JOINT HIGHWAY RESEARCH PROGRAM
PROJECT 77-02-3
SEALING CRACKS IN FLEXIBLE PAVEMENTS
FINAL REPORT

SCHOOL OF
CIVIL ENGINEERING
OKLAHOMA STATE UNIVERSITY

FIELD AND LABORATORY EVALUATION OF CRACK SEALANTS

by

Phillip G. Manke
Scott A. Hofener
Mark A. Smith

RESEARCH
REPORT

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CHAPTER I

INTRODUCTION

This study is the terminal portion of a three phase research project entitled "Sealing Cracks in Flexible Pavements." The project was initiated in response to a request from the Research Division of the Oklahoma Department of Transportation (ODOT) and began on July 1, 1976. The primary objective of the project was to evaluate the effectiveness of various materials and methods of application used for sealing flexible pavement cracks.

The initial phase of the research project was devoted to investigating and developing laboratory test procedures that could be used to predict performance of sealant materials (1). The second phase was a field study of crack dynamics, i.e., the observation and measurement of both horizontal and vertical movements at transverse pavement cracks under varying conditions of load and temperature (2). This final phase of the project involved the installation of several types of sealing materials in pavement cracks and monitoring the sealant behavior under actual highway conditions over a nineteen month period. Correlative laboratory tests were also performed on the respective sealants.

Six asphalt pavement crack sealants with varying properties were selected for this field and laboratory appraisal. These sealants included an asphalt cement, two asphalt emulsions and three rubberized asphalt products. Each sealing material was installed in a series of well-developed transverse cracks on a section of U.S. Highway 177 located in central

Oklahoma. The sealed cracks were inspected on a monthly basis for cohesive and/or adhesive type failure of the different sealants. The length of these failures or openings in the sealed cracks were measured and recorded. This data was then statistically analyzed to compare the sealants and determine any influence of crack spacing and crack pretreatment on sealant performance. Field results were compared with those obtained in the laboratory to ascertain the value of selected lab tests for predicting the field performance of the sealing materials.

CHAPTER II

LABORATORY TESTING

General

Selected laboratory tests were performed on six asphalt pavement crack sealing materials. These materials were: 1) an 85-100 penetration asphalt cement from an Oklahoma refinery, 2) a CRS-2 standard asphalt emulsion from an Oklahoma refinery, 3) a proprietary asphalt emulsion (ECRF) with a low viscosity base, 4) a proprietary rubberized asphalt (MSLV) containing granulated tire rubber, 5) a soft synthetic rubber polymer and asphalt blend (SOFS), and 6) a hard synthetic rubber polymer and asphalt blend (HARS). The latter two products are also proprietary crack sealing compounds. These materials were chosen on the basis of previous research and recommendations by the Research Division of ODOT.

Based on the results of previous work, the bond-ductility test, cone penetration test, and the resilience test were selected and performed on the various sealants used in the study. These tests are fully described in Iterim Report III (1). A "modified" ductility test was also devised and carried out on specimens of the sealants to check their response to low temperature elongation at a high rate of strain.

Sealant Preparation

The penetration grade asphalt cement and the three rubberized asphalt products required heating to fairly high temperatures in order to prepare samples for the penetration and resilience tests and to facilitate installation into simulated pavement cracks for the bond-ductility test procedure. Since some of these products have established maximum "safe" temperatures, i.e., temperatures above which the materials will gel, it was necessary to heat them in an oil-bath apparatus. The oil-bath permitted close control of the heating temperature of the material and prevented localized over-heating during the melting process. This apparatus has been previously described (1).

In order to test the base asphalt material contained in the emulsions the water was removed by evaporation. A quantity of the emulsion was placed in the oil-bath and heated to a temperature slightly above 212 F (100 C). The emulsion was heated at this temperature and stirred until all foaming had ceased. At this point practically all of the water had evaporated and the residual base asphalt material was then heated to a slightly higher temperature for pouring the test specimens.

After each sealant was heated to a recommended pouring temperature (Table I), it was poured into previously prepared test block specimens for the bond-ductility tests, and three ounce tins for the resilience and cone penetration tests.

Bond-Ductility Tests

The bond-ductility machine developed during the initial phase of the project provided a means of testing the selected sealants for their bonding characteristics and ductility behavior under conditions similar to those experienced in an actual pavement crack. This extension type machine is capable of testing multiple samples of a sealant in the form of sections of simulated sealed pavement cracks at precisely controlled rates of

TABLE I

SEALANT POURING TEMPERATURES

Type of Sealant	Pouring Temperature
Asphalt Cement (85-100)	250 F (121 C)
CRS-2 (base material)	250 F (121 C)
ECRF (base material)	250 F (121 C)
MSLV (granulated tire rubber blend)	300 F (149 C)
SOFS (soft synthetic rubber blend)	390 F (199 C)
HARS (hard synthetic rubber blend)	390 F (199 C)

tensile strain over a wide range of temperature conditions. A top view of the machine (in the freezer cabinet) with six sealant specimens being clamped in position for testing is shown in Figure 1.

Specimen Preparation

Test blocks, 6 in. (152 mm) long, 2 in. (51 mm) wide and 3 in. (76 mm) deep, were used to form the sides of a simulated crack for a sealant test specimen. These blocks were cut from a rectangular beam of compacted hot-mix asphalt concrete surface course mixture. The beams were compacted with a kneading compacter that had a modified tamping foot and a specially designed rectangular mold. The small test blocks were cut from beam specimens with a masonry saw.

Two test blocks were assembled with their uncut sides facing each other and an aluminum plate spacer between the blocks to form a simulated

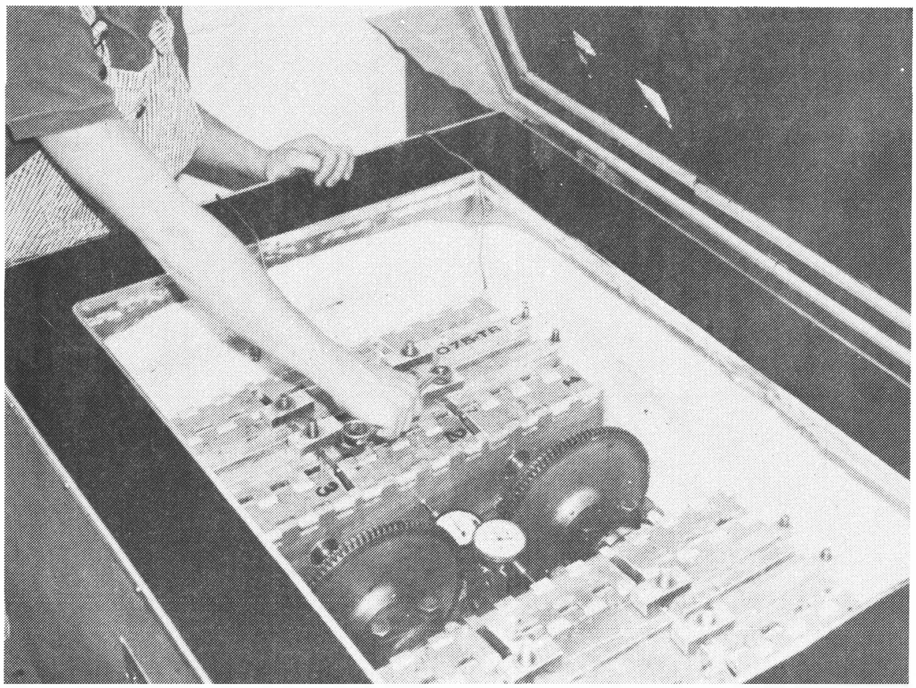

Figure 1. Bond-Ductility Machine with Six Sealant Specimens Being Clamped in Place for Testing

pavement crack mold having specified dimensions of length, width and depth. In one series of test specimens the simulated cracks were 1 in. (25.4 mm) deep and 0.25 in. (6.4 mm) wide and in a second series of specimens the cracks were 1 in. (25.4 mm) deep and 0.375 in. (9.5 mm) wide. Masking tape was used to hold the blocks in position and prevent leakage of the sealant. Hot sealant was then poured into these molds until the cracks were filled flush with the top surface of the facing test blocks. After cooling for 24 hours, the masking tape and aluminum spacers were removed and the sealant test specimens were stored in a freezer at 0 F (-17.8 C). Six test block specimens were prepared from each of the sealants for the bond-ductility tests.

Testing Procedure

Test block specimens of a given sealant were removed from the storage freezer and immediately secured in the clamping frames of the bond-ductility machine, which was installed in a separate freezer cabinet. After a period of time necessary to stabilize the temperature in the testing chamber at 0 ± 1 F (-17.8 ± 0.5 C), the machine was started and the test block specimens were subjected to a constant rate of tensile strain of 0.125 in. (3 mm) per hour. This strain rate was continued until the sealants between the test blocks had been stretched a predetermined distance. The 0.25 in. wide crack specimens were stretched or extended to 50 percent of the original crack width and the 0.375 in. wide specimens were extended to 100 percent of the original crack width. The purpose for changing the shape factor and amount of total strain applied to the two series of bond-ductility test specimens was to see if differences in performance of the three rubberized asphalt sealants could be determined.

After extension, the specimens were removed from the testing machine and inspected for any signs of failure. Failed test specimens were discarded and the aluminum spacers were replaced between the test blocks of those specimens that had not failed. These test specimens were placed on their sides and allowed to warm at ambient laboratory temperature for a minimum of 4 hours. The warmed specimens were then placed in a hydraulic press and slowly compressed to their original width. After compression, the specimens were returned to the storage freezer to cool back to the test temperature of 0 F.

An extension of the test specimens followed by compression to their original width constituted one complete cycle of the bond-ductility test. Test cycles were repeated until failure occurred or until the specimens completed 12 cycles without failing. When four of the total of six specimens had failed, the bond-ductility test was halted and failure was considered to be complete for that particular sealant.

Failures of the sealant specimens were determined by visual inspection after each extension phase of the test and were classified as to type, i.e., cohesive or adhesive failure. A cohesive failure was indicated when a separation or opening occurred in the body of the sealant. When separation occurred at the sealant/test block interface it was considered an adhesive type failure. The extent of separation in a specimen was measured linearly and when the length reached or exceeded 15 percent of the total simulated crack length, the sealant test specimen was considered to have failed completely. The results of the bond-ductility test were recorded as the number of test cycles that the six specimens of each individual sealant underwent before failure.

Cone Penetration Test

The cone penetration test is a standard test procedure (ASTM D 3407-78) for hot-poured joint sealants used on concrete and asphalt pavements (3). This test is similar to the standard penetration test except that a specially dimensioned cone shaped implement is used in place of the penetration needle. The test was performed on samples of the respective sealants to indicate the wide range of consistency that was represented by these crack sealing products at normal temperature. In order to perform this test on the two emulsion products, the emulsifying water was removed, as has been previously described, and the base asphalt cement was tested. The base asphalt cement of the ECRF sealant was an extremely soft material and the cone penetration value could not be determined. No relationship between the cone penetration values and the field performance of the sealants was found.

Resilience Test

This test is also a standard test procedure for concrete and asphalt pavement joint sealers (ASTM D 3407-78) and is used to determine a measure of the resilience or elasticity of a sealant. The test is performed using a ball shaped penetration tool which is pressed into the surface of a material sample to a specified depth and then released. The deformed specimen is allowed to recover for a short period and the amount of recovered depth of penetration of the ball is measured and expressed as the "recovery percentage." Previous laboratory testing (1) indicated that the results of this test on a particular sealant might have some relationship to the sealant's performance in the bond-ductility test.

Modified Ductility Test

This test was devised and implemented in the latter stages of the laboratory testing of the selected crack sealants to provide additional information regarding their behavior under a high rate of strain at low temperature. It was thought that the strain rate to which the installed crack sealers were subjected in the field during the winter months might greatly exceed the rate used in the bond-ductility test. While a rather common low-temperature ductility test is conducted at 39.2 F (4 C) with a rate of elongation of 10 mm per minute, the conditions of this "modified" test were even more rigorous.

Standard ductility test samples or briquets (ASTM D-113) were molded for each sealant and after cooling to laboratory temperature were stored in a freezer at 0 F. A plexiglass and plastic sheeting hood was devised to enclose the top of the water bath unit of a standard ductility machine and form a low-temperature test chamber. This arrangement is shown in Figure 2. Dry ice was placed in the bottom of the water bath and the temperature in the test chamber was lowered to 0 ± 3 F (-17.8 ± 5C) for testing. The ductility test briquets were removed from the freezer, placed in the test chamber of the ductility machine, and elongated at a rate of 5 cm per minute. During elongation the temperature of the test samples and that of the testing chamber were monitored with a telethermometer unit. The length of elongation of a sealant sample was recorded at the point where breakage occurred. If breakage or rupture did not occur in the sample, the test was terminated at an elongation of 25 cm.

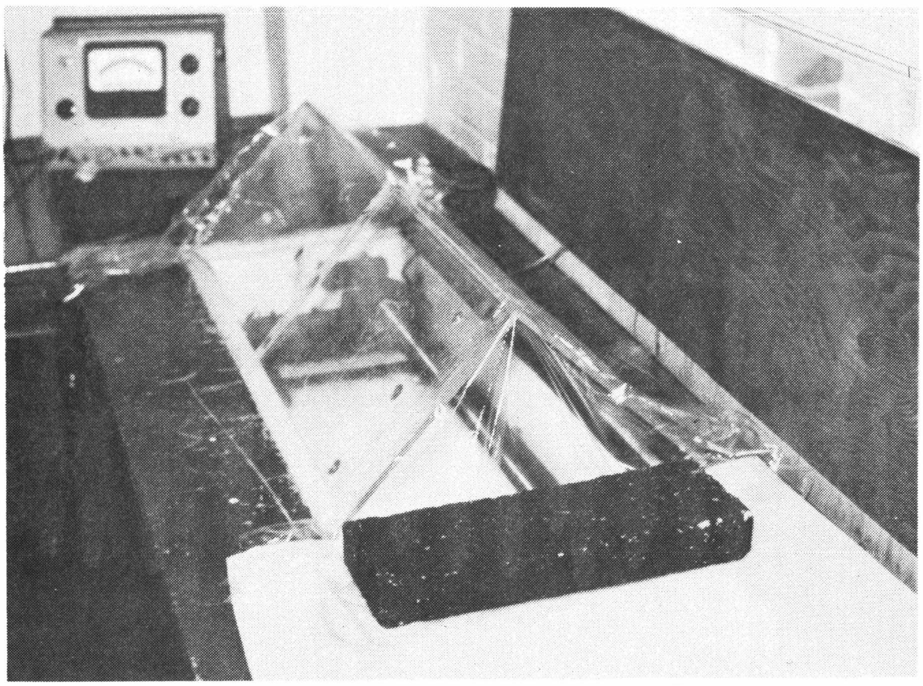

Figure 2. Modified Ductility Test Chamber

CHAPTER III

FIELD STUDY

General

This part of the overall project was designed to determine how the selected asphalt pavement crack sealants performed after their installation in a cracked section of highway pavement and exposure to seasonal weather conditions. Several pavement sections with well developed cracking were considered prospective sites for this field test program. The site selected was a two mile (3.2 km) section of U.S. Highway 177 beginning approximately four and a half miles (7.2 km) south of the junction with U.S. Highway 66, in Lincoln County, Oklahoma. This section of highway was oriented north and south with good stopping sight distance throughout and broad paved shoulders for parking the research vehicles without interferring with traffic.

