FIELD AND LABORATORY EVALUATION OF SELECTED FLEXIBLE PAVEMENT CRACK SEALANTS

By

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FLEXIBLE PAVEMENT CRACK SEALANTS

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PREFACE

This study is concerned with the evaluation of flexible pavement crack sealants. The primary objective of this study is to determine laboratory tests which will reliably predict the performance of a flexible pavement crack sealer after installation in an asphalt pavement crack.

The author wishes to express his appreciation to his major adviser, Dr. Phillip G. Manke, for his assistance throughout this study. Appreciation is also expressed to the other committee members, Dr. Larry Claypool, Dr. Garold D. Oberlender, and Dr. Richard DeVries, for their individual assistance in the preparation of the final manuscript.

Finally, special gratitude is expressed to my mother and father for their encouragement, and financial support.

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CHAPTER I

INTRODUCTION

This investigation is a continuation of a research project entitled "sealing cracks in flexible pavements." The proposal for this project was submitted and accepted by the Research Division of the Oklahoma Department of Transportation in February, 1976. The study has primarily been devoted to evaluating the effectiveness of various materials and methods of application for sealing flexible pavement cracks.

This study is the third phase of a three phase research approach. The initial phase was an evaluation of laboratory test procedures that could be used to predict the field performance of sealant materials. The second phase was a field study of crack dynamics in flexible pavements. This phase of the study, field testing, is designed to evaluate the effectiveness of various application procedures and sealing materials under actual highway conditions.

Six sealing materials of varying properties were selected for evaluation in this study. Each sealant was tested in the laboratory as well as in the field. The primary laboratory test of interest in this investigation was the Bond-Ductility test. Other laboratory tests such as the Cone Penetration test and Resilience test were also performed on each sealant.

Each of the six sealing materials was evaluated on a section of U.S. Highway 177, 4.5 miles south of U.S. Highway 66. The sealants were installed in transverse type cracks, since the relative movements of adjacent pavement sections were expected to be greater than for other type cracks. The controls for the experimental plan of the field evaluation of the sealants were, effective crack spacing, and type of crack treatment used prior to the installation of the sealants.

The sealants were inspected on a monthly basis. Failure of the sealants was measured and recorded as the length of each sealed crack which had opened. This data was used to determine if effective crack spacing and/or crack pretreatment had any relation to the performance of the sealant. This data was then compared to the laboratory evaluation of the sealants to determine if the sealants performance in the field could be predicted by their performance in the laboratory.

CHAPTER II

LITERATURE SURVEY

Sealants

The problem of sealing cracks in flexible pavements is, perhaps, more formidable than that of sealing joints in rigid pavements. Flexible pavement cracks have no regular or uniform interfacial space in which preformed sealing material can be placed, the irregular and often times contaminated (dust and moisture) interfacial surfaces can prevent good adherence of the sealing material (1).

There are basically two types of sealing materials currently being used for sealing cracks in flexible pavements, cold-poured, and hot-poured. Hot-poured material is the type of sealing material used most frequently. This is shown in an investigation conducted by Cook (2).

Hot-Poured Materials

Hot-poured sealants are either straight-run asphalt cements or asphalt cements that have been modified by the addition of mineral fillers and/or rubber (2, 3, 4, 5, and 6). The use of paving grade asphalt cements seems to be limited to certain types and widths of cracks (5), e.g., in a crack with a very narrow opening, these relatively viscous products do not penetrate deep enough into the crack to provide an effective seal.

It has been reported that the addition of rubber improves the flexibility, ductility, adhesion, and cohesion properties of asphalt cement (7 and 8). The beneficial aspects of using rubberized-asphalt, containing 20 to 35 percent rubber by weight, as a crack sealing material has been demonstrated by many investigators (2, 4, and 6). In some reports, the rubber additive was ground recycled tire rubber, which may have both economical and ecological advantages, and in others a synthetic type rubber was used (1).

Cold-Poured Materials

Cold-poured sealants include liquid asphalt materials such as cutbacks, standard emulsions, and rubber-asphalt emulsions (2, 3, 5, and 7). Apparently, little or no use of cold-poured elastomeric materials for sealing flexible pavement cracks has been reported (2). Most of the liquid asphalt products that have been used for sealing cracks are included in the following list recommended by the Asphalt Institute (5):

Cutbacks.	RC-70	
Emulsions	(Anionic) . .	RS-1
	(Anionic) . .	SS-1
	(Anionic) . .	SS-1h in slurry mix
	(Cationic). .	CRS-2
	(Cationic). .	CSS-1
	(Cationic). .	CSS-1h, in slurry mix

Laboratory Investigation of Sealants

Tons (9) summarized the major factors influencing the performance of a sealant as 1) the characteristics of a crack to be sealed, 2) properties of the sealant to be used, 3) properties and conditions of sealant crack interface, 4) quality of workmanship (related to application of the sealant), and 5) type of service to which the sealed crack is subjected.

Under various field conditions the sealants may fail in adhesion, cohesion, extrusion, or a combination of these three types of failures (1).

Based on the aforementioned factors affecting sealant performance and the respective types of sealant failure, some idea as to the properties and characteristics of a good sealant can be obtained. Tons (10) outlined what he called "The established criteria for a satisfactory crack sealer" as follows:

1. The sealer should possess a good adhesion property that will enable it to adhere firmly to the cracked surfaces to seal it effectively under any conditions.
2. The sealer should withstand repeated stretching and compression over long periods, i.e., it should have good cohesion characteristics.
3. The sealer should neither flow out of the crack nor change its properties when exposed to hot weather.
4. The sealer should not shrink excessively due to cooling or evaporation of solvents so as to eliminate the need for repeated pouring.
5. The sealer should not extrude or become tacky on its exposed surface during high summer temperatures.
6. The sealant should not react with asphalt, salt, oil, etc.
7. The sealant material should be durable and should neither harden nor soften with age.

The ASTM tentative specification, D 3405-75T (11), for hot-poured crack sealant materials stipulates these same requirements, with the addition of compatibility of the sealant with the asphalt binder in the pavement (1).

Selected Laboratory Tests

Bond-Ductility Test

This appears to be a basic test used by many investigators (2, 10, 11, 12, and 13) to evaluate a sealant material as to its bond or adherance to the cracked surfaces and its stretchability or ductility at low temperatures. Essentially the test consists of pouring sealants between spaced specimen blocks and then pulling the blocks apart at a specified rate on an extension machine. The temperature and amount of extension of the sealant are controlled. After a certain amount of extension is reached, the test samples are recompressed to their initial width at lab temperatures and this constitutes a cycle (1).

Penetration Test

This test is performed on hot-poured materials to obtain a measure of the consistency of the sealant. The test procedure is outlined in ASTM D 3407-75T (11) and employs a penetration cone instead of a penetration needle.

Resilience Test

This test procedure is outlined in ASTM D 3407-57T (11) and measures the capability of a sealant specimen to recover its size and shape after being deformed. A minimum recovery of 60 percent for a sealant is specified in ASTM D 3405-75T (11).

Field Application Experience

Many different crack sealing procedures have been reported in the literature. The essential repair techniques for sealing and/or correction of various forms of cracking are discussed in the Asphalt Institute's manual series No. 16 (5). According to the Asphalt Institute, these sealing procedures have proven to yield neat long-lasting results.

Field studies by many agencies have been conducted to evaluate various crack sealing techniques. The investigators concluded that the amount of failure noticed depended largely on the crack preparation procedures used, and that the extra care exercised in cleaning and preparing the cracks prior to sealing was justified by the results obtained (3 and 9).

Adhesion failure was reported to be the major and most frequently observed type of failure that occurred in the sealed cracks (9 and 14). Several approaches were tried to improve the bond between the sealer and the pavement. Cleaning the crack by some mechanical means, i.e., brooming or brushing, removed dust from the crack walls and loose paving materials. This provided cleaner and more stable crack surfaces and promoted better adhesion of the sealant. Excellent results were reported in a Minnesota field study (14) where a wire twist brush was used for this purpose.

Air-blowing and priming of the crack surfaces have also been used with conflicting results reported by various investigators. Apparently, air-blowing of the crack alone did not noticeably improve adhesion but it did allow the sealer to penetrate deeper into the crack. The reported results vary as to the effectiveness of priming cracks with a thin cutback or emulsion prior to sealing. Tons (3) believed that the prime penetrated and coated the dust on the crack walls, softened the pavement binder, and promoted better adhesion of the sealer. However, Walter's

(14) field tests of three different prime materials indicated that they should not be used. Also, slight overfilling of the sealed cracks, i.e., an overlap of sealant along the crack edges, seemed to prevent adhesion failures and provide longer service life (1).

Horizontal Movement of Asphalt Concrete Pavement

From previous research (1 and 14) it has been determined that horizontal movement at transverse cracks increases with increasing values of effective crack spacing (ECS). ECS is defined as the average distance to the first transverse crack on both sides of the crack in question. Basha (15) determined that under Oklahoma climatic conditions, the average maximum horizontal crack movement is about 0.25 in. and that crack movement increases with increasing values of ECS up to approximately 120 ft.

CHAPTER III

LABORATORY DESIGN

General

In this investigation six asphalt pavement crack sealing materials were selected for evaluation in both laboratory and field tests. The sealants were an 85-100 penetration asphalt cement, three rubberized asphalt cement products, and two asphalt emulsions. These materials were selected on the basis of previous research and recommendations by the Research and Development Division of the Oklahoma Department of Transportation.

The Bond-Ductility (BD) test, cone penetration test and the resilience test, comprised the laboratory tests used to evaluate the asphalt pavement crack sealants. These tests were selected on the basis of previous research performed by Manke and Baha (16).

The Bond-Ductility Test is a test in which an asphalt pavement crack sealant is tested under controlled temperatures, and stresses in a simulated pavement crack. The cone penetration and resilience tests are tests devised to measure the consistency of the asphalt sealing materials.

Sample Preparation

The 85-100 Penetration Asphalt Cement, and the three rubberized products used in this investigation are semi-solid materials at ambient temperatures. In order for testing of these materials to be performed they had to first be heated to a liquid state. To prevent localized overheating of the sealants during the heating process an oil-bath apparatus was used. The oil-bath apparatus, as illustrated in Figure 1, had a stainless steel metal beaker 5.5 in. in height, and 4.5 in. in diameter, in which the sealant was placed. This beaker set in an aluminum container which was filled with mineral oil. This whole unit was set on top of an electric heater which could be regulated to the desired energy output. Thermometers were placed in both the sealing material and the oil-bath. During the heating operation the sealant was stirred by the use of a 3.0 sq. in. stirring paddle attached to an electric mixer operating at 120 rpm.

In order to test the asphalt emulsions in the laboratory the water was first removed. This was done so that the base asphalt material could be tested. The water was removed from the emulsion by evaporation. A small amount of the emulsion was placed in the oil-bath apparatus previously described and heated to a temperature slightly above 212^{o}F. The asphalt emulsion was heated at this temperature until all foaming had ceased. At this point it was assumed that most of the water had evaporated from the emulsion leaving the base asphaltic material. This material was then heated to a higher temperature so that it could easily be poured into test specimens.

After each sealant had been heated to its recommended pouring temperature (Table I), it was poured into previously prepared test cracks for the BD tests, and 3 oz tins for the resilience and cone penetration tests.

