SHRP-H-354

Innovative Materials Development and Testing

Volume 3: Treatment of Cracks in Asphalt Concrete-Surfaced Pavements

Kelly L. Smith
A. Russell Romine
ERES Consultants, Inc.
Savoy, Illinois

Strategic Highway Research Program
National Research Council
Washington, DC 1993

SHRP-H-354
ISBN: 0-309-05611-X
Contract H-106
Product No.: 3003

Program Manager: *Don M. Harriott*
Project Manager: *Shashikant C. Shah*
Program Area Secretary: *Francine Burgess*
Production Editor: *Cara J. Tate*

October 1993

key words:
asphalt pavement
crack filling
crack sealing
crack treatment
filler materials
longitudinal cracks
maintenance
sealant materials
transverse cracks

Strategic Highway Research Program
National Academy of Sciences
2101 Constitution Avenue N.W.
Washington, DC 20418

(202) 334-3774

1.5M/NAP/1093

Preface

The results of the experiment described in this volume are confined to the materials, procedures, and equipment used in this SHRP study. Omission of other materials, procedures, and equipment should not be construed as an indication of non- or poor performance due to their not being selected for inclusion in the study. It was not feasible for SHRP to test all materials, procedures, and equipment available in all regions and in all localities. Many agencies are successfully placing repairs using materials, procedures, and equipment that were not included in the SHRP study. Highway agencies are encouraged to evaluate and select materials, procedures, and equipment that provide the most cost-effective repairs.

Acknowledgments

The research described herein was supported by the Strategic Highway Research Program (SHRP). SHRP is a unit of the National Research Council that was authorized by section 128 of the Surface Transportation and Uniform Relocation Assistance Act of 1987.

Special thanks go to the following state highway maintenance agencies:

- Texas State Department of Highways and Public Transportation—Abilene Maintenance District 8
- Kansas Department of Transportation—Wichita Maintenance District 5 (Area 6)
- Washington State Department of Transportation—Elma Maintenance District 3
- Iowa Department of Transportation—Des Moines Maintenance District 1
- Ministry of Transportation of Ontario—Brockville Maintenance Yard

The authors also wish to recognize Samuel Carpenter, Michael Darter, David Peshkin, Mike Belangie, Charles Smyth, and Henry Bankie, who provided technical expertise and valuable guidance throughout the SHRP H-106 project.

The following is a list of registered trademarks:

- Hi-Spec is a trademark of W.R. Meadows, Incorporated.
- Fiber Pave is a trademark of Hercules Incorporated.
- CRF is a trademark of Witco Corporation.
- BoniFibers is a trademark of Kapejo Incorporated.
- Dow Corning is a trademark of Dow Corning Corporation.
- Sof Rod is a trademark of Applied Extrusion Technologies, Incorporated.
- RoadSaver is a trademark of Crafco Incorporated.
- Parker-Kalon is a trademark of P-K Emhart.
- SAS is a trademark of Statistical Institute, Incorporated.

Contents

List of Figures

List of Tables

Abstract

Under the Strategic Highway Research Program (SHRP) Project H-106, a field experiment is being conducted to evaluate the performance of various materials and procedures used in treating (i.e., sealing and filling) cracks in pavements surfaced with asphalt concrete (AC). A total of four transverse crack-seal sites and one longitudinal crack-fill site were installed in 1991 at locations in the United States and Canada. At each site, several experimental "treatments" were applied by participating state maintenance departments. Each treatment consists of a material, a placement configuration, and a crack preparation procedure.

Performance data collected from five sequential field evaluations has revealed 100 percent failure of a proprietary emulsion sealant placed at one site, and 40 percent average failure of a fiberized asphalt sealant installed at all four crack-seal sites. The remaining experimental sealant materials have exhibited less than 10 percent overall failure, and all experimental crack-filler materials have exhibited less than 2 percent overall failure. In addition, the simple band-aid sealant configuration has experienced between four and twenty times more failure than the reservoir-and-flush and the recessed band-aid sealant configurations.

Executive Summary

The primary objective of SHRP H-106 is to identify, through comprehensive field and laboratory testing, the most cost-effective materials and installation methods for treatment of cracks in asphalt concrete. Toward this end, five experimental test sites were installed at the locations listed in table 1. In all, over 22,000 ft (6710 m) of cracking was treated with experimental sealant or filler materials.

A total of 82 treatments (31 distinct treatment types) were applied in the experiment and are being evaluated for performance. As noted above, each treatment consists of a material, a placement configuration, and a crack preparation procedure. Overall, 15 material products, 8 placement configurations, and 7 crack preparation procedures were employed in the experiment.

Approximately 18 months after installation, most of the crack treatments are performing very well (73 of 82 with less than 20 percent failure). In general, rubberized asphalts, silicone, and asphalt rubber products have performed the best. Elf CRS-2P emulsion failed completely at Des Moines during the first winter, and Kapejo BoniFiberized asphalt has shown very poor performance (> 50 percent failure) at the two Wichita subsites.

Among placement configurations for the rubberized asphalt sealants, the reservoir-and-flush and the recessed band-aid formats are performing best. Koch 9030 placed in the simple band-aid configuration is performing poorly (35 to 50 percent failure) at the two Wichita subsites.

All the treatments in the longitudinal crack-fill site are performing very well. Asphalt rubber, asphalt cement, and fiberized asphalt are all performing slightly better in relation to the two asphalt emulsions.

Table 1. Test site locations.

Test Site Location	Highway	Climatic Region	Maintenance Type
Abilene, TX	I-20 WB	Dry-nonfreeze	Crack-sealing
Wichita, KS (ideal- and adverse-conditions subsites)	Rte 254 EB & WB	Dry-freeze	Crack-sealing
Elma, WA	Rte 8 EB	Wet-nonfreeze	Crack-sealing
Des Moines, IA	I-35 NB	Wet-freeze	Crack-sealing
Prescott, ONT	Hwy 401 EB	Wet-freeze	Crack-filling

1

Introduction

Objectives

In this Strategic Highway Research Program (SHRP) H-106 experiment, two distinct asphalt concrete (AC) crack treatment activities are being studied: transverse crack-sealing and longitudinal crack-filling. Both activities are frequently performed by highway agencies in order to extend pavement life, preferably to the point where the cost-benefit of added pavement life exceeds the cost of conducting the operations.

Several different materials and methods are used in crack treatment operations, some of which are inherently better than others. In many cases, however, the relative effectiveness of materials and methods depends on the situations or conditions in which they are used. Several studies have been conducted in the past to assess the effectiveness of these items. While these individual studies have gradually advanced the state of the technology, the need for a more comprehensive investigation, such as that conducted in SHRP project H-106, has been long overdue.

The primary objective of the H-106 experiment is to determine the most effective and economical materials and methods for conducting crack-sealing and crack-filling operations. Secondary objectives include the identification of both performance-related material tests and quicker, safer installation practices. Toward these ends, a total of four transverse crack-seal test sites and one longitudinal crack-fill test site were constructed throughout the United States and Canada between March and August of 1991. The general locations of these test sites are shown in figure 1.

Scope

This report covers all aspects of the crack treatment portion of the H-106 project. The various aspects of planning, installing, and evaluating the experimental crack treatment sites constructed in the project are discussed in Chapters 2, 3, and 4. An in-depth performance

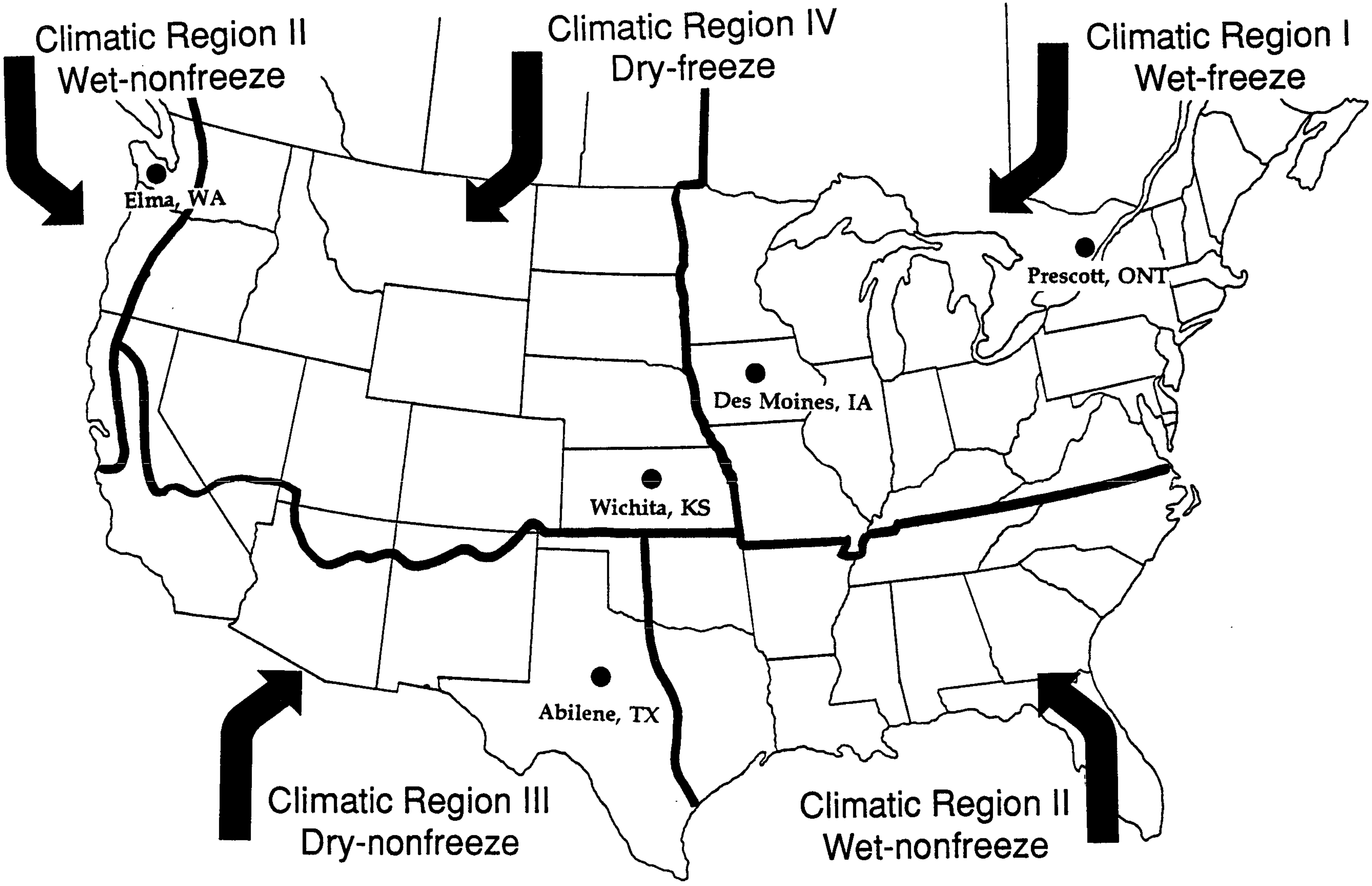


Figure 1. AC crack-treatment test site locations

analysis, conducted for the purpose of establishing useful trends or relationships among installation, laboratory testing, and field performance, is presented in chapter 5. Chapter 6 summarizes the preliminary findings and recommendations.

Project Overview

As stated previously, this project focuses on both transverse crack-sealing and longitudinal crack-filling operations. By definition, crack-sealing is the placement of specialized materials into and/or above "working" cracks in order to prevent the intrusion of water and incompressibles into the cracks ("working" cracks refer to cracks that undergo significant amounts of movement, generally ≥ 0.1 in [2.5 mm]). Crack-filling, on the other hand, is the placement of materials into "nonworking" cracks to substantially reduce water infiltration and reinforce adjacent cracks. Because of the predominant interest in, and need for, longer lasting crack sealants, the emphasis in this study has been placed on crack-sealing.

In the experiment, several different treatments were applied and are currently being evaluated for performance. The test sites containing these treatments are located on two- and four-lane highways of moderate traffic volume, representing four fundamental climatic regions, as shown in figure 1: dry-nonfreeze, dry-freeze, wet-nonfreeze, and wet-freeze. In order to examine the effects of ambient weather conditions during sealing operations, the site at Wichita, Kansas consisted of an ideal-conditions test lane and an adverse-conditions test lane. These two lanes are located adjacent to one another.

The basic character of each test site was formulated in the SHRP H-105 project and finalized just prior to installation. In all, ten material products were placed in the transverse crack-seal sites and six material products were placed in the longitudinal crack-fill site. Table 2 presents the entire list of materials, both primary and state-added, that were installed in the experiment.

The installation methodology for a particular material involved (1) the method of crack preparation; and (2) the configuration in which the material was placed. Table 3 lists the seven crack preparation procedures (designated 1 through 7) used, while figure 2 shows the eight placement configurations employed (designated A through H). Altogether, 13 unique installation methods were implemented. These methods are, herein, presented in the form A-3, D-4, E-6, etc.

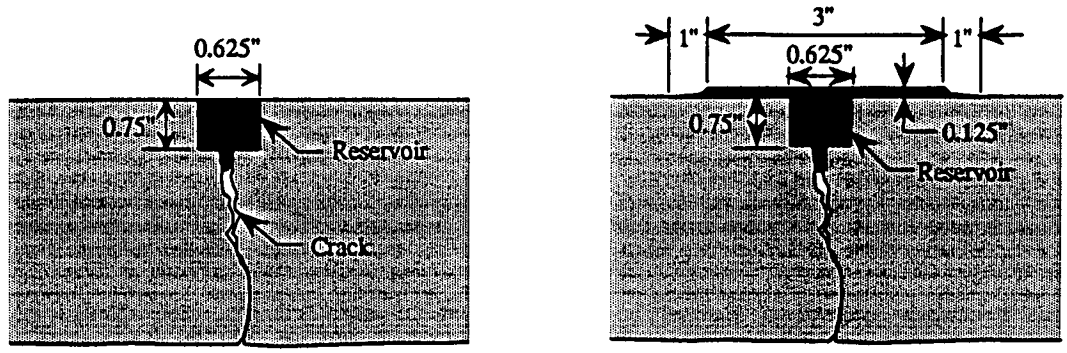
Table 4 provides a complete matrix of the treatments applied at each site. As can be seen, some materials were placed using only one method, while others were placed using several methods. A total of 31 treatments were applied in the experiment, some at multiple locations.

Table 2. List of material products installed in experiment

Product	Material Type	Test Site(s) Installed at
Primary Crack-Sealant Products		
Meadows Hi-Spec®	Rubberized Asphalt	Abilene, Elma, Wichita, Des Moines
Crafco RoadSaver® (RS) 515	Rubberized Asphalt	"
Koch 9030	Low-Modulus Rubberized Asphalt	"
Meadows XLM	Low-Modulus Rubberized Asphalt	"
Kapejo BoniFibers® + AC (AC-20)	Fiberized Asphalt	"
Dow Corning® 890-SL	Self-leveling Silicone	"
Primary Crack-Filler Products		
85-100 Pen. Graded AC	Asphalt Cement	Prescott
Witco CRF®	Emulsion	"
Crafco AR2	Asphalt Rubber	"
Hercules Fiber Pave® + AC (85-100 Pen. Graded)	Fiberized Asphalt	"
Additional Products		
Crafco RS 211	Rubberized Asphalt	Elma, Prescott
Crafco AR+	Rubberized Asphalt	Wichita
Koch 9000-S	Asphalt Rubber	"
Elf CRS-2P	Emulsion	Des Moines
Hy-Grade Kold Flo	Rubberized Emulsion	Prescott

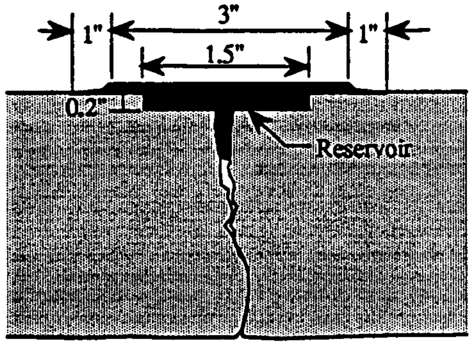
Table 3. Crack preparation procedures included in experiment

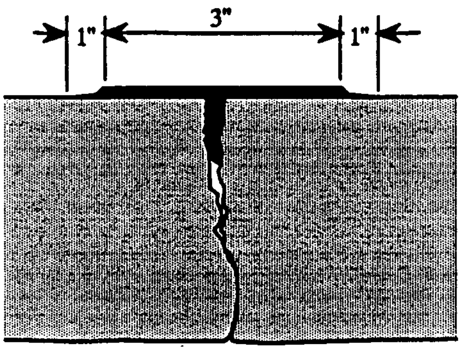
Designation	Crack Preparation Procedure
1	None
2	Wire brush and compressed air
3	Hot compressed air
4	Compressed air
5	Light sandblast, compressed air and backer rod
6	Compressed air and backer rod
7	Light sandblast, compressed air, and backer tape



Configuration A
Standard Reservoir-and-Flush

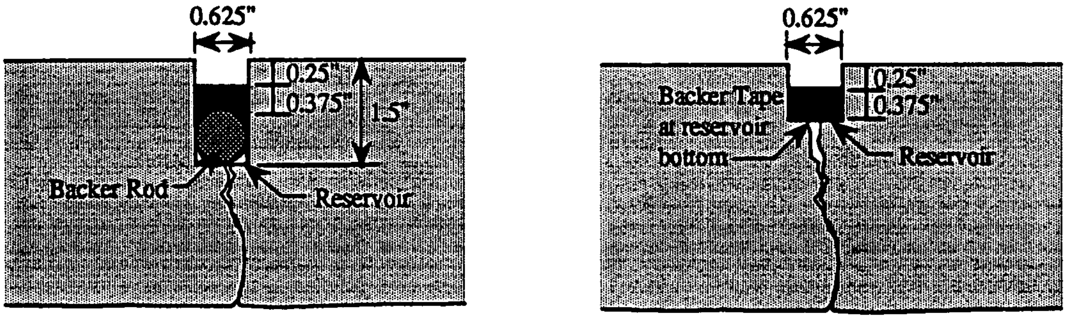
Configuration B
Standard Recessed Band-Aid





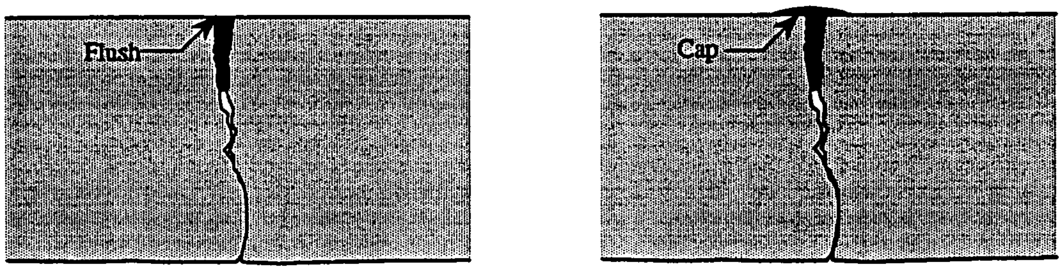
Configuration C
Shallow Recessed Band-Aid

Configuration D
Simple Band-Aid



Configuration E
Deep Reservoir-and-Recess

Configuration F
Standard Reservoir-and-Recess



Configuration G
Simple Flush-Fill

Configuration H
Capped

Figure 2. Material placement configurations used in experiment

Table 4. Summary of crack-seal and crack-fill installations

Treatment		Test Site				
Material	Method (Configuration-Preparation)	Abilene	Wichita (Ideal)	Wichita (Adverse)	Elma	Des Moines
Meadows Hi-Spec	A-2	▨	▨	▨	▨	✓
	A-3	✓	✓	✓	✓	✓
	B-3	✓	✓	✓	✓	✓
	C-3	▨	✓	✓	▨	✓
	D-3	✓	✓	✓	✓	✓
	D-4	✓	✓	✓	✓	✓
Crafco RS 515	B-3	✓	▨	▨	✓	✓
	C-3	▨	✓	✓	▨	✓
	D-3	✓	✓	✓	✓	✓
Koch 9030	B-3	✓	▨	▨	✓	✓
	C-3	▨	✓	✓	▨	✓
	D-3	✓	✓	✓	✓	✓
Meadows XLM	B-3	✓	▨	▨	✓	✓
	C-3	▨	✓	✓	▨	✓
	D-3	✓	✓	✓	✓	✓
Kapejo BoniFibers + AC	D-3	✓	✓	✓	✓	✓
Dow Corning 890-SL	E-5	✓	✓	▨	✓	✓
	E-6	▨	▨	✓	▨	▨
	F-7	▨	▨	✓	▨	▨

Configuration
A. Standard Reservoir-and-Flush
B. Standard Recessed Band-Aid
C. Shallow Recessed Band-Aid
D. Simple Band-Aid
E. Deep Reservoir-and-Recess
F. Standard Reservoir-and-Recess
G. Simple Flush-Fill
H. Capped

Preparation Procedure
1. None
2. Wire Brush and Compressed Air
3. Hot Compressed-Air Lance
4. Compressed Air
5. Light Sandblast, Compressed Air, and Backer Rod
6. Compressed Air and Backer Rod
7. Light Sandblast, Compressed Air, and Backer Tape

Table 4. Summary of crack-seal and crack-fill installations (cont)

Treatment		Test Site				
Material	Method (Configuration-Preparation)	Wichita (Ideal)	Wichita (Adverse)	Elma	Des Moines	Prescott
Asphalt Cement	G-1					✓
	G-4					✓
Witco CRF	G-4					✓
Crafco AR2	D-4					✓
	G-4					✓
Hercules Fiber Pave + AC	D-4					✓
Crafco AR+	B-3	✓	✓			
Koch 9000-S	B-3	✓	✓			
Crafco RS 211	B-3			✓		
	D-4					✓
Elf CRS-2P	G-4				✓	
Hy-Grade Kold Flo	G-4					✓

Configuration
A. Standard Reservoir-and-Flush
B. Standard Recessed Band-Aid
C. Shallow Recessed Band-Aid
D. Simple Band-Aid
E. Deep Reservoir-and-Recess
F. Standard Reservoir-and-Recess
G. Simple Flush-Fill
H. Capped

Preparation Procedure
1. None
2. Wire Brush and Compressed Air
3. Hot Compressed-Air Lance
4. Compressed Air
5. Light Sandblast, Compressed Air, and Backer Rod
6. Compressed Air and Backer Rod
7. Light Sandblast, Compressed Air, and Backer Tape

Test Site Characteristics

I-20, Abilene, Texas

This crack-seal test site, representing the dry-nonfreeze climate, is located between mileposts 278 and 282 in the westbound driving lane of Interstate 20 near Abilene, Texas. Its location is shown in figure 3. The pavement section was originally constructed in the mid-1960s using 3 in (76 mm) of AC, 8 in (203 mm) of crushed limestone base, and 16 in (406 mm) of crushed caliche subbase placed on a 6-in (152-mm) lime-stabilized subgrade. A 2.5-in (64-mm) AC overlay with a geofabric interlayer was placed in 1989.

Pavement condition at the time of installation was fairly good. Transverse cracks were the only significant form of distress present. These cracks were typically about 0.1 in (2.5 mm) wide and were spaced fairly regularly—between 50 and 60 ft (15.3 and 18.3 m). Very little spalling and secondary cracking was observed along the transverse cracks.

Two-way traffic on this four-lane interstate facility, as recorded in 1988, was approximately 19,900 vehicles per day (vpd). Data on the percentage of trucks were not available, but it is estimated to be fairly high—in the vicinity of 15 to 20 percent. Assuming a directional distribution of 50 percent and lane distribution of 60 percent, the amount of traffic traversing the test site (i.e., the westbound driving lane) would be nearly 6,000 vpd.

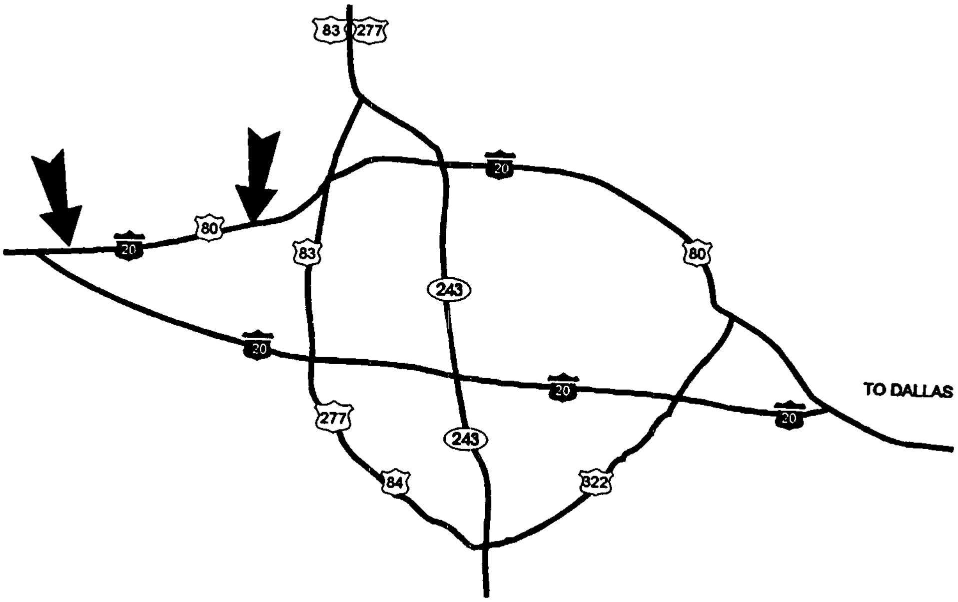


Figure 3. Abilene, Texas crack-seal test site

Rt 8, Elma, Washington

This wet-nonfreeze crack-seal test site is located between mileposts 0 and 7.25 in the eastbound passing lane of Route 8 near Elma, Washingon. Its location is shown in figure 4. The pavement section was originally constructed in 1964 as a full-depth AC pavement. An AC overlay in the mid-1980s, brought the total depth of AC to 9 in (229 mm).

When this road was selected as a crack-seal site, overall pavement condition was fairly good. Transverse cracks were present, typically at 75 to 100 ft (22.9 and 30.5 m). These cracks, ranging between 0.125 and 0.25 in (3.2 and 6.4 mm) wide, were accompanied by very few spalls and secondary cracks. Some rutting was evident in the wheelpaths, but usually to depths no greater than 0.25 in (6.4 mm).

During the winter and early spring of 1991, the surface course in the driving lane of this four-lane divided highway experienced some severe delamination due to heavy freeze-thaw cycles. The deterioration was sufficient to warrant full-depth repairs and the placement of a chip seal in this lane over much of the section. Hence, the original idea of sealing both lanes, to investigate the effects of traffic on sealant performance, had to be abandoned and only the cracks in the passing lane were sealed.

Two-way traffic on this facility is approximately 14,000 vpd, 9 percent of which is truck traffic. No lane-traffic distributions have been obtained; however, estimates from the field indicate that no more than 40 percent occupy the passing lane, which is where the experimental seals are located. Assuming a directional distribution of 50 percent, this would mean that the test site experiences no more than 2,800 vpd,, making it easily the lowest trafficked site.

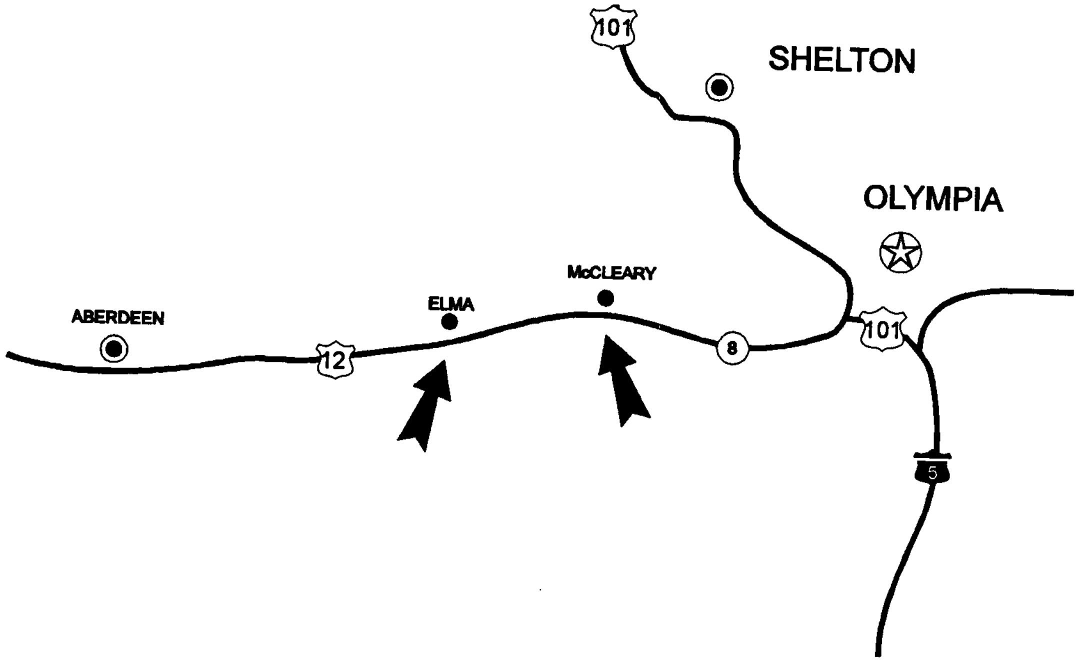


Figure 4. Elma, Washington crack-seal test site

Rt 254, Wichita, Kansas

This crack-seal site, representing the dry-freeze climatic zone, is located between mileposts 4.5 and 10.2 of Route 254 near Wichita, Kansas. Its location is shown in figure 5.

The eastbound lane of this two-lane highway represents the ideal-conditions lane while the westbound lane represents the adverse-conditions lane. The date of original construction for this pavement section was not available; however, it was constructed as a full-depth AC pavement. In the summer of 1989, rehabilitation was performed by milling off 1.5 in (38.1 mm) of the AC surface and placing a blend of recycled and new AC to a depth of 3 in (76.2 mm). Hence, the final cross section is composed of 12 in (305 mm) of AC.

As with the Abilene site, pavement condition at the time of installation was fairly good. Transverse cracks, between 0.094 and 0.188 in (2.4 and 4.8 mm) wide, were typically spaced between 60 and 80 ft (18.3 and 24.4 m) apart. Some of the transverse cracks exhibited a considerable degree of secondary cracking. To the extent possible, these cracks were excluded from the experiment.

Two-way traffic on this undivided highway was estimated to be 7,000 vpd in 1988, with 13 percent trucks. This figure is believed to be considerably higher now, judging from observations made during the installation and at the five subsequent field evaluations. Nevertheless, the amount of traffic traversing each test site would be at least 3,500 vpd, assuming a directional distribution of 50 percent.

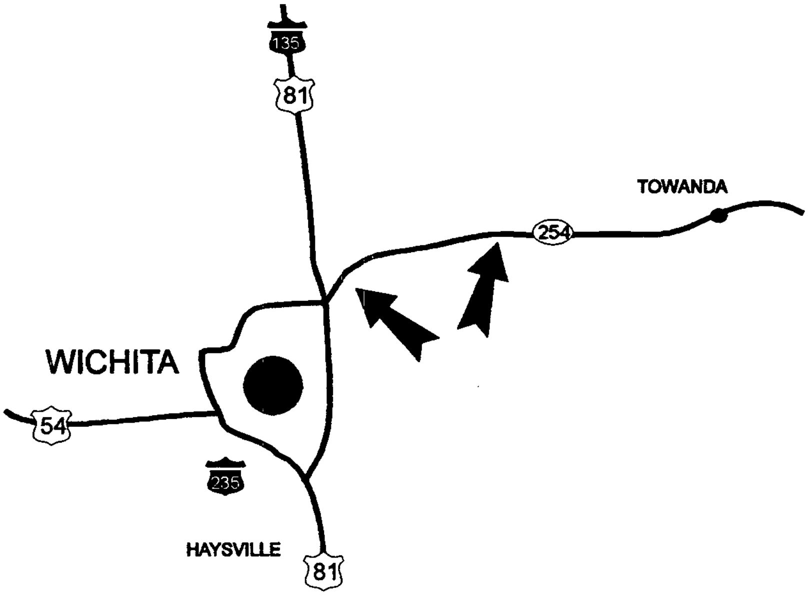


Figure 5. Wichita, Kansas crack-seal test site

I-35, Des Moines, Iowa

The location of this wet-freeze crack-seal site is between mileposts 93 and 102 in the northbound driving lane of Interstate 35 near Des Moines, Iowa. Figure 6 shows the location of the site in relation to Des Moines. The pavement section was originally constructed in 1965 with 10 in (254 mm) of jointed reinforced concrete pavement (JRCP) placed on a 4-in (102-mm) granular subbase. The joints were doweled and spaced 76.5 ft (23.3 m) apart. In 1988, some partial- and full-depth patching was done, followed by the placement of a 4-in (102-mm) AC overlay.

By the time this experimental site was installed, most of the transverse joints had reflected through the overlay. Several of the reflected cracks had been treated in 1989 with an emulsion material, of which only traces remained. On average, transverse cracks were 0.094 to 0.125 in (2.4 to 3.2 mm) wide and were accompanied by some spalls and secondary cracks. Some longitudinal cracks were present along the lane-shoulder joint.

Two-way traffic on this four-lane facility is 20,700 vpd, with approximately 20.5 percent trucks. Based on a 50 percent directional distribution and a 60 percent lane distribution, more than 6,200 vpd cross over the test site (i.e., the northbound driving lane).

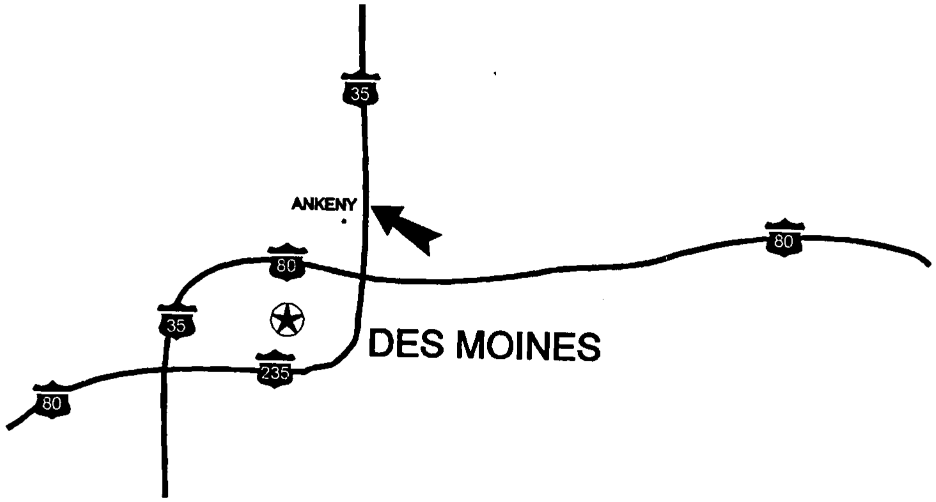


Figure 6. Des Moines, Iowa crack-seal test site

Hwy 401, Prescott, Ontario

The longitudinal crack-fill test site, constructed in the wet-freeze climate, is located between kilometerposts 716 and 718 in the eastbound lane of Highway 401 near Prescott, Ontario. Its location is shown in figure 7. The date of original construction for this pavement section was not available; however, the section was constructed as a 9-in (230-mm) jointed plain concrete pavement (JPCP) placed on 12 in (305 mm) of granular subbase. In 1979, a 5-in (127-mm) AC overlay was placed on the existing concrete surface.

Transverse reflective cracks had developed in both lanes in the mid-1980s, at which time they were sealed with a hot-applied rubberized asphalt. A fair percentage of these seals were observed to have failed at the time the crack-fill experiment was installed. The longitudinal centerline crack sealed in this experiment typically ranged from 0.125 to 0.188 in (3.2 to 4.8 mm) wide. Some segments of the crack were spalled or potholed, and tight alligator cracks ran along much of the crack length.

The two-way traffic for this four-lane divided highway was estimated in 1991 to be 12,000 vpd. The percentage of trucks was not available; however, it is believed to be at least 12 percent. Because of the location of the longitudinal crack, very little traffic crosses the crack-fill treatments.

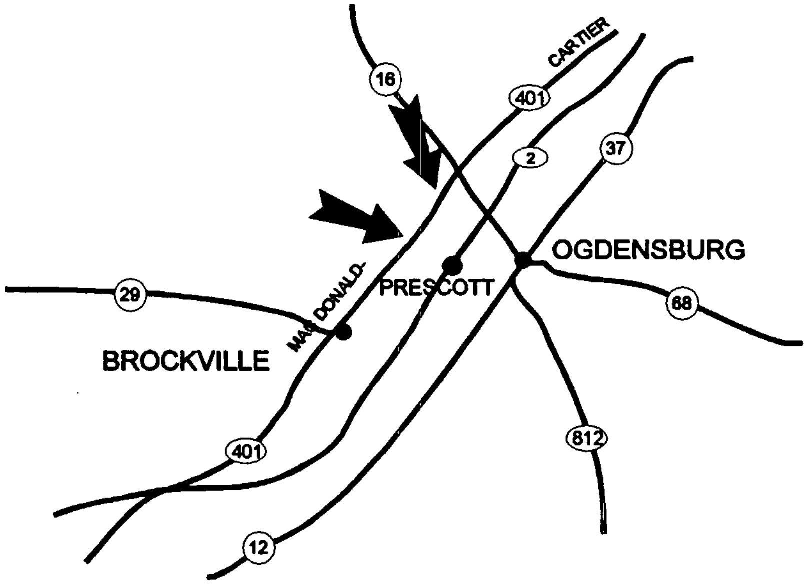


Figure 7. Prescott, Ontario crack-fill test site

2

Test Site Installations

After an extensive 4-month search for potential test sites, primary and backup test sites were selected in February 1991 (except the crack-fill site, which was selected in June 1991). These sites were selected based upon an overall rating of numerous characteristics, including the quantity and appropriateness of distress, the uniformity and future availability of the pavement section, and the ability and willingness of the local maintenance force to participate in the study.

The field installation process began in March 1991 with the Abilene test site and concluded in August 1991 with the Prescott test site. Upon completion, roughtly 22,000 ft (6710 m) of cracks were treated with the experimental materials.

Table 5 summarizes basic information regarding the layout and construction of each test site. As can be seen, each test site typically took between 1 and 2 weeks to lay out and construct. The actual time required at each site depended on the weather conditions encountered, the length of the test site, the number of materials that were to be placed, and the available resources of the participating agencies. For instance, at the 1-mi (1.6-km) Prescott test site, five materials were placed in 2 working days, two of which were cold-applied emulsions. In contrast, the two subsites at Wichita, each greater than 5 mi (8.1 km) long, took nearly 14 working days to construct. Eight materials were placed at each of these subsites, and a few days of inclement weather were experienced.

For the most part, the installations followed the *Experimental Design and Research Plan (EDRP)* originally developed in the SHRP H-105 project.[1] However, a few changes were made prior to and during the H-106 field installations. These included:

- Slight reduction in reservoir width for configurations A, B, and E (from 0.75 in to 0.63 in [19 mm to 16 mm]).
- Incorporation of two "no seal" test sections at Des Moines.
- Modification of installation methods for two Dow Corning 890-SL sections at Wichita adverse-conditions subsite (methods E-6 and F-7 were used instead of method E-5).

Table 5. Test site construction information

Test Site Location	Facility Type	Participating Agency	Activity	Test Site Duration (Layout and Construction)	Total Number of Layout and Construction Days
I-20 Abilene, TX	4-lane interstate	Texas State Dept. of Highways and Public Trans.	Transverse crack sealing	3-20 to 3-27	5
Rte 254 Wichita, KS	2-lane highway	Kansas DOT	Transverse crack sealing	4-10 to 5-2	10
Rte 8 Elma, WA	4-lane highway	Washington State DOT	Transverse crack sealing	4-22 to 4-27	3
I-35 Des Moines, IA	4-lane interstate	Iowa DOT	Transverse crack sealing	5-30 to 6-7	5
Hwy 401 Prescott, ONT	4-lane highway	Ontario Ministry of Transportation	Longitudinal crack filling	8-28 to 8-29	2

- Incorporation of six supplemental (state-added) material products for performance evaluation (see table 2.
- Incorporation of six additional test sections at Des Moines for investigating the performance of RS 515, 9030, and XLM sealants placed in configuration B.

Nearly every experimental treatment was replicated twice in the field to increase the statistical validity of performance analyses. The exceptions to this were the two Dow Corning 890-SL sections located in the Wichita adverse-conditions subsite. Here, methods E-6 and F-7 were used in one section each, replacing two sections allotted for method E-5.

Test Site Arrangements

Once each site was selected and approved for use, efforts were made to determine the resources needed for complete installation of the various test sites. This entailed the estimation of material requirements and a knowledge of the manpower and equipment available at each participating agency. For instance, one agency did not have access to a hot compressed-air lance; therefore, arrangements had to be made with an equipment manufacturer to lease one.

Initial material estimates were made based on the number of sections testing each material and the application rates associated with the various material configurations. A 25 percent wastage factor was then applied to each material estimate. After conversations with manufacturers and expert consultants, the hot-applied material estimates were again increased to ensure proper functioning of the asphalt kettle units and to reduce the likelihood of material overheating. A sufficient amount of material in the kettle vat helps safeguard against heating and application problems.

To further inform participating agencies about what to expect during the installations, Layout and Construction Plans (LCPs) were prepared and sent to the project supervisors at each agency. These plans presented the scope and objectives of the project and outlined the responsibilities of the participating agency and the SHRP contractor. Conceptual maps illustrating the proposed layout of test sections for treatments also were included in this document. Several copies of these maps were later made and distributed to field maintenance supervisors to assist them in coordinating the installations.

Installation Process

The sequence of activities at each installation was rather straightforward. Each experimental installation consisted of three primary phases:

1. Test site layout
2. Initial crack preparation (i.e., crack cutting)
3. Final crack preparation (i.e., crack cleaning) and material placement

Obviously, before any cracks could be prepared or material installed, the experimental test sections had to be laid out. Furthermore, since detailed inspection and documentation of cut cracks was required, the crack-cutting phase was conducted separately from the crack-cleaning and material-placement phase.

Test Site Layout

The location of the experimental test sections at each site depended on the highway facility type and the constraints associated with the pavement section. As can be seen in table 5, all of the sites except Wichita were four-lane facilities. Additionally, with the exception of Elma, the experimental test sections at each site were established in the (outside) driving lane. At Elma, the (inside) passing lane had to be used because of surface delaminations that occurred in the driving lane shortly before the scheduled installation.

The first phase in each experimental installation involved conducting a pavement survey and laying out the site. A cursory inspection of the cracks was made first to determine which were suitable for inclusion in the experiment. The criteria differed for transverse and longitudinal cracks. Suitable transverse cracks had to be full-lane-width cracks, accompanied by minimal edge deterioration (i.e., spalls, secondary cracks). Suitable longitudinal cracks, on the other hand, could be accompanied by a greater amount of edge deterioration. When suitable cracks were identified in the field, they were marked and numbered with spray paint.

Crack-seal treatments assigned to each test site were implemented in test sections consisting of 10 suitable transverse cracks. The test sections were arranged in random order to form a test replicate (see appendix A for the sequence of sections at each test site). This replicate of test sections was repeated so that two sets of each treatment were applied, as shown in figure 8. This design was also used at the crack-fill site, except the test sections consisted of twelve 25-ft (7.6-m) divisions of continuous longitudinal centerline crack. Crack-seal test sites ranged from 3.5 to 9 mi (5.6 to 14.5 km) long, depending primarily on the crack spacing and the number of sections proposed for each test site. The longitudinal crack-fill test site was approximately 1 mi (1.6 km) long.

Often, partial lane-width cracks and considerably deteriorated cracks were encountered in the crack-seal test sites. These cracks were either sealed with the experimental materials during installation or were sealed after installation using whatever material was available. However, treatments for these cracks are not evaluated.

Permanent marking tape was used on the shoulders to mark the test section boundaries. A three-digit code designating the treatment type used in the adjacent section was then spray-painted next to the strips of marking tape.

After each test site was laid out, the test sections, experimental cracks, and important permanent fixtures (i.e., milepost markers, bridges) were stationed. This stationing serves as a mapping reference in the event that remarking becomes necessary as a result at paint fading.

At the crack-seal sites, a detailed inspection of experimental cracks three through ten in each test section was performed. This inspection involved sketching the general pattern of each crack and recording the location(s) of deteriorated segments as a function of lane position (see figure 9). A similar, less-intensive inspection was done on experimental cracks five through twelve in each section at the crack-fill site. Since the longitudinal cracks were much straighter and more deteriorated, only the excessively wide or potholed crack segments were identified and recorded.

The next step in the layout phase involved the placement of Parker-Kalon® (P-K) nails to monitor horizontal crack movement throughout the year. The nails were driven flush into the pavement on each side of, and perpendicular to, experimental cracks. The nail heads were dimpled so that accurate measurements with a caliper could be taken during the installation and during each subsequent evaluation.

At the crack-seal sites, the nails were installed near the center of the experimental lane, roughly 5.5 in (138 mm) on each side of the last eight experimental cracks in each test section. At the crack-fill site, only two sets of nails were installed in each section. This was because little movement was anticipated and the variation in movement along the entire crack was expected to be small. With the exception of the Prescott site, this proved to be the most time-consuming step in the layout phase, occasionally taking more than a full day to complete.

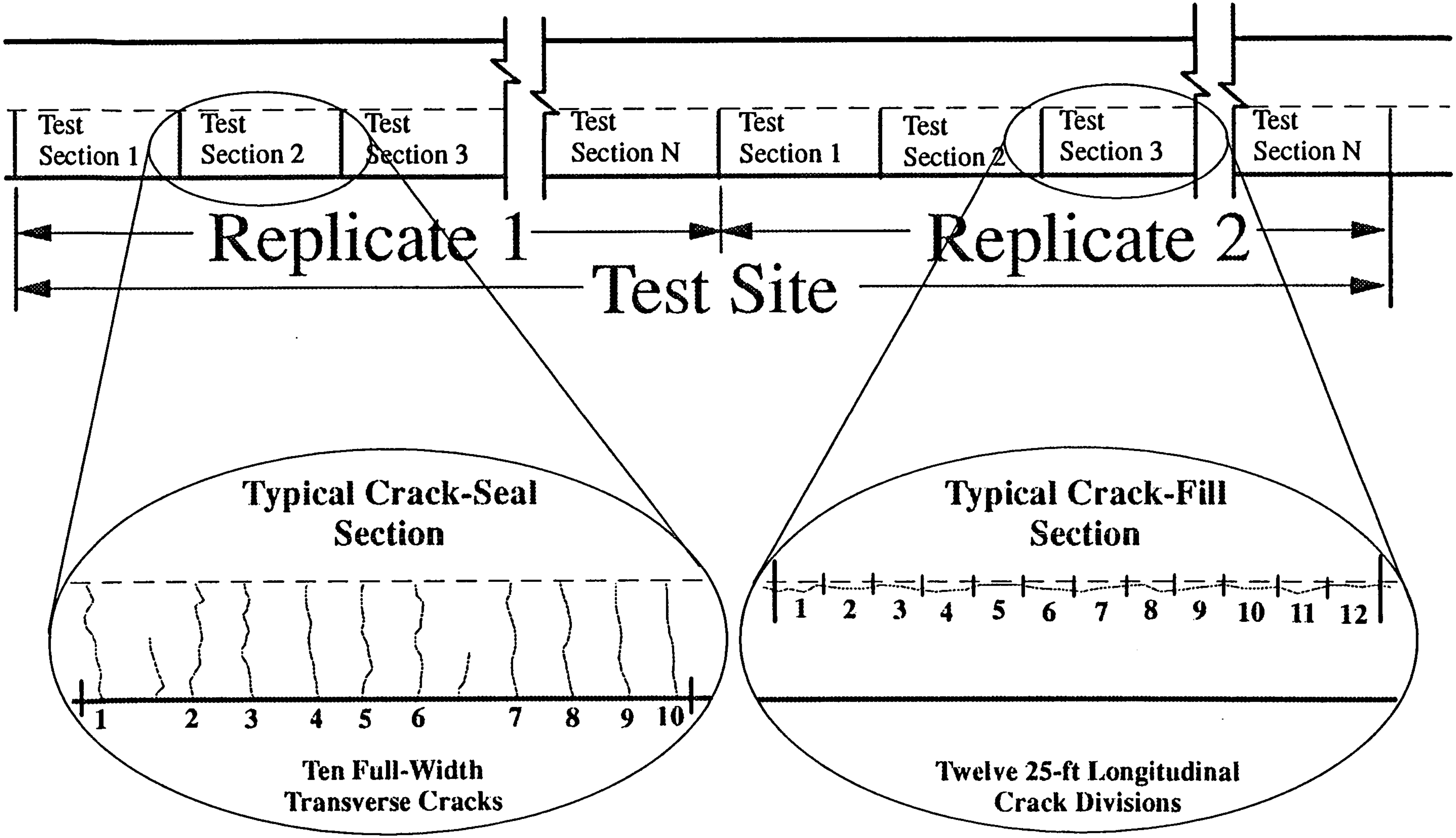


Figure 8. Conceptual layout of test sections at each test site

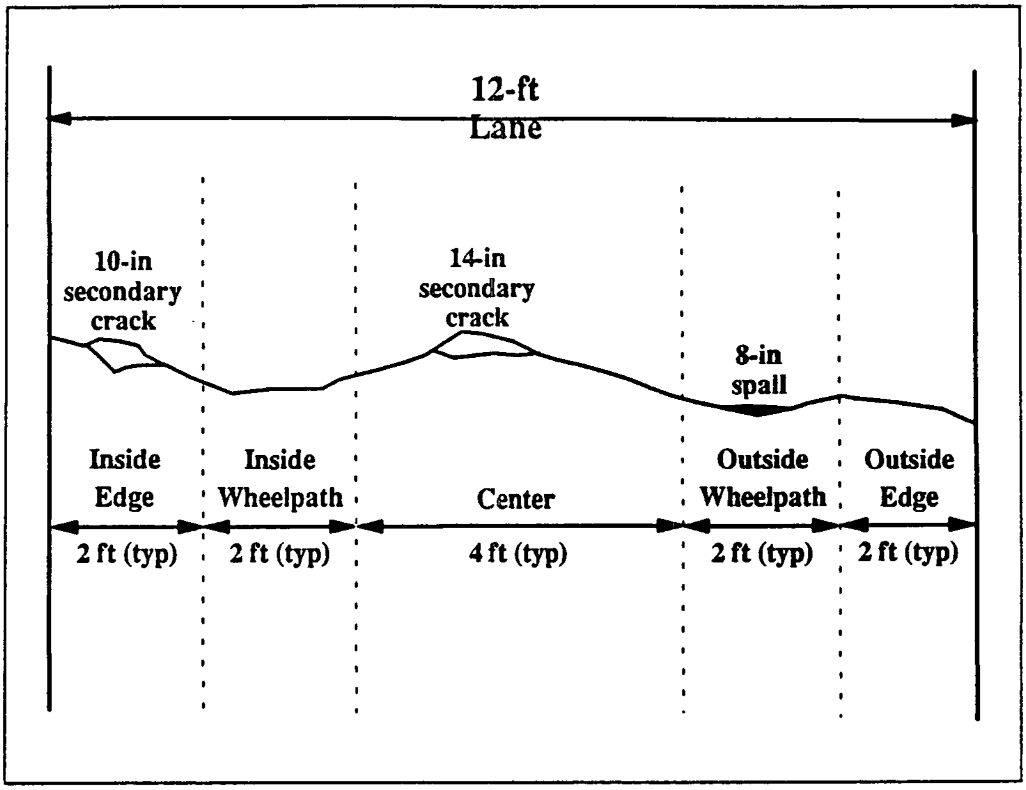


Figure 9. Initial inspection sketch of transverse crack

Although efforts were made during each layout to achieve uniformity among test sections, a final cursory survey was performed at each site to identify and record any global distresses (e.g., rutting, raveling) or localized features (e.g., drainage structures, superelevation) that could bias performance results.

Initial Crack Preparation

The next step was initial crack preparation or crack cutting. This phase, although labor-intensive, was rather simple and straightforward. Two two-person crews were usually deployed, one to cut the cracks and one to blow debris off of the roadway. In some cases, the machine operators were switched periodically for physical relief or training purposes. In the latter case, only productivity was sacrificed.

Project staff regularly checked work quality to the extent possible by measuring reservoir dimensions and inspecting the operator's ability to follow cracks with the router or saw.

Between 1 and 2 days of crack cutting was typical at each site. Lane closures were established for the cutting operations at Abilene, Elma, and Des Moines. At Wichita, temporary construction zones were set up using signs and flagmen.

Final Crack Preparation and Material Placement

In the final phase, maintenance crews cleaned cracks and installed the experimental materials. The crack-cleaning operation generally preceded the material installation operation by 3 to 5 minutes or 50 to 100 ft (15 to 30 m). This gave the project staff time to monitor the crack-cleaning activity. In most cases, the crack-cleaning crew had to be restrained from getting too far ahead of the installation operation.

At crack-sealing sites one of four methods were used for final crack preparation, depending on the sealant material that was installed. Sections where hot materials were applied were generally airblasted either with hot compressed air or conventional compressed air (preparation procedures 3 and 4, respectively). Two Hi-Spec sections at Des Moines used a combination of wirebrushing and compressed air (preparation procedure 2). Silicone sections involved more detailed preparation; crack reservoirs were lightly sandblasted and cleaned with compressed air, and then backer rod was installed. Crack preparation at the crack fill test site consisted primarily of conventional airblasting.