Type of Cracks

The majority of cracks in the pavement at the test site were the transverse type, i.e., cracks generally running perpendicular to the centerline of the pavement. The horizontal and vertical movements of the sides of such cracks are usually larger than for other types or patterns of cracks. Thus, greater stresses would be applied to the materials used to seal these cracks.

Some of the transverse cracks spanned the full width of the pavement

(24 ft) (7.3 m) and extended through the shoulders on each side. A good many of the cracks 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. (6.4 mm) to slightly greater than 1.0 in. (25.4 mm), depending on the age of the crack and the amount of breakage or spall of the crack edges from traffic loads. The depth of these cracks varied from several inches to several feet.

Crack Spacing

Previous investigations (2) (4) indicated the amount of horizontal movement at transverse cracks increases with the effective crack spacing (ECS). Horizontal crack movement, i.e., the extent of opening and closing of a transverse crack, is caused by thermal expansion and contraction of the pavement sections adjacent to the cracks. ECS is the average of the distances between adjacent transverse cracks on either side of a crack being studied.

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. A small ECS ranged from 15 to 25 ft (4.6 to 7.6 m), a medium ECS from 30 to 40 ft (9.1 to 12.2 m), and a large ECS was 45 ft (13.7 m) or greater. This classification system permitted direct comparison of the performance of the various crack sealing materials since there would be approximately equal strains in the sealants installed in cracks in each of these spacing categories.

Crack Survey

Following the selection of the test site, a detailed crack survey of this section of highway was performed. The length of the section was divided into 100 ft (30.5 m) segments or stations starting at the north end of the test site. The station numbers were painted on the west shoulder of the pavement to provide reference points for mapping the cracks and later for locating specific transverse cracks. All of the transverse cracks in the test section were mapped on special data sheets to show their general configuration, i.e., length, direction and location. The necessary measurements were made with a model 200 Rolatape. The cracks were then plotted to scale on the data sheet. A sample of a crack survey data sheet is shown in Figure 3.

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 3 shows three selected cracks in the south-bound lane, each with a different ECS. Only cracks extending across a full pavement lane were used. Thus, all transverse cracks selected for sealing were approximately 12 ft (3.6 m) in length.

The statistical design of the field test program involved six sealants, three ECS ranges, two types of crack pretreatment and three replications. Thus, a total of 108 transverse cracks were needed for the study. After the cracks were selected from the crack maps on the data sheets they 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

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

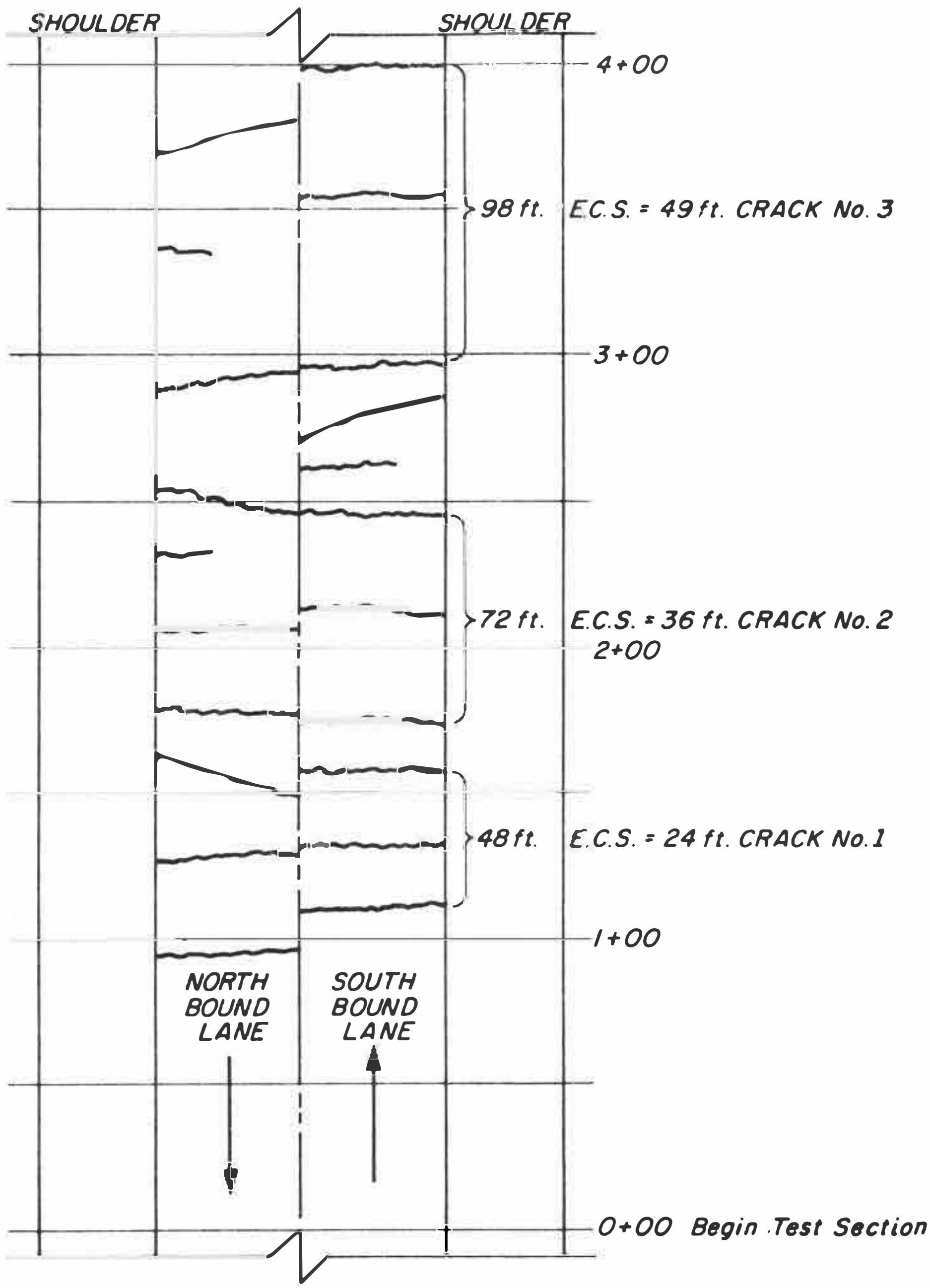

Figure 3. Crack Survey Data Sheet

selected cracks were located at the test section and their assigned numbers were painted with yellow paint on the paved shoulder 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 field installation of the sealants.

Pretreatment of Cracks

Measures taken to promote good adhesion between a sealing material and the sidewalls of a crack are generally considered to contribute to better performance of the sealant that is used. Crack preparation method was included as another variable in the experimental design of the field test program. The respective Maintenance Divisions of the ODOT 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 (5). A decision was made to limit the study to only two types of pretreatment of the cracks, air-blowing and a combination of wire brushing and air-blowing. It was believed that these two pretreatments would be the ones most frequently used in practice because of time and cost factors, and that they should provide sufficient data to indicate whether extra care in cleaning and preparing the cracks prior to sealing was justified.

Air-blowing of the cracks at the test site was accomplished using a standard 200 cfm (944 m^3/s) gasoline powered air compressor. The compressor was operated at a pressure of about 240 psi (1655 kPa) which was sufficient to remove all loose material or debris from a crack. Brushing of the cracks was done with a stiff bristle wire brush attached to a short handle, as shown in Figure 4. This operation, along with subsequent

Figure 4. Wire Brushing a Traverse Crack

air-blowing, removed dust and any loose paving material from the edges of the crack and the crack walls near the pavement surface.

Installation of Sealants

All of the crack sealants used in this study were installed at the test site during the fall and winter of 1979-80. The ODOT Division 4 maintenance force based in Chandler, Oklahoma, provided the necessary equipment and manpower needed for the crack sealing operation. Respective dates were established for installing each sealant but because of scheduling problems almost two months elapsed before the last sealant was installed. The type of sealant, date, and pavement surface temperature at the time of installation of each sealant is shown in Table II.

TABLE II

DATES OF SEALANT INSTALLATION AND PAVEMENT TEMPERATURE

Type of Sealant	Date of Installation	Pavement Surface Temperature
Asphalt Cement	Nov. 19, 1979	60 F (16 C)
SOFS	Nov. 29, 1979	45 F (7 C)
MSLV	Dec. 3, 1979	57 F (14 C)
HARS	Dec. 5, 1979	77 F (25 C)
CRS-2	Dec. 10, 1979	52 F (11 C)
ECRF	Jan. 17, 1980	64 F (18 C)

The double-wall melter, shown in Figure 5, 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 provide a source of uniform heat for the interior melting chamber and its contents. The melter is equipped with an internal agitator and a heavy-duty gear pump. Under pressure from the pump, melted sealant is injected in a crack through a valve controlled nozzle as illustrated in Figure 6. Tank and line thermometers enable the operator to closely control the melting chamber temperature and the line temperature of the sealant as it is pumped into a pavement crack. Sealant installation data is shown in Table III.

TABLE III

Sealant Installation Data

Type of Sealant	Type of Melter	Recommended Pouring Temp.	Field Pouring Temp.
Asphalt Cement	Double-wall	250 F (121 C)	250 F (121 C)
SOFS	Double-wall	390 F (199 C)	350 F (177 C)*
MSLV	Double-wall	350 F (177 C)	350 F (177 C)
HARS	Double-wall	390 F (199 C)	390 F (199 C)
CRS-2	Single-wall	160 F (71 C)	160 F (71 C)
ECRF	None	32-180F (0-82C)	67 F (19 C)

* Actual melting chamber temperature probably exceeded 400 F (204 C)

The pavement cracks were slightly overfilled with the high viscosity sealants and a V-shaped squeegee was used to strike off the excess material so that the crack was filled flush with the pavement surface. This is also shown in Figure 6.

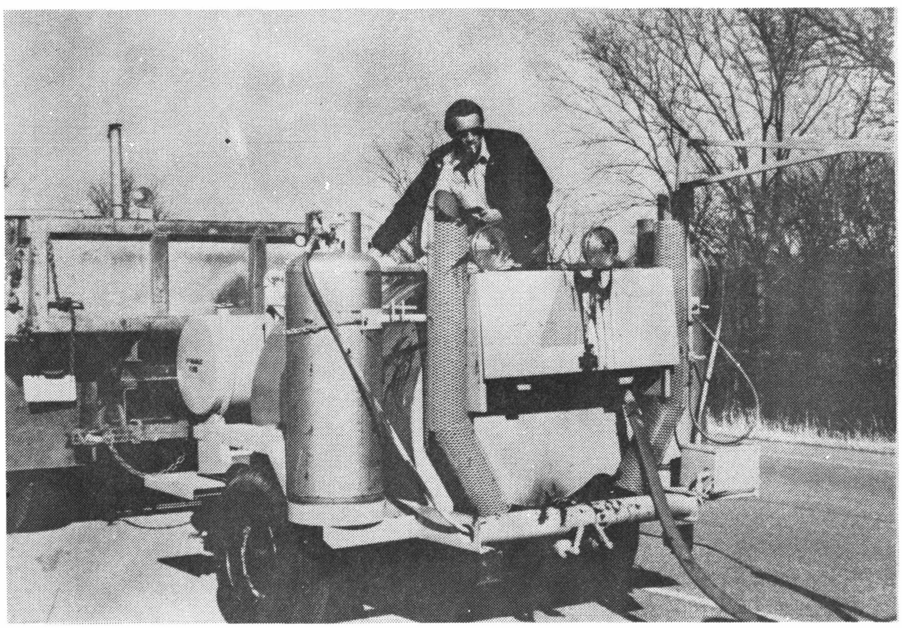

Figure 5. Double-Wall Melter

Figure 6. Installing High Viscosity Sealants

The CRS-2 emulsion was heated in a standard single-wall type melter. The ECRF emulsion required no heating prior to placement. Both emulsion sealants were poured into the cracks using trigger-actuated funnel bottom buckets. Immediately after the emulsions were poured, fine sand was broomed over the filled cracks to a depth of approximately 0.5 in. (12.7 mm) to prevent splashing and tracking of the emulsion by traffic. This operation is shown in Figure 7.

Inspection of Sealed Cracks

The sealed cracks in the test section were inspected periodically to determine the extent of failure, if any, exhibited by the respective sealants. The inspection sequence began in January, 1980, and continued through August, 1981. Monitoring of the crack sealant performance was planned and carried out on a monthly basis except that the filled cracks were examined during or immediately following periods of extremely cold or hot weather.

Prior to examination, the surface of the sealed cracks were cleaned by brooming and air-blowing. Failure of the crack sealants was determined by visual observation and subjectively classed as either adhesive or cohesive type. No extrusive type failures were observed in any of the sealants.

