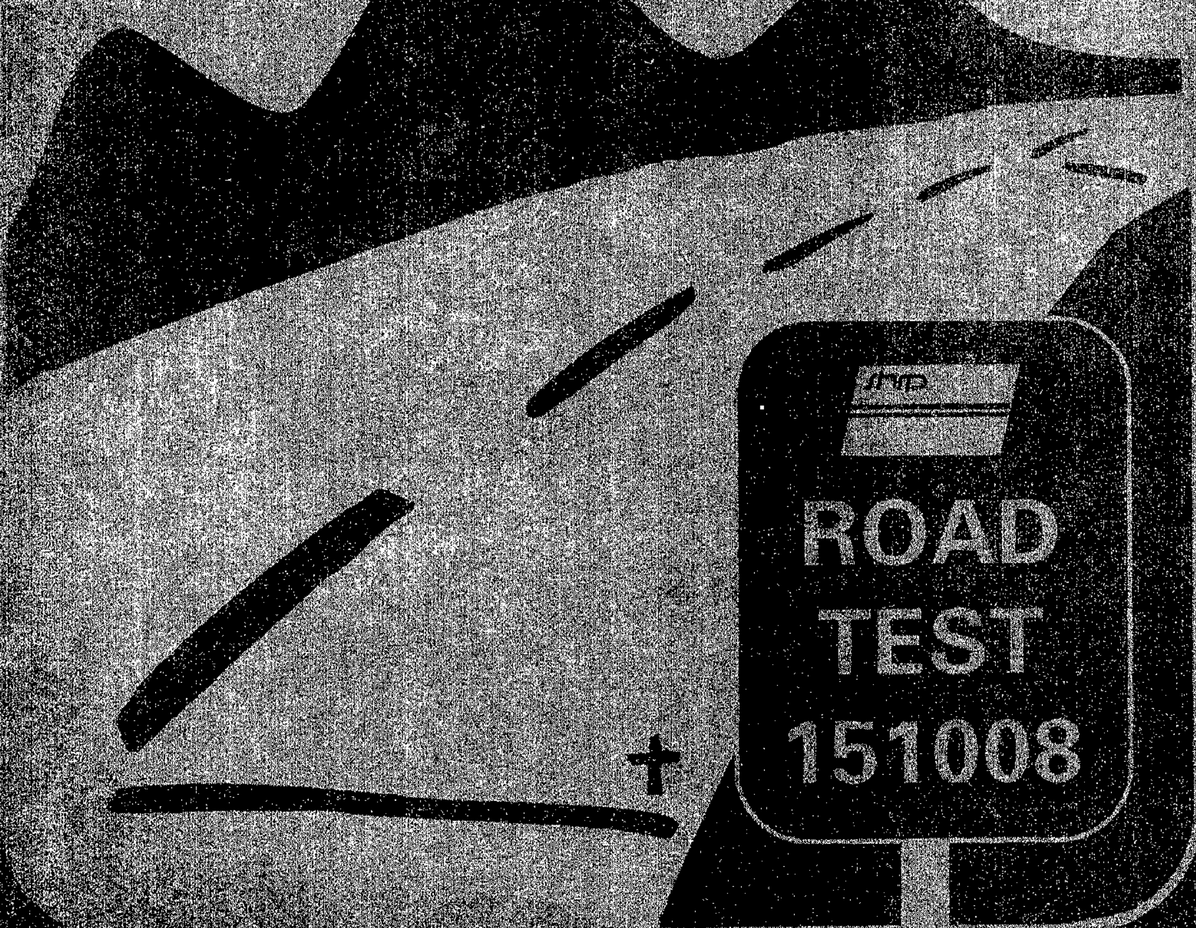
LTPP Pavement Maintenance Materials: SHRP Joint Reseal Experiment, Final Report

PB2000-102370

PUBLICATION NO. FHWA-RD-99-142

SEPTEMBER 1999



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Federal Highway Administration

Research, Development, and Technology
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LTPP

FOREWORD

Joint sealing and resealing on portland cement concrete pavements is a commonly performed highway maintenance operation. The Strategic Highway Research Program's (SHRP) H-106 joint reseal study was part of the most extensive pavement maintenance experiment ever conducted. The information derived from this study will contribute greatly toward advancing the state of the practice of joint sealing and resealing on portland cement concrete pavements.

This report provides information to pavement engineers and maintenance personnel on the results of the H-106 joint reseal experiment. It presents the performance and cost-effectiveness of various joint sealant materials and procedures for sealing joints on portland cement concrete pavements.

This report will be of interest to anyone concerned with the maintenance and rehabilitation of portland cement concrete pavements.

