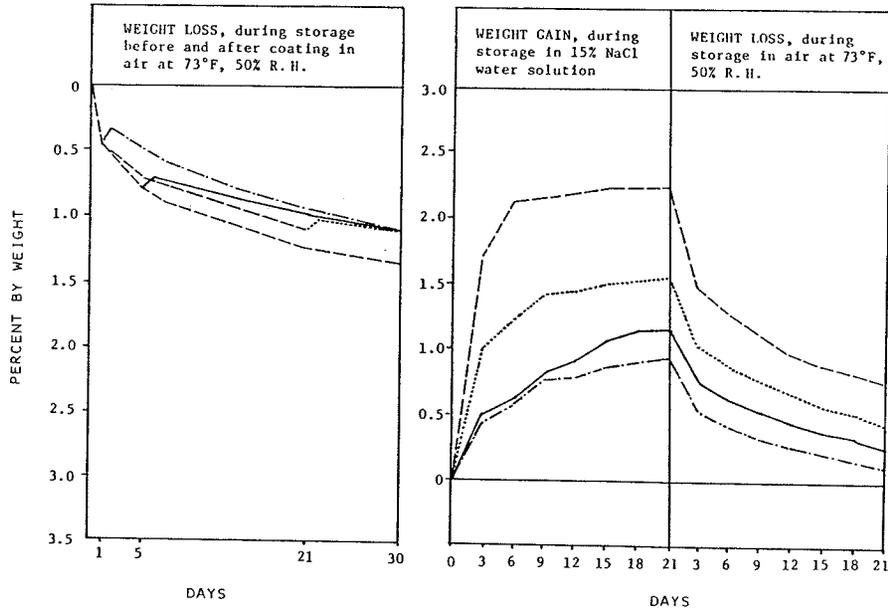


Fig. C-4 - Weight loss and gain data; coated after 1, 5 and 21 days of drying

C-12

MATERIAL 8-MM

COVERAGE (ft²/gal) 100/200

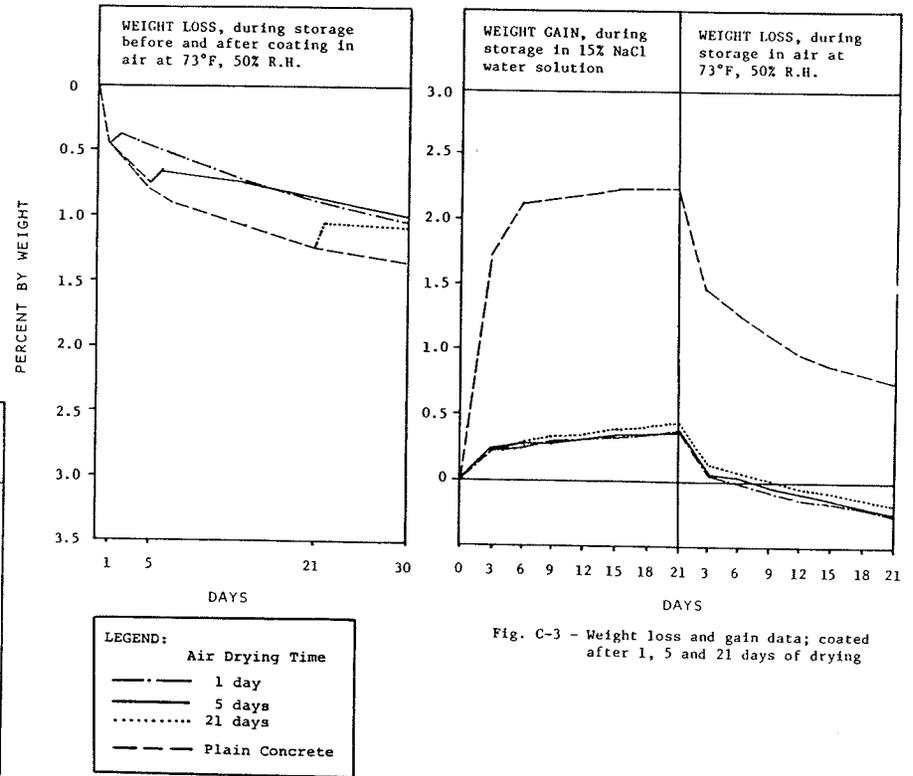


Fig. C-3 - Weight loss and gain data; coated after 1, 5 and 21 days of drying

C-11

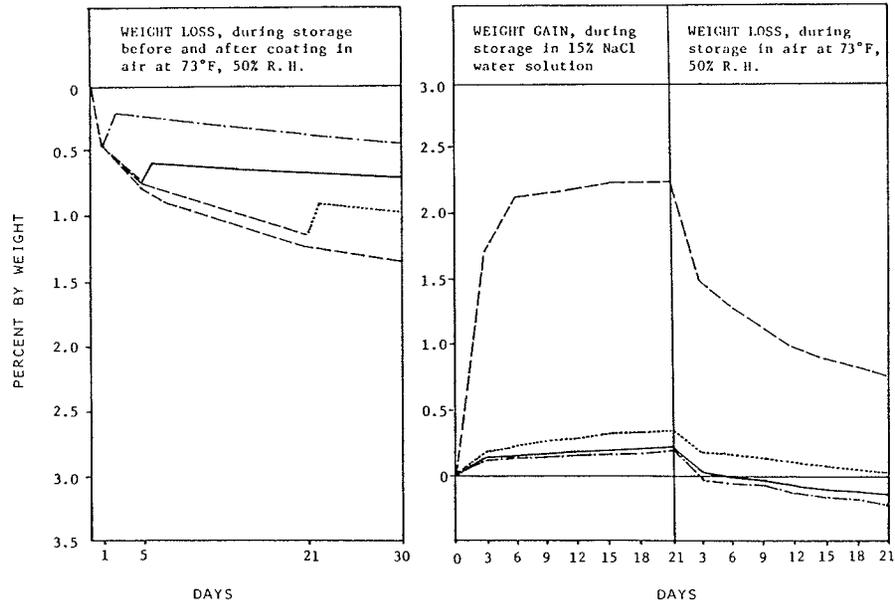


Fig. C-5 - Weight loss and gain data; coated after 1, 5 and 21 days of drying

C-13

TABLE C-4 - CHLORIDE ION CONTENT IN CONCRETE

Test No.	Days of drying before coating	Chloride ion content* (% by wt of concrete)
4-U	1	0.066 (0.019) ⁺
	5	0.064 (0.004)
	21	0.025 (0.004)
6-S	1	0.039 (0.001)
	5	0.027 (0.003)
	21	0.027 (0.003)
8-MM	1	0.021 (0.003)
	5	0.017 (0.001)
	21	0.026 (0.001)
10-PM	1	0.095 (0.001)
	5	0.106 (0.020)
	21	0.172 (0.000)
16-E	1	0.009 (0.005)
	5	0.016 (0.010)
	21	0.036 (0.004)
0-PC	-	0.212 (0.021)
0-PC**	-	0.002 -

* Average value from duplicate cubes

** Untested control cubes stored continuously in air

⁺ Range of chloride ion content from duplicate cubes

C-14

transmission (or weight loss characteristics) during the initial air drying period of 31 days. When these four materials were applied at either 1, 5 or 21 days and then allowed to dry for 30, 26 or 10 days, respectively, the final weight losses at 31 days for all test conditions including the uncoated concrete varied from 1.05 to 1.37 percent. The vapor transmission is generally somewhat decreased by these four materials since the uncoated control concrete had the highest weight losses of 1.35 to 1.37 percent. These data illustrate that these four materials do not significantly inhibit the normal exit of water vapor from freshly cured concrete or freshly wetted concrete.

The use of the 16-E material did result in significant reductions in the water vapor transmission characteristics. When applied after 1 or 5 days of air drying, the weight losses after coating were only 27 percent of the companion uncoated control concretes weight loss. The other four materials had weight losses under the same drying conditions after coating that ranged from 78 to 109 percent of the companion uncoated control concretes.

Weight Gain During Saltwater Soaking. The summary of the weight gain data is shown in Table C-5. The 4-U, 6-S and 8-MM materials show weight gains that are low and that are not significantly influenced by the number of days of air drying prior to coating. The 10-PM material exhibits high absorption values that were influenced by the number of air drying days. The lowest weight gain was when the coating was applied after 1 day of drying. The 16-E material exhibited extremely low absorption values that were also influenced by drying time prior to coating. The lowest weight gain was achieved when the coating was applied after 1 or 5 days of drying. This 16-E material, when applied after 1 or 5 days of drying, exhibited extremely low weight gains of

TABLE C-5 - SUMMARY OF FINAL WEIGHT GAIN AND RESIDUAL WEIGHT CHANGE DATA

Test No.	Days of drying before coating	Final weight gain		Final residual weight change (% by wt)	Weight loss/weight gain (%)
		(% by wt)	(% of control)		
4-U	1	0.61	27	-0.12	120
	5	0.63	28	-0.12	119
	21	0.55	25	-0.08	115
6-S	1	0.60	27	-0.12	120
	5	0.52	23	-0.15	129
	21	0.60	27	-0.07	112
8-MM	1	0.40	18	-0.23	158
	5	0.39	17	-0.21	154
	21	0.46	21	-0.16	135
10-PM	1	0.95	42	0.12	87
	5	1.14	51	0.28	75
	21	1.55	69	0.43	72
16-E	1	0.18	8	-0.21	217
	5	0.20	9	-0.13	165
	21	0.33	15	-0.15	145
0-PC		2.24	100	0.76	66

only 0.18 to 0.20 percent. These values are only 8 to 9 percent of the weight gain of the uncoated control cubes.

Water Vapor Transmission Following Saltwater Soaking. The data in Table C-5 show that all of the coated specimens, except the No. 10-PM specimens, lost more weight during the final 21 days of air drying than they had gained during the 21 days of soaking in saltwater. These data for materials 4-U, 6-S, 8-MM and 16-E also show that the number of days of air drying before coating did not significantly influence their vapor transmission qualities. The 10-PM material did not exhibit similar water vapor transmission qualities. The specimens lost only 72 to 87 percent of their weight gain during the soaking period by vapor transmission.

Chloride Ion Penetration Characteristics. The results of the chloride tests are summarized in Table C-6. Since the untested control cubes had extremely low chloride contents of only 0.002 percent by weight of concrete, the measured chloride values from Table C-4 have not been adjusted for this factor as they were in Series I. A plot of chloride content versus weight gain for all the specimens is given in Fig. C-6. The theoretical chloride solution strength relationship line of 9.2 percent is also shown for comparison purposes.

The results of these chloride tests show a good relationship between weight gain and chloride ion content. As shown in Table C-6, the tested uncoated control concrete exhibited a chloride ion content of 9.5 percent of the weight of solution absorbed. This compares very favorably with the theoretical value of 9.2 percent. The 6-S and 8-MM materials consistently show chloride values of about 4.5 to 6.5 percent by weight of the solution

TABLE C-6 - RELATIONSHIP BETWEEN WATER ABSORPTION AND CHLORIDE ION CONTENT

Test No.	Days of drying before coating	Chloride ion content (% by wt)	Weight gain after 21 days in 15% NaCl solution (% by wt)	Calculated percent chloride in solution absorbed
4-U	1	0.066	0.61	10.8
	5	0.064	0.62	10.3
	21	0.025	0.55	4.6
6-S	1	0.039	0.60	6.5
	5	0.027	0.52	5.2
	21	0.027	0.60	4.5
8-MM	1	0.021	0.40	5.3
	5	0.017	0.39	4.4
	21	0.026	0.46	5.7
10-PM	1	0.095	0.95	10.0
	5	0.106	1.14	9.3
	21	0.172	1.55	11.1
16-E	1	0.009	0.18	5.0
	5	0.016	0.20	8.0
	21	0.036	0.33	10.9
0-PC		0.212	2.24	9.5

C-18

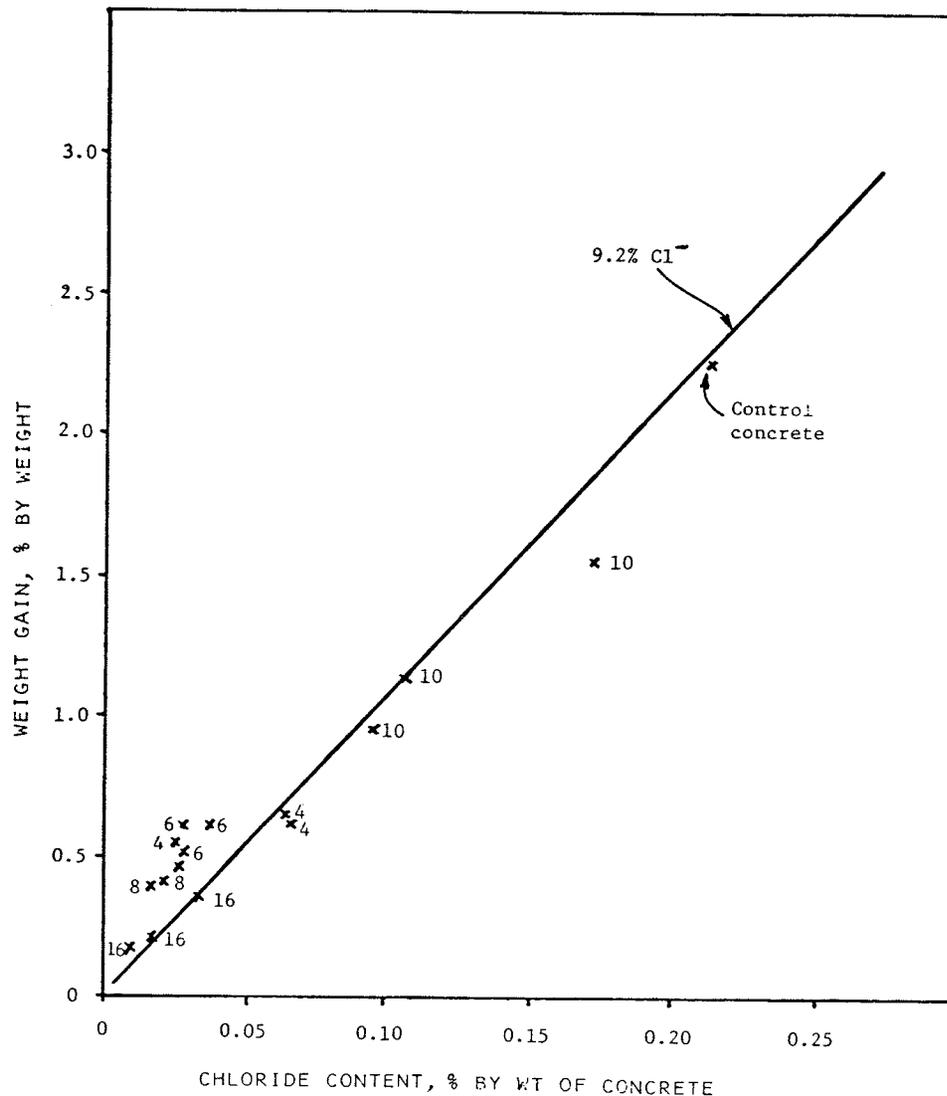


Fig. C-6 - Relationship between weight gain and chloride content

absorbed. These values appear to indicate a chloride screening capability for materials 6-S and 8-MM, irrespective of the moisture content condition of the concrete when coated.

The 4-U and 16-E materials show chloride screening capabilities, but only under certain conditions.

The 10-PM material shows normal chloride levels indicative of a lack of chloride screening capabilities.

Table C-7 summarizes the weight gain and chloride ion intrusion characteristics when compared to the uncoated control concrete.

Conclusions

The test results from the Series II investigations justify the following conclusions:

1. The materials labeled 4-U, 6-S, 8-MM and 10-PM can be applied after 1, 5 or 21 days of air drying following moist curing without a significant decrease in water vapor transmission characteristics when compared to uncoated concrete. The use of the 16-E material did cause moderate to significant reductions in water vapor transmission capabilities in all cases.
2. The weight gain characteristics of concretes coated with materials 4-U, 6-S and 8-MM are not significantly influenced by the number of days of air drying prior to coating. The 10-PM material was sensitive to coating age and the lowest weight gain was achieved when the coating was applied after 1 day of air drying. The 16-E material was also influenced by the length of air drying time prior to coating. The lowest weight gain was

TABLE C-7 - SUMMARY OF WEIGHT GAIN AND CHLORIDE CONTENT WHEN
 COMPARED TO CONTROL CONCRETE AS INFLUENCED BY
 DAYS OF AIR DRYING PRIOR TO COATING

Test No.	Days of Air Drying Prior to Coating					
	1		5		21	
	Weight gain*	Chloride content*	Weight gain*	Chloride content*	Weight gain*	Chloride content*
4-U	27.2	31.1	28.1	30.2	24.6	11.8
6-S	26.8	18.3	23.2	12.7	26.8	12.7
8-MM	17.9	9.9	17.4	8.0	20.5	12.3
10-PM	42.4	44.8	50.9	50.0	69.2	81.1
16-E	8.0	4.2	8.9	7.5	14.7	17.0

* Percent of control concrete weight gain or chloride content after salt water soaking

C-21

achieved when the coating was applied after 1 or 5 days of air drying.

Under the conditions of these tests, these five materials provided water absorption characteristics that were significantly reduced when compared to uncoated concrete, as follows, when using the best air drying time or times prior to coating:

Test No.	Reduction of Water Absorption into Concrete, %
16-E	91
8-MM	82
4-U	75
6-S	74
10-PM	58

- Following saltwater soaking, the materials 4-U, 6-S, 8-MM and 16-E exhibited an ability to lose more weight by water vapor transmission than they had gained by soaking in saltwater for 21 days. The 10-PM material did not exhibit this behavior.
- The chloride ion data show a good relationship to weight gain during the saltwater soaking. The 6-S, 8-MM and 16-E materials exhibit very low chloride ion contents, generally less than 0.03 percent by weight of concrete after this test. In general, these 6-S, 8-MM and 16-E materials show chloride contents that are not significantly influenced by drying time prior to

C-22

coating. The 4-U and 10-PM materials have higher chloride contents, generally ranging from 0.06 to 0.17 percent by weight of concrete. Their chloride values were sensitive to the length of air drying time prior to coating.