At the Wichita adverse-conditions subsite, the weather conditions often had to be artificially produced. This meant that water had to be poured into and over experimental cracks and then allowed to permeate the crack for a short time (approximately 5 to 10 minutes) prior to the cleaning/drying operation.

The manner in which experimental products were installed depended upon the type of material. Hot-applied materials were applied to cracks using the applicator system affixed to kettle units. This system consists primarily of a pump, hose, and wand. Cold-applied asphalt materials were placed using hand-held pour pots, and self-leveling silicone was dispensed from 29-oz (0.9-L) cartridges using either manual or air-powered caulking guns.

Once applied into or over the crack channels, asphalt materials were molded into desired configurations using the appropriate squeegees. The squeegees were generally run between 2 and 10 ft (0.6 and 3.0 m) behind the material applicator, depending on the material viscosity at placement. No finishing was required for the self-leveling silicone product.

In order to minimize tracking, traffic control had to be maintained long enough for the treatments to solidify or form a protective skin. On a couple occasions, maintenance vehicles (e.g., trucks pulling arrow boards, crash attenuator trucks) followed too closely behind the installation operation, causing some of the materials to be tracked.

Cleanup

After completing the installation of one hot-applied material, the asphalt kettle used in the installation had to be cleaned for preparation and application of the next hot-applied material. This meant first pumping as much of the old material out of the unit as possible. A few blocks (75 to 100 lb [34 to 45 kg]) of the next material to be installed were then loaded into the kettle vat and heated to application temperature. This material, mixed with remnants from the previous material, was then pumped from the vat and properly disposed. As a result, contamination by the previous material was all but eliminated and the kettle was prepared for formal loading and heating of the next material.

The cleanup associated with the fiberized asphalt materials was arduous and time-consuming. Therefore, these materials either were placed last (in cases where only one kettle was available), or were placed using a separate kettle.

Materials

Rubberized Asphalt

The hot-applied, rubberized asphalt product Meadows Hi-Spec served as the control sealant material for the transverse crack-seal experiment. Nearly one-third of the treatments at each site involved the use of Hi-Spec, as seen in table 4 of chapter 1.

Hi-Spec is packaged in 50-lb (22.7-kg) boxes, each containing two 25-lb (11.3-kg) blocks of sealant. These blocks were loaded into the kettles and heated to temperatures between 390° and 410°F (199° and 210°C). Although the manufacturer advised avoidance of prolonged heating or overheating to prevent decomposition, Hi-Spec was reported to be a little less sensitive to temperature than other hot-pour materials. Nevertheless, no heating problems were observed during the installations.

Even though Hi-Spec was placed in four different formats (configurations A, B, C, and D), the procedures used were similar. For cut cracks, the sealant was placed from the bottom up, overfilling the reservoir to the extent necessary for either flush or band-aid squeegeeing. For uncut cracks, enough sealant was applied to the crack to form the desired band dimensions with the band-aid squeegee. Figures 10 and 11, respectively, illustrate the Hi-Spec reservoir-and-flush and band-aid configurations employed.

Hi-Spec treatments were not without construction problems. Unanticipated down time at the Abilene site created a situation in which Hi-Spec had to be reheated for application the next day. Most of its original quality, however, was believed to have been retained by loading additional blocks of material during the reheating process.

Several Hi-Spec treatments at Wichita and Elma were subject to considerable amounts of bubbling. This bubbling occurred in both airblasted and hot-airblasted test sections and was believed to have been the result of capillary moisture emanating from saturated base layers. It was observed more in the uncut crack sections where the cleaning/drying operation was less effective because of the small crack channels. In order to minimize the bubbling, airblasting operators were instructed to be more meticulous in drying the cracks. Roughly 15 to 20 minutes of curing time typically was needed for the Hi-Spec.

Figure 10. Hi-Spec reservoir-and-flush configuration

Figure 11. Hi-Spec band-aid configuration

Modified Rubberized Asphalt

The three modified rubberized asphalt products (Crafco RS 515, Koch 9030, and Meadows XLM) were placed at each site using identical configurations and crack preparation procedures. Final crack preparation was accomplished using the heat lance, and configurations B, C, and D were employed, although not at every site.

Sealants RS 515 and 9030 came packaged in boxes, each containing two 25-lb (11.3-kg) blocks. Meadows XLM, on the other hand, came packaged in pails containing one 42-lb (19.1-kg) block, which made loading more difficult. Recommended heating temperatures for these products ranged from 350° to 370°F (177° to 188°C) for XLM and 380° to 400°F (193° to 204°C) for RS 515. While these heating temperatures were similar to these required for Hi-Spec, the softer asphalt bases necessitated closer temperature monitoring.

Heating problems for these products generally were avoided. The only severe overheating that occurred in the experiment took place at Abilene, where XLM was inadvertently heated to temperatures exceeding 400°F (204°C). Unfortunately, additional material was not available to replace the overheated batch. Although some gelling was noted, it was not significant. Most noticeable was the appearance of microbubbles in this sealant during placement.

As with Hi-Spec, some of these sealants experienced substantial bubbling during installation. At Elma, XLM and 9030 sustained considerable bubbling, and at Wichita, RS 515 bubbled. In each case, the exposed crack channels were dry; however, base layers were at least partially saturated, which is a condition conducive to capillary action.

Overall, application and finishing of these materials were quite similar. Occasionally, the viscosity of the products and the size of the crack reservoirs necessitated immediate reapplications. In these instances, sealant from the original application sank deep into the crack and left insufficient material at the surface to form the desired configuration.

Although traffic control was normally maintained for at least 30 to 60 minutes after each test section installation, these sealants usually cured 15 to 20 minutes after placement.

Fiberized Asphalt

Two types of fiber materials were installed in this experiment: Kapejo polyester fibers (BoniFibers) and Hercules polypropylene fibers (Fiber Pave 3010). Both were mixed with asphalt cement obtained from a local distributor. The blend of polyester fibers and AC-20 was placed at the five transverse crack-seal sites, while the blend of polypropylene fibers and 85-100 penetration-graded AC was placed at the longitudinal crack-fill site.

Polyester fiber is packaged in 20-lb (9.1-kg) bags, three per box. The fiber was pre-weighed (5 percent by weight of asphalt) at the maintenance yards and added on site to the asphalt cement, which was kept heated in the kettles (see figure 12). The entire process of adding

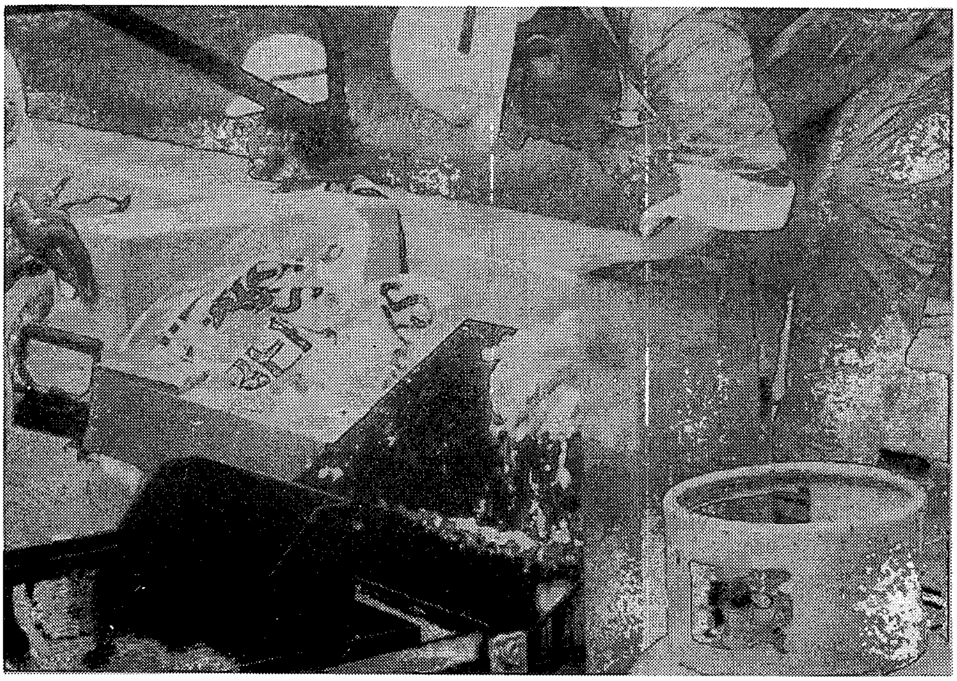


Figure 12. Addition of polyester fibers to asphalt cement

the fibers, thoroughly mixing the components, and heating to application temperature usually took between 1 and 2 hours, depending on the melter unit agitation system. Units with full-sweep agitation capabilities greatly expedited preparation.

The placement of BoniFiberized asphalt was standard at each test site. Final crack preparation was accomplished using the heat lance and the product was placed in the simple band-aid configuration. Application from some kettle units was occasionally difficult. For example, the unit used at Elma had poor pumping capabilities, and when the material temperature was not properly maintained, the hose clogged. This occurred twice; both times a torch was required to unclog the hose.

Curing time, with respect to all the other experimental materials, was perhaps lowest with this product because of the lower application temperature. Although traffic control was generally maintained for at least 30 to 60 minutes after placement, only 10 to 15 minutes were actually necessary.

As for construction deficiencies associated with this product, considerable bubbling did occur at the Elma and Wichita test sites. Again, water in the pavement system was believed to have caused most, if not all, of the bubbling.

Fiber Pave fiber is packaged in 36-lb (16.3 kg) bags. As before, the fiber was pre-weighed (7 percent by weight of asphalt) at the maintenance yard and then added to the asphalt cement on site. Although AC-20 was originally planned, a softer asphalt (85-100 penetration-graded asphalt cement) was used because of the climate.

Two replicate sections of Fiber Pave asphalt were constructed at the Prescott site. In both sections, cracks were blown clean using compressed air, and the fiberized asphalt was placed in the simple band-aid configuration.

The sensitivity of the Fiber Pave polypropylene fibers created some interesting problems during preparation. Since this particular type of fiber melts at temperatures over 300°F (149°C), the asphalt cement had to be kept below 300°F (149°C) throughout preparation and application. This was a difficult task, given that the kettle used did not have a full-sweep agitation system or adequate pumping capabilities. In fact, in the first attempt to mix the fibers with the asphalt, the asphalt was heated above 300°F (149°C) to foster the mixing process. This, of course, melted the fibers and the batch had to be discarded.

Preparation of the second batch was controlled more carefully. While it took significantly longer to mix (2 to 3 hours), a satisfactory product was obtained. The subsequent application also was successful, despite the strain placed on the kettle unit's pump.

Self-Leveling Silicone

Dow Corning 890-SL self-leveling silicone was placed in two replicate test sections at each transverse crack-seal site. Once the experimental cracks were cut, the standard installation sequence consisted of:

1. Light sandblasting of the crack reservoirs
2. Airblasting with compressed air
3. Placement of backer rod at a nominal depth of 0.63 in (16 mm)
4. Installation of sealant, recessed 0.25 in (6.4 mm) below the pavement surface

The backer rod used in the experiment was 0.88-in (22.4-mm) diameter closed-cell Sof® Rod. A roller-type insertion tool was used to install the backer rod below the pavement surface. Figure 13 shows backer rod installation.

Because of the small amount of material required for the experiment, 29-oz (857-ml) cartridges of 890-SL were purchased instead of the 40-gal (151-L) drums typically used in sealing projects. Both manual and air-powered caulking guns were used to dispense the silicone into the cracks. Figure 14 shows the in-place, recessed silicone.

Because of the unfamiliarity associated with installing 890-SL, a few construction mistakes occurred at the initial installation at Abilene. First, a few segments of sealant were placed too high (≤ 0.13-in [3.3-mm] recess), which often enabled vehicle tires to pull the material out during the curing process. A 0.25-in (6.4-mm) recess was used at the remaining test sites.

Second, several seals became contaminated with sand particles because the sand from the sandblasting operation had not been blown completely off the roadway and shoulder. Measures were taken at the other sites to prevent this from happening.

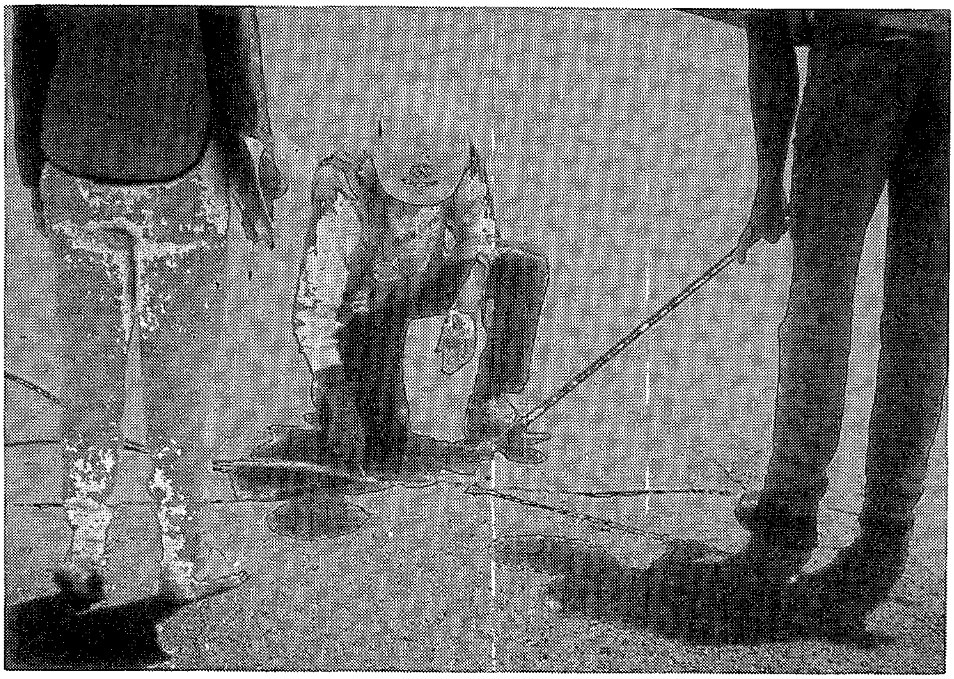


Figure 13. Backer rod installation

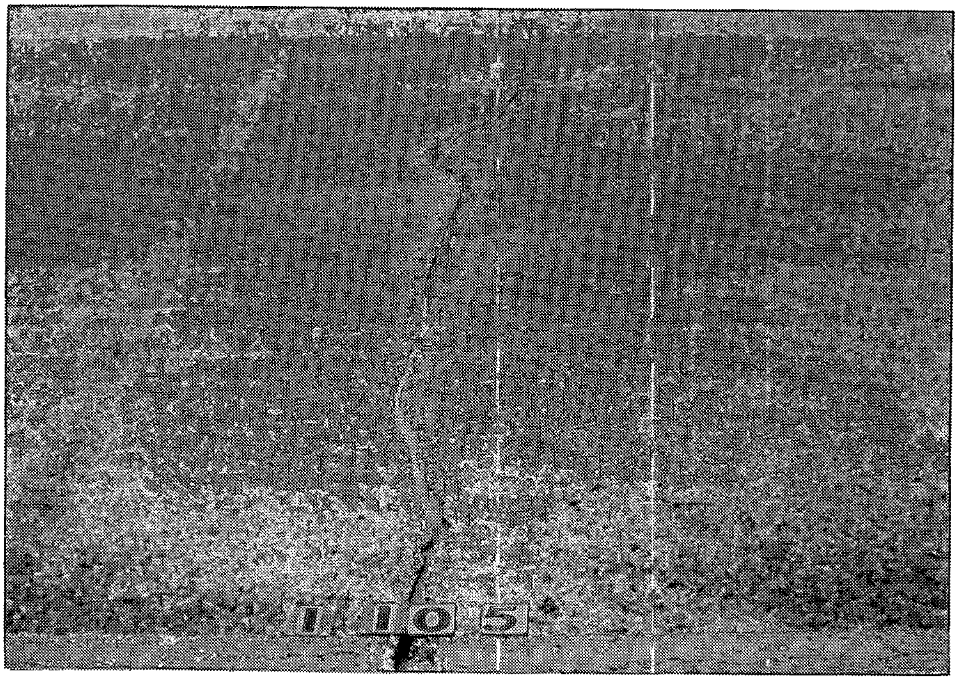


Figure 14. Dow Corning 890-SL deep reservoir-and-recess configuration

As mentioned previously, the standard 890-SL installation method (E-5) was replaced at the Wichita adverse-conditions subsite by two different methods (E-6 and F-7). In one section, method E-6 was used. This involved the elimination of light sandblasting, leaving only conventional airblasting for crack cleaning. This time-saving method was included to evaluate its cost-effectiveness. In the second section, method F-7 was employed. Here, a more shallow cut (0.5 in [12.7 mm] deep) was made and the reservoir was sandblasted and airblasted. Backer tape was then placed at the reservoir bottom instead of using backer rod. Because of the irregularity of the crack reservoir, it was more difficult to place the tape than to use backer rod.

Asphalt Rubber

The asphalt rubber product Crafco AR2 was placed as a filler material at the Prescott test site. Consisting of a selected blend of asphalt cement and vulcanized, granulated crumb rubber, this product is packaged in boxes containing two 25-lb (11.3-kg) blocks of material. The recommended heating temperatures range from 350° to 390°F (177° to 199°C).

The installation of AR2 took place without any construction problems. Crack preparation in all four AR2 sections was accomplished by conventional airblasting. The product was placed in the flush-fill configuration in two sections and in the simple band-aid format in the other two sections. Since most segments of the longitudinal crack were fairly wide (> 0.25 in [6.4 mm]), the crack usually was filled from the bottom up, overfilled, and then struck off with the appropriate squeegee. The high rubber content associated with AR2 resulted in a viscosity that resembled fiberized asphalt more than rubberized asphalt. However, it was easier to squeegee this material than fiberized asphalt.

Emulsion

Witco CRF was another filler material installed at Prescott. This proprietary (modified) emulsion is supplied in 55-gal (208-L) drums and requires no heating. The drum was loaded on the tailgate of a pickup truck, and was rolled and rotated end-over-end a few times to disperse asphalt particles that might have settled to the bottom during storage.

Two replicate sections of CRF were installed in the experiment. In these sections, crack cleaning was accomplished by conventional airblasting, hand-held pour pots were used to place the emulsion into the cracks, and a flush squeegee was used to strike off excess material. Figure 15 shows the placement of CRF in the flush-fill configuration.

Two basic problems were experienced with the installation of CRF. First, throughout the test sections a few short segments of deep, wide cracks permitted the highly liquid emulsion to run down into the pavement base, necessitating repeated applications to successfully fill the segments. Although the manufacturers recommendations suggested the placement of sand at the bottom of deep, wide cracks to serve as a barrier, such action was not taken in this case because of the small number of sizable cracks.

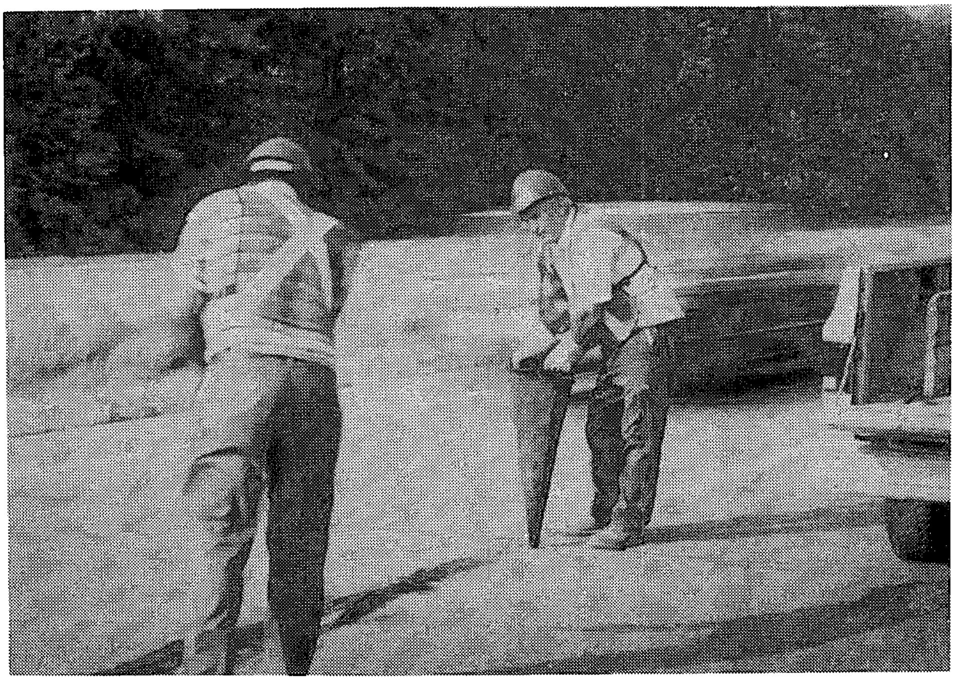


Figure 15. Witco CRF flush-fill configuration

Second, although lane closures were maintained for a few hours after placement, CRF tracked heavily when exposed to traffic. The emulsion typically "broke" within 30 minutes after application, and had formed a skin prior to the lane opening. Obviously, however, traffic was able to dislodge a good portion of the material from the crack. In this case, sand should have been used as a blotter to prevent tracking.

Equipment

Equipment played a crucial role in the experimental installations. Most participating agencies either possessed or could readily obtain the equipment necessary for getting the job done. However, a few special arrangements for equipment had to be made by the project staff prior to the installations. These arrangements included the following:

- Crafco Model 200 rotary-impact router (and operator) for use in Abilene
- L.A. Manufacturing Model "C" hot compressed-air lance for primary use in Abilene and backup use in Wichita and Des Moines
- Cimline Model 200 melter-applicator specially adjusted for use with fiberized asphalt application at Wichita and Des Moines

With the exception of configurations A and B at the two Wichita subsites, rotary-impact routers manufactured by Crafco were used to create reservoirs for the hot-applied materials at each crack-seal site. Pressed with a considerable amount of crack cutting and only one available router, it was decided at Wichita that two Cimline random crack saws, equipped with 8-in (203-mm) diamond blades, would be used to facilitate the cutting operations. These saws were not quite as productive as the routers, but provided smoother reservoir sidewalls, the effect of which will be assessed in future analyses. Figures 16 and 17 show the rotary-impact router and diamond blade dry saw used at the two Wichita subsites.

Although dry sawing was originally proposed for crack cutting in all the Dow Corning 890-SL sections, rotary-impact routers ultimately had to be used at Abilene and Elma. Maintenance crews at both of these sites made initial attempts to saw the cracks using 14-in (356-mm) diameter saws. However, the saws could not follow the cracks effectively and consequently caused significant damage. Because of this, the remaining cracks were cut with routers.

Various air compressors, made by Ingersoll Rand, Joy, Sullair, and Worthington, were used in the experiment. All of the air compressors used in the crack-seal installations were capable of providing 100 psi (689 kPa) of airblast. However, some of the units were not equipped with oil- and moisture-filtering systems. While oil contamination was not detected in these units, moisture was observed occasionally and confirmed by of holding a white cloth over the wand during operation. Such moisture was a cause for concern when airblasting was used to clean cracks immediately prior to installation.

Heat lances from three different manufacturers were used for final crack preparation: the L.A. Manufacturing model C, the Cimline Hot Rod, and the Seal All Torch. While each brand was very effective at removing debris and drying moisture, two general observations were noted. First, the push-button ignition switches furnished on some units often did not work and alternative lighting sources had to be used. Second, the units having high blast and heat capabilities (3000 ft/s and 3000°F [915 m/s and 1650°C]) were noticeably more efficient but required a extra caution to avoid burning the asphalt concrete. Figure 18 shows one of the heat lances used at Abilene.

Most sandblasting operations were conducted using Clemco blast machines connected to portable air compressors. Typically, one pass was made with the sandblaster along each side of a crack reservoir. A short time later, the reservoir and adjacent roadway were cleaned by airblasting. Sandblasting wands were held approximately 4 to 6 in (102 to 152 mm) from the reservoir. At Wichita, a wooden rod was attached to the wand to help direct the airblast (figure 19).

For the wirebrush-airblast cleaning procedure specified at Des Moines, a commercial power-driven brush was not available. As a substitute, a random crack saw, specially equipped with an 8-in (203-mm) wirebrush, was used. The wirebrush was somewhat stiff and had an occasional tendency to spall the crack-reservoir edges.

Many different kettle units, manufactured by Crafco, Cimline, Aeroil, and Marathon, were used for preparation and installation of hot-applied material. The kettles ranged widely in age, vat size, and heating and application features. In most instances, the materials took between 1.5 and 3 hours to heat to application temperatures. Heating time depended

Figure 16. Carbide-tipped rotary-impact router

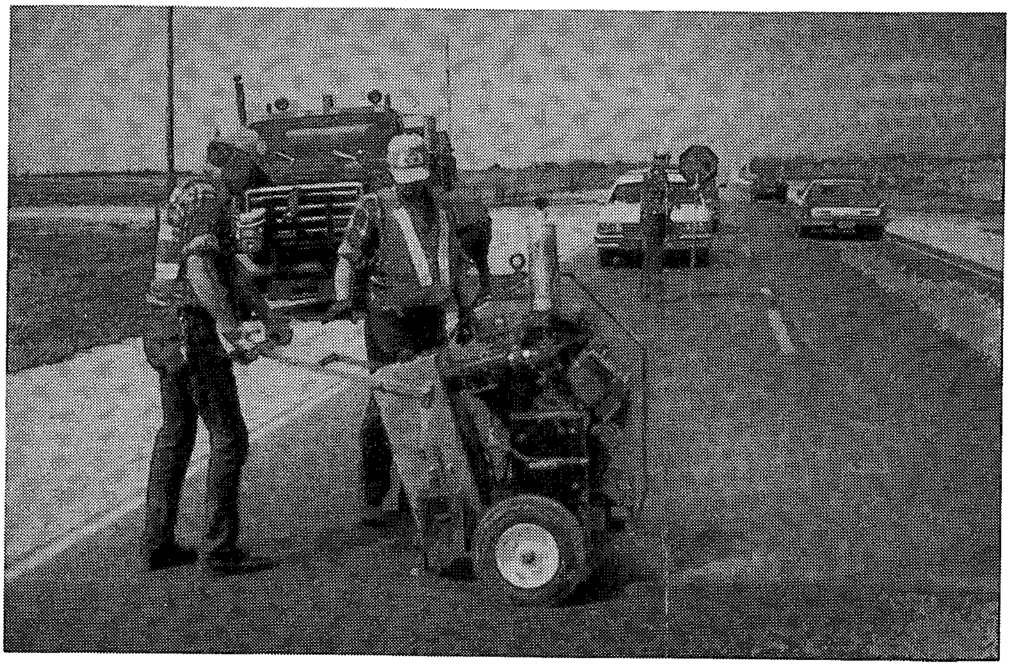


Figure 17. Random crack saw with 8-in (203-mm) diamond blade

Figure 18. Hot compressed-air lance

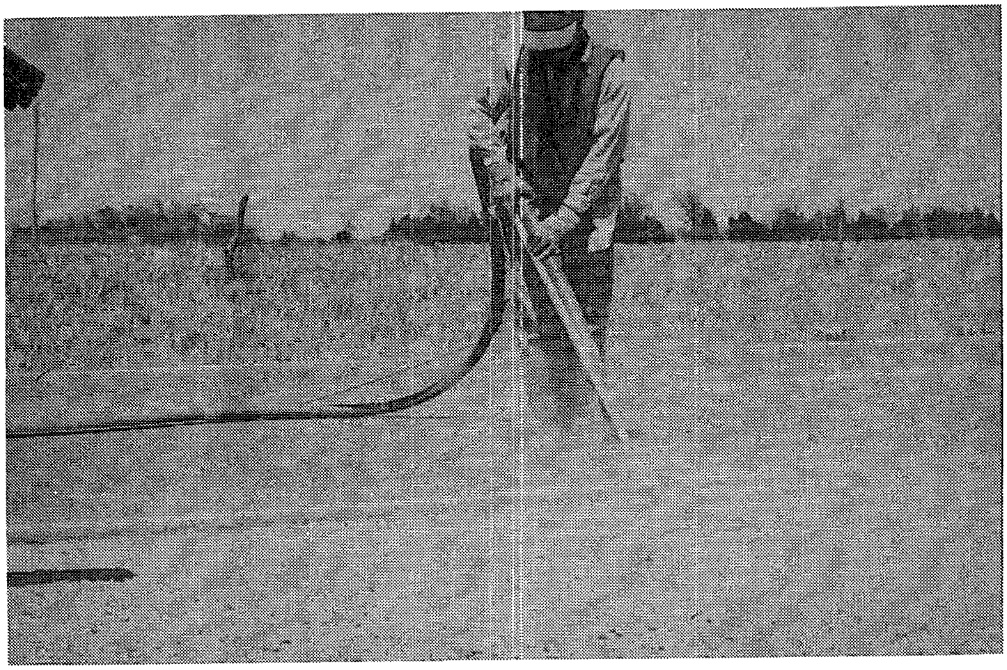


Figure 19. Sandblasting wand with wooden guide attached

primarily on the kettle size and the amount of material loaded into the vat. The 200-gal (757-L) melters usually required 1.5 to 2 hours, while the 400- and 500-gal (1514- and 1893-L) melters needed up to 3 hours.

Two additional factors that influenced heating time were the size of the material blocks and the type of agitation system on the kettle unit. Smaller blocks and full-sweep agitators provided greater exposure to heat, decreasing the amount of time needed for heating.

Two types of squeegees were fabricated by the project staff for the experiment: flush squeegees and band-aid squeegees. Both were prepared by forming 14-in (356-mm) straight industrial squeegees into a "U" configuration. The rubber inserts were removed beforehand and then reattached. A special cut (2.5 to 3 in [63.5 to 76.2 mm] wide x 0.13 to 0.19 in [3.3 to 4.8 mm] deep) was made in the rubber insert of the band-aid squeegee while the rubber insert of the flush squeegee was left flat.

Documentation

In addition to laying out the test site and coordinating the installations, project staff were charged with collecting as much pertinent information about the test site installations as possible. To simplify this task, eight different documentation forms were developed prior to the installations as part of the *EDRP*. Among the many items documented in these forms during the field installations were:

- Climatic conditions
- P-K nail measurements
- Periodic hot-applied material temperatures
- Crack conditions at placement
- In-place sealant dimensions
- Equipment brands and features
- Production rates
- Labor requirements

Appendix B includes a detailed discussion of the types of installation data collected and shows completed samples of the eight documentation forms used.

Photographic prints and slides were another form of documentation. Pictures of representative cracks in each test section were taken to help illustrate the condition of the cracks before, during, and after the installation process.

Table 6. Estimated volumes for primary material configurations

Configuration	Channel Dimensions, in[a]	Overband Dimensions, in[b]	Total Cross-Sectional Area, in^2	Volume (per 100 lin ft of crack), ft^3/100 lin ft	Volume, with 10 percent wastage, ft^3/100 lin ft
A	0.625 x 0.750	-	0.469	0.326	0.359
B	0.625 x 0.750	3.0 x 0.125	0.844	0.586	0.645
C	1.500 x 0.200	3.0 x 0.125	0.675	0.468	0.515
D	0.125 x 1.000	3.0 x 0.125	0.500	0.347	0.382
D[c]	0.175 x 1.500	3.0 x 0.125	0.638	0.443	0.487
E	0.625 x 0.375	-	0.234	0.163	0.179
G[c]	0.175 x 1.500	-	0.263	0.182	0.201

[a] Channel dimensions - nominal dimensions of material placed below pavement surface

[b] Overband dimensions - nominal dimensions of material placed above pavement surface

[c] Crack fill configurations

1 in = 25.4 mm
1 ft = 0.305 m

Cost and Productivity Data

Material Cost Data

The quantities of each primary material needed for the experiment were estimated prior to purchase. Estimates for each material were developed by summing the individual volumes associated with each proposed configuration and multiplying that sum by a wastage factor (usually 25 percent) and the material's unit weight. In every case, more than enough material was ordered.

Treatment application cost is an important factor in assessing overall cost-effectiveness. It is determined by multiplying the application rate (lb per 100 lin ft [30.5 m] of crack) by the total material cost (i.e., purchasing and shipping cost) on a per-pound basis. Since the actual application rates for each treatment during installation were unobtainable, tables 6 and 7 have been prepared as a resource for estimation of application rates and costs.

In table 6, the volume (per 100 lin ft [30.5 m] of crack) associated with each configuration has been computed, based on the nominal crack channel and overband dimensions listed. In table 7, the typical purchasing cost (January/February 1991) and typical unit weight for each material are provided. (Material shipping costs are not included because of the unavailability of some cost data and wide variations in the data obtained.) Application rates and application costs for each primary treatment were calculated based on the configuration volumes in table 6 and the material unit weights and costs in table 7.

Table 7. Primary material costs and estimated application rates and costs

Material	Material Cost, $/lb	Material Unit Weight, lb/ft^3	Estimated Application Rates for Primary Configurations, lb/100 lin ft of crack						Estimated Application Costs for Primary Configurations, $/100 lin ft of crack					
			A	B	C	D	E	G	A	B	C	D	E	G
Meadows Hi-Spec	0.285	69.4	24.9	44.8	35.7	26.5			7.10	12.75	10.15	7.55		
Crafco RS 515	0.41	72.2		46.6	37.2	27.6				19.10	15.25	11.30		
Koch 9030	0.35	68.7		44.3	35.4	26.2				15.50	12.40	9.15		
Meadows XLM	0.60	60.7		39.2	31.3	23.2				23.50	18.80	13.90		
Kapejo BoniFibers + AC	≈0.20 (≈1.25)[a]	65.9				25.2						5.05		
Dow Corning 890-SL	≈3.00	81.1					14.5						43.50 + 0.75	
AET Sof Rod (0.875 in)	$0.075/lin ft	-												
Asphalt Cement	≈0.15	62.7						12.6						1.90
Witco CRF	NA	61.8						12.4						NA
Crafco AR2	0.28	66.1				32.2		13.3				9.00		3.70
Hercules Fiber Pave + AC	≈0.24 (≈1.54)[a]	67.1				32.7						7.85		

[a] Cost of fibers only

NA Not Available

1 lb = 0.454 kg

1 lin ft = 0.305 lin m

1 in = 25.4 mm

Productivity

While the various operational procedures have been described throughout this section, two key aspects of these procedures have yet to be discussed. Productivity and labor requirements associated with sealing and filling operations are perhaps the most important factors because they influence treatment performance and account for roughly 80 percent of the costs, depending on the size of the project. Table 8 shows a summary of the typical labor, equipment, and time requirements for the various operations performed in the crack-treatment experiment.

Crack cutting typically was a one- or two-person operation, depending on the type of equipment used. For sawing operations, a spotter often was needed to help the saw operator maneuver the machine in difficult situations. Between 1 and 3 minutes per 12-ft (3.7-m) crack were typical for routing operations, whereas 2 to 5 minutes was the normal range for sawing operations. Obviously, crack spacing had an effect on production rate, but other factors did too; reservoir dimensions, pavement temperature, the type of aggregate in the asphalt concrete, and the level of wear on the cutting blades all seemed to affect the speed of the operations. Crack cutting was the limiting operation in the initial crack preparation phase.

Table 8 shows that sandblasting was the most labor-intensive and time-consuming crack-cleaning operation. Three—or sometimes four—persons were necessary for performing this task; airblasting and hot airblasting operations required two persons.

The installation of cold-applied materials generally required more labor and time than the installation of hot-applied materials. This was especially true of the installation of emulsions, where two pour pots were needed to expedite the operation. Silicone installation would have gone much more quickly had 40-gal (151 L) drums and appropriate pumps been used. The 29-oz (0.9-L) silicone cartridges had to be replaced continually, as two cartridges would seal only about three cracks.

In most instances, material application was the constraining operation in the final crack preparation and material installation phase. Cleaning operations often were held back to allow for optimum material placement, while squeegeeing often was held up by material application.

Comments

To help ensure the proper installation of the sealant and filler products, material manufacturers were asked to provide a representative at the installations. However, the initial contacts were not made in time to permit the presence of representatives at the first installation at Abilene. Their guidance would have been beneficial at this site. Representatives usually were present at the other sites. However, in some cases, the manufacturers could not find or afford to send representatives to observe the installations.

Table 8. Typical requirements for various installation procedures

Procedure	Required Labor (Number of Persons)	Required Equipment	Estimated Time for 10 Transverse Cracks, min[a]		Estimated Time for 300-ft of Longitudinal Crack, min[a]
			50-ft Spacing	95-ft Spacing	
Crack-Cutting					
Routing	1	Carbide-tipped rotary-impact router	20 to 25	20 to 30	–
Sawing	2	Diamond blade dry saw	30 to 40	50 to 60	–
Crack-Cleaning					
Airblasting	2	Air compressor, truck	12 to 18	15 to 20	10 to 15
Hot Airblasting	2	Hot compressed-air lance, air compressor, propane tank, truck	20 to 25	20 to 30	–
Sandblasting	2 to 3	Sandblaster, air compressor, truck	30 to 35	45 to 55	–
Wire Brushing	1	Wire brush unit or equivalent	NA	30 to 40	–
Hot-Applied Installation					
Material Application	2	Approved melter/applicator, truck	15 to 20[b]	25 to 30[b]	10 to 15[b]
Material Finishing	1	Squeegee	15 to 20	25 to 35	10 to 15
Silicone Installation					
Backer Rod Placement	1 to 2	Properly adjusted roller tool	12 to 18	20 to 25	–
Silicone Placement	2	Manual or air-powered caulking gun	35 to 45[b]	50 to 65	–
Emulsion Installation					
Emulsion Placement	2 to 3	Cornucopia pot(s), truck	–	–	20 to 30[b]
Material Finishing	1	Squeegee	–	–	20 to 30

[a] Times do not include operational delays.

[b] Constraining operation.

NA Not Available.

1 ft = 0.305 m

The *EDRP* required use of rotary-impact routers for crack-cutting in hot-applied material sections. Diamond blade dry saws were required for crack-cutting in the silicone sections. However, as discussed previously, rotary-impact routers were used in the silicone sections at Abilene and Elma, and diamond blade dry saws frequently were used in place of routers at Wichita. The stipulations in the *EDRP* were intended to allow for stronger performance correlations between test sites.

Because the effects of sealing conditions on performance were intended to be among the factors studied in this project, the ideal- and adverse-conditions subsites were included at Wichita. However, some of the test sections at Elma and the ideal subsite at Wichita could have been classified as adverse conditions, because the pavement systems were partially saturated during placement as a result of particularly wet weather at these locations (Elma receives roughly 85 in [2159 mm] of rain per year). Consequently, the presence of moisture in cracks was checked often and recorded prior to installation. Similarly, the formation of bubbles in hot-applied materials after placement was frequently monitored and documented.

3

Material Testing

Laboratory Tests Performed

Two sets of laboratory tests were conducted on the primary experimental materials: initial tests and supplemental performance tests. Initial tests ensured that the materials used in the experiment met the specifications maintained by the manufacturer. Supplemental performance tests were intended to strengthen correlations between laboratory-determined engineering properties and actual field performance.

In all, nine of the ten primary material products used in the experiment underwent laboratory testing. Each of the six primary sealant products distributed to the various sites for installation originated from one production batch. For instance, the Hi-Spec material placed at Abilene came from the same batch as the Hi-Spec placed at Elma, Wichita, and Des Moines. Samples of the six primary sealant materials and three primary filler materials were taken during installation from the Abilene and Prescott sites, respectively, and shipped to the laboratories for testing.

Several of the initial tests, particularly those run on the silicone and rubber-modified asphalt materials, were performance tests. These included ASTM D 3407 bond, resilience, penetration, and flow tests, as well as ASTM D 412 tensile stress and elongation tests. The remaining initial tests were general property-indicator tests. These included such tests as specific gravity, tack-free time (silicone), viscosity (CRF emulsion), and denier (fiber). The test procedures followed for each material product are listed in table 9.

The battery of supplemental performance tests was assembled to investigate major performance properties such as flexibility, adhesiveness, cohesiveness, resilience, and durability. At least one innovative or standard test was selected to correspond with each of these important properties. Most of the tests originally identified were performed successfully with few or no modifications. There were, however, a couple of tests that could not be conducted because of procedural or equipment problems. Table 10 lists the original battery of tests, the properties sought, and general comments about the conduct of each test.

Table 9. Designated initial test procedures

Material Type	Test Procedures
Rubberized Asphalt	ASTM D3407 and D70
Modified Rubberized Asphalt	Modified ASTM D3407 and D70
Silicone	ASTM C603, C679, D412, D1475, and D2240
Asphalt Rubber	ASTM D5078 and D70
Fiber	ASTM D1577, D3937, D2256, and D882
Emulsion	ASTM D244

Table 10. Target properties and modifications of supplemental performance tests

Test	Derived Procedure	Pertinent Property(s)	General Comments
Cone Penetration @ 0°F	ASTM D3407	Low temperature flexibility	Conducted @ 0°F
Softening Point	ASTM D36	High temperature tracking potential	None
Cold Bend	Utah Test	Cohesion	Conducted @ 0°F
Force Ductility	ASTM D113 & Utah Test	Flexibility	Ductility test run @ 39.2°F
Tensile Adhesion @ 75°F 1. PCC blocks 2. AC blocks 3. AC blocks, H_2O-immersed	ASTM D3583	Adhesion/cohesion	Standard test run using PCC blocks. Alternative tests run using AC blocks (water-soaked and unsoaked)
Modulus @ 1. 75°F 2. 39°F 3. 0°F	ASTM D412	Flexibility	Conducted at separation rate of 2 in/min instead of 20 in/min. Tests initially set up for 0°, 75°, and 140°F. Latter temperature changed to 39°F due to extreme material softness at 140°F.
Modulus after 504 hours Artificial Weathering	ASTM G23 & ASTM D412	Durability/flexibility	Performed @ 75°F only on silicone; rubber-modified asphalt sealant samples ran during hot cycles of weathering phase.
Track Abrasion	ASTM D3910	Durability	Test discontinued due to shearing and pull-up problems.
Modified Bond Tests 1. Reservoir configuration 2. Recessed band-aid configuration 3. Simple band-aid configuration	ASTM D3407	Adhesion/cohesion	PCC blocks and sealant material formed to required configuration. Samples subjected to 10 cycles of 100% extension @ -20°F and recompression to original width at room temperature.

1 in = 25.4 mm
°C = 5/9*(°F - 32)

Table 11. Initial test results for rubberized asphalt products and corresponding requirements

Test	D 3405 Criteria	Hi-Spec	Modified ASTM D3405 Criteria	RS 515	9030	XLM
Cone Penetration, dmm (77°F)	≤ 90	62.5	60 to 180	75.5	114.5	148.0
Flow, mm (77°F)	≤ 3	0.0	≤ 5	1.0	0.0	2.5
Bond, 50% extension (-20°F)	3 cycles	Pass	▨	▨	▨	▨
Bond, 100% extension (-20°F)	▨	▨	3 cycles	Pass	Pass	Pass
Resilience, % recovery (77°F)	≥ 60	63.7	≥ 35	38.3	83.7	16.0
Asphalt Compatibility	No failure	Pass	No failure	Pass	Pass	Pass

°C = 5/9*(°F - 32)
1 in = 25.4 mm

Test Results

In all, 38 tests were attempted, of which 36 were completed successfully. Generally, two or three replicates of each test were performed to provide more reliable results. The averages of these replicates were used in the analyses. With one exception, all nine material products tested passed the various initial test requirements. The one material that did not pass, Meadows XLM, failed only to meet the resilience specification of 35 percent recovery, as shown in table 11.

Looking at the initial test results for the four rubber-modified sealants, it is interesting to note the differences in softness (cone penetration test at 77°F [25°C]) and resilience. By far the softest material, XLM, exhibited poor resilience (16 percent recovery), seemingly making it susceptible to stone intrusion. The second-softest sealant, 9030, showed the best resilience with 84 percent recovery. Hi-Spec and RS 515 showed similar degrees of softness, but RS 515 was much lower in resilience than Hi-Spec (38 and 64 percent recovery, respectively).

Table 12 presents mean results for some of the more meaningful test parameters in the supplemental performance test program. Considered to be a good cold weather performance indicator, cone penetration at 0°F (-18°C) was performed on all of the primary materials except silicone and asphalt cement. In comparing penetration at 77°F (25°C) with penetration at 0°F (-18°C) for the four rubber-modified sealants, 9030 exhibited the smallest percentage of drop (47 percent), followed by XLM (60 percent), RS 515 (64 percent), and Hi-Spec (76 percent). Both fiberized asphalt materials completely resisted penetration at 0°F (-18°C), indicating highly inflexible materials at low temperatures.

Table 12. Supplemental test matrix for primary treatment materials

Test Procedure	Test Description	Meadows Hi-Spec	Crafco RS 515	Koch 9030	Meadows XLM	Kapejo Fiberized Asphalt	Dow Corning 890-SL	Witco CRF	Crafco AR2	Hercules Fiberized Asphalt
D3407	Cone Penetration (0°F)	15	27	60	60	0		23	4	0
D36	Softening Point	186	211	199	192	122		78	162	123
Utah	Cold Bend (0°F)	Pass	Pass	Pass	Pass					
D113/Utah	Force Ductility (39.2°F) Max Elongation, in	17.3	17.3	12.0	10.8	2.0			12.2	55.0
	Stress, lb/in^2	2.1	1.1	1.4	0.3	17.5			1.9	7.4
D3583	Tensile Adhesion (Std, 75°F) Max Elongation, %	704	515	441	547		606			
	Type of Failure	Adh	Adh	Adh	Adh		Adh/Coh			
	Tensile Adhesion (Modified #1, 75°F) Max Elongation, %	690	760	303	607		627			
	Type of Failure	Adh	Adh	Adh	Adh		Adh/Coh			
	Tensile Adhesion (Modified #2, 75°F) Max Elongation, %	683	680	336	539		486			
	Type of Failure	Adh	Adh	Adh	Adh		Adh			
D412	Modulus Test (0°F) Tensile Strength, lb/in^2	61.1	66.2	16.4	14.9		45.1			
	Ultimate Elongation, %	425	868	1093	1035		4566			
	Stress @ 150% Elongation, lb/in^2	46.2	37.9	7.3	4.3		9.4			
	Modulus Test (39°F) Tensile Strength, lb/in^2	33.0	26.5	7.7	10.5					
	Ultimate Elongation, %	960	1255	620	960					
	Stress @ 150% Elongation, lb/in^2	18.9	13.6	4.7	2.8					
	Modulus Test (75°F) Tensile Strength, lb/in^2	10.6	7.7	8.6	4.8		43.8			
	Ultimate Elongation, %	863	910	832	915		2096			
	Stress @ 150% Elongation, lb/in^2	7.1	3.8	4.6	2.0		11.0			
D3407 Modified	Modified Bond #1 (77°F) % Debonding	1.2	0.2	0.0	0.0		0.0			
	Modified Bond #2 (77°F) % Debonding	0.5	5.2	6.3	0.0					
	Modified Bond #3 (77°F) % Debonding	0.7	2.9	0.7	0.0					

°C = 5/9*(°F - 32)
1 lb/in^2 = 6.89 kPa

As expected, softening points for the rubber-modified materials were sufficiently high (>160 °F [71°C]) to prevent tracking problems in the summer. CRF and the two fiberized asphalt materials, however, exhibited low softening points (<125°F [52°C]). This is an important observation, especially for the fiberized asphalt materials that were placed in the simple band-aid configuration.

In the cold-bend test, 0.125 x 1 x 1 in (3 x 25 x 25 mm) material samples were bent to a 90° angle over a 1.125-in (29-mm) mandrel in a period of 2 seconds. The samples and mandrel were conditioned to 0°F (-18°C). None of the four rubberized asphalt sealants developed cracks, thereby passing the test.

The force-ductility test, a modified version of the ASTM D 113 ductility test, was conducted at 39.2°F (4°C). In the test, briquette material specimens were pulled apart at a rate of 0.4 in/min (10 mm/min) until ultimate rupture. Load-deformation plots were generated from each run. Results from the test showed XLM incurred the lowest buildup of force through 150 percent elongation, followed by RS 515, 9030, AR2, Hi-Spec, and the two fiberized materials (see figure 20).

In a similar test—the ASTM D 412 modulus test—dumbbell-shaped material samples were pulled apart at a rate of 2 in/min (51 mm/min) until rupture (see figure 21). Results showed that XLM and 890-SL consistently developed the lowest forces at various temperatures, as illustrated in figures 22 through 24. At 73°F (23°C) and 50 percent elongation, Hi-Spec exhibited forces four times those of XLM and 890-SL. For RS 515 and 9030, the factor was approximately two. At the more critical temperature of 0°F (-18°C), the factors of force over 890-SL at 50 percent elongation were 14.8 for Hi-Spec, 12.6 for RS 515, 2.8 for 9030, and 1.6 for XLM.

Further examination of the force-elongation plots shows 890-SL was least affected by temperature. In going from 73°F to 0°F (25°C to -18°C), 50 percent more force was required. This compares with 167 percent for XLM, 115 percent for 9030, 950 percent for RS 515, and 517 percent for Hi-Spec.

The tensile adhesion test, illustrated in figure 25, was conducted to provide an indication of a material's ability to extend without experiencing cohesion loss or adhesion loss. Three variations of the test were performed on each of the four rubberized asphalt sealants and the silicone sealant. The first variation used portland cement concrete blocks, and the second variation used asphalt concrete blocks. A third variation, also using asphalt concrete blocks, included a phase during which the sealant-block system was soaked in water prior to testing. In each variation, 0.5 x 2.0 x 2.0 in (13 x 51 x 51 mm) material specimens were tested at 77°F (25°C) using constant separation rates of 0.5 in/min (13 mm/min).