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Research and Development

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Technical Report Documentation Page

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
FHWA-RD-99-142		

4. Title and Subtitle	5. Report Date
LTPP PAVEMENT MAINTENANCE MATERIALS: SHRP Joint Reseal Experiment, Final Report	September 1999
	6. Performing Organization Code
7. Author(s)	8. Performing Organization Report No.
L.D. Evans, M.A. Pozsgay, K.L. Smith, and A.R. Romine	
9. Performing Organization Name and Address	10. Work Unit No. (TRAIS)
ERES Consultants A Division of Applied Research Associates, Inc. 505 W. University Avenue Champaign, IL 61820-3915	11. Contract or Grant No. DTFH61-93-C-00051
12. Sponsoring Agency Name and Address	13. Type of Report and Period Covered
Office of Infrastructure R&D Federal Highway Administration 6300 Georgetown Pike McLean, Virginia 22101-2296	Final Report October 1993 - June 1999
	14. Sponsoring Agency Code

15. Supplementary Notes

FHWA Contracting Officer's Technical Representative (COTR): Shahed Rowshan, HRDI

Project Consultants: Charlie Smyth

16. Abstract

The Strategic Highway Research Program (SHRP) H-106 maintenance experiment and the Federal Highway Administration (FHWA) Long-Term Monitoring (LTM) of Pavement Maintenance Materials Test Sites project studied the resealing of joints in concrete pavements. The purpose of joint resealing is to reduce the amount of water entering a pavement structure and to prevent the filling of joints with incompressible materials.

Although joint resealing is a common maintenance practice, premature seal failure is frequent, leading to additional repair and expenditures. The purpose of this study, then, was to address the merits and deficiencies of current joint resealing materials, designs, and practices. The study evaluated the relative performance of selected sealant materials, as well as the effect of selected sealant installation methods. The study also identified sealant material properties and tests that correlate well with field performance. The effect of joint seal performance on pavement life was not addressed in this study.

This report documents the entire PCC joint resealing study, including the installation of 31 unique joint seal treatments (i.e., combinations of sealant material and installation method) at 5 different test sites, the laboratory testing of experimental sealant materials, and the 7-year performance monitoring of the various joint seal treatments. It also discusses the results of comprehensive statistical analyses conducted on material performance and laboratory testing data. The results of a detailed cost-effectiveness analysis are also presented.

17. Key Words	18. Distribution Statement
Concrete pavement, pavement maintenance, joints, joint resealing, joint sealant, performance, service life, cost-effectiveness	No restrictions. This document is available to the public through the National Technical Information Service, Springfield, Virginia 22161.

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No of Pages	22. Price
Unclassified	Unclassified	164	

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APPROXIMATE CONVERSIONS TO SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
in	inches	25.4	millimeters	mm
ft	feet	0.305	meters	m
yd	yards	0.914	meters	m
mi	miles	1.61	kilometers	km
		AREA		
in^2	square inches	645.2	square millimeters	mm^2
ft^2	square feet	0.093	square meters	m^2
yd^2	square yards	0.836	square meters	m^2
ac	acres	0.405	hectares	ha
mi^2	square miles	2.59	square kilometers	km^2
		VOLUME		
fl oz	fluid ounces	29.57	milliliters	mL
gal	gallons	3.785	liters	L
ft^3	cubic feet	0.028	cubic meters	m^3
yd^3	cubic yards	0.765	cubic meters	m^3

NOTE: Volumes greater than 1000 l shall be shown in m^3.

Symbol	When You Know	Multiply By	To Find	Symbol
		MASS		
oz	ounces	28.35	grams	g
lb	pounds	0.454	kilograms	kg
T	short tons (2000 lb)	0.907	megagrams (or "metric ton")	Mg (or "t")
		TEMPERATURE (exact)		
°F	Fahrenheit temperature	5(F-32)/9 or (F-32)/1.8	Celcius temperature	°C
		ILLUMINATION		
fc	foot-candles	10.76	lux	lx
fl	foot-Lamberts	3.426	candela/m^2	cd/m^2
		FORCE and PRESSURE or STRESS		
lbf	poundforce	4.45	newtons	N
lbf/in^2	poundforce per square inch	6.89	kilopascals	kPa