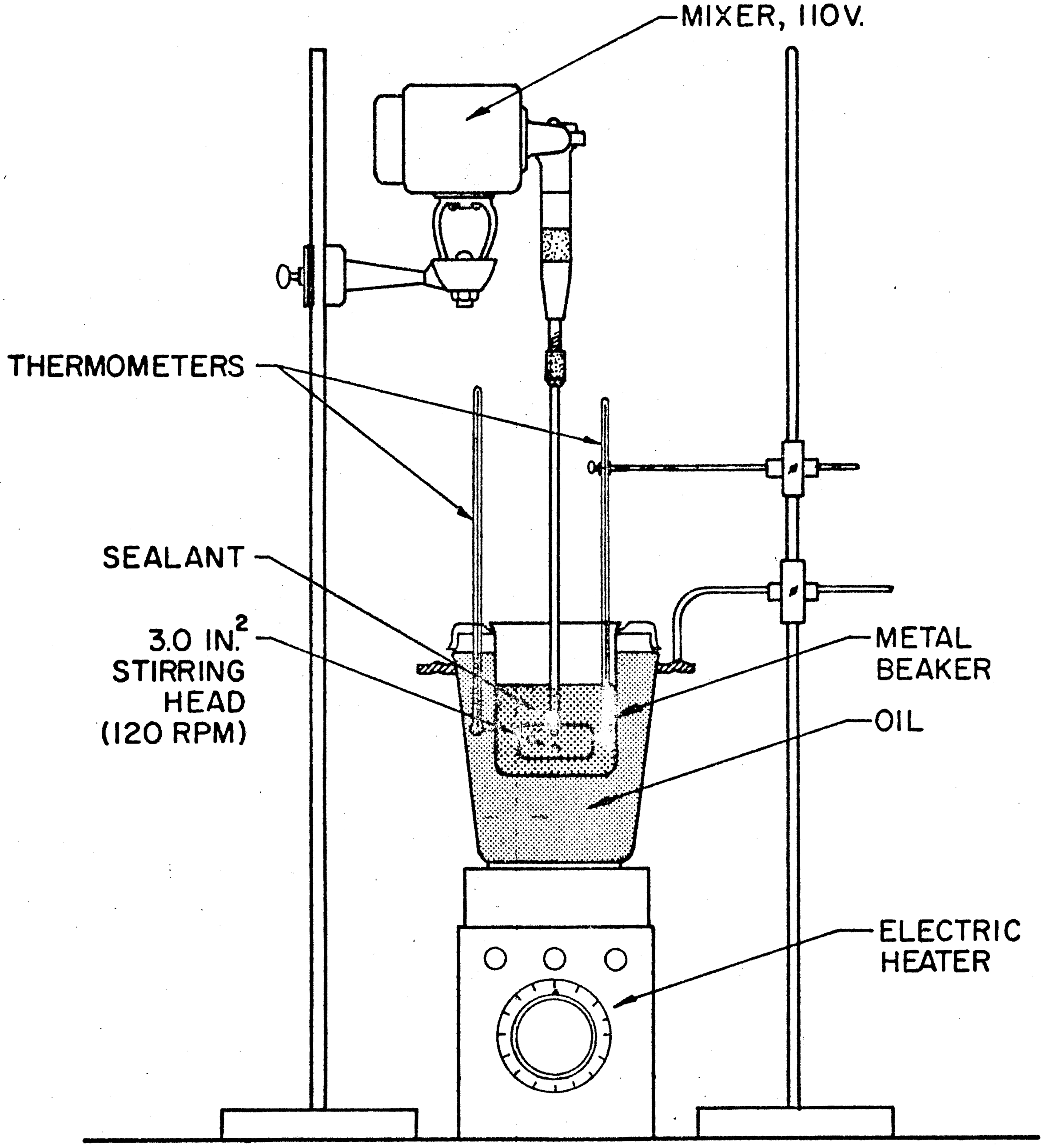

Figure 1. Sealant Evaporation and Heating Equipment.

TABLE I

SEALANT POURING TEMPERATURES

Type of Sealant	Pouring Temperature
Asphalt Cement 85-100 Penetration	325°F
Synthetic Rubber (soft)	390°F
Ground Rubber (MS-LV)	350°F
Ground Rubber (hard)	390°F
CRS Emulsion (base material)	250°F
CRF Emulsion (base material)	250°F

Bond-Ductility Test

The test procedure which was of primary interest in this research was the bond-ductility test. The bond-ductility machine developed for this project was designed to test multiple samples of sealant materials poured between spaced specimen blocks of asphalt concrete. These blocks are clamped in the machine and pulled apart at a controlled rate of tensile strain under low temperature conditions. The design of this machine with six sealant specimens clamped in place and ready for testing is shown in Figure 2.

Bond-Ductility Specimen Block Preparation

The asphalt blocks used to simulate pavement cracks for the bond-ductility test were molded from an ODOT type "C" surface course hot-mix. The mixture was obtained from a hot-mix plant in Perkins, Oklahoma. The mix was shoveled into a 30 gal. metal garbage can at the plant and brought

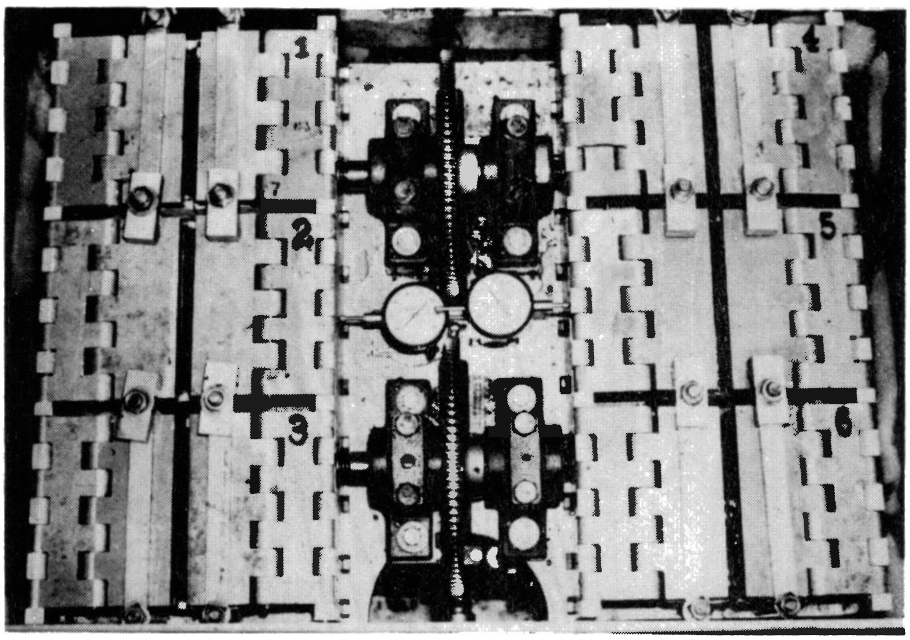

Figure 2. Bond-Ductility Machine With Six Asphalt Sealant Specimens Clamped in Place Ready for Testing.

back to the laboratory where it was divided into 6000 g batches and placed in paper sacks. When an asphalt block was to be molded one of the 6000 g batches was heated to 250^{o}F and placed in a kneading compactor conforming to ASTM D-1516 specifications (11). A 2 in. by 4 in. steel tamping foot was mounted on the booster ram of the compactor and a specially designed cranking carriage and mold replaced the turntable on the machine (Figure 3). The hot mix samples were compacted into bars 12 in. long, 4 in. wide, and 3 in. deep. The bars were then removed from the mold (Figure 4) and allowed to cool for a period of not less than 24 hours. The compacted bars were then cut into blocks, 6 in. long, 2 in. wide, and 3 in. deep. The cutting of the asphalt concrete bars was performed with a electric masonry saw (Figure 5). After the blocks were cut, they were washed and dried. Simulated asphalt pavement cracks were then constructed using pairs of these blocks.

Moulding of Test Specimens

The cut blocks used for the bond-ductility tests were placed on either side of an aluminum spacer with the uncut sides of the blocks facing towards the spacer. The aluminum spacers were 6 in. long, 0.25 in. wide, and 3.0 in. deep. A section was cut from the top of the spacers to allow the sealant to be molded to the crack dimensions of 6 in. long, 0.25 in. wide, and 1.0 in. depth. This is illustrated in Figure 6. The aluminum spacers were coated with a thin layer of silicon grease to prevent sticking of the sealants. The greased spacer was then placed between its test blocks to form a simulated pavement crack. This assembly was then taped together for the installation of the sealant.

The heated sealant was poured into the simulated test cracks

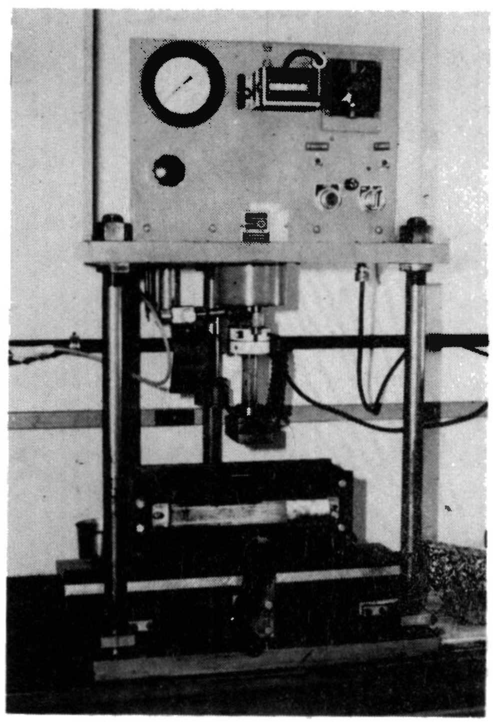

Figure 3. Kneading Compactor With
Bar Mold and Carriage.

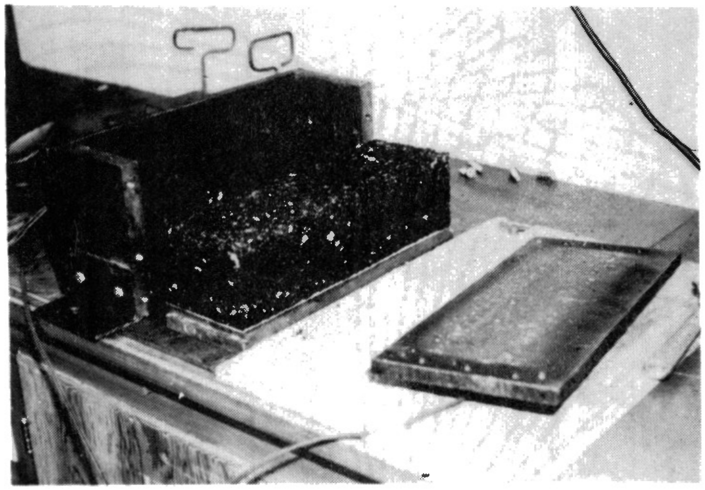

Figure 4. A Compacted Asphalt Concrete Bar Being Removed From the Compaction Mold.

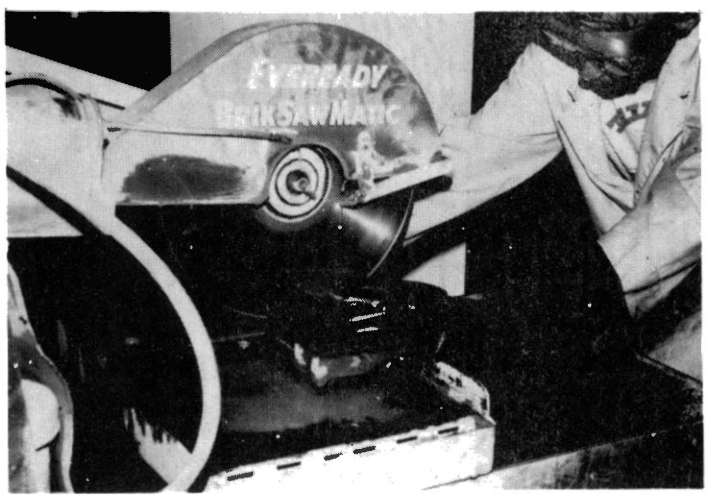

Figure 5. Sawing of Molded Asphalt Concrete Blocks.

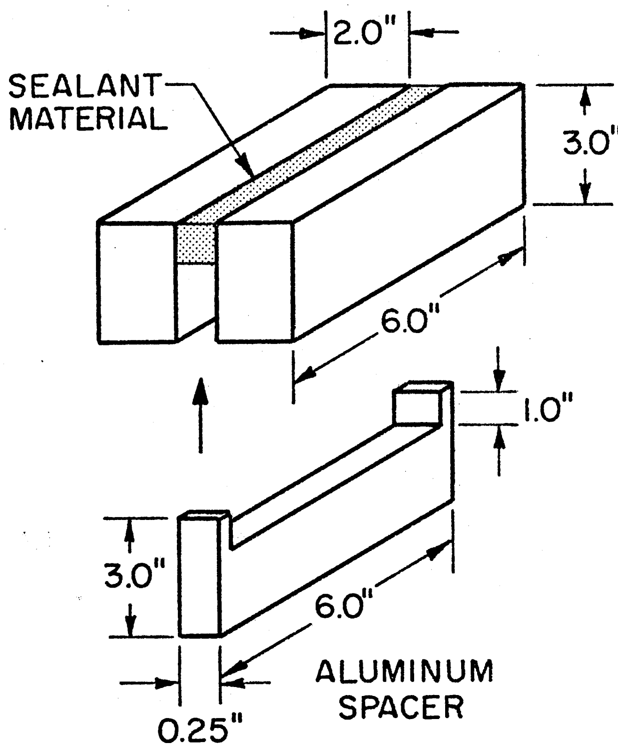

Figure 6. Molding of Bond-Ductility Specimens.

directly from the metal beaker in which it was melted. Six test block specimens were prepared for each sealant. The sealants were allowed to cool for not less than 48 hours. The spacers and tape were removed from the test block specimens before testing.

Testing of Bond-Ductility Crack Specimens

The test block specimens were placed in a freezer and cooled to 0°F before they were tested. All six test blocks of a single sealant were then clamped into the Bond-Ductility machine which was installed in a separate freezer so that the temperature of the simulated crack test specimens could be maintained at 0°F during the test. The test blocks were then pulled apart at extension rate of 0.125 in./hr, until a 50% extension of the sealants original crack width had been obtained.