Under the conditions of these tests, these five materials provide chloride intrusion values that were significantly reduced when compared to uncoated concrete, as follows, when using the best air drying periods prior to coating:

<u>Test No.</u>	<u>Reduction in Chloride Content in Concrete, %</u>
16-E	94
8-MM	91
4-U	88
6-S	87
10-PM	55

- Materials 6-S and 8-MM appear to act as chloride screens since their absorbed chloride contents were less than the 9.2 percent solution strength, irrespective of the number of days of air drying prior to coating.
- The overall performance of these five coating materials can be rated as follows when using water absorption and chloride intrusion characteristics along with the best air drying period as the comparison basis:

C-23

<u>Performance Position No.</u>	<u>Material</u>	<u>No. of Days of Drying Prior to Coating for Best Performance</u>
1	16-E	1 to 5
2	8-MM	1 to 5
3	6-S	5 to 21
4	4-U	21
5	10-PM	1

C-24

APPENDIX D

SERIES III LABORATORY TESTS - EFFECT OF USING DIFFERENT COATING APPLICATION RATES UPON WATER ABSORPTION, WATER VAPOR TRANSMISSION AND CHLORIDE ION INTRUSION CHARACTERISTICS

Introduction

During the Series II laboratory tests, the specimens were coated with five selected materials, using the manufacturer's recommended application rates and number of coats, after being allowed 1, 5 and 21 days of air drying prior to being coated. The Series III tests were undertaken to be essentially the same as the Series II tests with the following exceptions:

- The air drying time after the 21 day moist-curing period in plastic bags was held constant at 5 days prior to applying the coatings.
- The application rates were varied.

The objective of Series III was to determine the influence of various application rates of these five materials on water absorption, water vapor transmission and chloride ion intrusion characteristics.

Test Materials and Procedures

Concrete Characteristics. The nominal 4 in. cubes were made with the same materials as used in Series II. The significant properties of the fresh and hardened concrete were as follows:

	<u>S.S.D. quantities/yd³</u>
Cement content, lb	445
Sand content, lb	1498
Coarse aggregate content, lb	1708

D-1

<u>S.S.D. quantities/yd³</u>		<u>Test No.</u>	<u>Coverage Rate ft²/gallon</u>
Water content, lb	221	8-MM	100/200 - Normal 100 (Prime coat only) 200 (Finish coat only)
Plastic unit weight, pcf	143.41		
Air content, %	5.9	10-PM	125/125 180/180 250/250 - Normal
Net w/c (S.S.D.) by weight	0.497		
Slump, in.	3-1/2	16-E	90/90 120/120 - Normal 150/150
Average 28-day compressive strength, psi	4400		

All the cubes were cast using the same procedures and forms as described in Series I. As with Series I and II, duplicate cube specimens were used to produce a test sample.

Test Procedures. The cubes were cured, sandblasted, coated, air dried, soaked, and tested for chloride in the same manner as described in Series II for specimens allowed 5 days of air drying prior to coating.

Application Rates. The manufacturers of these five materials were requested to specify the three different application rates for this Series III investigation. These application rates as then suggested by these five companies are as follows:

<u>Test No.</u>	<u>Coverage Rate,* ft²/gallon</u>
4-U	150/150 200/200 - Normal 250/250
6-S	50 100 - Normal 200

*100/200 = 100 ft²/gallon for the first coat,
200 ft²/gallon for the second coat.

D-2

Test Results and Discussion

The change of weight during the initial drying and coating periods are given in Table D-1. The weight gains and weight losses during the following saltwater soaking and final air drying periods are given in Table D-2. These data are also depicted graphically in Figs. D-1 to D-5. Results of the chloride content tests are given in Table D-3.

Vapor Transmission Characteristics Following Coating. The data in Table D-1 indicate that the application of four of these materials, labeled 4-U, 6-S, 8-MM and 10-PM, did not significantly alter the water vapor transmission (weight loss) characteristics during the initial air drying period of 26 days after the coating. When these four materials were applied at these three different application rates, the weight loss changes during the 26 days of air drying after coating exhibited water vapor weight losses ranging from 80 to 110 percent of the uncoated control cubes. The 6-S specimens exhibited slightly higher weight losses in this period than did the uncoated control specimens. The other three materials exhibited weight losses in this period somewhat less than the uncoated specimens.

D-3

TABLE D-1 - AVERAGE WEIGHT LOSS IN AIR AT 73°F and 50% R.H.
BEFORE AND AFTER COATING

Test No.	Coverage rate (ft ² /gal)	Weight loss, percent by weight				
		Before coating (5 days in air)	After coating			
			1 day	7 days	14 days	26 days
4-U	150/150	-0.73	-0.68	-0.83	-0.96	-1.10
	200/200	-0.78	-0.69	-0.86	-1.00	-1.11
	250/250	-0.75	-0.71	-0.89	-1.03	-1.17
6-S	50	-0.83	-0.80	-1.05	-1.19	-1.31
	100	-0.81	-0.73	-1.02	-1.13	-1.28
	200	-0.84	-0.82	-1.09	-1.22	-1.35
8-MM	100/200	-0.73	-0.62	-0.76	-0.88	-1.01
	100 (primer)	-0.76	-0.76	-1.03	-1.16	-1.28
	200 (finish)	-0.84	-0.83	-1.02	-1.16	-1.31
10-PM	125/125	-0.77	-0.61	-0.78	-0.94	-1.04
	180/180	-0.78	-0.66	-0.81	-0.93	-1.06
	250/250	-0.81	-0.70	-0.85	-0.98	-1.10
16-E	90/90	-0.82	-0.40	-0.45	-0.49	-0.53
	120/120	-0.74	-0.60	-0.66	-0.68	-0.71
	180/180	-0.76	-0.60	-0.72	-0.79	-0.87
0-PC		-0.80	-0.87	-0.91	-1.25	-1.37

D-4

TABLE D-2 - AVERAGE WEIGHT CHANGE DURING SOAKING AND DRYING PERIODS

Test No.	Coverage rate (ft ² /gal)	Weight change after days of soaking (%)								Net weight change after days of drying (%)						
		3 6 9 12 15 18 21 21 (Range)*								3 6 9 12 15 18 21						
		3	6	9	12	15	18	21	21 (Range)*	3	6	9	12	15	18	21
4-U	150/150	0.31	0.37	0.42	0.44	0.50	0.52	0.57	(0.04)	0.18	0.11	0.05	-0.01	-0.05	-0.09	-0.13
	200/200	0.33	0.36	0.44	0.47	0.48	0.55	0.62	(0.04)	0.17	0.11	0.05	-0.01	-0.05	-0.09	-0.12
	250/250	0.32	0.38	0.49	0.52	0.56	0.62	0.66	(0.01)	0.22	0.15	0.09	0.03	-0.01	-0.05	-0.10
6-S	50	0.27	0.32	0.33	0.34	0.42	0.44	0.46	(0.02)	0.07	0.02	-0.03	-0.07	-0.11	-0.13	-0.17
	100	0.27	0.33	0.36	0.39	0.45	0.46	0.52	(0.03)	0.08	0.03	-0.01	-0.06	-0.09	-0.11	-0.15
	200	0.31	0.33	0.38	0.38	0.41	0.43	0.55	(0.00)	0.07	0.02	-0.02	-0.07	-0.11	-0.13	-0.17
8-MM	100/200	0.25	0.27	0.28	0.32	0.35	0.37	0.39	(0.01)	0.06	0.01	-0.04	-0.09	-0.14	-0.19	-0.21
	100 (primer)	0.24	0.29	0.37	0.40	0.52	0.54	0.58	(0.00)	0.15	0.10	0.05	0.00	-0.04	-0.06	-0.10
	200 (finish)	0.48	0.49	0.60	0.63	0.69	0.71	0.73	(0.04)	0.34	0.26	0.19	0.12	0.07	0.04	-0.01
10-PM	125/125	0.28	0.31	0.42	0.45	0.52	0.53	0.55	(0.06)	0.25	0.17	0.12	0.06	0.02	-0.02	-0.07
	180/180	0.38	0.38	0.51	0.54	0.56	0.60	0.62	(0.04)	0.28	0.21	0.14	0.09	0.04	0.01	-0.04
	250/250	0.52	0.64	0.84	0.93	1.07	1.14	1.14	(0.10)	0.77	0.64	0.54	0.45	0.39	0.34	0.28
16-E	90/90	0.12	0.16	0.17	0.19	0.20	0.20	0.20	(0.04)	0.04	-0.01	-0.04	-0.07	-0.09	-0.11	-0.15
	120/120	0.12	0.14	0.15	0.17	0.17	0.18	0.20	(0.03)	0.03	-0.01	-0.03	-0.06	-0.08	-0.10	-0.13
	180/180	0.15	0.15	0.16	0.19	0.19	0.22	0.23	(0.03)	0.03	-0.01	-0.04	-0.07	-0.10	-0.11	-0.15
0-PC		1.71	2.12	2.16	2.20	2.23	2.24	2.24	(0.11)	1.48	1.28	1.12	0.99	0.90	0.83	0.76

* Range in weight gain after 21 days of soaking of duplicate specimens

D-5

MATERIAL 4-U
 COVERAGE (ft²/gal) 150/150; 200/200; 250/250

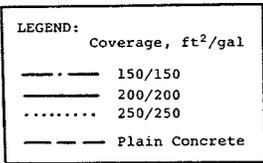
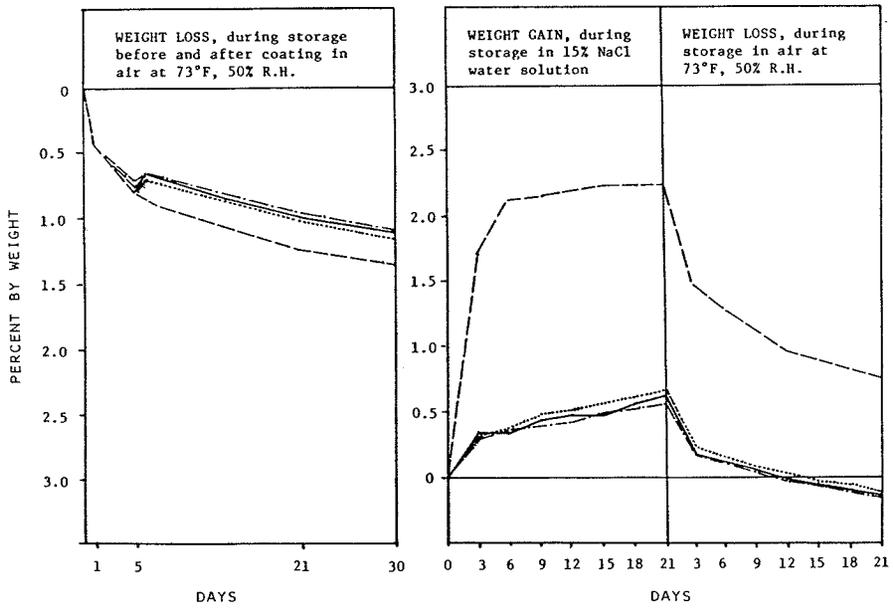


Fig. D-1 - Weight loss and gain data; coated after 5 days of drying

D-6

MATERIAL 6-S
 COVERAGE (ft²/gal) 50, 100 and 200

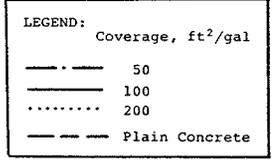
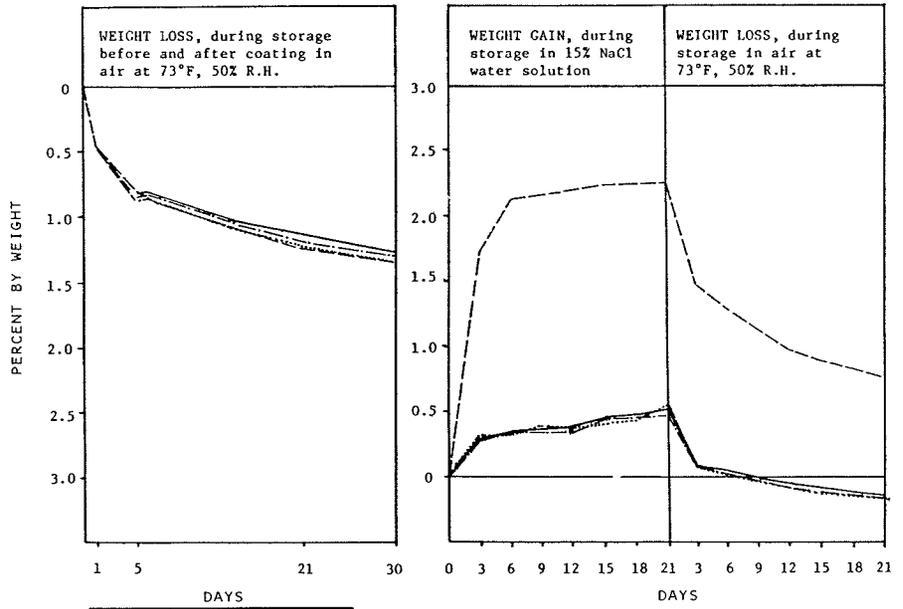
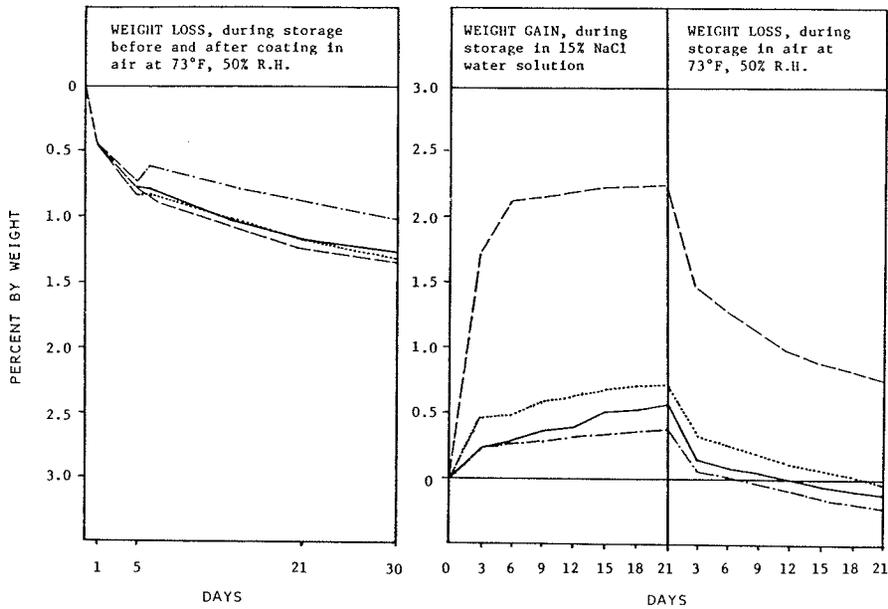


Fig. D-2 - Weight loss and gain data; coated after 5 days of drying

D-7

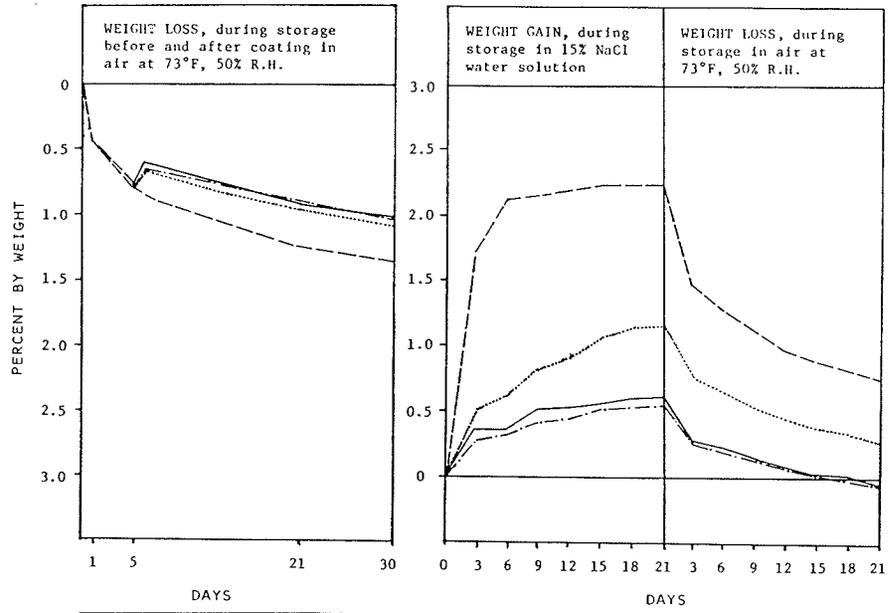
MATERIAL 8-MM COVERAGE (ft²/gal) 100/200; Primer (100); and Finish (200)



LEGEND:
 Coverage, ft²/gal
 - - - 100/200
 — 100 (Primer)
 ····· 200 (Finish)
 - · - Plain Concrete

Fig. D-3 - Weight loss and gain data; coated after 5 days of drying

MATERIAL 10-PM COVERAGE (ft²/gal) 125/125; 180/180; 250/250



LEGEND:
 Coverage, ft²/gal
 - - - 125/125
 — 180/180
 ····· 250/250
 - · - Plain Concrete