The tensile adhesion test results yielded a few interesting observations. First, the small material shape factor (width/depth = 0.25) associated with this test produced much higher extension loads than in other load-deformation tests. This effect was most apparent with 890-SL silicone. Second, water-immersed specimens normally incurred greater stresses during extension than nonimmersed specimens. Likewise, specimens bonded to AC blocks

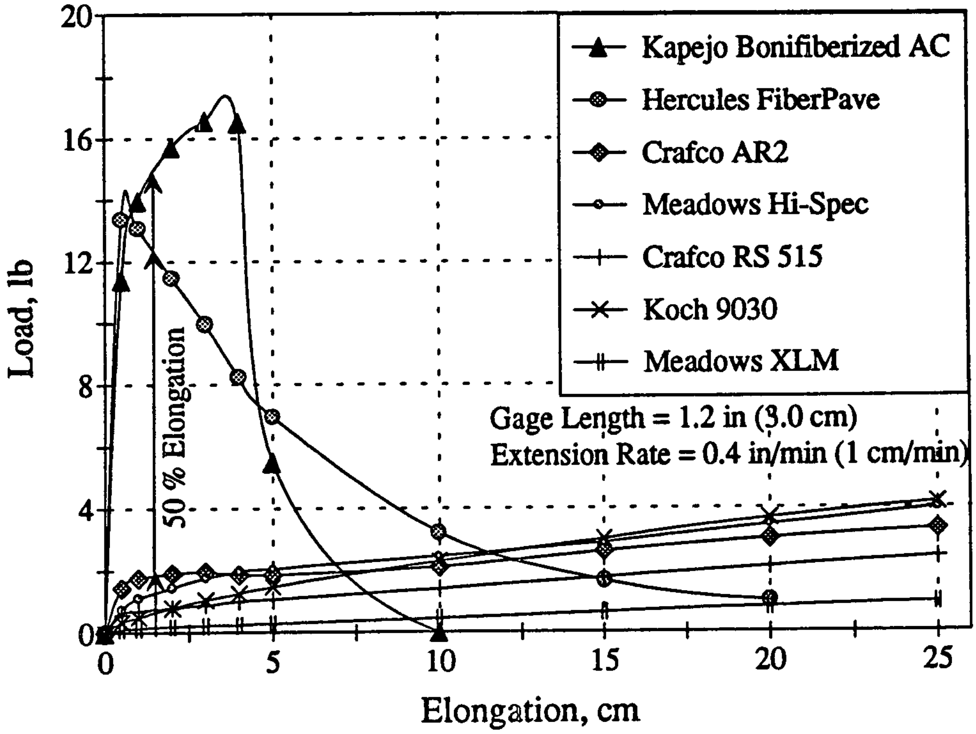


Figure 20. Force-ductility load-elongation curves for various primary materials

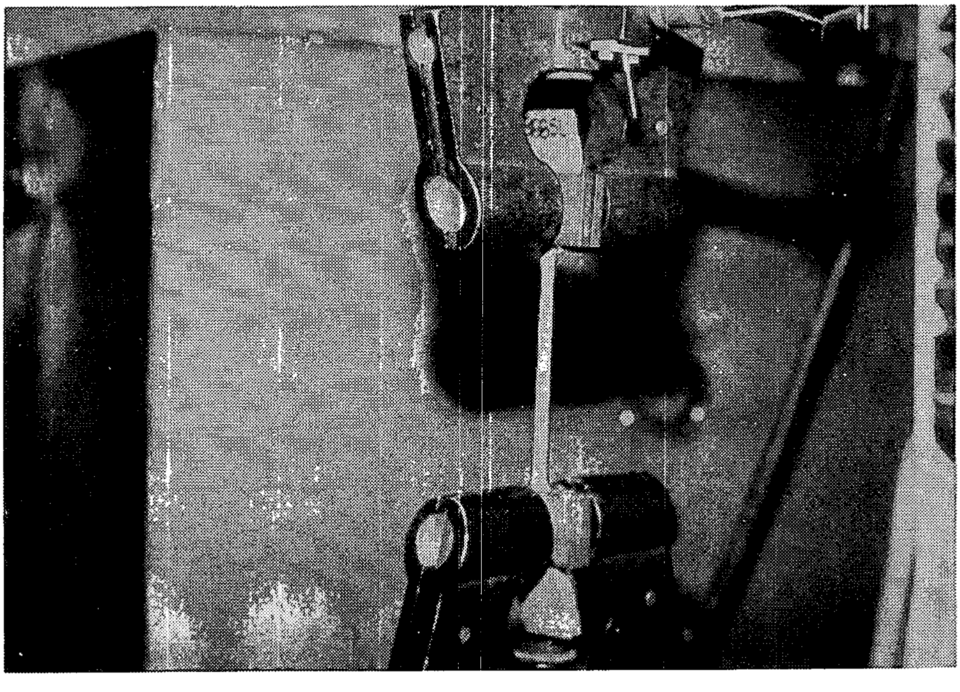


Figure 21. ASTM D 412 modulus testing

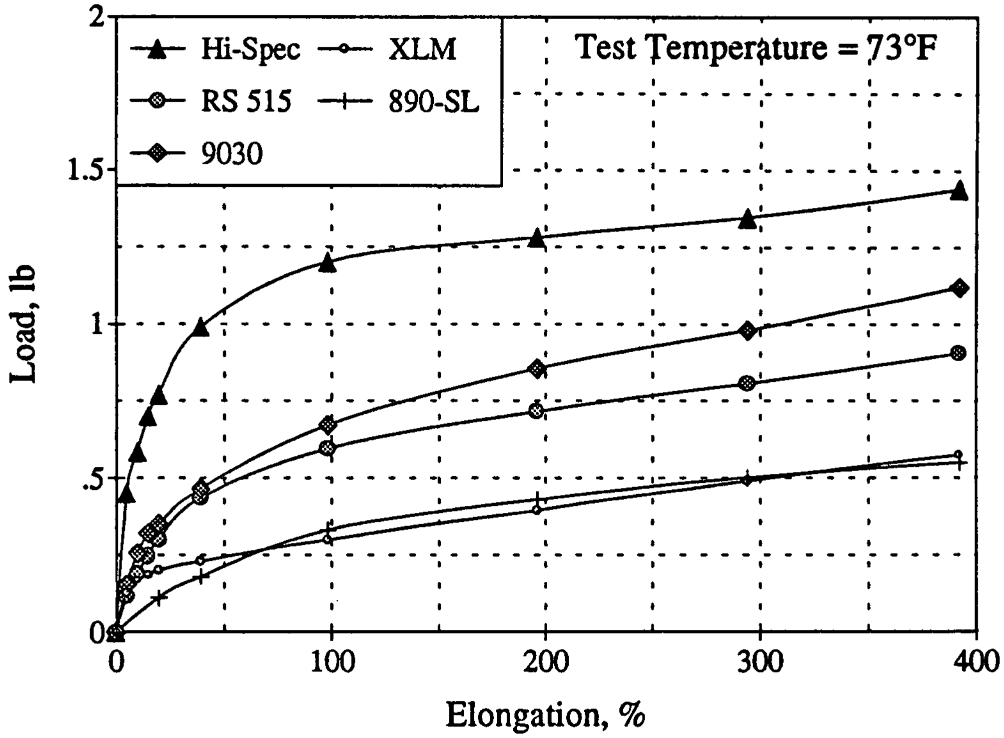


Figure 22. Load-elongation curves for modulus test conducted at 73°F (23°C)

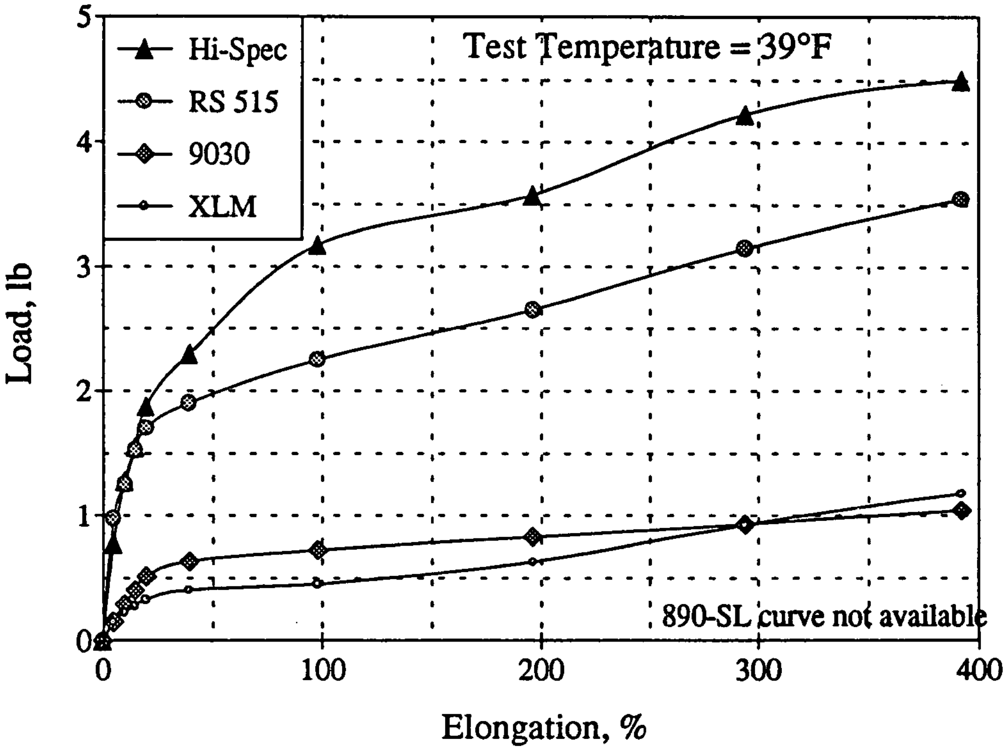


Figure 23. Load-elongation curves for modulus test conducted at 39°F (4°C)

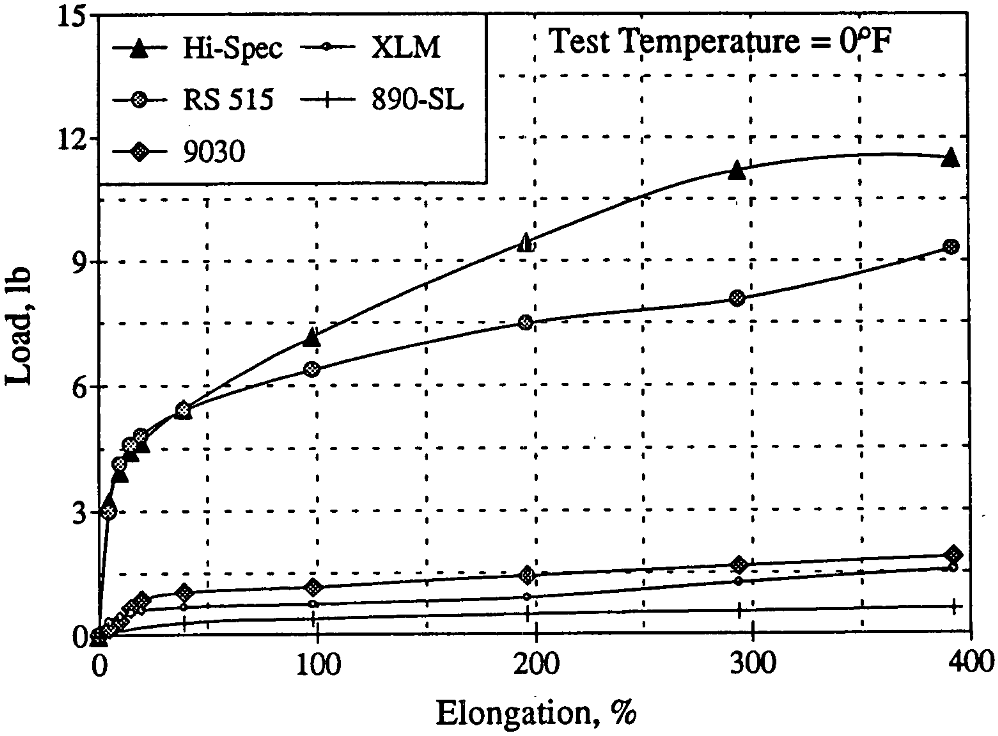


Figure 24. Load-elongation curves for modulus test conducted at 0°F (-18°C)

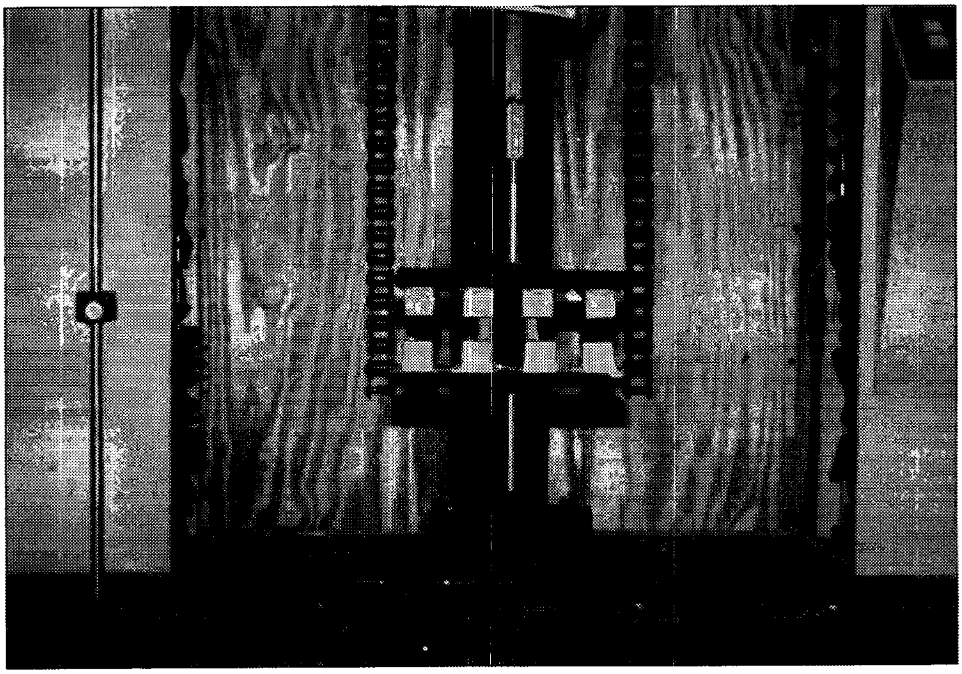


Figure 25. ASTM D 3583 tensile adhesion testing

normally incurred greater stresses than specimens bonded to PCC blocks. Finally, Koch 9030 exhibited adhesion failure at significantly lower deformations. Maximum elongations for Hi-Spec, RS 515, XLM, and 890-SL were between 57 and 92 percent greater than the maximum elongation exhibited by 9030.

Three modified bond tests (ASTM D 3407) were devised to test sealants placed in shapes representative of configurations B, D, and E used in the field. In each test, materials were subjected to 10 cycles of 100 percent extension at -20°F (-29°C) and recompression at room temperature.

XLM showed excellent performance in all three test formats, experiencing no adhesion or cohesion loss. Both 890-SL and 9030 also showed no losses when placed in the recessed format. With the exception of XLM, sealants placed in the recessed band-aid configuration became fully debonded at the bottom of the crack reservoir. The 9030 sealant exhibited the highest percentage of debonding in this format (6.3 percent).

A complete summary of initial and supplemental performance test results are provided in table C-3 of appendix C. In addition, figures C-1 through C-10 illustrate the various D 412 and D 3583 load-deformation curves for different sealants.

4

Field Performance

Since the spring/summer 1991 installation, each treatment has been evaluated for field performance five times. With the exception of the Prescott crack fill site, which was constructed in August 1991, the original plan of conducting evaluations at strategic times after installation was closely followed. These evaluations took place at the following intervals:

- 1 month
- 3 months
- 9 months
- 12 months
- 18 months

The first evaluation was conducted with the intention of recording any construction-related failures or distresses. With the notable exceptions of 890-SL and XLM at Abilene, such observations were limited. As expected after installation, 890-SL had experienced some pull-out problems because of an inadequate recess, as well as considerable sand intrusion during the curing process. XLM, on the other hand, showed significant early overband wear as a result of overheating prior to placement.

The third evaluation at each site was conducted in January and February 1992 in order to determine the extent to which cracks were opening during the coldest time of year. The ages of the crack fillers and sealants at that time were approximately 6 and 9 months, respectively. As a result of the combined action of crack movement and overband wear, significant increases in treatment failure were recorded during these evaluations.

The fifth and final round of evaluations under the H-106 contract was performed in the fall of 1992. While some treatment distresses had progressed steadily since the third- and fourth-round evaluations, the overall number of failures increased only slightly, as seen in figure 26.

Prior to each evaluation, the project staff was responsible for contacting the participating state maintenance agency and selecting the day(s) to do the evaluation. Normally, the smaller test sites, such as Abilene, Elma, and Prescott, were evaluated in 1 day. The two Wichita subsites and the Des Moines site, however, normally took 2 days to evaluate. For each evaluation, an additional day was allotted in case of rain or the need for test section remarking.

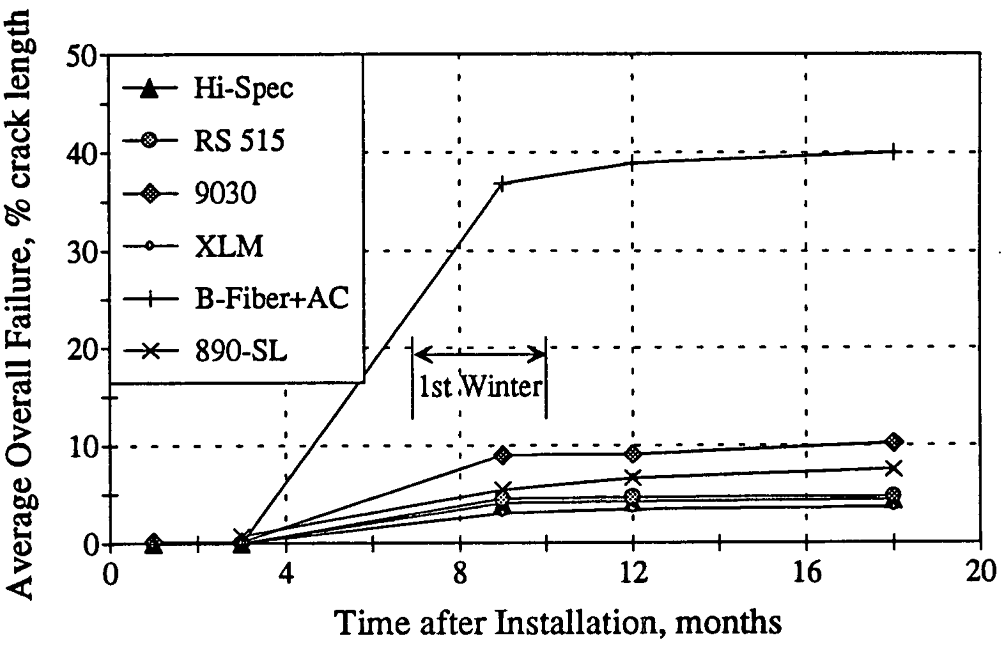


Figure 26. Time progression of primary sealant failures

Traffic control for the evaluations at Abilene, Elma, and Des Moines normally were conducted as moving operations, using two or three trucks equipped with arrowboards and crash attenuators. At Prescott, the passing lane was coned off, while at Wichita, flagpersons were used.

Performance Data Collection

Several types of performance data were collected routinely in the crack-treatment field evaluations. Although test sections consisted of either 10 transverse cracks or 12 longitudinal crack divisions, only the treated cracks or crack divisions in each section were inspected regularly.

As with the initial inspection of the cracks treated in the experiment, the treatments were examined over 2- and 4-ft (0.6- and 1.2-m) segments (i.e., lane position) at the crack-seal sites and over 5-ft (1.5-m) segments at the crack-fill site. Along each segment, the treatments were examined for the presence, amount, and severity of the following distresses:

- Weathering
- Pull-out
- Overband wear
- Tracking

- Extrusion
- Stone intrusion
- Adhesion loss
- Cohesion loss
  - tensile/shear forces
  - bubbling
- Edge deterioration

Appendix D includes a more detailed discussion of the evaluation criteria associated with each of these distresses.

Most distresses represented a reduction in a treatment's ability to perform its function (i.e., to keep water and incompressibles out of the crack channel). Examples of these distresses include partial-depth adhesion and cohesion loss and overband wear. On the other hand, some distresses, such as full-depth pull-outs and full-depth adhesion and cohesion loss, signified a treatment's failure to perform its function. These distresses were termed "failure distresses." The total amount of failure distress observed in a treatment formed the basis for performance comparison.

In the majority of the cases, only one failure distress was observed over a particular portion of crack. Sometimes, however, two types of failure distress were observed over the same portion of crack. To avoid overassessing the actual amount of treatment failure, the overall amount of failure for each evaluation segment was recorded during the evaluations. Thus, if 4 in (102 mm) of full-depth adhesion loss and 4 in (102 mm) of high-severity secondary cracking were found to exist over the same portion of the crack, 4 in (102 mm) of overall failure were recorded.

In the first evaluation, the presence of five construction-related distresses were considered. These included construction bubbles, material sagging, sand intrusion, overband wear, and tracking. As mentioned previously, the most notable construction-related distresses were observed at Abilene, where 890-SL experienced sand intrusion and pull-outs during curing and XLM exhibited high levels of overband wear.

Simultaneously with the treatment evaluations, distance measurements between P-K nail sets were taken across each experimental crack using the 12-in (305-mm) digital caliper. These measurements were taken to determine how much each crack moves during a year. Climatic data, such as air temperature and cloud cover, were recorded after each test section evaluation was completed.

Finally, in addition to the evaluation and P-K distance measurements, nondestructive and destructive tests were performed on some of the treatments. Coin tests were performed regularly on the elastic-type seals during moderate- and warm-weather evaluations (temperature > 50°F [10°C]) to give a rough indication of the material's elasticity. Pull-out tests were occasionally conducted during cold-weather evaluations to indicate material flexibility.

Performance evaluation forms were prepared before the first round of evaluations as part of the *Evaluation and Analysis Plan (EAP)*.[2] Examples of completed evaluation forms are provided in figures D-1 through D-3 in appendix D.

Summary of Performance Data

This section presents a general overview of crack treatment performance to date. Appendix D provides numerous tables and figures that provide more detail about the various treatment distresses recorded during each evaluation.

Crack-Seal Experiment

Construction bubbles were prevalent in many of the hot-applied seals placed at Wichita and Elma. These bubbles primarily were the result of intermittent rain that kept underlying base layers partially or fully saturated throughout the installation. Although cleaning/drying operations normally removed existing moisture along bond interfaces, moisture often had a tendency to be drawn up from the crack depths into the hot sealant, producing bubbles. While construction bubbles did evolve into both partial- and full-depth cohesion losses, the overall amount of these distresses was well below 1 percent.

Crack movement, as experienced between the time of installation and the winter evaluation (evaluation 3), was most significant at the Wichita and Des Moines test sites. As shown in table 13, the average crack openings at these sites were aproximately 0.06 in (1.5 mm), compared to 0.01 and 0.02 in (0.3 and 0.5 mm) for Elma and Abilene and 0.04 in (1.0 mm) for Prescott.

The primary reason for the differences in crack movement observed among sites was the observed changes in air temperature between the time of installation and the winter evaluation. For example, the average change in air temperature for Des Moines was 52°F (29°C), whereas for Elma it was 8°F (4°C). At Abilene, the effect of the geofabric interlayer appeared to restrict crack movement. While the average change in air temperature in Abilene was similar to that in Wichita, crack movement was roughly one-third that experienced at Wichita. As expected, the longitudinal crack at Prescott underwent minimal movement over a wide range in air temperature (86° to 15°F [30° to -9°C]).

The primary distresses observed to date include overband wear, pull-outs, adhesion loss, cohesion loss (tensile forces), and edge deterioration. The high-severity or full-depth levels of the last four distresses constituted nearly all of the failures recorded in the experiment.

Figure 27 shows the relative overband wear levels based on data averaged over all sites. From a material standpoint, fiberized asphalt and the low-modulus rubberized asphalt sealants generally have experienced greater wear. Tackiness and the lack of resilience in warm weather have caused the fiberized asphalt overbands to experience both wear and a flattening

Table 13. Average air temperatures at critical periods and corresponding crack movements

Test Site	Average Air Temperature During Installation, °F	Average Air Temperature During Winter Evaluation, °F	Average Crack Movement, in	Crack Movement Range, in
Abilene	75	53	0.020	0.000 to 0.070
Wichita (Ideal)	62	33	0.062	0.000 to 0.137
Wichita (Adverse)	61	38	0.053	0.004 to 0.126
Elma	58	50	0.013	0.000 to 0.044
Des Moines	77	25	0.060	0.000 to 0.288
Prescott	86	15	0.041	0.020 to 0.086

°C = 5/9*(°F - 32)

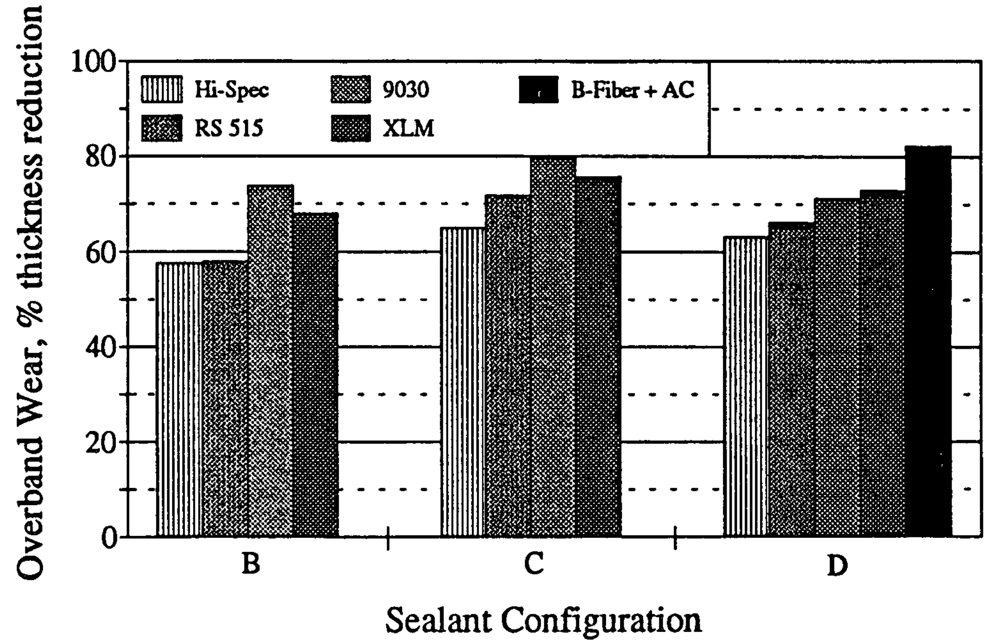


Figure 27. Average overband wear levels after 18 months (all sites)

effect not exhibited by the other sealants. Among the rubberized asphalt products, XLM and 9030 have experienced very high overband wear, followed by RS 515 and Hi-Spec.

As expected, traffic had a direct impact on overband wear, both on a site basis and a lane-position basis. Figure 28 clearly shows major distinctions in overband wear between Des Moines (20,700 two-way Average Daily Traffic [ADT]) and Elma (7,000 two-way ADT) for 10 overbanded sealants.

High-severity pull-outs accounted for less than 2 percent of all failures in the crack-seal experiment. Most pull-outs were observed at Abilene and Des Moines in overbanded seal sections. Figure 29 illustrates a typical full-depth pull-out of a 9030 band-aid seal at Abilene.

Full-depth adhesion loss accounted for about 8 percent of all crack-seal failures and were manifested primarily in configurations A, B, C, and E. Figure 30 shows the average adhesion loss among all sites for the various primary sealants. Except for Hi-Spec in configuration A and XLM in configuration C, the hot-applied sealants experienced little adhesion loss.

Approximately 82 percent of all seal failures emerged as full-depth cohesion loss due to tension created by crack movement. Figure 31 shows the average cohesion loss among all sites for the various primary treatments. The materials that experienced this type of failure most frequently were those that had little or no flexibility. For instance, CRS-2P emulsion placed flush in uncut cracks at Des Moines showed 100 percent failure with the opening of cracks in colder weather. Fiberized asphalt also experienced considerable amounts of cohesion failure at Abilene, Wichita, and Des Moines, because of the combination of high wear and substantial crack movement at these locations.

Cohesion loss was observed primarily in the simple band-aid seals. Typically, a crack in the sealant band forms directly over and along one of the transverse crack edges. The little material that actually penetrates the transverse crack at installation is normally unable to adhere to the sidewalls, thereby allowing full propagation of the crack to the surface of the seal.

The remaining 8 percent of all seal failures were manifested as high-severity edge deterioration. This type of failure distress occurred predominantly in the silicone and fiberized asphalt sections. An average of 10 percent of the crack length in fiberized asphalt sections exhibited spalling at the crack edges. This was particularly apparent at the Wichita subsites.

Nationally, the E-5 silicone treatment averaged 6 percent high-severity edge deterioration. The majority of these failures were attributed directly or indirectly to missed crack or secondary crack segments that were not sealed during installation. Most of the deteriorated edge segments observed are believed to be outgrowths of these unsealed auxiliary crack segments, propagating from the combined forces of climate and traffic. Figure 32 illustrates a typical spall and secondary crack associated with an 890-SL silicone seal at Abilene.

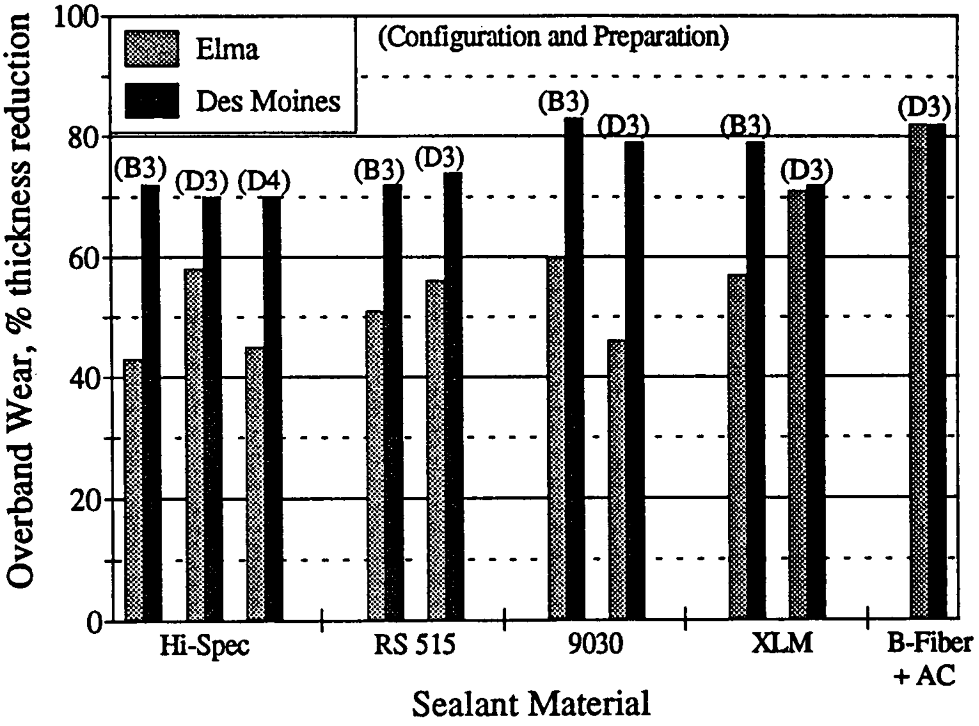


Figure 28. Effects of traffic level on overband wear (Elma versus Des Moines)

Figure 29. High-severity pull-out of Koch 9030 band-aid seal at Abilene

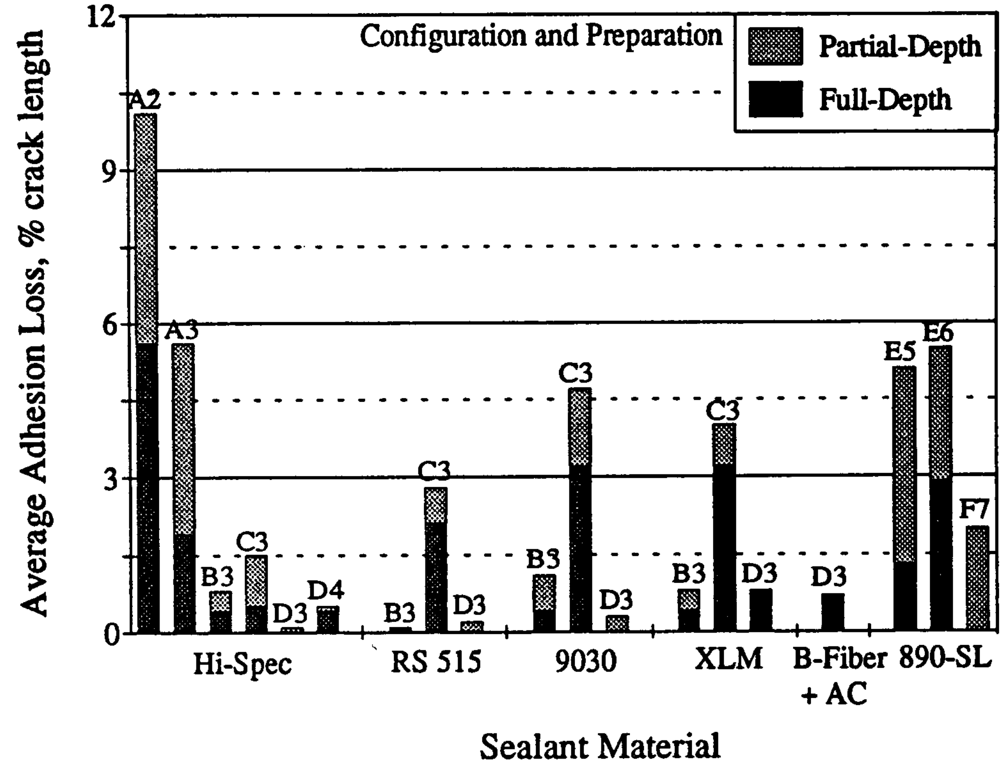


Figure 30. Average adhesion loss for primary sealants (all sites)

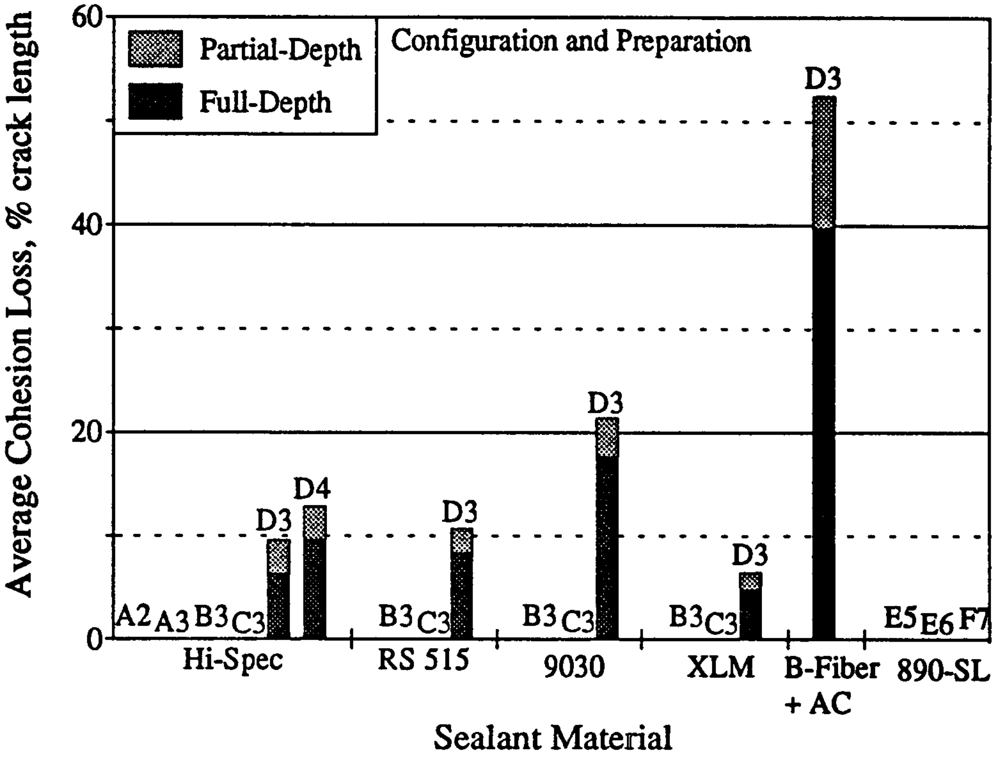


Figure 31. Average cohesion loss for primary sealants (all sites)

Figure 32. Typical spall and secondary crack adjacent to 890-SL seal

As discussed previously, the "bottom line" in the analysis of treatment performance is overall failure. Although the criteria for performance assessment vary among highway agencies, the performance rating criteria established by Belangie are generally accepted and appear as follows:[3]

Rating	Failure Level (percent)
Very Good	0 to 10
Good	10 to 20
Fair	20 to 35
Poor	35 to 50
Very Poor	50 to 100

Figure 33 shows the average percentages of failure for the primary crack-seal treatments. It is apparent from this figure that Kapejo BoniFiberized asphalt is the only primary sealant with poor overall performance. The performance of the remaining sealants is good to very good.

Table 14 provides a more detailed account of performance, listing the individual percentages of treatment failure experienced at each test site. In all, 56 of the 74 crack-seal treatments show very good performance (<10 percent failure). Another nine crack-seal treatments show good performance (between 10 and 20 percent failure).

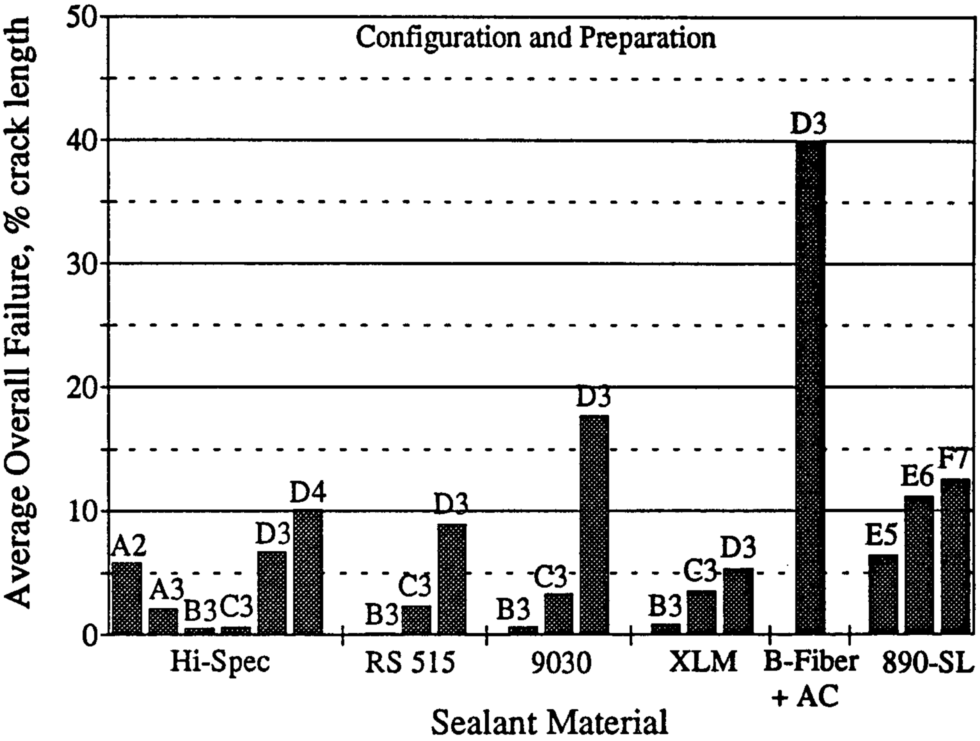


Figure 33. Average overall failure for primary sealants (all sites)

Crack-Fill Experiment

Fourteen months after installation, the longitudinal crack-filler materials at Prescott have performed extremely well. Despite an average crack opening measurement greater than that at Elma and Abilene, few adhesion and cohesion failures were observed. The most significant observed failures, as a percentage of crack length, were the following:

- Witco CRF – Approximately 1.5 percent tracking failure
- Hy-Grade Kold Flo – 1.7 percent full-depth adhesion loss
- Asphalt Cement – 0.8 percent full-depth cohesion loss

Each crack-fill treatment exhibited some form of nonfailure distress. For the materials placed in flush-fill configurations (CRF, Kold Flo, AR2, and asphalt cement), a sagging phenomenon was common when the cracks opened up in the winter. Very little debonding or significant internal cracking was observed in the sagged material segments. The emulsions (CRF and Kold Flo), which were partly tracked out of the cracks shortly after placement, showed the greatest degree of sagging, ranging from 0.25 to 0.75 in (6.4 to 19.1 mm) below the surface. Asphalt cement and AR2 generally sagged no more than 0.25 in (6.4 mm).

Overband wear for the Fiber Pave and AR2 treatments was relatively high, whereas for the RS 211 treatment, overband wear remained low.

Table 14. Percentage of overall failure for various crack-seal treatments at each test site

Material	Installation Method (Cfg-Prep)	Average Overall Failure, Percent Crack Length				
		Abilene	Wichita (Ideal)	Wichita (Adverse)	Elma	Des Moines
Hi-Spec	A-2					5.8
	A-3	1.9	4.9	3.2	0.1	0.3
	B-3	0.0	1.1	1.0	0.0	0.3
	C-3		0.7	0.8		0.3
	D-3	0.3	18.1	6.1	0.0	9.0
	D-4	2.6	22.9	19.4	0.0	5.5
RS 515	B-3	0.3			0.0	0.0
	C-3		0.1	0.6		6.2
	D-3	0.0	19.4	12.5	0.1	12.5
9030	B-3	0.3			0.0	1.4
	C-3		6.0	3.8		0.1
	D-3	2.2	37.5	36.8	0.0	11.8
XLM	B-3	0.8			0.0	1.5
	C-3		0.8	9.7		0.0
	D-3	1.5	21.5	2.7	0.0	0.8
B-Fiber + AC	D-3	45.1	60.4	67.4	0.0	27.1
890-SL	E-5	11.1	6.3		1.3	6.9
	E-6			11.1		
	F-7			12.5		
RS 211	B-3				0.0	
AR+	B-3		0.7	0.7		
9000-S	B-3		0.2	0.1		
CRS-2P	G-4					100.0

5

Analysis

This chapter presents the results of the analyses performed on the various types of installation, field performance, and laboratory testing data. As stated in chapter 1, the primary objective of this project is to determine the most effective and economical materials and methods for conducting crack-sealing and crack-filling operations. To accomplish this objective, a cost-effectiveness analysis has been used, in which the total cost of applying a treatment is weighed against how long the treatment performs. Material, labor, and equipment cost data, as well as operational productivity and treatment performance data, were required to perform this analysis.

Other project objectives included finding correlations between field performance and laboratory testing and identifying quicker, safer installation practices. New information or advances in both of these areas will greatly benefit highway agencies.

Statistical Methodology

The analysis of data was performed using SAS® statistical software. Before formal statistical analysis, however, data files containing the desired types of raw data were compiled using computerized spreadsheets. These data files were converted into ASCII format for easy reading by the SAS program. Command files were created which consisted of various SAS statements designed to read the raw data, perform the desired statistical analyses, and produce the final output.

For the analysis of treatment performance, as characterized by various distresses in the field, the SAS GLM (general linear model) procedure with the MANOVA (multivariate analysis of variance) option was used. This test procedure compared the univariate means for various independent variables (i.e., treatment type, lane position) and identified any statistically significant differences among those means. The procedure then enacted Tukey's Studentized Range (Honestly Significant Difference) analysis at a confidence level of 95 percent to determine the ranking of means and to group the means into performance categories or levels having statistically significant differences. In this report, level 1 represented highest performance, followed by level 2, level 3, and so on. For example, in figure 34 the 890-SL

E-5 treatment at Abilene is performing significantly worse than the remaining in terms of full-depth adhesion loss.

Correlation analyses between laboratory test results and field performance were made using the SAS Correlation (CORR) procedure. In the procedure, comparisons between the means of various laboratory tests and field distresses were made at the 95 percent confidence level. The strength of a relationship was measured by the Pearson correlation coefficient (r). Coefficients near 0 indicated poor relationships, while those near 1 or -1 represented strong relationships. Positive r values indicated direct relationships, while negative r values signified indirect relationships.

Field Performance

Comparison of Treatments

Results of the Tukey comparisons of full-depth adhesion loss are illustrated in figures 34 through 37. These comparisons represent treatments at Des Moines, Abilene, and Wichita. (Tukey rankings for treatments at Elma and Prescott are not shown because there were negligible amounts of adhesion failure and, consequently, no statistically significant differences.)

Based on these analyses, it is apparent that more substantial full-depth adhesion loss has occurred at Wichita and Des Moines. And, while no one material was uniquely prone to adhesion failure, configurations A and C seemed more susceptible than configuration B.

As seen in figures 36 and 37, treatments in the adverse-conditions subsite at Wichita showed only slightly more adhesion failure than treatments in the ideal-conditions subsite. For 11 treatments applied in both the adverse and ideal subsites, the average adhesion failure was 1.7 and 0.8 percent, respectively. This small difference occurred despite the fact that the average moisture rating for the 11 treatments was roughly 1 point higher for the adverse subsite. This gives at least some indication of the effectiveness of the heat lance in drying moist crack channels.

The RS 515 and Hi-Spec seals at Wichita and the 9030 seals at Elma showed surprisingly small amounts of adhesion loss, despite their placement above moist base layers. The high rate of adhesion failure for 890-SL at Abilene was the result of insufficient recessment during installation ($\leq$ 0.13-in [3.2-mm] recess).

Figures 38 through 41 show the performance rankings and groupings among treatments at Des Moines, Abilene, and Wichita with respect to full-depth cohesion loss. (As with adhesion loss, treatments at Elma and Prescott exhibited insignificant amounts of cohesion loss.) These figures show the poor performance by CRS-2P at Des Moines and the consistent low-level performance of BoniFiberized asphalt.