APPROXIMATE CONVERSIONS FROM SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
mm	millimeters	0.039	inches	in
m	meters	3.28	feet	ft
m	meters	1.09	yards	yd
km	kilometers	0.621	miles	mi
		AREA		
mm^2	square millimeters	0.0016	square inches	in^2
m^2	square meters	10.764	square feet	ft^2
m^2	square meters	1.195	square yards	yd^2
ha	hectares	2.47	acres	ac
km^2	square kilometers	0.386	square miles	mi^2
		VOLUME		
mL	milliliters	0.034	fluid ounces	fl oz
L	liters	0.264	gallons	gal
m^3	cubic meters	35.71	cubic feet	ft^3
m^3	cubic meters	1.307	cubic yards	yd^3
		MASS		
g	grams	0.035	ounces	oz
kg	kilograms	2.202	pounds	lb
Mg (or "t")	megagrams (or "metric ton")	1.103	short tons (2000 lb)	T
		TEMPERATURE (exact)		
°C	Celcius temperature	1.8C + 32	Fahrenheit temperature	°F
		ILLUMINATION		
lx	lux	0.0929	foot-candles	fc
cd/m^2	candela/m^2	0.2919	foot-Lamberts	fl
		FORCE and PRESSURE or STRESS		
N	newtons	0.225	poundforce	lbf
kPa	kilopascals	0.145	poundforce per square inch	lbf/in^2

* SI is the symbol for the International System of Units. Appropriate rounding should be made to comply with Section 4 of ASTM E380.

(Revised September 1993)

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CHAPTER 1. INTRODUCTION

Objectives

The resealing of joints in concrete pavements is a common maintenance activity performed by many State and local highway agencies. The purpose of joint resealing is to reduce the amount of water entering a pavement structure and to prevent the filling of joints with incompressible materials. Water entering a pavement structure through joints can lead to pumping, faulting, base and subbase erosion, and loss of support. Incompressible materials filling pavement joints can result in joint spalling, blowups, buckling, or shattered slabs. Although joint resealing is a common maintenance practice, premature seal failure is frequently experienced, leading to additional repair and expenditure.

To address the merits and deficiencies of current joint resealing materials, designs, and practices, the Strategic Highway Research Program (SHRP) and the Federal Highway Administration (FHWA) consecutively sponsored one of the most extensive joint seal investigations ever undertaken. In the spring and summer of 1991, five joint resealing test sites were installed throughout the United States (U.S.) under the SHRP H-106 project (Innovative Materials Development and Testing) using various materials and installation methods under a range of climatic conditions. Periodic, intensive performance evaluations were conducted until the completion of that project in March 1993. Believing that additional information could be obtained from these test sites, the FHWA authorized a follow-up project (Long-Term Monitoring [LTM] of Pavement Maintenance Materials Test Sites) in September 1993, which provided for continued annual test site evaluation through 1997.

In this study, the goal of improving the performance of joint resealing materials and methods was approached from three directions, each having a specific objective. A primary objective of the study was to evaluate the relative performance of selected sealant materials in joint resealing projects based on carefully designed and controlled field installations. A second objective was to determine the effect of selected sealant configurations, or installation methods, on sealant performance, based on the results of the field installations. A last major objective was to identify sealant material properties and tests that correlate well with field performance. The effect of joint seal performance on pavement life was not addressed in this study.

Direct results expected from the study included the length of time that each sealant material effectively functions under conditions representative of each climatic region in the United States and Canada. Also, the sealant installation methods that allow sealant materials to perform adequately for the longest period of time were to be identified. Finally, a better understanding of specific material properties and tests that correlate well with field performance was expected. Production and cost information collected during installation of the test sites, along with field service life data, was intended to allow comparison of each material and installation procedure based on cost-effectiveness.

In the spring of 1991, joint resealing test sites were installed in five U.S. States in four climatic regions under the SHRP H-106 project. The intent was to compare the performance of different sealant materials and various installation methods. The materials and methods used in this project were those identified under the SHRP H-105 project (Smith et al., 1991). Regular evaluation of the performance of the sealants used at these test sites continued under the SHRP H-106 and FHWA LTM project through the fall of 1997.

Scope

This report describes the several phases of the joint resealing study, beginning with a discussion in chapter 1 of the materials and methods used, as well as descriptions of the selected test sites. Details of the installation of materials at each test site are described in chapter 2, including pre-installation measurements, joint preparation and sealant placement procedures, production rates, and other observations. Included in chapter 3 are descriptions of the laboratory tests performed on the sealant materials and discussions of the results of these tests. Summaries of the field performance data collected in the 82 months after test site installation are shown in chapter 4, noting the types of sealant system distress observed and the amount of overall failure for each material to date. Chapter 5 summarizes the analysis of field and laboratory performance, including a discussion of the methodology used for statistical analysis. Lastly, the observations and recommendations from the study to date are presented in chapter 6.

Project Overview

Between April and June 1991, a total of 1,600 joints were resealed at 5 test sites using 12 sealant materials and 4 methods of installation. As seen below and in figure 1, the sites were located on moderate to high-volume, four-lane highway or interstate pavements in four climatic regions. Two sites were constructed in the wet-freeze region to compare the effect of short- and long-jointed pavements on sealant performance.