Fig. D-4 - Weight loss and gain data; coated after 5 days of drying

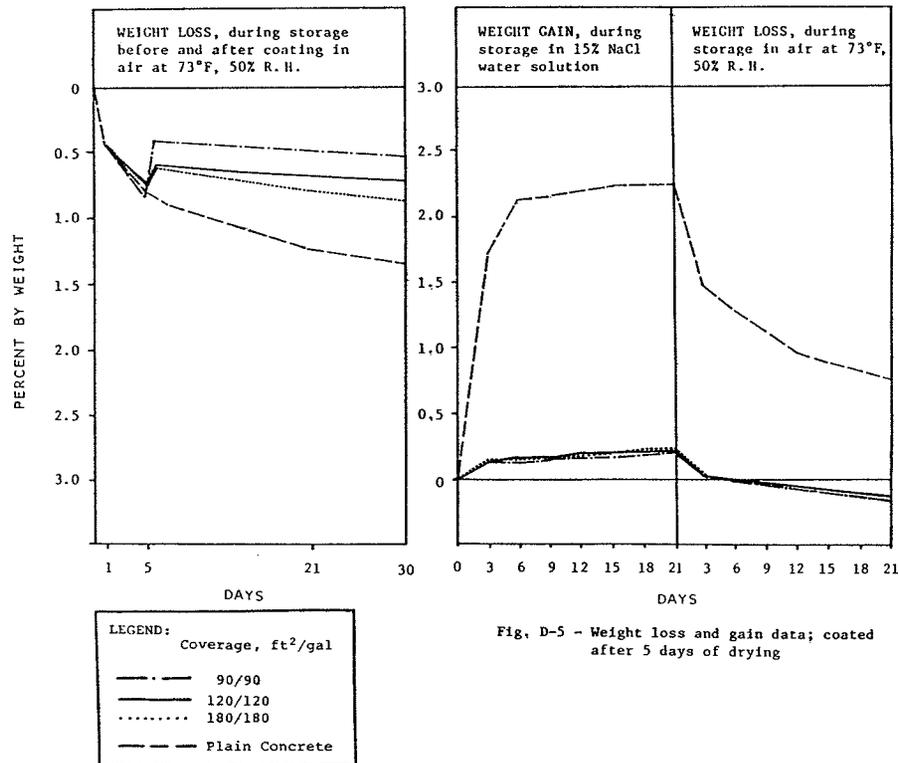


Fig. D-5 - Weight loss and gain data; coated after 5 days of drying

D-10

Test No.	Coverage rate (ft ² /gal)	Chloride ion content* (% by wt of concrete)
4-U	150/150	0.063 (0.005) ⁺
	200/200	0.064 (0.004)
	250/250	0.067 (0.000)
6-S	50	0.024 (0.002)
	100	0.027 (0.003)
	200	0.035 (0.001)
8-MM	100/200	0.017 (0.001)
	100 (primer)	0.038 (0.002)
	200 (finish)	0.063 (0.005)
10-PM	125/125	0.048 (0.002)
	180/180	0.065 (0.020)
	250/250	0.106 (0.020)
16-E	90/90	0.017 (0.002)
	120/120	0.016 (0.010)
	180/180	0.021 (0.006)
0-PC		0.212 (0.021)

* Average value from duplicate cubes

⁺ Range in chloride ion content from duplicate cubes

D-11

The use of the 16-E material resulted in significant reductions in water vapor transmission capabilities. When applied at the rates of 90/90, 120/120 and 180/180 ft²/gallon, the weight losses during this 26 day air drying period were only 26, 22 and 54 percent of that of the uncoated control cubes during the same time period.

Weight Gain During the Saltwater Soaking. The summary of the final weight gain data after 21 days in saltwater is given in Table D-4 and shows that materials 4-U, 6-S and 16-E are not significantly influenced by the use of their three different tested application rates. The differences in water absorption were only 15 to 20 percent more as their coverage rates per ft² were decreased by 70 to 400 percent. The 6-S material exhibited the least weight change sensitivity to variation in coverage rate.

The 8-MM material showed very high water absorption characteristics when the prime coat or finish coat were used singularly. When the 8-MM material was used in the normal two-coat manner, the water absorption value of 0.39 percent was only 17 percent of the uncoated control cubes and this performance exceeded all other materials except for material 16-E.

The 10-PM material provided weight gain performance that corresponded to the application rate coverage. Thus, when the rate was doubled, from 250/250 to 125/125 ft²/gallon, the absorption was reduced by approximately 50 percent.

The 16-E material exhibited the lowest absorption characteristics of all materials with values of 0.20, 0.20 and 0.23 percent weight gain for the three coverage rates. These values are only 9 to 10 percent of the absorption value of the uncoated control cubes. The performance of this material was also relatively insensitive to coverage rate variation.

TABLE D-4 - SUMMARY OF FINAL WEIGHT GAIN AND RESIDUAL WEIGHT CHANGE DATA

Test No.	Coverage rate (ft ² /gal)	Final weight gain		Final residual weight change (% by wt)	Weight loss/ weight gain (%)
		(% by wt)	(% of control)		
4-U	150/150	0.57	25	-0.13	123
	200/200	0.62	28	-0.12	119
	250/250	0.66	29	-0.10	115
6-S	50	0.46	21	-0.17	137
	100	0.52	23	-0.15	129
	200	0.55	25	-0.17	131
8-MM	100/200	0.39	17	-0.21	154
	100 (primer)	0.58	26	-0.10	117
	200 (finish)	0.73	33	-0.01	101
10-PM	125/125	0.55	25	-0.07	113
	180/180	0.62	28	-0.04	106
	250/250	1.14	51	0.28	75
16-E	90/90	0.20	9	-0.15	175
	120/120	0.20	9	-0.13	165
	180/180	0.23	10	-0.15	165
0-FC		2.24	100	0.76	66

Water Vapor Transmission Following Saltwater Soaking. The data in Table D-4 and Figs. D-1 to D-5 show that all the coated specimens except 10-PM (250/250) lost more weight during the final 21 days of air drying than they had gained during the 21 days of saltwater soaking. These data suggest good to excellent water vapor transmission qualities for all test conditions within Series III.

The highest ratio of weight loss to weight gain was always achieved with all five materials with the maximum application, primarily because it also always provided the lowest weight gain.

Chloride Ion Penetration Characteristics. The results of the chloride tests are summarized in Table D-5. A plot of chloride content versus weight gain for all the specimens is shown in Fig. D-6. The theoretical line representing the chloride ion solution strength of 9.2 percent is shown also for comparison purposes.

The results show a good correlation between weight gain and chloride ion content. The 6-S and 8-MM (normal only) materials consistently show chloride values of 4.5 to 6.5 percent by weight of the solution absorbed. These values appear to indicate a chloride screening capability for these two materials.

The 4-U, 10-PM and 16-E materials show chloride values ranging from 8.0 to 11.1 percent by weight of the solution absorbed. Their average value was 9.5 percent, which is the same value measured on the uncoated control cubes. These values compare very favorably with the theoretical value of 9.2 percent. These data indicate little if any chloride screening capabilities for materials 4-U, 10-PM or 16-E, irrespective of the coverage rate.

TABLE D-5 - RELATIONSHIP BETWEEN WATER ABSORPTION AND CHLORIDE ION CONTENT

Test No.	Coverage rate (ft ² /gal)	Chloride ion content (% by wt)	Weight gain after 21 days in 15% NaCl solution (% by wt)	Calculated percent chloride in solution absorbed
4-U	150/150	0.063	0.57	11.1
	200/200	0.064	0.62	10.3
	250/250	0.067	0.66	10.2
6-S	50	0.024	0.46	5.2
	100	0.027	0.52	5.2
	200	0.035	0.55	6.4
8-MM	100/200	0.017	0.39	4.4
	100 (primer)	0.038	0.58	6.6
	200 (finish)	0.063	0.73	8.6
10-PM	125/125	0.048	0.55	8.7
	180/180	0.065	0.62	10.5
	250/250	0.106	1.14	9.3
16-E	90/90	0.017	0.20	8.5
	120/120	0.016	0.20	8.0
	180/180	0.021	0.23	9.1
0-PC		0.212	2.24	9.5

D-15

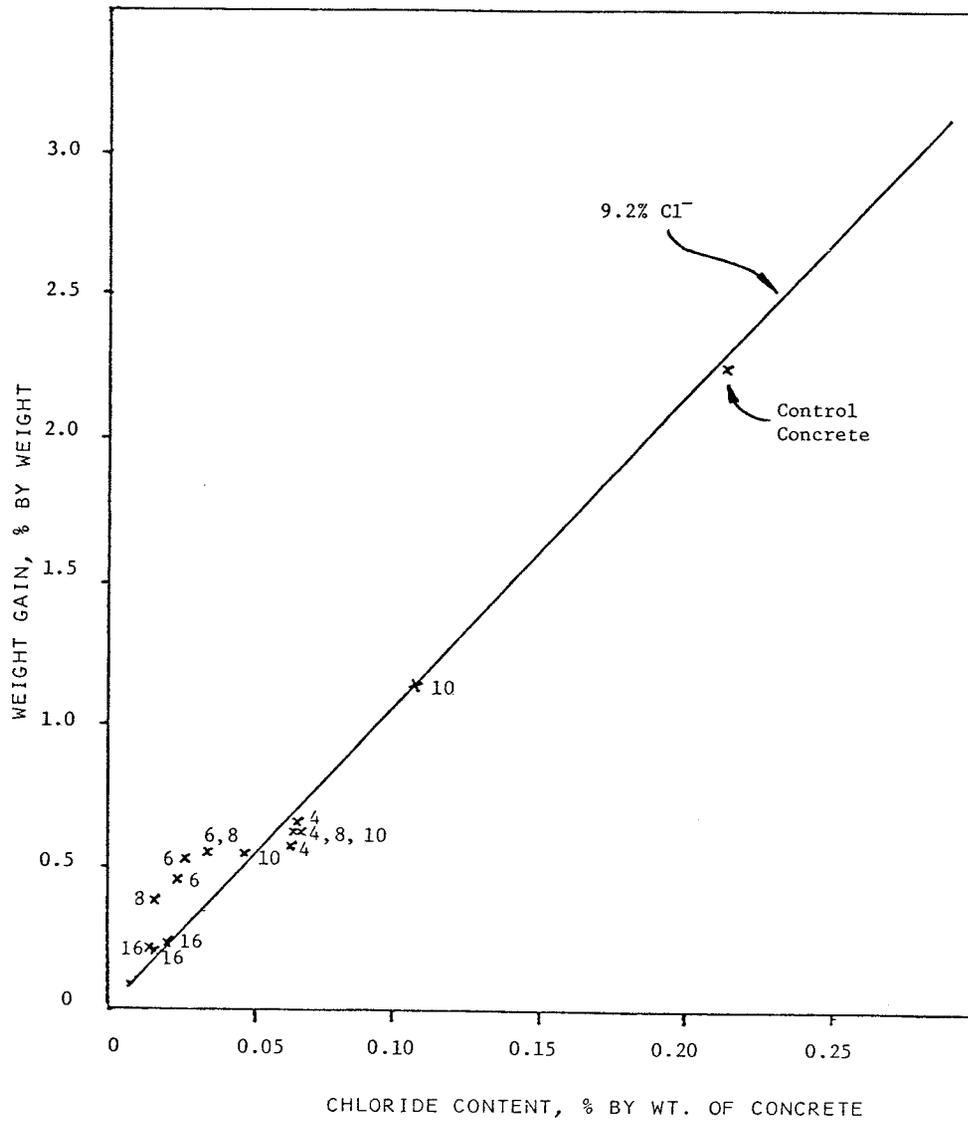


Fig. D-6 - Relationship between weight gain and chloride content

Conclusions

The test results from the Series III investigations justify the following conclusions:

1. Materials 4-U, 6-S, 8-MM and 10-PM can be applied with the different coverage rates tested without causing a significant decrease in water vapor transmission characteristics when compared to uncoated concrete. The use of the 16-E material did cause moderate to severe reductions in water vapor transmission capabilities.
2. The water absorption characteristics of concretes coated with materials 4-U, 6-S and 16-E are not significantly influenced by the use of different application rates as used in this investigation. Both the 6-S and 16-E materials were very insensitive to coverage rate variations with regard to weight gain. The 8-MM material showed very low weight gain characteristics when used in the normal two-coat manner. When used in single coats of prime coat or finish coat, the water absorption was very high. The 10-PM material exhibited weight gain performance that correlated to coverage rate.

Under the conditions of these tests, these five materials provided water absorption characteristics that were reduced significantly when compared to uncoated control cubes, as follows, when using the maximum application rate which always provided the best performance:

<u>Test No.</u>	<u>Reduction of Water Absorption into Concrete, %</u>
16-E	91
8-MM	83
6-S	79
4-U	75
10-PM	75

3. Following saltwater soaking, all five materials except 10-PM (250/250) exhibited good to excellent water vapor transmission by losing more weight during air drying than they had absorbed during saltwater soaking.
4. The chloride ion data show a good relationship to weight gain during the saltwater soaking. The 6-S, 8-MM (normal coverage) and 16-E materials exhibited very low chloride ion contents, generally lower than 0.025 percent by weight of concrete. These materials had their lowest chloride contents when used at their maximum application rates. The 4-U and 10-PM materials had higher chloride contents, generally ranging from 0.05 to 0.11 percent by weight of concrete. The 4-U material was insensitive to coverage rate variation as regards chloride intrusion, while the chloride contents of 10-PM were directly related to coverage rate.

Under the conditions of these tests, these five materials provided chloride intrusion characteristics that were significantly reduced when compared to uncoated concrete, as follows,

D-18

when using the maximum application rate which resulted in the lowest chloride contents:

<u>Test No.</u>	<u>Reduction in Chloride Content in Concrete, %</u>
16-E	92
8-MM	92
6-S	89
10-PM	77
4-U	70

5. Materials 6-S and 8-MM appear to act as chloride screens since their absorbed chloride contents were consistently and significantly less than the 9.2 percent solution strength, irrespective of coverage rate.
6. The overall performance of these five coating materials can be rated as follows, regarding reductions in water absorption and chloride intrusion, when used at the best coverage rates:

<u>Performance Position No.</u>	<u>Material</u>	<u>Best Coverage Rates ft²/gal</u>
1	16-E	90/90 to 120/120
2	8-MM	100/200
3	6-S	50 to 100
4	10-PM	125/125
5	4-U	150/150 to 200/200

D-19

APPENDIX E

SERIES IV LABORATORY TESTS - ACCELERATED WEATHERING TESTS

Introduction

Following completion of the literature search and the Series I laboratory screening tests, five materials were selected for the Series IV accelerated weathering tests. These materials are the same materials that were tested in the Series II and III laboratory studies. They are as follows:

1. Polyurethane - No. 4
2. Alkyl-Alkoxy Silane - No. 6
3. Methyl Siloxane and Methyl Methacrylate, Ethylacrylate - No. 8
4. Polyisobutyl Methacrylate - No. 10
5. Epoxy - No. 16

The Series II, III and IV laboratory tests were concurrent; therefore, the results from the Series II and III tests were not available prior to initiating the Series IV accelerated weathering tests.

The Series IV accelerated weathering tests were undertaken to subject unreinforced concrete slabs and cracked reinforced concrete slabs to accelerated weathering tests in the laboratory to simulate long-term exposure to the environments found in southern climates and also in northern climates, where freezing and thawing occurs. These tests were similar to weathering tests of concrete previously used by the PCA (57) and by WJE.

Two accelerated weathering test methods were used. One method emphasized alternate exposure of the slabs to a solution of 15 percent NaCl salt-water followed by exposure to ultraviolet light and infrared heat with the

solution removed. This procedure simulated the alternate wet and dry environment found in southern climate regions where periodic saltwater splash or spray is common, but freezing is not encountered.

The other test method utilized an accelerated weathering cycle where the slabs were exposed to a wider range of environmental conditions which included acid, saltwater, infrared heat, ultraviolet light, fresh water rinse, and realistic overnight freezing and thawing. This procedure appears appropriate for bridge surfaces in northern climates.

The objective of Series IV was to determine the influence of 24 weeks of accelerated laboratory weathering tests on the performance of these five materials when applied on unreinforced concrete and on cracked reinforced concrete. The performance was judged by making visual observations of the surface condition, by taking periodic copper-copper sulfate half cell corrosion potential readings on the cracked reinforced concrete slabs, and by measuring the chloride ion contents in the unreinforced concrete slabs at the end of the test period.

Test Program

The test program layout is shown in Table E-1. Each accelerated test method required 15 different test conditions as shown. Duplicate slab specimens were used. This resulted in the testing of 30 slabs for each climate condition, or a total of 60 slabs for the entire Series IV program.

As noted in Table E-1, three types of control slabs were tested. Uncoated slabs were made of unreinforced concrete and cracked reinforced concrete. In addition, unreinforced concrete slabs treated with boiled linseed oil were tested as control specimens.

TABLE E-1 - TEST SPECIMEN LAYOUT FOR SERIES IV WEATHERING TESTS
FOR BOTH SOUTHERN AND NORTHERN CLIMATES

Material No.	Description and number of slab specimens			
	Plain		Cracked	
	Unreinforced concrete		Reinforced concrete [∇]	
	Normal [*]	BLO	Normal [*]	
4-U	2	—	2	
6-S	2	—	2	
8-MM	2	—	2	
10-PM	2	2 ⁺	2	
16-E	2	2 ⁺	2	
0-PC (Control)	2	2 [#]	2	

* Concrete treated with surface penetrant or coating only

+ Concrete pretreated with boiled linseed oil (BLO) plus sandblasting plus ultraviolet light prior to surface sealing with penetrant or coating

Boiled linseed oil plus ultraviolet light

∇ With crack width of 0.010 in.