The specimens were then unclamped and removed from the BD machine. After inspection of the sealants the spacers were inserted back into the unfailed specimens (the field specimens were discarded). These specimens were then allowed to warm at ambient temperature for a period of not less than 24 hours. They were then recompressed to their original 0.25 in. width by the use of a hydraulic sample ejecter. The specimens were then returned to the freezer for the beginning of another test cycle.

Failure of the asphalt crack sealants after each cycle of testing in the bond-ductility machine was determined by visual inspection. Anytime the sealant had pulled away from the bond-ductility test blocks (adhesive failure), or the sealant itself had broken, (cohesive failure) in 15 percent of more of its simulated crack length, failure of the test specimen was considered total. The results of the bond-ductility tests were then recorded as the average number of tested cycles the six test specimens of each individual sealant underwent before failure.

Cone Penetration Test: (ASTM D 3407-75T)

A cone penetration test was made on each sealant to obtain a measure of its consistency. The difference between this test and the standard penetration test (ASTM D 5) is that a special cone shaped implement is used in place of a standard penetration needle. The total moving weight of the cone and attachments was 150± 0.1 g. This is a tentative standard penetration test for joint sealants for concrete pavements.

Resilience Test: (ASTM D 3407-75T)

A tentative standard resilience test for joint sealants for concrete and asphalt pavements was also performed on the six asphalt pavement crack sealers used in this study. In comparing the results of this test to the results of the bond-ductility tests it appeared that there might be some relationship between the tests. The sealants which had a high percentage of recovery in the resilience test, tested well in the bond-ductility test.

CHAPTER IV

FIELD STUDY PROCEDURE

General

The field study portion of this investigation was designed to determine how selected asphalt pavement crack sealants would perform after their installation in a cracked segment of flexible highway pavement. The test site was established on a section of U.S. Highway 177, approximately four and one half miles south of the junction with U.S. Highway 66, in Lincoln county, Oklahoma. The primary consideration for the selection of this field site was the well developed system of transverse cracks in the asphalt concrete pavement.

The section of highway selected for this investigation was approximately one mile in length, with good stopping sight distance and broad paved shoulders for parking the research vehicles. During the field operations adequate precautions were taken to insure the safety of all personnel involved. Bright colored reflective vests and hard hats were required to be worn by the research personnel working at the test site. Warning signs and flagmen were provided by the Oklahoma Department of Transportation (ODOT) to control traffic during the sealant installation operations and the subsequent crack inspection visits.

Type of Cracks

The sealants were installed only in transverse cracks, i.e., cracks generally running perpendicular to the centerline of the pavement. The horizontal and vertical movements of the sides of such cracks were considered to be greater than for other types of patterns of cracks. Thus, greater tensile and compressive stresses would be induced in the materials used to seal them.

Some of the transverse cracks spanned the full width of the pavement (24.0 ft) and extended through the shoulders on each side. Others were considered to be "half" and "partial" type transverse cracks depending on their length or extent in the pavement surface. The width of these cracks at the surface of the pavement ranged from 0.25 in. to slightly greater than 1.0 in., depending on the age of the crack and the amount of breakage or spall of the crack edges from traffic loads. The depth of the cracks varied from several inches to several feet.

Spacing of Cracks

Previous investigations by Walters (14) and Basha (15) have indicated that the amount of horizontal movement at transverse cracks increases with the effective crack spacing (ECS). ECS is the average of the distances between adjacent transverse cracks on either side of a crack being studied. This relationship is shown in Figure 7. The horizontal crack movement, i.e., the extent of opening and closing of a crack, is caused by thermal expansion and contraction of the adjacent pavement sections. This is illustrated in Figure 8.

ECS was one of the factors or variables considered in the experimental design of the field test program. Due to the irregular spacing of the transverse cracks in the test section of U.S. Highway 177, the cracks were categorized into three ECS ranges, small, medium, and large.

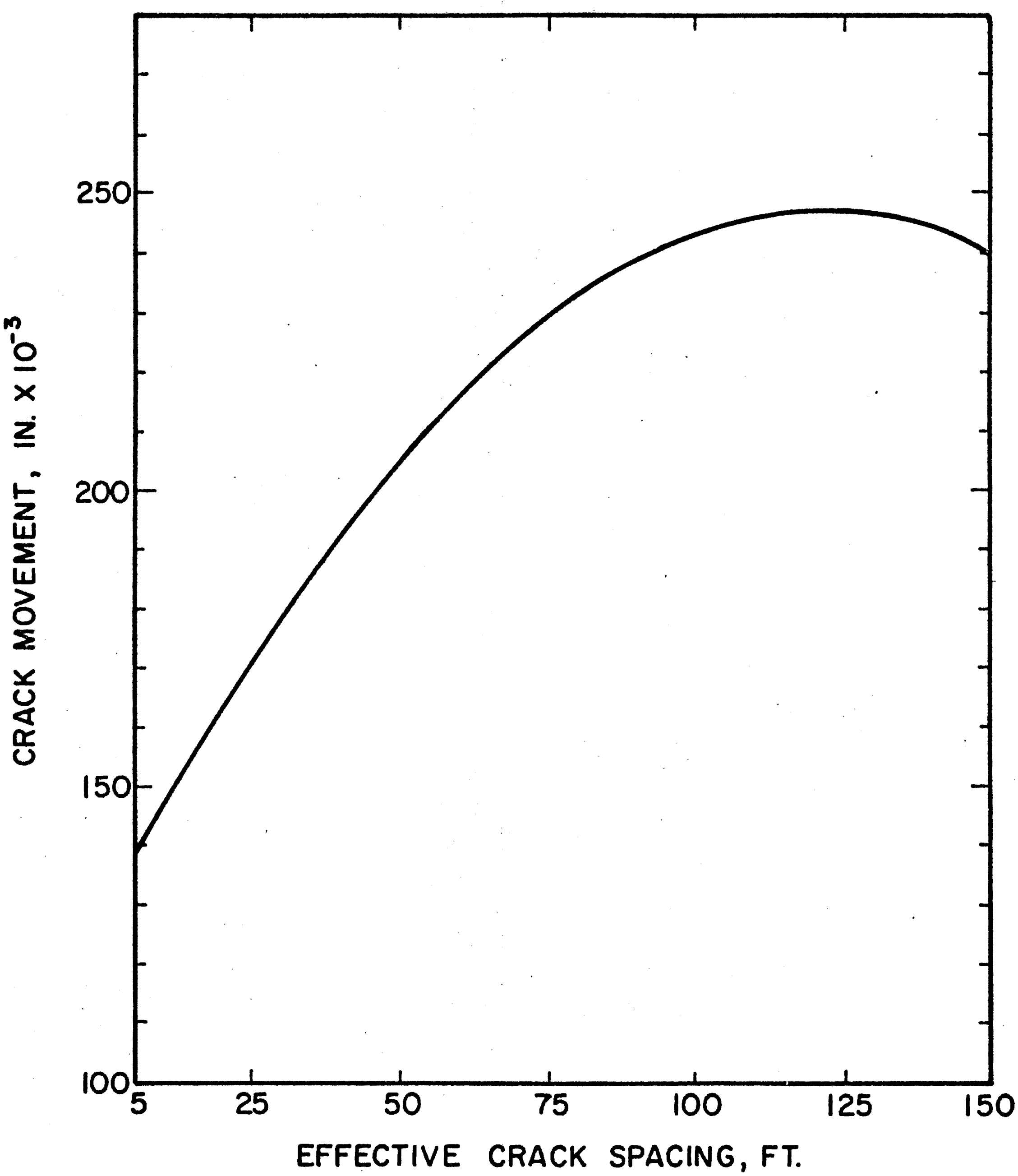

Figure 7. Relationship Between Effective Crack Spacing and Horizontal Crack Movement.

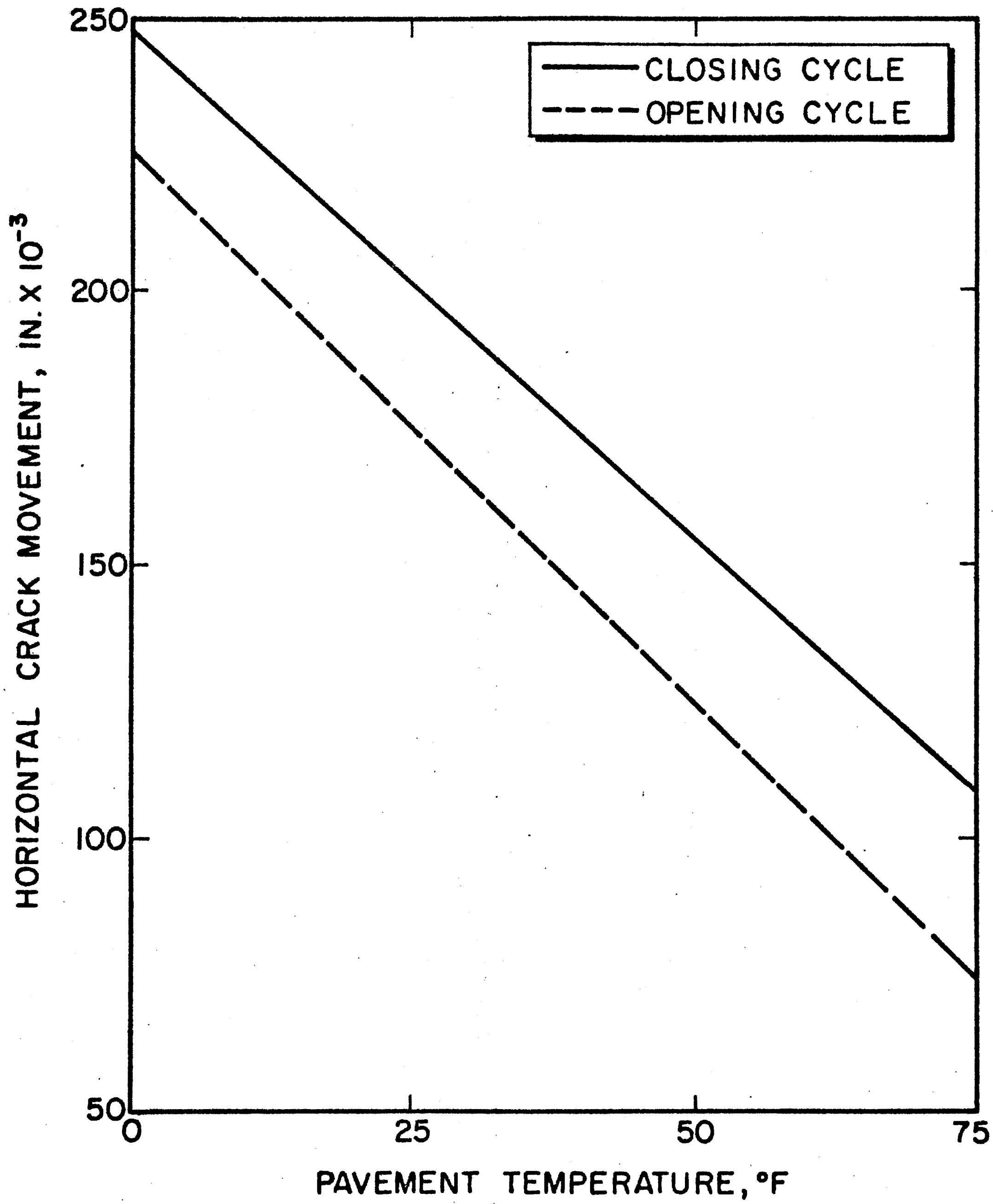

Figure 8. Relationship Between Pavement Temperature and Horizontal Crack Movement (Max. ECS = 123 ft).

A small ECS ranged between 15 and 25 ft, a medium ECS between 30 and 40 ft, and a large ECS was 45 ft or greater. This classification system permitted direct comparison of the performance of the various sealants studied since the sealant strains in each of these spacing categories were approximately equal.

Crack Survey

Following the selection of the field site, a detailed crack survey of this section of highway was performed. The length of the section was first divided into 100 ft segments. Starting at the north end of the test section the 100 ft segments were numbered as stations. The station numbers were painted on the west shoulder of the highway to provide reference points for mapping the cracks in the pavements, and later for locating specific transverse cracks. All of the transverse cracks in the test section were mapped on special data sheets (Figure 9) designed to show their general configuration, i.e., length, direction, and location. The necessary measurements were performed with a model 200 Rolatape. The cracks were then plotted to scale on the data sheets.

These crack maps were used to select the cracks that were to be sealed. The selection was based on scaling the distances between cracks and locating those that fell in one of the desired ECS ranges. Figure 9 shows three cracks in the south-bound lane, each with a differen ECS. It can also be noted from Figure 9 that only cracks extending across a full pavement lane were used. Thus, all transverse cracks selected for this investigation were approximately 12 ft in length.