To determine whether a surface evident crack or failure extended through the full depth of the sealant, water was poured into the failure from a plastic squeeze bottle and the penetration of the water or its lack of penetration was noted. This is illustrated in Figure 8. The linear extent of failure or cracking in the surface of the sealant was then measured to the nearest inch (25.4 mm) using a model MM 12 Rolatape

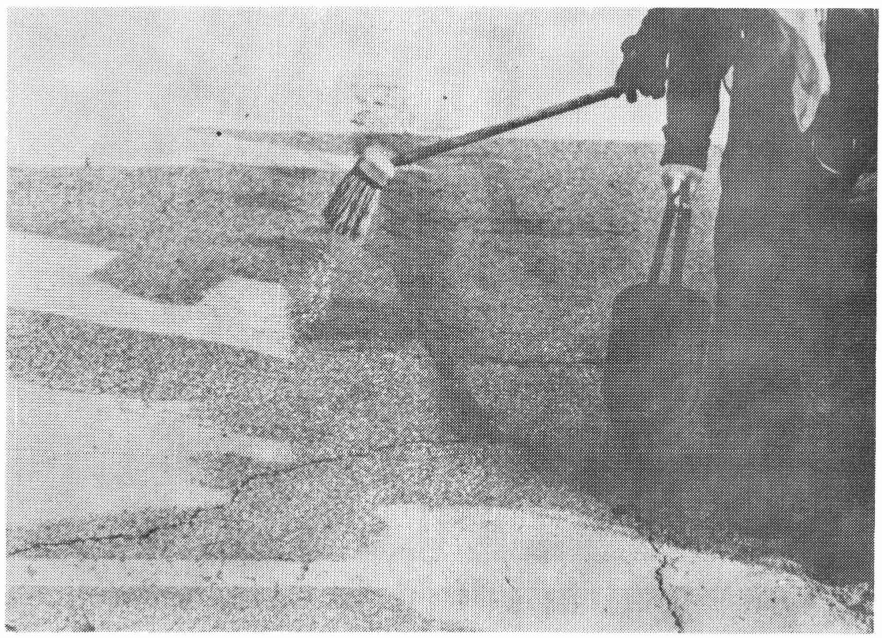

Figure 7. Installing and Sanding Emulsion Sealants

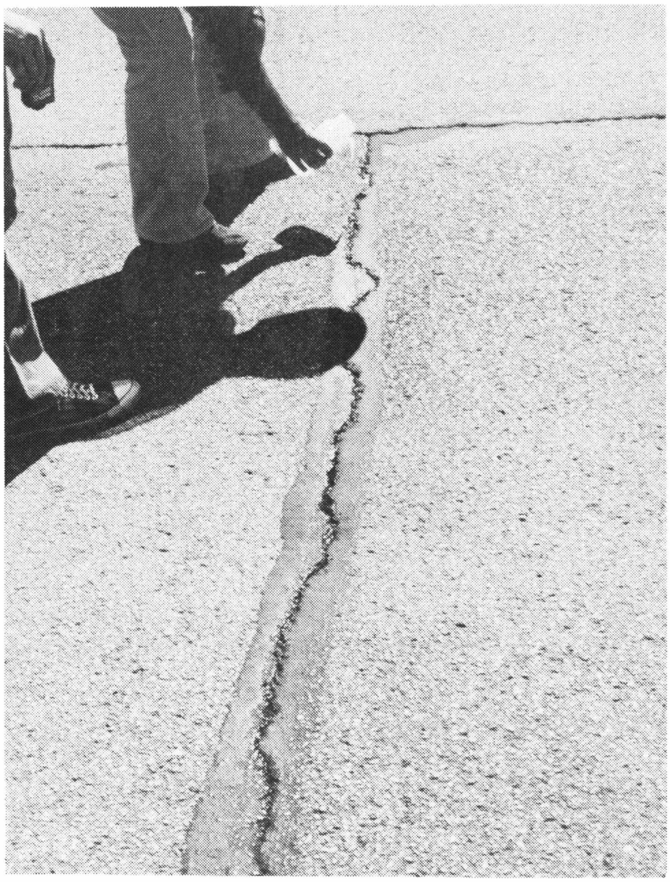

Figure 8. Testing Sealant Failures with Water

Figure 9. Measuring Failed Length of a Sealed Crack

as shown in Figure 9. Failed lengths for each sealed crack were expressed as a percentage of the total length of the crack.

Data Processing

Following each inspection, the collected field data was punched on computer cards similar to the one shown in Figure 10. A card showing the type of sealant, pretreatment, ECS, date of inspection, percent of failure observed and other pertinent information was made for each sealed transverse crack. These cards became part of the data deck used with the Statistical Analysis System (SAS) program (6). This program was run on the Oklahoma State University's IBM 370/168 computer and it performed the necessary computations for a statistical analysis of the input data.

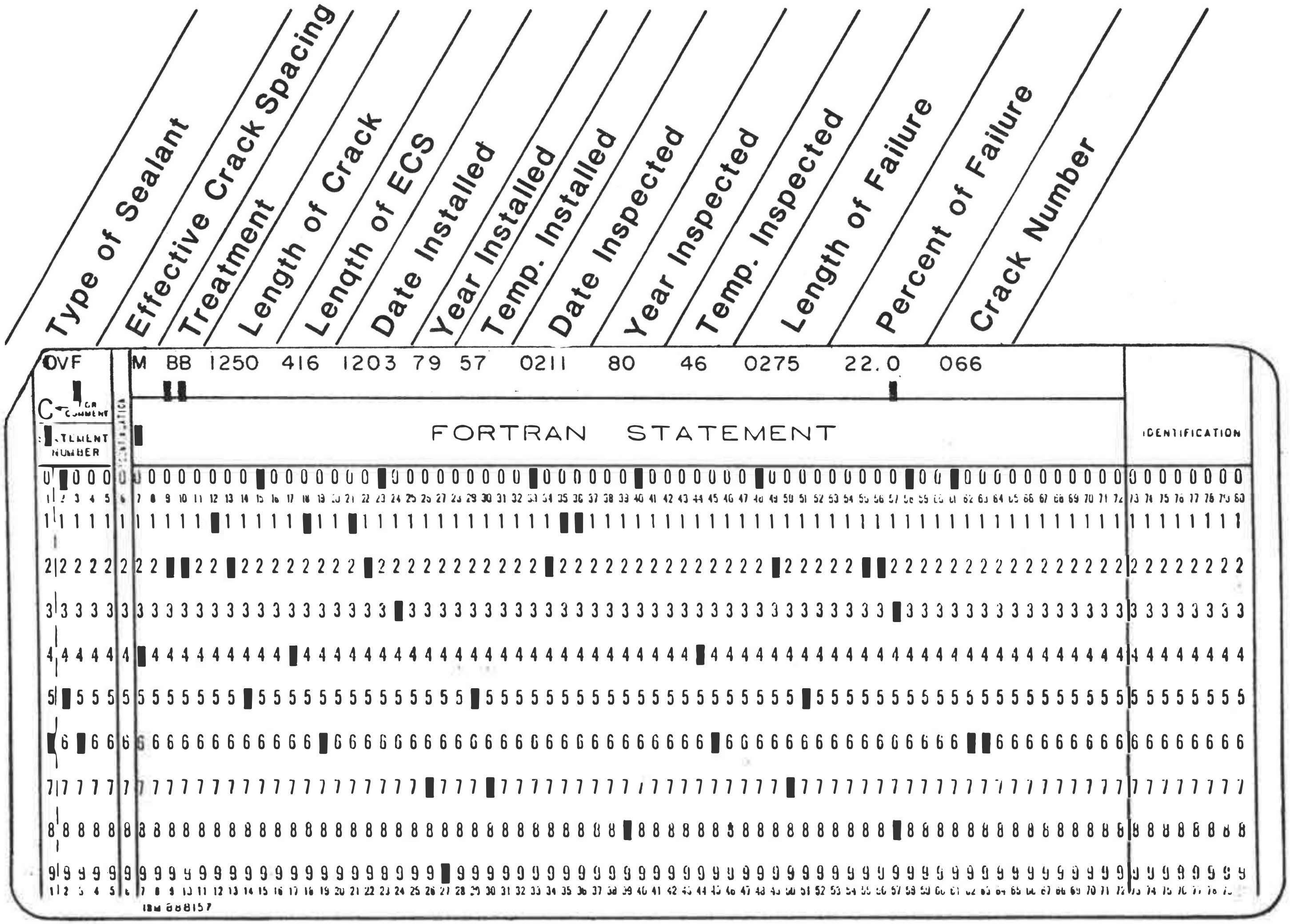

Figure 10. Computer Card with Field Data

CHAPTER IV

RESULTS AND DISCUSSION

General

In this section, the information developed during the laboratory testing will be discussed and related to the results obtained from the field study for each of the respective sealants. The statistical data derived from the field observations of sealant performance are presented through bar charts plotted to show time and the crack variables versus average percent of sealed crack footage that failed during the nineteen month test period.

Statistical tests performed by the SAS computer program examined the field data for each sealant to determine if there was evidence of difference in a sealant's performance due to ECS and/or type of crack pretreatment used. The results of these tests indicated the observed significance level ($\hat{\alpha}$), and the acceptance or rejection of the null hypothesis was based on a reasonable significance level of 0.05.

The assumption that there is no difference or relationship between the crack variables and the performance of a crack sealant is called the null hypothesis. While a significance level of 0.05 is not a clear cutoff point between acceptance or rejection of this hypothesis, as the observed significance level becomes closer to the reasonable significance level, the stronger the evidence becomes that a relationship does exist. If the observed significance level is greater than 0.05, this does not necessarily prove that the null hypothesis is correct. It merely means that the data does not give adequate evidence for rejecting it.

Field and Laboratory Evaluation

85 - 100 Penetration Asphalt Cement

Simulated crack width and total strain or elongation had no influence on the performance of test block specimens of this sealant. All of the specimens of asphalt cement in the two series of bond-ductility tests failed during elongation in the first cycle. These failures were cohesive in nature and showed the material to be extremely brittle at the low test temperature. Due to its brittle behavior, the asphalt cement was not used in the "modified" ductility test. The laboratory test results for all sealants are summarized in Table IV.

The bond-ductility test results correlated well with the amount and type of failure observed in the field for this sealant. The overall field performance is shown in Figure 11. As shown in this graph, the asphalt cement exhibited large amounts of failure during the cold winter months of the study period. Over 80 percent of the sealed crack lengths failed within two months of installation. During the warmer spring and summer months the amount of observable failure decreased to less than 3 percent in August, 1981. High ambient temperatures cause the pavement to expand, closing the crack and giving a failure in the sealant a "healed" appearance. The high summer temperatures also aid this healing process in that the asphalt cement softens and expands to permit good adhesion at breaks in the sealant surface and any entrapped granular materials is surrounded and compressed into the sealant mass.

Asphalt cement hardens with time and exposure to the elements. Thus,

TABLE IV

SUMMARY OF LABORATORY TEST RESULTS

Sealant	Bond-Ductility Test, (no. cycles to failure)		Modified Ductility Test (cm)	Resilience Test (% Recovery)	Cone Penetration Test (0.1 mm)
	Series 1*	Series 2†			
85-100 Pen. A.C.	0	0	---	1.7	66
CRS-2 (base)	0	0	0.1	1.0	80
ECRF (base)	12	12	0.2	---	--
ECRF (base + sand)		5			
MSLV	12	7	0.8	39.0	45
SOFS	12	12	25.0	34.0	115
HARS	12	9	7.0	35.0	69

* Simulated crack width = 0.25 in. (6.4 mm); elongation = 50%

† Simulated crack width = 0.375 in. (9.5 mm); elongation = 100%

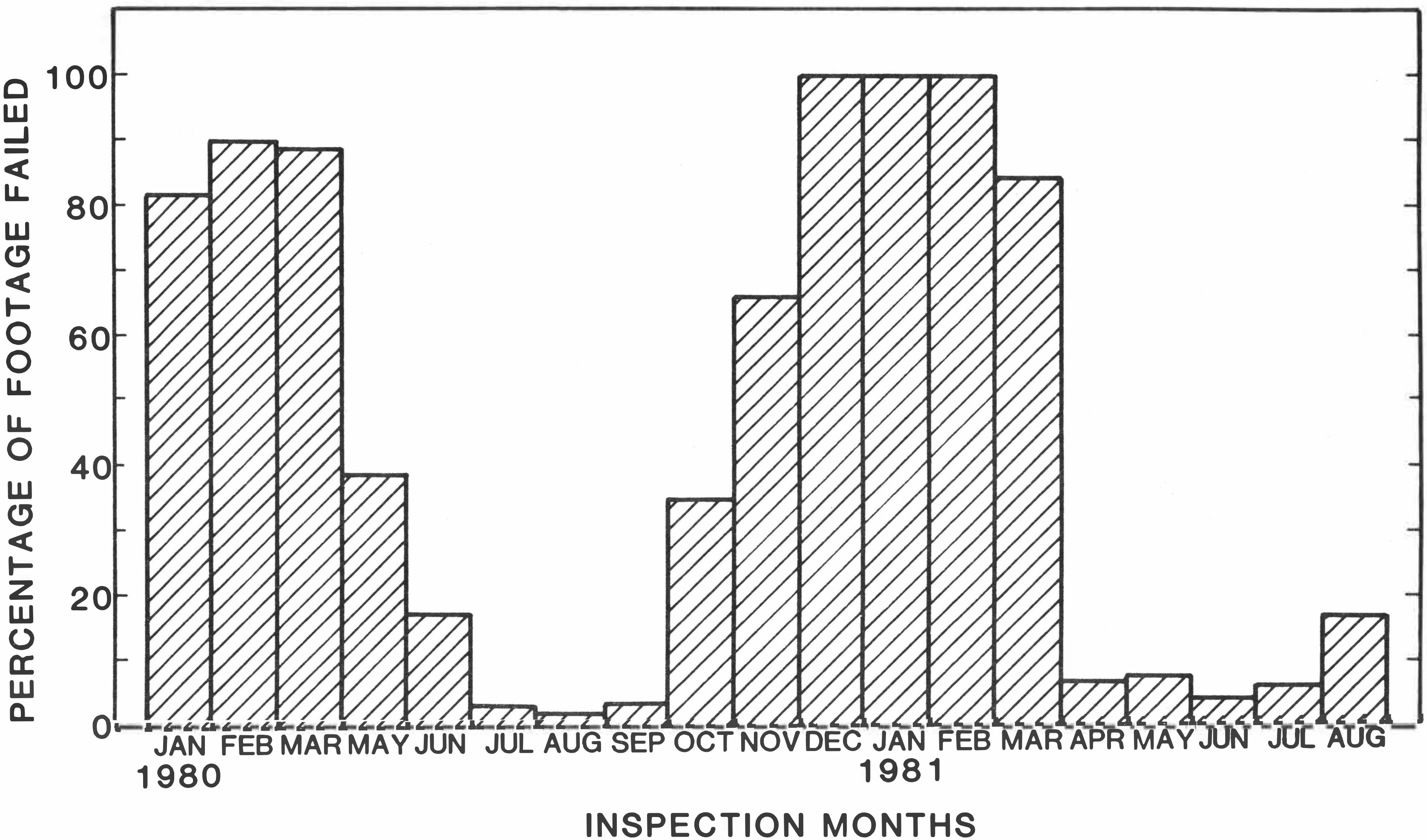

Figure 11. Field Performance of 85-100 Pen AC Sealant

the complete failure of the cracks sealed with asphalt cement during the second winter of the study was not unexpected. The increased hardness of this sealant is also evident in the larger amounts of failure observed during the second summer following its installation. Figure 12 shows a view of an asphalt cement sealed crack that has failed throughout its entire length.

Figure 13 shows the average percent failure for the asphalt cement and two other sealants installed in cracks within the various ECS ranges. Figure 14 shows the effects of crack pretreatment on the average amount of failure exhibited by these same sealants. With respect to the asphalt cement, the small differences in average percent failure as well as the magnitude of the observed significance level shown in both figures indicates there is little, if any, relationship between the performance of this material and the crack variables, i.e., ECS and crack pretreatment. The interaction diagram, Figure 15, which combines the effects of ECS and crack pretreatment against the percentage of crack footage failed for the asphalt cement, also shows that any relationship between the crack variables and sealant performance can not be substantiated by the data.