E-3

Test Materials and Procedures

Concrete Characteristics. Fifteen 3.0 ft³ batches of concrete were made with the same materials as used in Series II and III. The significant average properties for the fresh and hardened concrete were as follows:

<u>S.S.D. quantities/yd³</u>	
Cement content, lb	450
Sand content, lb	1515
Coarse aggregate content, lb	1726
Water content, lb	232
Plastic unit weight, pcf	145.3
Air content, %	5.7
Net w/c (S.S.D.) by weight	0.516
Slump, in.	3.5
Average 28-day compressive strength, psi	5210

The ranges in slump, w/c, and air content were 2.75 to 4.0 in., 0.510 to 0.519 and 5.0 to 6.4 percent, respectively.

Significant properties of the Eau Claire aggregates are as follows:

<u>Aggregate Size</u>	<u>Specific Gravity (S.S.D.)</u>	<u>Absorption, Percent (S.S.D.)</u>
3/4 to 1/2 in.	2.680	1.06
1/2 to 3/8 in.	2.637	1.00
3/8 to 3/16 in.	2.661	1.34
Sand	2.645	0.94

E-4

Specimen Fabrication Procedures

The 60 concrete slabs were cast in special resin-coated wood forms without the use of form release agents so that chemical contamination of the test surfaces could not occur. The test slabs were 5 in. thick and 12 in. square. The forms were constructed with holes in the appropriate side forms to position the No. 4 reinforcing bars to maintain exactly 1 in. of clear cover as shown in Fig. E-1. In all test slabs, the test surface which was exposed to the accelerated weathering was the bottom surface as cast. Two layers of concrete were cast and consolidated by table vibration. The No. 4 reinforcing bars were new, grey-colored bars with absolutely no evidence of rust.

As indicated in Fig. E-1, a dike about 1 in. high was attached to the test surface so that the saltwater could be ponded during testing.

The slabs were covered with wet burlap and plastic sheets for the initial overnight curing. They were then stripped from the forms and cured under polyethylene film until age 21 days. The top test surfaces were slightly sandblasted at age 18 to 20 days to remove the portland cement skin or laitance, which normally wears off by natural weathering. At age 21 days, they were then stored on their sides in air in a laboratory room at 60 to 70 degrees F for 5 days of air drying. At about age 28 days, the four sides of each test specimen were coated with two coats of the high-solids epoxy (No. 16) to minimize lateral moisture movement in the slabs during the accelerated weathering tests.

These 12 x 12 x 5 in. specimens have a volume/surface ratio of about 1.4 in.; therefore, 5 days of air drying should allow a weight loss (about

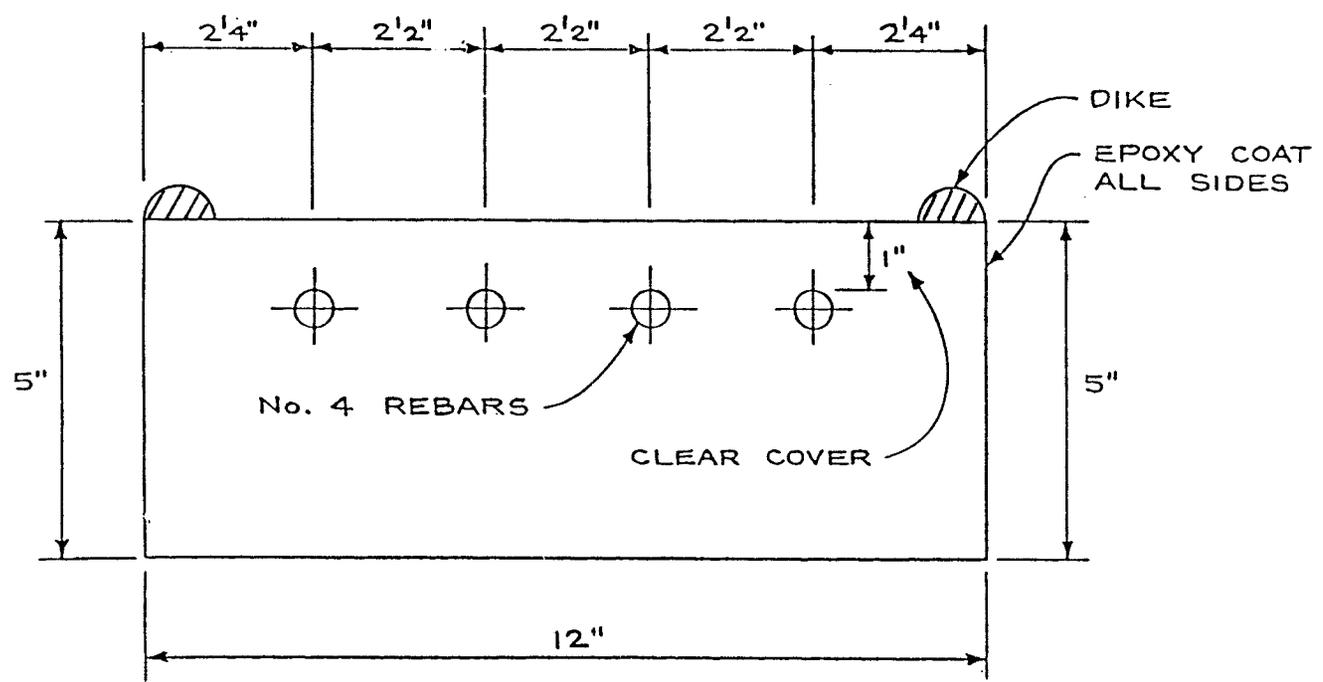


Fig. E-1 - Cross-Sectional View of all Test Specimens and Reinforcing Details for Reinforced Concrete Specimens for Series IV Tests

370 gms per slab) of about 30 percent of the water loss that would normally require three years to occur if no additional moisture were added.

Coating Procedures

The top surface of the "normal" specimens were coated by brush at an age of 26 days with the selected coatings. The coatings for these "normal" specimens were then allowed a 16 day air curing period prior to starting the weathering tests at an age of 42 days.

The companion "BLO" specimens were pretreated at an age of 26 and 27 days with a normal two-coat boiled linseed oil formulation. This linseed oil pretreatment was then given a 7 day cure, during which the slabs were subjected to an ultraviolet light exposure at 70 degrees F, to accelerate aging. These "BLO" specimens were then again lightly sandblasted to simulate natural weathering and aging of the pretreated surfaces. Following this pretreatment period, the specimens were coated with the five selected coatings, at an age of 34 days. The coatings were then allowed a 16 day air curing period prior to starting the weathering tests, at an age of 50 days.

The manufacturer's normal coverage rates were used as follows:

<u>Material No.</u>	<u>Coverage Rate, ft²/gal</u>
4-U	200/200
6-S	100
8-MM	100/200
10-PM	250/250
16-E	120/120
2-BLO	360/600

Cracking Procedures

Two reinforced slab specimens for each material were intentionally cracked flexurally across the bars at mid-bar-length after the initial 21 day moist-curing period. A machine was adapted to apply flexural loads to the slabs. Prior to cracking the slabs, the bottom slab surface at midspan was cut transverse to the bars with a saw to a depth of 2.5 in. This allowed flexural cracking above this saw cut on the test surface without creating a flexural bond failure of the embedded bars during the cracking process. Earlier trials showed that the type of cracking desired could not be created without this modification in these short, deep and heavily reinforced "beams". After the top surface was flexurally cracked, three holes, 1/2 in. in diameter and 3/4 in. deep, were drilled into the top concrete surface directly vertically through the crack. After these holes were drilled, the slab was again loaded until an average crack width of 0.015 to 0.020 in. was produced. The holes were then partially filled with a sanded epoxy. A steel cylinder plug, somewhat smaller than the drilled hole, then was slowly floated down into the sanded epoxy. Heat was applied to accelerate the setting of the epoxy, the load was removed and the flexural crack maintained an average width of about 0.010 in. Previous tests have shown that this technique will hold a crack open at the same nominal width for months.

The saw cuts on the bottom surfaces were then completely filled with a flexible caulking.

Ultraviolet Light Apparatus

Typical monthly totals for normal ultraviolet light radiation (with wave lengths from 2950 to 3950 A⁰) for winter and summer months for typical northern and southern cities are as follows:

	<u>Winter</u>	<u>Summer</u>
Chicago	2460*	8470*
New York	2380	6520
Phoenix	4650	9980
Miami	4600	6700

* Watt-hours/sq meter/month. From National Oceanographic and Atmospheric Administration, Boulder, Colorado, and National Climate Center, Ashville, North Carolina.

The ultraviolet source used during these accelerated weathering tests in Series IV to accelerate aging of the slabs pretreated with boiled linseed oil prior to coating these slabs with the five materials, and also during the subsequent 24 week northern and southern climate accelerated weathering tests, consisted of standard 48 in. long, four lamp fluorescent fixtures and 40 watt ultraviolet lamps (W-F40BL). The lamps operated at 430 milliamps, which provided about 28 to 35 watts/sq meter since the lamps were positioned 6 in. above each slab with a distance from the fixture centerline to the edge of the slab of 6 in. Three slabs were positioned under each 48 in. long fixture.

By using average values of monthly winter and summer ultraviolet radiation for northern and southern regions, along with average number of hours of daylight per month, the following tabulation was prepared which lists the approximate normal ultraviolet radiation from the sun per typical yearly-average day.

	<u>Approximate Yearly-Average Daily Intensity, watt-hours/sq meter/day</u>
Northern Regions	170
Southern Regions	212

During the northern climate accelerated tests, the slabs received 3 hours per day for 5 days a week of exposure. Thus, these northern climate slabs received about 95 watt-hours/sq meter/day, 5 days a week, for 24 weeks. During the southern climate tests, the slabs received 68 hours of continuous ultraviolet exposure per week. Thus, the southern climate slabs received about 750 watt-hours/sq meter/day, 2.83 days per week, for 24 weeks.

The total cumulative ultraviolet light exposure during the 24-week testing was about 9,000 watt-hours/sq meter for the northern climate tests and 50,000 watt-hours/sq meter for the southern climate tests. These values are equivalent to about 54 yearly-average northern days and 240 yearly-average southern days of ultraviolet radiation exposure.

The specimens treated, or pretreated, with linseed oil received 7 days of continuous ultraviolet light exposure at 70 degrees F in the same apparatus to age the linseed oil prior to the application of the 10-PM and 16-E coatings. These specimens, six each for the northern and southern climate tests, thus received about 5000 watt-hours/sq meter of ultraviolet exposure during this preliminary aging process prior to coating the specimens and starting the actual accelerated weathering tests.

Southern Climate Test Procedure. This test method was based upon a weekly cycle. For the first 100 hours of each week, the test surface was ponded with about 1/2 in. of 15 percent NaCl saltwater solution in a laboratory at 60 to 70 degrees F. The ponded surface was covered with plastic film which was held tight with rubber bands to prevent evaporation. Following this 100 hour exposure, the saltwater was removed, the slabs were rinsed with fresh water and drained, then moved into a heat chamber at 100 degrees F which contained the ultraviolet lights. These (nonponded) slabs remained in this

ultraviolet and heat exposure for 68 continuous hours. After this exposure, they were removed from the chamber and immediately reponded with a fresh saltwater solution. This 7 day cycle (168 hours) was repeated 24 times.

Northern Climate Test Procedure. This test method was based upon a daily cycle, with no activity on weekends. The following 24 hour cycle was repeated 5 days (4 nights of freezing) a week for 24 weeks.

- 15 hour overnight freeze in air at 15 ± 5 degrees F (4 nights a week). The diked test surface was empty.
- 2 hour thaw in laboratory air at 60 to 70 degrees F (4 days a week). The diked test surface was empty.
- 3 hour exposure to ultraviolet radiation and infrared heat at 100 ± 5 degrees F. The diked test surface was empty.
- 3 hour soak period with 15 percent NaCl and 0.02 molar sulfurous acid water solution on test surface (fresh solution each day).
- Remove test solution, rinse with fresh water and drain.
- Return to air freezer room.

The specimens were stored in a thawed non-test condition over each weekend.

The northern climate test solution contained a 0.02 molar sulfurous acid component to simulate the acids found in the rains and atmosphere in northern industrial regions. This solution strength was used by PCA (57) and WJE in previous accelerated weathering tests.

Corrosion Activity Test Procedures. The cracked, reinforced specimens were monitored with copper-copper sulfate half cell readings on a weekly basis for the first 6 weeks, and then every other week. Each of the four electrically isolated embedded bars projected from the slab about 1 in. on each end. A small hole was drilled into one end of each bar for the voltmeter electrical attachment. The projecting ends were protected from corrosion by applying multiple coats of an epoxy resin.

The half cell contact was made to the non-coated bottom surface (pre-wetted) since all side surfaces and most test surfaces were coated. A potential reading was taken on each bar by positioning the half cell near the center of the slab and directly over the bar. The readings were taken when the concrete temperatures were about 70 degrees F for the northern climate tests, and about 100 degrees F for the southern climate tests.

Visual Inspection and Photographs. During the 24 week test period, visual inspections of the slabs were made along with notes and photographs. While deterioration in coatings or concrete is generally visible to the naked eye, black and white photographs were found to be unsatisfactory in illustrating such conditions. At the end of the tests, black and white prints, color prints, and color slide photographs were taken of each test condition. These photographs are being stored by NCHRP for future use.

Chloride Ion Test Procedures. Following the photographing of the specimens at the conclusion of the tests, powder samples were taken from each of the 36 unreinforced concrete test slabs and two untested, unreinforced control slabs. Fig. E-2 shows a plan view of a slab indicating the locations for

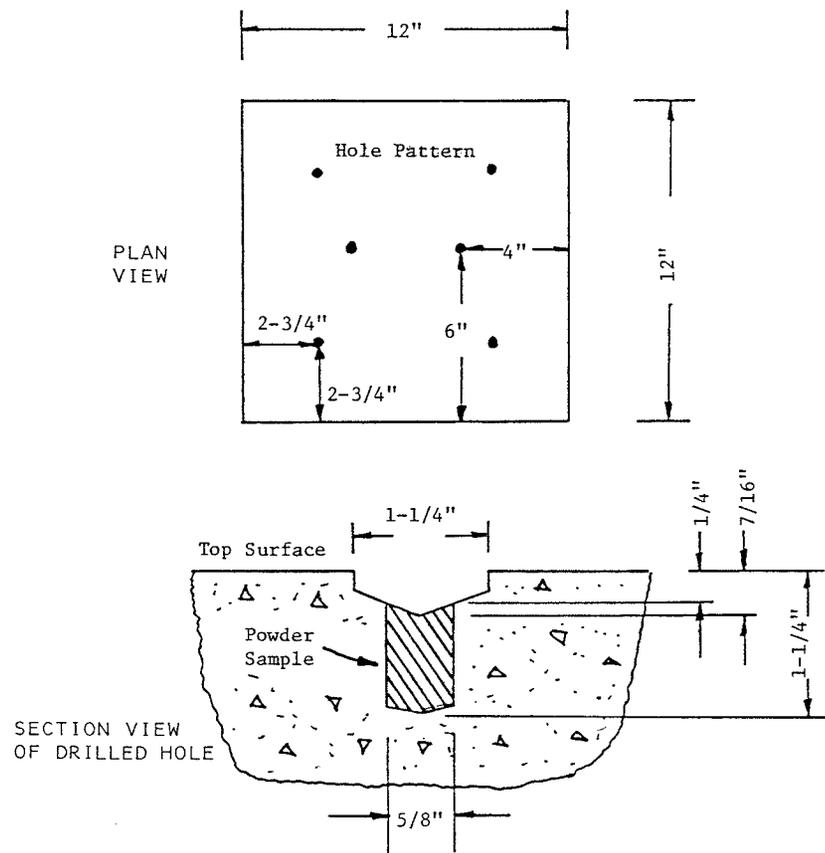


Fig. E-2 - Chloride Ion Powder Sample Test Holes and Hole Details.

E-13

the six drilled holes in each slab and a cross-sectional view of the drilled hole. Each hole was first drilled with a 1-1/4 in. diameter bit to a depth of approximately 7/16 in. to provide for total removal of concrete above the 1/4 in. depth plane in the area of the final 5/8 in. diameter hole. After drilling all six initial 1-1/4 in. holes, the powder was vacuumed from each hole and discarded and the top surface brushed clean. The final 5/8 in. diameter holes were then drilled to a total nominal depth of 1-1/4 in. The cross-hatched area in Fig. E-2 shows the location of the tested powder sample. The powder from the six holes in each slab was removed and combined into one composite sample. The resulting 38 samples were tested by Erlin, Hime Associates, Inc. using an acid-digestion, potentiometric titration procedure.

The actual depth of each hole was then determined with a depth micrometer. The average depth of all 228 holes in the 38 samples was 1.243 in. The range in measured hole depth was from 1.183 to 1.330 in.

Condition of Embedded Reinforcing Bars at Conclusion of Tests. The 96 bars in the 24 reinforced concrete slabs that had been intentionally cracked prior to applying the coating materials were examined at the end of the tests. The four reinforcing bars from each slab were carefully removed and inspected for degree of corrosion. The amount of the bar surface that was corroded and the degree of the corrosion were estimated from this visual inspection.