A total of 108 cracks were needed for this study. After the cracks to be used were selected from the survey maps they were assigned numbers.

O.S.U. School of Civil Engineering — Sheet No. 1

CRACK SURVEY DATA

High No.: U.S. 177 — Survey Direction: South — Date: Fall, 1979

By: S. A. Hofener — Site Description: 4.5 Miles South of U.S. 66 Junction

Crack Pattern and Crack Number	Station	Remarks

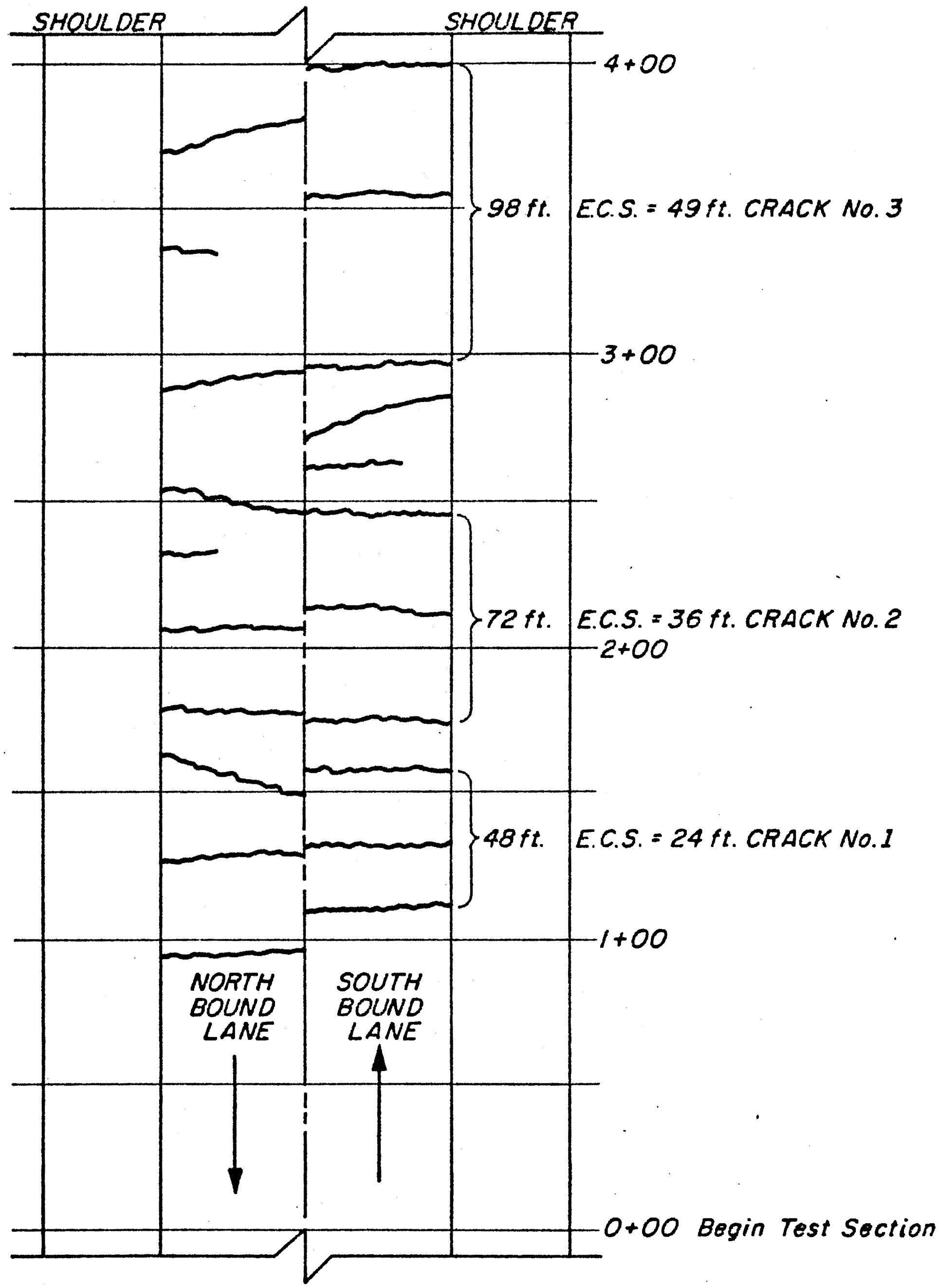

Figure 9. Crack Survey Map.

These cracks were numbered consecutively starting at the north end of the test section and proceeding south in the south-bound lane. At the south end of the test section, the numbering was continued back in the north-bound lane. The selected cracks were located at the test section and their assigned numbers were painted with yellow paint on the paved shoulders adjacent to each crack. This crack numbering system was used to assign a particular sealing material and crack preparation method to each of the selected cracks and greatly facilitated the actual field installation of the sealants.

Pretreatment of Cracks

The respective Maintenance Divisions of the Oklahoma Department of Transportation use a variety of crack preparation techniques prior to sealing operations. These techniques include brooming, brushing, air-blowing, and routing; either individually or in some combination (1). Since routing requires expensive specialized equipment and greatly increases the time and cost of the sealing operation, it was decided to limit the study to only two types of pretreatment of the cracks, i.e., air-blowing and a combination of wire brushing and air-blowing. It was considered that these two pretreatments would be the ones most frequently used in practice and would be enough to indicate whether extra care in cleaning and preparing the cracks prior to sealing was justified.

Air-blowing the cracks was accomplished using a standard 200 cu ft per min air compressor fitted with a length of hose attached to a short piece of 0.75 in metal pipe. The compressor was operated at a pressure of about 240 PSI which was sufficient to remove all loose material or debris from the crack.

Brushing of the cracks was done with a stiff bristle wire brush attached to a short handle, as shown in Figure 10. This operation, along with subsequent air-blowing, removed dust from the crack walls and any loose paving material from the crack. Logically, this provides cleaner, more stable crack surfaces and promotes better adhesion of the sealant.

Installation of Sealants

All of the asphalt pavement crack sealants used in this investigation were installed in the winter of 1979-80. The Oklahoma Department of Transportation provided the necessary equipment and manpower needed for the installation of each sealant. A full day was designated for the installation of each sealant and because of scheduling problems, it took almost two months to install all six sealants. The type of sealant, date of installation, and the pavement surface temperature at the time each sealant was installed is illustrated in Table II.

TABLE II

TEMPERATURES AND DATES OF SEALANT INSTALLATION

Type of Sealant	Date of Installation	Pavement Surface Temperature
85-1 Pen A.C.	Nov. 19, 1979	60°F
Synthetic Rubber (soft)	Nov. 29, 1979	45°F
MS-LV	Dec. 3, 1979	57°F
Synthetic Rubber (hard)	Dec. 5, 1979	77°F
CRS-2 Emulsion	Dec. 10, 1979	52°F
CRF Emulsion	Jan. 17, 1980	64°F

Figure 10. Brushing Transverse Crack Prior to Air-Blowing.

Sealant Application

The double-wall melter, shown in Figure 11, was used to heat and install the high viscosity sealants, i.e., the asphalt cement and the rubberized asphalt products. Oil contained in the external jacket of this unit is heated by two propane fired burners and provides a source of uniform heat for the melting chamber and its contents. The melter is equiped with an internal agitator and a heavy-duty gear pump. Tank and line thermometers enable the operator to closely control the melting and pouring temperatures of the sealants. Sealant installation data is shown in Table III.

TABLE III

SEALANT INSTALLATION DATA

Type of Sealant	Type of Melter	Recomended Pouring Temp.	Actual Pouring Temp.
85-100 Pen A.C.	Double-Wall	250°F	250°F
Synthetic Rubber (soft)	Double-Wall	390°F	350°F
MS-LV	Double-Wall	350°F	350°F
Synthetic Rubber (hard)	Double-Wall	390°F	390°F
CRS-2 Emulsion	Single-Wall	160°F	160°F
CRF Emulsion	None	Ambient	Ambient

The pavement cracks were slightly overfilled with the sealants. After filling of each crack a squeegee was used to spread and remove the

Figure 11. Oklahoma Department of Transportation Double-Wall Melter.

excess material from the roadway. This operation is illustrated in Figure 12.

The CRS-2 emulsion was heated in a standard single-wall melter. The CRF emulsion required no heating prior to placement. Immediately after the emulsified sealants were poured in the cracks, sand was sprinkled over the filled cracks to prevent splashing and tracking of the emulsion by traffic. This operation is illustrated in Figure 13.

Inspection of Filled Cracks

The sealed cracks in the test section were inspected periodically to ascertain the extent of failure exhibited by the respective sealants. The inspections were made during the late winter months and early spring of 1980. The cracks were examined during or following, periods of extremely cold weather. Monitoring of the cracks will be continued on a monthly basis during the coming summer and fall seasons.

Prior to examination, the sealed cracks were cleaned by brooming and air-blowing. Failure of the crack sealants was determined by visual observation, and subjectively classified as to type, i.e., adhesion, cohesion, or extrusive. The linear extent of failure or cracking in the surface of the sealant was measured to the nearest 0.1 of an inch using a small digitally reading roller tape measure. To determine whether the surface evident failure extended through the full depth of the sealant, water was poured into the crack from a plastic squeeze bottle and its penetration or lack of penetration noted. This is illustrated in Figure 14.

The percentage of total length of a given crack that failed was determined from these measurements. This data for all combinations of

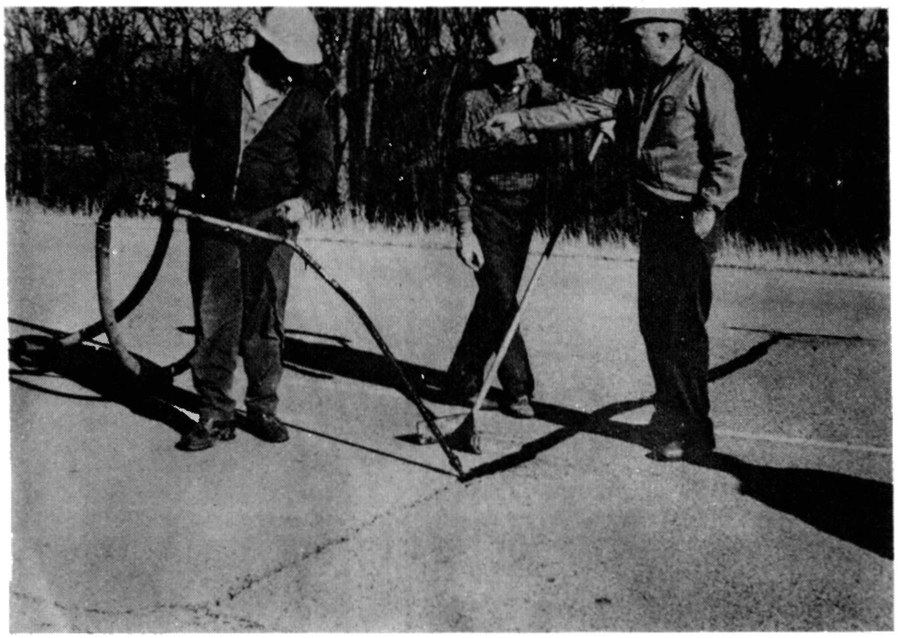

Figure 12. Application and Squeegeeing of Sealants.

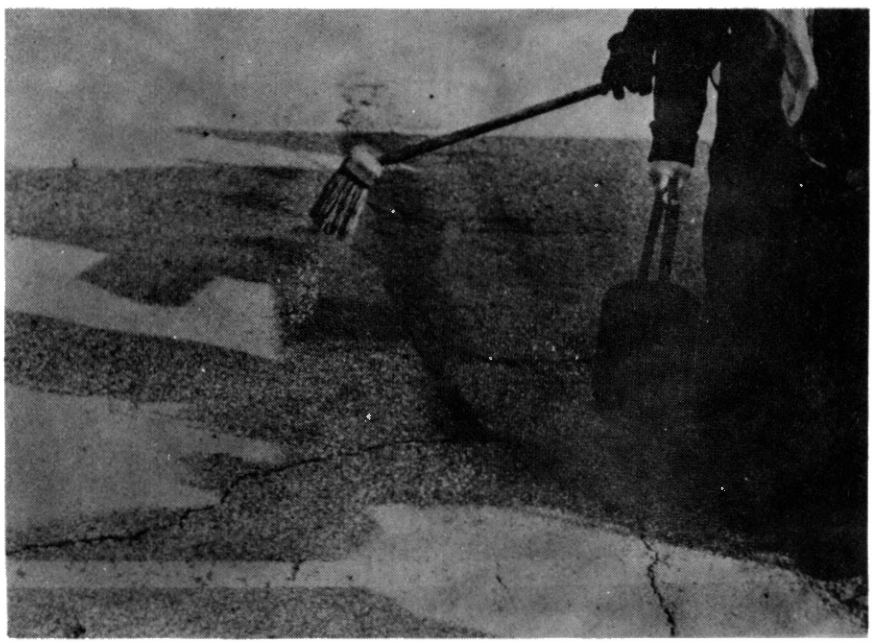

Figure 13. Application and Sanding of Emulsions.