CRS-2 Emulsion

The laboratory test results for the base asphalt of the CRS-2 emulsion (Table IV) are similar to those of the 85 - 100 penetration asphalt cement. While this material was slightly softer than the asphalt cement at laboratory temperature, it had a comparable resilience value and all of the bond-ductility test specimens failed cohesively during the first cycle. The very low "modified" ductility test values provided additional evidence of the sealant's inability to withstand tensile stress at low

Figure 12. Cohesive Failure in Asphalt Cement Sealed Crack

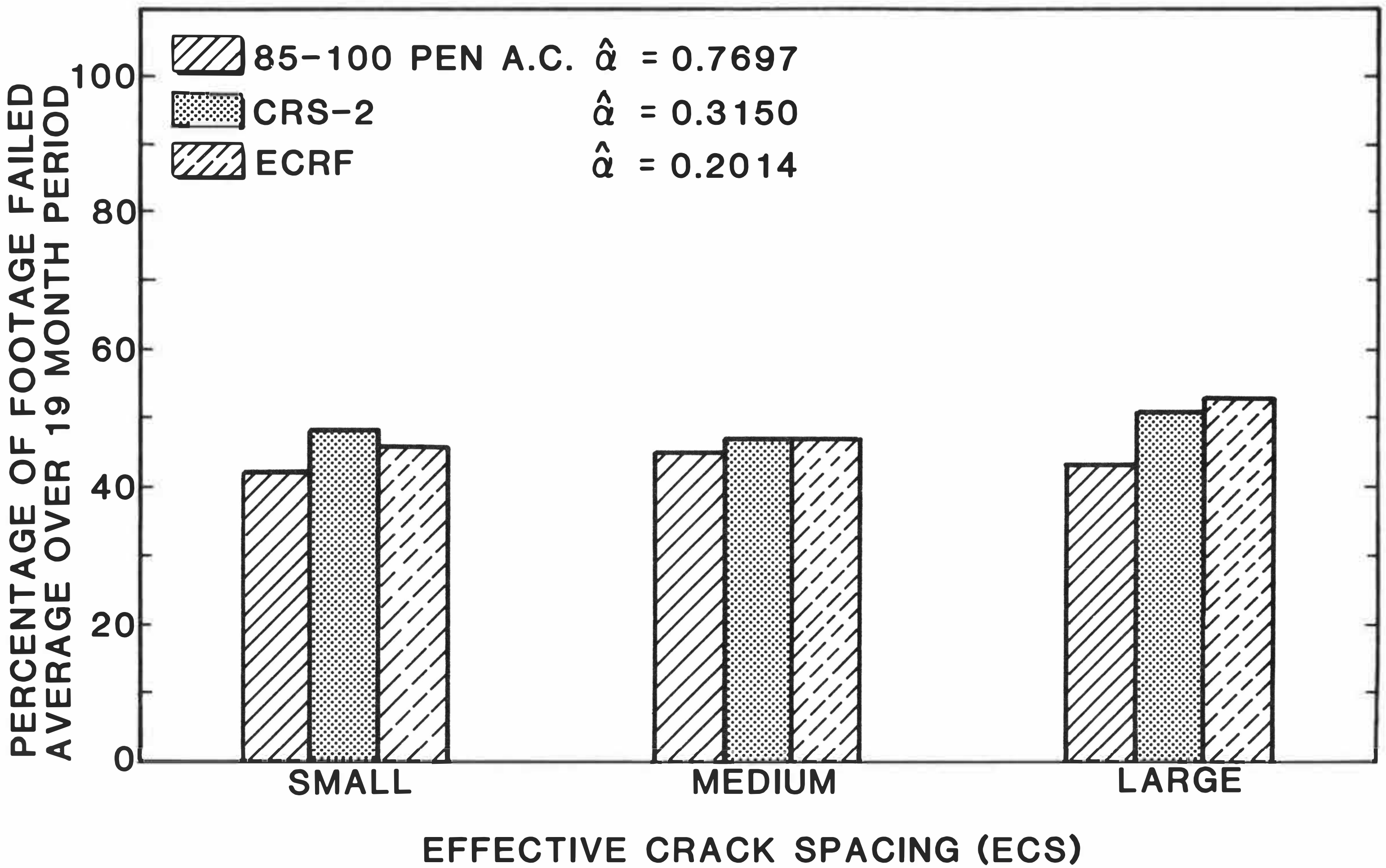

Figure 13. Percent of Sealed Crack Failure Vs. ECS for 85-100 Pen AC, CRS-2, and ECRF Sealants

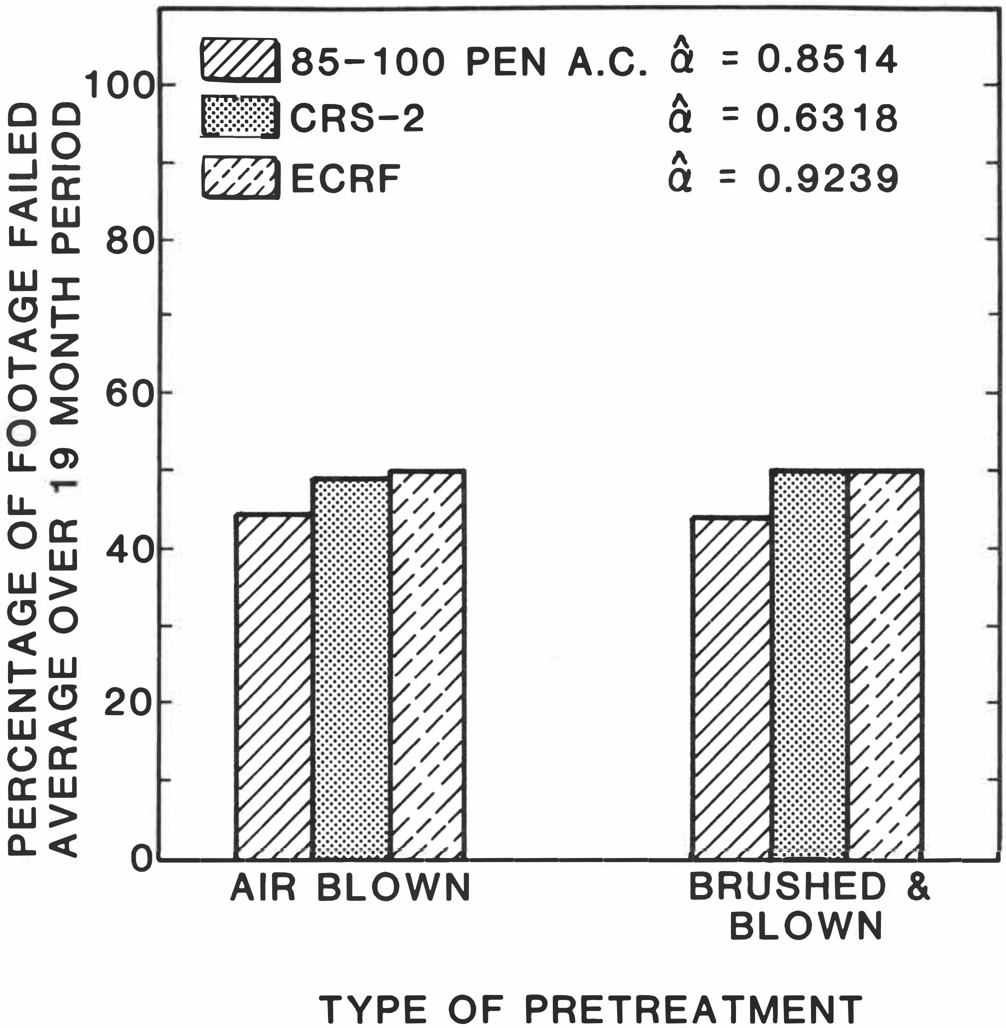

Figure 14. Percent of Sealed Crack Failure Vs. Crack Pretreatment for 85-100 Pen AC CRS-2, and ECRF Sealants

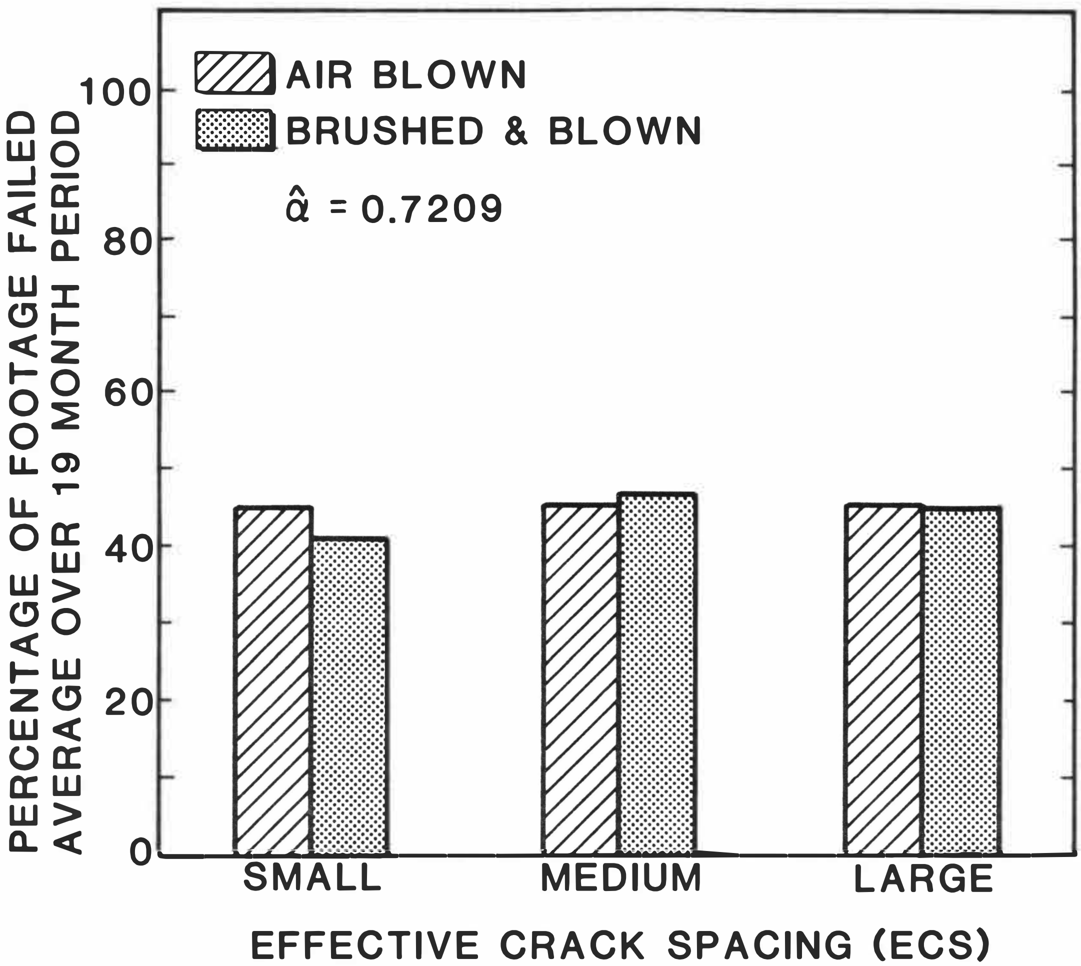

Figure 15. Interaction of ECS and Crack Pretreatment for 85-100 Pen AC Sealant

temperature.

The bond-ductility test performance of the CRS-2 emulsion proved to be an excellent indicator of the sealant's behavior in the cracks at the field test site. At the time of the first inspection, approximately one month after installation, 97 percent of the total length of sealed cracks had failed and these failures were predominantly the cohesive type of failure. The total amount of failure reached 100 percent during both the first and second winter at the test site as shown in Figure 16. The amount of failure reduced drastically as the warmer summer months approached and, as in the case of the asphalt cement sealant, the material provided an effective seal for the cracks during these periods. However, the evident failure was slightly greater during the second summer. This is probably related to additional hardening of the base asphalt cement from aging and exposure as well as an indication of increased amounts of incompressible materials that collected in the opened cracks during the previous winter months.

At the time of the rapid and complete failure of the CRS-2 emulsion sealant in its first winter of exposure, the bond-ductility tests had not been performed in the laboratory, and some thoughts were advanced as to why this extent of failure had occurred. It was postulated that the celerity of failure was due to incomplete setting of the emulsion prior to exposure to below freezing temperatures. After being poured into a pavement crack, the cationic emulsion in contact with the crack bottom and sides and the free surface breaks rapidly to form an asphalt skin or film that inhibits evaporation and/or drainage of the emulsifying water and retards complete setting in the bulk of the installed sealant. When the pavement temperature drops below 32 F (0 C) prior to complete setting,

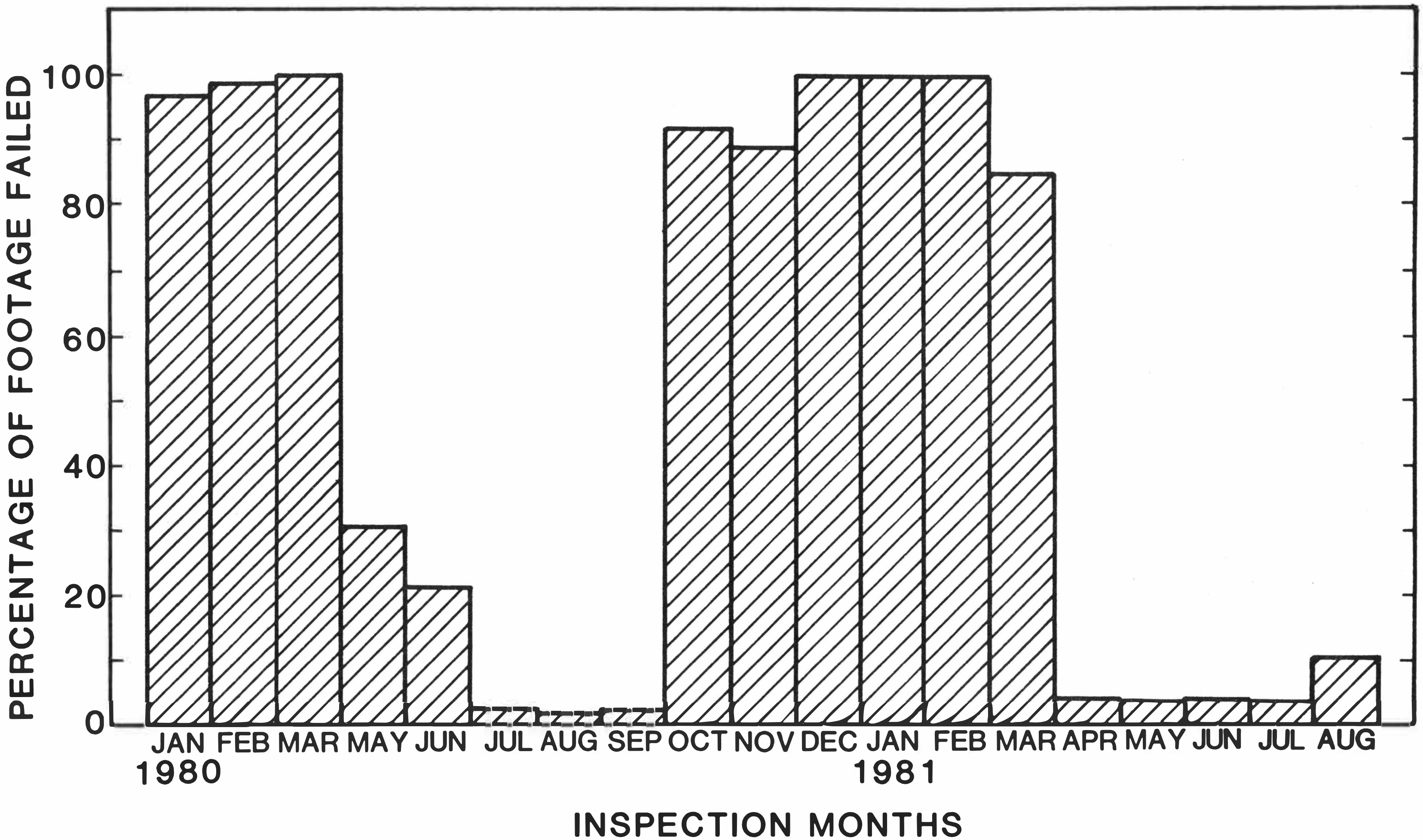

Figure 16. Field Performance of CRS-2 Sealant

the remaining emulsion freezes and becomes brittle with little or no tensile strength to resist the applied stresses from adjacent pavement sections. Evidence to substantiate this concept was observed both at the field test site and in preliminary laboratory tests of partially set bond-ductility specimens of the emulsion type sealants. Apparently, a long period of time (several months) may be required for complete setting or breaking of this type of sealant in a pavement crack.