- Interstate 17—Phoenix, Arizona — Dry-nonfreeze region
- Interstate 77—Columbia, South Carolina — Wet-nonfreeze region
- Interstate 25—Ft. Collins, Colorado — Dry-freeze region
- Interstate 80—Grinnell, Iowa — Wet-freeze region (short-jointed portland cement concrete [PCC])
- U.S. 127—Frankfort, Kentucky — Wet-freeze region (long-jointed PCC)

Sealant Materials

Six of the sealant materials recommended in the SHRP H-105 report for use in the full-scale testing were rubberized asphalt containing various blends of polymers, rubbers, and asphalt cements. The remaining three materials were silicone sealant: one non-self-leveling and two self-leveling. The following seven sealant products were installed at four of the five test sites:

- Crafco RoadSaver® (RS) 231 — Low-modulus rubberized asphalt sealant
- Koch 9005 — Rubberized asphalt sealant
- Koch 9030 — Low-modulus rubberized asphalt sealant

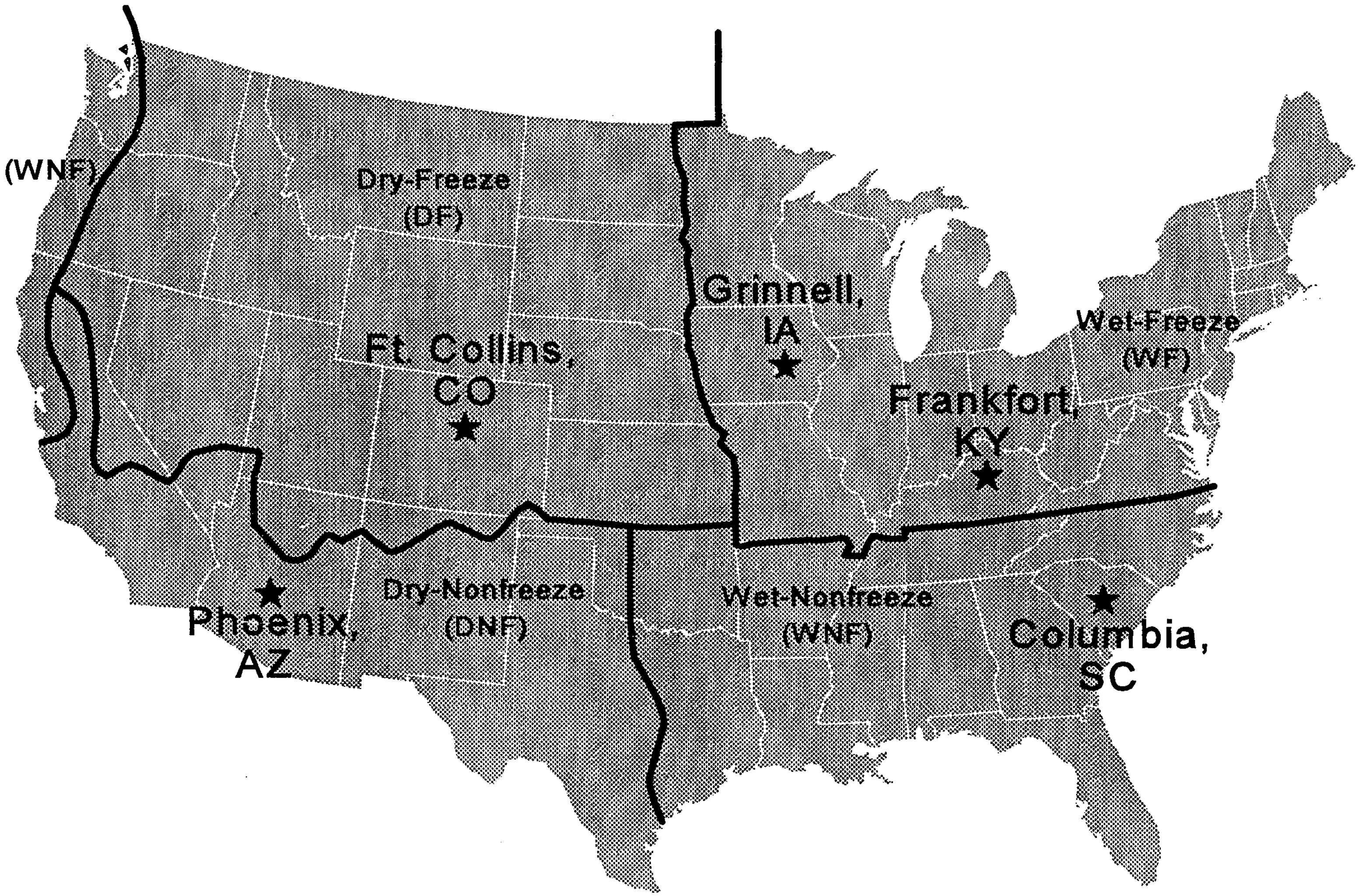


Figure 1. Locations of joint resealing test sites and climatic regions.