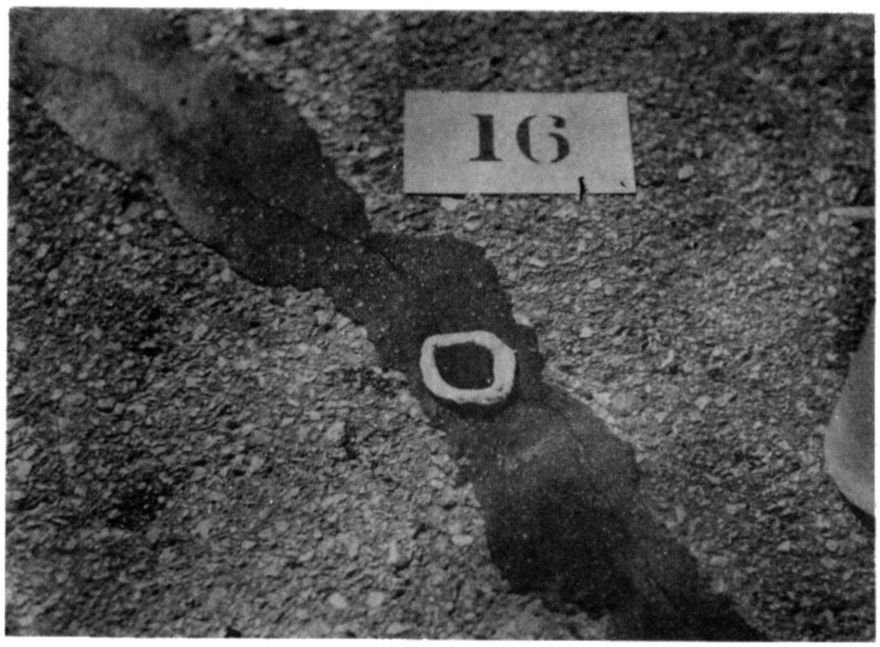

Figure 14. Water Testing Deepness of Sealants Failure.

crack pretreatment and ECS were statistically analyzed to determine whether there was any difference between these variables and the amount of failure exhibited by each sealant.

Computer Program

The data collected from each inspection was punched on computer cards. A card similar to that Shown in Figure 15 was made for each sealed transverse crack with the type of sealant, pretreatment, spacing and other pertinent information punched in the card. The Statistical Analysis System (SAS) Code (9) was used for the analysis of the data.

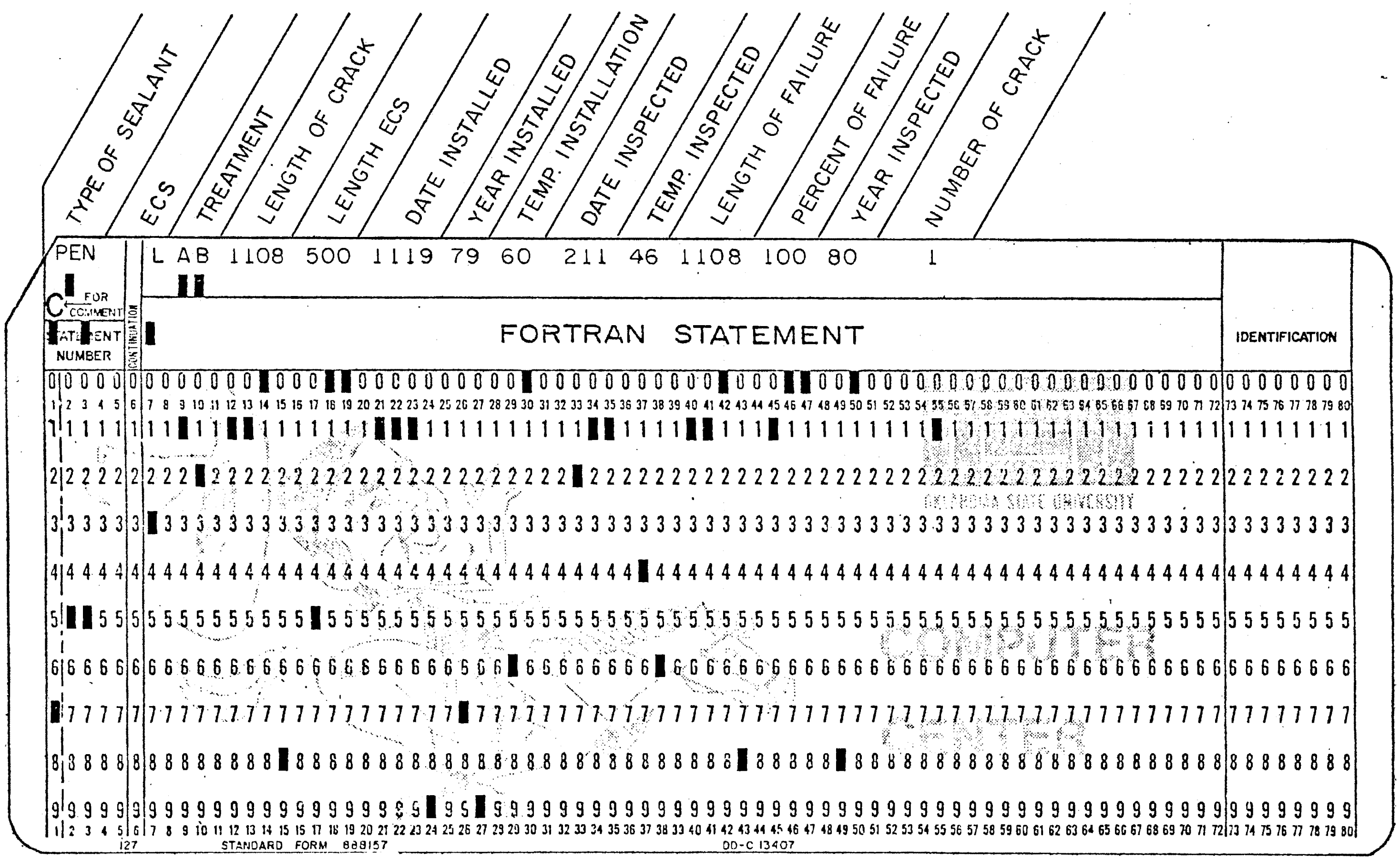

Figure 15. Computer Card With Field Data.

CHAPTER V

RESULTS AND DISCUSSION

General

The sealed cracks in the test section established on U.S. Highway No. 177 were examined periodically after the sealants were installed. The first inspection was made January 9, 1980 and subsequent inspections on February 11, and March 31 of 1980. As previously discussed, the sealed cracks were examined for adhesive or cohesive types of failure that had occurred. The length of failure of each sealed crack was measured and recorded as percentage of footage failed.

The results of the overall field performance of each asphalt pavement crack sealant are illustrated in Figure 16. In this bar graph the total percentage of failure of each sealant at the time of each inspection is shown. The three rubberized sealants had very low percentages of failure, while the 85-100 penetration asphalt cement, and the two emulsions exhibited high percentages. In the case of the synthetic rubber (hard) sealant no failure was observed during the reporting period.

The measurements of these sealant failures were used as input data for a statistical analysis. The experimental plan used for this analysis was that of Randomized Blocks. In this analysis each sealant was treated separately to determine differences in sealant performance due to their ECS and/or type of crack pretreatment used. There were eighteen Asphalt pavement transverse cracks assigned to each sealant with three replications of every possible combination of ECS and crack pretreatment.

The SAS program (17) was used to conduct tests for evidence of real differences in the observed values. The results of these tests indicated the observed significance level and acceptance or rejection of the null-hypothesis (no-differance) was based on a reasonable significance level value of 0.05. That is a significance level value less than 0.05 would indicate the existance of a definite similarity between ECS or crack pretreatment and amount of sealant failure. In the case of an observed significance level value greater than 0.05 the relationship between ECS or crack pretreatment cannot be substantiated by this analysis. Because measurements were taken from the same cracks and not from randomly selected cracks at each inspection, it was suspected that the magnitude of the experimental error would be reduced. Smaller experimental errors give smaller observed significance levels and a tendency to reject the null-hypothesis. This usually becomes critical when the observed significance level is close to the rejection level. Fortunately, the observed significance levels in this study were, in most cases, either very high or very low.

The significance levels for each sealant and their treatments are illustrated on subsequent graphs. Interaction diagrams are also drawn for combination of treatments for each sealant. This type of diagram would indicate if there is a difference in sealant performance and one of the treatment combinations, i.e., the CRF emulsion performs best in a transverse crack which has only been air-blown and has a medium ECS. In this case there was a significance level of 0.9156 which would indicate that this statement is not always true. Therefore you would say that this difference is not significant. In some cases the diagrams look as if there is treatment interaction but the significance levels indicate there is not. For this reason the F values are included on the interaction diagrams. In the case of the synthetic rubber (hard) sealant there was no failure exhibited during the duration of this study. So there was essentially no data to analyze, and there are no significance levels shown.

CRS-2 and CRF Emulsions

Field Evaluation

The CRS-2 and CRF emulsions exhibited the greatest amount of failure. At the time of the first inspection, approximately 97 percent of the sealed crack length (based on 18 cracks approximately 12 ft in length or 126 linear feet of sealed crack length) of the CRS-2 emulsion had failed. Due to the late installation date (January 17, 1980), of the CRF emulsion, it was not inspected at the time of the initial inspection, January 9, 1980. At the time of the second inspection (February 11, 1980), approximately four weeks after the initial inspection, over 90 percent of the sealed crack length of the CRF emulsion had failed. These results are illustrated in Figure 16.

The failures in the emulsion sealants were primarily cohesive in nature (Figure 17). The celerity of these failures is attributed to the incomplete setting of the emulsion prior to exposure to below freezing temperatures. After being poured into a pavement crack, the surfaces of the cationic emulsions in contact with the crack bottom and sides and the free surface break rapidly to form an asphalt skin or film that retards evaporation and/or drainage of the emulsifying water from the bulk of the

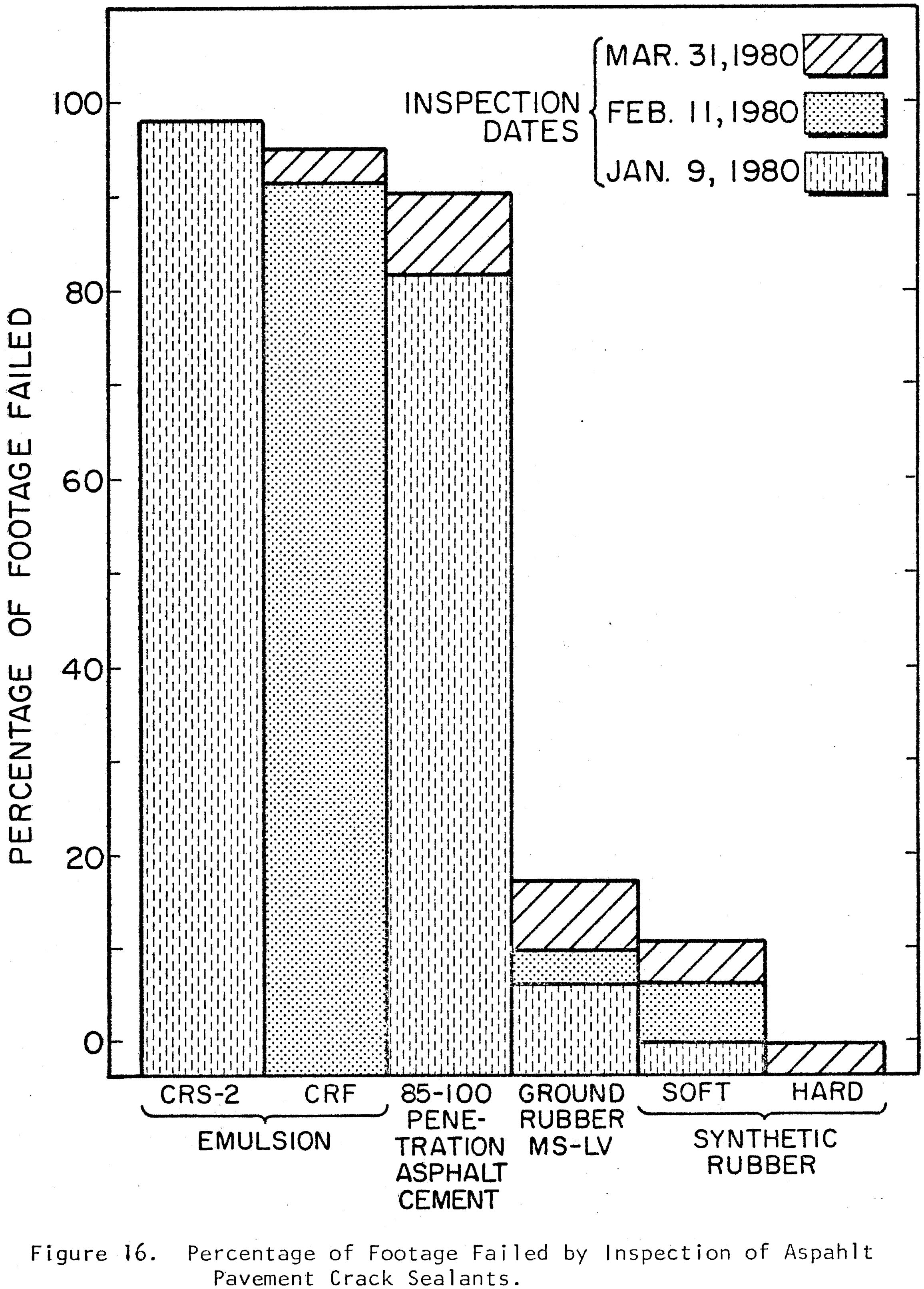

Figure 16. Percentage of Footage Failed by Inspection of Aspahlt Pavement Crack Sealants.