Test Results and Observations

Visual Inspection of Surfaces at Conclusion of Tests. The test surface of each specimen was visually inspected at the conclusion of the tests. Duplicate slabs exhibited essentially identical surface appearances at the end of the tests. Details from this inspection follow:

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Southern Climate - Unreinforced Slabs. All nine test conditions exhibited no surface deterioration of the uncoated or coated concrete. The uncoated control concrete did exhibit more surface pinholes than did the eight coated test conditions. The specimens coated with 16-E or (BLO + 16-E) turned a dark brownish-yellow color. Pinholes were evident through the 16-E coating. About 80 percent of the test surfaces of the 4-U specimens had turned a light brownish-yellow color; the remainder of the surface was grey. The 6-S, 10-PM, (BLO + 10-PM), 2-BLO, and the uncoated control specimens showed no color difference; i.e., they were still light grey. The 8-MM specimen was a slightly darker grey than the uncoated control slabs. All surfaces appeared to be in excellent condition except for these color changes which were apparently caused by ultraviolet light exposure.

Northern Climate - Unreinforced Slabs. All nine test conditions, except 16-E and (BLO + 16-E), exhibited some degree of surface deterioration of the concrete. The uncoated control slabs showed a uniform aggregate exposure (about 1/8 in. deep) with the general appearance of old concrete. The following tabulation describes the individual surface conditions:

<u>Material No.</u>	<u>Surface Condition</u>
4-U	Uniform light etch, few coarse aggregates showing. Yellowish-brown discoloration.
6-S	Uniform deep etch, coarse aggregates showing, same appearance as uncoated control specimens.

<u>Material No.</u>	<u>Surface Condition</u>
8-MM	Fifty percent of original concrete surface totally intact, 50 percent of surface with moderate etch, some coarse aggregates visible.
10-PM	Uniform light etch, few coarse aggregates showing.
16-E	Epoxy surface totally intact with no concrete visible.
2-BLO	Uniform moderate etch with some coarse aggregates showing, less etch than control concrete.
BLO + 10-PM	Uniform light etch with few coarse aggregates showing.
BLO + 16-E	Yellowish color under epoxy coating on 70 percent of area. Epoxy totally intact with no concrete visible.
O-PC (Control Concrete)	Uniform deep etch with coarse aggregates showing.

This northern climate exposure testing did not result in discoloration of the 16-E specimens as was previously described in the southern climate testing.

Southern Climate - Cracked Reinforced Slabs. The surface condition of the concrete and the color of the coated surfaces were the same as described for the unreinforced southern climate slabs previously discussed.

Rust was evident on the test surface along the crack in the following specimens: 4-U, 8-MM, 10-PM and the control concrete.

Northern Climate - Cracked Reinforced Slabs. The surface condition of the concrete and the color of the coated surfaces were the same as described for the nonreinforced northern climate slabs previously discussed.

Rust was evident on the test surface along the crack in the following specimens: 6-S, 10-PM and the control concrete.

The 16-E coating cracked along the crack. Some surface deterioration of the concrete was evident along the crack. The width of this concrete etching was about 1/8 to 1/4 in.

Corrosion Potential Tests. The individual copper-copper sulfate half cell voltage readings for the eight bars in the duplicate slabs for the northern and southern climate tests on the uncoated control specimens and the specimens coated with 6-S and 8-MM are shown in Figs. E-3 to E-8 as typical data. The four bars in duplicate slabs are shown by different symbols. These typical data show that the voltage variations among the eight bars in duplicate slabs can be significant at a given age and that significant voltage variation can occur within duplicate slabs. Such variations may be caused by variations in crack width, in anode/cathode locations, coating performance and concrete surface deterioration.

While significant voltage variations occurred from bar to bar under the same test conditions in duplicate specimens, there appear to be significant differences in voltage as affected by coating material when average voltage data are compared. Figs. E-9 and E-10 show average voltages obtained from the eight bars in duplicate slabs for the control specimens and the five coated specimens for the southern and northern climate testing, respectively. The uncoated control specimens exhibited the highest voltages throughout the

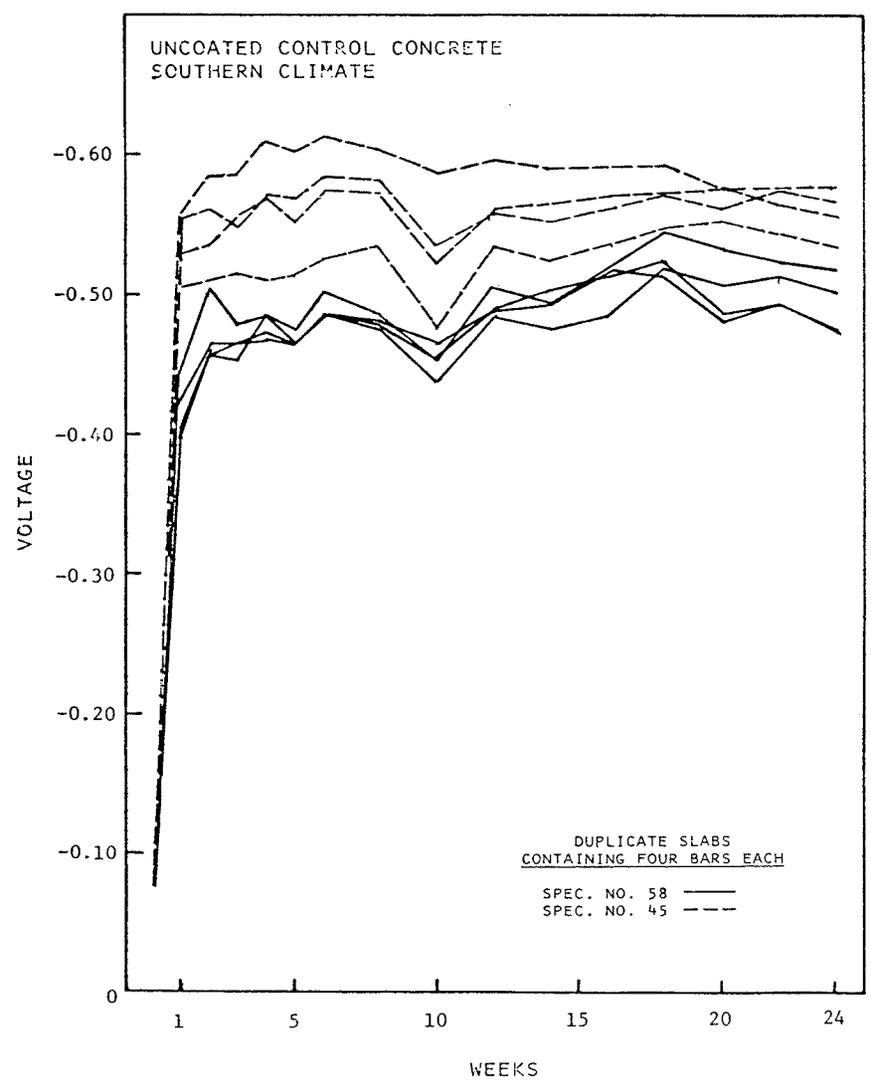


Fig. E-3 - Voltage of steel bars as related to Cu-CuSO₄ half cell vs. weeks of testing (control concrete, southern climate)

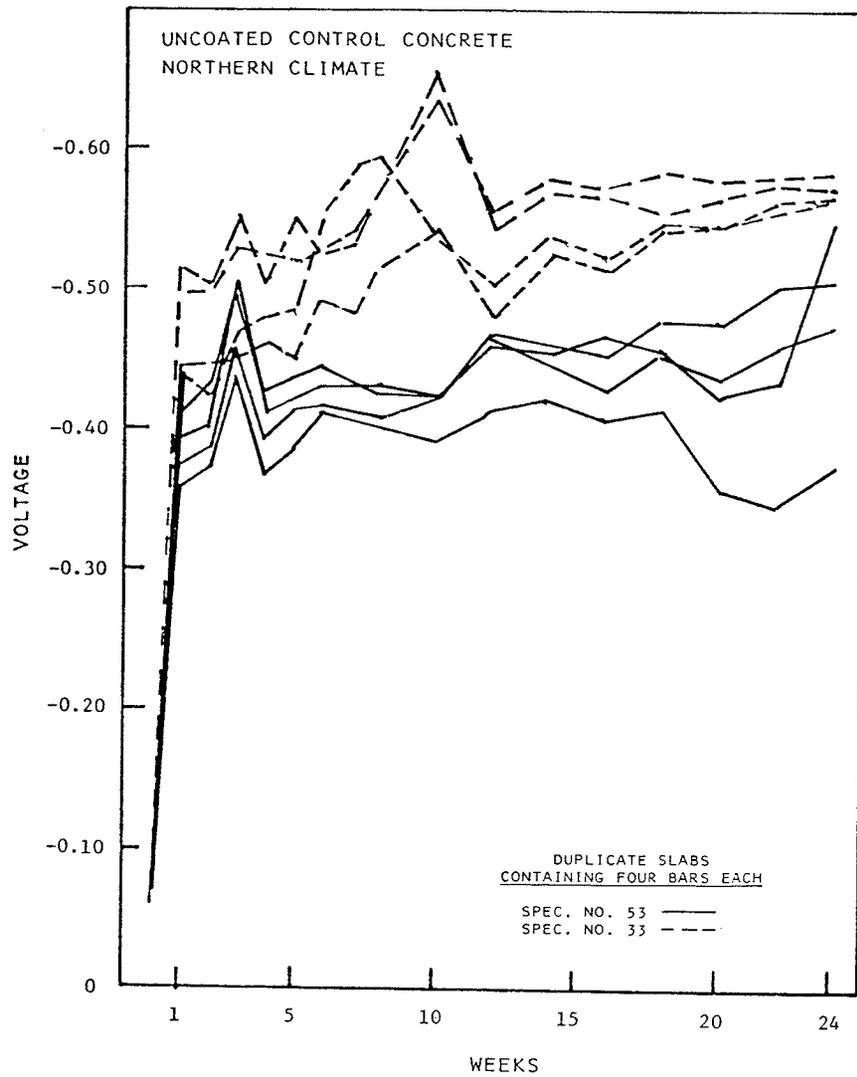


Fig. E-4 - Voltage of steel bars vs. Cu-CuSO₄ half cell vs. weeks of testing (control concrete, northern climate)

E-19

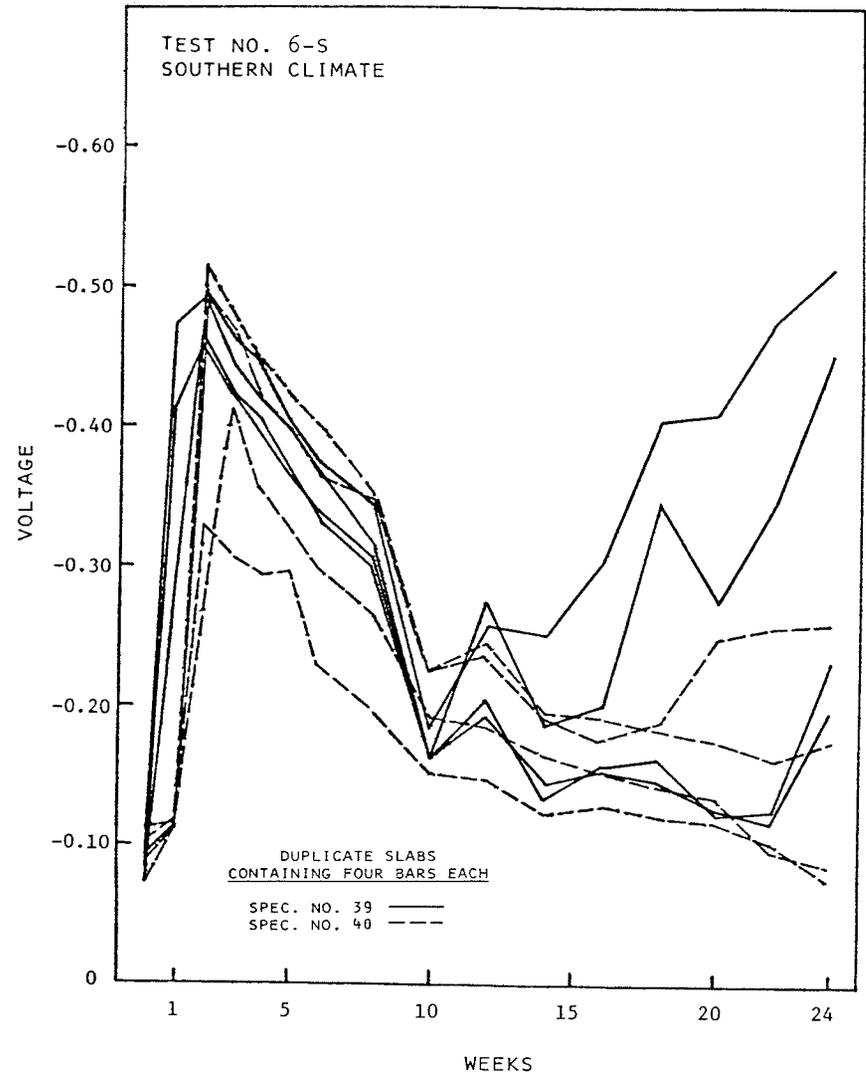


Fig. E-5 - Voltage of steel bars vs. Cu-CuSO₄ half cell vs. weeks of testing (6-S, southern climate)

E-20

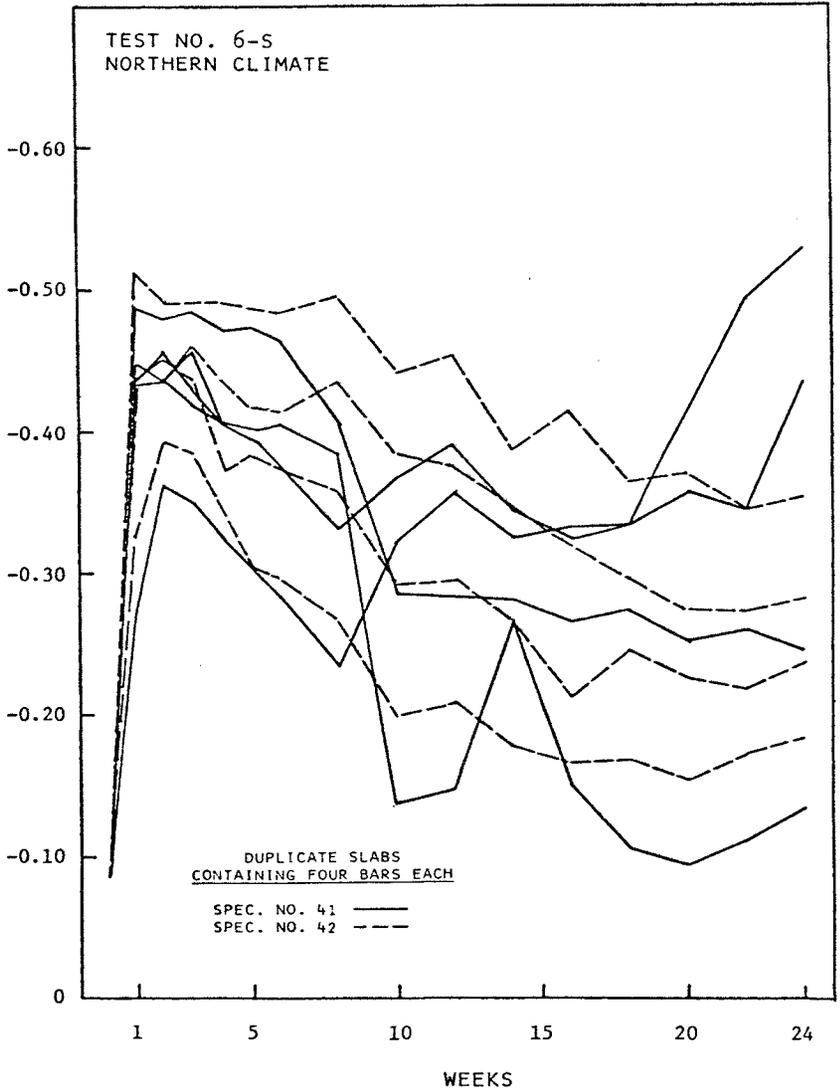


Fig. E-6 - Voltage of steel bars vs. Cu-CuSO₄ half cell vs. weeks of testing (6-S, northern climate)

E-21

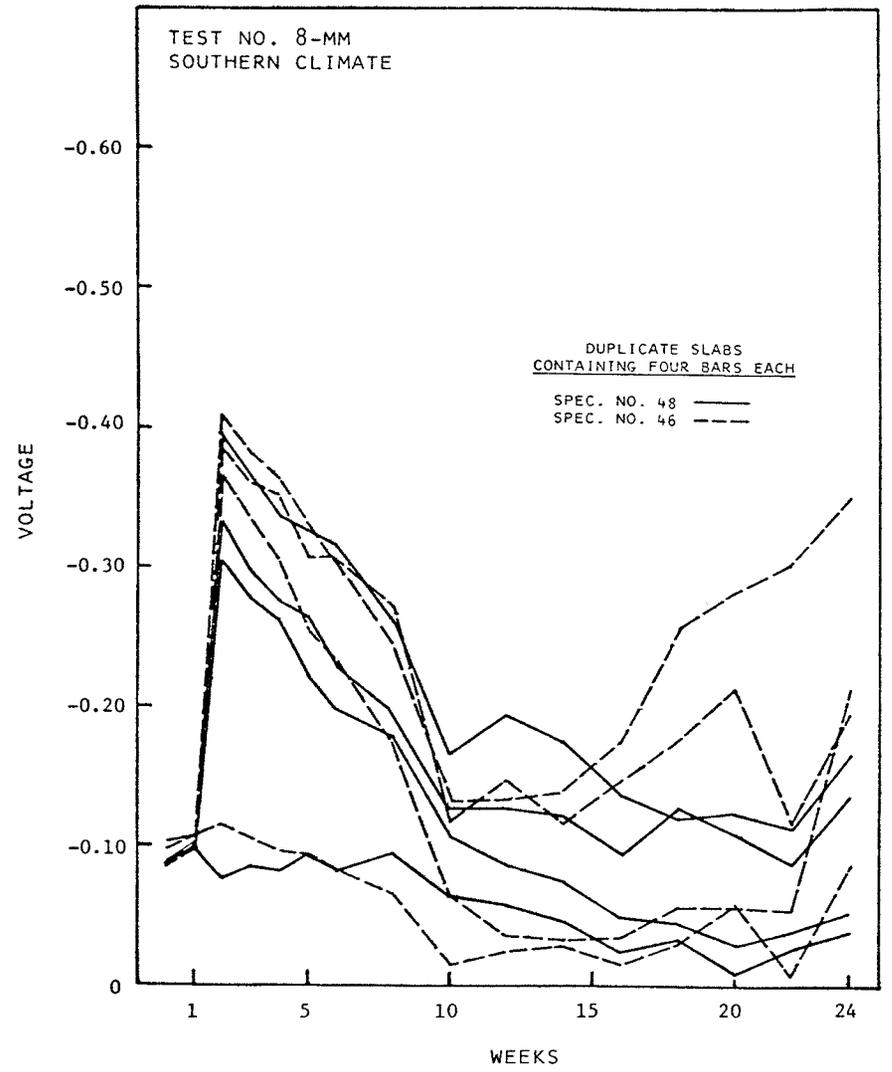


Fig. E-7 - Voltage of steel bars vs. Cu-CuSO₄ half cell vs. weeks of testing (8-MM, southern climate)