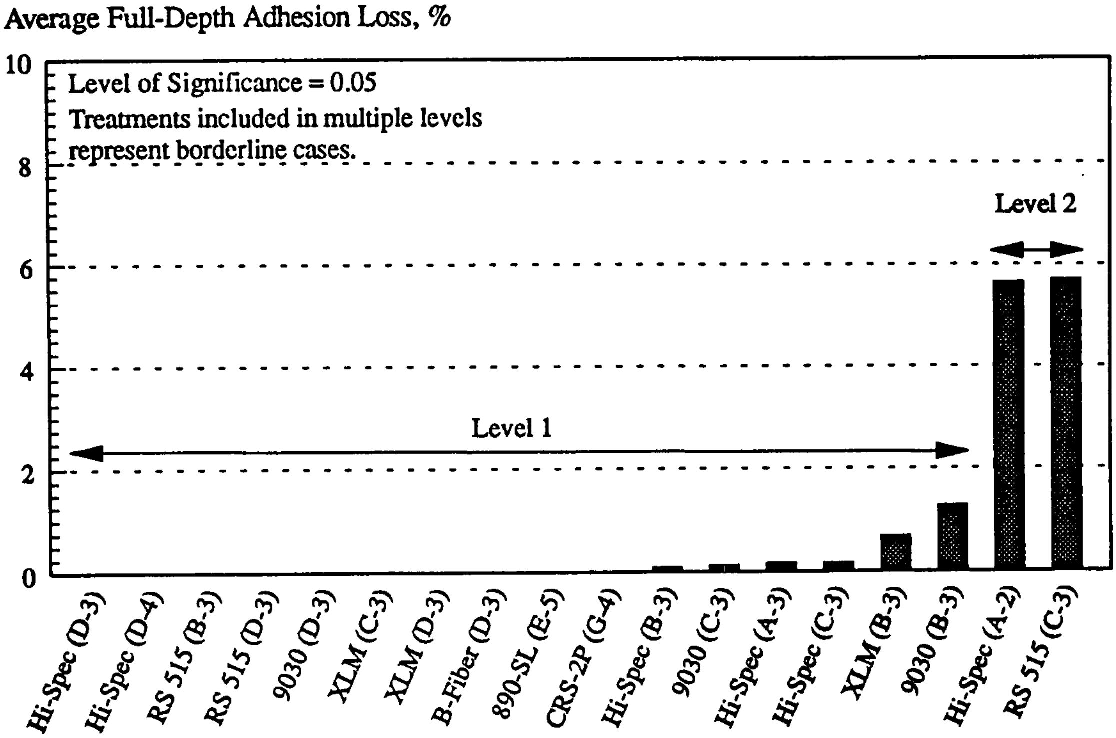


Figure 34. Tukey analysis of full-depth adhesion loss at Des Moines

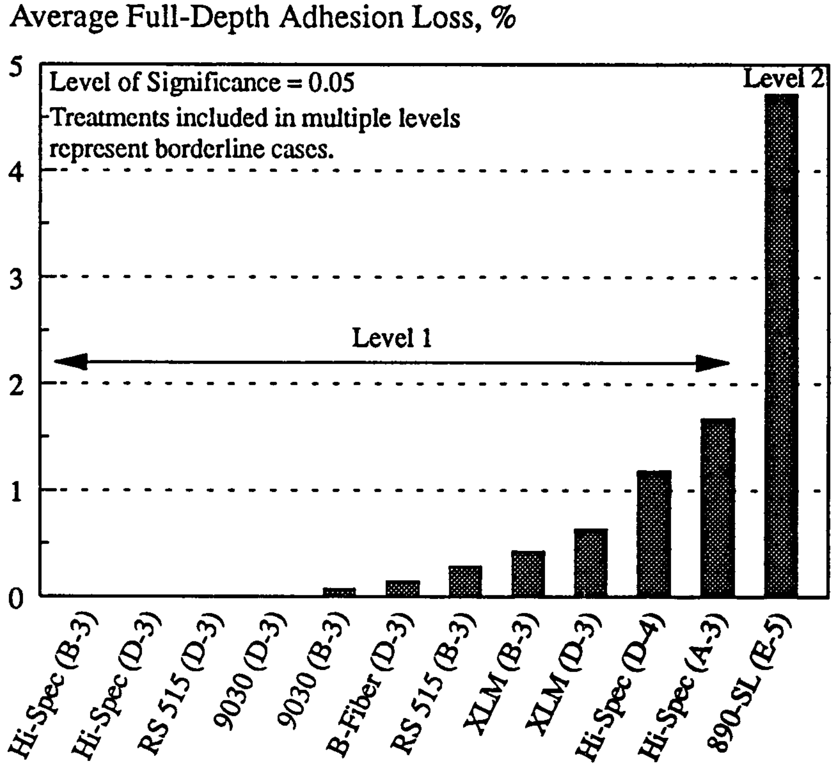


Figure 35. Tukey analysis of full-depth adhesion loss at Abilene

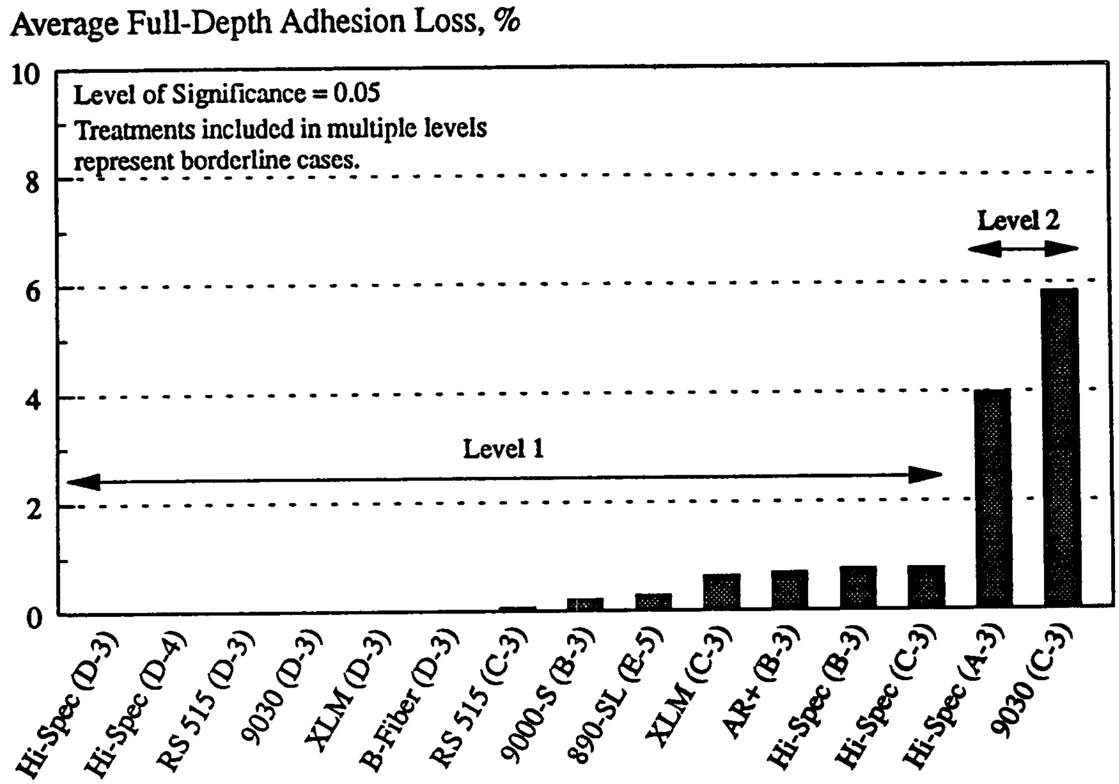


Figure 36. Tukey analysis of full-depth adhesion loss at Wichita ideal subsite

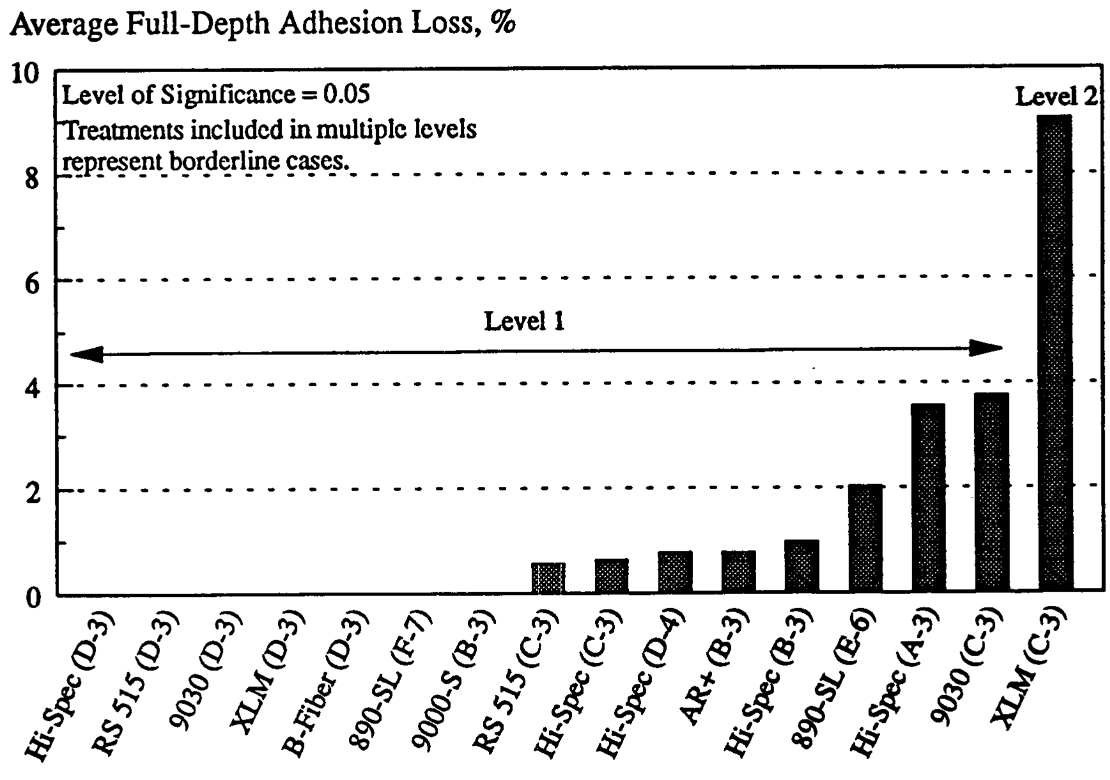


Figure 37. Tukey analysis of full-depth adhesion loss at Wichita adverse subsite

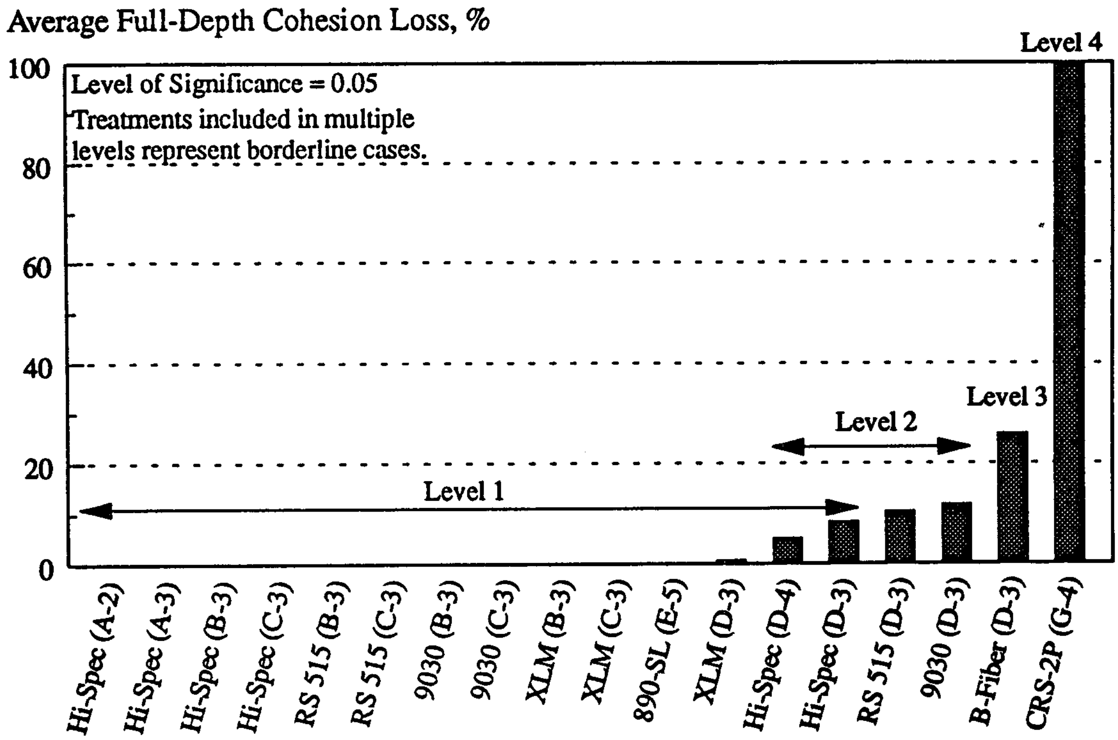


Figure 38. Tukey analysis of full-depth cohesion loss at Des Moines

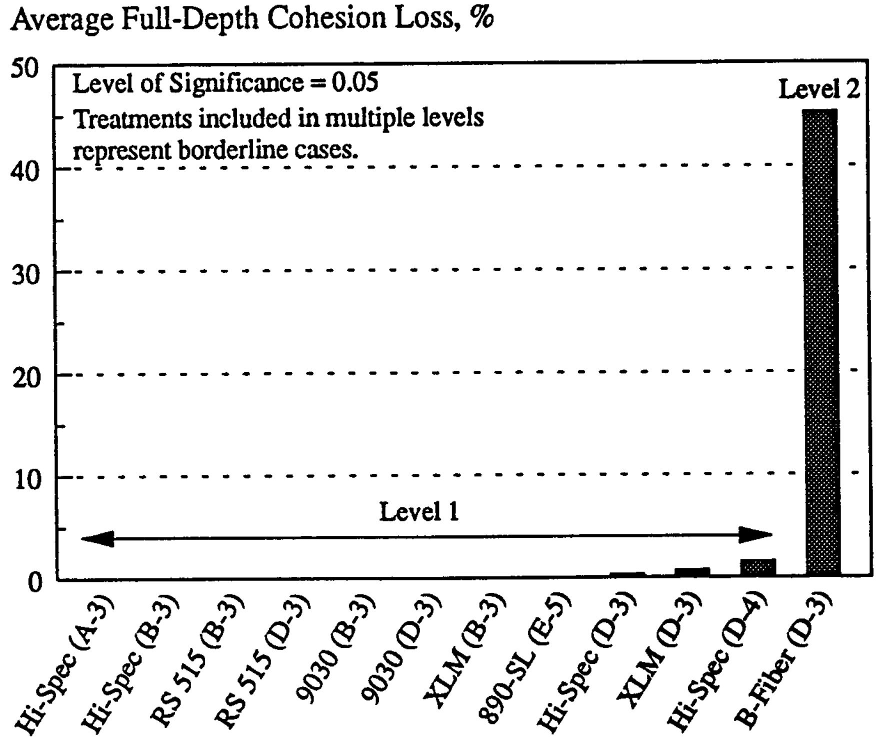


Figure 39. Tukey analysis of full-depth cohesion loss at Abilene

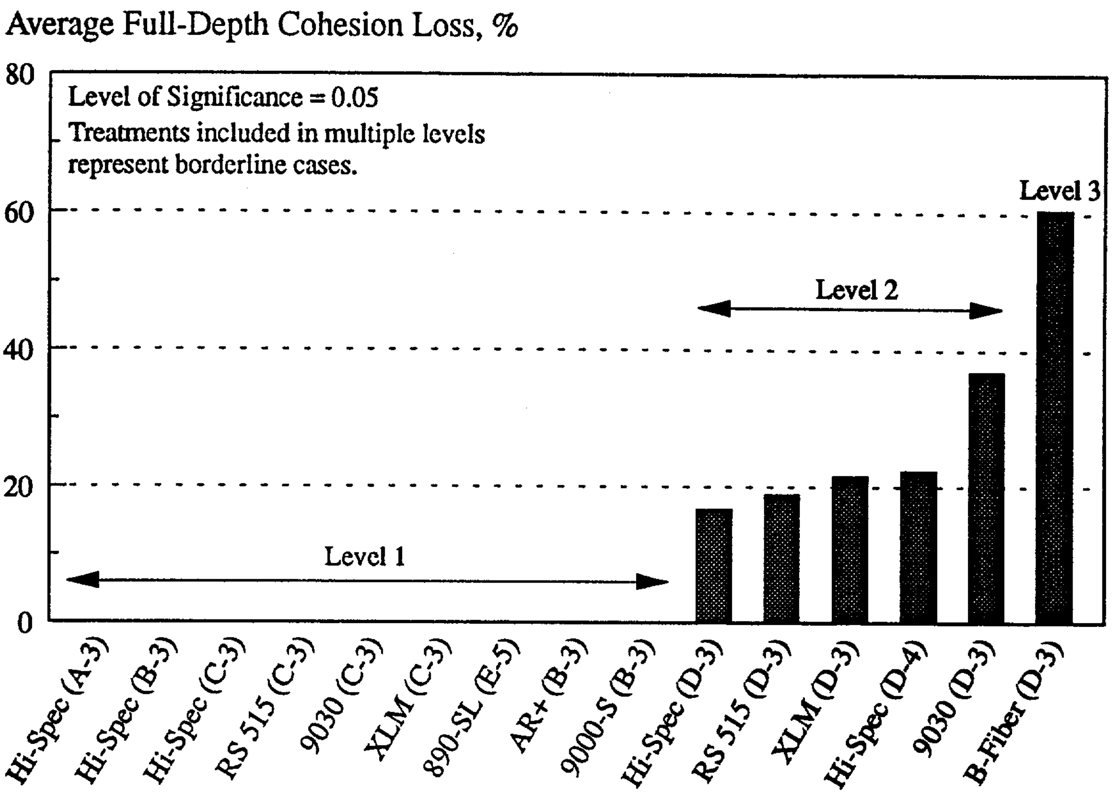


Figure 40. Tukey analysis of full-depth cohesion loss at Wichita ideal subsite

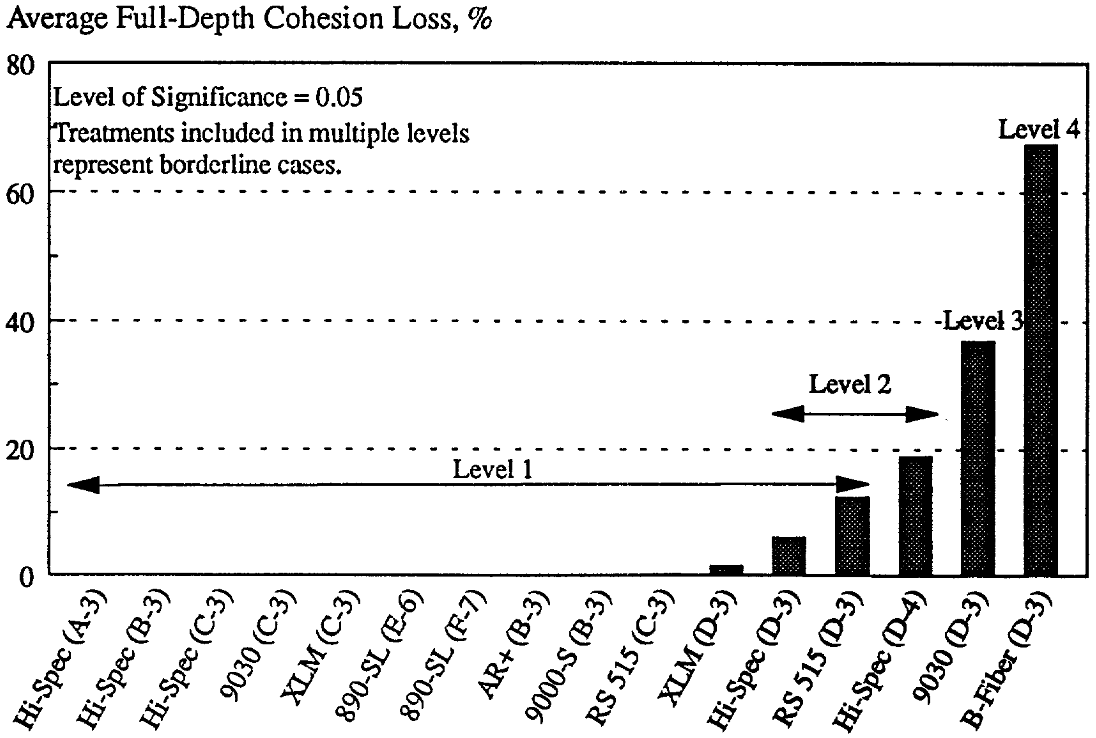


Figure 41. Tukey analysis of full-depth cohesion loss at Wichita adverse subsite

Because of the lack of a true reservoir, configuration C was most prone to this type of failure. Interestingly, Hi-Spec showed a greater tendency for cohesion failure in this configuration than the other rubberized asphalt sealants, which seems to relate to the stress-strain characteristics of these materials as revealed by ductility and modulus test results.

Figures 42 through 45 show the results of Tukey comparisons for the high-severity edge deterioration associated with each treatment at Des Moines, Abilene, and Wichita. (As before, treatments at Elma and Prescott exhibited insignificant amounts of edge deterioration.)

As can be seen, the primary differences were found in 890-SL, BoniFiberized asphalt, and CRS-2P emulsion. At nearly every site, the former two products exhibited significantly more damage than the other materials. In the case of BoniFiberized asphalt, almost all of the damage occurred in the form of spalling along segments with extremely high overband wear and full-depth cohesion loss.

Finally, figures 46 through 51 show the significantly poorer overall performance of CRS-2P at Des Moines and of BoniFiberized asphalt at Abilene, Des Moines, and Wichita. In addition, 890-SL in its three configurations generally exhibited a lower level of performance than other treatments. As for the performance of configurations, it is apparent that the simple band-aid configuration (configuration D) also has performed at a lower level than its companion configurations.

As further evidence of the statistically poorer performance associated with the simple band-aid configuration, table 15 shows the overall performance of the four rubberized asphalt placement configurations. The first column lists the average overall failure rate for each configuration based on data from Hi-Spec treatments. The second column lists the factor of failure by which configuration D is greater than configurations A, B, and C. Columns three and four present similar statistics based on data from all rubberized asphalt treatments (i.e., Hi-Spec, RS 515, 9030, and XLM). Obviously, configuration D has failed at a rate of at least four times that of configurations A, B, and C.

Effects of Lane Position on Performance

An analysis of variance performed on the primary failure distresses as a function of lane position (i.e., inside wheelpath, outside edge) revealed some interesting observations. First, no statistically significant differences were found among the five lane positions with respect to full-depth adhesion loss. This would suggest that tire contact, on the whole, has little impact on adhesion loss.

Full-depth cohesion loss was another matter. In general, the wheelpaths contained significantly more full-depth cohesion loss than the center and edge positions. This is because the overbands in the wheelpaths are considerably thinner and are unable to accommodate crack movements as well as overbands located in the less-trafficked positions. This is confirmed by the fact that at Elma, where overband wear is much lower than other sites, there are no significant differences in full-depth cohesion loss among the positions.

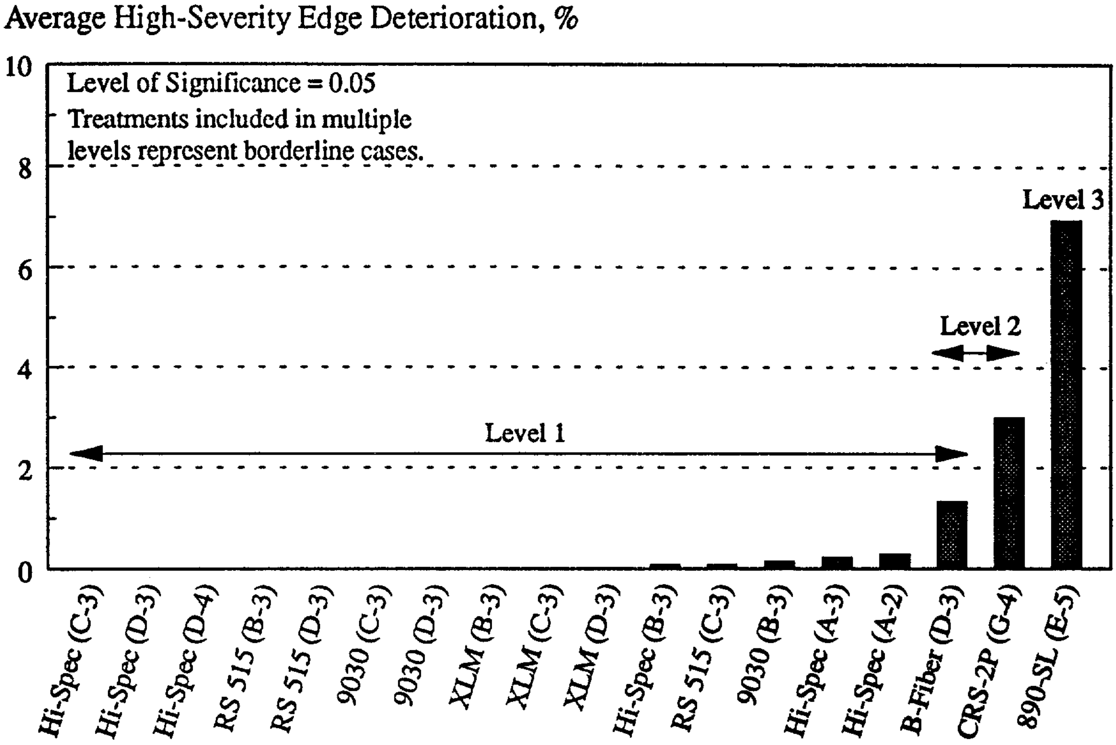


Figure 42. Tukey analysis of high-severity edge deterioration at Des Moines

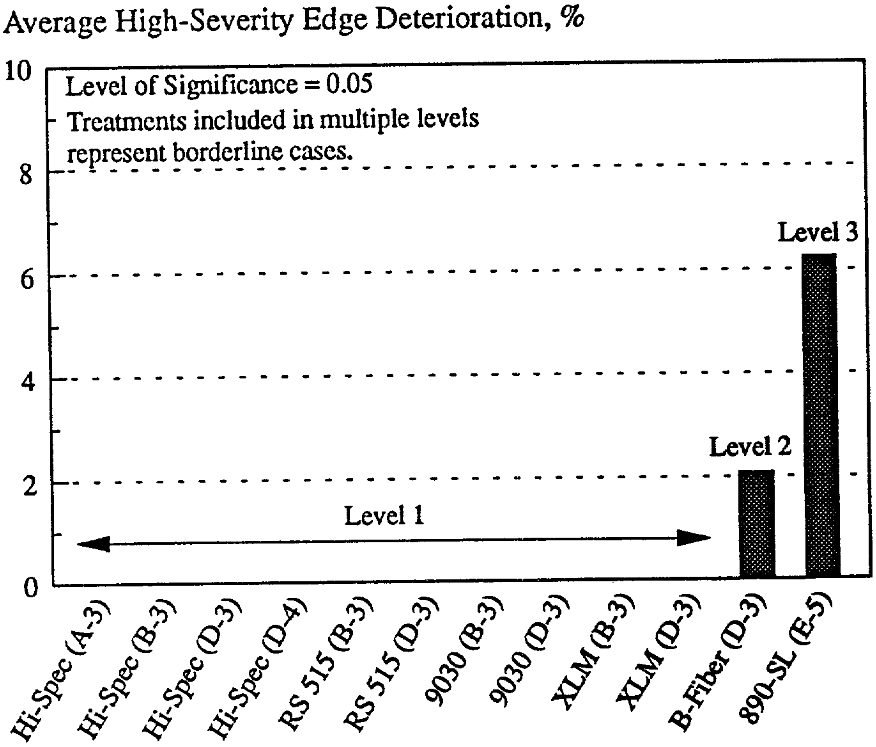


Figure 43. Tukey analysis of high-severity edge deterioration at Abilene

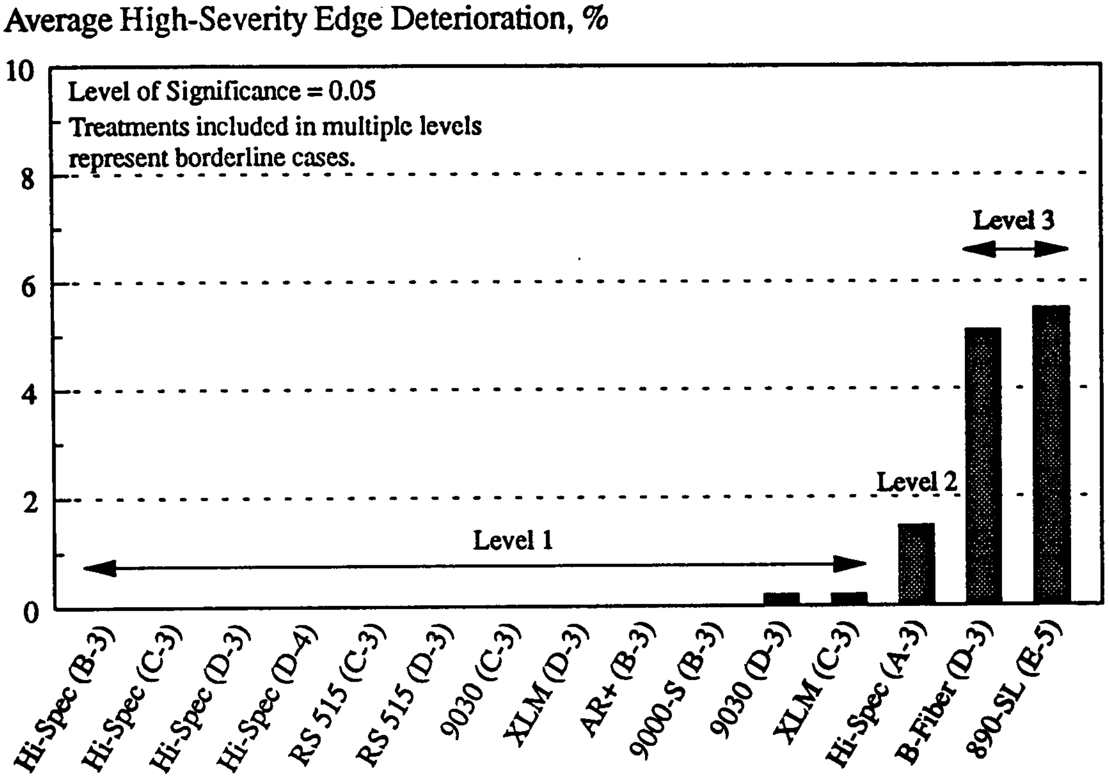


Figure 44. Tukey analysis of high-severity edge deterioration at Wichita ideal subsite

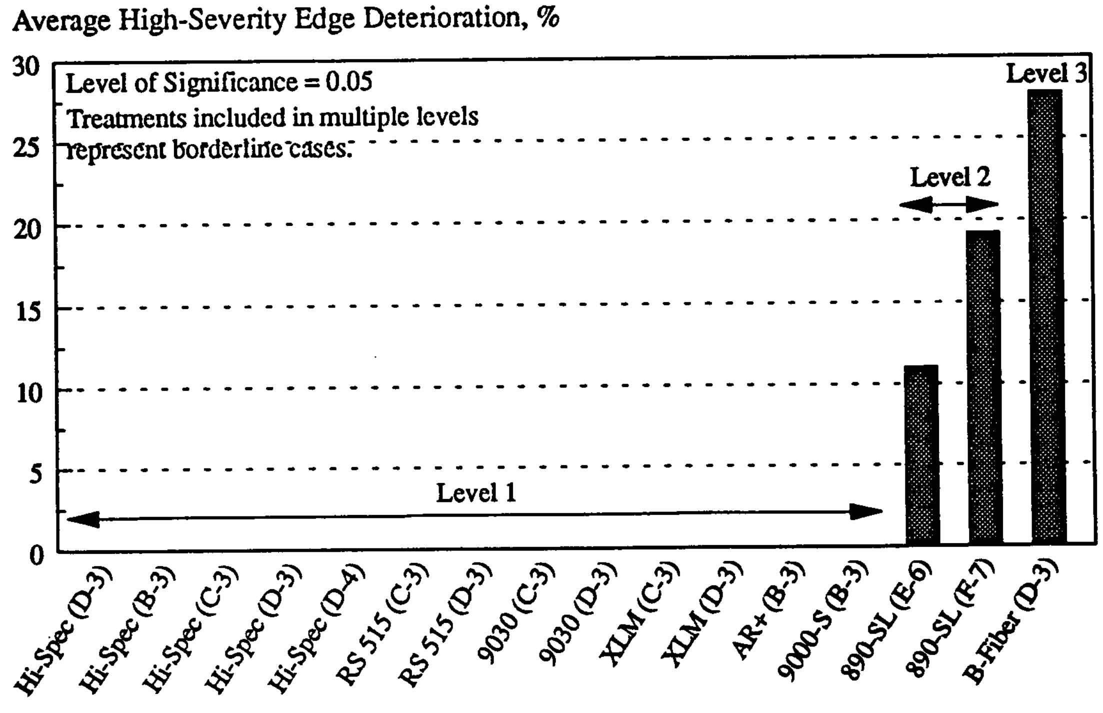


Figure 45. Tukey analysis of high-severity edge deterioration at Wichita adverse subsite

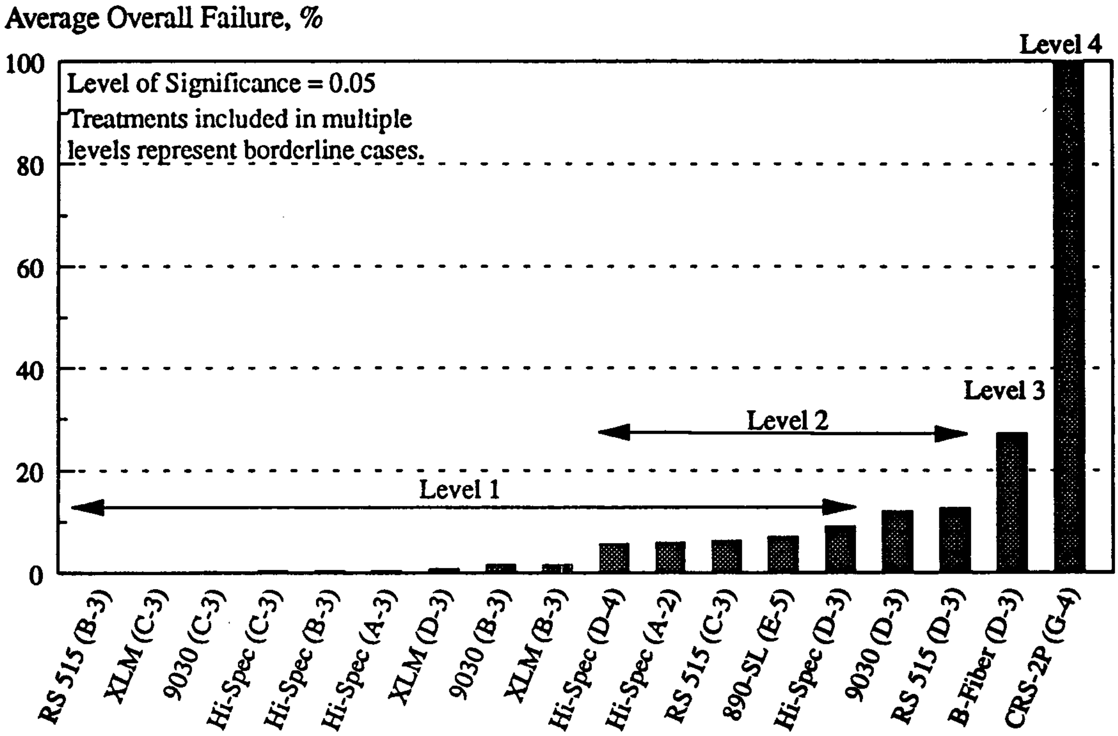


Figure 46. Tukey analysis of overall failure at Des Moines

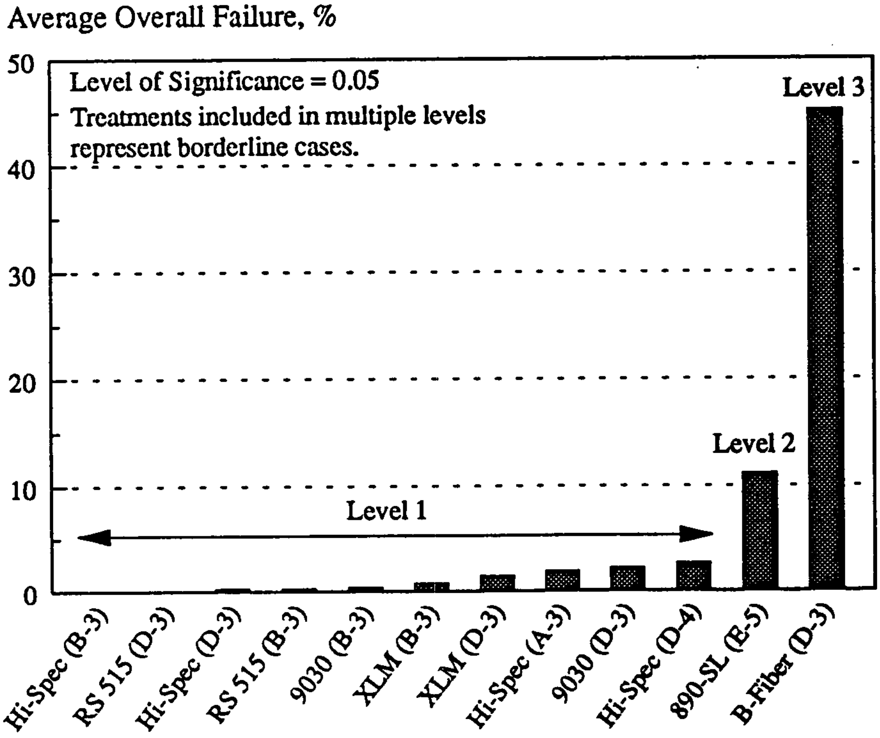


Figure 47. Tukey analysis of overall failure at Abilene

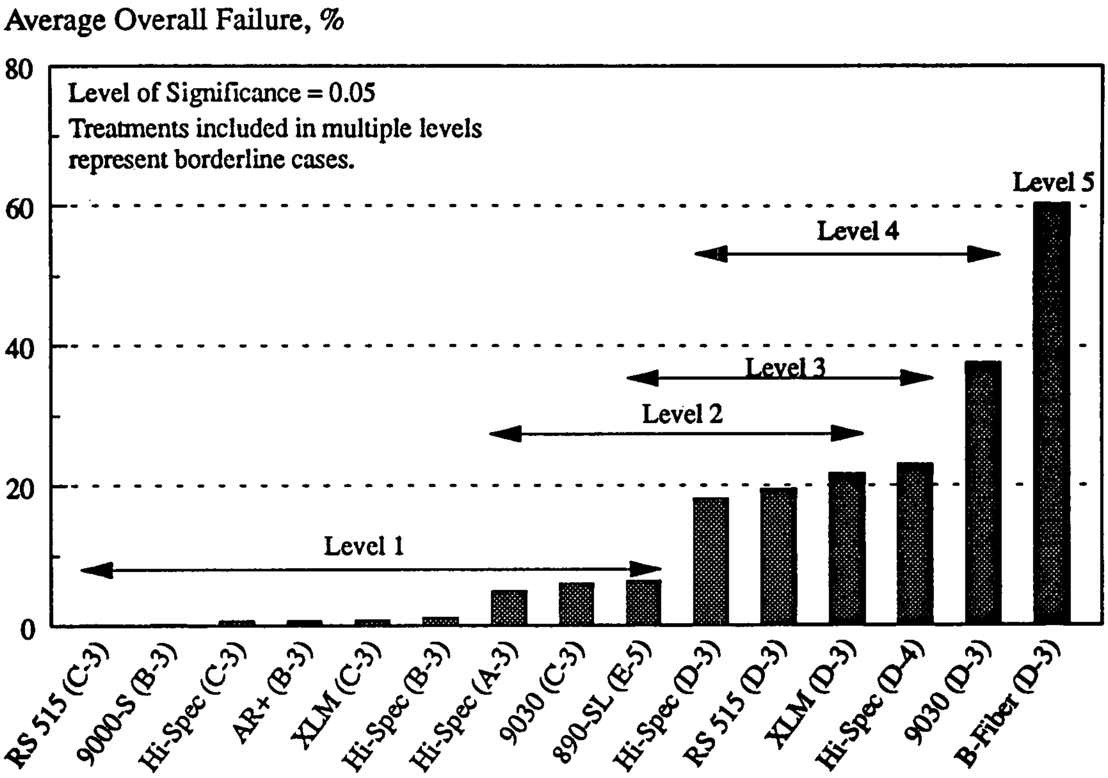


Figure 48. Tukey analysis of overall failure at Wichita ideal subsite

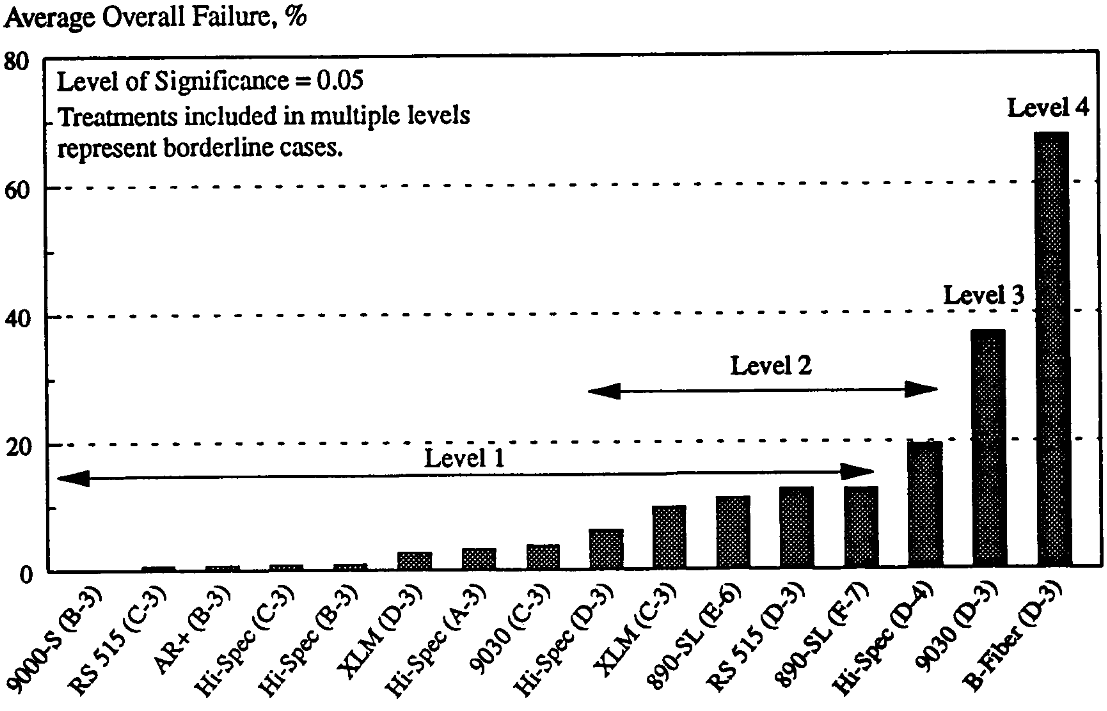


Figure 49. Tukey analysis of overall failure at Wichita adverse subsite

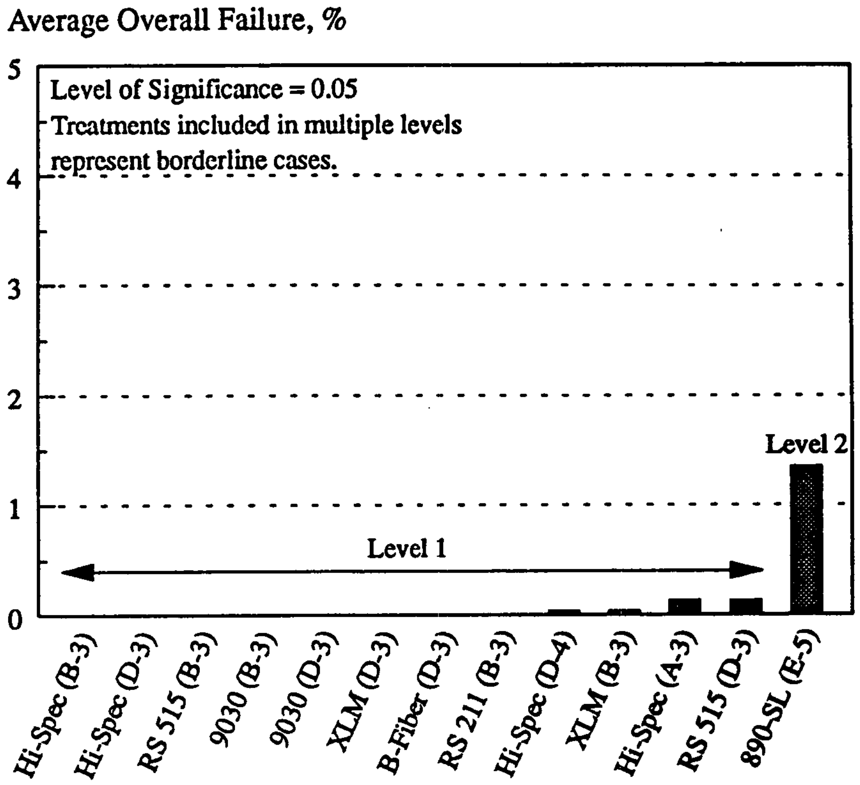


Figure 50. Tukey analysis of overall failure at Elma

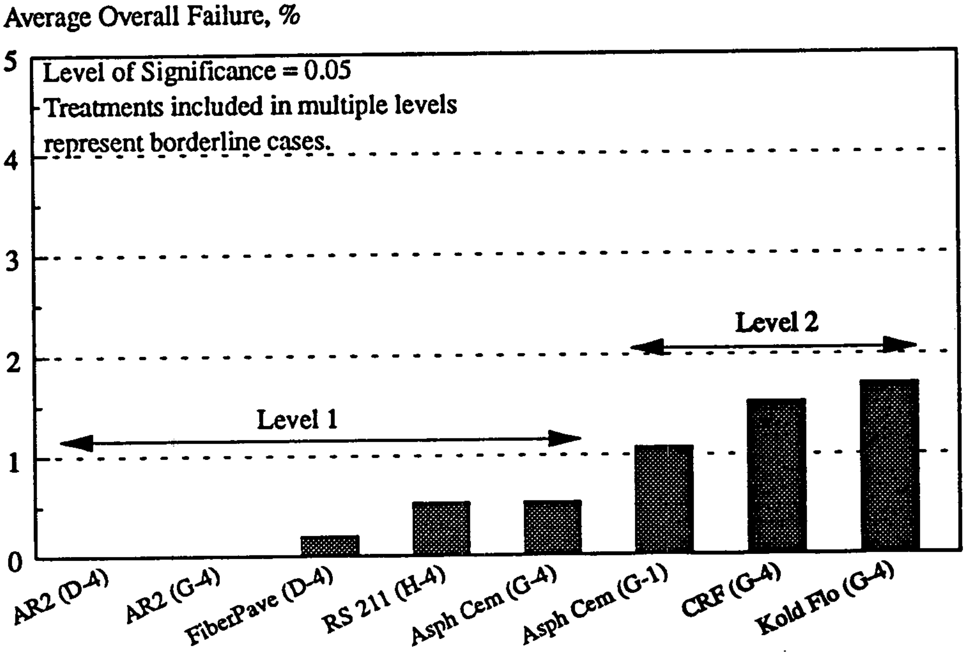


Figure 51. Tukey analysis of overall failure at Prescott

Table 15. Comparison of failure rates for rubberized asphalt configurations

Configuration	Meadows Hi-Spec Treatments		All Rubberized Asphalt Treatments	
	Average Failure, percent	Factor (config D/config X)	Average Failure, percent	Factor (config D/config X)
A	2.1	4.0	2.7	3.6
B	0.5	16.8	0.5	19.4
C	0.6	14.0	2.4	4.0
D	8.4	▨	9.7	▨

High-severity edge deterioration in the wheelpaths was found to be significantly different only at the two Wichita sites. This was primarily the result of wheelpath spalling in the BoniFiberized asphalt sections.

Overall failure generally was significantly greater in the wheelpaths than in the edge and center positions. This is only fitting since cohesion and edge deterioration, which together constituted approximately 88 percent of all failures, occurred mostly in the wheelpaths.

Effects of Crack Movement on Performance

Undoubtedly, horizontal crack movement played an important role in the formation of adhesion and cohesion losses. Figure 52 shows the relationships between crack movement and adhesion/cohesion failure for the various primary crack sealants in all configurations at all sites. The data points in each graph represent the amount of failure exhibited by various seals corresponding to the amount of extension undergone by those seals (as derived from initial crack-channel width and maximum measured crack movement).

Although the correlations range from weak to moderately strong, there appears to be a general trend among the four rubberized asphalt sealants. At 50 percent extension, XLM exhibited the least amount of failure, followed closely by Hi-Spec and RS 515. Koch 9030 showed the highest amount of failure at 50 percent extension. This is an interesting observation, considering that most failures resulted from cohesion loss and that 9030 exhibited modulus characteristics (in the laboratory) considerably lower than Hi-Spec and RS 515. The higher level of overband wear experienced by 9030 in the field may partially explain this phenomenon.

As for the remaining two materials, it is clear that 890-SL can handle extensions below 50 percent quite well, given the configurations used. And, while the sealant extension-failure relationship exhibited by fiberized asphalt is very poor, it does show the high probability of complete failure for even minimal crack movements. This becomes particularly evident as overband wear increases.

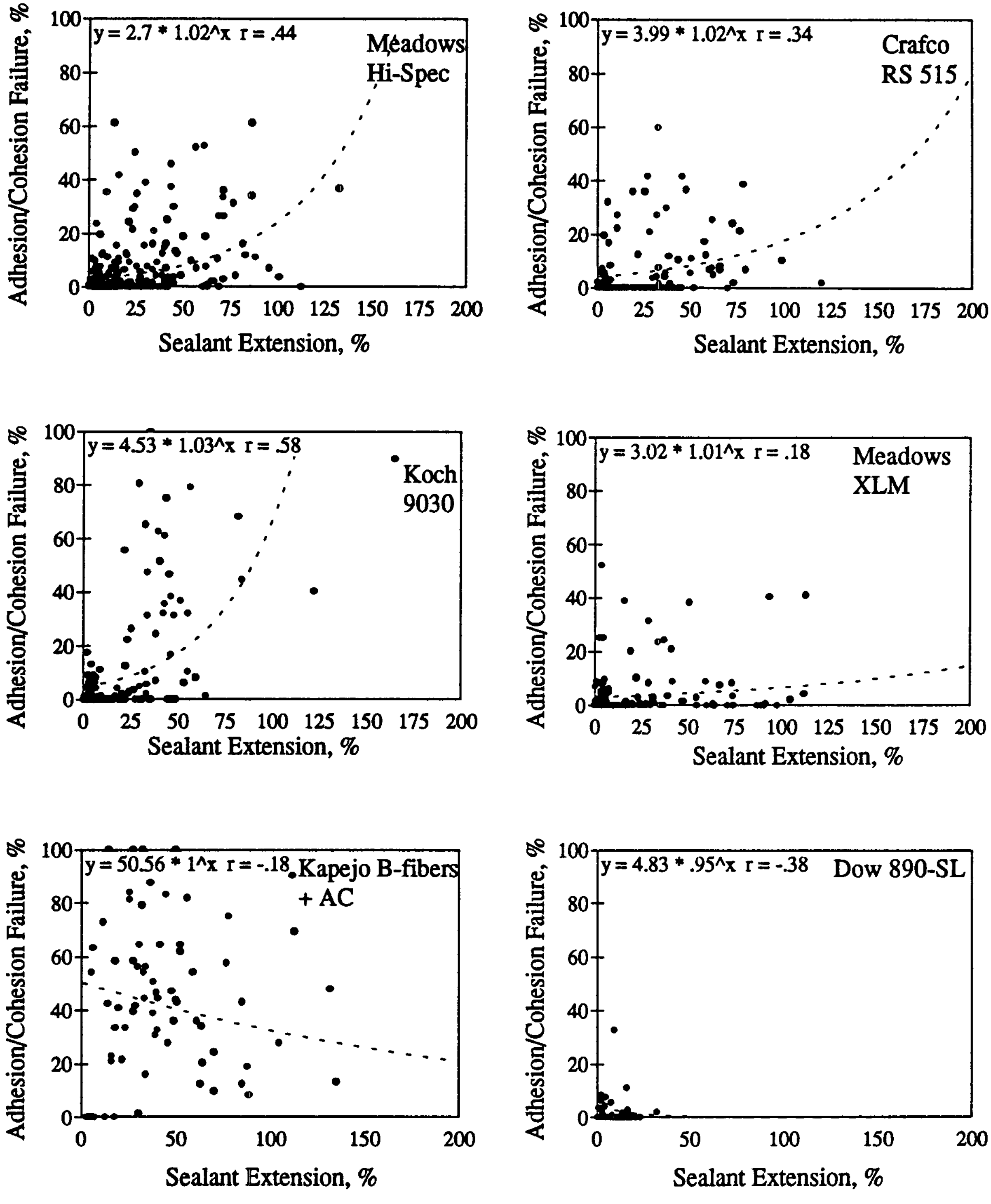


Figure 52. Relationships between sealant extension and adhesion/cohesion failure

Comparison of Treatments by Site

The purpose of installing crack-seal test sections at different locations throughout the United States was to learn whether certain materials or methods would work better in particular climates; that is, to determine the effect climatic conditions (i.e., precipitation, temperature) on the performance of sealing procedures and materials.

With so many different variables involved (e.g., pavement design, traffic, installation factors) and inadequate time to do a proper statistical analysis, only a short assessment of treatment performance among sites is provided. This assessment centers around the information provided in table 16. In this table, the overall failure rates for nine crack-seal treatments common to each site (Abilene, Des Moines, Elma, and Wichita ideal subsite) are presented in increasing order. In most instances, treatments showed progressively more failure in extreme climates (Des Moines and Wichita) than moderate climates (Elma and Abilene). Only three of the nine treatments showed minimal increases in failure from moderate to extreme climates. These treatments were 890-SL E-5 and Hi-Spec A-3 and B-3. In the case of the former, the 11.1 percent failure rate was largely affected by installation mistakes. The fact that the Hi-Spec A-3 and B-3 treatments showed substantially smaller increases in failure between sites than Hi-Spec D-3 and D-4 treatments thus far lends credence to the use of configurations A and B on a national scale.

Laboratory-Performance Correlations

In attempting to make correlations between laboratory testing and field performance, the results from 22 distinct test parameters were compared statistically with seven field performance distresses for the six primary sealant materials (Hi-Spec, RS 515, 9030, XLM, BoniFiberized asphalt, and 890-SL). The mean test results were compared with the current levels of field distresses on a site-by-site basis as well as an overall basis. Because of the small sampling of test results, however, the correlation analysis focused on overall comparisons.

Table 17 lists the correlations that were originally anticipated between field manifestations and laboratory tests. Some tests, such as the standard bond and cold bend tests, revealed no differences between the materials and thus were not included in the correlation analysis.

Results of interest from the analysis are shown in table 18. Most of the correlations are quite weak. The strongest relationships observed are those of two force ductility parameters (maximum elongation and load at 150 percent elongation) with cohesion loss and cone penetration at 77°F (25°C) with overband wear.

While cone penetration at 77°F (25°C) is normally used to indicate flexibility, it was found to relate fairly well with overband wear. Generally, the softer the material, the more wear it was prone to incur for a given traffic level. The premise of the latter relationship is that

Table 16. Assessment of treatment performance by site

	Material (Method)								
	Hi-Spec (A-3)	Hi-Spec (B-3)	Hi-Spec (D-3)	Hi-Spec (D-4)	RS 515 (D-3)	9030 (D-3)	XLM (D-3)	B-Fiber + AC (D-3)	890-SL (E-5)
Test Site (Percent Failure)	Elma (0.1)	Elma (0.0)	Elma (0.0)	Elma (0.0)	Abilene (0.0)	Elma (0.0)	Elma (0.0)	Elma (0.0)	Elma (1.4)
	Des Moines (0.4)	Abilene (0.0)	Abilene (0.3)	Abilene (2.6)	Elma (0.1)	Abilene (2.2)	Des Moines (0.8)	Des Moines (27.1)	Wichita (6.3)
	Abilene (1.9)	Des Moines (0.4)	Des Moines (9.0)	Des Moines (5.5)	Des Moines (12.5)	Des Moines (11.8)	Abilene (1.4)	Abilene (45.1)	Des Moines (6.9)
	Wichita (4.9)	Wichita (1.1)	Wichita (18.1)	Wichita (22.9)	Wichita (19.4)	Wichita (37.5)	Wichita (21.5)	Wichita (60.4)	Abilene (11.1)

Table 17. Fundamental material properties and corresponding analysis variables

Material Property	Field Manifestations	Laboratory Tests
Durability	Tracking	Softening Point Flow (140 °F)
	Abrasion/Wear	Cone Penetration (77 °F)
Flexibility	Adhesion Loss Cohesion Loss Pavement Surround Damage	Cone Penetration (0 °F) Cold Bend (0 °F) Force Ductility (39.2 °F) Modulus (0, 39, and 73.4 °F) Tensile Adhesion (75 °F)
Adhesiveness/Cohesiveness	Adhesion Loss Cohesion Loss Pull-Outs	Standard Bond (-20 °F) Modified Bond (-20 °F) Tensile Adhesion (75 °F) Modulus (0, 39, and 73.4 °F)

Table 18. Selected laboratory test/field performance correlation results

Test Parameter	Pearson Correlation Coefficients for Field Distresses						
	Overband Wear	Low-Severity Pull-Out	High-Severity Pull-Out	Partial Adhesion Loss	Full Adhesion Loss	Partial Cohesion Loss	Full Cohesion Loss
Cone Penetration, 0 °F (3-A)	0.036	▨	▨	▨	▨		
Cone Penetration, 77 °F (4-A)	0.555	▨	▨	▨	▨		
Flow, 140 °F (5-A)	0.308	▨	▨	▨	▨	▨	▨
Force Ductility (11-A)	▨	▨	▨	▨	▨	-0.528	-0.684
Force Ductility (11-K)	▨	▨	▨	▨	▨	0.599	0.761
Tensile Adhesion, Std (12-B)	▨	-0.167	-0.034	0.185	-0.003	▨	▨
Tensile Adhesion, Mod #1 (13-B)	▨	-0.035	-0.067	0.039	-0.111	▨	▨
Tensile Adhesion, Mod #2 (14-B)	▨	-0.045	-0.146	-0.074	-0.149	▨	▨
Tensile Strength, 0 °F (15-A)	▨	▨	▨	▨	▨	-0.083	-0.169
Ultimate Elongation, 0 °F (15-B)	▨	▨	▨	▨	▨	-0.396	-0.292
Stress @ 15% Elong, 0 °F (15-C)	▨	▨	▨	▨	▨	0.125	-0.018
Tensile Strength, 39 °F (16-A)	▨	▨	▨	▨	▨	-0.040	-0.195
Ultimate Elongation, 39 °F (16-B)	▨	▨	▨	▨	▨	-0.226	-0.279
Stress @ 15% Elong, 39 °F (16-C)	▨	▨	▨	▨	▨	0.020	-0.126
Tensile Strength, 75 °F (17-A)	▨	▨	▨	▨	▨	-0.371	-0.306
Ultimate Elongation, 75 °F (17-B)	▨	▨	▨	▨	▨	-0.414	-0.340
Stress @ 15% Elong, 75 °F (17-C)	▨	▨	▨	▨	▨	-0.252	-0.248
Modified Bond #1 (19-B)	▨	-0.166	-0.138	-0.025	-0.084	▨	▨
Modified Bond #2 (20-B)	▨	0.001	0.204	-0.231	-0.072	▨	▨
Modified Bond #3 (21-B)	▨	-0.027	0.037	-0.222	-0.212	▨	▨

better elongation characteristics and reduced stresses during elongation result in less cohesion loss. This premise, however, was not supported by the correlation coefficients associated with the ASTM D 412 modulus test, as one might have expected.

It is clear from table 18 that the performance data collected thus far are not distinct enough to permit strong correlations. With time, and the subsequent decline in sealant performance, better correlations may be evident.

Cost-Effectiveness

While treatment performance in itself is quite important, cost-effectiveness is often the criterion preferred for selection of materials and procedures. A cost-effectiveness analysis is intended to be performed in this experiment; however, at this point, there is an insufficient level of failure in the field. As a preview for future cost-effectiveness analyses, the following sections describe the major inputs and the equation necessary for calculating cost-effectiveness. In addition, appendix E contains an example of a cost-effectiveness calculation.

Material Costs

When acquiring material for a particular crack treatment project, a purchase cost is associated with it and, in all likelihood, a shipping cost. Material manufacturers normally base purchasing costs on a $/lb basis. Depending on the amount of material purchased and how far it has to be transported, a shipping cost is added to the purchasing cost.

For the purpose of calculating cost-effectiveness, the total material cost (purchasing and shipping), expressed in terms of *dollars per pound ($/lb)*, will be used.

Placement Costs

Placement costs consist of the labor costs and equipment costs associated with applying a treatment. For calculating cost-effectiveness, the information on labor and equipment costs will be expressed on a *dollars per day ($/day)* basis. The value of labor costs should be for the entire maintenance crew, including supervisors. Likewise, the value of equipment costs should be for the entire fleet of equipment.

Productivity

Productivity depends largely on the type of operations involved in the treatment process, and on the skill and ambition of the crew and the circumstances surrounding the operation (i.e., type and size of highway facility, traffic level, crack density). The appropriate input for productivity will be *linear feet of crack treated per day (lin ft/day).*

Material Application Rate

The rate of material application refers to the quantity of material used over a specified length of cracking. This rate depends primarily on the placement configuration used and, to a lesser extent, the unit weight of the material. The inputted material application rate will be in *pounds per lin feet of crack (lb/lin ft).*

Service Life of Treatment

As illustrated previously, treatment performance is measured by the amount of overall failure incurred. In order to conduct a cost-effectiveness analysis, a standard level of failure must be specified for all treatments. This standard level is generally taken to be 50 percent, which, as discussed in chapter 4, represents the beginning of very poor performance, according to Belangie.[3]

For this experiment, the service life of a treatment will be defined by the estimated time between installation and 50 percent failure. For input into the cost-effectiveness calculations, service life will be expressed in *years (yrs).*

Cost-Effectiveness Equations

The total installation cost, on a *dollars per lin ft of crack ($/lin ft)* basis, will be calculated for each treatment using the following equation:

$$F = (A \times B) + (C/D) + (E/D) \qquad \text{Eq. 1}$$

where:

F = Total installation cost, $/lin ft
A = Cost of purchasing and shipping material, $/lb
B = Material application rate (including wastage), lb/lin ft of crack
C = Placement cost (labor & equipment), $/day
D = Production rate, lin ft of crack per day
E = User delay cost, $/day

Once the total installation cost is determined, the average annual cost for that treatment will be calculated using the following equation:

$$I = F \times \left[\frac{G \times (1 + G)^H}{(1 + G)^H - 1} \right] \qquad \text{Eq. 2}$$

where:

I = Average annual cost, $/lin ft of crack
F = Total installation cost, $/lin ft of crack
G = Interest rate, percent
H = Estimated service life of treatment (time to 50 percent failure), yrs

6

Preliminary Findings

The SHRP H-106 project is the most comprehensive pavement surface maintenance experiment that has ever been conducted. The crack treatment information presented in this report is slightly more than a preview of information forthcoming with continued monitoring of the test sites. As more performance data becomes available a much better understanding will be reached as to which materials and methods are more effective and economical.

Observations

Based on the information available to date, the following observations have been made about the experiment in general and the materials, methods, and equipment that were used.

General

- Most of the crack treatments are performing very well after 18 months of service. Of 82 total treatments (sealants and fillers), 64 have exhibited less than 10 percent failure, and 73 have exhibited less than 20 percent failure.

- Most laboratory test/field performance correlations examined thus far are weak. The strongest relationships were observed between force ductility parameters and cohesion loss and between cone penetration at 77°F (25°C) and overband wear.

- Transverse crack-seal performance, as intimated by cohesion loss, edge deterioration, and overall failure, is significantly poorer in the wheelpaths of a lane than in the center or on the edges. This does not hold true for adhesion loss.

Materials

- Dow Corning 890-SL self-leveling silicone should be recessed no shallower than 0.25 in (6.4 mm) so that traffic does not pull it out during curing.

- Low-modulus rubberized asphalt sealants have experienced higher rates of overband wear than standard rubberized asphalt sealants. Consequently, using thinner bands has often resulted in more cohesion and adhesion losses in cracks undergoing significant movement.