Figure 17. Cohesive Failure of CRS-2 Emulsion.

installed sealant. This has been observed both in the laboratory and field portions of this study. A lengthy period of time (several weeks) may be required for complete setting or breaking of this type of sealant. If the pavement temperature drops below 32°F prior to complete setting, the remaining emulsion freezes and becomes quite brittle. With little or no tensile strength, the emulsion sealant in a crack cannot resist the applied stresses from adjacent pavement sections.

The observed significance levels for the CRS-2 emulsion shown in Figure 18 and 19 are low enough to indicate that there is a relationship between sealant performance, and ECS and crack pretreatment. The observed significance levels for the CRF emulsion also shown in these figures indicates that the null-hypothesis in these cases cannot be rejected and that ECS and crack pretreatment seem to have no affect on this sealants performance.

The observed significance level shown in Figure 20 indicates that there may be some interaction between ECS and crack pretreatment for the CRS-2 Emulsion. This means that a certain combination of ECS and crack pretreatment may produce the best sealant performance. The interaction diagram shown in Figure 21 of the CRF Emulsion shows a observed significance level of 0.9156, since this is out of the significance range of 0.05, the null-hypothesis cannot be rejected, and no statement of relationship can be made. The interaction diagrams show sealant performance versus crack pretreatment and ECS. Logically the closer the resemblance of the lines, the less interaction exhibited, and the higher the significance level value.

It is projected that the performance of the emulsion sealants will improve with age. Observations in May, 1980, after the spring warming

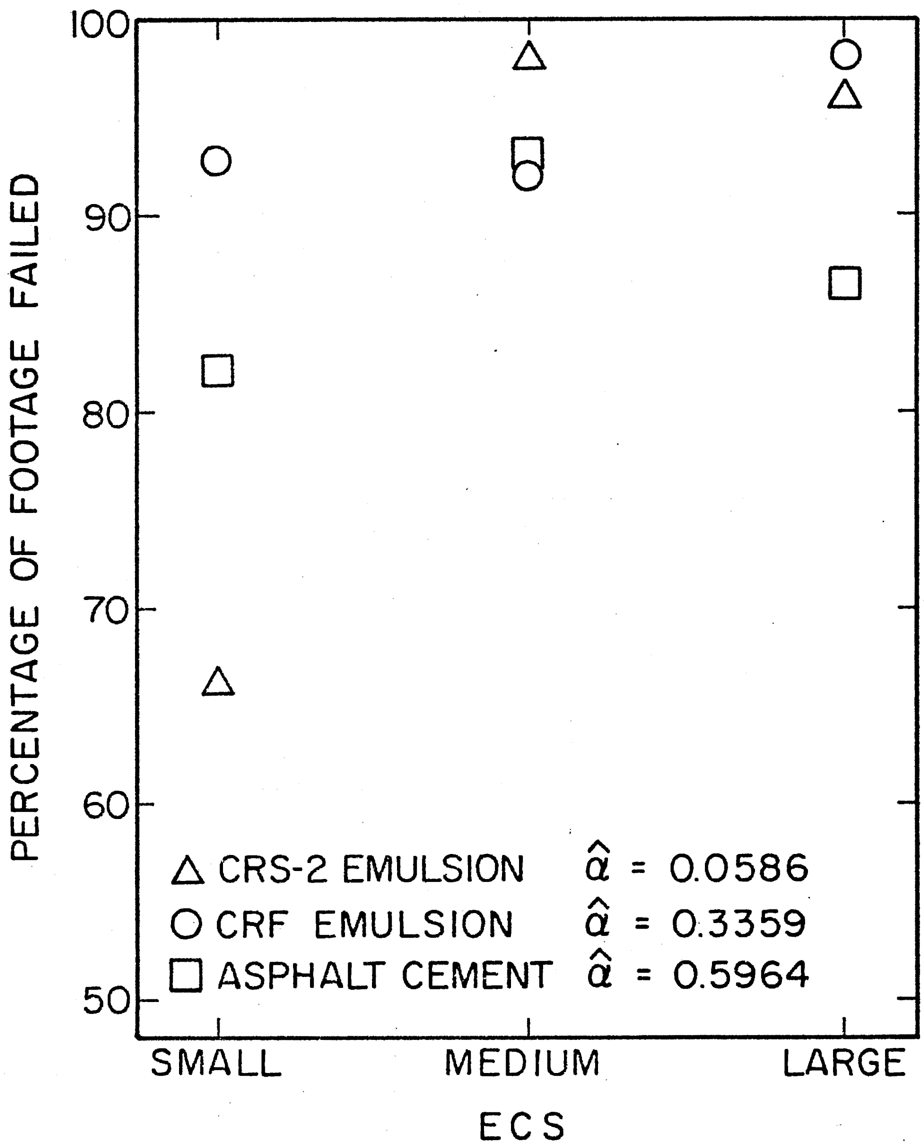

Figure 18. Percentage of Footage Failed vs. ECS for the CRS-2 and CRF Emulsions and 85-100 Pen AC and the Respective Observed Significance Levels.

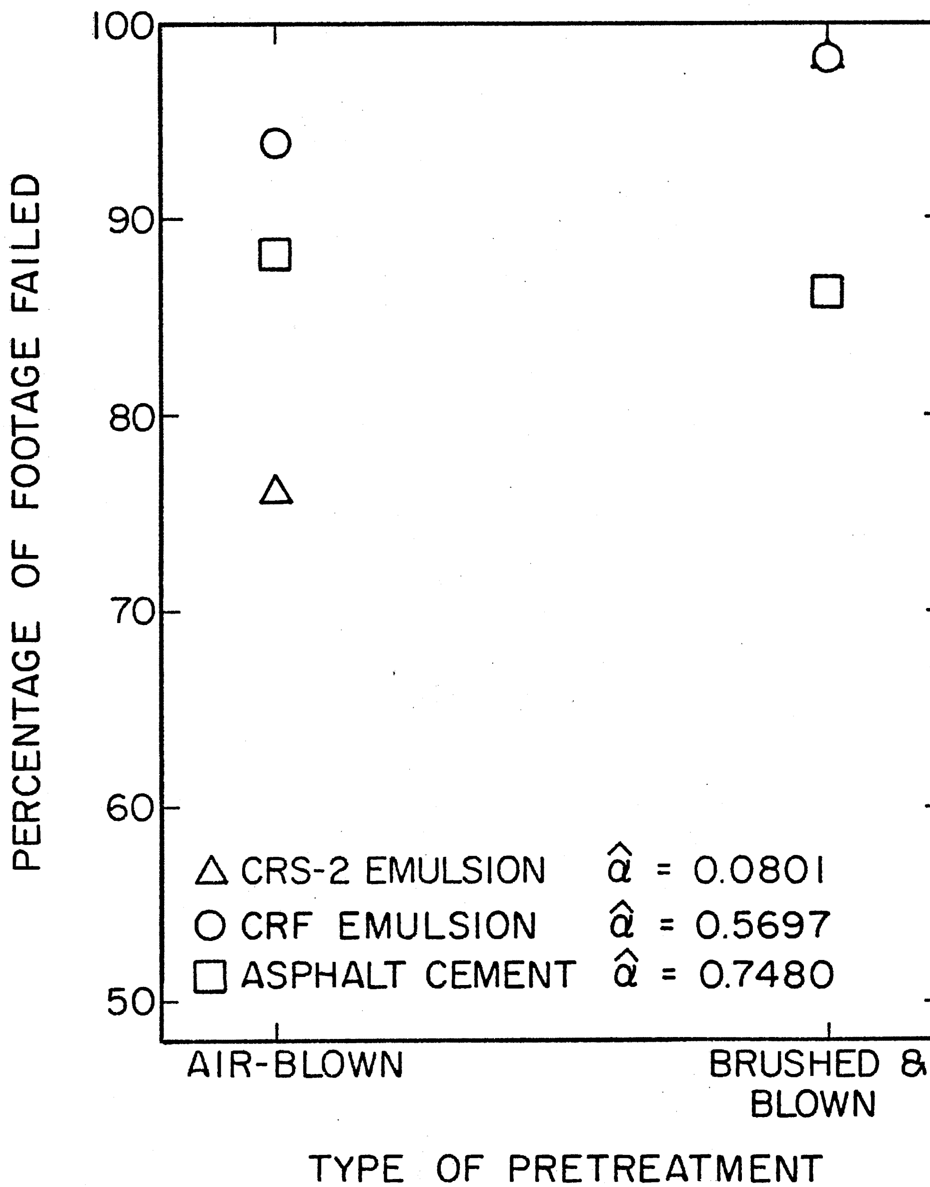

Figure 19. Percentage of Footage Failed vs. Crack Pretreatment for the CRS-2 and CRF Emulsions and 85-100 Pen AC and the Respective Observed Significance Levels.

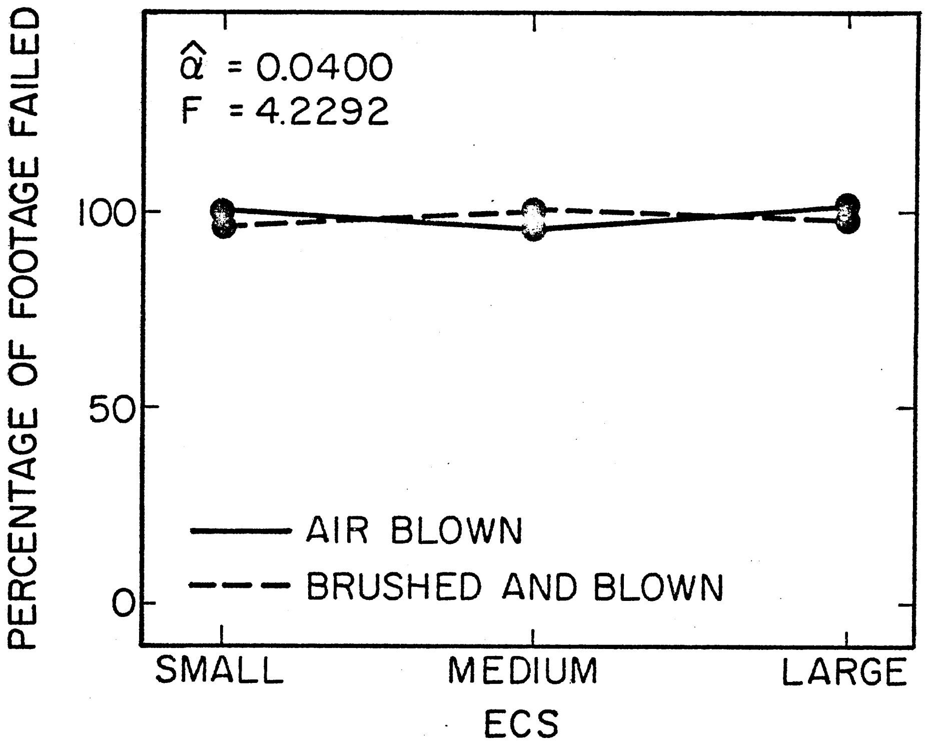

Figure 20. Interaction of Crack Pretreatment and ECS for the CRS-2 Emulsion and Observed Significance Levels.