E-22

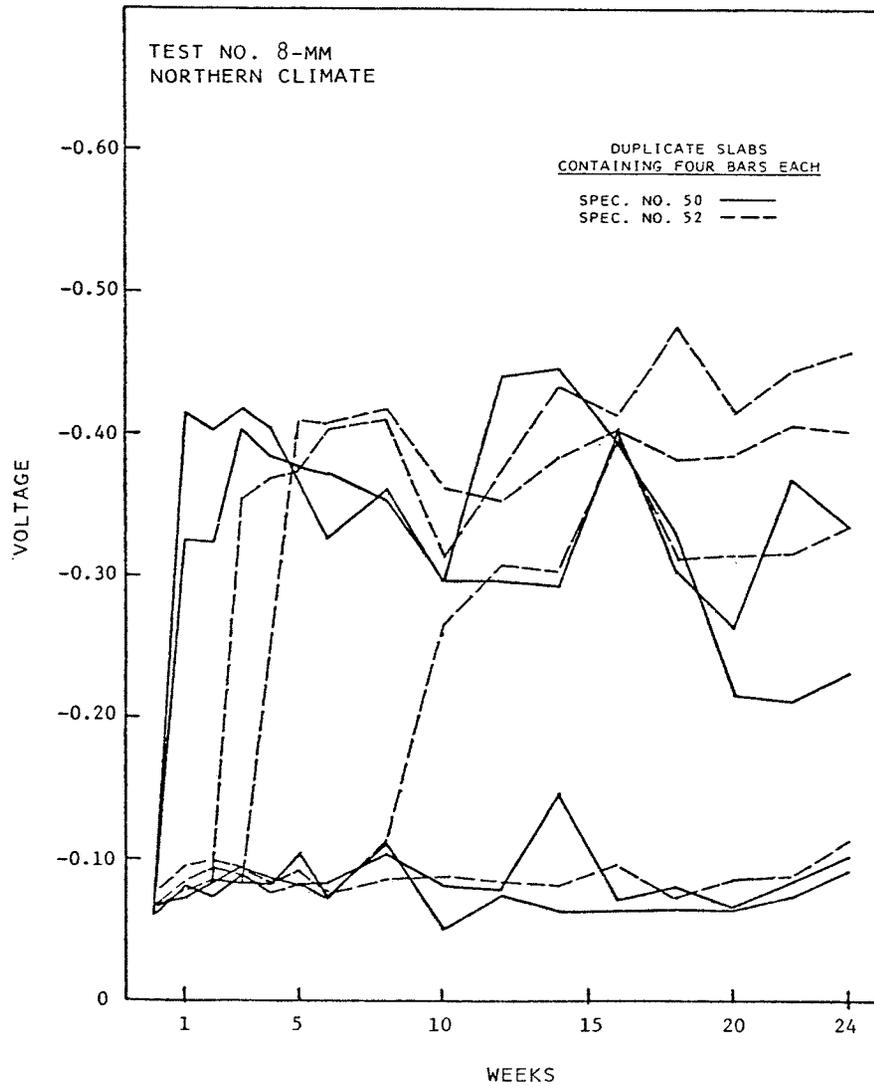


Fig. E-8 - Voltage of steel bars vs. Cu-CuSO₄ half cell vs. weeks of testing (8-MM, northern climate)

E-23

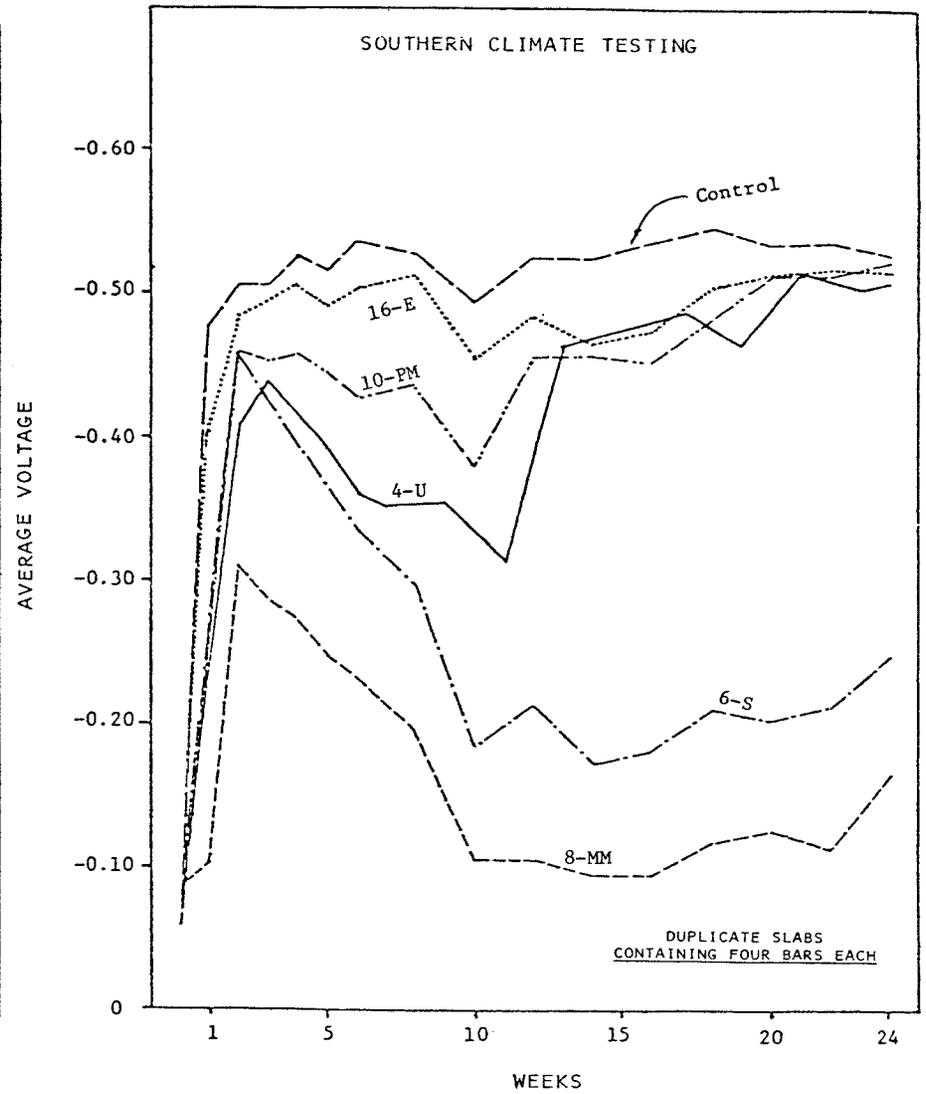


Fig. E-9 - Average voltage of steel bars as related to Cu-CuSO₄ half cell vs. weeks of testing (all tests, southern climate)

E-24

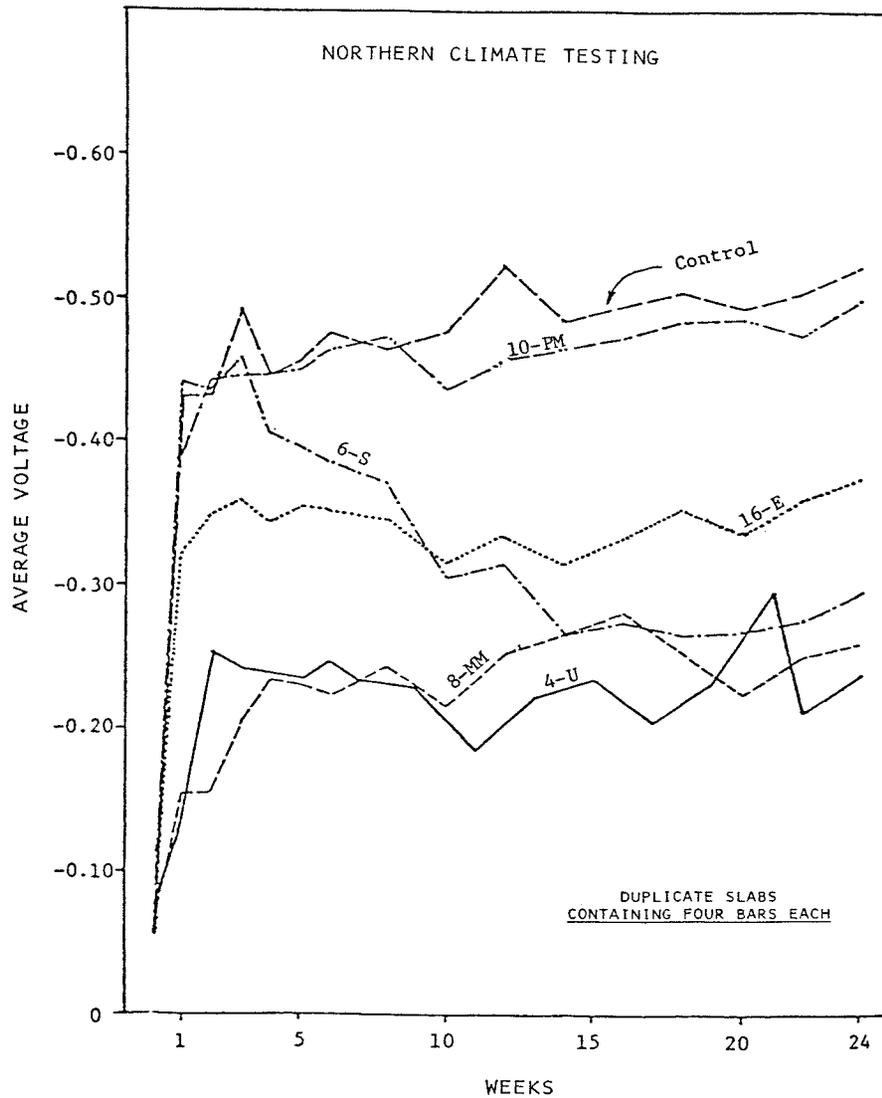


Fig. E-10 - Average voltage of steel bars as related to Cu-CuSO_4 half cell vs. weeks of testing (all tests, northern climate)

E-25

24 week testing, regardless of the exposure. The southern climate testing voltages for the control specimens were slightly higher than those for the northern climate specimens. The voltages for these control specimens ranged from -0.45 to -0.55 volts and were rather uniform throughout the entire testing period. The coated specimens typically had lower average voltages than the controls, with some coated specimens having numerically less than -0.20 average voltage at the end of the 24 weeks of testing. All specimens showed a rapid rise in potential at the beginning of the test. Some specimens then showed a rather uniform decrease in this initial voltage potential down to a rather low and constant level.

The following coating materials showed average voltage potentials less than -0.35 volts at the conclusion of the tests:

Southern Climate:	6-S, 8-MM
Northern Climate:	4-U, 6-S, 8-MM

Corrosion Products on Bars. The 96 reinforcing bars in the cracked reinforced concrete slabs were removed and visually examined. Each slab contained four bars, each of which had 1 in. of cover. Each bar was visually examined and measured to determine approximately the amount and degree of corrosion on the surfaces. This was done to determine where the corrosion activity was furthest advanced and whether the half cell readings correlated with the visual observations. Observations from these examinations are as follows:

1. The southern climate testing produced more voluminous corrosion products on the bars compared to the northern climate testing. Many southern climate bars exhibited practically full-length, full-perimeter corrosion products.

E-26

2. The corrosion products were always more pronounced on the top of the bar, which was closest to the ponded test surface.
3. In the southern climate tests, the eight bars from the duplicate slabs coated with 8-MM exhibited the least corrosion, varying from none, to slight, to moderate. The half cell voltages for these 8-MM duplicate specimens were also the lowest, with an average of about -0.12 volts during the final 14 weeks of testing.
4. In the southern climate tests, all eight bars in the duplicate slabs coated with 6-S showed moderate corrosion activity. The half cell voltages were in the range of about -0.20 volts during the final 14 weeks of testing.
5. In the southern climate tests, the eight bars in each duplicate set of slabs coated with 4-U, 10-PM, 16-E and the uncoated control slabs were severely corroded. These corrosion products were generally full-length and covered the entire perimeter. As previously discussed, the corrosion products on the top surface of the bar were more pronounced than on the bottom surface. These slabs had average half cell readings in the range of -0.45 to -0.55 volts during the final 12 weeks of testing.
6. Thus, the half cell data from the southern climate tests show a correlation between average voltage reading during the final 14 weeks of testing and the amount and degree of corrosion products found on the bars at the end of the 24 week test period.
7. The northern climate testing generally produced only slight to moderate corrosion products on the bars. The only bars with severe corrosion products were the uncoated control specimens.

8. With the northern climate testing, the specimens coated with 8-MM and 4-U had the least corrosion; those coated with 6-S and 16-E had slightly more corrosion, and the control specimens and those coated with 10-PM had the greatest degree of corrosion. This order of degree of visual corrosion correlates with the magnitude of the average half cell voltages measured.

Chloride Content of Concretes. At the end of the test period, the chloride content was determined in the 38 unreinforced concrete slabs by extracting powder samples as described previously. The test results are given in Table E-2. The untested concrete control specimens had a total chloride ion content of 0.002 percent by weight of concrete, a negligible amount.

The tested concrete control slabs had average total chloride ion contents of 0.547 and 0.182 percent for the southern and northern climate tests, respectively. This difference between the two exposures is reasonable since the southern climate specimens received 100 hours of saltwater soaking per week while the northern climate specimens received only 15 hours of saltwater soaking per week. In addition, the southern climate specimens received 68 hours of continuous heat at 100 degrees F with ultraviolet light just prior to being ponded with the saltwater, which would increase the suction rate of the test surfaces. The northern climate specimens on the other hand received only 3 hours of heat at 100 degrees F with ultraviolet light just prior to being ponded with saltwater each day.

TABLE E-2 - TOTAL CHLORIDE ION CONTENTS AFTER
24-WEEK ACCELERATED WEATHERING TESTS

Material No.	Chloride ion content, % by wt of concrete					
	Southern climate			Northern climate		
	No. 1	No. 2	Avg.	No. 1	No. 2	Avg.
4-U	0.516	0.507	0.512	0.138	0.069	0.104
6-S	0.033	0.004	0.019	0.027	0.061	0.044
8-MM	0.004	0.002	0.003	0.016	0.031	0.024
10-PM	0.505	0.526	0.516	0.081	0.094	0.088
16-E	0.004	0.072	0.038	0.007	0.004	0.006
0-PC (Control)	0.528	0.565	0.547	0.204	0.159	0.182
Pretreated with boiled linseed oil						
2-BLO + 10-PM	0.002	0.024	0.013	0.005	0.004	0.005
2-BLO + 16-E	0.002	0.038	0.020	0.004	0.004	0.004
2-BLO	0.004	0.004	0.004	0.006	0.002	0.004
		<u>No. 1</u>	<u>No. 2</u>	<u>Avg.</u>		
Untested control concrete		0.002	0.002	0.002		

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The following tabulation shows the performance of the five tested coating materials by listing the percent reduction of chloride content in these slabs as compared with the uncoated control specimens.

Overall Performance Rating	Material No.	Reduction in Chloride Content in Concrete*, %	
		Northern Exposure	Southern Exposure
1	16-E	97	93
2	8-MM	87	99
3	6-S	76	97
4	10-PM	52	6
5	4-U	43	7

* As compared to tested uncoated control concrete

The above tabulation shows that the performance of the 16-E and 8-MM materials was excellent for both exposures, the performance of the 6-S material was excellent in the southern exposure where the top surface of the concrete did not deteriorate as contrasted to the fair to good performance for the 6-S material in the northern climate tests where the top concrete surface did deteriorate. The 4-U and 10-PM materials showed relatively poor performance for either exposure, but particularly the southern.

The chloride content data indicate excellent performance of the specimens treated with linseed oil (2-BLO) that underwent these two environmental tests. This performance is in sharp contrast to the poor performance of boiled linseed oil as reported in the Series I tests in Appendix B. Series IV slabs (2-BLO) exhibited the lowest and most consistent chloride content data of all materials tested in this series. The chloride contents of the specimens pretreated with linseed oil followed by coatings with 10-PM or 16-E were

E-30

also very low. This was particularly evident with the 10-PM coating whose chloride contents were reduced by 98 percent and 94 percent, respectively, for the southern and northern climate exposures when pretreated with linseed oil versus when they were not pretreated with linseed oil. As stated previously, these slabs, treated and pretreated with linseed oil, received about 5,000 watt-hours/sq meter of ultraviolet radiation at 70 degrees F to accelerate aging of the oil prior to starting the tests (2-BLO) or prior to applying the two coatings (2-BLO + 10-PM and 2-BLO + 16-E). This ultraviolet light exposure prior to starting the tests appears to have cured the linseed oil into an extremely water repellent coating.