- Emulsified asphalts can perform satisfactorily as fillers in cracks that undergo little movement. Sanding after application is recommended, particularly for moderate and wide cracks, to prevent tracking and pull-outs by traffic during curing.

- Fiberized asphalt placed in a simple band-aid configuration does not provide good long-term performance in cracks that undergo significant amounts of movement (> 0.05 in [1.3 mm]). In addition, a higher rate of overband wear can be expected with this material than with rubber-modified materials, which can impact service life.

Methods

- Reservoir-type configurations, in which sealant is placed flush or in a band-aid, provide better short-term performance than the simple band-aid configuration. However, it is essential that cutting equipment (i.e., routers and saws) be capable of closely following the existing crack and cause little, if any, pavement spalling or fracturing.

- The standard recessed band-aid (configuration B) shows slightly better short-term performance than the wide recessed band-aid (configuration C). However, the wider, shallower cut associated with configuration C permits faster, more accurate cutting, which results in fewer weakened segments.

- Although high-pressure airblasted sections are generally showing slightly more adhesion failure than hot airblasted sections, no statistically significant differences have been observed between the two procedures.

Equipment

- Rotary-impact routers are significantly faster and more maneuverable than random crack saws when used for cutting cracks.

- The hot compressed-air lance appears to perform slightly better in situations in which it is used to dry moist crack channels prior to material installation, as experienced at the Wichita crack-seal site.

Recommendations

The SHRP H-106 project has laid the foundation for and taken the first steps toward improving technology for sealing and filling cracks in asphalt concrete. While definite progress has been made, there is room for additional improvement. The following recommendations are offered to interested highway maintenance agencies and agencies responsible for furthering the research established in H-106.

- **Take a little extra planning time before performing treatment operations.** As the old carpentry saying goes, "Measure twice, cut once." Taking time to assess the condition of the pavement and its cracks, as well as looking ahead to possible scheduled rehabilitation, will help in determining whether or not to seal or fill and which materials and methods to use.

- **Transfer the technology.** The information gathered under the H-106 program will be put to its best use when it reaches all individuals affiliated with crack treatment operations. This includes agency policy-makers, supervisors, and crewpersons.

- **Continue periodic monitoring of test installations and analysis of experimental data.** The time and effort required to continually evaluate and analyze field performance and cost-effectiveness may seem like a large investment, but the benefits of doing so will be great.

- **Set up regional testing centers for continued testing.** While the SHRP H-105 and H-106 projects have attempted to identify the most promising materials, procedures, and equipment, many items were not evaluated or have recently entered the market. The ability to continually evaluate new materials, procedures, and equipment as they enter the market is invaluable to agencies involved in sealing/filling operations.

Appendix A

Test Site Layouts

The crack treatment test sites were laid out end-to-end in two replicates. Each replicate contained test sections consisting of 10 cracks treated using one combination of material and method. The following tables present the sequential layout of experimental treatments in the form of test sections at each site.

Table A-1. Randomized order of treatments at Abilene crack-seal test site

Test Section	Treatment (Material and Method)
1	Dow Corning 890-SL, E-5
2	Meadows Hi-Spec, D-3
3	Meadows Hi-Spec, B-3
4	Meadows Hi-Spec, D-4
5	Meadows SofSeal XLM, B-3
6	Koch 9030, B-3
7	Crafco RS 515, D-3
8	Kapejo BoniFibers + AC, D-3
9	Meadows Hi-Spec, A-3
10	Crafco RS 515, B-3
11	Meadows SofSeal XLM, D-3
12	Koch 9030, D-3

Table A-2. Randomized order of treatments at Wichita crack-seal test site

Test Section	Treatment (Material and Method)	
	Ideal-Conditions Lane	Adverse Conditions Lane
1	Meadows SofSeal XLM, D-3	Meadows SofSeal XLM, D-3
2	Meadows Hi-Spec, C-3	Meadows Hi-Spec, C-3
3	Meadows Hi-Spec, D-4	Meadows Hi-Spec, D-4
4	Crafco RS 515, D-3	Crafco RS 515, D-3
5	Kapejo BoniFibers + AC, D-3	Kapejo BoniFibers + AC, D-3
6	Koch 9030, C-3	Koch 9030, C-3
7	Meadows Hi-Spec, D-3	Meadows Hi-Spec, D-3
8	Dow Corning 890-SL, E-5	Dow Corning 890-SL, E-6 and F-7
9	Meadows Hi-Spec, B-3	Meadows Hi-Spec, B-3
10	Koch 9030, D-3	Koch 9030, D-3
11	Crafco RS 515, C-3	Crafco RS 515, C-3
12	Meadows Hi-Spec, A-3	Meadows Hi-Spec, A-3
13	Meadows SofSeal XLM, C-3	Meadows SofSeal XLM, C-3
14	Crafco AR+, B-3	Crafco AR+, B-3
15	Koch 9000-S, B-3	Koch 9000-S, B-3

Table A-3. Randomized order of treatments at Elma crack-seal test site

Test Section	Treatment (Material and Method)
A	Crafco RS 211, B-3
1	Dow Corning 890-SL, E-5
2	Koch 9030, D-3
3	Meadows Hi-Spec, B-3
4	Meadows Hi-Spec, D-4
5	Meadows SofSeal XLM, B-3
6	Koch 9030, B-3
7	Crafco RS 515, D-3
8	Kapejo BoniFibers + AC, D-3
9	Meadows Hi-Spec, A-3
10	Crafco RS 515, B-3
11	Meadows SofSeal XLM, D-3
12	Meadows Hi-Spec, D-3

Table A-4. Randomized order of treatments at Des Moines crack-seal test site

Test Section	Treatment (Material and Method)
1	Meadows SofSeal XLM, D-3
2	Meadows Hi-Spec, C-3
3	Koch 9030, C-3
4	Meadows Hi-Spec, D-4
5	Crafco RS 515 (D - 3)
6	Kapejo BoniFibers + AC, D-3
7	Meadows SofSeal XLM, C-3
8	Koch 9030, B-3
9	Meadows Hi-Spec, D-3
10	Dow Corning 890-SL, E-5
11	Meadows Hi-Spec, B-3
12	Koch 9030, D-3
13	Crafco RS 515, B-3
14	Meadows Hi-Spec, A-3
15	Meadows SofSeal XLM, B-3
16	Crafco RS 515, C-3
17	Meadows Hi-Spec, A-2
18	Elf CRS-2P, G-4

Table A-5. Randomized order of treatments at Prescott crack-fill test site

Test Section	Treatment (Material and Method)
A	Crafco RS 211, H-4
1	Crafco AR2, G-4
2	Witco CRF, G-4
3	Asphalt Cement, G-4
4	Hercules Fiber Pave + AC, D-4
5	Asphalt Cement, G-1
6	Crafco AR2, D-4
7	Hy-Grade Kold Flo, G-4

Appendix B

Installation Data

Several types of data were collected at each field installation. Included in this appendix are descriptions of the types of data recorded and illustrations of the forms used to record the data. Tables B-1 through B-6 also are provided that show summaries of installation data for each experimental treatment applied.

Forms

Work Log and Weather Conditions

Work accomplishments, construction occurrences, and ambient weather conditions were recorded for each day of the installation process. Air temperatures were taken periodically throughout each day, primarily for assessing crack widths as a function of temperature. Figure B-1 shows the field form used for documenting this data.

Test Section Layout

All experimental cracks, test section boundaries, roadway structures, and milepost markers were stationed with a survey wheel to the nearest foot, as illustrated in figure B-2.

Pre-Existing Crack Data

After a test site was fully laid out in the field (i.e., experimental cracks and test sections marked) in preparation for the installation process, the first group of installation data was collected. These data represented the pre-existing conditions for each experimental crack and were documented on copies of the form shown in figure B-3.

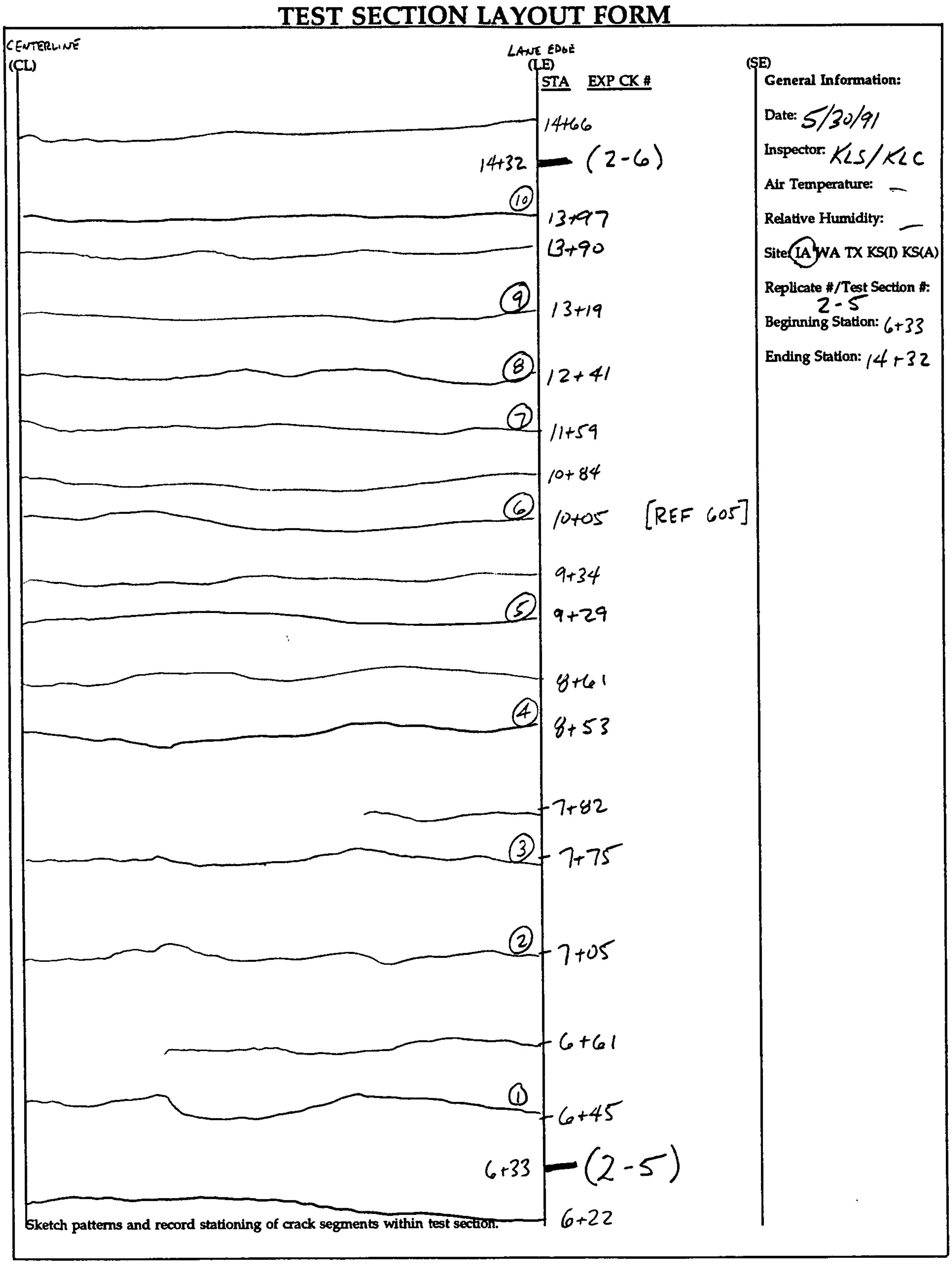
WORK JOURNAL / CLIMATIC CONDITION CHART

General Information [INSTALLATION]

Date: 6/6/91
Inspector: KLS/KLC
Test Site: [✓ IA] WA TX KS(I) KS(A) ONT

Time	Air Temperature (°F)	Relative Humidity (%)	Clouds (%)	Work Activity	Replicate #/ Test Section #
6:00 a.m.				6:15	
6:30				Initial Heating of:	
7:00	62	25	20	- XLM	
7:30				- 9030	
8:00					
8:30				8:45	
9:00	69	25	25	Final Heating	
9:30				9:30	
10:00				Sealing in Replicate #1	
10:30	75	30	25	Sections: 1-1 (XLM)	
11:00				1-3 (9030)	
11:30				1-7 (XLM)	
12:00 p.m.				1-8 (9030)	
12:30	80	30	15	1-12 (9030)	
1:00				1-15 (XLM)	
1:30					
2:00					
2:30				2:40 Sealing in Replicate #2	
3:00	81	35	40	Sections: 2-1 (XLM)	
3:30				2-3 (9030)	
4:00				2-7 (XLM)	
4:30				2-8 (9030)	
5:00				2-12 (9030)	
5:30	78	35	50	5:45 2-15 (XLM)	
6:00					

Figure B-1. Work journal and climatic condition chart



TEST SECTION LAYOUT FORM

CENTERLINE
(CL)

LANE EDGE
(LE)

(SE)

STA EXP CK #

14+66

14+32 (2-6)

⑩ 13+97

13+90

⑨ 13+19

⑧ 12+41

⑦ 11+59

10+84

⑥ 10+05 [REF 605]

9+34

⑤ 9+29

8+61

④ 8+53

7+82

③ 7+75

② 7+05

6+61

① 6+45

6+33 (2-5)

6+22

Sketch patterns and record stationing of crack segments within test section.

General Information:

Date: 5/30/91

Inspector: KLS/KLC

Air Temperature: —

Relative Humidity: —

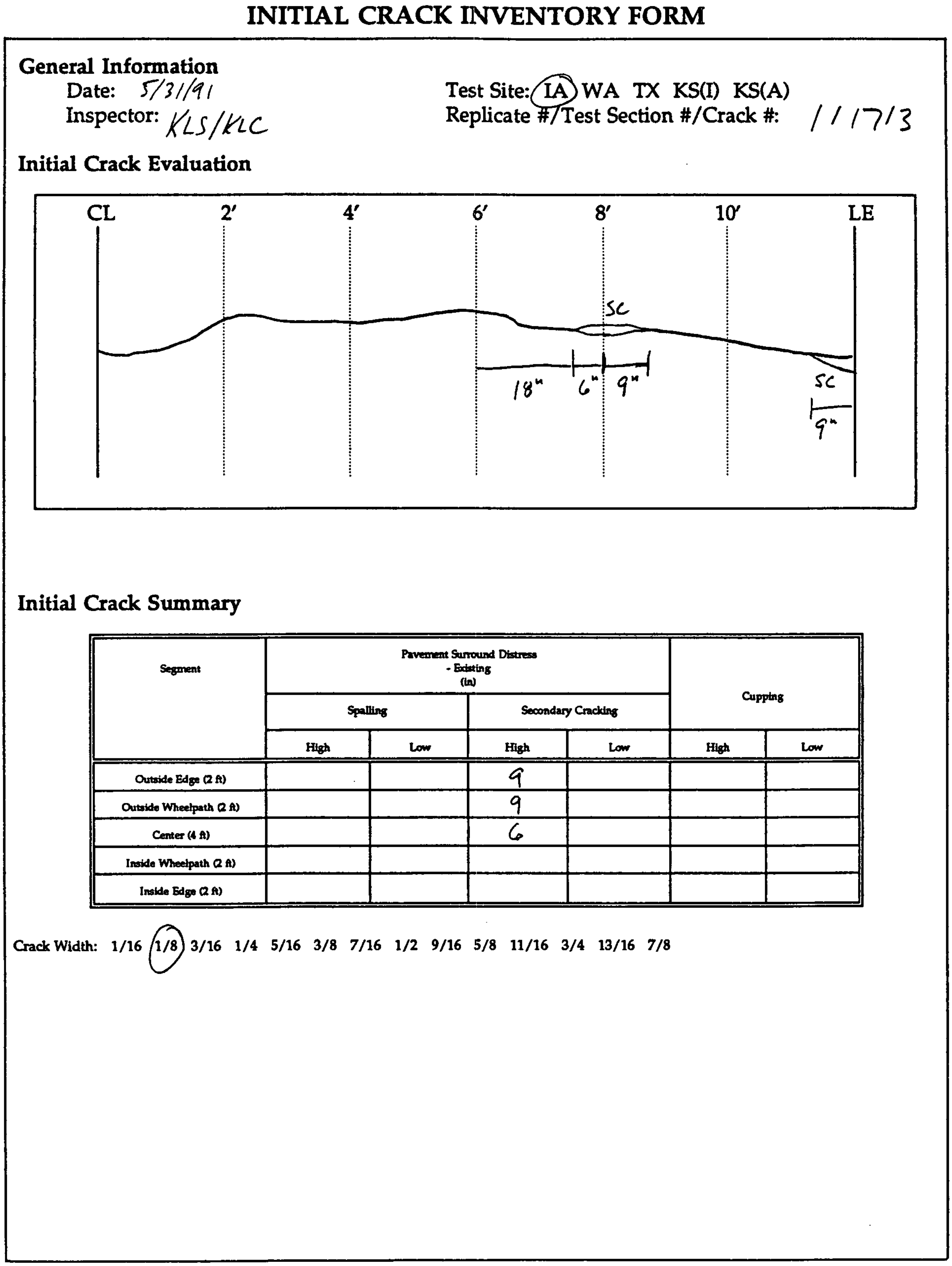
Site: [✓ IA] WA TX KS(I) KS(A)

Replicate #/Test Section #: 2-5

Beginning Station: 6+33

Ending Station: 14+32

Figure B-2. Test section layout form



INITIAL CRACK INVENTORY FORM

General Information

Date: 5/31/91

Inspector: KLS/KLC

Test Site: [✓ IA] WA TX KS(I) KS(A)

Replicate #/Test Section #/Crack #: 1/1/17/3

Initial Crack Evaluation

Initial Crack Summary

Segment	Pavement Surround Distress - Existing (in)				Cupping	
	Spalling		Secondary Cracking			
	High	Low	High	Low	High	Low
Outside Edge (2 ft)			9			
Outside Wheelpath (2 ft)			9			
Center (4 ft)			6			
Inside Wheelpath (2 ft)						
Inside Edge (2 ft)						

Crack Width: 1/16 [✓ 1/8] 3/16 1/4 5/16 3/8 7/16 1/2 9/16 5/8 11/16 3/4 13/16 7/8

Figure B-3. Initial crack inventory form

First, average crack widths were measured and recorded. Then, individual crack maps were sketched showing the general crack patterns and the approximate positions and dimensions of edge deterioration observed along the experimental cracks. To simplify analyses, distress dimensions were measured in the longitudinal and transverse directions. This information was recorded as a baseline condition for monitoring the development of additional edge deterioration caused by crack-cutting operations and/or traffic applications.

To facilitate the documentation of edge deterioration along a transverse crack, the crack was broken down into five positions (see figure 9). These positions included:

- Inside edge (2 ft [0.6 m])
- Inside wheelpath (2 ft [0.6 m])
- Center (4 ft [1.2 m])
- Outside wheelpath (2 ft [0.6 m])
- Outside edge (2 ft [0.6 m])

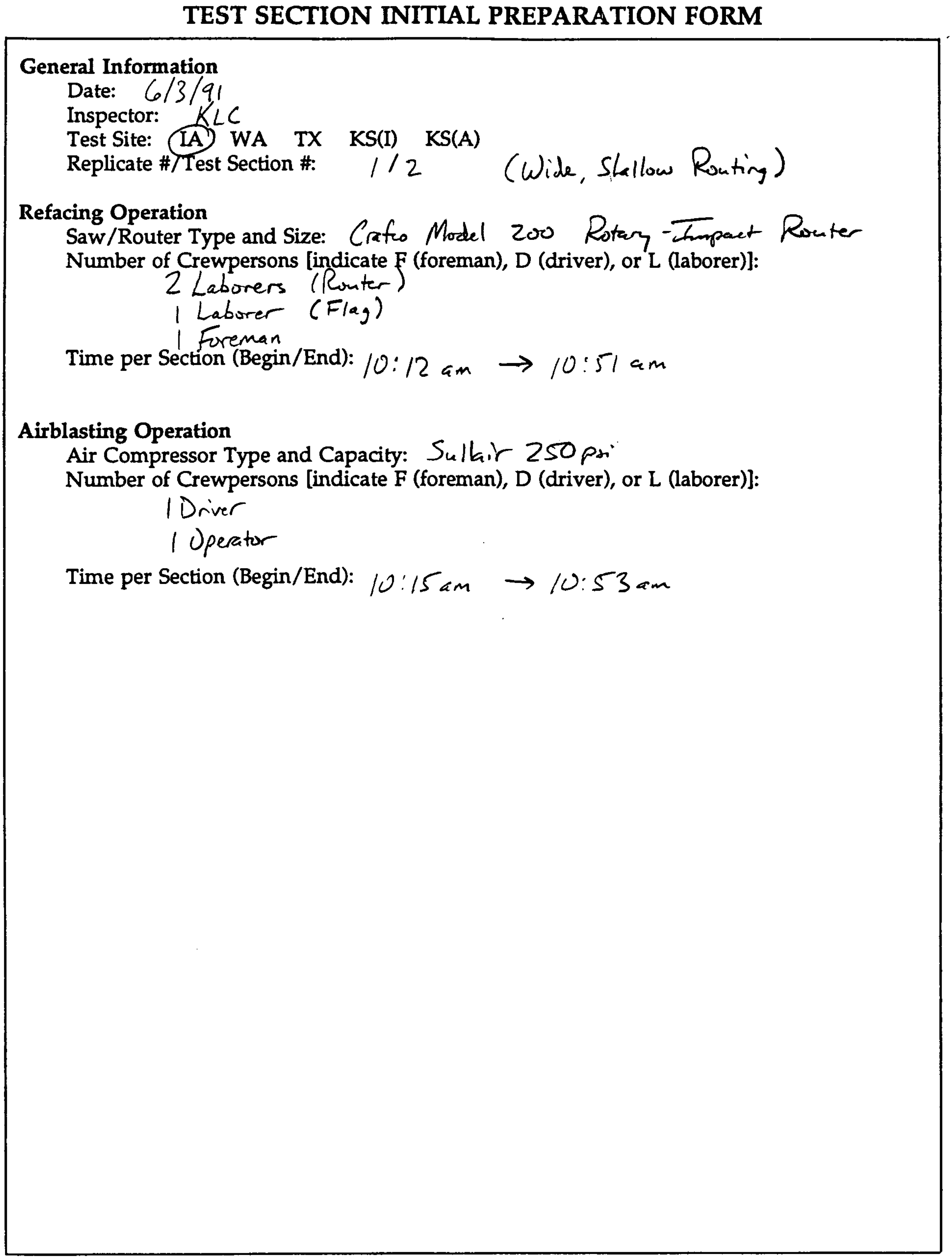
By partitioning the transverse cracks in this way, the effects of traffic on the sealant system could be evaluated. The 25-ft (7.6-m) longitudinal crack divisions at Prescott were broken down into five 5-ft (1.5-m) segments, but only to facilitate the evaluations.

Crack-Cutting Data

Information about crack-cutting operations and the resulting crack reservoir conditions was recorded on copies of the forms shown in figures B-4 and B-5. After specified experimental cracks were cut and quickly blown free of dust and debris, they were reinspected for edge deterioration as described in the previous section. During the reinspection, three additional distress phenomena were monitored: missed cracks, neglected cracks, and "islands." A missed crack denoted a segment of crack missed in the cutting operation because of the inability of the operator or the equipment to accurately follow the crack. Missed cracks resulted in <u>two</u> adjacent defects: the original crack and the nearby channel cut. In places where secondary cracks existed, the cutting operator had the option of cutting only the primary crack and neglecting the secondary crack or cutting both the primary crack <u>and</u> the secondary crack. In the latter case, an "island" of pavement surrounded by channel cuts was created. Although both cracks and crack reservoirs were eventually sealed, it was desirable to see how fast these distressed segments would deteriorate with time.

Material Preparation Data

For hot-applied materials, a material heating log was kept that showed the intermittent temperatures of a product in the kettle vat during the heating and application phases. Copies of the form shown in figure B-6 were used for documenting this information. Temperature readings were taken from both the temperature gauge mounted on the kettle and a hand-held thermometer probe that was inserted into the material in the vat.



TEST SECTION INITIAL PREPARATION FORM

General Information

Date: 6/3/91

Inspector: KLC

Test Site: [✓ IA] WA TX KS(I) KS(A)

Replicate #/Test Section #: 1 / 2 (Wide, Shallow Routing)

Refacing Operation

Saw/Router Type and Size: Crafco Model 200 Rotary-Impact Router

Number of Crewpersons [indicate F (foreman), D (driver), or L (laborer)]:

2 Laborers (Router)

1 Laborer (Flag)

1 Foreman

Time per Section (Begin/End): 10:12 am → 10:51 am

Airblasting Operation

Air Compressor Type and Capacity: Sullair 250 psi

Number of Crewpersons [indicate F (foreman), D (driver), or L (laborer)]:

1 Driver

1 Operator

Time per Section (Begin/End): 10:15 am → 10:53 am

Figure B-4. Test section initial preparation form

REFACED CRACK INVENTORY FORM

General Information

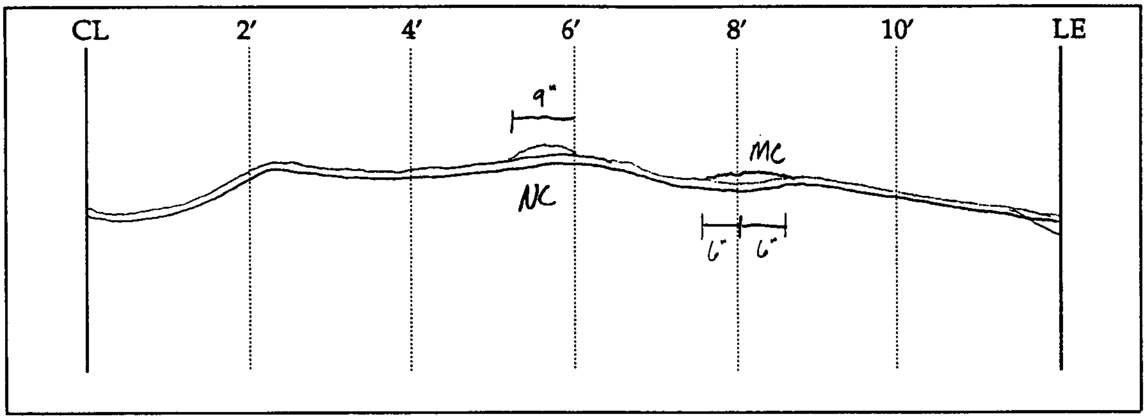
Date: 6/3/91

Inspector: KLS

Test Site: [✓ IA] WA TX KS(I) KS(A)

Replicate #/Test Section #/Crack #: 1/17/13

Refaced Crack Evaluation



Refaced Crack Summary

Segment	Pavement Surround Distress Due to Channel Creation (in)				
	Spalling		Secondary Cracking		Missed Crack
	High	Low	High	Low	
Outside Edge (2 ft)					
Outside Wheelpath (2 ft)					6"
Center (4 ft)			9"		6"
Inside Wheelpath (2 ft)					
Inside Edge (2 ft)					

Average Channel Width (in): 9/16

Average Channel Depth (in): 11/16

Channel Creation Operation: [Saw] [✓ [Router]]

Figure B-5. Refaced crack inventory form

KETTLE TEMPERATURE MONITORING CHART

This form is to be completed by the person responsible for each melter/applicator. Readings using the thermometer provided by the H-106 contractor will be taken at 30 min (± 5 min) time intervals. One form will be completed for each sealant/filler material and for each day. Temperatures will be reported in degrees Fahrenheit.

Date: 6-5-91
Name of Kettle Tender: Gary B.
Kettle Type: Cimline 200
Kettle Size (gal): 200 Gal

Sealant/Filler Mtl: M-HiSpec C-515 K-9030 M-XLM [✓ K-BoniFbrs] C-AR2 H-FbrPave AC

Time	Thermometer Reading	Gage Reading
6:00 am		
6:30		
7:00	280	250
7:30	290	290
8:00	330	320
~~8:30~~ 8:15		320
9:00	310	310
9:30	310	320
10:00	310	320
10:30	300	310
11:00	310	330
11:30		
12:00 p.m.		
12:30		
1:00		
1:30		
2:00		
2:30		
3:00		
3:30		
4:00		
4:30		
5:00		
5:30		
6:00		

(ADDED FIBERS)

(INSTALLATION)

The following times will be recorded as the sealant/filler is heated:

Begin Heating: 6:10 am
Product Liquified:
Product at Application Temp:

Nozzle Temperature Readings

Lines may be cleared and application temperature readings may be taken after the sealant/filler in the kettle has remained at application temperature for at least 30 minutes.

Trial 1
Time: 9:30 [✓ am]/pm
Nozzle Temp: 305 °F
Kettle Temp: 320 °F
Kettle Gage: 310 °F

Trial 2
Time: 11:00 [✓ am]/pm
Nozzle Temp: 305 °F
Kettle Temp: 330 °F
Kettle Gage: 315 °F

Figure B-6. Kettle temperature monitoring chart

Final Crack Preparation and Material Installation Data

Just prior to installation, a digital caliper was used to measure the distances between sets of dimpled P-K nails installed across each experimental crack during layout. These distances served as base references for determining the amount of horizontal movement a particular crack experiences at various times throughout the year. Distances were recorded using copies of the form illustrated in figure B-7.

Information regarding final crack preparation and material installation was documented on forms identical to the one shown in figure B-8. Due to the lack of a standard procedure for evaluating crack channels for cleanliness and moisture, subjective ratings were used to assess each crack following the cleaning/drying operations. A five-point scale, with "1" designating "dirty" and "5" designating "very clean", was used to evaluate crack channel cleanliness. Similarly, a five-point scale was used to gauge the presence of moisture, with "1" indicating "no moisture present" and "5" indicating "moisture present on bonding surfaces".

NAIL PLUG MONITORING CHART

[INSTALLATION]

General Information

Date: 6/7/91
Inspector: KLS/KLC

Test Site: [✓ IA] WA TX KS(I) KS(A)
Material: [✓ 1] 2 3 4 5 6 7 8

Material	Configuration	Cleaning Procedure
(1) Hi-Spec	(A) 0.63" x 0.75" Channel & Flush	(1) None
(2) 34515	(B) 0.63" x 0.75" Channel & Band-Aid	(2) Wire Brush & Compressed Air
(3) 9030	(C) 1.5" x 0.2" Channel & Band-Aid	(3) HCA Lance
(4) XLM	(D) Band-Aid	(4) Compressed Air
(5) BoniFibers	(E) Channel & Recess	(5) Light Sandblast, Compressed Air, & Backer Rod
(6) 890 SL		
(7) Other ________		
(8) Other ________		

Crack Movement Record

(C-3) (D-4) (D-3)

Crack Number	Replicate #/Test Section #: 1/2 Material: [✓ 1] 2 3 4 5 6 7 8 Configuration: A B [✓ C] D E Preparation: 1 2 [✓ 3] 4 5		Replicate #/Test Section #: 1/4 Material: [✓ 1] 2 3 4 5 6 7 8 Configuration: A B C [✓ D] E Preparation: 1 2 3 [✓ 4] 5		Replicate #/Test Section #: 1/9 Material: [✓ 1] 2 3 4 5 6 7 8 Configuration: A B C [✓ D] E Preparation: 1 2 [✓ 3] 4 5	
	Time	Reading	Time	Reading	Time	Reading
1	9:08am	—	9:40am	—	10:40am	—
2		—		—		—
3		10.605		10.404		10.804
4		10.316		10.651		10.798
5		10.573		10.524		10.495
6		10.534		11.203		10.820
7		10.529		10.585		10.570
8		10.664		10.467		10.374
9		10.546		10.927		10.485
10	9:16am	10.859	9:45am	10.808	10:46am	10.595

(B-3) (A-3) (A-2)

Crack Number	Replicate #/Test Section #: 1/11 Material: [✓ 1] 2 3 4 5 6 7 8 Configuration: A [✓ B] C D E Preparation: 1 2 [✓ 3] 4 5		Replicate #/Test Section #: 1/14 Material: [✓ 1] 2 3 4 5 6 7 8 Configuration: [✓ A] B C D E Preparation: 1 2 [✓ 3] 4 5		Replicate #/Test Section #: 1/17 Material: [✓ 1] 2 3 4 5 6 7 8 Configuration: [✓ A] B C D E Preparation: 1 [✓ 2] 3 4 5	
	Time	Reading	Time	Reading	Time	Reading
1	11:04 am	—	11:38am	—	12:19pm	—
2		—		—		—
3		10.516		10.611		10.721
4		10.740		10.718		10.355
5		10.626		10.238		10.675
6		10.659		10.700		10.555
7		10.565		10.882		10.643
8		10.346		10.301		10.581
9		10.471		10.330		10.134
10	11:10am	10.573	11:45am	10.554	12:24pm	10.726

Figure B-7. Nail plug monitoring chart

TEST SECTION FINAL PREPARATION & INSTALLATION FORM

General Information:
Date: 6/7/91
Inspector: KLS/KLC
Test Site: [✓ IA] WA TX KS(I) KS(A)
Replicate #/Test Section #: 1 / 2 (Hi-Spec C-3 Treatment)

Material	Configuration	Preparation Procedure
[✓ (1) Hi-Spec]	(1) 0.63" x 0.75" Channel & Flush	(1) None
(2) 34515	(2) 0.63" x 0.75" Channel & Band-Aid	(2) Wire Brush & Compressed Air
(3) 9030	[✓ (3) 1.5" x 0.2" Channel & Band-Aid]	[✓ (3) HCA Lance]
(4) XLM	(4) Band-Aid	(4) Compressed Air
(5) BoniFibers	(5) Channel & Recess	(5) Light Sandblast, Compressed Air, & Backer Rod
(6) 890 SL		
(7) Other ______		
(8) Other ______		

Final Preparation
Brush Type and Size: —
Time (Begin/End): —
Compressed Air Unit Type and Capacity: Sullair 250psi
Heat Lance Type and Model: Cimline Hot Rod Lance
Time (Begin/End): 9:15 → 9:42
Total Number of Crewpersons [Indicate F, D, or L]:
1 Driver, 1 Operator

Installation & Finishing
Melter/Applicator Type and Size: Cimline 200 gal
Finishing Apparatus Type: Band-Aid Squeegee
Time (Begin/End): 9:20 → 9:45
Total Number of Crewpersons [Indicate F, D, or L]:
1 Driver
1 Applicator
1 Squeegeer

Application Checklist

	Crack Number										Comments
	1	2	3	4	5	6	7	8	9	10	
Sealant Overheating											No
Sealant Bubbling											Yes, small amounts
Crack Cleanliness											→ GOOD
Crack Moisture											→ NONE APPARENT
Overband Thickness, in	1/8	3/32	1/8	1/8	3/32	1/8	1/8	1/8	1/8	1/8	
Overband Width, in											→ 3"
Depth to Backer Rod, in											—
Depth of Recess, in											—

Miscellaneous Information
Approximate Amount of Material Used (lb): ??
Blotting Required: Yes (If yes, sand or tp) [✓ No] → Traffic Cones Set Up

Figure B-8. Final crack preparation and material installation form

Table B-1. Des Moines test section installation summary

Test Site	Material	Replicate	Configuration	Preparation Procedure	Date of Installation	Avg Original Crack Width, in	Avg Crack Reservoir Width, in	Avg Crack Reservoir Depth, in	Type of Cut (Rout, Saw)	Avg Final Crack Width, in	Avg Crack Cleanliness Rating	Avg Crack Moisture Rating	Avg Band-Aid Thickness, in	Avg Band-Aid Width, in	Avg Backer Rod Depth, in	Avg Depth of Recess, in	Material Overheating	Material Bubbling	Bubbles - Low, in	Bubbles - Medium, in	Bubbles - High, in	Sunken Material - Low, in	Sunken Material - High, in	Stone Intrusion - Low, in	Stone Intrusion - Med, in	Stone Intrusion - High, in
IA	1	1	A	2	31-May-91	0.106	0.563	0.727	Rout	0.563	4	2	N/A	N/A	N/A	N/A	No	2	18	0	0	0	0	0	0	0
IA	1	2	A	2	03-Jun-91	0.098	0.563	0.704	Rout	0.563	4	2	N/A	N/A	N/A	N/A	No	2	72	0	0	0	0	0	0	0
IA	1	1	A	3	31-May-91	0.106	0.563	0.711	Rout	0.563	4	2	N/A	N/A	N/A	N/A	No	2	90	0	0	0	0	0	0	0
IA	1	2	A	3	03-Jun-91	0.102	0.563	0.719	Rout	0.563	4	2	N/A	N/A	N/A	N/A	No	2	108	18	0	0	0	0	0	0
IA	1	1	B	3	31-May-91	0.110	0.563	0.625	Rout	0.563	4	2	0.094	2.75	N/A	N/A	No	2	90	0	0	0	0	0	0	0
IA	1	2	B	3	03-Jun-91	0.106	0.563	0.735	Rout	0.563	4	2	0.094	3.00	N/A	N/A	No	2	120	6	0	0	0	0	0	0
IA	1	1	C	3	31-May-91	0.106	1.500	0.235	Rout	1.500	4	2	0.094	2.75	N/A	N/A	No	2	126	18	0	0	0	0	0	0
IA	1	2	C	3	31-May-91	0.113	1.500	0.196	Rout	1.500	4	2	0.094	3.00	N/A	N/A	No	2	72	72	0	0	0	0	0	0
IA	1	1	D	3	31-May-91	0.102	N/A	N/A	N/A	0.102	4	2	0.094	2.75	N/A	N/A	No	2	114	12	0	0	0	0	0	0
IA	1	2	D	3	03-Jun-91	0.106	N/A	N/A	N/A	0.106	4	2	0.094	3.00	N/A	N/A	No	2	120	24	0	0	0	0	0	0
IA	1	1	D	4	31-May-91	0.106	N/A	N/A	N/A	0.106	3	2	0.094	2.75	N/A	N/A	No	2	108	36	0	0	0	0	0	0
IA	1	2	D	4	31-May-91	0.106	N/A	N/A	N/A	0.106	3	2	0.094	3.00	N/A	N/A	No	2	102	24	0	0	0	0	0	0
IA	2	1	B	3	31-May-91	0.106	0.563	0.696	Rout	0.563	4	2	0.094	3.00	N/A	N/A	No	2	44.3	0	0	0	0	0	0	0
IA	2	2	B	3	03-Jun-91	0.086	0.563	0.750	Rout	0.563	4	2	0.094	3.00	N/A	N/A	No	1	36	0	0	0	0	0	0	0
IA	2	1	C	3	31-May-91	0.106	1.500	0.211	Rout	1.500	4	1	0.094	3.00	N/A	N/A	No	1	144	0	0	0	0	0	0	0
IA	2	2	C	3	03-Jun-91	0.082	1.500	0.211	Rout	1.500	4	2	0.094	3.00	N/A	N/A	No	2	126	0	0	0	0	0	0	0
IA	2	1	D	3	31-May-91	0.110	N/A	N/A	N/A	0.110	4	1	0.094	3.00	N/A	N/A	No	1	0	0	0	0	0	0	0	0
IA	2	2	D	3	03-Jun-91	0.102	N/A	N/A	N/A	0.102	4	2	0.094	3.00	N/A	N/A	No	2	138	6	0	0	0	0	0	0
IA	3	1	B	3	31-May-91	0.106	0.563	0.672	Rout	0.563	4	2	0.094	3.00	N/A	N/A	No	2	0	0	0	0	0	0	0	0
IA	3	2	B	3	03-Jun-91	0.098	0.563	0.680	Rout	0.563	4	2	0.094	3.00	N/A	N/A	No	2	18	0	0	0	0	0	0	0
IA	3	1	C	3	31-May-91	0.110	1.500	0.243	Rout	1.500	4	2	0.094	3.00	N/A	N/A	No	2	0	0	0	0	0	0	0	0
IA	3	2	C	3	31-May-91	0.106	1.500	0.235	Rout	1.500	4	2	0.094	3.00	N/A	N/A	No	2	12	0	0	0	0	0	0	0
IA	3	1	D	3	31-May-91	0.102	N/A	N/A	N/A	0.102	4	2	0.094	3.00	N/A	N/A	No	2	0	0	0	0	0	0	0	0
IA	3	2	D	3	03-Jun-91	0.090	N/A	N/A	N/A	0.090	4	2	0.094	3.00	N/A	N/A	No	2	0.25	0	0	0	0	0	0	0
IA	4	1	B	3	31-May-91	0.106	0.563	0.704	Rout	0.563	4	2	0.094	3.00	N/A	N/A	No	2	0	0	0	0	0	0	0	0
IA	4	2	B	3	03-Jun-91	0.098	0.563	0.688	Rout	0.563	4	2	0.094	3.00	N/A	N/A	No	2	0	0	0	0	0	0	0	0
IA	4	1	C	3	31-May-91	0.117	1.501	0.235	Rout	1.501	4	2	0.094	3.06	N/A	N/A	No	2	0	0	0	0	0	0	0	0
IA	4	2	C	3	03-Jun-91	0.094	1.500	0.219	Rout	1.500	4	2	0.094	3.00	N/A	N/A	No	2	0	0	0	0	0	0	0	0
IA	4	1	D	3	31-May-91	0.110	N/A	N/A	N/A	0.110	4	2	0.094	3.00	N/A	N/A	No	2	0	0	0	0	0	0	0	0
IA	4	2	D	3	31-May-91	0.110	N/A	N/A	N/A	0.110	4	2	0.094	3.00	N/A	N/A	No	2	54	0	0	0	0	0	0	0
IA	5	1	D	3	31-May-91	0.110	N/A	N/A	N/A	0.110	4	1	0.094	3.00	N/A	N/A	No	1	0	0	0	0	0	0	0	0
IA	5	2	D	3	03-Jun-91	0.113	N/A	N/A	N/A	0.113	4	1	0.094	3.00	N/A	N/A	No	1	144	0	0	0	0	0	0	0
IA	6	1	E	5	31-May-91	0.098	0.563	1.617	Saw	0.563	5	1	N/A	N/A	0.657	0.235	No/A	N/A	0	0	0	0	0	0	0	0
IA	6	2	E	5	03-Jun-91	0.110	0.563	1.750	Saw	0.563	5	1	N/A	N/A	0.649	0.250	No/A	N/A	0	0	0	0	0.4	144	0	0
IA	E	1	G	4	31-May-91	0.106	N/A	N/A	N/A	0.106	NA	NA	N/A	N/A	N/A	N/A	NoA	NA	0	0	0	0	0	0	0	0
IA	E	2	G	4	03-Jun-91	0.106	N/A	N/A	N/A	0.106	NA	NA	N/A	N/A	N/A	N/A	NoA	NA	0	0	0	0	0	0	0	0

Table B-2. Abilene test section installation summary

Test Site	Material	Replicate	Configuration	Preparation Procedure	Date of Installation	Avg Original Crack Width, in	Avg Crack Reservoir Width, in	Avg Crack Reservoir Depth, in	Type of Cut (Rout, Saw)	Avg Final Crack Width, in	Avg Crack Cleanliness Rating	Avg Crack Moisture Rating	Avg Band-Aid Thickness, in	Avg Band-Aid Width, in	Avg Backer Rod Depth, in	Avg Depth of Recess, in	Material Overheating	Material Bubbling	Bubbles - Low, in	Bubbles - Medium, in	Bubbles - High, in	Sunken Material - Low, in	Sunken Material - High, in	Stone Intrusion - Low, in	Stone Intrusion - Med, in	Stone Intrusion - High, in
TX	1	1	A	3	20-Mar-91	0.094	0.625	0.750	Rout	0.625	4	1	N/A	N/A	N/A	N/A	No	1	0	0	0	1.9	0	0	0	0
TX	1	2	A	3	20-Mar-91	0.094	0.625	0.750	Rout	0.625	4	1	N/A	N/A	N/A	N/A	No	1	0	0	0	0	0	0	0	0
TX	1	1	B	3	20-Mar-91	0.094	0.625	0.719	Rout	0.625	4	1	0.094	2.50	N/A	N/A	No	1	2.25	0	0	0	0	0	0	0
TX	1	2	B	3	20-Mar-91	0.094	0.625	0.750	Rout	0.625	4	1	0.094	2.50	N/A	N/A	No	1	0	0	0	0	0	0	0	0
TX	1	1	D	3	20-Mar-91	0.094	N/A	N/A	N/A	0.094	4	1	0.094	2.50	N/A	N/A	No	1	6	0	0	0	0	0	0	0
TX	1	2	D	3	20-Mar-91	0.094	N/A	N/A	N/A	0.094	4	1	0.094	2.50	N/A	N/A	No	1	72	0	0	0	0	0	0	0
TX	1	1	D	4	20-Mar-91	0.094	N/A	N/A	N/A	0.094	4	1	0.094	2.50	N/A	N/A	No	1	0	0	0	0	0	0	0	0
TX	1	2	D	4	20-Mar-91	0.094	N/A	N/A	N/A	0.094	4	1	0.094	2.50	N/A	N/A	No	1	72	0	0	0	0	0	0	0
TX	2	1	B	3	20-Mar-91	0.094	0.625	0.750	Rout	0.625	4	1	0.094	2.50	N/A	N/A	No	1	0	0	0	0	0	0	0	0
TX	2	2	B	3	20-Mar-91	0.094	0.625	0.750	Rout	0.625	4	1	0.094	2.50	N/A	N/A	No	1	0	0	0	0	0	0	0	0
TX	2	1	D	3	20-Mar-91	0.094	N/A	N/A	N/A	0.094	4	1	0.094	2.50	N/A	N/A	No	1	0	0	0	0	0	0	0	0
TX	2	2	D	3	20-Mar-91	0.094	N/A	N/A	N/A	0.094	4	1	0.094	2.50	N/A	N/A	No	1	0	0	0	0	0	0	0	0
TX	3	1	B	3	20-Mar-91	0.094	0.625	0.750	Rout	0.625	4	1	0.094	2.50	N/A	N/A	No	2	0	0	0	0	0	0	0	0
TX	3	2	B	3	20-Mar-91	0.094	0.625	0.750	Rout	0.625	4	1	0.094	2.50	N/A	N/A	No	2	0	0	0	0	4.1	0	0	0
TX	3	1	D	3	20-Mar-91	0.094	N/A	N/A	N/A	0.094	4	1	0.094	2.50	N/A	N/A	No	2	0	0	0	0	0	0	0	0
TX	3	2	D	3	20-Mar-91	0.094	N/A	N/A	N/A	0.094	4	1	0.094	2.50	N/A	N/A	No	2	0	0	0	0	0	0	0	0
TX	4	1	B	3	20-Mar-91	0.094	0.625	0.750	Rout	0.625	4	1	0.094	2.50	N/A	N/A	Yes	1	144	0	0	0	0	0	0	0
TX	4	2	B	3	20-Mar-91	0.094	0.625	0.734	Rout	0.625	4	1	0.094	2.50	N/A	N/A	Yes	1	0	144	0	0	0	0	0	0
TX	4	1	D	3	20-Mar-91	0.094	N/A	N/A	N/A	0.094	4	1	0.094	2.50	N/A	N/A	Yes	1	0	144	0	0	0	0	0	0
TX	4	2	D	3	20-Mar-91	0.094	N/A	N/A	N/A	0.094	4	1	0.094	2.50	N/A	N/A	Yes	1	0	144	0	0	0	0	0	0
TX	5	1	D	3	20-Mar-91	0.094	N/A	N/A	N/A	0.094	4	1	0.094	2.50	N/A	N/A	No	1	0	0	0	1.4	0	0	0	0
TX	5	2	D	3	20-Mar-91	0.094	N/A	N/A	N/A	0.094	4	1	0.094	2.50	N/A	N/A	No	1	0	0	0	0	0	0	0	0
TX	6	1	E	5	20-Mar-91	0.094	0.750	1.250	Rout	0.750	5	1	N/A	N/A	0.566	0.117	No/A	N/A	0	0	0	0	0	5	25	0
TX	6	2	E	5	20-Mar-91	0.094	0.750	1.250	Rout	0.750	5	1	N/A	N/A	0.609	0.121	No/A	N/A	0	0	0	0	0	0	3	0

Table B-3. Wichita ideal subsite test section installation summary

Test Site	Material	Replicate	Configuration	Preparation Procedure	Date of Installation	Avg Original Crack Width, in	Avg Crack Reservoir Width, in	Avg Crack Reservoir Depth, in	Type of Cut (Rout, Saw)	Avg Final Crack Width, in	Avg Crack Cleanliness Rating	Avg Crack Moisture Rating	Avg Band-Aid Thickness, in	Avg Band-Aid Width, in	Avg Backer Rod Depth, in	Avg Depth of Recess, in	Material Overheating	Material Bubbling	Bubbles - Low, in	Bubbles - Medium, in	Bubbles - High, in	Sunken Material - Low, in	Sunken Material - High, in	Stone Intrusion - Low, in	Stone Intrusion - Med, in	Stone Intrusion - High, in
KS (I)	1	1	A	3	11-Apr-91	0.156	0.563	0.836	Saw	0.563	4	2	N/A	N/A	N/A	N/A	No	3	19.9	0	0	1	0	0	0	0
KS (I)	1	2	A	3	12-Apr-91	0.156	0.563	0.719	Saw	0.563	4	2	N/A	N/A	N/A	N/A	No	3	128	0	0	0	0	0	0	0
KS (I)	1	1	B	3	11-Apr-91	0.180	0.563	0.797	Saw	0.563	4	2	0.094	3.00	N/A	N/A	No	3	125	0	0	0	0	0	0	0
KS (I)	1	2	B	3	12-Apr-91	0.156	0.563	0.696	Saw	0.563	4	2	0.094	3.00	N/A	N/A	No	3	120	6	0	0	0	0	0	0
KS (I)	1	1	C	3	11-Apr-91	0.113	1.375	0.204	Rout	1.375	4	1	0.094	3.00	N/A	N/A	No	1	139	4.88	0	0	0	0	0	0
KS (I)	1	2	C	3	11-Apr-91	0.156	1.375	0.352	Rout	1.375	4	2	0.094	3.00	N/A	N/A	No	3	120	10.1	0	0	0	0	0	0
KS (I)	1	1	D	3	16-Apr-91	0.137	N/A	N/A	N/A	0.137	4	1	0.094	3.00	N/A	N/A	No	1	135	0	0	0	0	0	0	0
KS (I)	1	2	D	3	17-Apr-91	0.156	N/A	N/A	N/A	0.156	4	2	0.094	3.00	N/A	N/A	No	3	131	7.5	0	0	0	0	0	0
KS (I)	1	1	D	4	16-Apr-91	0.133	N/A	N/A	N/A	0.133	3	1	0.094	3.00	N/A	N/A	No	1	36	0	0	0	0	0	0	0
KS (I)	1	2	D	4	17-Apr-91	0.156	N/A	N/A	N/A	0.156	3	2	0.094	3.00	N/A	N/A	No	3	132	0	0	0	0	0	0	0
KS (I)	2	1	C	3	11-Apr-91	0.180	1.375	0.227	Rout	1.375	4	3	0.094	2.50	N/A	N/A	No	3	0	0	0	16	4.5	0	0	0
KS (I)	2	2	C	3	12-Apr-91	0.156	1.375	0.188	Rout	1.375	4	3	0.094	2.50	N/A	N/A	No	3	76.9	3	0	1.5	0	0	0	0
KS (I)	2	1	D	3	16-Apr-91	0.152	N/A	N/A	N/A	0.152	4	3	0.094	2.50	N/A	N/A	No	4	67.1	10.5	0	0	0	0	0	0
KS (I)	2	2	D	3	17-Apr-91	0.156	N/A	N/A	N/A	0.156	4	3	0.094	2.50	N/A	N/A	No	3	36	0	0	0	0	0	0	0
KS (I)	3	1	C	3	11-Apr-91	0.168	1.375	0.196	Rout	1.375	4	1	0.094	2.50	N/A	N/A	No	1	3.75	0	0	88	4.5	6	0	0
KS (I)	3	2	C	3	11-Apr-91	0.156	1.375	0.235	Rout	1.375	4	1	0.094	2.50	N/A	N/A	No	1	8.25	0	0	16	0	0	0	0
KS (I)	3	1	D	3	17-Apr-91	0.156	N/A	N/A	N/A	0.156	4	1	0.094	2.50	N/A	N/A	No	1	3.38	0	0	0	0.3	0	0	0
KS (I)	3	2	D	3	17-Apr-91	0.172	N/A	N/A	N/A	0.172	4	1	0.094	2.50	N/A	N/A	No	1	101	0	0	0	0	0	0	0
KS (I)	4	1	C	3	11-Apr-91	0.184	1.375	0.258	Rout	1.375	4	1	0.094	3.00	N/A	N/A	No	1	119	6.75	0	0.8	0	0	0	0
KS (I)	4	2	C	3	12-Apr-91	0.156	1.375	0.211	Rout	1.375	4	1	0.094	3.00	N/A	N/A	No	1	144	0	0	5.6	0	0	0	0
KS (I)	4	1	D	3	15-Apr-91	0.133	N/A	N/A	N/A	0.133	4	1	0.094	3.00	N/A	N/A	No	1	126	0	0	0	0	0	0	0
KS (I)	4	2	D	3	17-Apr-91	0.156	N/A	N/A	N/A	0.156	4	1	0.094	3.00	N/A	N/A	No	1	90	0	0	0	0	0	0	0
KS (I)	5	1	D	3	16-Apr-91	0.125	N/A	N/A	N/A	0.125	4	1	0.094	2.50	N/A	N/A	No	1	96.4	0	0	39	0	0	0	0
KS (I)	5	2	D	3	17-Apr-91	0.156	N/A	N/A	N/A	0.156	4	1	0.094	2.50	N/A	N/A	No	1	87	0	0	0	0	0	0	0
KS (I)	6	1	E	5	16-Apr-91	0.133	0.625	1.430	Saw	0.625	5	1	N/A	N/A	0.625	0.242	No/A	N/A	0	0	0	0	0	146	0	0
KS (I)	6	2	E	5	17-Apr-91	0.156	0.625	1.453	Saw	0.625	5	1	N/A	N/A	0.625	0.250	No/A	N/A	0	0	0	0	1.1	108	0	0
KS (I)	8	1	B	3	11-Apr-91	0.168	0.563	0.860	Saw	0.563	NA	NA	NA	NA	N/A	N/A	NoA	NA	0	0	0	0	0	0	0	0
KS (I)	8	2	B	3	12-Apr-91	0.156	0.563	0.688	Saw	0.563	NA	NA	NA	NA	N/A	N/A	NoA	NA	0	0	0	0	0	0	0	0
KS (I)	9	1	B	3	11-Apr-91	0.164	0.563	0.867	Saw	0.563	NA	NA	NA	NA	N/A	N/A	NoA	NA	1.88	0	0	0	0	0	0	0
KS (I)	9	2	B	3	12-Apr-91	0.144	0.563	0.735	Saw	0.563	NA	NA	NA	NA	N/A	N/A	NoA	NA	54	0	0	0	0	0	0	0