• Meadows Sof-Seal®	Low-modulus rubberized sealant
• Dow Corning® 888	Non-self-leveling silicone sealant
• Dow Corning® 888-SL	Self-leveling silicone sealant
• Mobay Baysilone 960-SL	Self-leveling silicone sealant

Two rubberized asphalt sealants were installed at the Arizona site only, replacing Sof-Seal and Koch 9030. These sealants were as follows:

• Crafco RS 221	Rubberized asphalt sealant
• Meadows Hi-Spec®	Rubberized asphalt sealant

Several participating States requested that additional sealants be installed and evaluated at their test sites. The following three additional sealants were installed at individual test site locations:

• Crafco RS 903-SL	Self-leveling silicone sealant
• Mobay Baysilone 960	Self-leveling silicone sealant
• Koch 9050	Self-leveling, one-part polysulfide sealant

Crafco RS 903-SL was placed at the Arizona site, Mobay Baysilone 960 was placed at the Grinnell site, and Koch 9050 was placed at the Colorado and Kentucky sites.

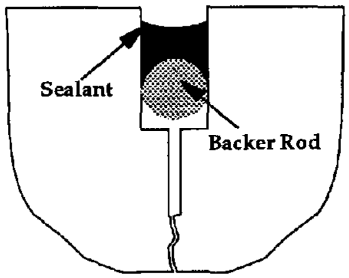
At the Iowa site, 10 joints of Dow Corning 888 silicone and 10 joints of Dow Corning 888-SL silicone were installed using a primer provided by Dow Corning Corporation. This resulted from reported trouble with silicone sealants adhering to the joint faces at other sites and some early adhesion failures. A primer was also used with Koch 9005 in 10 joints at the Kentucky site to evaluate the effect of primer on hot-applied sealant performance.

Preparation Methods

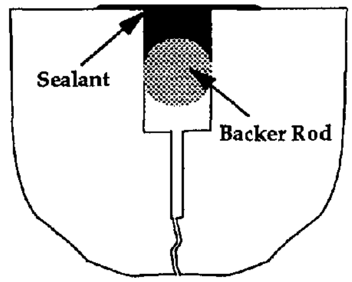
Four joint preparation and sealant installation methods were used to place the sealants at the sites. Each of these methods is designated as a configuration and is shown in figure 2. Configuration 1 indicates that the joint faces were resawed to 12.7 mm wide, the walls were sandblasted and airblasted, backer rod was installed, and sealant was installed in the recommended thickness about 6.4 mm below the pavement surface.

Joints sealed using configuration 2 were also resawed, sandblasted, airblasted, and backer rod was installed. In addition, the pavement surface was sandblasted and airblasted about 25.4 mm on either side of the joint and the sealant was installed about 12.7 mm thick with a 2-mm by 34-mm overband extending onto the pavement surface about 11 mm on either side of the joint edge.

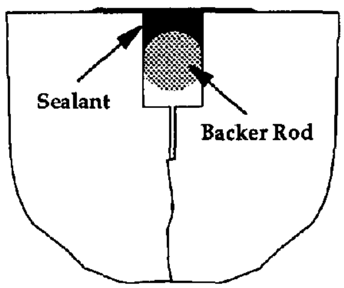
Resawing was not used for joints prepared using configuration 3. Instead, a joint plow attached to a tractor was scraped against both sides of the joint to remove most of the original sealant. The plowed joints were then airblasted to remove loose debris, backer rod was installed, and the sealant was installed using an overband, as with configuration 2.



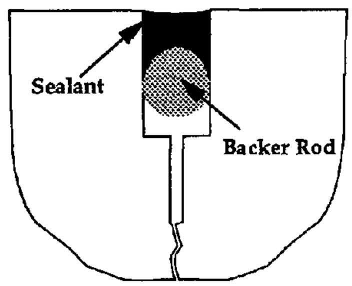
Method 1 Configuration
Saw and Recessed



Method 2 Configuration
Saw and Overband



Method 3 Configuration
Plow and Overband



Method 4 Configuration
Saw and Flush-fill

Figure 2. Joint seal configurations.

Configuration 4, used at two sites, required resawing, sandblasting, airblasting, and installing backer rod. Then the sealant was installed about 12.7 mm thick, with the sealant surface flush with the pavement surface. All four configurations were used for the hot-applied sealants; only configuration 1 was used for the silicones and polysulfide.

Two sets of 10 joints were installed at random locations along the test site for each material-configuration combination used at the 5 sites. A summary of the materials and procedures used at the test sites is shown in table 1. The layout of the material–configuration combinations for each test site is shown in tables A-1 and A-2 in appendix A.