Specimens treated with linseed oil have been tested for water absorption and chloride intrusion in Series I and IV using different coating and ultraviolet light aging techniques. The tabulation below lists the ultraviolet light exposure applied prior to starting the tests, the number of double coats of boiled linseed oil used, the water absorption, if measured, and the chloride content after these various tests:

Test Series No.	No. of Double Coats (360/600)	Ultraviolet Light Exposure watt-hours/sq meter	Chloride Content Percent by Weight of Concrete	Weight Gain Percent of Weight
I	1	0	0.209	2.19
I*	1	0	0.219	2.33
I	1	200	0.229	2.37
I	2	200+	0.094	1.34
IV	1	5000	0.002	----

* Supplementary data from other WJE tests.

+ Ultraviolet light exposure between first and second double coat as described in Series I tests.

These data suggest that exposure to large amounts of ultraviolet light radiation immediately after applying the boiled linseed oil and prior to starting any water soaking or accelerated weathering tests may have a significant effect on the linseed oil, and that such a treated linseed oil penetrant becomes relatively impervious to chloride ion from saltwater.

Correlation of Series IV Accelerated Weathering Tests with Series II Tests

The Series II tests on 4 in. cubes incorporated the same coverage rates from the five coating materials and the same 5 day air drying period after the 21 day moist curing period as did the Series IV accelerated weathering tests. As a result, it is possible to compare the chloride content of the cubes from Series II (with 5 days of drying) with the chloride content from the Series IV slabs after their respective testing periods. The chloride contents from the cubes were determined on half-cube specimens which were 4 in. square and 2 in. thick. The chloride contents from the slabs were from drilled samples taken from 1/4 in. to 1-1/4 in. below the test surface. Thus, there is a dimensional difference in where the chloride contents were taken as related to the exposed test surface.

Fig. E-11 shows the comparison of these two sets of data on chloride contents for the five coating materials and the control concrete for the northern and southern climate testing. The line of equality is shown for comparison purposes. For the northern climate tests, three materials, 4-U, 6-S and 8-MM, show more chloride in the slabs than in the cubes after the tests. Two materials, 16-E and 10-PM, and the control concrete show less chloride in the slabs than in the cubes after the tests. These data from the northern climate testing show a reasonable relationship of the two test

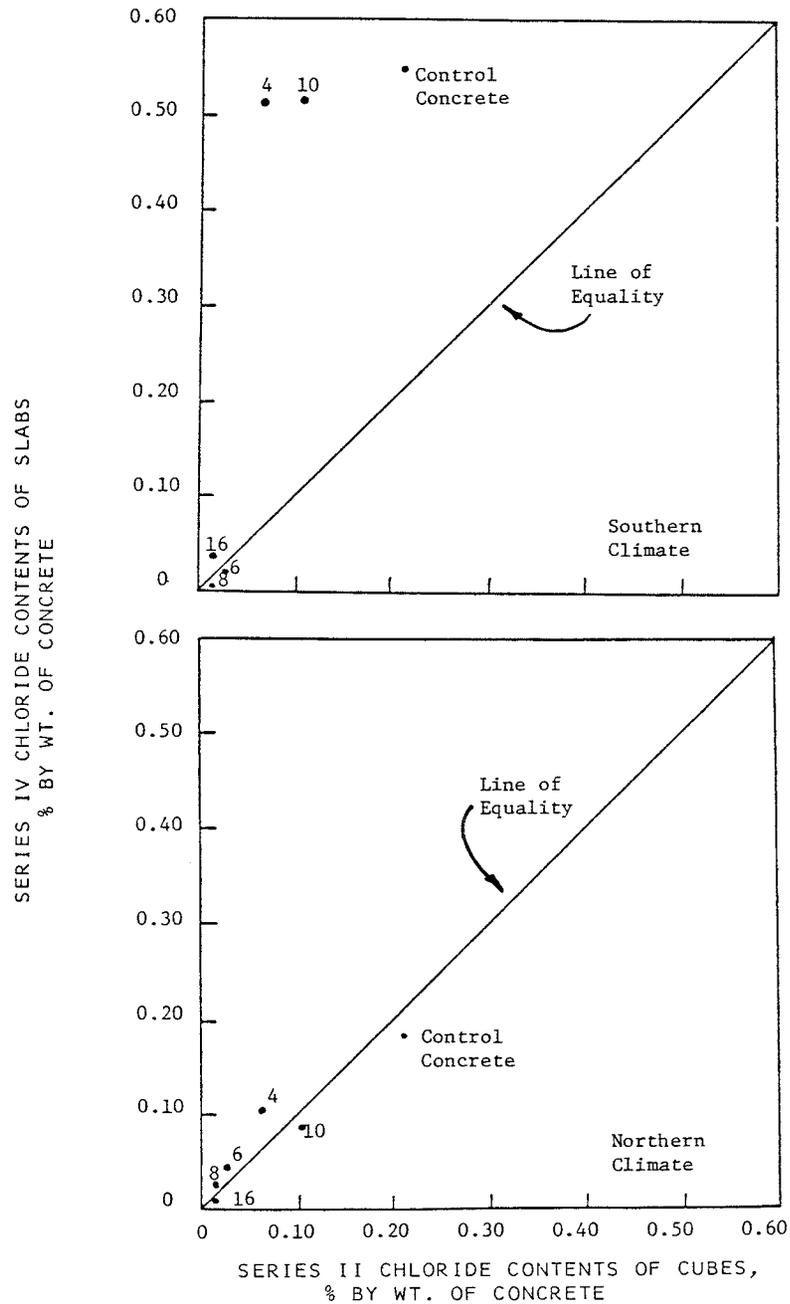


Fig. E-11 - Relationship between Series II and IV chloride contents

methods for final chloride content. This is somewhat unexpected since the slabs from four of the five coating materials exhibited concrete surface deterioration after the 24 week long northern climate accelerated weathering tests.

For the southern climate testing, three materials, 4-U, 10-PM and 16-E, show more chloride in the slabs than in the cubes. The control concrete, the 4-U and 10-PM materials exhibited dramatically more chloride in the slabs than in the cubes. The 6-S and 8-MM specimens show less chloride in the slabs than in the cubes after the tests. These data for the southern climate tests show that a reasonable correlation did not occur between the two test methods for final chloride contents. The reasons for this lack of correlation may be as follows:

1. The slabs were exposed to about 50,000 watt-hours/sq meter of ultraviolet radiation, which apparently deteriorated the 4-U and 10-PM coatings during the 24 week testing.
2. The slabs were exposed to a severe alternate wetting and drying cycle for 24 weeks. This caused the uncoated control slabs to absorb significantly more saltwater than when the Series II uncoated control cubes were merely soaked in saltwater for 21 days without repeated wetting and drying.

Coating materials 6-S, 8-MM and 16-E show reasonable correlations between slab and cube chloride contents, irrespective of the accelerated weathering test method used.

Conclusions and Observations

The test results from the Series IV accelerated weathering tests justify the following significant conclusions and observations:

Southern Climate Exposure

1. All test conditions exhibited no deterioration of the concrete surfaces.
2. The 16-E and 4-U coatings discolored to a brownish-yellow color, probably from the ultraviolet light exposure.
3. The cracked, reinforced concrete slabs coated with 6-S and 8-MM exhibited average copper-copper sulfate half cell readings less than -0.25 volts at the conclusion of the tests. These specimens also exhibited the least amount of corrosion products on the embedded bars.
4. The southern climate exposure provided much more corrosion products on the embedded bars when compared to the bars from the northern climate tests. The corrosion products were generally full-length and full-perimeter.
5. The cracked, reinforced concrete slabs coated with 4-U, 10-PM and 16-E and the uncoated control slabs had bars that were severely corroded and that exhibited half cell readings ranging from -0.45 to -0.55 volts during the final 12 weeks of testing.
6. The chloride content of the uncoated concrete was very high at 0.547 percent by weight of concrete, at the end of the test. The use of coating materials 4-U, 6-S, 8-MM, 10-PM and 16-E reduced this chloride content by 7, 97, 99, 6 and 93 percent,

respectively. Thus, materials 6-S, 8-MM and 16-E provided excellent barriers to the saltwater during this accelerated weathering test.

Northern Climate Exposure

1. All test conditions, except those slabs coated with 16-E or (BLO + 16-E), exhibited some degree of surface deterioration of the concrete. Based upon previous tests on similar concrete with the same aggregates, w/c ratio and air contents, it is believed that the primary surface deterioration was caused by the acid exposure. The deepest deterioration was on the control slabs and those coated with 6-S. These slabs had the appearance of old concrete, with a uniform aggregate exposure of about 1/8 in. Those coated with 4-U, 10-PM and 2-BLO exhibited uniform but light to moderate etching. The slabs coated with 8-MM retained about 50 percent of the original concrete surface while the remaining 50 percent exhibited a moderate etch. The slabs coated with 16-E or (BLO + 16E) exhibited no surface deterioration.
2. The cracked, reinforced slabs coated with 16-E exhibited a deterioration of the concrete along the crack. The 16-E material eventually failed to span the crack, allowing minor surface deterioration along the crack.
3. None of the coating materials except 4-U exhibited any discoloration.
4. The cracked, reinforced concrete slabs coated with 4-U, 6-S and 8-MM exhibited average copper-copper sulfate half cell voltage

readings less than -0.30 at the conclusion of the tests. These specimens also exhibited the least amount of corrosion products on the bars.

5. The only bars with severe corrosion products on the bars were those from the uncoated control slabs.
6. The chloride content of the uncoated concrete was relatively high, at 0.182 percent by weight of concrete. The use of coating materials 4-U, 6-S, 8-MM, 10-PM and 16-E reduced this value by 43, 76, 87, 52 and 97 percent, respectively. Thus, materials 8-MM and 16-E provided excellent barriers to the salt-water during this accelerated weathering test.

General

1. The duplicate slabs had essentially identical surface appearances at the end of the tests.
2. Significant variations were observed in the copper-copper sulfate half cell voltages between the four bars within a given slab and also between duplicate slabs. Such variations were probably caused by variations in crack width, locations of local anodes and cathodes, coating performance, pinholes in the coating, and deterioration of the concrete surface. However, a reasonable correlation did exist between the average measured half cell voltage obtained from the eight bars in a duplicate pair of slabs during the latter portions of the tests and the amount of corrosion products found on the embedded bars at the conclusion of the tests.

3. The corrosion activity was always more advanced on the top of the embedded bar, which was closest to the ponded test surface.
4. The southern climate exposure testing was more severe than the northern climate testing in terms of chloride intrusion and degree of corrosion on the bars.
5. The control specimens coated with boiled linseed oil and those pretreated with the oil prior to coating with 10-PM and 16-E exhibited extremely low chloride contents at the end of the testing, irrespective of the exposure. This excellent performance of the linseed oil treated concrete is in sharp contrast to the relatively poor performance of linseed oil during the Series I tests. It appears that this excellent performance in Series IV may relate to the exposure of these freshly linseed oil treated slabs to about 5000 watt-hours/sq meter of ultraviolet radiation immediately after the application of the two-coat linseed oil treatment. The normally coated cubes in Series I were not subjected to any ultraviolet radiation. It appears that this process produced a durable and impervious coating when eventually subjected to the southern and northern climate tests, which included additional exposure to ultraviolet radiation.
6. The chloride contents from the Series IV southern and northern climate tests on slabs were compared with the chloride contents of the cubes as tested in Series II. Both Series II and Series IV used the same coverage rates, curing procedures and the same air drying period after curing prior to coating. This comparison provides a reasonable correlation for the northern

climate exposure. The correlation for the southern climate exposure was not reasonable for several materials. This lack of correlation appears to relate to the severe nature of the southern climate test which incorporated significant ultraviolet radiation and alternate wetting and drying procedures. Materials 6-S, 8-MM and 16-E exhibited reasonable correlations between these two test methods (slabs versus cubes), irrespective of the weathering test. These three materials also provided very good to excellent overall performance.

These conclusions and observations appear to suggest that future testing by accelerated methods should include alternate wetting and drying cycles and appropriate ultraviolet light exposure since both procedures appear to create severe but realistic environments to determine coating performance on portland cement concrete.