Table B-4. Wichita adverse subsite test section installation summary

Test Site	Material	Replicate	Configuration	Preparation Procedure	Date of Installation	Avg Original Crack Width, in	Avg Crack Reservoir Width, in	Avg Crack Reservoir Depth, in	Type of Cut (Rout, Saw)	Avg Final Crack Width, in	Avg Crack Cleanliness Rating	Avg Crack Moisture Rating	Avg Band-Aid Thickness, in	Avg Band-Aid Width, in	Avg Backer Rod Depth, in	Avg Depth of Recess, in	Material Overheating	Material Bubbling	Bubbles - Low, in	Bubbles - Medium, in	Bubbles - High, in	Sunken Material - Low, in	Sunken Material - High, in	Stone Intrusion - Low, in	Stone Intrusion - Med, in	Stone Intrusion - High, in
KS (A)	1	1	A	3	14-Apr-91	0.148	0.563	0.743	Saw	0.563	4	3	N/A	N/A	N/A	N/A	No	3	6.75	0	0	0	0	0	0	0
KS (A)	1	2	A	3	12-Apr-91	0.156	0.563	0.719	Saw	0.563	4	3	N/A	N/A	N/A	N/A	No	3	102	0	0	0	0	0	0	0
KS (A)	1	1	B	3	14-Apr-91	0.160	0.563	0.758	Saw	0.563	4	3	0.094	3.00	N/A	N/A	No	3	144	0	0	0	0	0	0	0
KS (A)	1	2	B	3	12-Apr-91	0.200	0.563	0.727	Saw	0.563	4	3	0.094	3.00	N/A	N/A	No	3	0	144	0	0	0	0	0	0
KS (A)	1	1	C	3	14-Apr-91	0.172	1.375	0.219	Rout	1.375	4	3	0.094	3.00	N/A	N/A	No	3	101	0	0	1	0	0	0	0
KS (A)	1	2	C	3	15-Apr-91	0.110	1.375	0.223	Rout	1.375	4	3	0.094	3.00	N/A	N/A	No	3	130	0	0	1.8	0	0	0	0
KS (A)	1	1	D	3	16-Apr-91	0.148	N/A	N/A	N/A	0.148	4	3	0.094	3.00	N/A	N/A	No	3	126	0	0	0	0	0	0	0
KS (A)	1	2	D	3	16-Apr-91	0.117	N/A	N/A	N/A	0.117	4	3	0.094	3.00	N/A	N/A	No	3	140	0	0	0	0	0	0	0
KS (A)	1	1	D	4	16-Apr-91	0.156	N/A	N/A	N/A	0.156	3	3	0.094	3.00	N/A	N/A	No	3	138	0	0	0	0	0	0	0
KS (A)	1	2	D	4	16-Apr-91	0.110	N/A	N/A	N/A	0.110	3	3	0.094	3.00	N/A	N/A	No	3	16.3	0	0	0	0	0	0	0
KS (A)	2	1	C	3	14-Apr-91	0.160	1.375	0.227	Rout	1.375	4	4	0.094	3.00	N/A	N/A	No	3	25.1	1.88	0	0	0	0	0	0
KS (A)	2	2	C	3	12-Apr-91	0.160	1.375	0.231	Rout	1.375	4	4	0.094	3.00	N/A	N/A	No	3	144	0	0	0.8	0	0	0	0
KS (A)	2	1	D	3	16-Apr-91	0.156	N/A	N/A	N/A	0.156	4	3	0.094	2.50	N/A	N/A	No	3	144	0	0	0	0	0	0	0
KS (A)	2	2	D	3	16-Apr-94	0.110	N/A	N/A	N/A	0.110	4	4	0.094	3.00	N/A	N/A	No	3	110	0	0	0	0	0	0	0
KS (A)	3	1	C	3	14-Apr-91	0.211	1.375	0.250	Rout	1.375	4	2	0.094	2.50	N/A	N/A	No	1	16.1	0	0	12	0	0	0	0
KS (A)	3	2	C	3	15-Apr-91	0.110	1.375	0.211	Rout	1.375	4	2	0.094	2.50	N/A	N/A	No	1	14.6	0	0	6.3	0	0	0	0
KS (A)	3	1	D	3	16-Apr-91	0.156	N/A	N/A	N/A	0.156	4	2	0.094	2.50	N/A	N/A	No	1	72	0	0	0	0	0	0	0
KS (A)	3	2	D	3	16-Apr-91	0.148	N/A	N/A	N/A	0.148	4	2	0.094	2.50	N/A	N/A	No	1	21.8	0	0	0	0	0	0	0
KS (A)	4	1	C	3	15-Apr-91	0.168	1.375	0.215	Rout	1.375	4	2	0.094	3.00	N/A	N/A	No	2	5.25	0	0	0	0	0	0	0
KS (A)	4	2	C	3	14-Apr-91	0.117	1.375	0.239	Rout	1.375	4	1	0.094	3.00	N/A	N/A	No	1	38.3	0	0	0	0	0	0	0
KS (A)	4	1	D	3	16-Apr-91	0.156	N/A	N/A	N/A	0.156	4	2	0.094	3.00	N/A	N/A	No	2	75.8	0	0	0	0	0	0	0
KS (A)	4	2	D	3	16-Apr-91	0.141	N/A	N/A	N/A	0.141	4	1	0.094	3.00	N/A	N/A	No	1	34.1	0	0	0	0	0	0	0
KS (A)	5	1	D	3	16-Apr-91	0.141	N/A	N/A	N/A	0.141	4	3	0.094	2.50	N/A	N/A	No	3	132	0	0	0	0	0	0	0
KS (A)	5	2	D	3	16-Apr-91	0.125	N/A	N/A	N/A	0.125	4	3	0.094	2.50	N/A	N/A	No	3	137	0	0	0	0	0	0	0
KS (A)	6	2	E	6	16-Apr-91	0.133	0.617	1.446	Saw	0.617	3	1	N/A	N/A	0.641	0.250	No/A	N/A	0	0	0	0	0	0	0	0
KS (A)	6	1	F	7	16-Apr-91	0.133	0.602	1.438	Saw	0.602	5	1	N/A	N/A	0.625	0.250	No/A	N/A	0	0	0	0	0	144	0	0
KS (A)	8	1	B	3	15-Apr-91	0.117	0.563	0.766	Saw	0.563	NA	NA	NA	NA	N/A	N/A	NoA	NA	0	0	0	0	0	0	0	0
KS (A)	8	2	B	3	15-Apr-91	0.148	0.563	0.758	Saw	0.563	NA	NA	NA	NA	N/A	N/A	NoA	NA	0	0	0	0	0	0	0	0
KS (A)	9	1	B	3	15-Apr-91	0.133	0.563	0.750	Saw	0.563	NA	NA	NA	NA	N/A	N/A	NoA	NA	0	0	0	4.9	0	0	0	0
KS (A)	9	2	B	3	15-Apr-91	0.133	0.563	0.750	Saw	0.563	NA	NA	NA	NA	N/A	N/A	NoA	NA	2.63	0	0	0.5	0	0	0	0

Table B-5. Elma test section installation summary

Test Site	Material	Replicate	Configuration	Preparation Procedure	Date of Installation	Avg Original Crack Width, in	Avg Crack Reservoir Width, in	Avg Crack Reservoir Depth, in	Type of Cut (Rout, Saw)	Avg Final Crack Width, in	Avg Crack Cleanliness Rating	Avg Crack Moisture Rating	Avg Band-Aid Thickness, in	Avg Band-Aid Width, in	Avg Backer Rod Depth, in	Avg Depth of Recess, in	Material Overheating	Material Bubbling	Bubbles - Low, in	Bubbles - Medium, in	Bubbles - High, in	Sunken Material - Low, in	Sunken Material - High, in	Stone Intrusion - Low, in	Stone Intrusion - Med, in	Stone Intrusion - High, in
WA	1	1	A	3	22-Apr-91	0.180	0.625	0.719	Rout	0.625	4	3	N/A	N/A	N/A	N/A	No	1	144	0	0	24	0	0	0	0
WA	1	2	A	3	22-Apr-91	0.156	0.625	0.774	Rout	0.625	4	3	N/A	N/A	N/A	N/A	No	3	72	54	0	61	0.8	0	0	0
WA	1	1	B	3	22-Apr-91	0.164	0.625	0.742	Rout	0.625	4	3	0.094	3.00	N/A	N/A	No	3	130	0	0	68	1.5	0	0	0
WA	1	2	B	3	22-Apr-91	0.160	0.625	0.750	Rout	0.625	4	3	0.094	2.50	N/A	N/A	No	3	76.1	55.9	0	35	0	0	0	0
WA	1	1	D	3	23-Apr-91	0.141	N/A	N/A	N/A	0.141	4	3	0.063	3.00	N/A	N/A	No	3	54	90	0	3.8	0	0	0	0
WA	1	2	D	3	23-Apr-91	0.152	N/A	N/A	N/A	0.152	4	3	0.086	2.50	N/A	N/A	No	3	54	90	0	1.5	0	0	0	0
WA	1	1	D	4	23-Apr-91	0.121	N/A	N/A	N/A	0.121	3	3	0.094	3.00	N/A	N/A	No	3	40.1	0	0	59	0	0	0	0
WA	1	2	D	4	23-Apr-91	0.149	N/A	N/A	N/A	0.149	3	3	0.094	2.50	N/A	N/A	No	3	144	0	0	0	0.6	0	0	0
WA	2	1	B	3	22-Apr-91	0.160	0.625	0.766	Rout	0.625	4	3	0.094	2.50	N/A	N/A	No	3	129	0	0	16	0	0	0	0
WA	2	2	B	3	22-Apr-91	0.133	0.625	0.750	Rout	0.625	4	3	0.094	2.50	N/A	N/A	No	3	126	18	0	20	0	0	0	0
WA	2	1	D	3	22-Apr-91	0.156	N/A	N/A	N/A	0.156	4	3	0.094	2.50	N/A	N/A	No	3	144	0	0	1.3	0	0	0	0
WA	2	2	D	3	22-Apr-91	0.160	N/A	N/A	N/A	0.160	4	3	0.094	2.50	N/A	N/A	No	3	144	0	0	0	0	0	0	0
WA	3	1	B	3	22-Apr-91	0.144	0.625	0.735	Rout	0.625	4	3	0.094	3.00	N/A	N/A	No	3	144	0	0	33	5.3	0	0	0
WA	3	2	B	3	22-Apr-91	0.156	0.625	0.789	Rout	0.625	4	3	0.094	3.00	N/A	N/A	No	3	113	19.5	0	35	5.3	0	0	0
WA	3	1	D	3	23-Apr-91	0.102	N/A	N/A	N/A	0.102	4	3	0.094	3.00	N/A	N/A	No	3	3.38	0	0	13	0	0	0	0
WA	3	2	D	3	23-Apr-91	0.141	N/A	N/A	N/A	0.141	4	3	0.094	3.00	N/A	N/A	No	3	72	72	0	3.1	0	0	0	0
WA	4	1	B	3	22-Apr-91	0.156	0.625	0.735	Rout	0.625	4	3	0.094	3.00	N/A	N/A	No	3	144	0	0	29	1.4	0	0	0
WA	4	2	B	3	22-Apr-91	0.152	0.625	0.766	Rout	0.625	4	3	0.094	3.00	N/A	N/A	No	3	144	0	0	25	0	0	0	0
WA	4	1	D	3	23-Apr-91	0.129	N/A	N/A	N/A	0.129	4	3	0.070	3.00	N/A	N/A	No	3	108	18	0	6.8	2.6	0	0	0
WA	4	2	D	3	23-Apr-91	0.164	N/A	N/A	N/A	0.164	4	3	0.094	3.00	N/A	N/A	No	3	144	0	0	2.8	0	0	0	0
WA	5	1	D	3	23-Apr-91	0.148	N/A	N/A	N/A	0.148	4	3	0.094	2.50	N/A	N/A	No	3	0	0	0	2.6	1	0	0	0
WA	5	2	D	3	23-Apr-91	0.137	N/A	N/A	N/A	0.137	4	3	0.094	2.50	N/A	N/A	No	1	0	0	0	11	0.5	0	0	0
WA	6	1	E	5	22-Apr-91	0.148	0.688	1.414	Rout	0.688	5	1	N/A	N/A	0.617	0.235	No/A	N/A	0	0	0	0	0	126	0	0
WA	6	2	E	5	22-Apr-91	0.152	0.688	1.399	Rout	0.688	5	1	N/A	N/A	0.625	0.242	No/A	N/A	0	0	0	0	0	144	0	0
WA	7	1	B	3	23-May-91	0.125	0.625	0.750	Rout	0.625	4	1	0.094	3.00	N/A	N/A	No	1	0	0	0	0	0	0	0	0
WA	7	2	B	3	23-May-91	0.121	0.625	0.703	Rout	0.625	4	1	0.094	3.00	N/A	N/A	No	1	0	0	0	4.3	0	0	0	0

Table B-6. Prescott test section installation summary

Test Site	Material	Replicate	Configuration	Preparation Procedure	Date of Installation	Avg Original Crack Width, in	Avg Crack Reservoir Width, in	Avg Crack Reservoir Depth, in	Type of Cut (Rout, Saw)	Avg Final Crack Width, in	Avg Crack Cleanliness Rating	Avg Crack Moisture Rating	Avg Band-Aid Thickness, in	Avg Band-Aid Width, in	Avg Backer Rod Depth, in	Avg Depth of Recess, in	Material Overheating	Material Bubbling	Bubbles - Low, in	Bubbles - Medium, in	Bubbles - High, in	Sunken Material - Low, in	Sunken Material - High, in	Stone Intrusion - Low, in	Stone Intrusion - Med, in	Stone Intrusion - High, in
ON	7	1	H	4	NA	NA	N/A	N/A	N/A	NA	NA	NA	N/A	N/A	N/A	N/A	NoA	NA	0	300	0	0	0	0	0	0
ON	7	2	H	4	NA	0.152	N/A	N/A	N/A	0.152	NA	NA	N/A	N/A	N/A	N/A	NoA	NA	0	300	0	0	0	0	0	0
ON	A	1	G	1	27-Aug-91	0.121	N/A	N/A	N/A	0.121	1	1	N/A	N/A	N/A	N/A	No	1	0	0	0	0	0	0	0	0
ON	A	2	G	1	27-Aug-91	0.137	N/A	N/A	N/A	0.137	1	1	N/A	N/A	N/A	N/A	No	1	0	0	0	0	0	0	0	0
ON	A	1	G	4	27-Aug-91	0.125	N/A	N/A	N/A	0.125	3	1	N/A	N/A	N/A	N/A	No	1	0	0	0	0	0	0	0	0
ON	A	2	G	4	27-Aug-91	0.144	N/A	N/A	N/A	0.144	3	1	N/A	N/A	N/A	N/A	No	1	0	0	0	0	0	0	0	0
ON	B	1	G	4	27-Aug-91	0.144	N/A	N/A	N/A	0.144	3	1	N/A	N/A	N/A	N/A	No/A	N/A	0	0	0	286	14	0	0	2
ON	B	2	G	4	27-Aug-91	0.137	N/A	N/A	N/A	0.137	3	1	N/A	N/A	N/A	N/A	No/A	N/A	0	0	0	295	4.9	0	0	2
ON	C	1	D	4	27-Aug-91	0.148	N/A	N/A	N/A	0.148	3	1	0.094	4.00	N/A	N/A	No	1	0	0	0	0	0	0	0	0
ON	C	2	D	4	27-Aug-91	0.137	N/A	N/A	N/A	0.137	3	1	0.094	4.00	N/A	N/A	No	1	0	0	0	0	0	0	0	0
ON	C	1	G	4	27-Aug-91	0.137	N/A	N/A	N/A	0.137	3	1	N/A	N/A	N/A	N/A	No	1	0	0	0	0	0	0	0	0
ON	C	2	G	4	27-Aug-91	0.168	N/A	N/A	N/A	0.168	3	1	N/A	N/A	N/A	N/A	No	1	0	0	0	0	0	0	0	0
ON	D	1	D	4	27-Aug-91	0.152	N/A	N/A	N/A	0.152	3	1	0.156	4.00	N/A	N/A	No	1	0	0	0	0	0	0	0	0
ON	D	2	D	4	27-Aug-91	0.152	N/A	N/A	N/A	0.152	3	1	0.156	4.00	N/A	N/A	No	1	0	0	0	0	0	0	0	0
ON	F	1	G	4	27-Aug-91	0.156	N/A	N/A	N/A	0.156	3	1	N/A	N/A	N/A	N/A	No/A	N/A	0	0	0	300	0	0	0	1
ON	F	2	G	4	27-Aug-91	0.133	N/A	N/A	N/A	0.133	3	1	N/A	N/A	N/A	N/A	No/A	N/A	0	0	0	299	1.5	0	0	1

Appendix C

Material Testing Data

This appendix includes tables showing the initial test requirements and complete test results (initial and supplemental performance tests) for the primary experimental materials. Tables C-1 and C-2 show the requirements set forth in the initial testing program for each primary material. Table C-3 shows the entire list of tests conducted and the corresponding mean results of each test parameter for the various materials.

Illustrations of the load-deformation characteristics of various primary sealants subjected to ASTM D 412 (modulus) and ASTM D 3583 (tensile adhesion) tests are provided in figures C-1 through C-10.

Table C-1. Initial test requirements for rubber-modified asphalt materials

Test	Procedure	Requirement		
		Rubberized Asphalt (Hi-Spec)	Modified Rubberized Asphalt (RS 515, 9030, XLM)	Asphalt Rubber (AR2)
Bond (-20°F, 3 cycles, 50% extension)	ASTM D3407	3 cycles - No Failure	▨	▨
Bond (-20°F, 3 cycles, 100% extension)	ASTM D3407	▨	3 cycles - No Failure	▨
Cone Penetration, dmm (39.2°F)	ASTM D3407 Modified	▨	▨	≥ 15
Cone Penetration, dmm (77°F)	ASTM D3407	≤ 90	60 - 180	≤ 70
Flow, mm (140°F)	ASTM D3407	≤ 3	≤ 5	▨
Resilience, % (77°F)	ASTM D3407	≥ 60	≥ 35	≥ 30
Asphalt Compatibility (140°F)	ASTM D3407	No Failure	No Failure	No Failure
Softening Point	ASTM D36	▨	▨	≥ 150
Specific Gravity (60°F)	ASTM D70	1.071 - 1.183	RS 515: 1.116 - 1.234 9030: 1.002 - 1.108 XLM: 0.922 - 1.020	0.968 - 1.070

°C = 5/9*(°F - 32)

Table C-2. Initial test requirements for silicone, fiber, and emulsion materials

Test	Procedure	Requirement			
		Silicone (890-SL)	Fiber		Emulsion (CRF)
			(BoniFiber)	(Fiber Pave)	
Ultimate Elongation, % (75°F)	ASTM D412	≥ 1400			
Tensile Stress @ 150% Elongation (75°F)	ASTM D412	≤ 20			
Extrusion Rate, gm/min (73°F, 50 % RH)	ASTM C603	300 - 400			
Tack Free Time, min (73°F, 50 % RH)	ASTM C679	180 - 300			
Shore 00 Durometer Hardness, (73°F, 50 % RH)	ASTM D2240	35 - 45			
Density, gm/ml (77°F)	ASTM D1475	1.283 - 1.418			
Denier (Fineness)	ASTM D1557		3.0 - 6.0	13.0 - 17.0	
Length, mm	As Measured		5.8 - 7.0	8 - 12	
Crimps	ASTM D3937		None	None	
Color	As Observed		White	Gray	
Break Elongation, %	ASTM D2256		24 - 42	≥ 33	
Tensile Strength, ksi	ASTM D882		≥ 70	≥ 40	
Moisture Regain, % (70°F, 50% RH)	ASTM D2654		-	< 0.1	
Saybolt Viscosity, sec (77°F)	ASTM D244				25 - 150
Residue, %	ASTM D244				≥ 64
Miscibility	ASTM D244				No Coagulation
Sieve, %	ASTM D244				≤ 0.10

°C = 5/9*(°F - 32)

Table C-3. Mean laboratory test results for primary material products

Test Designation	Test Description	Number of Test Replicates	Mean Test Results								
			Hi-Spec	RS 515	9030	XLM	B-Fiber + AC	890-SL	CRF	AR2	Fiber Pave + AC
1-A	Bond (-20°F, 3 cycles, 50% ext)	3	Pass								
2-A	Bond(-20°F, 3 cycles 100% ext)	3		Pass	Pass	Pass					
3-A	Cone Penetration, dmm (0°F)	2	15	27	60	60	0		23	4	0
4-A	Cone Penetration, dmm (77°F)	2	63	76	115	148				55	
5-A	Flow, mm (140°F)	2	0	1	0	2.5					
6-A	Resilience, % recovery (77°F)	3	64	38	84	16				39	
7-A	Asphalt Compatibility (140°F)	1	Pass	Pass	Pass	Pass				Pass	
8-A	Softening Point	2	186	211	199	192	122		78	162	123
9-A	Specific Gravity (60°F)	1	1.1	1.2	1.1	1.0		1.3		1.1	
10-A	Cold Bend (0°F)	2	Pass	Pass	Pass	Pass					
11-A	Force Ductility - Max Elongation, in (39.2°F)	2	17	17	12	11	2			12	55
11-B	Force Ductility - Max Load, lb		5.2	2.6	4.5	0.9	18			3.3	13
11-C	Force Ductility - Max Engineering Stress, psi		33	17	29	6	113			21	86
11-D	Force Ductility - Max Engineering Strain, in/in		15	15	22	22	1.7			10	24
11-E	Force Ductility - Max True Stress, psi		495	234	632	57	210			210	141
11-F	Force Ductility - Max True Strain, in/in		2.8	2.8	3.1	2.4	1.0			2.5	3.1
11-G	Force Ductility - Area Under Engineering Curve, psi		52	28	62	5.1	20			26	36
11-H	Force Ductility - Area Under True Curve, psi		334	182	402	33	129			170	237
11-I	Force Ductility - Asphalt Modulus, psi		32	15	21	4.5	424			46	330
11-J	Force Ductility - Polymer Modulus, psi		565	211	728	64	NA			208	NA
11-K	Force Ductility - Load @ 150% Elongation, lb		2.1	1.1	1.4	0.3	16.0			1.0	7.4
12-A	Tensile Adhesion (Std - PCC blocks) - Max Elongation, in	3	3.5	2.6	2.2	2.7		3.1			
12-B	Tensile Adhesion (Std) - Max Elongation, %		704	515	441	547		606			
12-C	Tensile Adhesion (Std) - Type of Failure		Adh	Adh	Adh	Adh		Adh/Coh			
13-A	Tensile Adhesion (Mod #1: AC blocks) - Max Elongation, in	3	3.5	3.8	1.5	3.0		3.1			
13-B	Tensile Adhesion (Mod #1) - Max Elongation, %		690	760	303	607		627			
13-C	Tensile Adhesion (Mod #1) - Type of Failure		Adh	Adh	Adh	Adh		Adh/Coh			

1 in = 25.4 mm
°C = 5/9*(°F - 32)
1 psi = 6.895 kPa

Table C-3. Mean laboratory test results for primary material products (cont.)

Test Designation	Test Description	Number of Test Replicates	Mean Test Results								
			Hi-Spec	RS 515	9030	XLM	B-Fiber + AC	890-SL	CRF	AR2	Fiber Pave + AC
14-A	Tensile Adhesion (Mod #2: AC blocks, H_2O-soaked) - Max Elongation, in	3	3.4	3.4	1.7	2.7		2.4			
14-B	Tensile Adhesion (Mod #2) - Max Elongation, %		683	680	337	539		485			
14-C	Tensile Adhesion (Mod #2) - Type of Failure		Adh	Adh	Adh	Adh		Adh			
15-A	412 Test (0°F) - Tensile Strength, psi	2	61	66	16	15		45			
15-B	412 Test (0°F) - Ultimate Elongation, %		425	868	1093	1035		4566			
15-C	412 Test (0°F) - Tensile Stress @ 150 % Elongation, psi		46	38	7.3	4.3		9.4			
15-D	412 Test (0°F) - Midpoint Thickness, in		0.3	0.2	0.3	0.3		0.2			
16-A	412 Test (39°F) - Tensile Strength, psi	2	33	27	7.7	10					
16-B	412 Test (39°F) - Ultimate Elongation, %		960	1255	620	960					
16-C	412 Test (39°F) - Tensile Stress @ 150 % Elongation, psi		19	14	4.7	2.8					
16-D	412 Test (39°F) - Midpoint Thickness, in		0.2	0.2	0.3	0.3					
17-A	412 Test (75°F) - Tensile Strength, psi	2	11	7.7	8.6	4.8		44			
17-B	412 Test (75°F) - Ultimate Elongation, %		863	910	832	915		2096			
17-C	412 Test (75°F) - Tensile Stress @ 150 % Elongation, psi		7.1	3.8	4.6	2		11			
17-D	412 Test (75°F) - Midpoint Thickness, in		0.3	0.3	0.3	0.3		0.2			
18-A	412 Test After Weathering (75°F) - Tensile Strength, psi	3	NA	NA	NA	NA		41.2			
18-B	412 Test After Weathering (75°F) - Ultimate Elongation, %		NA	NA	NA	NA		1552			
18-C	412 Test After Weathering (75°F) - Tensile Stress @ 150% Elongation, psi		NA	NA	NA	NA		9.63			
18-D	412 Test After Weathering (75°F) - Midpoint Thickness, in		NA	NA	NA	NA		0.16			
19-A	Modified Bond #1 (Channel) - Type of Failure	2	Adh	Adh	None	None		None			
19-B	Modified Bond #1 (Channel), % Debonding		1.15	0.18	0.0	0.0		0.0			
20-A	Modified Bond #2 (recessed Band-Aid) - Type of Failure	2	Adh	Adh	Adh	None					
20-B	Modified Bond #2 (Recessed Band-Aid), % Debonding		0.52	5.21	6.25	0.0					
21-A	Modified Bond #3 (Band-Aid) - Type of Failure	2	Adh	Adh	Adh	None					
21-B	Modified Bond #3 (Band-Aid), % Debonding		0.71	2.86	0.71	0.0					
22-A	Brookfield Viscosity, cPs	2	3738	3338	1275	3720					

1 in = 25.4 mm
°C = 5/9*(°F - 32)
1 psi = 6.895 kPa

Table C-3. Mean laboratory test results for primary material products (cont.)

Test Designation	Test Description	Number of Test Replicates	Mean Test Results								
			Hi-Spec	RS 515	9030	XLM	B-Fiber + AC	890-SL	CRF	AR2	Fiber Pave + AC
23-A	Denier (Fineness)	3					4.27				4.4
24-A	Length, mm	3					7				9
25-A	Crimps	3					None				None
26-A	Color	3					White				Gray
27-A	Break Elongation, %	3					29.27				32.8
28-A	Tensile Strength, ksi	3					98933				34602
29-A	Moisture Regain, %	3					0.443				0.457
30-A	Saybolt Viscosity, sec	2							51.5		
31-A	Residue, %	2							67		
32-A	Miscibility	2							Pass		
33-A	Sieve Test, %	2							0.1		
34-A	Extrusion Rate, gm/min (73°F and 50% RH)	1						2.8			
35-A	Tack-Free Time, min (77°F and 50% RH)	1						180			
36-A	Shore 00 Durometer (77°F and 50% RH)	3						50			

1 in = 25.4 mm
°C = 5/9*(°F - 32)
1 gm = 0.035 oz
1 ksi = 6895 kPa

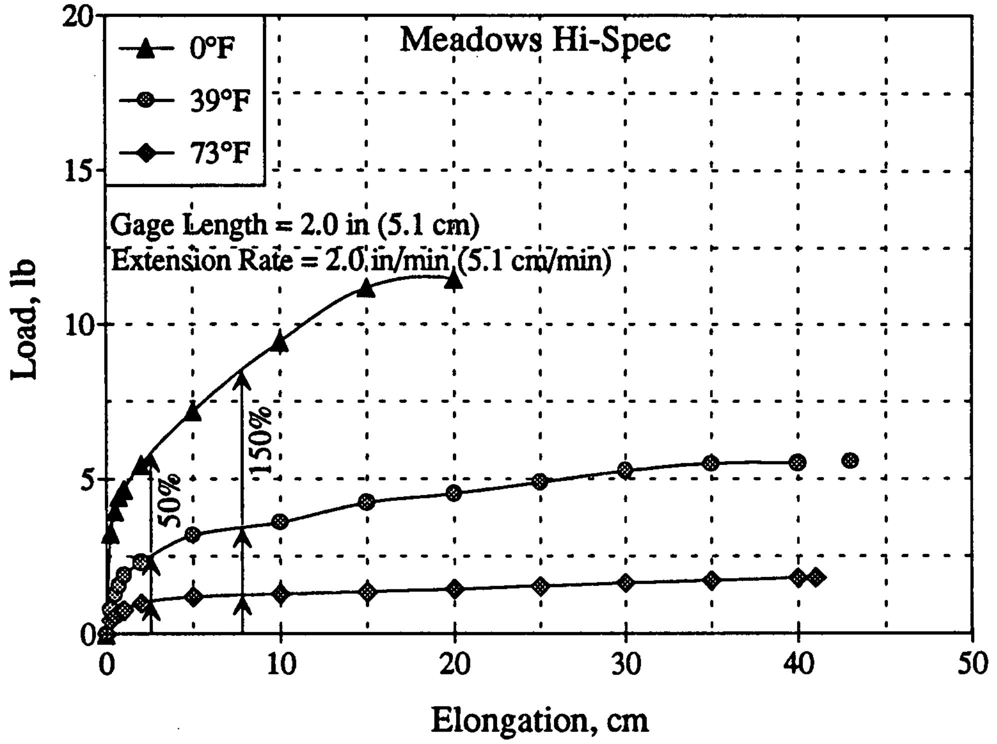


Figure C-1. ASTM D 412 load-deformation curves for Hi-Spec

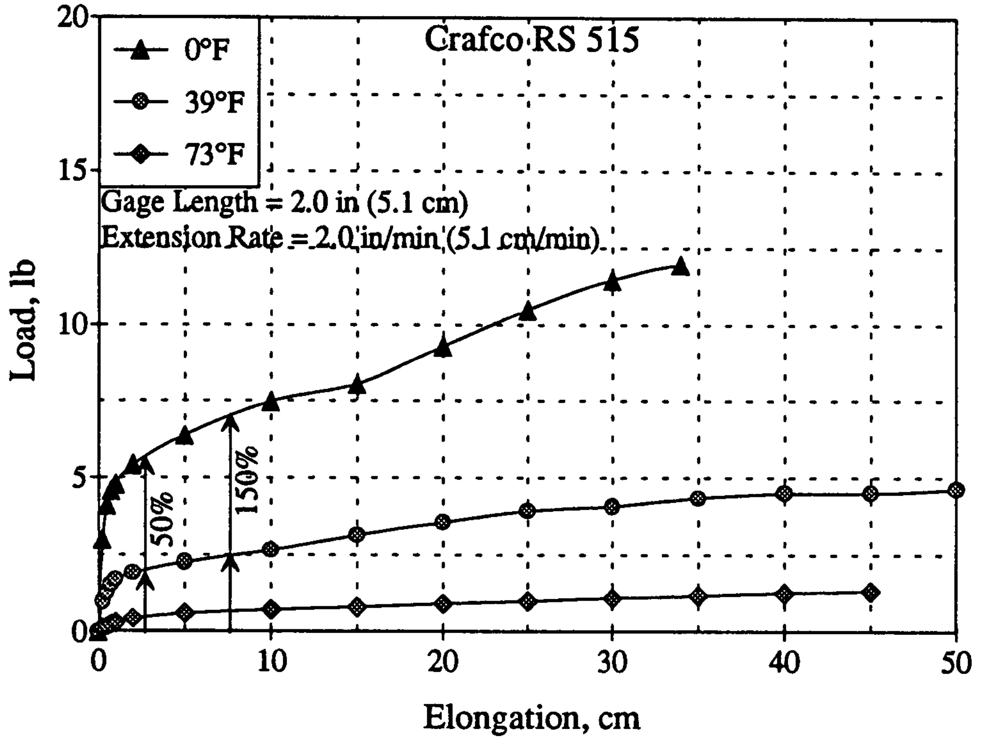


Figure C-2. ASTM D 412 load-deformation curves for RS 515

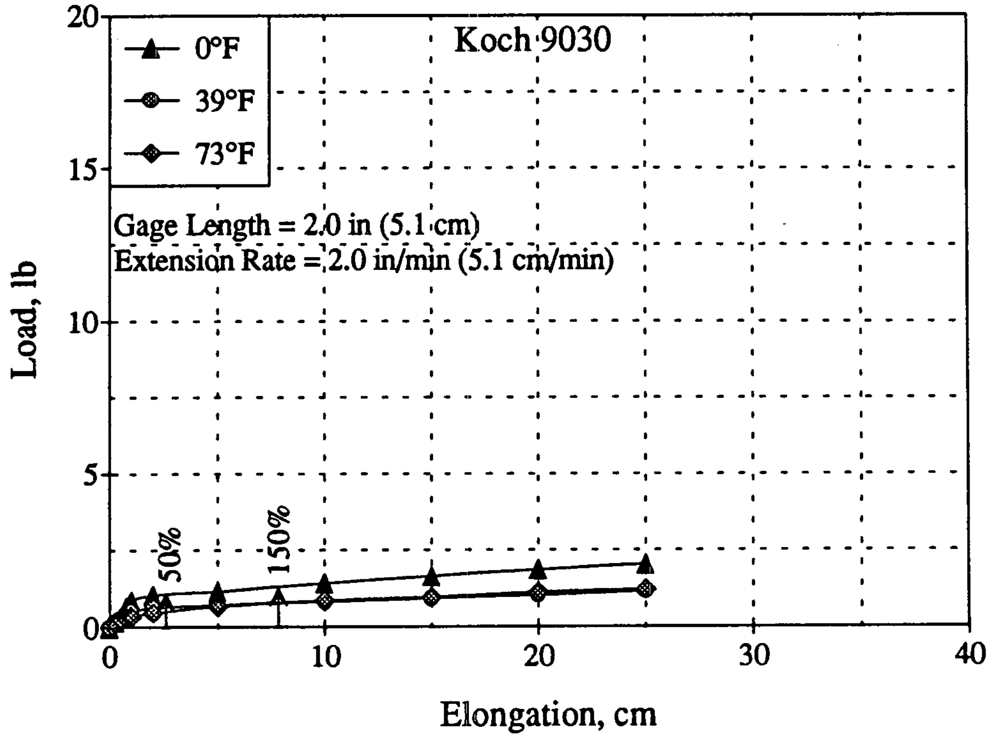


Figure C-3. ASTM D 412 load-deformation curves for 9030

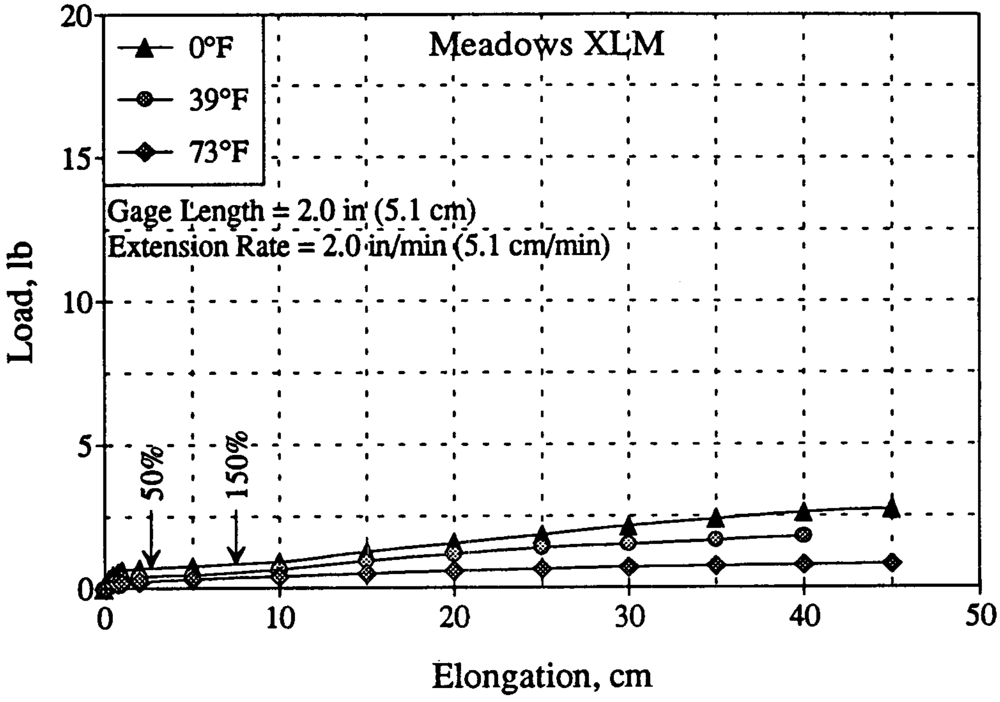


Figure C-4. ASTM D 412 load-deformation curves for XLM

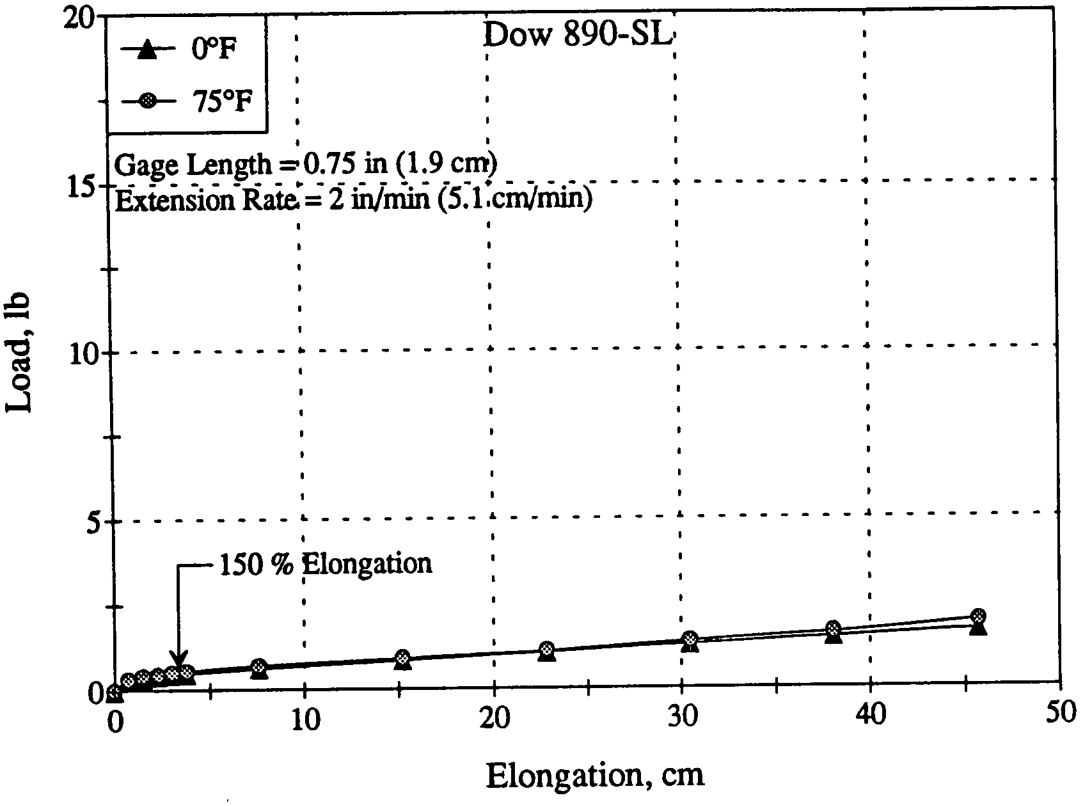


Figure C-5. ASTM D 412 load-deformation curves for 890-SL

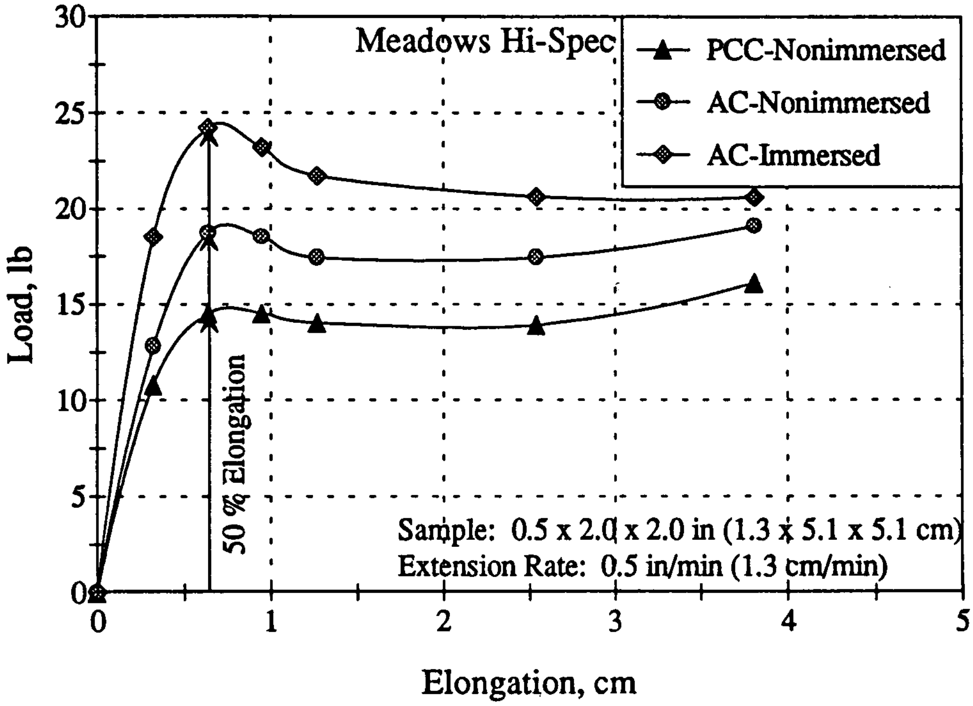


Figure C-6. ASTM D 3583 load-deformation curves for Hi-Spec

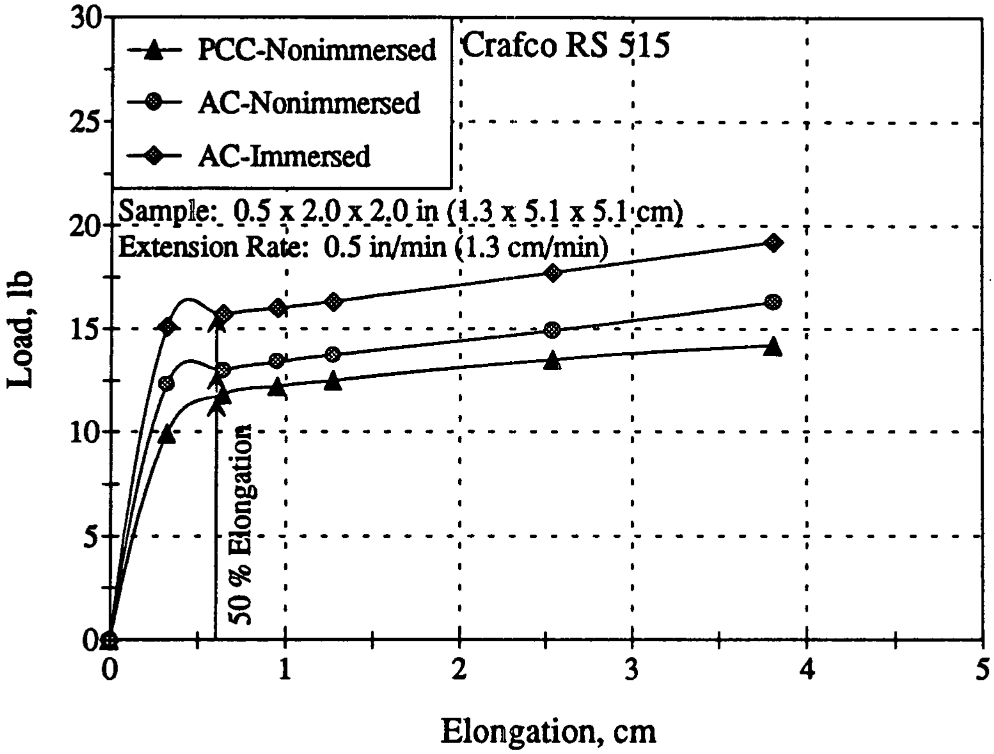


Figure C-7. ASTM D 3583 load-deformation curves for RS 515

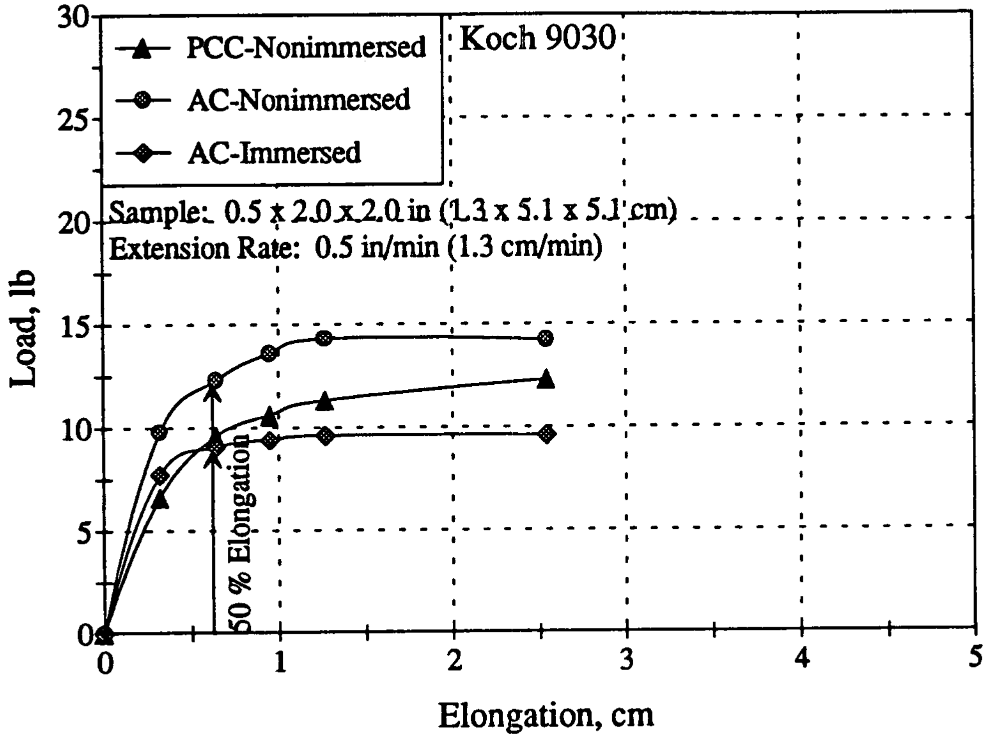


Figure C-8. ASTM D 3583 load-deformation curves for 9030

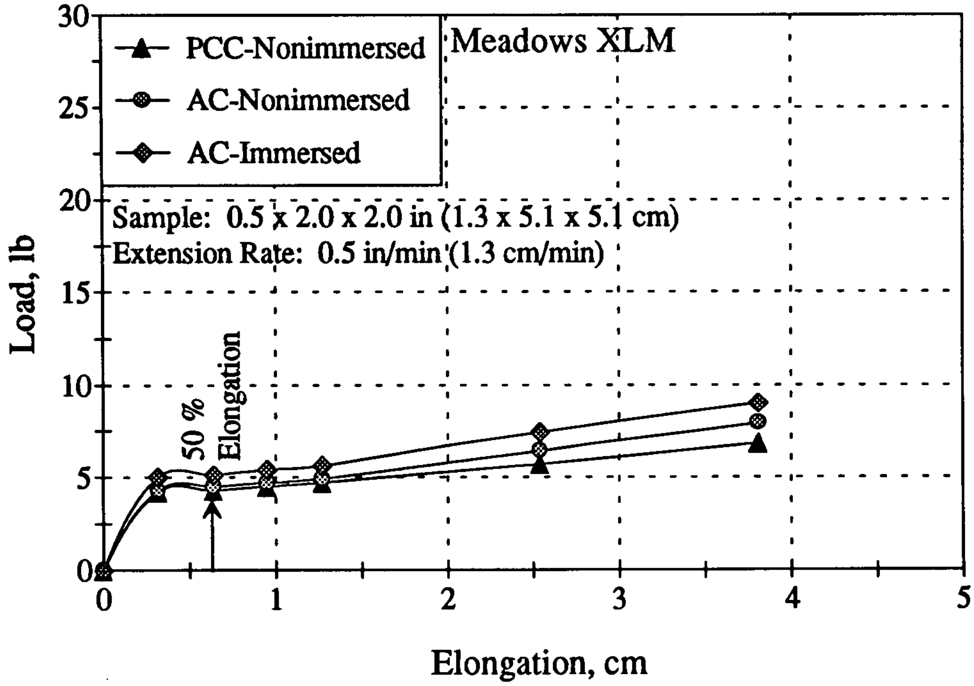


Figure C-9. ASTM D 3583 load-deformation curves for XLM

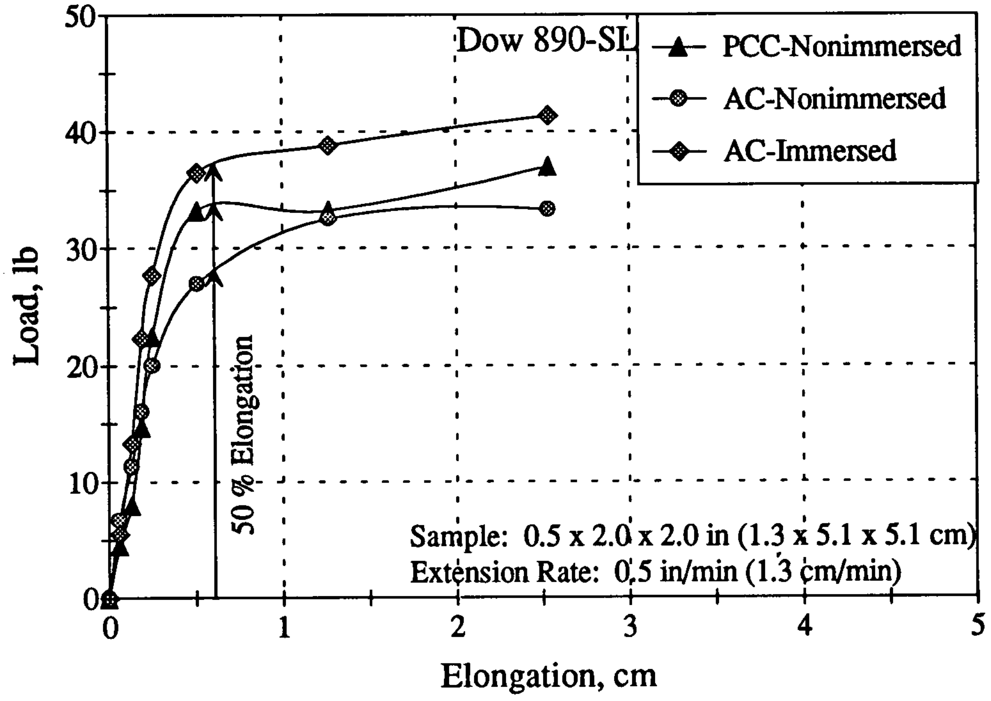


Figure C-10. ASTM D 3583 load-deformation curves for 890-SL

Appendix D

Field Performance Data

This appendix includes the various documentation forms and summary tables and charts associated with the field performance of the experimental treatments. Figure D-1 shows the performance documentation forms used at each test site evaluation. Summaries of the more important performance distresses, on a test section basis, are provided in tables D-1 through D-6. Summary graphs for various distresses observed in evaluation 5 at each site are illustrated in figures D-2 through D-22.