The initial failure of this sealant is explained reasonably well by the foregoing discussion. However, the drastic increase in the amount of crack failure, about 90 percent, between September and October, 1980, must be associated with the nature or response at low temperatures of the base asphalt cement from which the emulsion was made. After over seven months of field exposure, including a hotter than normal summer, setting of the emulsion was complete. In the two series of bond-ductility tests, involving different crack widths and total elongations of the base asphalts, the material failed internally in all test block specimens during the first cycle of elongation. As stated previously, these results relate extremely well with the amount and type of failure observed in the field. Figure 17, illustrates the cohesive type of failure that occurred in cracks sealed with the CRS-2 emulsion.

As can be seen in Figures 13 and 14, the average amount of failure was essentially the same for the sealed cracks in all three ranges of effective crack spacing and for the different types of pretreatment. The magnitude of the observed significance levels for the CRS-2 emulsion shown on these figures indicate that the null hypothesis cannot be rejected. That is, the data show little evidence of a relationship between sealant performance and either ECS or crack pretreatment. In Figure 18, the

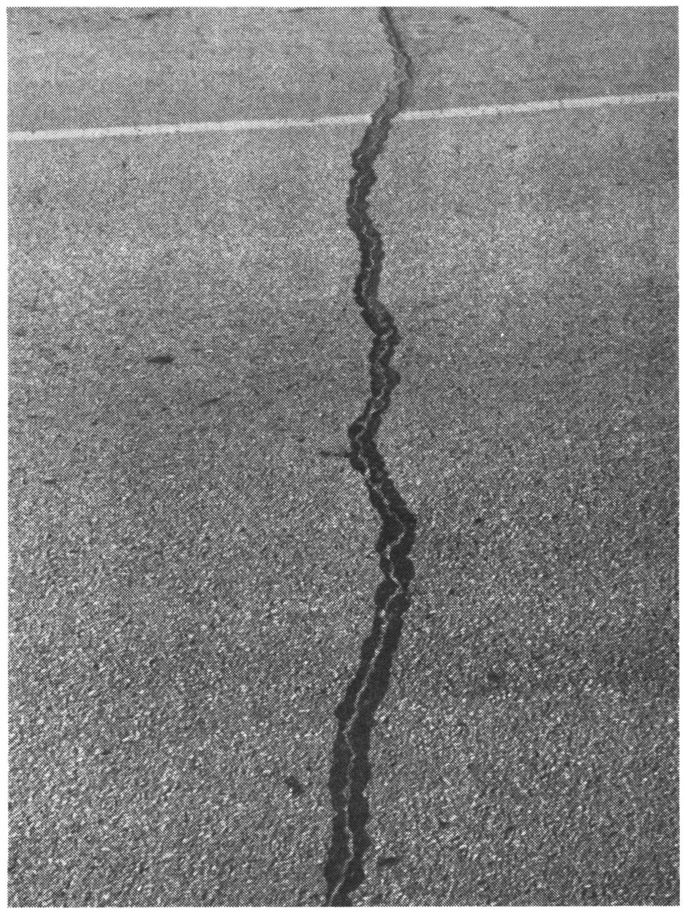

Figure 17. Cohesive Failure in CRS-2 Sealed Crack

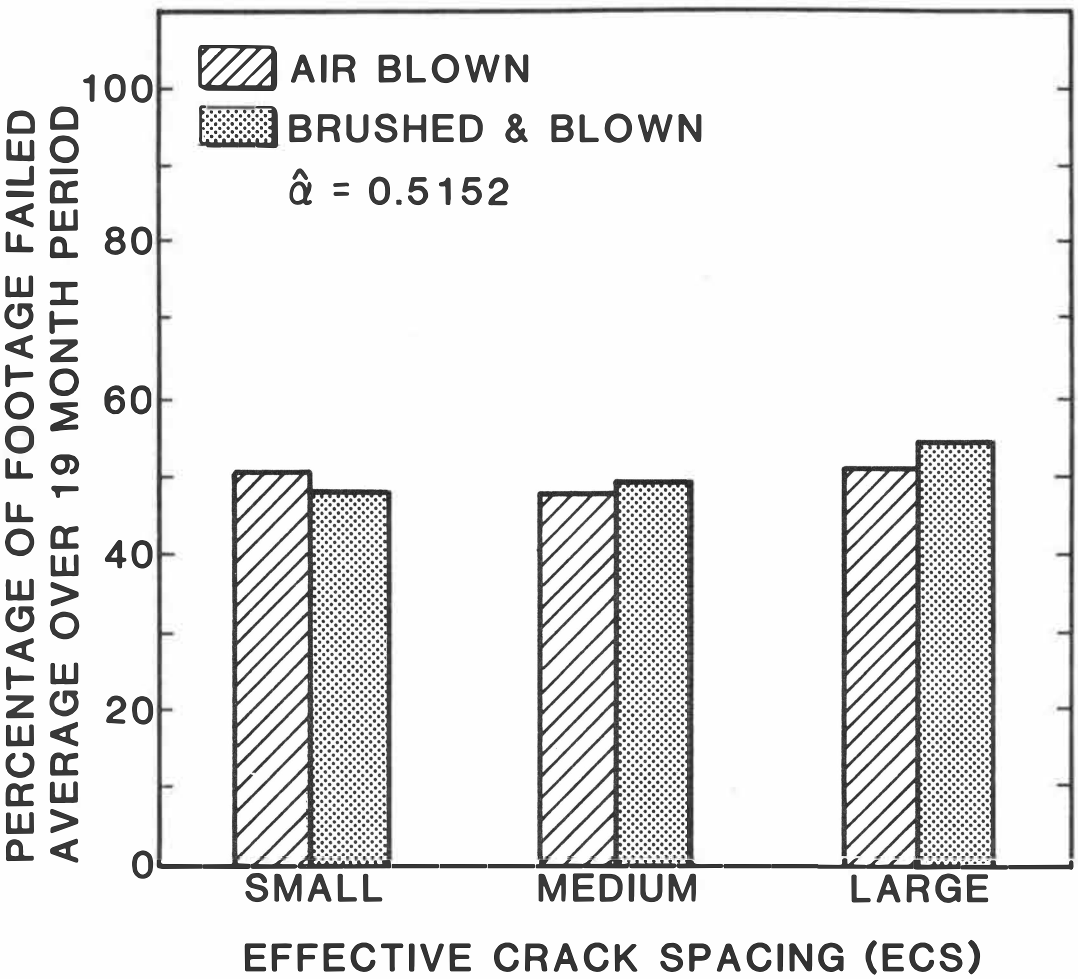

Figure 18. Interaction of ECS and Crack Pretreatment for CRS-2 Sealant

failure percentages and the observed significance level demonstrate very little, if any, interaction between the crack variables and sealant failure.

ECRF Emulsion

The base asphalt of the ECRF emulsion was an extremely soft and sticky material at laboratory temperature and test values for resilience and cone penetration could not be determined. This material remained relatively soft and pliable at 0 F (-17.8 C) and two series of bond-ductility specimens completed twelve test cycles without failure (see Table IV). However, as illustrated in Figure 19, the field performance of this sealant followed the same pattern of failure as the CRS-2 emulsion and the asphalt cement, i.e., extremely high percentages of cohesive type failure occurred during the fall and winter months.

This discrepancy between the field and laboratory performances of the sealant can be attributed to several causes. As previously discussed, the initial failures closely followed installation of the sealant and were due to freezing of the emulsion prior to the occurrence of complete setting. Seven weeks after being installed, liquid emulsion could be exposed by breaking through the surface "skin" of the sealant in the cracks and in preliminary tests of partially set bond-ductility specimens ice crystals were observed in the cohesive fracture planes of the test specimens.

Another probable cause of the large amount of in-service failures of the emulsion type sealants can be associated with the application procedure. Immediately after pouring, fine sand was spread over the top of the sealed crack to prevent splashing and tracking of the emulsion by traffic. Subsequently, this sand settled and/or was pressed into the soft

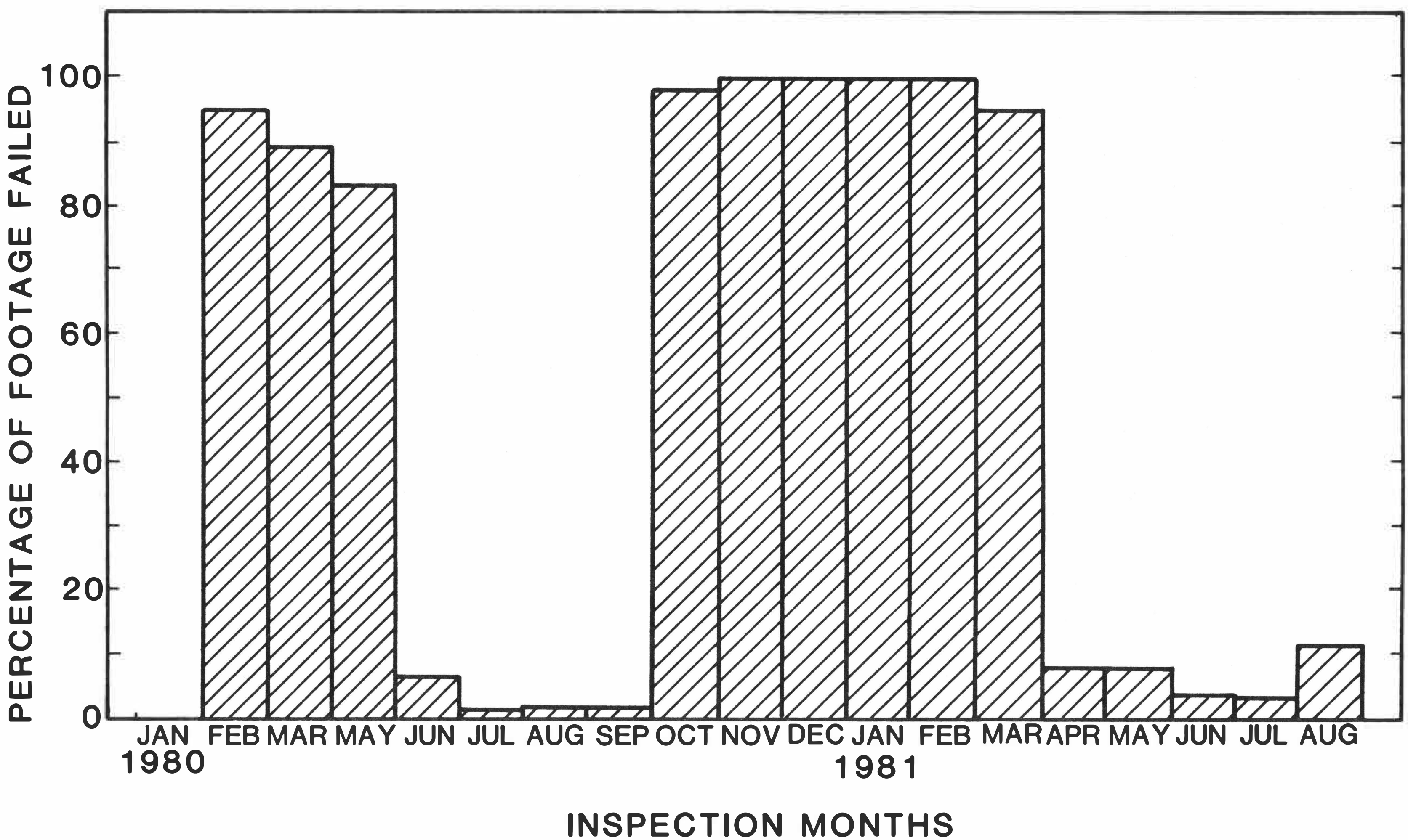

Figure 19. Field Performance of ECRF Sealant

sealant by vehicle tires. The addition of sizeable quantities of fine-grained mineral matter effectively increases the viscosity and hardens an asphalt material (7). Apparently, the fine sand cover served as a filler material to harden the base asphalt and promote brittleness of the sealant at low temperatures.

This effect of a sand filler on the performance of the ECRF emulsion base was demonstrated by a separate set of bond-ductility tests. Twenty-five percent by volume of minus No. 10 river sand was added to the base asphalt and this "filled" material was used to prepare the test block specimens. As shown in Table IV, these specimens underwent an average of only five bond-ductility cycles before failing while the specimens that did not contain sand went twelve complete cycles without failure. It should be noted that twelve cycles was an arbitrary cut-off point for the tests and the unsanded specimens could have completed additional test cycles.

Although the unsanded base asphalt material is capable of adapting to low rates of strain in the bond-ductility test without failing, the "modified" ductility test showed a specimen elongation of only 0.2 cm before breaking occurred. This base material, while soft and pliable at 0 F (-17.8 C), is highly susceptible to brittle fracture when the rate of strain is greatly increased. In this regard, its behavior is analogous to that of the popular children's toy, "Silly Putty."