INFRARED SPECTRA FOR MATERIALS USED IN SERIES IV TESTS

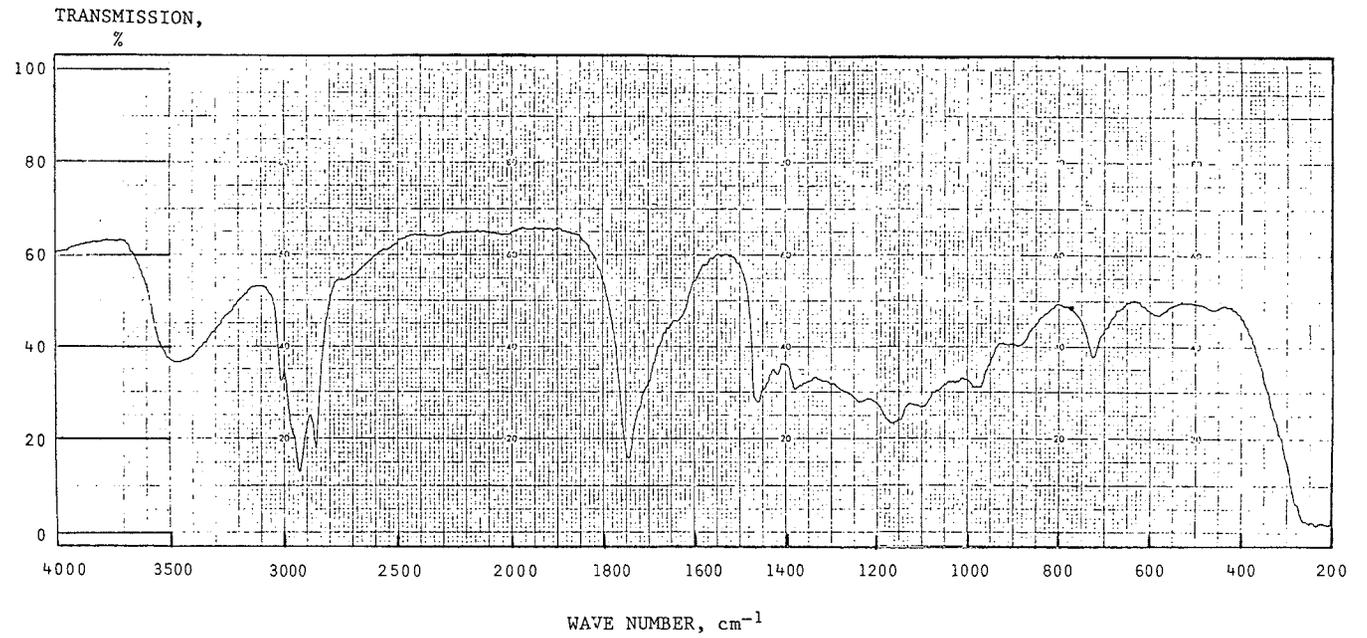


Fig. F-1 - Infrared spectra of Material No. 2

F-1
F-2

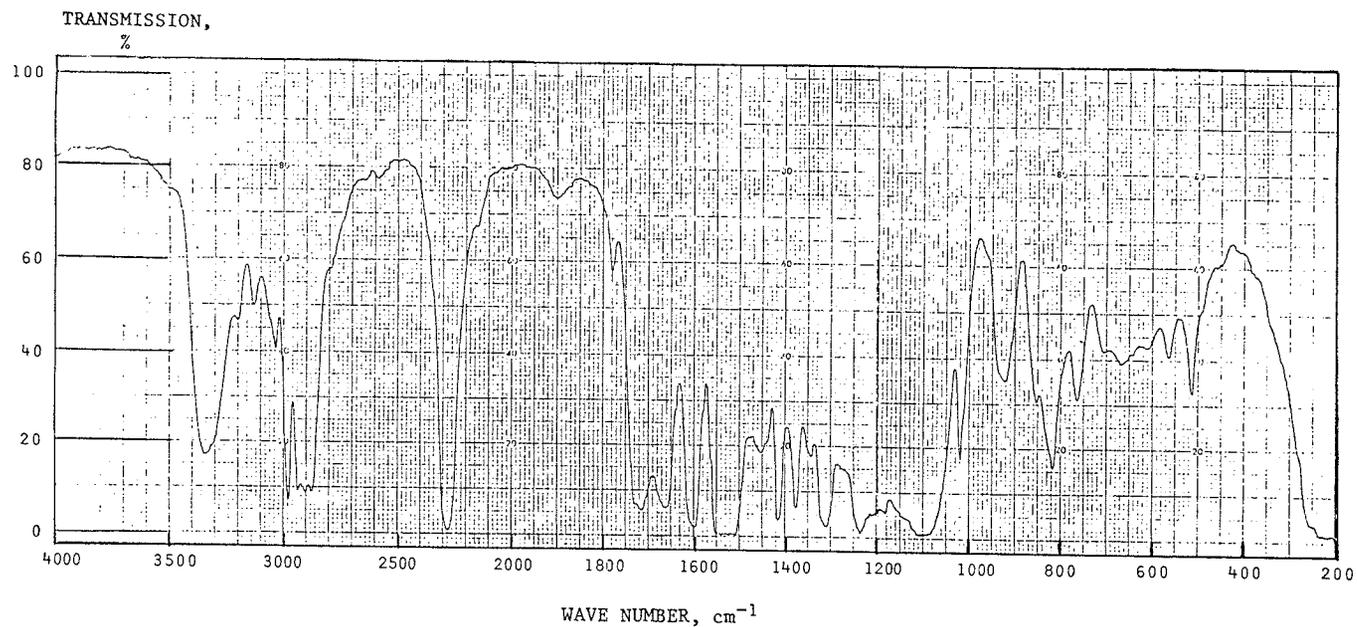


Fig. F-2 - Infrared spectra of Material No. 4

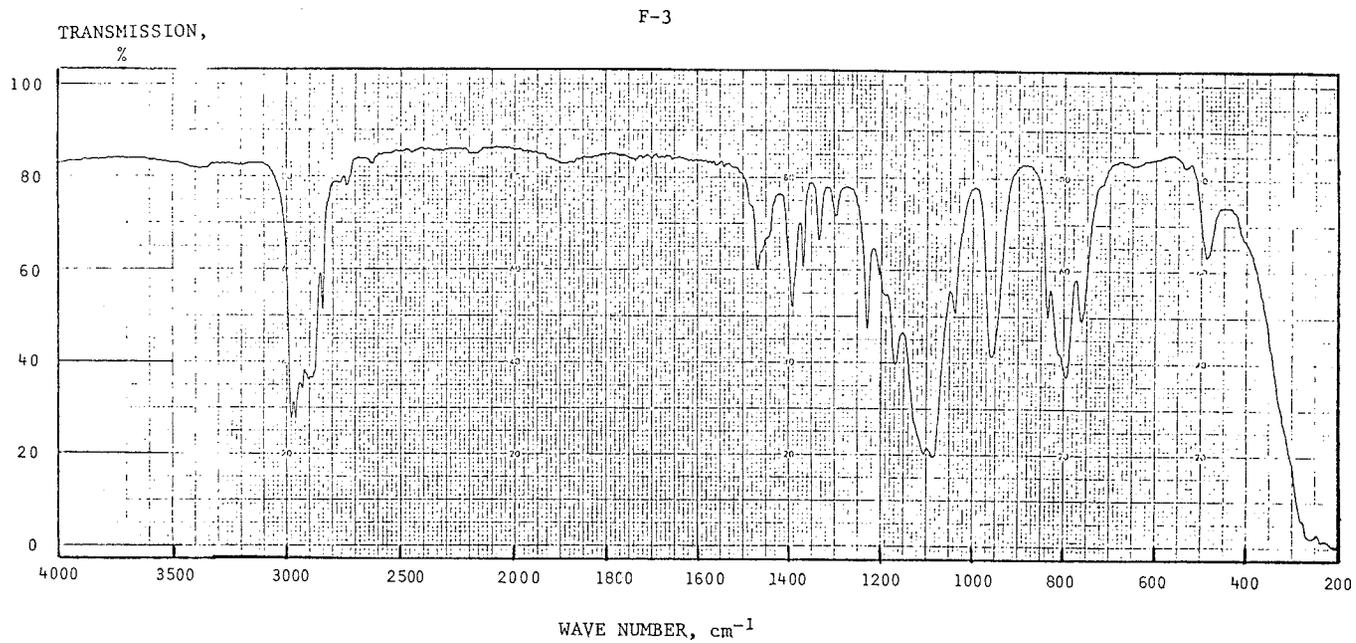


Fig. F-3 - Infrared spectra of Material No. 6

F-4

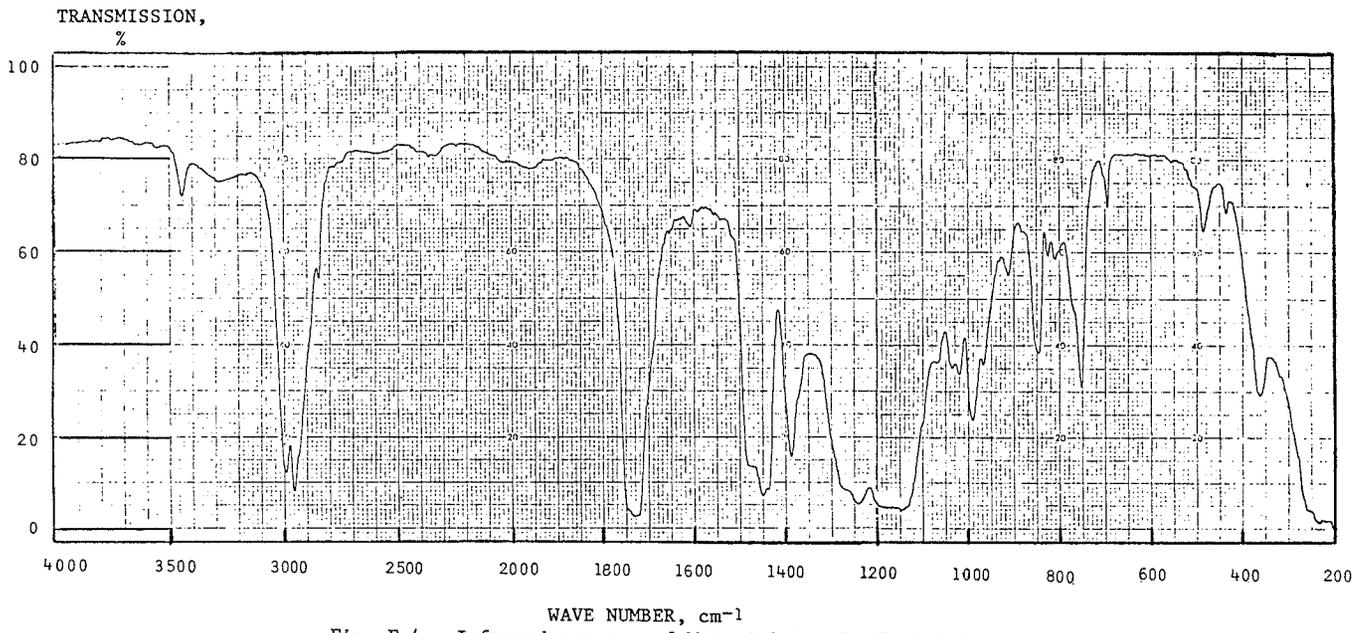


Fig. F-4 - Infrared spectra of Material No. 8 - Finish Coat

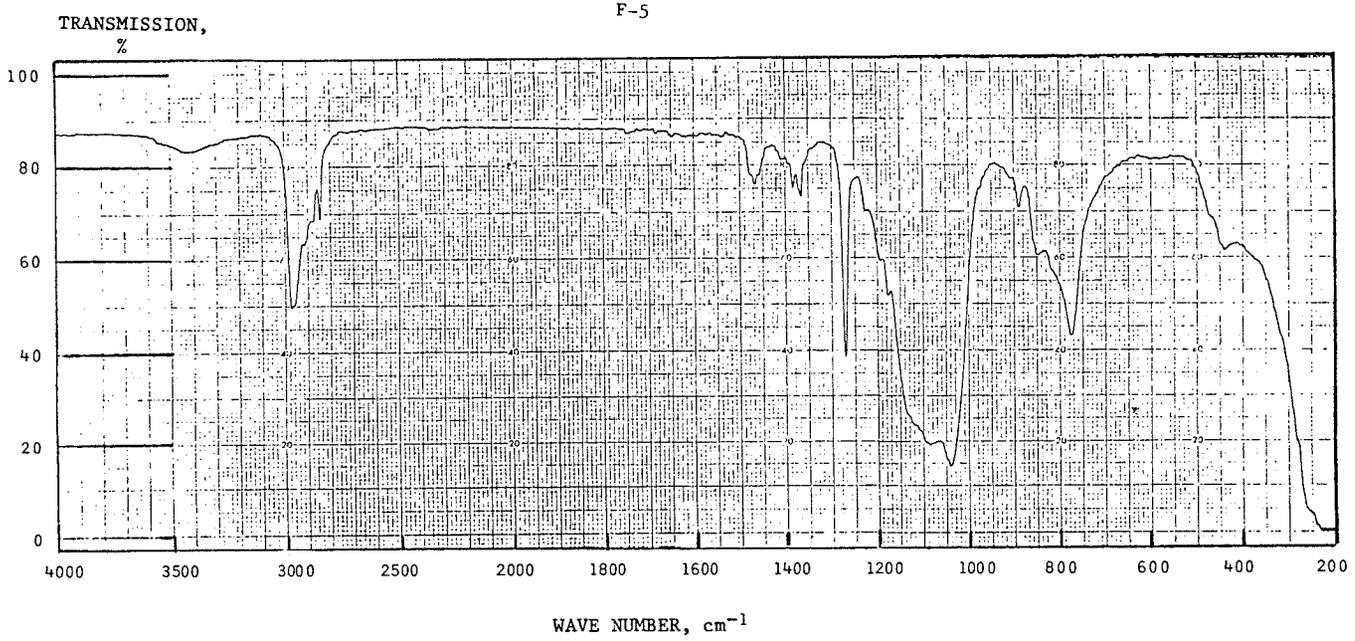


Fig. F-5 - Infrared spectra of Material No. 8 - Primer

F-6

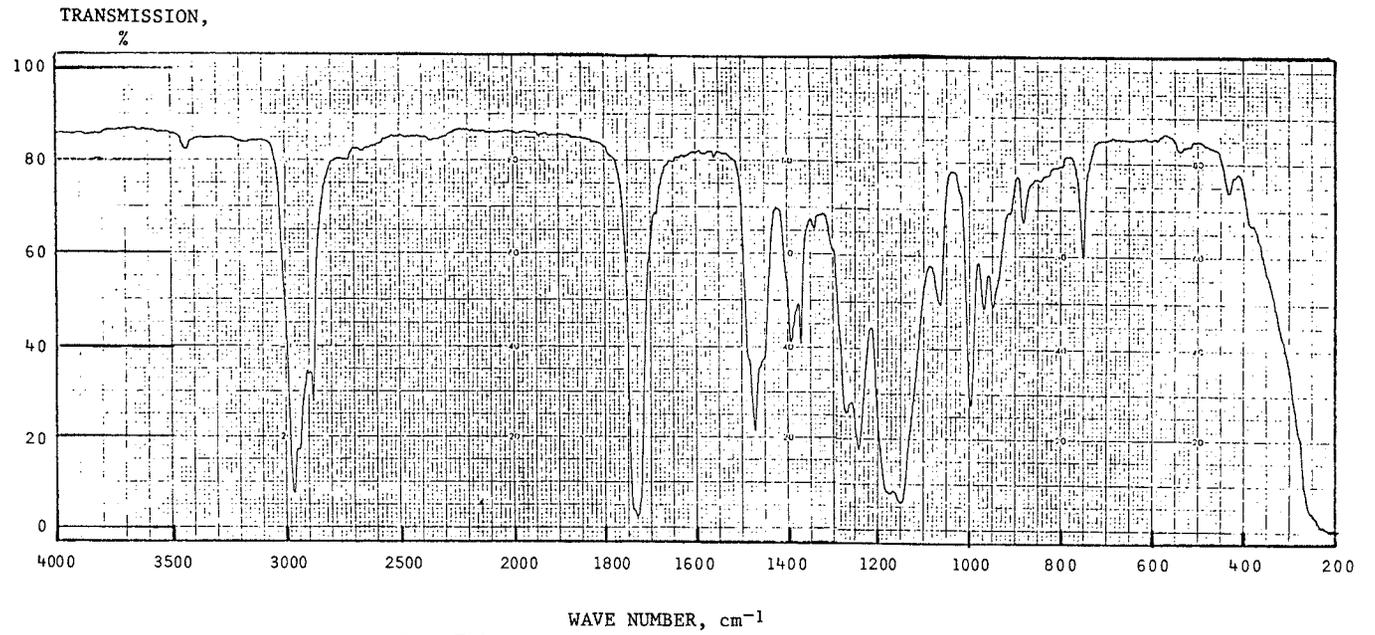


Fig. F-6 - Infrared spectra of Material No. 10

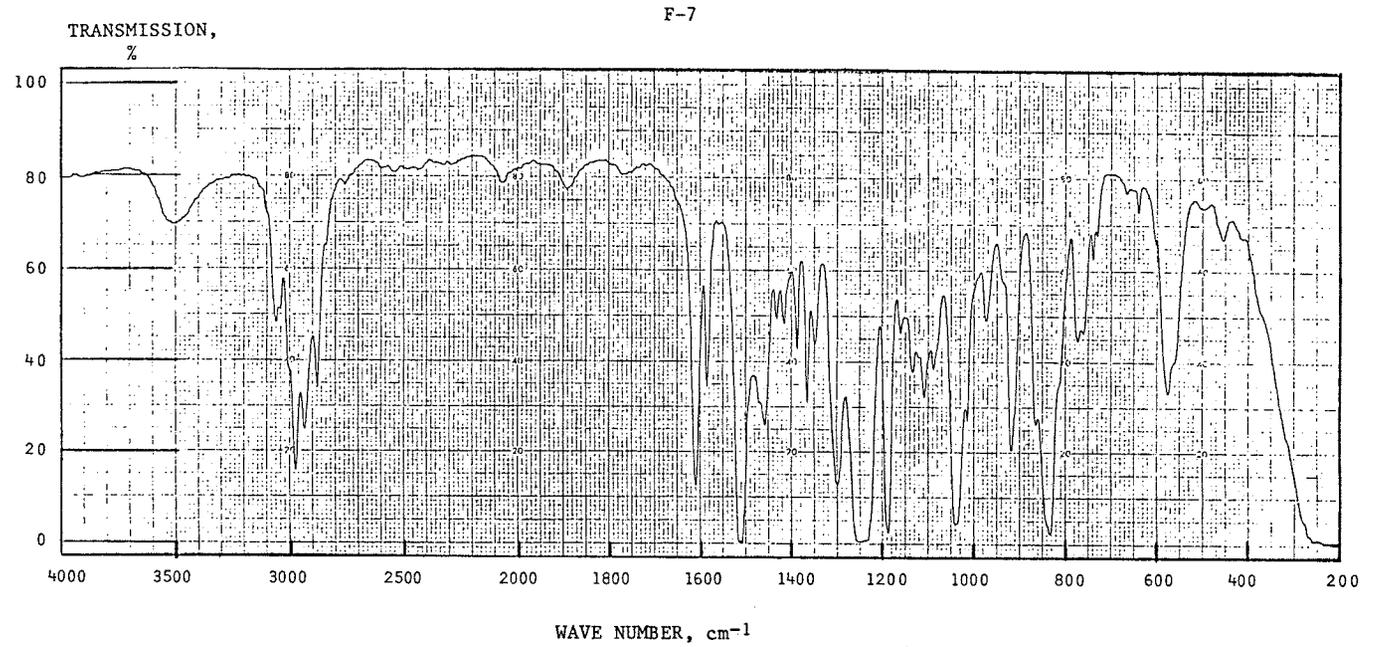


Fig. F-7 - Infrared spectra of Material No. 16 - Part A

F-8

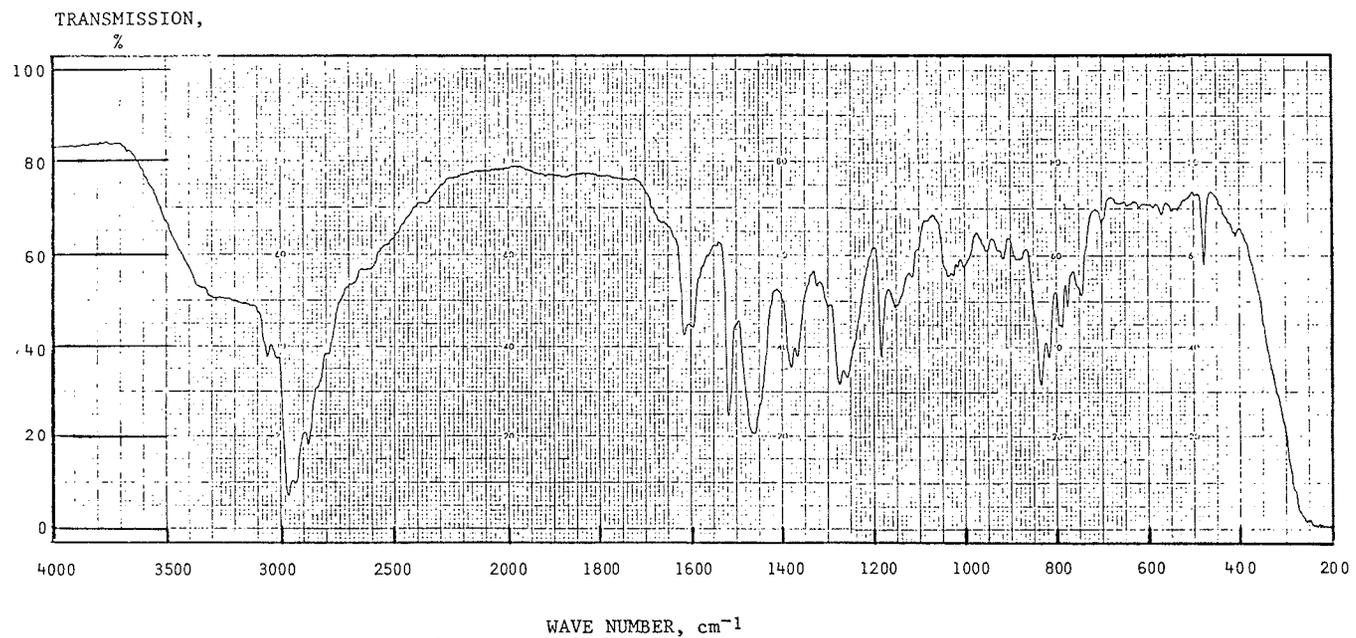


Fig. F-8 - Infrared spectra of Material No. 16 - Part B

F-9

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TRANSPORTATION RESEARCH BOARD

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