CRACK SEALANT EVALUATION FORM

Date, Eval #1: 7/1/91 Eval #2: 9/12/91 Eval #3: 2/10/92 Eval #4: 5/13/92 Eval #5: 8/27/92
Replicate: [✓ 1] 2
Section: 1 2 3 4 5 6 7 8 [✓ 9] 10 11 12 13 14 15 16 17 18 19 20
Material: [✓ (1) M-HS] (2) C-515 (3) K-9030 (4) M-XLM (5) K-BF (6) D-890SL (7)_____ (8)_____
PK Measurement: INSTALL 10.820 EVAL #1 10.822 EVAL #2 10.818 EVAL #3 10.884 EVAL #4 10.841 EVAL #5 10.854
Site: [✓ 1A] WA TX KS(I) KS(A)
Crack: 1 2 3 4 5 [✓ 6] 7 8 9 10

Segment	Construction Related Distresses						
	Const. Bubbles			Sunken Sealant		Stone Intrusion	
	Low	Med	Hi	Low	Hi	Low	Hi
IE (2')							
IWP (2')							
C (4')							
OWP (2')							
OE (2')							

Segment	Weathering														
	Eval #1			Eval #2			Eval #3			Eval #4			Eval #5		
	None	Low	Hi	None	Low	Hi	None	Low	Hi	None	Low	Hi	None	Low	Hi
IE (2')	/			/			/			/			/		
IWP (2')	/			/			/			/			/		
C (4')	/			/			/			/			/		
OWP (2')	/			/			/			/			/		
OE (2')	/			/			/			/			/		

Segment	Pull-Outs (in)									
	Eval #1		Eval #2		Eval #3		Eval #4		Eval #5	
	Low	Hi	Low	Hi	Low	Hi	Low	Hi	Low	Hi
IE (2')										
IWP (2')										
C (4')										
OWP (2')										
OE (2')										

Segment	Tracking (in)									
	Eval #1		Eval #2		Eval #3		Eval #4		Eval #5	
	Low	Hi	Low	Hi	Low	Hi	Low	Hi	Low	Hi
IE (2')										
IWP (2')										
C (4')										
OWP (2')										
OE (2')										

Segment	Wear (in)									
	Eval #1		Eval #2		Eval #3		Eval #4		Eval #5	
	Low	Hi	Low	Hi	Low	Hi	Low	Hi	Low	Hi
IE (2')			X			X		X		X
IWP (2')			X			X		X		X
C (4')			X		X			X		X
OWP (2')			X			X		X		X
OE (2')			X			X		X		X

Segment	Extrusion (in)									
	Eval #1		Eval #2		Eval #3		Eval #4		Eval #5	
	Low	Hi	Low	Hi	Low	Hi	Low	Hi	Low	Hi
IE (2')										
IWP (2')										
C (4')										
OWP (2')										
OE (2')										

Figure D-1. Field performance evaluation form

CRACK SEALANT EVALUATION FORM (CONTINUED)

Segment	*Stone Intrusion (L/ft)*									
	Eval #1		Eval #2		Eval #3		Eval #4		Eval #5	
	Low	Hi	Low	Hi	Low	Hi	Low	Hi	Low	Hi
IE (2')										
IWP (2')										
C (4')										
OWP (2')										
OE (2')										

Segment	*Adhesion (in)*									
	Eval #1		Eval #2		Eval #3		Eval #4		Eval #5	
	Ptl Depth	Full Depth	Ptl Depth	Full Depth	Ptl Depth	Full Depth	Ptl Depth	Full Depth	Ptl Depth	Full Depth
IE (2')										
IWP (2')										
C (4')										
OWP (2')										
OE (2')										

Segment	*Cohesion (in)*																			
	Eval #1				Eval #2				Eval #3				Eval #4				Eval #5			
	Tensile Stress		Bubbling		Tensile Stress		Bubbling		Tensile Stress		Bubbling		Tensile Stress		Bubbling		Tensile Stress		Bubbling	
	Ptl Depth	Full Depth	Ptl Depth	Full Depth	Ptl Depth	Full Depth	Ptl Depth	Full Depth	Ptl Depth	Full Depth	Ptl Depth	Full Depth	Ptl Depth	Full Depth	Ptl Depth	Full Depth	Ptl Depth	Full Depth	Ptl Depth	Full Depth
IE (2')																				
IWP (2')									6				6				6			
C (4')									5	9			5	9			5	9		
OWP (2')									5	6			5	6			5	6		
OE (2')																	2			

Segment	*Pavement Surround Failure - Secondary Cracking (in)*									
	Eval #1		Eval #2		Eval #3		Eval #4		Eval #5	
	Low	Hi	Low	Hi	Low	Hi	Low	Hi	Low	Hi
IE (2')										
IWP (2')					3		3		3	
C (4')										
OWP (2')										
OE (2')										

Segment	*Overall Crack Failure (in)*				
	Eval #1	Eval #2	Eval #3	Eval #4	Eval #5
IE (2')					
IWP (2')					
C (2')			9	9	9
OWP (2')			6	6	6
OE (2')					

* Constitutes a failure distress.

Coin Test Rating: Good Fair Poor

Figure D-1. Field performance evaluation form (cont.)

Table D-1. Des Moines 18-month field performance summary

Material	Replicate #	Configuration	Prep Procedure	Avg Crack/Reservoir Width, in	Avg Crack Movement, in	Avg Elongation, %	Temp Difference, F	Avg Low-Severity Pull-Out, in	Avg High-Severity Pull-Out, in	Avg Band-Aid Wear, %	Avg Prt'l-Dpth Adhesion Loss, in	Avg Full-Dpth Adhesion Loss, in	Avg Prt'l-Dpth Cohesion Loss, in	Avg Full-Dpth Cohesion Loss, in	Avg Prt'l-Dpth Bubbling, in	Avg Full-Depth Bubbling, in	Avg Low-Severity Damage, in	Avg High-Severity Damage, in	Avg Overall Failure, in
Hi-Spec	1	A	2	0.563	0.021	3.774	-58	0.0	0.0	N/A	2.4	0.0	0.0	0.0	0.1	0.0	11.4	0.4	0.4
Hi-Spec	2	A	2	0.563	0.049	8.659	-39	0.0	0.0	N/A	10.6	16.3	0.0	0.0	0.0	0.0	3.0	0.5	16.5
				0.563	0.035	6.217	-48.5	0.0	0.0	N/A	6.5	8.1	0.0	0.0	0.1	0.0	7.2	0.4	8.4
Hi-Spec	1	A	3	0.563	0.053	9.347	-58	0.0	0.0	N/A	11.3	0.3	0.0	0.0	0.8	0.0	11.8	0.4	0.5
Hi-Spec	2	A	3	0.563	0.051	9.059	-38	0.0	0.0	N/A	2.4	0.3	0.0	0.0	0.1	0.0	1.6	0.3	0.5
				0.563	0.052	9.203	-48	0.0	0.0	N/A	6.8	0.3	0.0	0.0	0.4	0.0	6.7	0.3	0.5
Hi-Spec	1	B	3	0.563	0.042	7.482	-37	0.0	0.0	73.1	1.9	0.3	0.0	0.0	0.0	0.0	7.9	0.1	0.4
Hi-Spec	2	B	3	0.563	0.023	4.107	-51	1.6	0.4	70.0	0.0	0.0	0.0	0.0	0.1	0.3	3.1	0.0	0.6
				0.563	0.033	5.795	-44	0.8	0.2	71.6	0.9	0.1	0.0	0.0	0.1	0.1	5.5	0.1	0.5
Hi-Spec	1	C	3	1.500	0.049	3.267	-32	0.3	0.0	72.6	2.8	0.5	0.0	0.0	0.3	0.0	16.8	0.0	0.5
Hi-Spec	2	C	3	1.500	0.073	4.883	-57	0.8	0.3	71.0	0.6	0.0	0.0	0.0	1.1	0.0	6.4	0.0	0.3
				1.500	0.061	4.075	-44.5	0.5	0.1	71.8	1.7	0.3	0.0	0.0	0.7	0.0	11.6	0.0	0.4
Hi-Spec	1	D	3	0.102	0.083	82.459	-35	0.1	0.0	70.0	0.0	0.0	31.8	22.8	0.0	0.0	12.8	0.0	22.8
Hi-Spec	2	D	3	0.106	0.041	39.788	-52	3.0	2.3	70.0	0.0	0.0	0.8	0.5	0.3	0.3	2.6	0.0	3.0
				0.104	0.062	61.123	-43.5	1.6	1.1	70.0	0.0	0.0	16.3	11.6	0.1	0.1	7.7	0.0	12.9
Hi-Spec	1	D	4	0.106	0.063	58.051	-35	0.5	0.3	70.5	0.6	0.0	10.5	13.9	0.3	0.0	11.6	0.0	14.1
Hi-Spec	2	D	4	0.106	0.043	43.140	-56	1.9	1.5	70.0	0.1	0.0	0.3	0.6	0.0	0.3	6.8	0.0	1.6
				0.106	0.053	50.596	-45.5	1.2	0.9	70.3	0.4	0.0	5.4	7.3	0.1	0.1	9.2	0.0	7.9
RS 515	1	B	3	0.563	0.048	8.504	-53	0.1	0.0	74.7	0.0	0.0	0.0	0.0	0.0	0.0	21.3	0.0	0.0
RS 515	2	B	3	0.563	0.027	4.818	-50	1.5	0.0	70.0	0.1	0.0	0.0	0.0	0.0	0.0	7.0	0.0	0.0
				0.563	0.037	6.661	-51.5	0.8	0.0	72.3	0.1	0.0	0.0	0.0	0.0	0.0	14.1	0.0	0.0
RS 515	1	C	3	1.500	0.053	3.533	-56	2.3	0.0	74.2	0.6	1.8	0.0	0.0	0.1	0.0	3.5	0.0	1.8
RS 515	2	C	3	1.500	0.104	6.925	-52	3.4	1.0	70.5	3.6	14.6	0.0	0.0	0.0	0.0	3.0	0.4	16.0
				1.500	0.078	5.229	-54	2.8	0.5	72.3	2.1	8.2	0.0	0.0	0.1	0.0	3.3	0.2	8.9
RS 515	1	D	3	0.110	0.066	60.416	-33	0.8	0.3	78.9	0.0	0.0	19.4	22.5	0.0	0.0	4.5	0.0	22.8
RS 515	2	D	3	0.102	0.070	69.194	-54	4.0	4.6	70.0	0.0	0.0	6.8	8.4	0.0	0.0	1.8	0.0	13.1
				0.106	0.068	64.805	-43.5	2.4	2.4	74.4	0.0	0.0	13.1	15.4	0.0	0.0	3.1	0.0	17.9

Table D-1. Des Moines 18-month field performance summary (cont.)

Material	Replicate #	Configuration	Prep Procedure	Avg Crack/Reservoir Width, in	Avg Crack Movement, in	Avg Elongation, %	Temp Difference, F	Avg Low-Severity Pull-Out, in	Avg High-Severity Pull-Out, in	Avg Band-Aid Wear, %	Avg Prt'l-Dpth Adhesion Loss, in	Avg Full-Dpth Adhesion Loss, in	Avg Prt'l-Dpth Cohesion Loss, in	Avg Full-Dpth Cohesion Loss, in	Avg Prt'l-Dpth Bubbling, in	Avg Full-Depth Bubbling, in	Avg Low-Severity Damage, in	Avg High-Severity Damage, in	Avg Overall Failure, in
9030	1	B	3	0.563	0.106	18.872	-39	0.0	0.0	74.2	2.9	2.8	0.0	0.0	0.0	0.0	25.8	0.0	3.5
9030	2	B	3	0.563	0.053	9.392	-51	0.1	0.0	91.9	0.4	0.9	0.0	0.0	0.1	0.0	2.9	0.4	1.3
				0.563	0.080	14.132	-45	0.1	0.0	83.0	1.6	1.8	0.0	0.0	0.1	0.0	14.3	0.2	2.4
9030	1	C	3	1.500	0.077	5.108	-32	0.0	0.0	79.9	4.6	0.1	0.0	0.0	0.0	0.0	6.0	0.0	0.1
9030	2	C	3	1.500	0.033	2.225	-56	0.1	0.0	78.9	0.6	0.3	0.0	0.0	0.0	0.0	3.3	0.0	0.3
				1.500	0.055	3.667	-44	0.1	0.0	79.4	2.6	0.2	0.0	0.0	0.0	0.0	4.6	0.0	0.2
9030	1	D	3	0.102	0.050	49.067	-61	0.1	1.1	71.0	0.0	0.0	3.9	7.5	0.0	0.0	6.6	0.0	8.6
9030	2	D	3	0.090	0.041	51.569	-49	0.4	0.0	86.1	0.0	0.0	6.0	26.1	0.0	0.0	0.6	0.0	26.1
				0.096	0.045	50.318	-55	0.3	0.6	78.6	0.0	0.0	4.9	16.8	0.0	0.0	3.6	0.0	17.4
XLM	1	B	3	0.563	0.067	11.945	-60	8.6	2.3	77.3	0.3	0.0	0.0	0.0	0.0	0.0	2.3	0.0	2.3
XLM	2	B	3	0.563	0.087	15.364	-38	0.4	0.0	80.9	1.0	2.0	0.0	0.0	0.0	0.0	0.4	0.0	2.0
				0.563	0.077	13.655	-49	4.5	1.1	79.1	0.6	1.0	0.0	0.0	0.0	0.0	1.3	0.0	2.1
XLM	1	C	3	1.501	0.042	2.790	-37	0.5	0.0	78.9	0.1	0.0	0.0	0.0	0.0	0.0	11.9	0.0	0.0
XLM	2	C	3	1.500	0.055	3.650	-51	0.0	0.0	78.3	0.0	0.0	0.0	0.0	0.0	0.0	4.1	0.0	0.0
				1.501	0.048	3.220	-44	0.3	0.0	78.6	0.1	0.0	0.0	0.0	0.0	0.0	8.0	0.0	0.0
XLM	1	D	3	0.110	0.078	73.017	-27	0.0	0.0	71.0	0.0	0.0	0.3	0.0	0.0	0.0	9.3	0.0	0.0
XLM	2	D	3	0.110	0.091	82.003	-58	0.0	0.3	72.6	0.0	0.0	6.9	1.9	0.0	0.0	5.4	0.0	2.1
				0.110	0.085	77.510	-42.5	0.0	0.1	71.8	0.0	0.0	3.6	0.9	0.0	0.0	7.3	0.0	1.1
B-Fiber + AC	1	D	3	0.110	0.074	67.544	-27	0.4	2.0	86.1	0.0	0.0	57.1	46.1	0.0	0.0	9.1	3.8	49.5
B-Fiber + AC	2	D	3	0.113	0.099	87.473	-49	0.5	1.3	78.3	0.0	0.0	55.9	28.8	0.0	0.0	2.1	0.1	29.3
				0.111	0.086	77.509	-38	0.4	1.6	82.2	0.0	0.0	56.5	37.4	0.0	0.0	5.6	1.9	39.4
890SL	1	E	5	0.563	0.083	14.698	-38	0.0	0.0	N/A	0.0	0.0	0.0	0.0	0.0	0.0	18.4	13.4	13.4
890SL	2	E	5	0.563	0.059	10.546	-49	0.0	0.0	N/A	0.1	0.0	0.0	0.0	0.0	0.0	12.4	6.9	7.3
				0.563	0.071	12.622	-43.5	0.0	0.0	N/A	0.1	0.0	0.0	0.0	0.0	0.0	15.4	10.1	10.3
CRS-2P	1	G	4	0.106	NA	NA	NA	0.0	0.0	N/A	0.0	0.0	0.0	144.0	0.0	0.0	2.8	2.8	144.0
CRS-2P	2	G	4	0.106	NA	NA	NA	0.0	0.0	N/A	0.0	0.0	0.0	144.0	0.0	0.0	1.0	5.9	144.0
				0.106	NA	NA	NA	0.0	0.0	N/A	0.0	0.0	0.0	144.0	0.0	0.0	1.9	4.3	144.0

Table D-2. Abilene 18-month field performance summary

Material	Replicate #	Configuration	Prep Procedure	Avg Crack/Reservoir Width, in	Avg Crack Movement, in	Avg Elongation, %	Temp Difference, F	Avg Low-Severity Pull-Out, in	Avg High-Severity Pull-Out, in	Avg Band-Aid Wear, %	Avg Prt'l-Dpth Adhesion Loss, in	Avg Full-Dpth Adhesion Loss, in	Avg Prt'l-Dpth Cohesion Loss, in	Avg Full-Dpth Cohesion Loss, in	Avg Prt'l-Dpth Bubbling, in	Avg Full-Depth Bubbling, in	Avg Low-Severity Damage, in	Avg High-Severity Damage, in	Avg Overall Failure, in
Hi-Spec	1	A	3	0.625	0.031	4.920	-31	0.0	0.0	N/A	7.6	3.6	0.0	0.0	0.4	0.0	4.0	0.0	3.6
Hi-Spec	2	A	3	0.625	0.016	2.520	-30	0.0	0.0	N/A	2.6	1.3	0.0	0.0	0.5	0.0	0.0	0.1	1.8
				0.625	0.023	3.720	-30.5	0.0	0.0	N/A	5.1	2.4	0.0	0.0	0.4	0.0	2.0	0.1	2.7
Hi-Spec	1	B	3	0.625	0.024	3.840	-35	0.0	0.0	42.5	0.0	0.0	0.0	0.0	0.4	0.0	0.0	0.0	0.0
Hi-Spec	2	B	3	0.625	0.010	1.520	-29	0.0	0.0	57.5	0.1	0.0	0.0	0.0	0.4	0.0	0.4	0.0	0.0
				0.625	0.017	2.680	-32	0.0	0.0	50.0	0.1	0.0	0.0	0.0	0.4	0.0	0.2	0.0	0.0
Hi-Spec	1	D	3	0.094	0.036	38.564	-43	0.0	0.0	66.7	0.4	0.0	7.9	0.5	0.0	0.0	0.8	0.0	0.5
Hi-Spec	2	D	3	0.094	0.017	17.686	-30	0.0	0.0	68.3	0.0	0.0	2.9	0.4	0.3	0.0	0.0	0.0	0.4
				0.094	0.026	28.125	-36.5	0.0	0.0	67.5	0.2	0.0	5.4	0.4	0.1	0.0	0.4	0.0	0.4
Hi-Spec	1	D	4	0.094	0.019	19.681	-34	0.0	0.0	60.8	0.0	0.4	11.0	1.6	0.0	0.0	0.0	0.0	2.0
Hi-Spec	2	D	4	0.094	0.018	19.548	-30	0.1	1.3	67.5	0.0	3.0	7.0	2.5	0.0	0.0	0.0	0.0	5.6
				0.094	0.018	19.614	-32	0.1	0.6	64.2	0.0	1.7	9.0	2.1	0.0	0.0	0.0	0.0	3.8
RS 515	1	B	3	0.625	0.023	3.660	-31	0.0	0.0	45.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
RS 515	2	B	3	0.625	0.013	2.060	-28	0.0	0.0	56.4	0.3	0.8	0.0	0.0	0.0	0.0	0.0	0.0	0.8
				0.625	0.018	2.860	-29.5	0.0	0.0	51.1	0.1	0.4	0.0	0.0	0.0	0.0	0.0	0.0	0.4
RS 515	1	D	3	0.094	0.035	36.968	-34	0.0	0.0	70.5	0.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
RS 515	2	D	3	0.094	0.016	17.021	-26	0.0	0.0	58.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
				0.094	0.025	26.995	-30	0.0	0.0	64.5	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Table D-2. Abilene 18-month field performance summary (cont.)

Material	Replicate #	Configuration	Prep Procedure	Avg Crack/Reservoir Width, in	Avg Crack Movement, in	Avg Elongation, %	Temp Difference, F	Avg Low-Severity Pull-Out, in	Avg High-Severity Pull-Out, in	Avg Band-Aid Wear, %	Avg Prt'l-Dpth Adhesion Loss, in	Avg Full-Dpth Adhesion Loss, in	Avg Prt'l-Dpth Cohesion Loss, in	Avg Full-Dpth Cohesion Loss, in	Avg Prt'l-Dpth Bubbling, in	Avg Full-Depth Bubbling, in	Avg Low-Severity Damage, in	Avg High-Severity Damage, in	Avg Overall Failure, in
9030	1	B	3	0.625	0.041	6.480	-40	0.0	0.0	76.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.8	0.8
9030	2	B	3	0.625	0.017	2.660	-31	0.0	0.0	80.4	0.1	0.3	0.0	0.0	0.0	0.0	0.0	0.0	0.3
				0.625	0.029	4.570	-35.5	0.0	0.0	78.3	0.1	0.1	0.0	0.0	0.0	0.0	0.0	0.4	0.5
9030	1	D	3	0.094	0.019	19.814	-35	0.0	0.0	79.9	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
9030	2	D	3	0.094	0.014	15.027	-31	1.1	6.1	80.9	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	6.1
				0.094	0.016	17.420	-33	0.6	3.1	80.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	3.1
XLM	1	B	3	0.625	0.031	5.020	-20	0.0	0.0	93.4	0.0	0.0	0.0	0.0	0.1	0.5	0.4	0.6	1.0
XLM	2	B	3	0.625	0.005	0.760	-22	0.0	0.0	92.9	1.8	1.1	0.0	0.0	0.4	0.0	0.0	0.1	1.3
				0.625	0.018	2.890	-21	0.0	0.0	93.2	0.9	0.6	0.0	0.0	0.3	0.3	0.2	0.4	1.1
XLM	1	D	3	0.094	0.017	17.686	-17	0.4	0.0	91.9	0.0	1.3	4.8	1.9	0.0	0.0	0.0	0.0	3.6
XLM	2	D	3	0.094	0.015	15.957	-17	0.3	0.0	86.1	0.0	0.5	0.1	0.0	0.0	0.0	0.0	0.0	0.5
				0.094	0.016	16.822	-17	0.3	0.0	89.0	0.0	0.9	2.4	0.9	0.0	0.0	0.0	0.0	2.1
B-Fiber + AC	1	D	3	0.094	0.030	32.314	-29	0.0	0.0	92.9	0.0	0.0	9.6	58.0	0.0	0.0	1.0	3.4	58.0
B-Fiber + AC	2	D	3	0.094	0.016	17.420	-24	0.0	0.0	94.0	0.0	0.4	8.3	72.1	0.0	0.0	0.0	2.9	72.1
				0.094	0.023	24.867	-26.5	0.0	0.0	93.4	0.0	0.2	8.9	65.1	0.0	0.0	0.5	3.1	65.1
890SL	1	E	5	0.750	0.043	5.783	-42	0.0	5.1	N/A	30.1	10.3	0.0	0.0	0.0	0.0	0.6	14.4	22.9
890SL	2	E	5	0.750	0.018	2.450	-36	2.3	1.1	N/A	9.9	3.4	0.0	0.0	0.0	0.0	1.1	4.1	8.3
				0.750	0.031	4.117	-39	1.1	3.1	N/A	20.0	6.8	0.0	0.0	0.0	0.0	0.9	9.3	15.6

Table D-3. Wichita ideal subsite 18-month field performance summary

Material	Replicate #	Configuration	Prep Procedure	Avg Crack/Reservoir Width, in	Avg Crack Movement, in	Avg Elongation, %	Temp Difference, F	Avg Low-Severity Pull-Out, in	Avg High-Severity Pull-Out, in	Avg Band-Aid Wear, %	Avg Prt'l-Dpth Adhesion Loss, in	Avg Full-Dpth Adhesion Loss, in	Avg Prt'l-Dpth Cohesion Loss, in	Avg Full-Dpth Cohesion Loss, in	Avg Prt'l-Dpth Bubbling, in	Avg Full-Depth Bubbling, in	Avg Low-Severity Damage, in	Avg High-Severity Damage, in	Avg Overall Failure, in
Hi-Spec	1	A	3	0.563	0.070	12.433	-37	0.0	0.0	N/A	13.3	8.1	0.0	0.0	1.5	0.0	1.8	3.6	10.4
Hi-Spec	2	A	3	0.563	0.039	6.883	-29	0.0	0.0	N/A	7.5	3.3	0.0	0.0	1.4	0.0	1.4	0.6	3.9
				0.563	0.054	9.658	-33	0.0	0.0	N/A	10.4	5.7	0.0	0.0	1.4	0.0	1.6	2.1	7.1
Hi-Spec	1	B	3	0.563	0.066	11.723	-37	0.0	0.0	65.0	0.5	2.0	0.0	0.0	0.9	0.0	3.5	0.0	2.0
Hi-Spec	2	B	3	0.563	0.065	11.523	-25	0.0	0.0	58.3	0.1	0.3	0.0	0.0	0.9	0.9	1.6	0.0	1.1
				0.563	0.065	11.623	-31	0.0	0.0	61.7	0.3	1.1	0.0	0.0	0.9	0.4	2.6	0.0	1.6
Hi-Spec	1	C	3	1.375	0.060	4.345	-27	0.0	0.0	59.2	1.5	0.3	0.0	0.0	2.0	0.0	0.0	0.0	0.0
Hi-Spec	2	C	3	1.375	0.031	2.264	-21	0.0	0.0	66.7	1.6	2.0	0.0	0.0	0.5	0.0	1.5	0.0	2.0
				1.375	0.045	3.305	-24	0.0	0.0	62.9	1.6	1.1	0.0	0.0	1.3	0.0	0.8	0.0	1.0
Hi-Spec	1	D	3	0.137	0.072	56.038	-38	0.0	0.0	70.0	0.0	0.0	0.9	25.9	0.0	1.5	0.0	0.0	27.4
Hi-Spec	2	D	3	0.156	0.045	28.766	-21	0.0	0.0	67.5	0.0	0.0	2.5	22.6	0.1	1.4	0.0	0.0	23.8
				0.146	0.059	42.402	-30	0.0	0.0	68.8	0.0	0.0	1.7	24.3	0.1	1.4	0.0	0.0	25.6
Hi-Spec	1	D	4	0.133	0.055	42.659	-26	0.0	0.0	50.0	0.0	0.0	0.9	23.8	0.0	0.6	0.0	0.0	24.4
Hi-Spec	2	D	4	0.156	0.061	38.782	-22	0.0	0.0	56.7	0.0	0.0	6.4	40.8	0.0	0.8	0.0	0.0	41.5
				0.144	0.058	40.720	-24	0.0	0.0	53.3	0.0	0.0	3.6	32.3	0.0	0.7	0.0	0.0	32.9
RS 515	1	C	3	1.375	0.062	4.527	-25	0.0	0.0	71.0	0.4	0.3	0.0	0.0	0.4	0.0	0.3	0.0	0.3
RS 515	2	C	3	1.375	0.051	3.727	-21	0.0	0.0	66.4	0.0	0.0	0.0	0.0	0.3	0.0	1.9	0.0	0.0
				1.375	0.057	4.127	-23	0.0	0.0	68.7	0.2	0.1	0.0	0.0	0.3	0.0	1.1	0.0	0.1
RS 515	1	D	3	0.152	0.066	43.938	-26	0.0	0.0	61.7	0.0	0.0	0.5	5.9	0.0	0.0	0.0	0.0	5.9
RS 515	2	D	3	0.156	0.034	21.635	-21	0.0	0.0	72.6	0.0	0.0	0.6	48.0	0.0	1.9	0.0	0.0	49.9
				0.154	0.050	32.786	-24	0.0	0.0	67.1	0.0	0.0	0.6	26.9	0.0	0.9	0.0	0.0	27.9
9030	1	C	3	1.375	0.081	5.900	-38	0.0	0.0	82.5	0.3	9.6	0.0	0.0	0.1	0.0	0.1	0.0	9.6
9030	2	C	3	1.375	0.057	4.136	-31	0.0	0.0	82.0	4.4	7.1	0.0	0.0	0.1	0.0	1.3	0.0	7.6
				1.375	0.069	5.018	-35	0.0	0.0	82.2	2.3	8.4	0.0	0.0	0.1	0.0	0.7	0.0	8.6

Table D-3. Wichita ideal subsite 18-month field performance summary (cont.)

Material	Replicate #	Configuration	Prep Procedure	Avg Crack/Reservoir Width, in	Avg Crack Movement, in	Avg Elongation, %	Temp Difference, F	Avg Low-Severity Pull-Out, in	Avg High-Severity Pull-Out, in	Avg Band-Aid Wear, %	Avg Prt'l-Dpth Adhesion Loss, in	Avg Full-Dpth Adhesion Loss, in	Avg Prt'l-Dpth Cohesion Loss, in	Avg Full-Dpth Cohesion Loss, in	Avg Prt'l-Dpth Bubbling, in	Avg Full-Depth Bubbling, in	Avg Low-Severity Damage, in	Avg High-Severity Damage, in	Avg Overall Failure, in
9030	1	D	3	0.156	0.059	38.061	-37	0.0	0.0	78.9	0.0	0.0	8.1	70.5	0.0	0.0	0.0	0.4	70.5
9030	2	D	3	0.172	0.059	34.987	-31	0.0	0.0	68.3	0.5	0.0	9.8	36.3	0.0	0.3	0.0	0.1	36.5
				0.164	0.059	36.524	-34	0.0	0.0	73.6	0.3	0.0	8.9	53.4	0.0	0.1	0.0	0.3	53.5
XLM	1	C	3	1.375	0.050	3.636	-37	0.0	0.0	79.4	0.9	0.1	0.0	0.0	1.4	0.0	0.9	0.3	0.1
XLM	2	C	3	1.375	0.059	4.270	-37	0.0	0.0	68.5	0.5	1.8	0.0	0.0	1.4	0.1	1.9	0.3	2.1
				1.375	0.054	3.953	-37	0.0	0.0	74.0	0.7	0.9	0.0	0.0	1.4	0.1	1.4	0.3	1.1
XLM	1	D	3	0.133	0.046	39.950	-22	0.0	0.1	77.8	0.0	0.0	7.4	40.9	0.0	0.0	0.0	0.0	41.0
XLM	2	D	3	0.156	0.081	51.832	-39	0.0	0.8	80.3	0.0	0.0	2.4	20.3	0.0	0.8	1.8	0.0	21.5
				0.144	0.063	45.891	-31	0.0	0.4	79.1	0.0	0.0	4.9	30.6	0.0	0.4	0.9	0.0	31.3
B-Fiber + AC	1	D	3	0.125	0.067	59.044	-22	0.0	0.0	71.0	0.0	0.0	0.9	89.8	0.0	0.0	0.3	5.0	89.8
B-Fiber + AC	2	D	3	0.156	0.069	43.990	-21	0.0	0.0	78.3	0.0	0.0	20.4	83.4	0.0	0.0	1.8	9.6	83.5
				0.141	0.068	51.517	-22	0.0	0.0	74.7	0.0	0.0	10.6	86.6	0.0	0.0	1.0	7.3	86.6
890SL	1	E	5	0.625	0.088	14.060	-29	0.0	0.0	N/A	2.4	0.3	0.0	0.0	0.0	0.0	3.1	10.4	10.6
890SL	2	E	5	0.625	0.093	14.960	-36	0.0	0.0	N/A	0.3	0.5	0.0	0.0	0.0	0.0	4.9	5.4	7.6
				0.625	0.091	14.510	-33	0.0	0.0	N/A	1.3	0.4	0.0	0.0	0.0	0.0	4.0	7.9	9.1
AR+	1	B	3	0.563	NA	NA	NA	0.0	0.0	61.4	2.3	1.9	0.0	0.0	0.1	0.0	4.6	0.0	1.9
AR+	2	B	3	0.563	NA	NA	NA	0.0	0.0	58.3	0.8	0.1	0.0	0.0	0.1	0.0	0.3	0.0	0.1
				0.563	NA	NA	NA	0.0	0.0	59.8	1.5	1.0	0.0	0.0	0.1	0.0	2.4	0.0	1.0
9000-S	1	B	3	0.563	NA	NA	NA	0.0	0.0	61.7	2.6	0.3	0.0	0.0	0.0	0.0	1.8	0.0	0.3
9000-S	2	B	3	0.563	NA	NA	NA	0.0	0.0	64.3	5.8	0.3	0.0	0.0	0.3	0.0	3.4	0.0	0.3
				0.563	NA	NA	NA	0.0	0.0	63.0	4.2	0.3	0.0	0.0	0.1	0.0	2.6	0.0	0.3

Table D-4. Wichita adverse subsite 18-month field performance summary

Material	Replicate #	Configuration	Prep Procedure	Avg Crack/Reservoir Width, in	Avg Crack Movement, in	Avg Elongation, %	Temp Difference, F	Avg Low-Severity Pull-Out, in	Avg High-Severity Pull-Out, in	Avg Band-Aid Wear, %	Avg Prt'l-Dpth Adhesion Loss, in	Avg Full-Dpth Adhesion Loss, in	Avg Prt'l-Dpth Cohesion Loss, in	Avg Full-Dpth Cohesion Loss, in	Avg Prt'l-Dpth Bubbling, in	Avg Full-Depth Bubbling, in	Avg Low-Severity Damage, in	Avg High-Severity Damage, in	Avg Overall Failure, in
Hi-Spec	1	A	3	0.563	0.066	11.745	-16	0.0	0.0	N/A	2.6	3.0	0.0	0.0	0.1	0.0	7.1	0.3	3.0
Hi-Spec	2	A	3	0.563	0.033	5.928	-28	0.0	0.0	N/A	5.5	7.3	0.0	0.0	0.1	0.0	6.6	0.1	6.1
				0.563	0.050	8.837	-22	0.0	0.0	N/A	4.1	5.1	0.0	0.0	0.1	0.0	6.9	0.2	4.6
Hi-Spec	1	B	3	0.563	0.053	9.369	-20	0.0	0.0	55.0	2.1	2.5	0.0	0.0	0.5	0.0	3.9	0.0	2.5
Hi-Spec	2	B	3	0.563	0.048	8.459	-27	0.0	0.0	67.7	0.6	0.3	0.0	0.0	0.3	0.0	1.9	0.0	0.3
				0.563	0.050	8.914	-23.5	0.0	0.0	61.4	1.4	1.4	0.0	0.0	0.4	0.0	2.9	0.0	1.4
Hi-Spec	1	C	3	1.375	0.030	2.200	-15	0.0	0.0	66.7	0.9	0.1	0.0	0.0	1.0	0.1	6.8	0.6	0.8
Hi-Spec	2	C	3	1.375	0.036	2.627	-19	0.0	0.0	65.5	0.3	1.6	0.0	0.0	0.9	0.0	0.9	0.0	1.6
				1.375	0.033	2.414	-17	0.0	0.0	66.1	0.6	0.9	0.0	0.0	0.9	0.1	3.8	0.3	1.2
Hi-Spec	1	D	3	0.148	0.052	34.334	-18	0.0	0.5	68.3	1.1	0.0	0.0	4.5	0.3	0.0	0.0	0.0	5.0
Hi-Spec	2	D	3	0.117	0.040	34.994	-25	0.0	0.0	68.0	0.0	0.0	1.8	12.6	0.4	0.3	0.0	0.0	12.8
				0.133	0.046	34.664	-21.5	0.0	0.3	68.2	0.6	0.0	0.9	8.6	0.3	0.1	0.0	0.0	8.9
Hi-Spec	1	D	4	0.156	0.038	24.451	-16	0.0	0.0	67.5	0.0	0.0	3.0	7.1	1.8	0.1	3.1	0.0	7.3
Hi-Spec	2	D	4	0.110	0.037	34.498	-25	0.0	0.0	65.5	1.8	2.3	4.3	46.5	0.0	0.5	0.0	0.0	48.8
				0.133	0.038	29.474	-20.5	0.0	0.0	66.5	0.9	1.1	3.6	26.8	0.9	0.3	1.6	0.0	28.0
RS 515	1	C	3	1.375	0.046	3.336	-7	0.0	0.0	78.3	0.3	0.8	0.0	0.0	0.0	0.0	3.4	0.0	1.1
RS 515	2	C	3	1.375	0.036	2.591	-11	0.0	0.0	70.4	0.9	0.8	0.0	0.1	0.0	0.0	0.3	0.1	0.6
				1.375	0.041	2.964	-9	0.0	0.0	74.4	0.6	0.8	0.0	0.1	0.0	0.0	1.8	0.1	0.9
RS 515	1	D	3	0.156	0.060	38.542	-31	0.0	0.0	66.7	2.3	0.0	3.3	15.4	0.0	0.0	4.1	0.0	15.4
RS 515	2	D	3	0.110	0.034	34.747	-11	0.0	0.0	70.5	0.0	0.0	4.3	21.0	0.0	0.0	0.0	0.0	21.0
				0.133	0.047	36.644	-21	0.0	0.0	68.6	1.1	0.0	3.8	18.2	0.0	0.0	2.1	0.0	18.2
9030	1	C	3	1.375	0.068	4.927	-28	5.3	0.0	82.0	2.1	9.5	0.0	0.0	0.0	0.0	7.1	0.0	9.5
9030	2	C	3	1.375	0.044	3.209	-19	0.0	0.0	74.2	1.0	1.4	0.0	0.0	0.0	0.0	5.1	0.0	1.4
				1.375	0.056	4.068	-23.5	2.6	0.0	78.1	1.6	5.4	0.0	0.0	0.0	0.0	6.1	0.0	5.4

Table D-4. Wichita adverse subsite 18-month field performance summary (cont.)

Material	Replicate #	Configuration	Prep Procedure	Avg Crack/Reservoir Width, in	Avg Crack Movement, in	Avg Elongation, %	Temp Difference, F	Avg Low-Severity Pull-Out, in	Avg High-Severity Pull-Out, in	Avg Band-Aid Wear, %	Avg Prt'l-Dpth Adhesion Loss, in	Avg Full-Dpth Adhesion Loss, in	Avg Prt'l-Dpth Cohesion Loss, in	Avg Full-Dpth Cohesion Loss, in	Avg Prt'l-Dpth Bubbling, in	Avg Full-Depth Bubbling, in	Avg Low-Severity Damage, in	Avg High-Severity Damage, in	Avg Overall Failure, in
9030	1	D	3	0.156	0.063	40.625	-27	0.1	0.0	72.3	0.0	0.0	13.9	41.4	0.0	0.0	4.3	0.0	41.4
9030	2	D	3	0.148	0.069	48.060	-16	0.0	0.0	81.5	0.1	0.0	9.4	64.6	0.0	0.0	1.3	0.0	64.6
				0.152	0.066	44.342	-21.5	0.1	0.0	76.9	0.1	0.0	11.6	53.0	0.0	0.0	2.8	0.0	53.0
XLM	1	C	3	1.375	0.076	5.545	-30	0.5	0.0	71.6	1.8	5.4	0.0	0.0	0.3	0.0	3.3	0.0	5.4
XLM	2	C	3	1.375	0.041	3.018	-11	0.0	0.0	76.3	3.4	21.5	0.0	0.0	0.6	0.0	3.1	0.5	21.9
				1.375	0.059	4.282	-20.5	0.3	0.0	73.9	2.6	13.4	0.0	0.0	0.4	0.0	3.2	0.3	13.6
XLM	1	D	3	0.156	0.070	44.872	-40	0.8	0.4	63.3	0.0	0.0	0.1	1.9	1.0	1.0	0.6	0.0	3.3
XLM	2	D	3	0.141	0.050	35.700	-13	0.5	1.4	76.5	0.0	0.0	1.0	2.3	0.0	0.9	0.5	0.0	4.5
				0.148	0.060	40.286	-26.5	0.6	0.9	69.9	0.0	0.0	0.6	2.1	0.5	0.9	0.6	0.0	3.9
B-Fiber + AC	1	D	3	0.141	0.047	36.206	-23	0.0	0.0	76.3	0.0	0.0	21.3	99.5	0.0	0.0	5.3	35.0	100.8
B-Fiber + AC	2	D	3	0.125	0.046	39.769	-29	0.0	0.0	81.5	0.0	0.0	7.0	93.5	0.0	0.0	0.0	44.8	93.5
				0.133	0.047	37.988	-26	0.0	0.0	78.9	0.0	0.0	14.1	96.5	0.0	0.0	2.6	39.9	97.1
890SL	1	F	7	0.617	0.082	13.359	-24	0.0	0.0	N/A	2.0	0.0	0.0	0.0	0.0	0.0	9.4	18.4	18.4
890SL	2	E	6	0.602	0.108	18.035	-39	0.0	0.0	N/A	2.6	2.9	0.0	0.0	0.0	0.0	2.4	13.5	16.4
				0.610	0.095	15.697	-31.5	0.0	0.0	N/A	2.3	1.4	0.0	0.0	0.0	0.0	5.9	15.9	17.4
AR+	1	B	3	0.563	NA	NA	NA	0.0	0.0	61.7	0.4	0.3	0.0	0.0	0.0	0.0	0.9	0.0	0.3
AR+	2	B	3	0.563	NA	NA	NA	0.9	0.0	70.5	0.6	2.0	0.0	0.0	0.0	0.0	0.0	0.0	1.8
				0.563	NA	NA	NA	0.4	0.0	66.1	0.5	1.1	0.0	0.0	0.0	0.0	0.4	0.0	1.0
9000-S	1	B	3	0.563	NA	NA	NA	0.0	0.0	63.3	0.1	0.0	0.0	0.0	0.1	0.0	3.6	0.0	0.1
9000-S	2	B	3	0.563	NA	NA	NA	0.0	0.0	73.1	0.1	0.0	0.0	0.0	0.0	0.0	4.5	0.0	0.0
				0.563	NA	NA	NA	0.0	0.0	68.2	0.1	0.0	0.0	0.0	0.1	0.0	4.1	0.0	0.1

Table D-5. Elma 18-month field performance summary

Material	Replicate #	Configuration	Prep Procedure	Avg Crack/Reservoir Width, in	Avg Crack Movement, in	Avg Elongation, %	Temp Difference, F	Avg Low-Severity Pull-Out, in	Avg High-Severity Pull-Out, in	Avg Band-Aid Wear, %	Avg Prt'l-Dpth Adhesion Loss, in	Avg Full-Dpth Adhesion Loss, in	Avg Prt'l-Dpth Cohesion Loss, in	Avg Full-Dpth Cohesion Loss, in	Avg Prt'l-Dpth Bubbling, in	Avg Full-Depth Bubbling, in	Avg Low-Severity Damage, in	Avg High-Severity Damage, in	Avg Overall Failure, in
Hi-Spec	1	A	3	0.625	0.017	2.740	-10	0.0	0.0	N/A	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.1
Hi-Spec	2	A	3	0.625	0.018	2.860	-5	0.0	0.0	N/A	0.9	0.0	0.0	0.0	0.8	0.3	0.0	0.0	0.3
				0.625	0.018	2.800	-7.5	0.0	0.0	N/A	0.4	0.0	0.0	0.0	0.4	0.2	0.0	0.0	0.2
Hi-Spec	1	B	3	0.625	0.017	2.700	-12	0.8	0.0	37.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Hi-Spec	2	B	3	0.625	0.021	3.280	-8	0.0	0.0	49.17	0.0	0.0	0.0	0.0	0.8	0.0	0.0	0.0	0.0
				0.625	0.019	2.990	-10	0.4	0.0	43.33	0.0	0.0	0.0	0.0	0.4	0.0	0.0	0.0	0.0
Hi-Spec	1	D	3	0.141	0.017	13.040	-9	0.0	0.0	60.83	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Hi-Spec	2	D	3	0.152	0.010	7.370	-5	0.0	0.0	54.17	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
				0.146	0.013	10.205	-7	0.0	0.0	57.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Hi-Spec	1	D	4	0.121	0.017	13.862	-12	0.0	0.0	50	0.0	0.0	2.3	1.1	0.0	0.0	0.0	0.0	0.1
Hi-Spec	2	D	4	0.149	0.018	13.313	-7	0.0	0.0	40.31	0.0	0.0	0.6	0.0	0.0	0.0	0.0	0.0	0.0
				0.135	0.017	13.587	-9.5	0.0	0.0	45.16	0.0	0.0	1.4	0.6	0.0	0.0	0.0	0.0	0.1
RS 515	1	B	3	0.625	0.013	2.080	-6	0.0	0.0	47.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
RS 515	2	B	3	0.625	0.011	1.780	-4	0.0	0.0	54.17	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
				0.625	0.012	1.930	-5	0.0	0.0	50.83	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
RS 515	1	D	3	0.156	0.016	10.424	-8	0.3	0.4	58.33	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.4
RS 515	2	D	3	0.160	0.009	5.764	-5	0.0	0.0	53.33	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
				0.158	0.012	8.094	-6.5	0.1	0.2	55.83	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2
9030	1	B	3	0.625	0.011	1.780	-8	0.5	0.0	60	0.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
9030	2	B	3	0.625	0.019	2.980	-10	0.0	0.0	59.69	1.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
				0.625	0.015	2.380	-9	0.3	0.0	59.84	1.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Table D-5. Elma 18-month field performance summary (cont.)

Material	Replicate #	Configuration	Prep Procedure	Avg Crack/Reservoir Width, in	Avg Crack Movement, in	Avg Elongation, %	Temp Difference, F	Avg Low-Severity Pull-Out, in	Avg High-Severity Pull-Out, in	Avg Band-Aid Wear, %	Avg Prt'l-Dpth Adhesion Loss, in	Avg Full-Dpth Adhesion Loss, in	Avg Prt'l-Dpth Cohesion Loss, in	Avg Full-Dpth Cohesion Loss, in	Avg Prt'l-Dpth Bubbling, in	Avg Full-Depth Bubbling, in	Avg Low-Severity Damage, in	Avg High-Severity Damage, in	Avg Overall Failure, in
9030	1	D	3	0.102	0.010	10.200	-7	0.0	0.0	43.33	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
9030	2	D	3	0.141	0.010	7.206	-9	0.0	0.0	49.17	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
				0.121	0.010	8.703	-8	0.0	0.0	46.25	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
XLM	1	B	3	0.625	0.014	2.260	-10	0.0	0.0	51.67	0.3	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0
XLM	2	B	3	0.625	0.007	1.040	-6	1.5	0.0	61.56	0.0	0.0	0.0	0.0	2.1	0.1	0.0	0.0	0.1
				0.625	0.010	1.650	-8	0.8	0.0	56.61	0.1	0.0	0.0	0.0	1.1	0.1	0.1	0.0	0.1
XLM	1	D	3	0.129	0.009	7.630	-7	0.0	0.0	68.54	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
XLM	2	D	3	0.164	0.009	5.668	-5	0.0	0.0	73.13	0.0	0.0	1.9	0.0	0.4	0.0	0.1	0.0	0.0
				0.147	0.009	6.649	-6	0.0	0.0	70.83	0.0	0.0	0.9	0.0	0.2	0.0	0.1	0.0	0.0
B-Fiber + AC	1	D	3	0.148	0.006	3.656	-1	0.0	0.0	81.46	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
B-Fiber + AC	2	D	3	0.137	0.011	8.224	-10	0.0	0.0	82.5	0.0	0.0	2.5	0.0	0.0	0.0	0.0	0.0	0.0
				0.143	0.008	5.940	-5.5	0.0	0.0	81.98	0.0	0.0	1.3	0.0	0.0	0.0	0.0	0.0	0.0
890SL	1	E	5	0.688	0.017	2.544	-11	0.0	0.0	N/A	0.6	0.6	0.0	0.0	0.0	0.0	1.4	1.5	2.1
890SL	2	E	5	0.688	0.010	1.490	-6	0.0	0.0	N/A	0.0	0.0	0.0	0.0	0.0	0.0	3.5	1.8	1.8
				0.688	0.014	2.017	-8.5	0.0	0.0	N/A	0.3	0.3	0.0	0.0	0.0	0.0	2.4	1.6	1.9
RS 211	1	B	3	0.625	NA	NA	NA	0.0	0.0	31.77	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
RS 211	2	B	3	0.625	NA	NA	NA	0.0	0.0	39.48	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
				0.625	NA	NA	NA	0.0	0.0	35.63	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Table D-6. Prescott 18-month field performance summary

Material	Replicate #	Configuration	Prep Procedure	Avg Crack/Reservoir Width, in	Avg Crack Movement, in	Avg Elongation, %	Temp Difference, F	Avg Low-Severity Pull-Out, in	Avg High-Severity Pull-Out, in	Avg Band-Aid Wear, %	Avg Prt'l-Dpth Adhesion Loss, in	Avg Full-Dpth Adhesion Loss, in	Avg Prt'l-Dpth Cohesion Loss, in	Avg Full-Dpth Cohesion Loss, in	Avg Prt'l-Dpth Bubbling, in	Avg Full-Depth Bubbling, in	Avg Low-Severity Damage, in	Avg High-Severity Damage, in	Avg Overall Failure, in
RS 211	1	G	4	0.152	NA	NA	NA	0.0	0.0	30.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2.8
RS 211	2	G	4	NA	NA	NA	NA	0.0	0.0	30.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.5
					NA	NA	NA	0.0	0.0	30.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.6
AC	1	G	1	0.121	0.048	39.418	-74	0.0	0.0	N/A	0.0	0.0	2.6	0.0	0.0	0.0	0.0	0.0	0.4
AC	2	G	1	0.137	0.032	23.692	-75	0.0	0.0	N/A	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	6.0
				0.129	0.040	31.555	-74.5	0.0	0.0	N/A	0.0	0.0	1.3	0.0	0.0	0.0	0.0	0.0	3.2
AC	1	G	4	0.125	0.043	34.642	-74	0.0	0.0	N/A	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.6
AC	2	G	4	0.144	0.051	35.194	-74	0.0	0.0	N/A	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.6
				0.135	0.047	34.918	-74	0.0	0.0	N/A	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.6
CRF	1	G	4	0.144	0.051	36.192	-74	0.0	0.0	N/A	0.0	0.0	40.4	0.0	0.0	0.0	0.0	0.0	0.0
CRF	2	G	4	0.137	0.031	22.671	-72	0.0	0.0	N/A	0.0	0.0	0.6	0.8	0.0	0.0	0.0	0.0	0.0
				0.141	0.041	29.432	-73	0.0	0.0	N/A	0.0	0.0	20.5	0.4	0.0	0.0	0.0	0.0	0.0
AR2	1	D	4	0.148	0.029	19.929	-63	0.0	0.0	70.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
AR2	2	D	4	0.137	0.056	41.342	-64	0.0	0.0	70.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
				0.143	0.043	30.636	-63.5	0.0	0.0	70.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
AR2	1	G	4	0.137	0.066	48.426	-63	0.0	0.0	N/A	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
AR2	2	G	4	0.168	0.039	23.527	-62	0.0	0.0	N/A	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
				0.152	0.052	35.976	-62.5	0.0	0.0	N/A	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
FiberPave	1	D	4	0.152	0.071	46.904	-72	0.0	0.0	70.0	0.5	0.0	9.5	0.6	0.0	0.0	0.0	0.0	0.6
FiberPave	2	D	4	0.152	0.036	23.392	-72	0.0	0.5	70.0	0.0	0.0	2.0	0.0	0.0	0.0	0.0	0.0	0.5
				0.152	0.053	35.148	-72	0.0	0.3	70.0	0.3	0.0	5.8	0.3	0.0	0.0	0.0	0.0	0.6
Kold Flo	1	G	4	0.156	0.037	23.397	-68	0.0	0.0	N/A	52.1	3.5	0.0	0.0	0.0	0.0	0.0	0.0	3.5
Kold Flo	2	G	4	0.133	0.051	38.614	-66	0.0	0.0	N/A	45.4	5.9	0.0	0.0	0.0	0.0	0.0	0.0	6.8
				0.144	0.044	31.006	-67	0.0	0.0	N/A	48.8	4.7	0.0	0.0	0.0	0.0	0.0	0.0	5.1