The bar graphs in Figure 13 show a slight increase in percent failure of the ECRF sealant with increased ECS. However, the observed significance level ($\hat{\alpha}$ = 0.2014) is still too large to imply more than a minor connection. Similarly, the statistical data shown in Figures 14 and 20 indicate no differences for crack pretreatment or for interaction

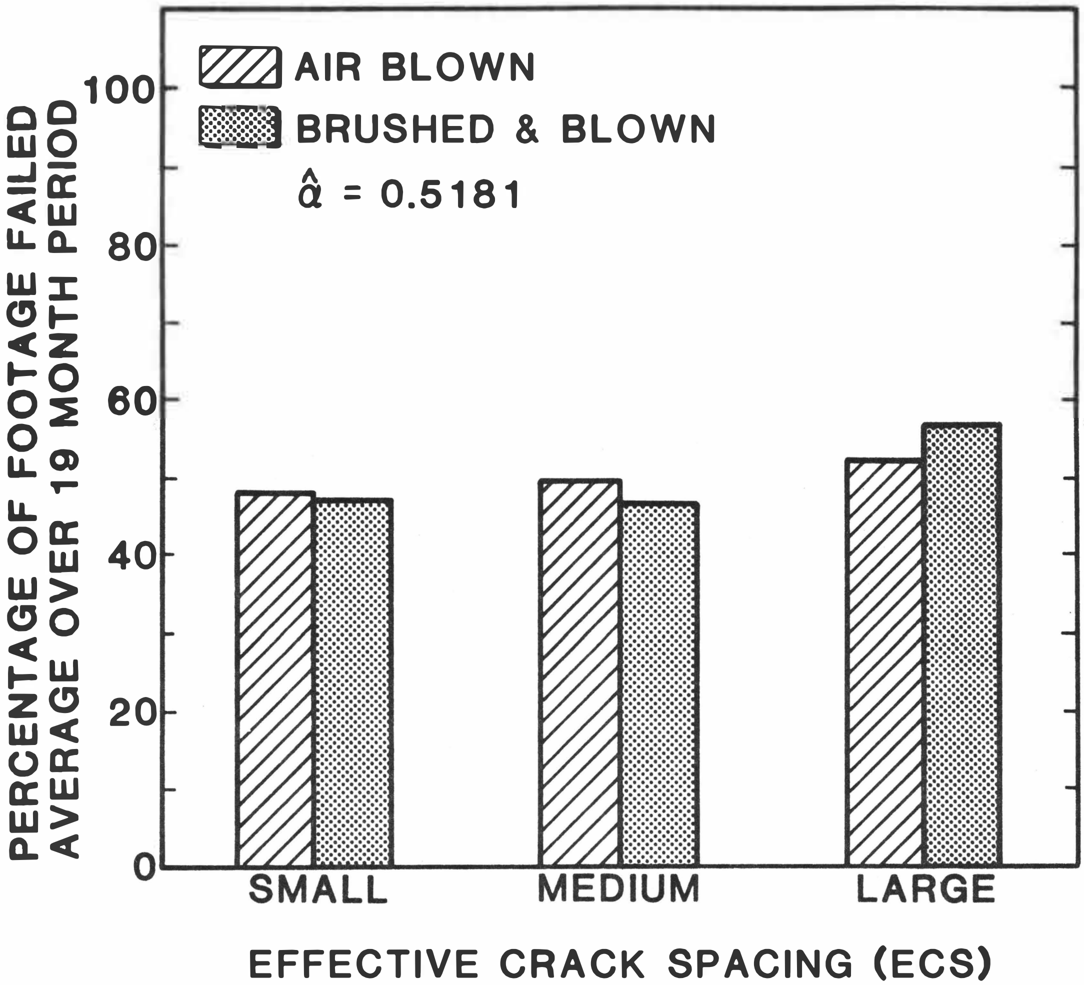

Figure 20. Interaction of ECS and Crack Pretreatment for ECRF Sealant

of the two crack variables.

MSLV (Rubberized Asphalt)

The MSLV sealant is a highly viscous asphalt cement containing ground reclaimed tire rubber. It had the highest percentage of recovery in the resilience test of all the sealants and performed well in the two series of bond-ductility tests (see Table IV). The failures observed in the 100 percent elongation series were the adhesive type where separation occurred between the sealant and the sides of the test blocks. These results checked favorably with the amount and type of failure exhibited by the sealant during its first year in the cracks at the test site.

Figure 21 shows less than 15 percent failure of the MSLV during the first winter and, as with the other sealants, a decline in the amount of failed length in the following summer months. During the second winter, however, there was a sharp increase in the amount of failure with more than 70 percent occurring in February, 1981. A significant increase in the percent of failure in the second summer can also be noted. There was a perceptible hardening of this sealant with time and exposure to weathering that contributed to the progressive deterioration of the sealed cracks. Although adhesive type failures predominated, some cohesive failures were observed. Cohesive or internal type failures in this sealant were indicated by its small amount of elongation in the "modified" ductility test. Figure 22 shows a crack with a combination of both types of failure in the MSLV sealer. The exposed aggregate near the edges of the crack resulted from traffic wear of the thin film of sealant spread by the squeegee during installation.

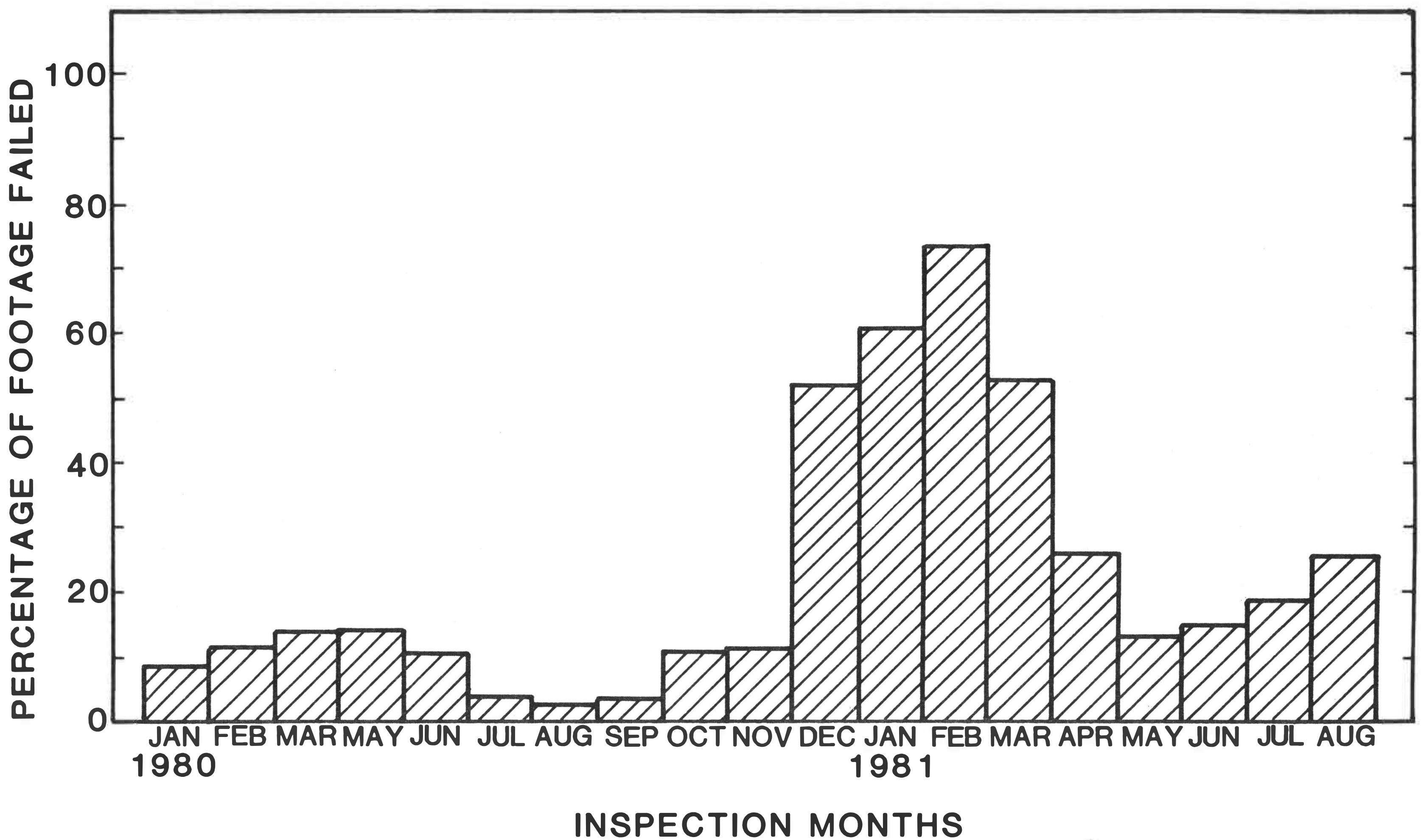

Figure 21. Field Performance of MSLV Sealant

Figure 22. Adhesive and Cohesive Failures in MSLV Sealed Crack

From field observations, it was evident that this material had difficulty in developing good bond at the sealant/crack wall interface and, due to its highly viscous nature, it did not penetrate deeply in the more narrow cracks associated with the small ECS range. These observations were supported by the results of the statistical analysis. The significance levels for the MSLV, as shown in Figures 23 and 24, indicate rejection of the null hypothesis. That is, the performance of this sealant is influenced by the spacing of the cracks and the type of pretreatment. The amount of failure can be reduced by wire brushing and air-blowing of a crack before installing the sealant and also by sealing only those cracks falling within the medium ECS range. The interaction diagram in Figure 25 also shows that there is sufficient statistical evidence that failure can be reduced by using this combination of the two crack variables.

SOFS (Rubberized Asphalt)

The soft synthetic rubber polymer and asphalt blend performed well in the respective laboratory tests (Table IV). It exhibited high resilience, excellent bond-ductility at low temperature, and had the greatest elongation of all the sealants in the "modified" ductility test. In this latter test the specimens were stretched (at 0 F) at a rate of strain approximately equal to 1000 times that used in the bond-ductility test and they elongated to a length of 25 cm without any sign of failure. Figure 26 shows the ductility specimens at the conclusion of this test. When these elongated specimens were allowed to warm at ambient lab temperature, they recovered to almost their original length and shape, demonstrating the highly elastic nature of this material.

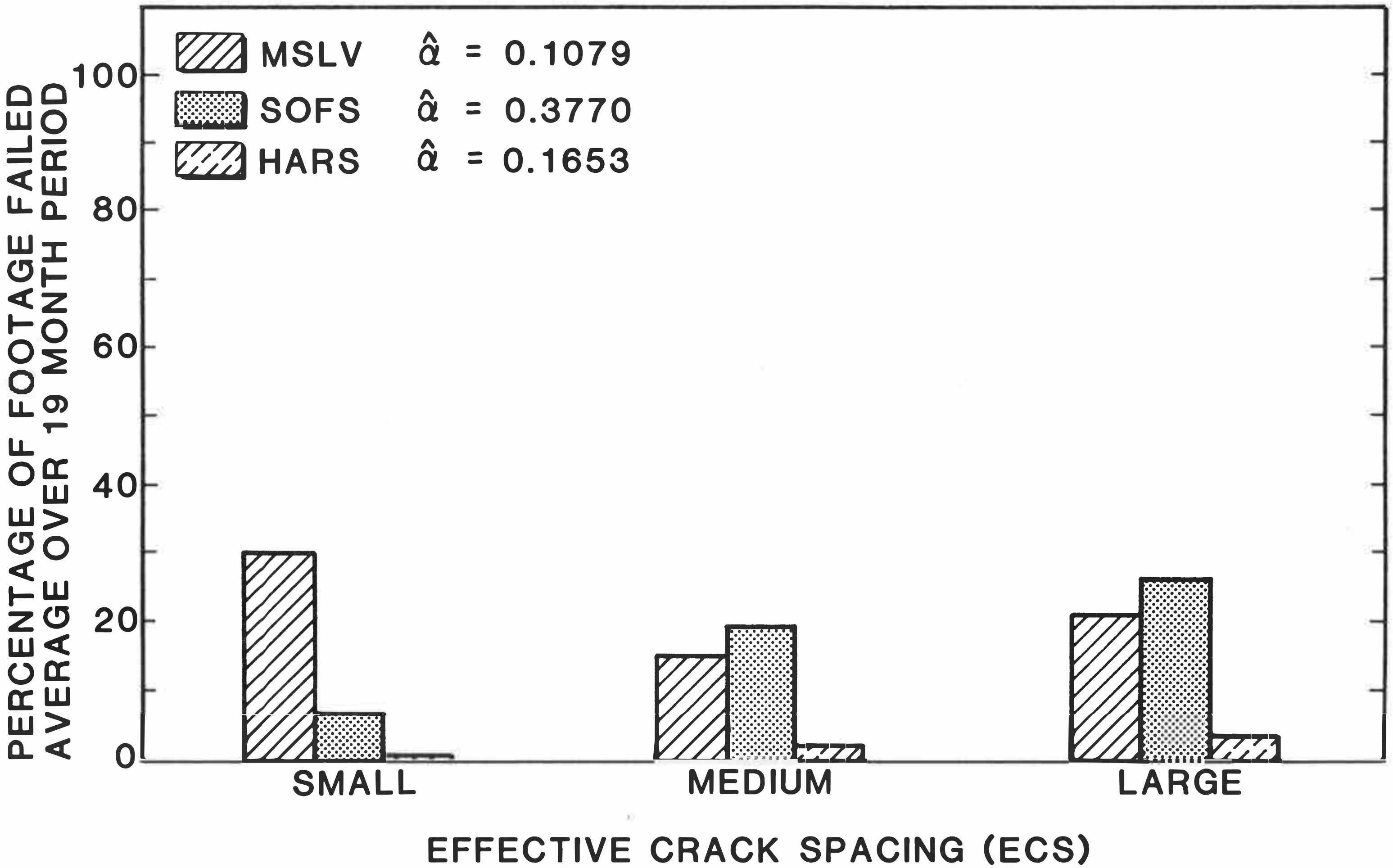

Figure 23. Percent of Sealed Crack Failure Vs. ECS for MSLV, SOFS, and HARS Sealants