Test Site Characteristics

Several criteria were used in selecting test sites for use in the joint seal repair experiment. Five sites were chosen from the 28 sites that were preliminarily inspected. Additional information about the characteristics and locations of these selected test sites is listed in table 2 and in the following sections.

Table 1. Summary of materials and procedures used for joint seal installation.

Sealant Material	Config.	Procedures	AZ	SC	CO	IA	KY
Crafco RS 221 (1)*	1	Saw, sandblast, recessed sealant	✓				
	2	Saw, sandblast, overband sealant	✓				
	3	Plow, airblast, overband sealant					
	4	Saw, sandblast, flush sealant	✓				
Crafco RS 231 (2)	1	Saw, sandblast, recessed sealant	✓	✓	✓	✓	✓
	2	Saw, sandblast, overband sealant	✓	✓	✓	✓	✓
	3	Plow, airblast, overband sealant		✓		✓	✓
	4	Saw, sandblast, flush sealant	✓		✓		
Koch 9005 (3)	1	Saw, sandblast, recessed sealant	✓	✓	✓	✓	✓
	2	Saw, sandblast, overband sealant	✓	✓	✓	✓	✓
	3	Plow, airblast, overband sealant		✓		✓	✓
	4	Saw, sandblast, flush sealant	✓		✓		
Koch 9030 (4)	1	Saw, sandblast, recessed sealant		✓	✓	✓	✓
	2	Saw, sandblast, overband sealant		✓	✓	✓	✓
	3	Plow, airblast, overband sealant		✓		✓	✓
	4	Saw, sandblast, flush sealant			✓		
Meadows Hi-Spec (5)*	1	Saw, sandblast, recessed sealant	✓				
	2	Saw, sandblast, overband sealant	✓				
	3	Plow, airblast, overband sealant					
	4	Saw, sandblast, flush sealant	✓				
Meadows Sof-Seal (6)	1	Saw, sandblast, recessed sealant		✓	✓	✓	✓
	2	Saw, sandblast, overband sealant		✓	✓	✓	✓
	3	Plow, airblast, overband sealant		✓		✓	✓
	4	Saw, sandblast, flush sealant			✓		
Dow 888 (7)	1	Saw, sandblast, recessed sealant	✓	✓	✓	✓	✓
Dow 888-SL (8)	1	Saw, sandblast, recessed sealant	✓	✓	✓	✓	✓
Mobay 960-SL (9)	1	Saw, sandblast, recessed sealant	✓	✓	✓	✓	✓
Mobay 960 (A)	1	Saw, sandblast, recessed sealant				✓	
Crafco 903-SL (B)	1	Saw, sandblast, recessed sealant	✓				
Koch 9050 (C)	1	Saw, sandblast, recessed sealant			✓		✓
Dow 888 w/ Primer (D)	1	Saw, sandblast, primer, recessed sealant				✓	
Dow 888-SL w/ Primer (E)	1	Saw, sandblast, primer, recessed sealant				✓	
Koch 9005 w/ Primer (F)	1	Saw, sandblast, primer, recessed sealant					✓

* SHRP material code.

Table 2. Test site characteristics for the joint seal repair project.

Test Site	Route	Number of Lanes, 2 dir	2-direction ADT, vpd	Annual Precip., mm [a]	Annual Days < 0°C [a]
Phoenix, AZ	I-17	6	100,000	178	17
Ft. Collins, CO	I-25	4	27,000	381	158
Grinnell, IA	I-80	4	19,000	787	135
Frankfort, KY	U.S. 127	4	14,000	1,118	94
Columbia, SC	I-77	4	19,400	1,245	31

[a] Historical averages from the *Climatic Atlas of the United States* (U.S. Department of Commerce, 1983).

I-17, Phoenix, Arizona

In the dry-nonfreeze region, the SHRP joint resealing test site was located in the northbound and southbound passing lanes of I-17 in Phoenix between the Buckeye Road and VanBuren Road exits (milepost [MP] 198.8 to MP 199.8). Its location is shown in figure 3.

In 1993, this pavement carried more than 100,000 vehicles per day (vpd) in both directions; however, the amount of truck traffic in the passing lanes was believed to be very small. It was constructed in 1963 using a 229-mm portland cement concrete (PCC) over a granular base and subbase. Most contraction joints were perpendicular to the roadway and spaced about 4.6 m apart.

The sealant previously used in the joints of the northbound pavement was asphalt based, and the sealant in the joints of the southbound lane was coal-tar based. Immediately prior to seal installation in the spring of 1991, the pavement was ground longitudinally to restore a level profile. Many joints in the northbound lane contained steel crack inducers that were sawed out before installation of the test materials. Air temperatures at this site since installation reportedly dropped to a minimum of 1°C on January 8, 1997.