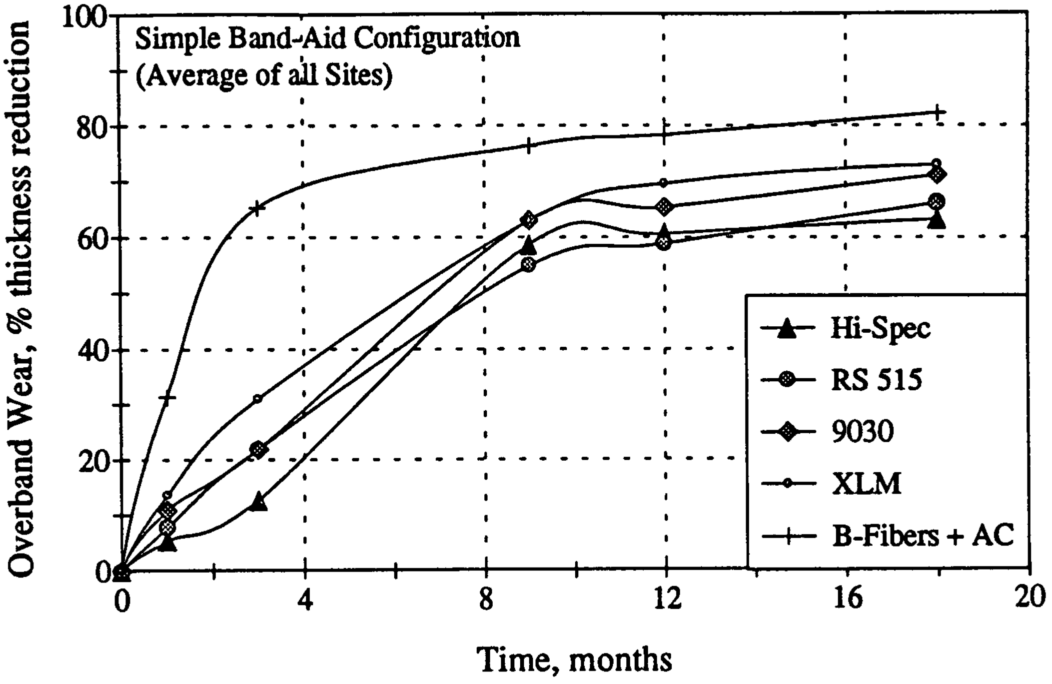


Figure D-2. Progression of overband wear for primary sealants

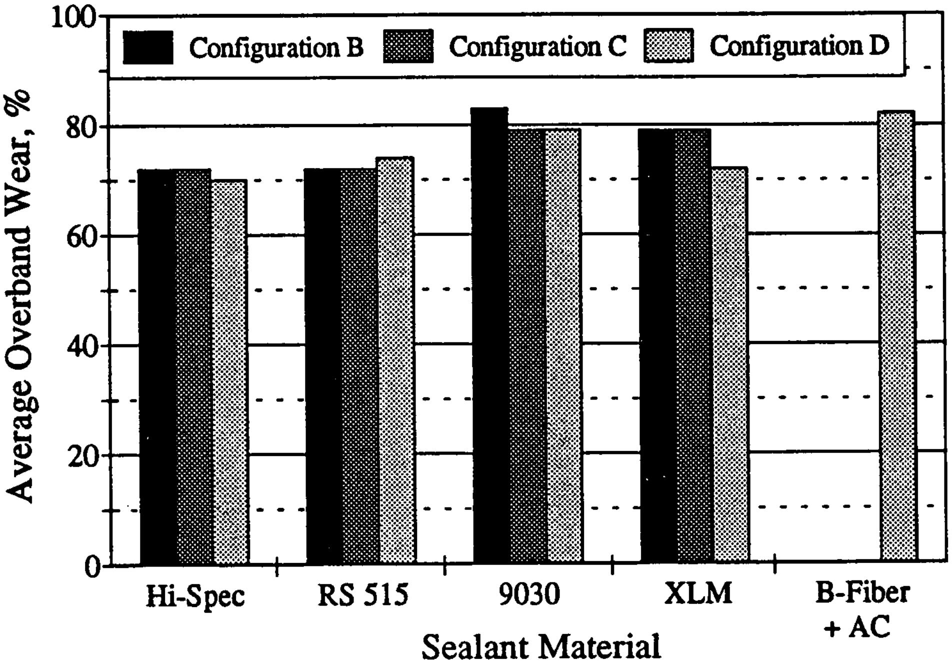


Figure D-3. Overband wear at Des Moines

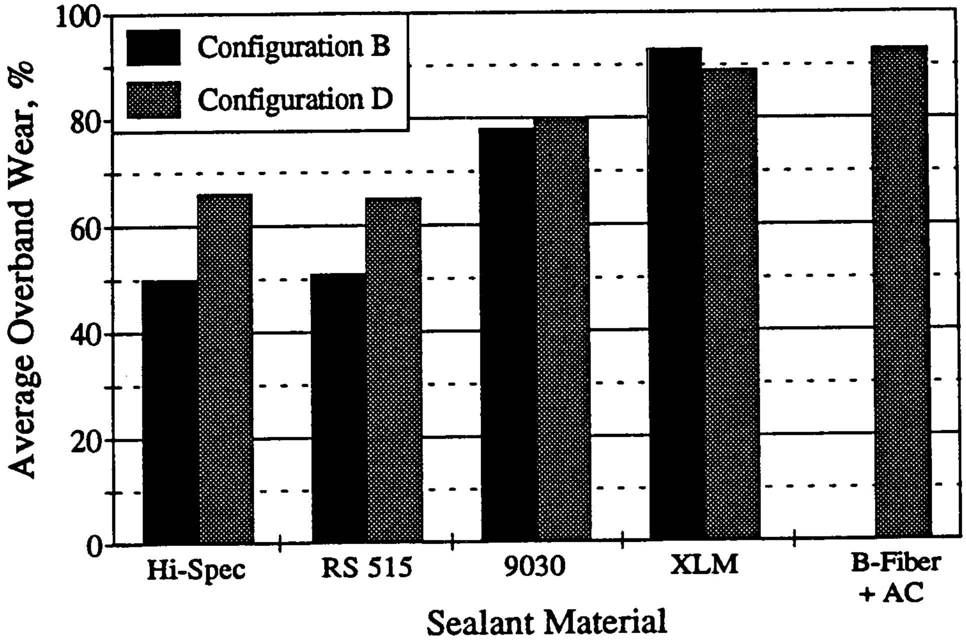


Figure D-4. Overband wear at Abilene

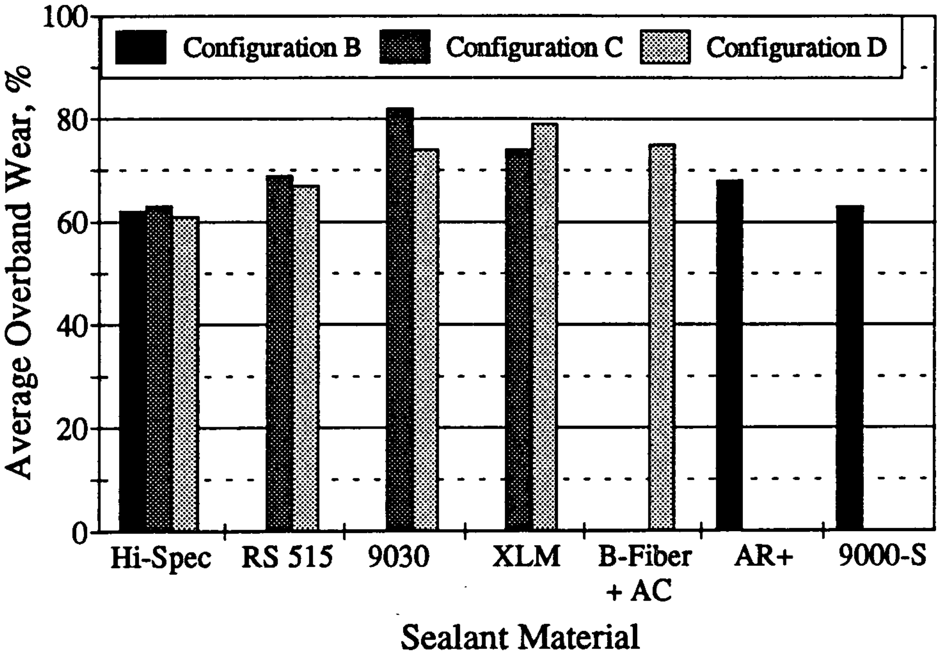


Figure D-5. Overband wear at Wichita ideal subsite

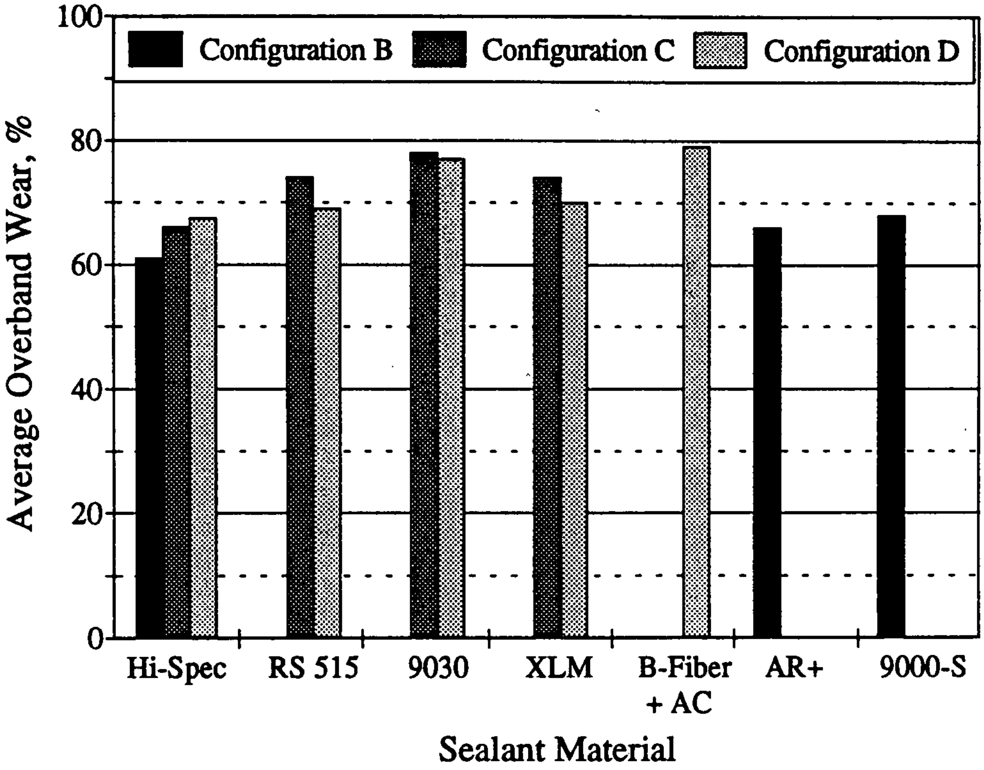


Figure D-6. Overband wear at Wichita adverse subsite

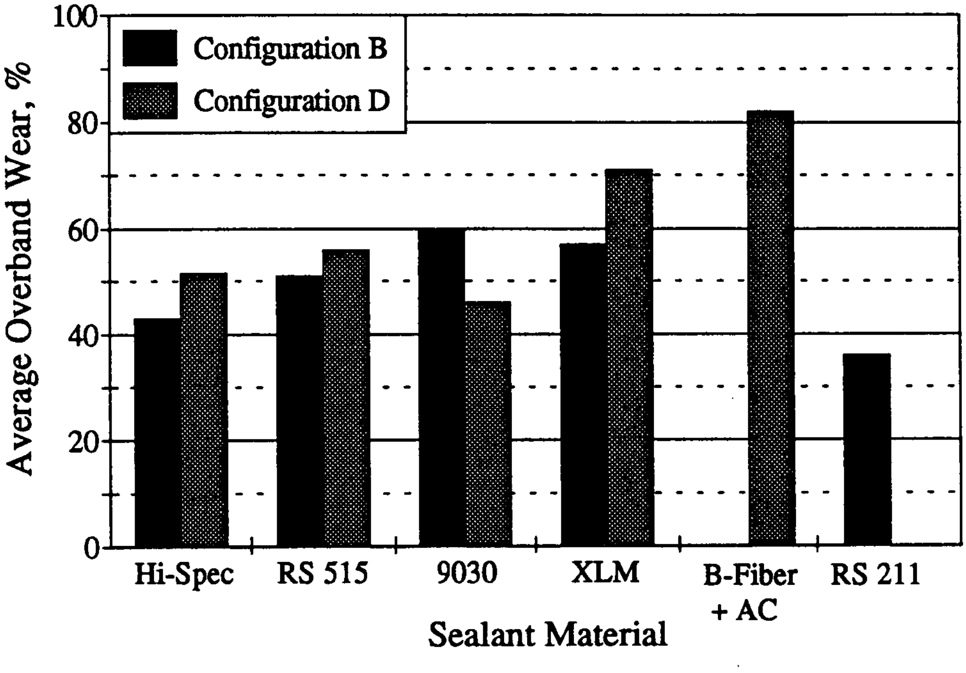


Figure D-7. Overband wear at Elma

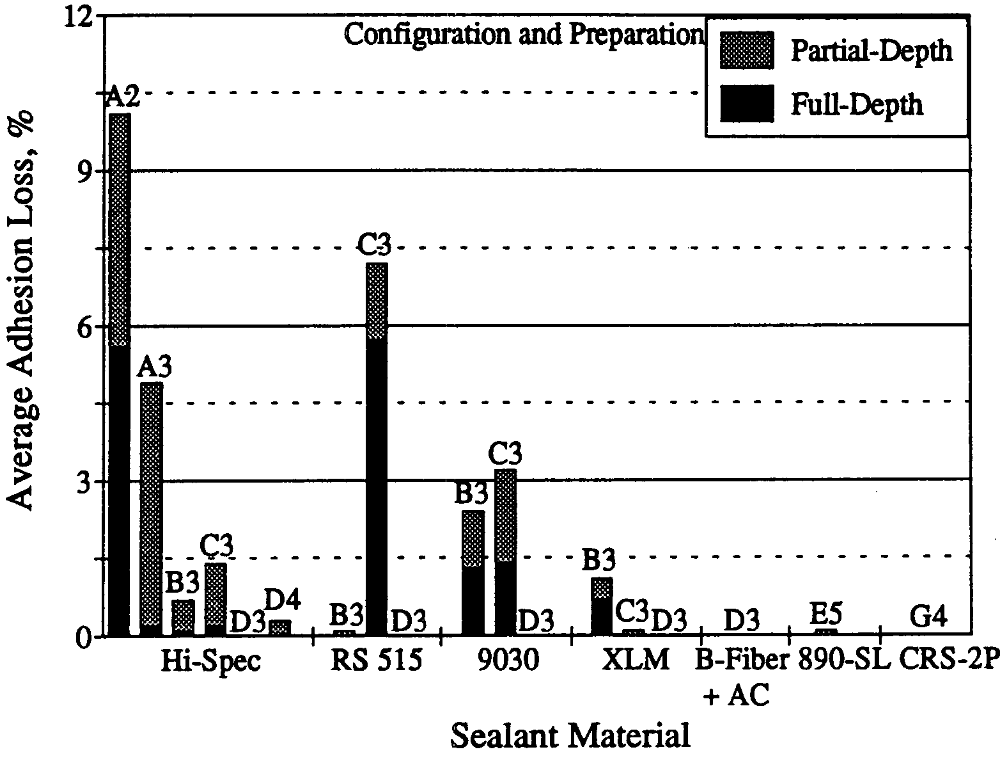


Figure D-8. Average adhesion loss at Des Moines

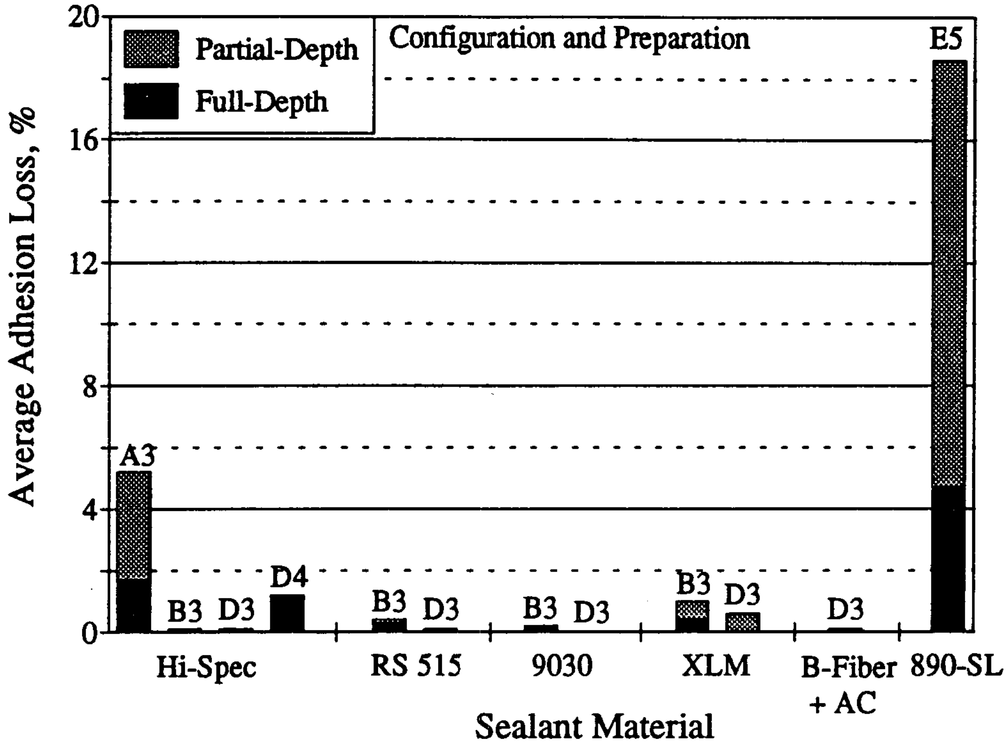


Figure D-9. Average adhesion loss at Abilene

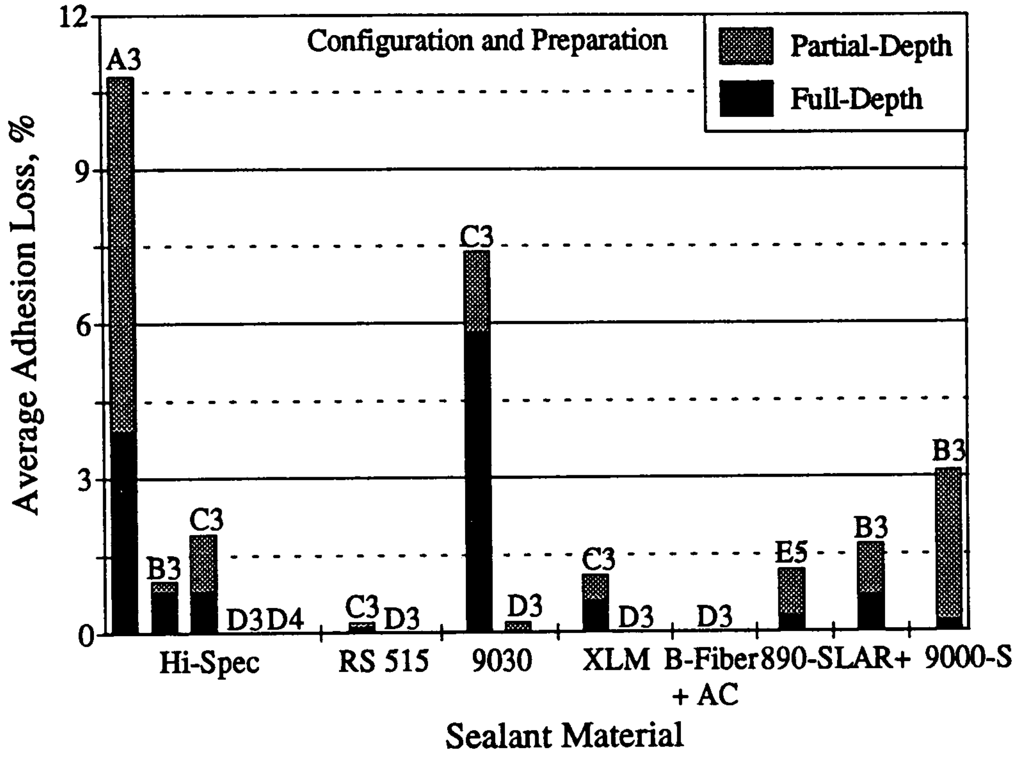


Figure D-10. Average adhesion loss at Wichita ideal subsite

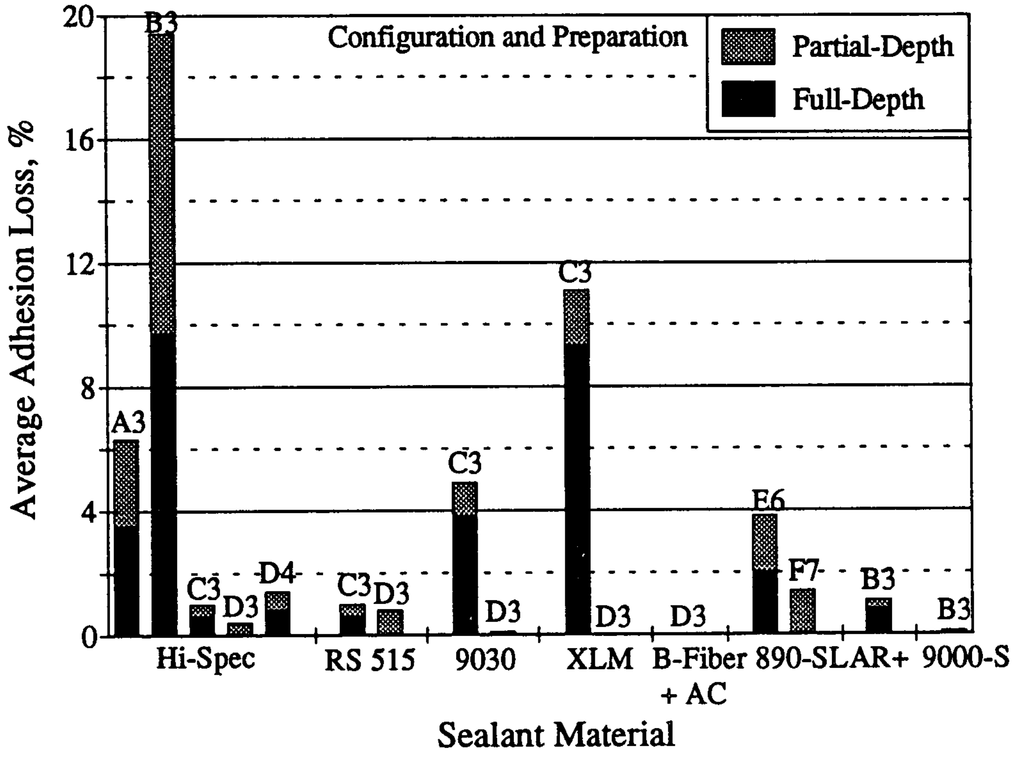


Figure D-11. Average adhesion loss at Wichita adverse subsite

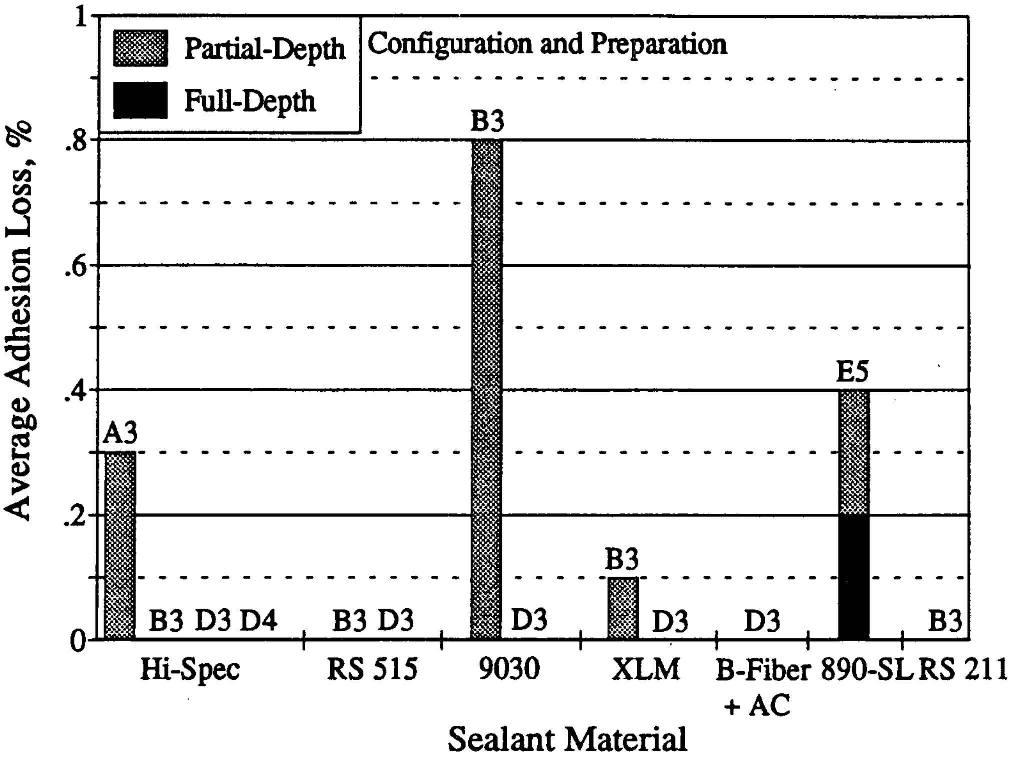


Figure D-12. Average adhesion loss at Elma

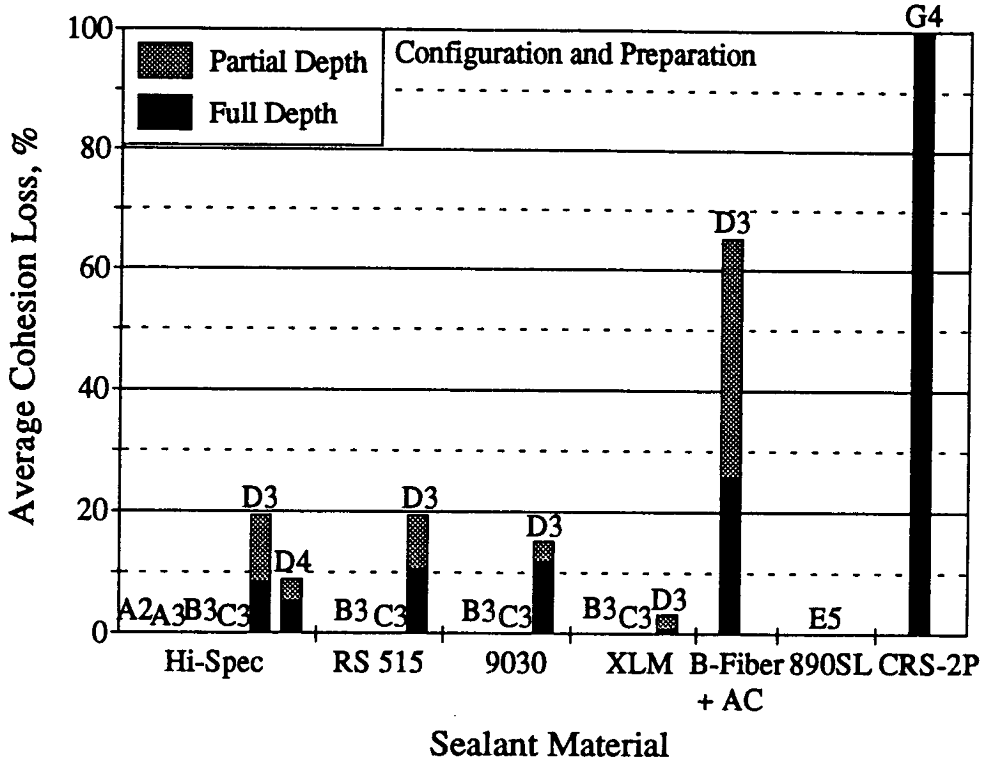


Figure D-13. Average cohesion loss at Des Moines

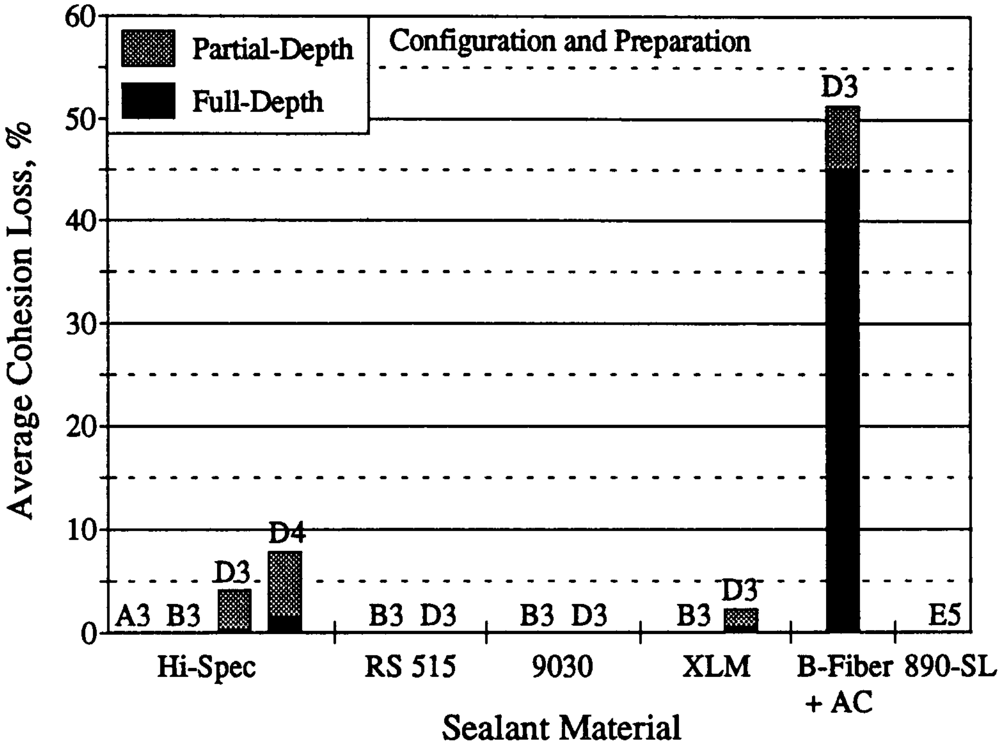


Figure D-14. Average cohesion loss at Abilene

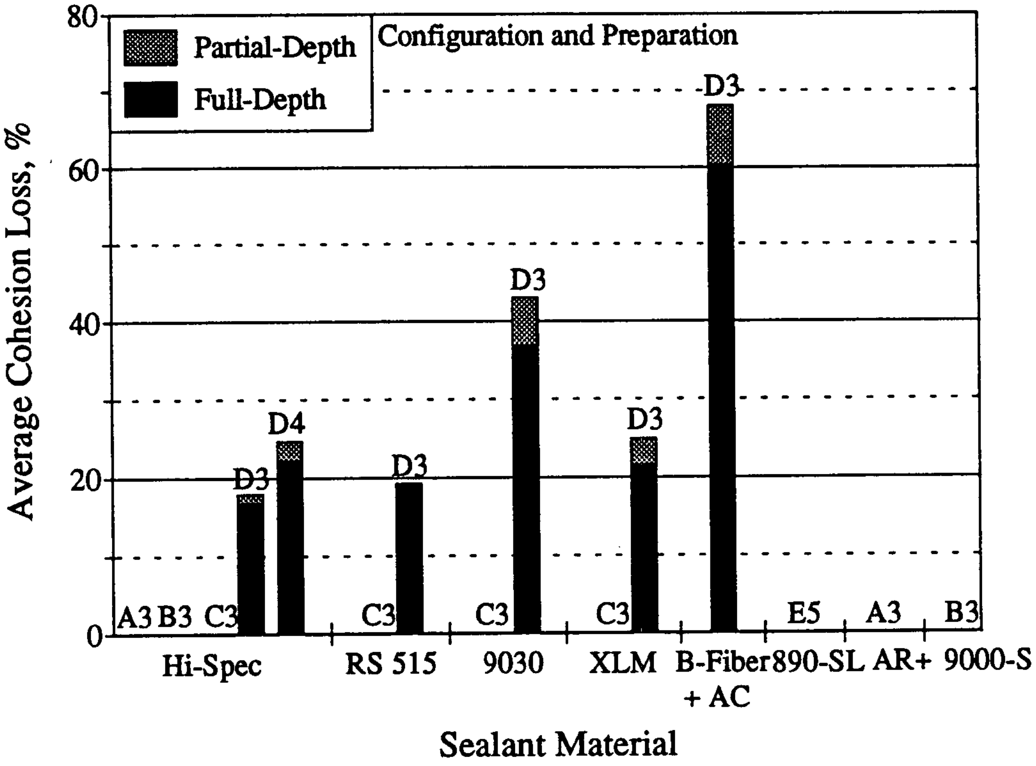


Figure D-15. Average cohesion loss at Wichita ideal subsite

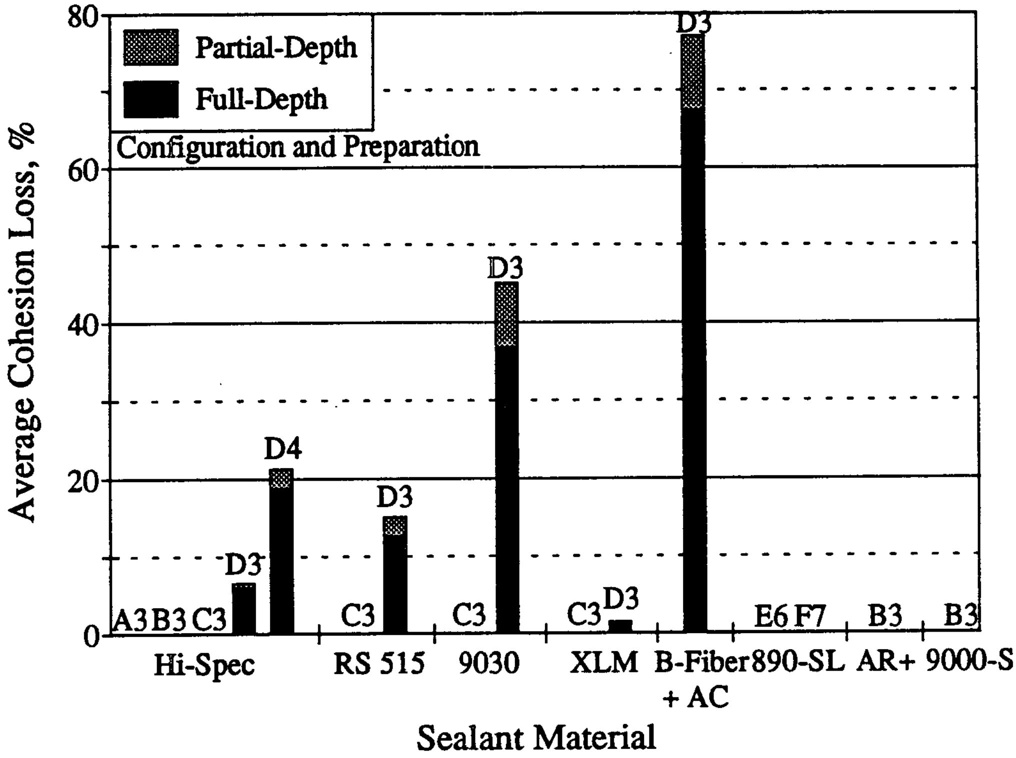


Figure D-16. Average cohesion loss at Wichita adverse subsite

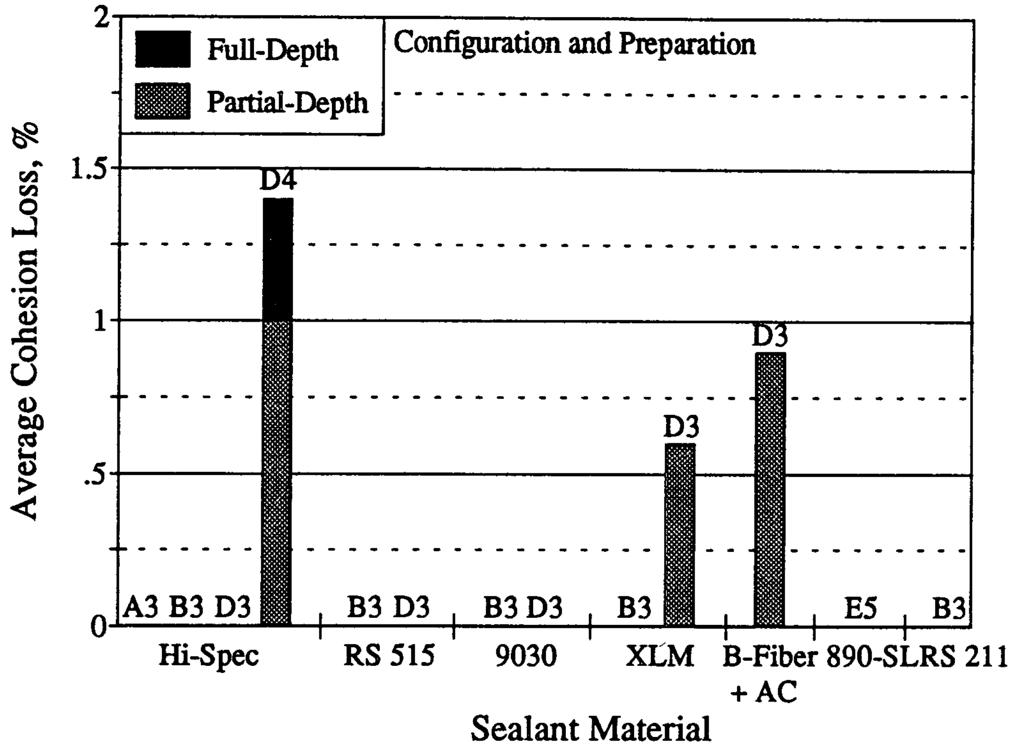


Figure D-17. Average cohesion loss at Elma

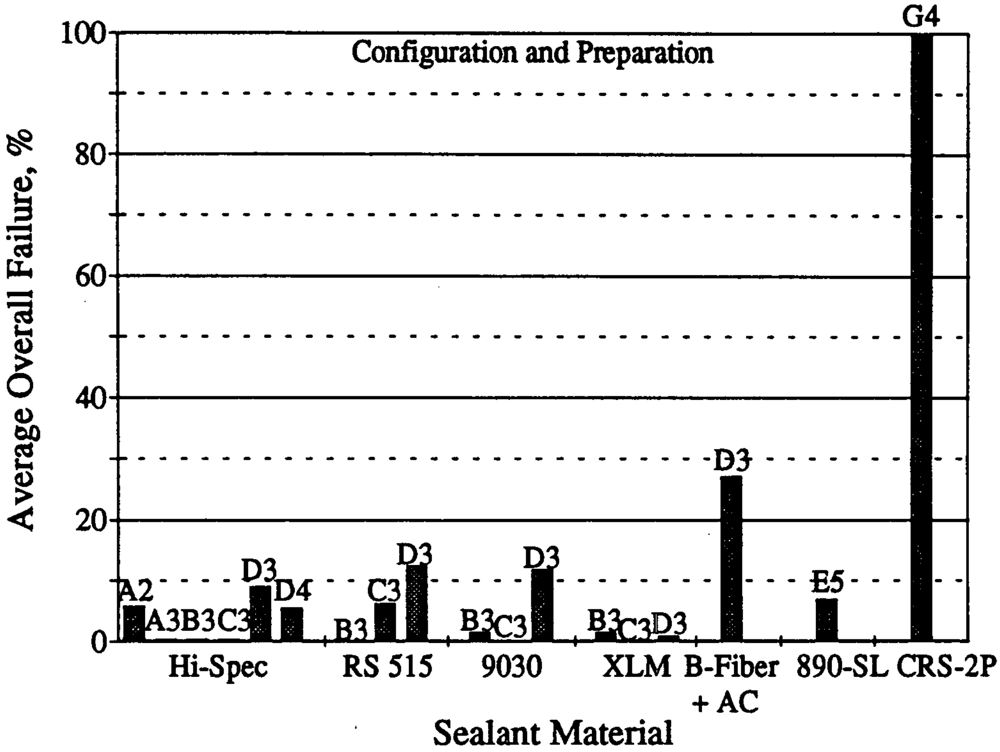


Figure D-18. Average overall failure at Des Moines

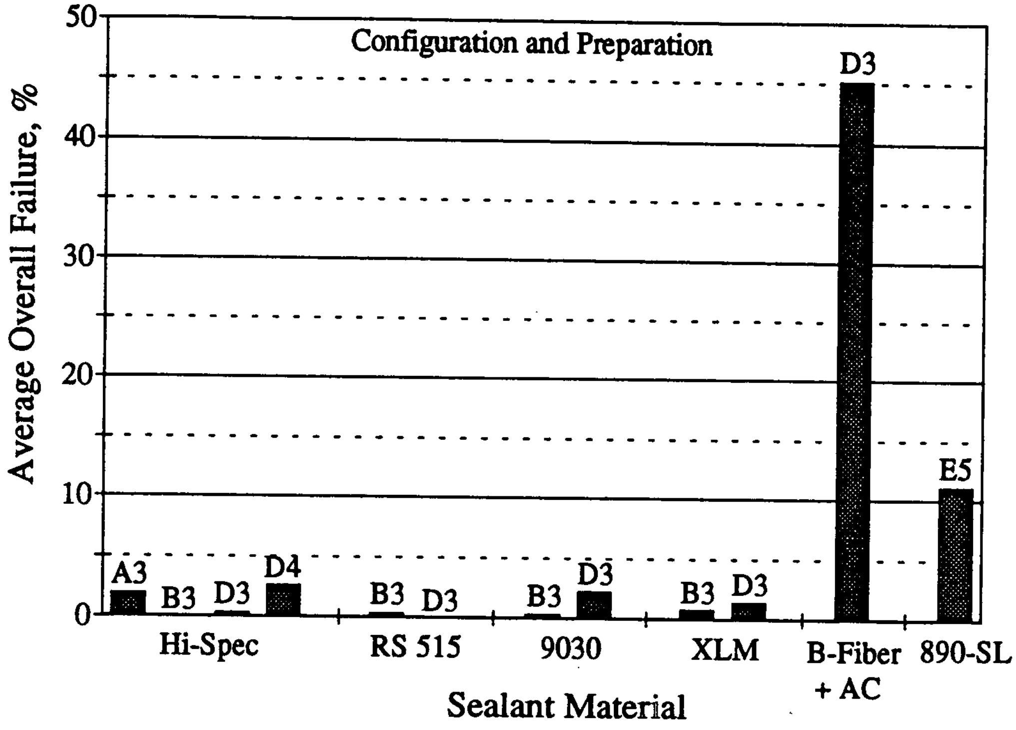


Figure D-19. Average overall failure at Abilene

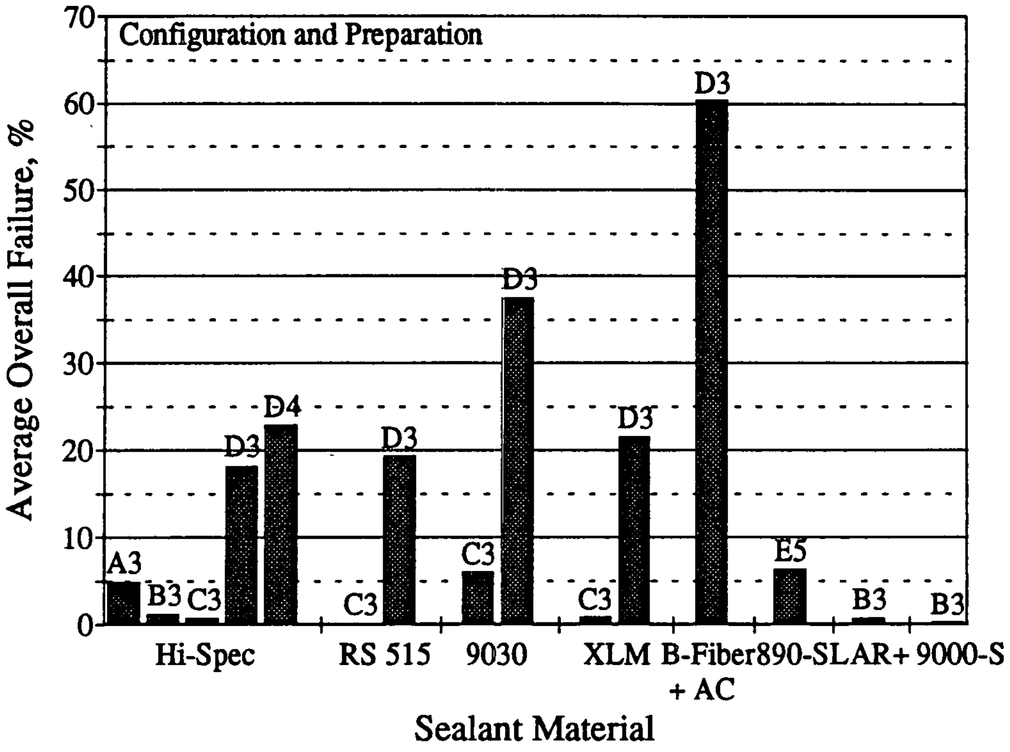


Figure D-20. Average overall failure at Wichita ideal subsite

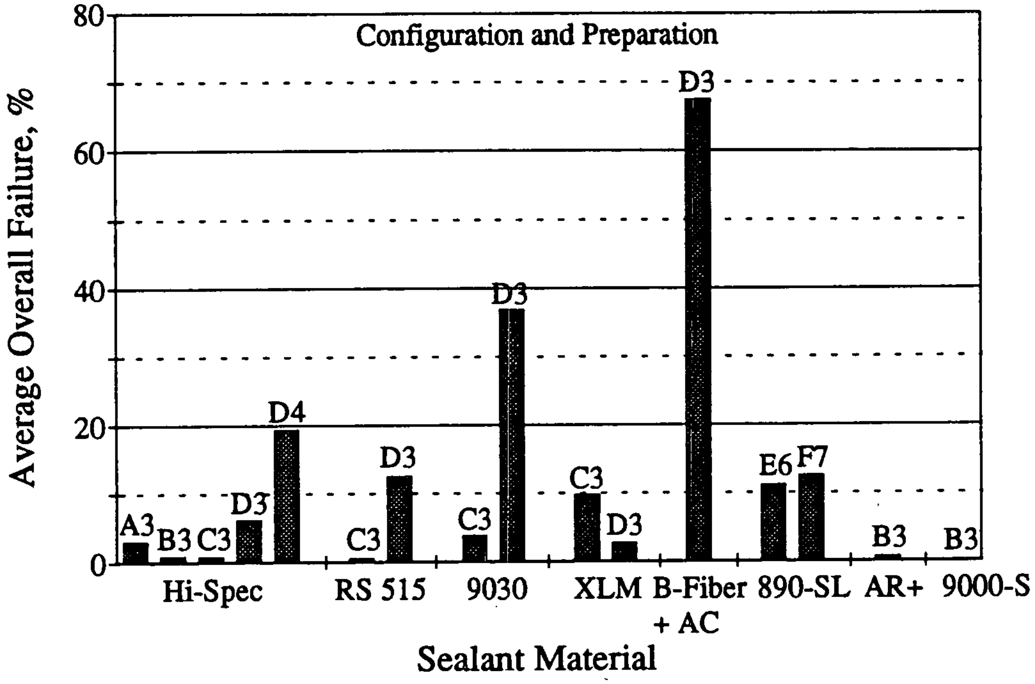


Figure D-21. Average overall failure at Wichita adverse subsite

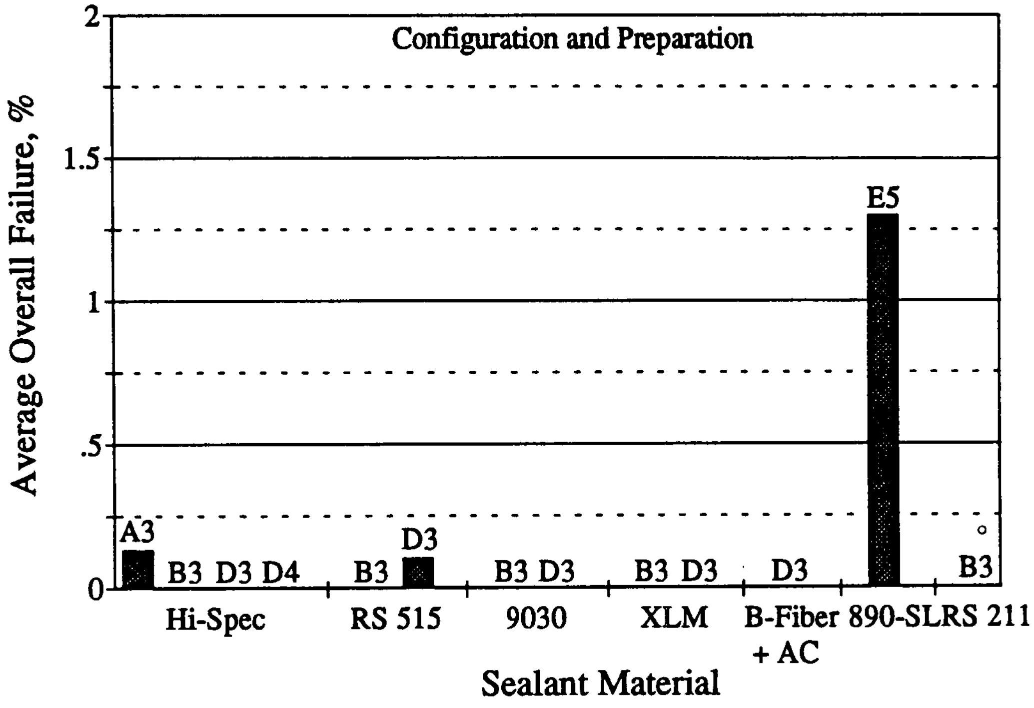


Figure D-22. Average overall failure at Elma

Appendix E

Cost-Effectiveness

The following is an illustration of the method for computing material cost-effectiveness using complete cost, performance, and productivity information and the equations presented in chapter 5. In the exercise, two treatment options are being considered by a maintenance agency for an AC transverse crack-sealing project. They are:

Option #1

Rubberized Asphalt, unit weight = 9.5 lb/gal (or 71.1 lb/ft^3)
Standard Recessed Band-Aid Configuration (Config B)
Material and Shipping Cost: $ 0.65/lb
Estimated Production Rate: 3,000 lin ft of crack per day
Estimated Service Life: 3 years

Option #2

Low-Modulus Rubberized Asphalt, unit weight = 8.9 lb/gal (or 66.6 lb/ft^3)
Shallow Recessed Band-Aid Configuration (Config C)
Material and Shipping Cost: $ 0.86/lb
Estimated Production Rate: 2,500 lin ft of crack per day
Estimated Service Life: 5 years

The following assumptions are made for both options:

- Same wastage factors (15 percent)
- 10 laborers, each @ $120/day
- 1 supervisor @ $200/day
- Equipment costs = $500/day
- User delay cost = $2,000/day

Application rates are computed on the following pages and the actual cost-effectiveness analysis is illustrated in figure E-1.

Option #1

Cross-sectional area of reservoir = (0.5 in x 0.5 in) + (4 in x 0.125 in)
= 0.75 in^2 (0.00521 ft^2)

Volume of reservoir (1 lin ft of crack) = 1 ft x 0.00521 ft^2
= 0.00521 ft^3

Gross Application Rate (no waste) = 71.1 lb/ft^3 x 0.00521 ft^3
= 0.37 lb/lin ft of crack

Net Application Rate (15% waste) = 1.15 x 0.37 lb/lin ft
= 0.43 lb/lin ft of crack

Option #2

Cross-sectional area of reservoir = (1.5 in x 0.188 in) +(4 in x 0.125 in)
= 0.782 in^2 (0.00543 ft^2)

Volume of reservoir (1 lin ft of crack) = 1 ft x 0.00543 ft^2
= 0.00543 ft^3

Gross Application Rate (no waste) = 66.6 lb/ft^3 x 0.00543 ft^3
= 0.36 lb/lin ft of crack

Net Application Rate (15% waste) = 1.15 x 0.36 lb/lin ft
= 0.41 lb/lin of crack

Placement Cost (both options)

Labor cost = (10 lab x \$120/lab) + (1 sup x \$200/sup)
= \$1,400/day

Equipment cost = \$500/day

Placement cost = \$1,400/day + \$500/day
= \$1,900/day

Based on the calculations in figure E-1, option #2, with an average annual cost of \$0.44/lin ft, is more cost-effective than option #1, with an average annual cost of \$0.58/lin ft.

	Option #1	Option #2
A. Cost of purchasing and shipping material	$ 0.65/lb	$ 0.86/lb
B. Net application rate	0.43 lb/lin ft	0.41 lb/lin ft
C. Placement cost (labor & equipment)	$ 2,250/day	$ 1,900/day
D. Production rate	3,000 lin ft/day	2,500 lin ft/day
E. User delay cost	$ 2,000/day	$ 2,000/day
F. Total installation cost F = (A x B) + (C/D) + (E/D)	(0.65 x 0.43) + (1900/3000) + (2000/3000) = $ 1.58/lin ft	(0.86 x 0.41) + (1900/2500) + (2000/2500) = $ 1.91/lin ft
G. Interest rate	5.0 percent	5.0 percent
H. Estimated service life (time to 50 percent failure)	3 years	5 years
I. Average annual cost $I = \frac{F \text{ x } \{[G \text{ x } (1 + G)^H]}{(1 + G)^H - 1}$	$\frac{1.58 \text{ x } [0.05 \text{ x } (1 + 0.05)^3]}{[(1 + 0.05)^3 - 1]} = \$\ 0.58\text{/lin ft}$	$\frac{1.91 \text{ x } [0.05 \text{ x } (1 + 0.05)^5]}{[(1 + 0.05)^5 - 1]} = \$\ 0.44\text{/lin ft}$

Figure E-1. Sample cost-effectiveness analysis

References

1. Evans, L.D., et al, "SHRP H-106—Experimental Design and Research Plan," Strategic Highway Research Program, Contract SHRP-89-H-106, February 1991, revised October 1991.

2. Evans, L.D., et al, "SHRP H-106—Evaluation and Analysis Plan," Strategic Highway Research Program, Contract SHRP-89-H-106, February 1991, revised September 1991 and February 1992.

3. Belangie, M.C. and D. I. Anderson, "Crack Sealing Methods and Materials for Flexible Pavements—Final Report," Utah Department of Transportation, Report No. FHWA/UT-85/1, May 1985.

Highway Operations Advisory Committee

Dean M. Testa, *chairman*
Kansas Department of Transportation

Clayton L. Sullivan, *vice-chairman*
Idaho Transportation Department

Ross B. Dindio
The Commonwealth of Massachusetts Highway Department

Richard L. Hanneman
The Salt Institute

Rita Knorr
American Public Works Association

David A. Kuemmel
Marquette University

Magdalena M. Majesky
Ministry of Transportation of Ontario

Michael J. Markow
Cambridge Systematics, Inc.

Gerald M. (Jiggs) Miner
Consultant

Richard J. Nelson
Nevada Department of Transportation

Rodney A. Pletan
Minnesota Department of Transportation

Michel P. Ray
The World Bank

Michael M. Ryan
Pennsylvania Department of Transportation

Bo H. Simonsson
Swedish Road and Traffic Research Institute

Leland Smithson
Iowa Department of Transportation

Arlen T. Swenson
John Deere

Anwar E.Z. Wissa
Ardaman and Associates, Inc.

John P. Zaniewski
Arizona State University

Liaisons

Ted Ferragut
Federal Highway Administration

Joseph J. Lasek
Federal Highway Administration

Frank N. Lisle
Transportation Research Board

Byron N. Lord
Federal Highway Administration

Mohamed Y. Shahin
U.S. Army Corps of Engineers

Harry Siedentopf
Federal Aviation Administration

Jesse Story
Federal Highway Administration

Expert Task Group

E.B. Delano
Consultant

Peter A. Kopac
Federal Highway Administration

Frank N. Lisle
Transportation Research Board

Barry D. Martin
Saskatchewan Highways and Transportation

Richard Nicholson
QUIKRETE Technical Center

Leland Smithson
Iowa Department of Transportation

Arlen T. Swenson
John Deere

A. Haleem Tahir
American Association of State Highway and Transportation Officials