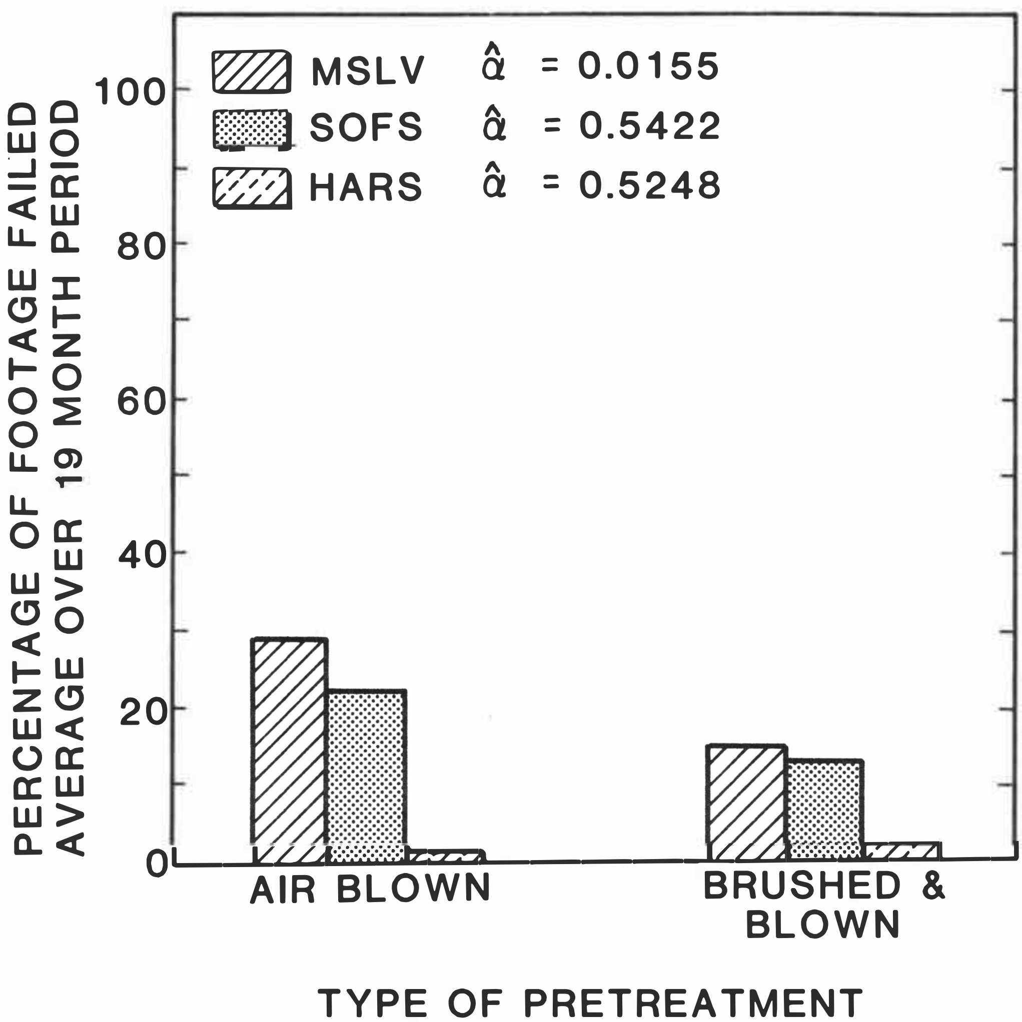

Figure 24. Percent of Sealed Crack Failure Vs. Crack Pretreatment for MSLV, SOFS, and HARS Sealants

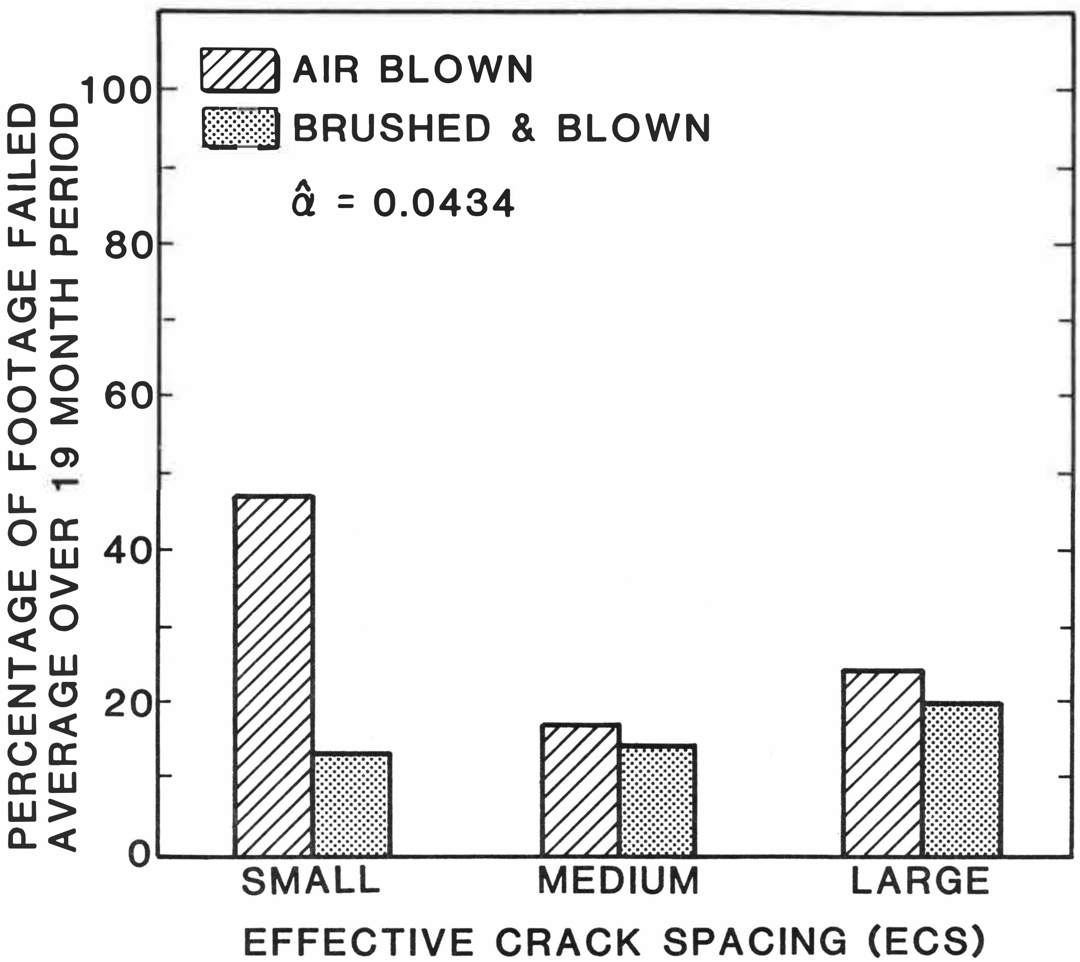

Figure 25. Interaction of ECS and Crack Pretreatment for MSLV Sealant

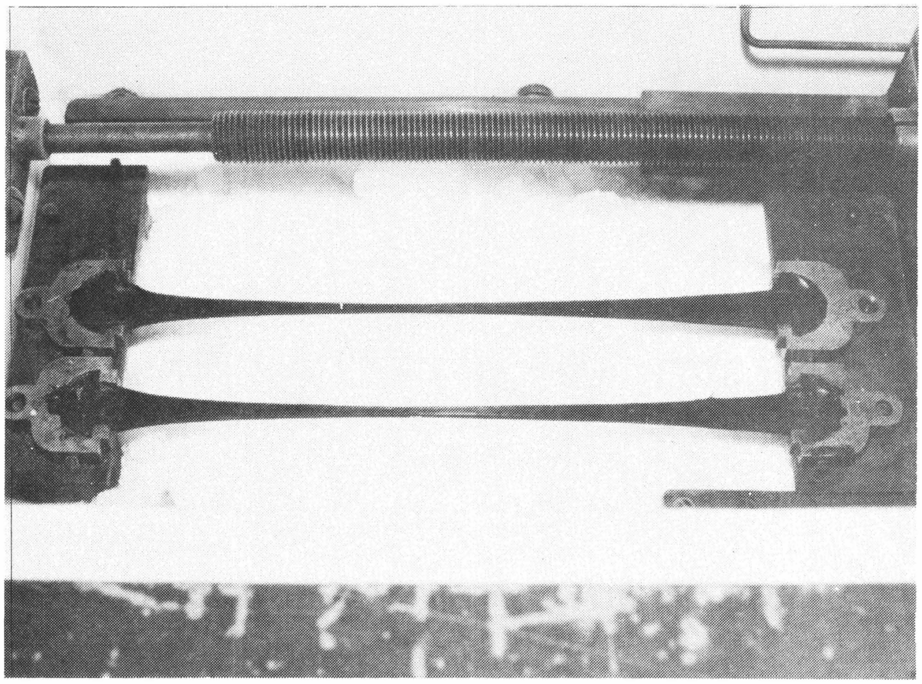

Figure 26. Elongation of SOFS Sealant Specimens in Modified Ductility Test

While there were no bonding or adhesion problems with this sealant in the bond-ductility tests, some major adhesive type failures occurred in the field. The overall performance of the SOFS sealant is shown in Figure 27. During the first three months after installation the percent of failure rose to about 17 percent. The failure percentage remained at this level through the summer, increased to approximately 32 percent during the second winter, and then fell back to its previous level in the summer of 1981.

The preliminary failure percentage was due to a number of failures where, under the action of traffic, the applied sealant was pulled completely out of the cracks in rubber-band like strips. This is illustrated in Figure 28. The cause of this rather unusual type of failure was attributed to overheating of the sealant during the melting process and a concomitant decrease in adhesiveness of the material. Subsequent investigation indicated that there was not enough of the material in the double-wall melter to cover the inner chamber thermometer stem and provide an accurate temperature reading. The manufacturer of this product warns that heating above a temperature of 410 F (210 C) will cause the material to gel. Problems encountered in cleaning this material out of the melter and pump attested to the fact that gelling had occurred.

Despite those few unique failures that occurred shortly after installation, the balance of the SOFS that remained in place functioned as an effective crack sealant and its field behavior correlated well with the laboratory test results. The performance of this sealant was better than the asphalt cement, the two emulsions, and the MSLV product. By comparison its maximum percent of failure was substantially less than the others as was its variation in total percent failure during the study period.

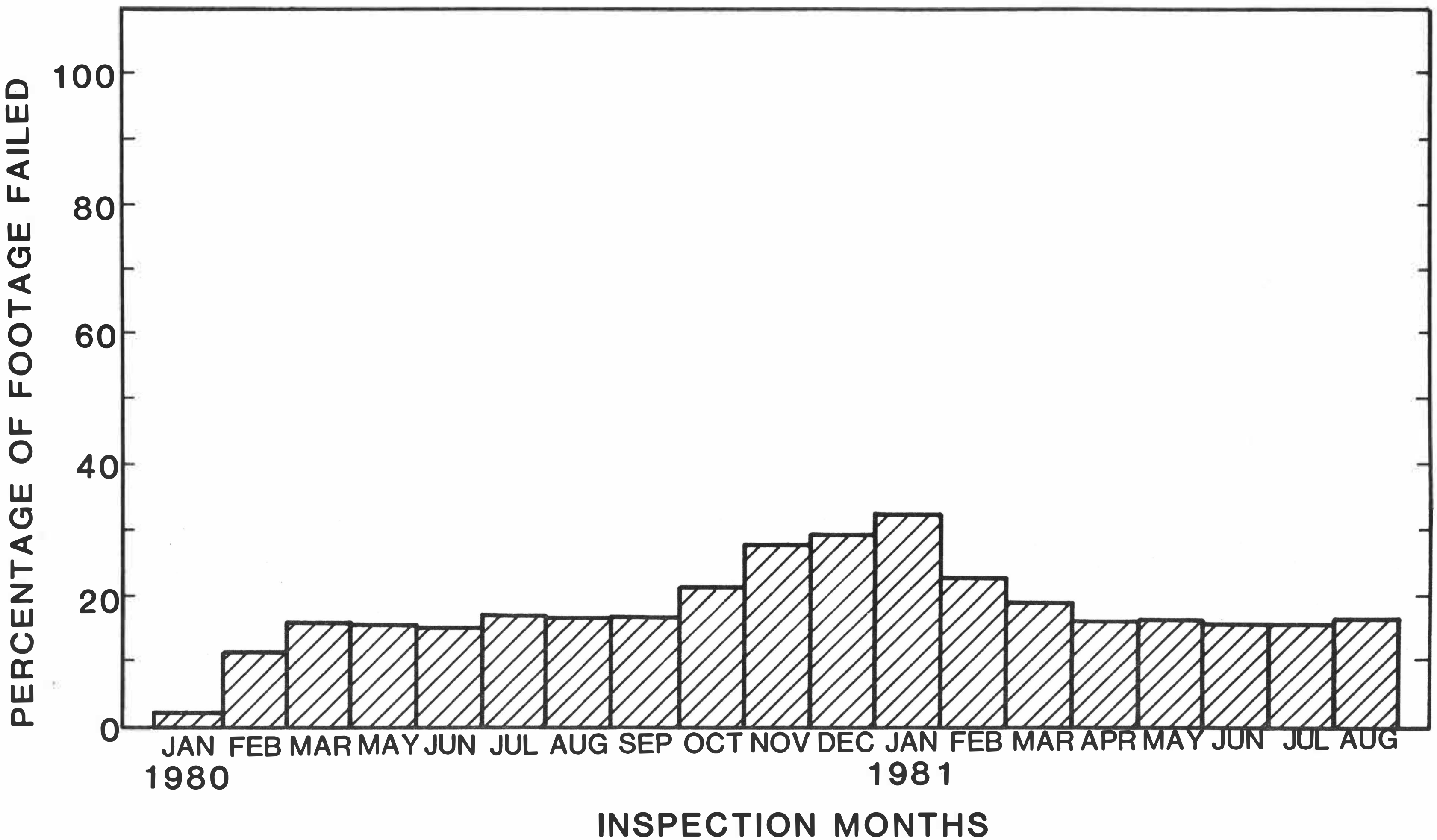

Figure 27. Field Performance of SOFS Sealant

Figure 28. Rubber-Band Type Failure of SOFS Sealant

While Figure 23 shows an increase in failure percentage with increasing ECS, the observed significance level for the SOFS indicates there is not sufficient evidence in the data to substantiate such a relationship. The significance levels in Figures 24 and 29 are also large enough to preclude inference of a direct relation between sealant performance and the crack variables.

HARS (Rubberized Asphalt)

The HARS and SOFS sealants are manufactured by the same company and are similar products in that both contain a rubber polymer which has been blended with an asphalt cement. The essential difference in the two products is their consistency as indicated by the respective cone penetration values in Table IV, HARS being a much harder or stiffer material at normal temperatures. Based on the results of the "modified" ductility test and the two series of bond-ductility tests as indicators, this material should fulfill the major requirements for an effective crack sealant. That is, a serviceable crack sealing material should possess good adhesive or bonding qualities, good tensile strength, and the capability of withstanding high rates of strain at all temperatures to which it might be subjected in field usage.