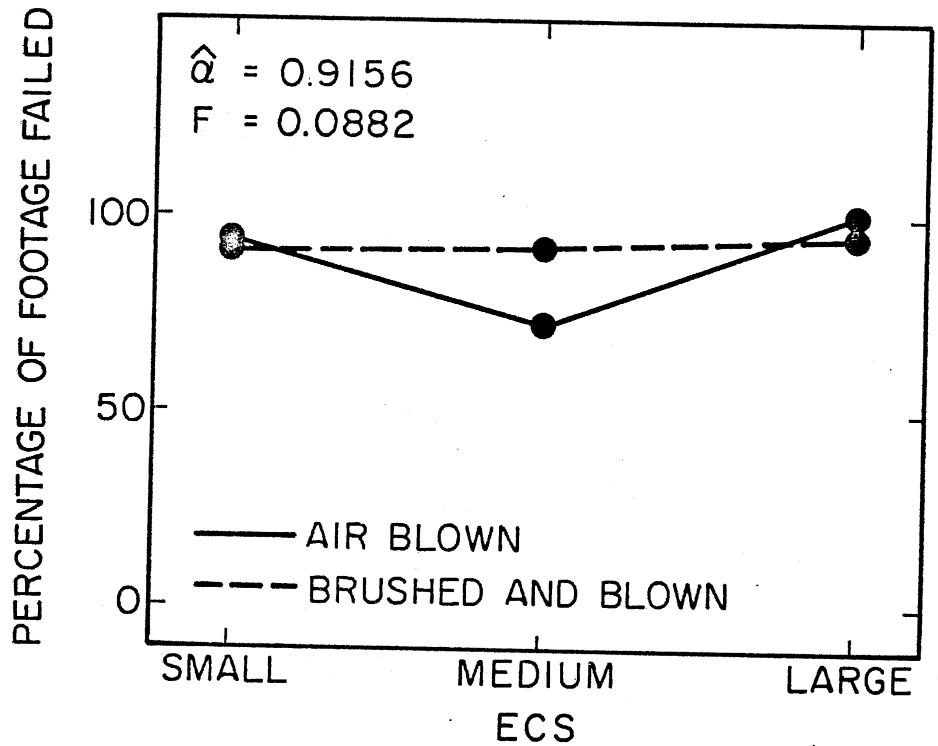

Figure 21. Interaction of Crack Pretreatment and ECS for the CRF Emulsion and Observed Significance Levels.

trend, indicate the cohesive type failures in these sealants are closing or "healing." Inspections during the coming summer and fall months will substantiate or refute these preliminary observations and provide additional data on their overall behavior.

Laboratory Evaluation

The base materials of the CRS-2 and CRF emulsions were evaluated in the three primary laboratory tests used in this investigation. All six BD test specimens of the CRS-2 emulsion failed in their first cycle. The emulsion was brittle at the test temperature and the failures were cohesive in nature. The percentage of recovery in the resilience test was 1.0, which is very low. This indicates the materials ability to resume its original shape following deformation is very poor. The penetration value of this material was 80. These results and their comparison to the laboratory results of the other sealants used in this investigation are shown in Table IV.

The base material of the CRF emulsion at $0^{o}F$ was soft and pliable. This material performed very well in the BD test. All six test specimens completed twelve BD cycles without failure. Because of the softness of this material the resilience and cone penetration tests could not be performed. This was the only sealant in this investigation which tested well in the BD test and did not perform well in the field. Possible reasons for this were discussed previously.

85-100 Penetration Asphalt Cement (85-100 Pen AC)

Field Evaluation

The 85-100 Pen AC exhibited over 80 percent failure of its sealed

TABLE IV

SUMMARY OF LABORATORY TESTS

Sealant	Bond Ductility No. Cycles To Failure	Resilience % Recovery	Penetration (cone) 1/10 cm of depth
AC 85-100	0	1.7	66
CRS-2	0	1.0	80
CRF	12	None	None
Latex Rubber (soft)	12	34	115
Latex Rubber (hard)	12	35	69
Ground Rubber (MS-LV)	12	39	45

crack length at the time of its first inspection. At the time of its second inspection the percentage of failure had risen to over 90 percent where it remained through the time of the third inspection. The reason for this high percentage of failure was thought to be due to the brittleness of this material at $0^{o}F$. The failures exhibited by this material in the field appeared to be choesive in nature (Figure 22). The results of its overall field performance are illustrated in Figure 16.

The observed significance levels shown in Figure 18 and 19 indicate that there is little, if any, relationship between sealant performance, and ECS and crack pretreatment, respectively. The interaction diagram shown in Figure 23 also indicates no significance. These significance tests like those of the emulsions may be slightly biased due to the large percentages and sporadic types of failures exhibited by these sealants.

Laboratory Evaluation

All six BD test specimens of the 85-100 pen AC failed in their first cycle of the BD test. The percentage of recovery in the resilience test was 1.6 percent. The cone penetration value was 66. These results are shown in Table IV.

Ground Rubber MS-LV

Field Evaluation

The Ground Rubber MS-LV exhibited less than 20 percent failure during the period of this investigation. Although this sealant was superior to the non-rubberized sealants it did not perform as well as the synthetic rubber products. This is illustrated in Figure 16. The failures exhibited by this sealant were cohesive in nature and were sporadically located.

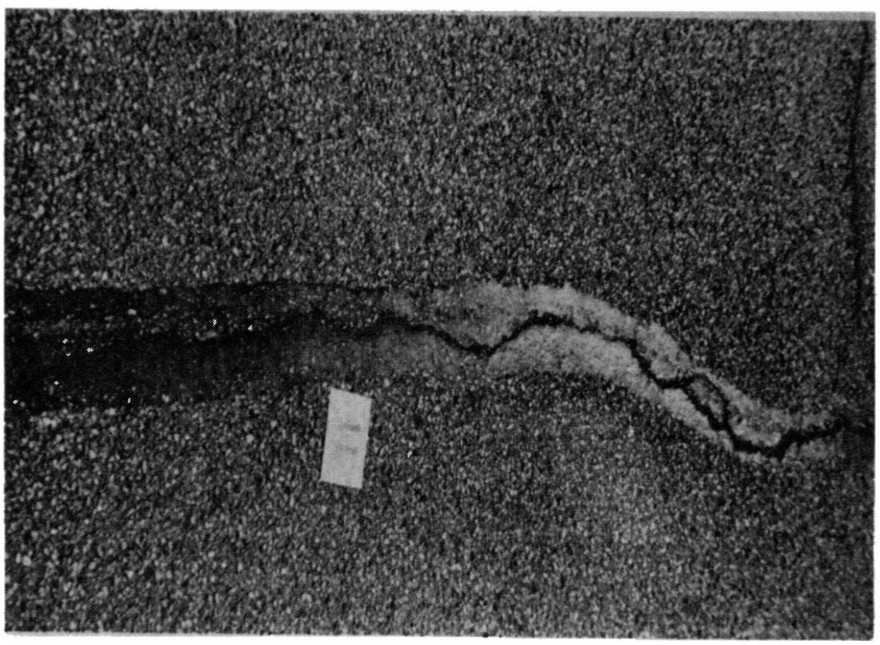

Figure 22. Cohesive Type Failure of 85-100 Pen AC.

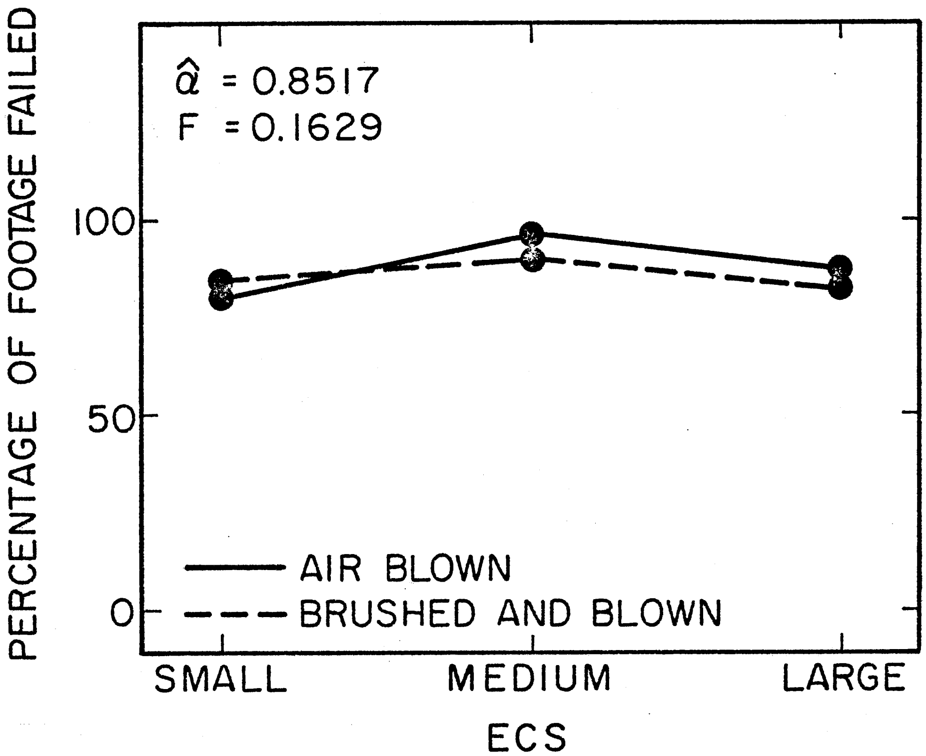

Figure 23. Interaction of Crack Pretreatment and ECS for the 85-100 Pen AC Sealant and Observed Significance Levels.

Some of the sealed cracks exhibited no failure while others exhibited as much as 45 percent failure.

The observed significance levels for the ground rubber product as shown in Figures 24 and 25, indicate rejection of the null-hypothesis. Apparently the performance of this sealant is influenced by the spacing of the cracks and the type of crack pretreatment. The observed significance level for the interaction of ECS and crack pretreatment, shown in Figure 26, indicates rejection of the null-hypothesis (no difference). It appears that the amount of sealant failure is reduced by wire-brushing and air-blowing for the small and large ECS range.

Laboratory Evaluation

The results of the BD test for the MS-LV product were very good. All six test specimens of the sealant withstood at least 12 freeze-thaw cycles without failure. The cone penetration value was 45 and the percent recovery in the resilience test was 39. These values are illustrated in Table IV.

Synthetic Rubber (Soft)

Field Evaluation

During this investigative period the synthetic rubber (soft) sealant exhibited less than 15 percent failure. Unlike the other sealants, this material failed adhesively. Where failure occurred it was due to the applied sealant pulling away from the pavement surface in rubber-band like strips, this is illustrated in Figure 27. Exactly what caused this type of failure is not known but a possibility may be that it is a result of

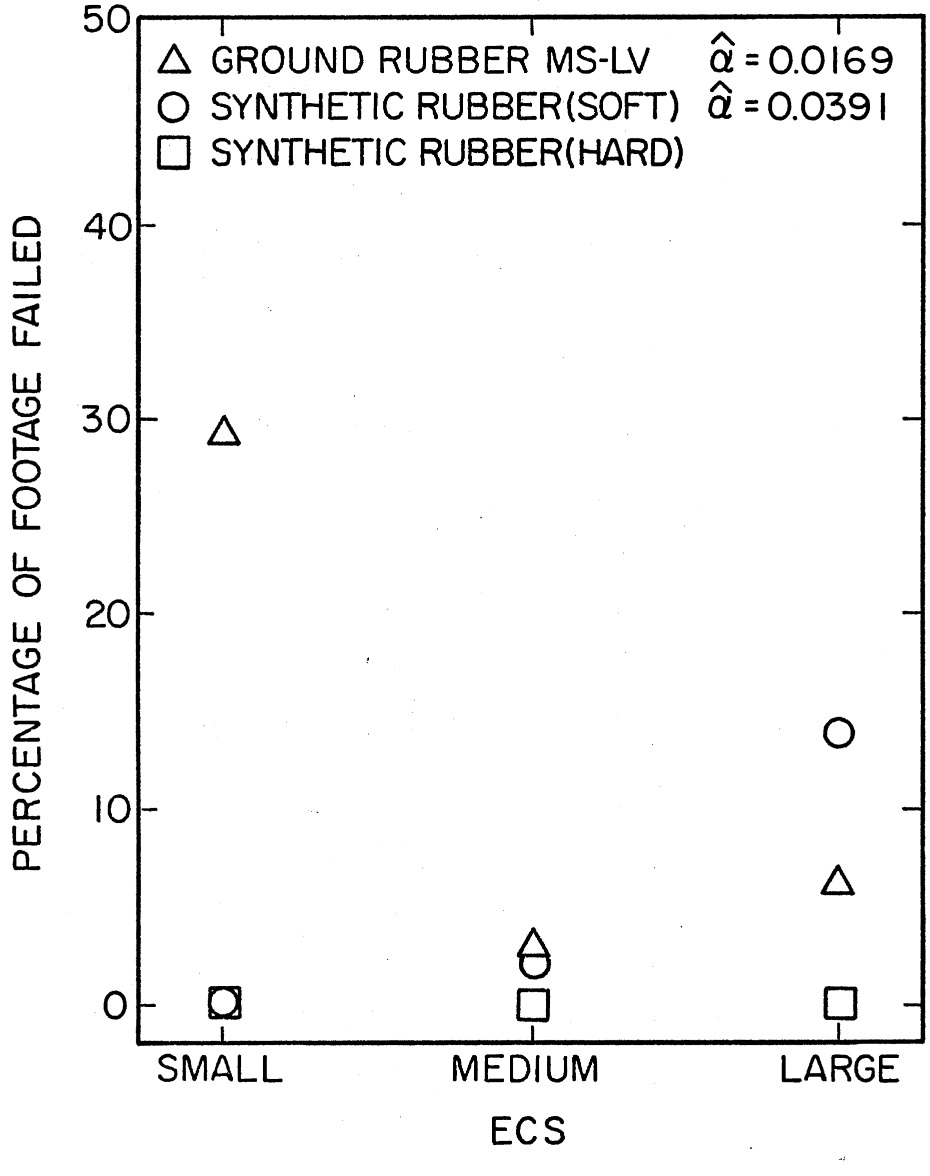

Figure 24. Percentage of Footage Failed vs. ECS for the Ground Rubber (MS-LV). Synthetic rubber (soft), and the synthetic rubber (hard) sealants and the respective observed significance levels.