I-25, Ft. Collins, Colorado

A second test site, constructed in a dry-freeze climate, was located in the outside northbound lane of I-25 just south of Ft. Collins, Colorado (MP 260.4 to MP 261.3). Its location is shown in figure 4. Reconstructed in 1988, this pavement consisted of a 203-mm jointed plain concrete (JPC) pavement with a 203-mm jointed plain concrete overlay. Skewed contraction joints were sawed in the overlay with spacings between 3.7 and 4.6 m, and the joints were sealed with a coal-tar-based sealant that had severely deteriorated by 1991. The pavement surface was tined about 3.18 mm deep on 13-mm centers, and the tining continued through all joints.

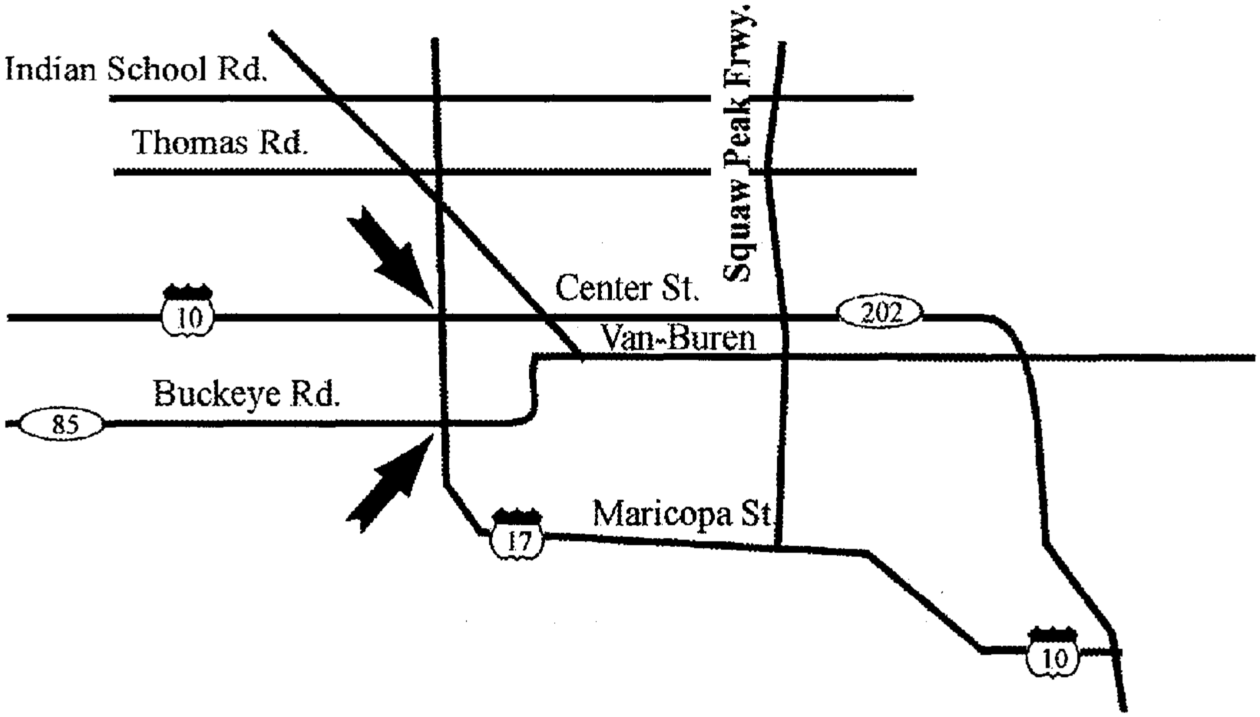


Figure 3. Phoenix, Arizona joint reseal test site.