The HARS sealant proved to be superior to all of the sealants tested in the field. This material was installed in the test site cracks on December 5, 1979, and there were no evident failures in the sealed cracks for almost 11 months. As shown in Figure 30, the maximum amount of failure (predominantly adhesive type) was less than 10 percent and this occurred during the second winter. During the summer of 1981, this failure percentage dropped to less than 0.2 percent. Like the other sealants used,

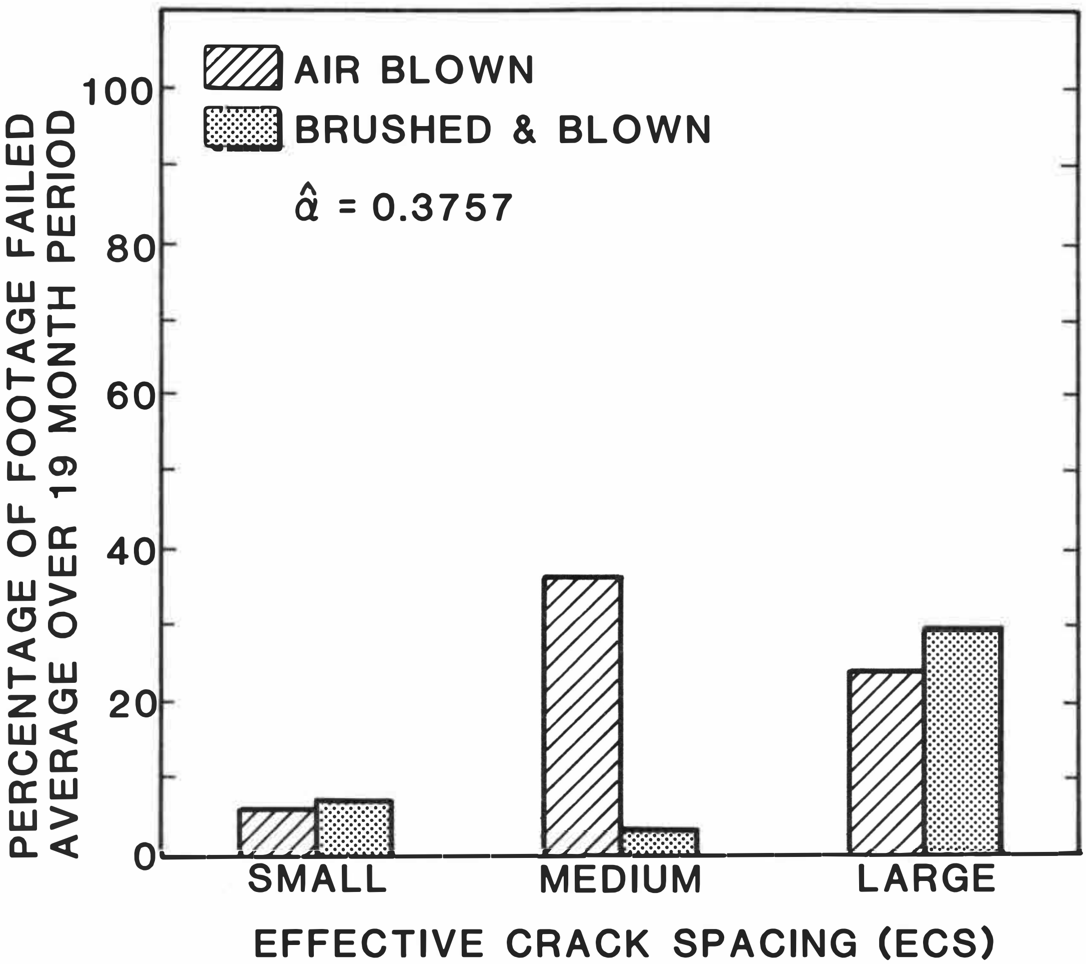

Figure 29. Interaction of ECS and Crack Pretreatment for SOFS Sealant

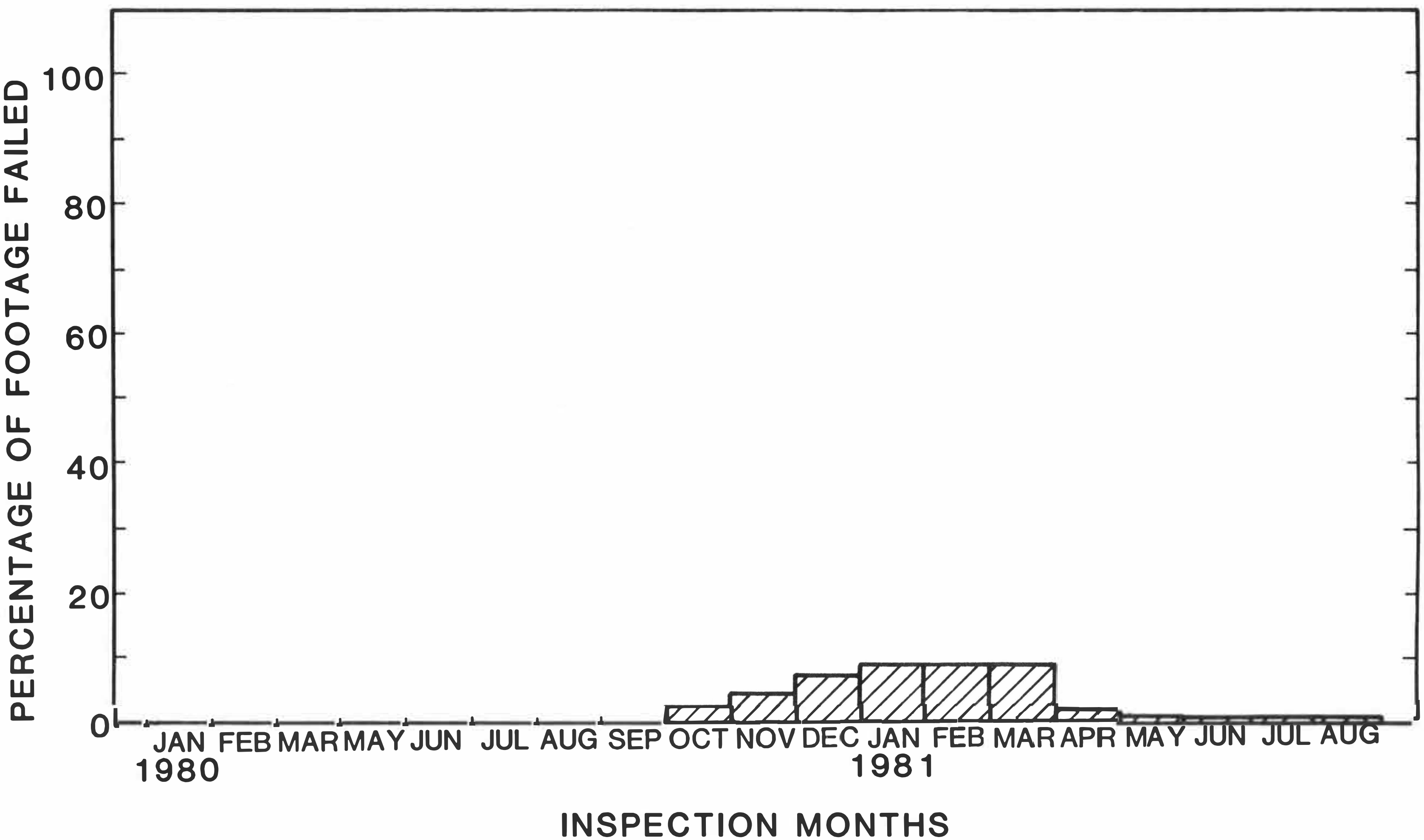

Figure 30. Field Performance of HARS Sealant

the amount of observed failure progressively increased with time, but in this case at a much lower rate. The performance of this material indicates that it will adequately function as a flexible pavement crack sealant for at least 3 to 4 years before resealing is necessary.

The bar graphs in Figures 23, 24, and 31 suggest some minor influence of OCS and crack pretreatment on the amount of failure experienced by the HARS material. However, no valid statement of such relationships can be made because of the magnitudes of the observed significance levels.

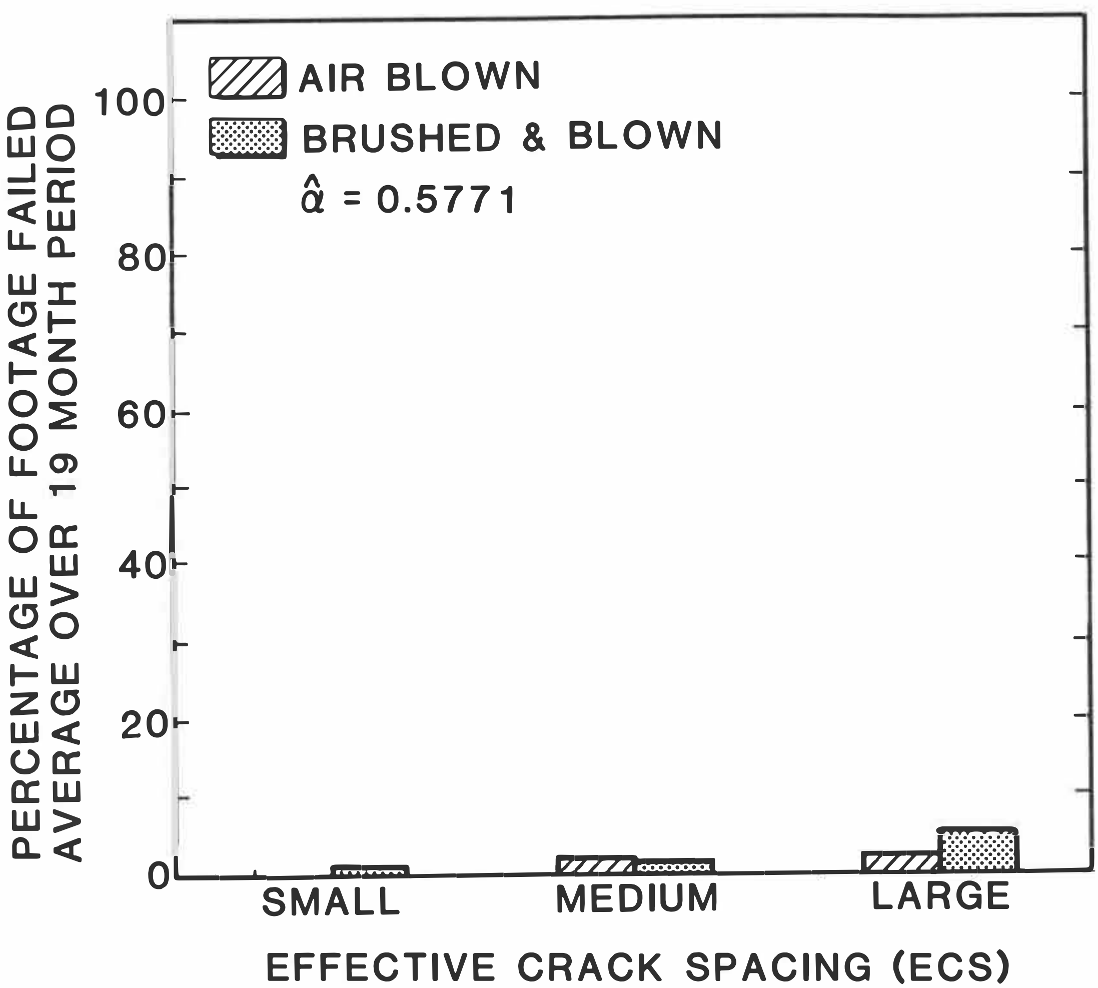

Figure 31. Interaction of ECS and Crack Pretreatment for HARS Sealant

CHAPTER V

CONCLUSIONS AND RECOMMENDATIONS

Conclusions

The purpose of this laboratory and field investigation of six flexible pavement crack sealants was twofold. The first objective was to ascertain if the results of selected laboratory tests on these sealants had any correlation with their performance under actual in-service conditions. The second objective was to evaluate and compare the performance of the installed sealants and determine if different crack spacings or type of crack pretreatment influenced the amount of sealant failure. Based on the information compiled during the period of this study the following conclusions are made:

1. The bond-ductility test results provided a reliable indication of the field performance of the installed crack sealing materials. Those materials that completed seven or more test cycles without failure were the most effective sealants during the field study period.

2. The results of the "modified" ductility tests correlated well with sealant performance in both the bond-ductility test and in the field. The sealants that had low-temperature elongation of 7 cm or more at the high strain rate, completed the greatest number of bond-ductility cycles and exhibited the least amount of in-service failure.

3. The resilience test values of the crack sealants containing rubber were much greater than for the standard asphalt products. However,

no significant relationship between resilience at 77 F (25 C) and field performance of the sealants could be determined.

4. The elastomeric sealants, HARS and SOFS, were superior to the other crack sealing products in both the laboratory and field tests. When properly installed, these materials can maintain an effective seal in flexible pavement cracks for several years.

5. During the first year of installation, the total amount of failure of the rubberized asphalt, MSLV, was much less than that of the asphalt cement and the emulsion products. However, the sealing capability of this material is drastically reduced by weathering with a corresponding progressive incidence of adhesive and cohesive type failures.

6. The 85-100 penetration asphalt cement and the CRS-2 and ECRF emulsions did not fulfill the requirements for effective crack sealants. Cracks sealed with these materials failed completely during the fall and winter months when a water tight seal is essential to prevent cold weather deterioration at a pavement crack.

7. The effective crack spacing (ECS) and the type of crack pretreatment had little influence on the performance of the respective sealants. The only relationships indicated by the statistical data were associated with the MSLV sealant which did not penetrate well in narrow cracks and which was prone to adhesive failures.

Recommendations

In regard to the analyses and conclusions made in this investigation, the following recommendations are presented:

1. The bond-ductility test should be adopted as the primary

laboratory test for the evaluation of flexible pavement crack sealing products proposed for use on Oklahoma highways.

2. Some type of low-temperature, high strain rate ductility test should also be used in the laboratory evaluative procedure to determine the elastic characteristics of sealants.

3. Consideration should be given to the use of field tests in conjunction with laboratory testing to verify the expected performance of prospective crack sealants.

4. Air-blowing is the minimum type of crack pretreatment to be used before installation of sealants. Although not justified by this study, wire brushing to loosen dust and incoherent pavement particles at the crack edges before air-blowing logically promotes better adhesion of the sealant and should be done.

5. With the prevalent climatic conditions in Oklahoma, the elastomeric type sealants (containing synthetic rubber polymers) and possibly other rubber-asphalt blend sealants should be used for all crack sealing operations throughout the state. Such materials have better adhesive and ductile properties at low temperatures and are thus more durable sealants than standard asphalt products.

6. In order to promote the adoption and use of elastomeric products for crack sealing, small scale field test sections should be established in the various ODOT Maintenance Divisions to demonstrate the effectiveness of these sealants and to compare their performance with those sealants normally employed by the respective divisions.

7. Comprehensive benefit-cost analyses of crack sealing operations should be made for each Maintenance Division. Such analyses are needed

to properly assess the economic advantages of using more expensive seal-ants which are capable of maintaining an effective seal over several years of service.

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