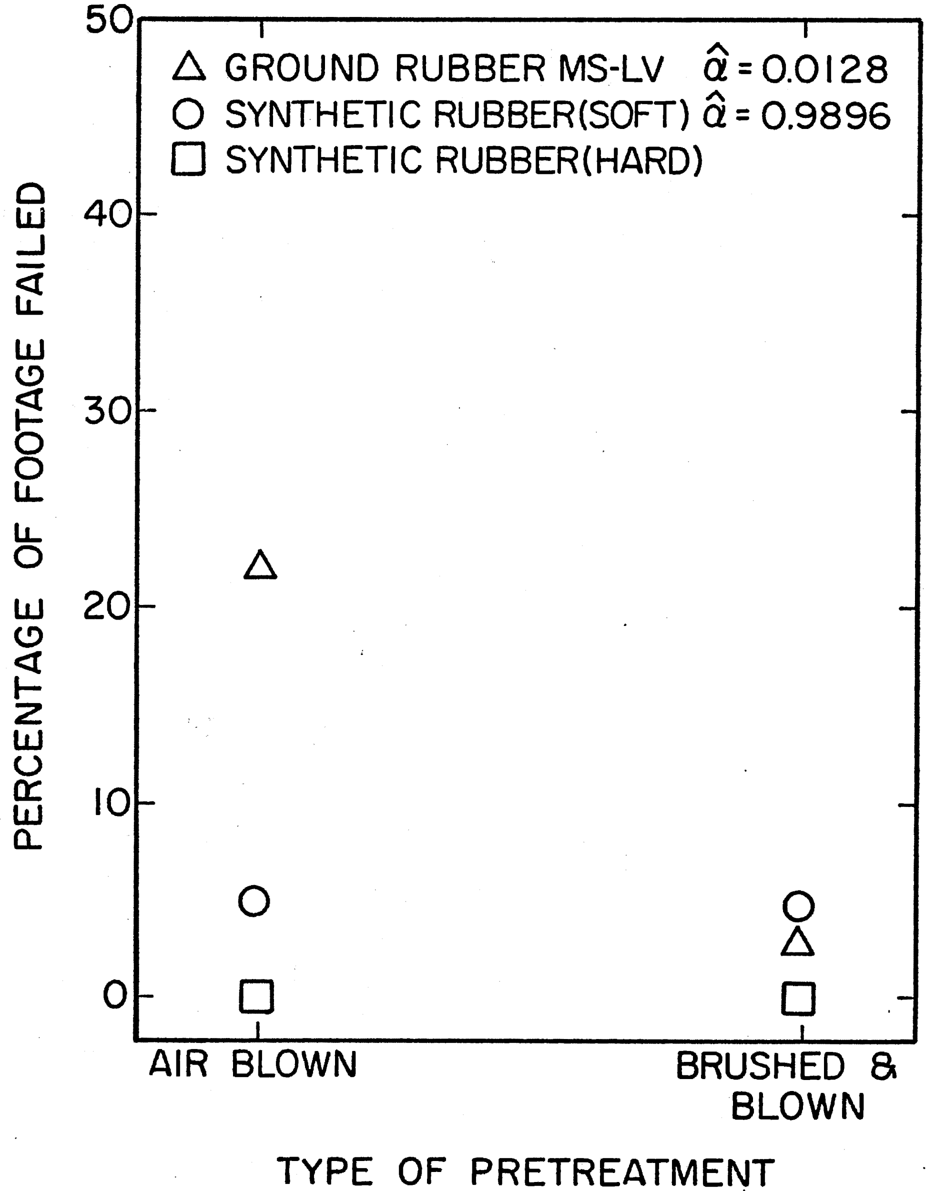

Figure 25. Percentage of Footage Failed vs. Crack Pretreatment for the Ground Rubber (MS-LV). Synthetic rubber (soft), and the Synthetic rubber (hard) sealants and the respective observed significance levels.

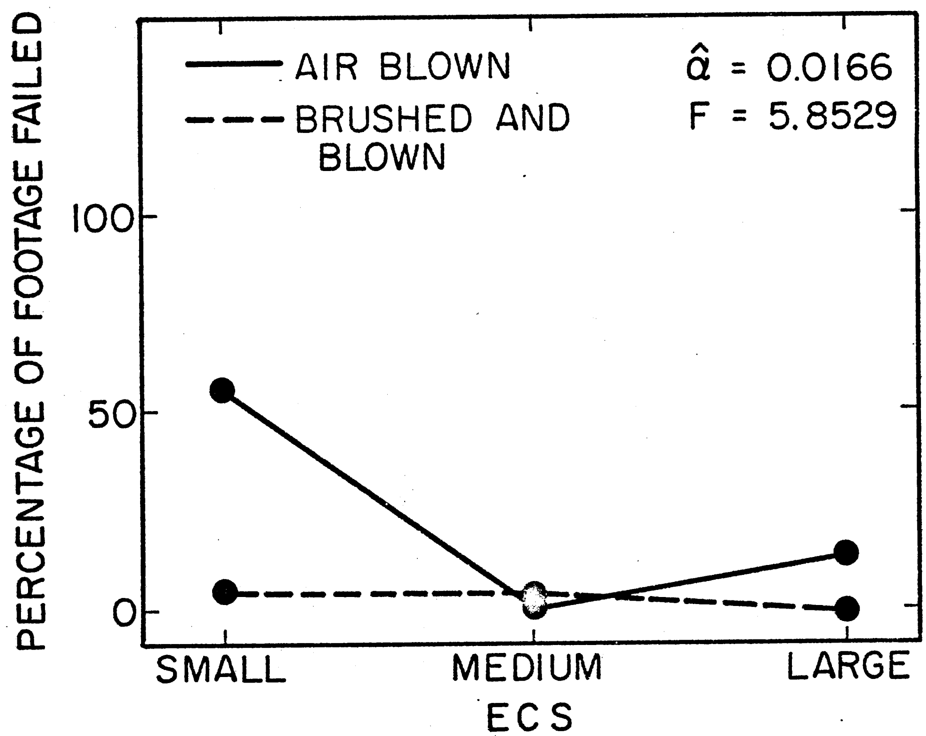

Figure 26. Interaction of Crack Pretreatment and ECS for the Ground Rubber (MS-LV) Sealant and Observed Significance Levels.

Figure 27. Rubber-Band Type Failure of Synthetic Rubber (Soft) Sealant.

poor field application. By referring to Table III it can be seen that this sealant was not applied at its recommended pouring temperature. The temperature recorded in this table may not be accurate. It is suspected that at the time of heating there was not enough material in the double-wall melter to cover the inner chamber thermometer stem. This may have caused over-heating and subsequent damage of the material.

The observed significance level of the comparison of sealant performance to ECS (Figure 24) indicates difference. In the comparison of sealant performance to crack pretreatment there appears to be no difference (Figure 25). The interaction diagram (Figure 28) also indicates no difference of ECS and crack pretreatment.

Laboratory Evaluation

The synthetic rubber (soft) sealant exhibited no failures in 12 cycles of the BD test. This sealant remained slightly soft at $0^{o}F$, there were no problems with adhesion failure in the laboratory which leads one to wonder about its field performance. The cone penetration value for this sealant was 45 and its percent recovery in the resilience test was 35.

Synthetic Rubber (Hard)

Field Evaluation

The synthetic rubber (hard) sealant exhibited no failures during the duration of this investigation. The statistical analysis which was performed on the field data of the other sealants in this research could not be performed on this sealant due to lack of data.

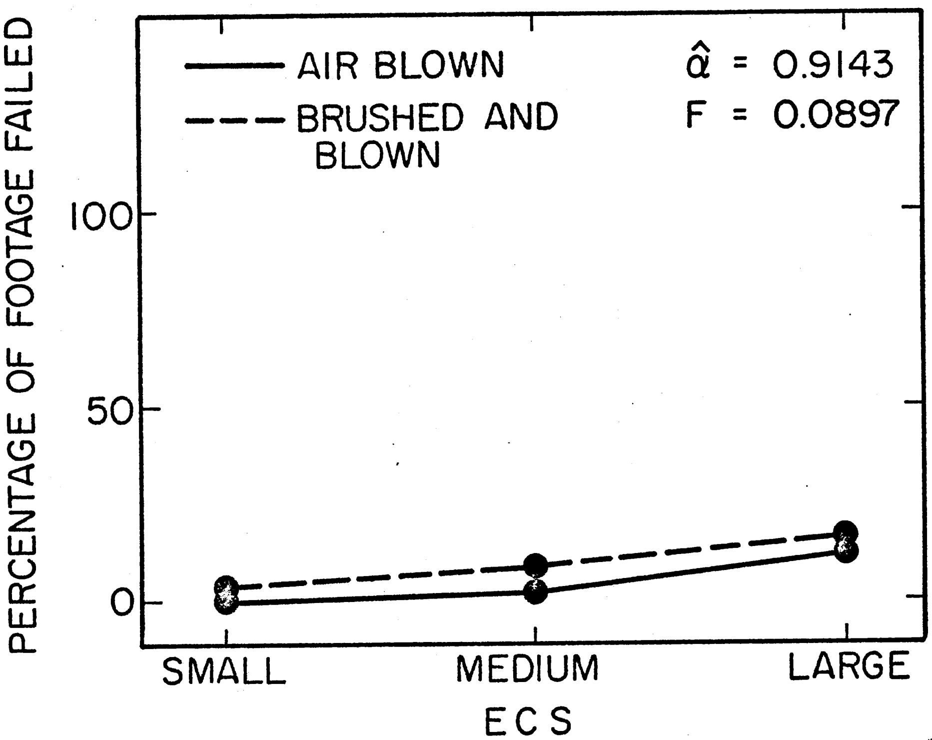

Figure 28. Interaction of Crack Pretreatment and ECS for the Synthetic Rubber (Soft) Sealant and Observed Significance Levels.

Laboratory Evaluation

The synthetic rubber (hard) sealant went the full 12 cycle duration of the BD test. The cone penetration value of this sealant was 69 and the percent recovery in the resilience test was 35. These results and their comparisons are illustrated in Table IV.

CHAPTER VI

CONCLUSIONS

This laboratory and field investigation was directed towards substantiating that a relationship exists between the performance of asphalt pavement crack sealers in the field and in the Bond-Ductility Laboratory test. The secondary objective of this research was to establish what kind of crack pretreatment is necessary to ensure good sealant performance. Based on the information compiled during the period of this study the following conclusions are made:

1. With the exception of the CRF emulsion, all of the sealants which performed well in the Bond-Ductility test exhibited none or small amounts of failure in the field. The CRF emulsion did not have time to set properly before it was subjected to cold temperatures and subsequent pavement stresses.
2. The sealants which had high percentages of recovery in the resilience test, performed well in the Bond-Ductility test and exhibited little or no failure in the field.
3. The sealants which performed best in the field and laboratory evaluation are the, synthetic rubber (hard), synthetic rubber (soft), and ground rubber (MS-LV). These were the rubberized or elastomeric sealants studied in this investigation.

4. The effective crack spacing influenced the performance of the synthetic rubber (soft), ground rubber (MS-LV), and the CRS-2 emulsion.

5. Air-blowing was sufficient crack pretreatment for all of the sealants with the exception of the CRS-2 emulsion. In this particular case the CRS-2 emulsion in the cracks which were brushed and blown exhibited more failure than the sealant in the cracks which were only air-blown.

6. The predominant type of sealant failure observed in the field evaluation portion of this study was cohesive.

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