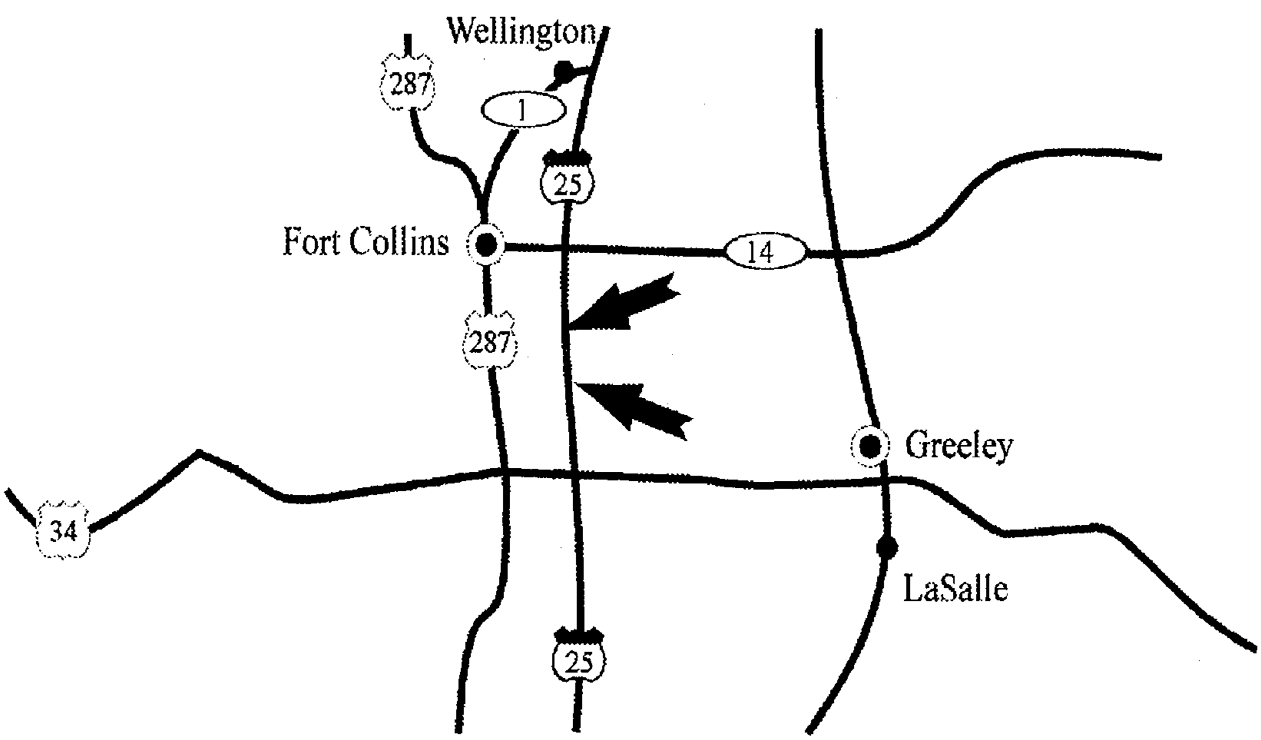


Figure 4. Fort Collins, Colorado joint reseal test site.

Two-way traffic on the roadway was more than 27,000 vpd (1993). Both the traffic lane and the tied PCC shoulder were in excellent condition. Since sealant installation, the pavement experienced many freeze-thaw cycles and a minimum temperature of -28°C on February 3, 1996.

I-80, Grinnell, Iowa

The joint seal test site constructed in a wet-freeze region on short-jointed pavement was located in the outside eastbound lane of I-80 near Grinnell, Iowa (MP 188.0 to MP 189.3). Figure 5 shows its location. The pavement containing this site was reconstructed in 1985 using a 254-mm, doweled PCC surface over a granular subbase of variable thickness. The surface was tined with grooves 3.2 mm to 4.8 mm deep on 13-mm centers, and skewed joints were sawed with 6.1-m spacings. The outside slab width was 4 m, with the shoulder line painted 0.3 m from the outside slab edge.

Carrying more than 19,000 vpd in 1993, with a high percentage of trucks, the pavement remains in excellent condition. The original seal was a non-self-leveling silicone that had failed in adhesion at some locations. After joint seal installation, the minimum air temperature experienced by this pavement was -32°C on February 3, 1996.

U.S. 127, Frankfort, Kentucky

The second test section located in the wet-freeze region was installed in a long-jointed concrete pavement section on U.S. 127 in Frankfort, Kentucky (MP 9.9 to MP 10.6). Figure 6 shows the location of the Kentucky test site. The pavement was originally constructed in 1974 using a reinforced 228-mm PCC surface over a 127-mm granular base. Joints perpendicular to the roadway were sawed on 15.2-m centers, typically. The pavement was in generally good condition, with some large spalls evident and a few spall patches in place. Joint seal had been missing from the joints for a long time, as evidenced by many joints being filled with dirt and sand. In 1993, traffic on the roadway was about 14,000 vpd, with only a small amount of truck traffic.

This roadway was the best of the long-jointed pavements available, but it was the least ideal of the test sites due to slight variations in traffic level, deteriorated pavement conditions, and changes in pavement grade and superelevation. At installation, about 50 percent of the slabs included in the test section contained mid-slab cracks that were nonworking. The remaining slabs were uncracked. The site contained a slight grade, one curve that was less than 3 degrees, and five side roads that contributed only small amounts of traffic to the roadway. The experimental sections were constructed in the outside northbound lane and the outside and inside southbound lanes, resulting in the majority of morning traffic using the southbound lanes and the evening traffic using the northbound lanes. The net traffic on each lane was believed to be about the same. A gravel pit was located at the south end of the test site, providing truck traffic in both directions. Since joint seal installation, several joints deteriorated, requiring asphalt concrete (AC) and PCC maintenance patching. The minimum air temperature since seal installation was -23°C on February 4, 1996.

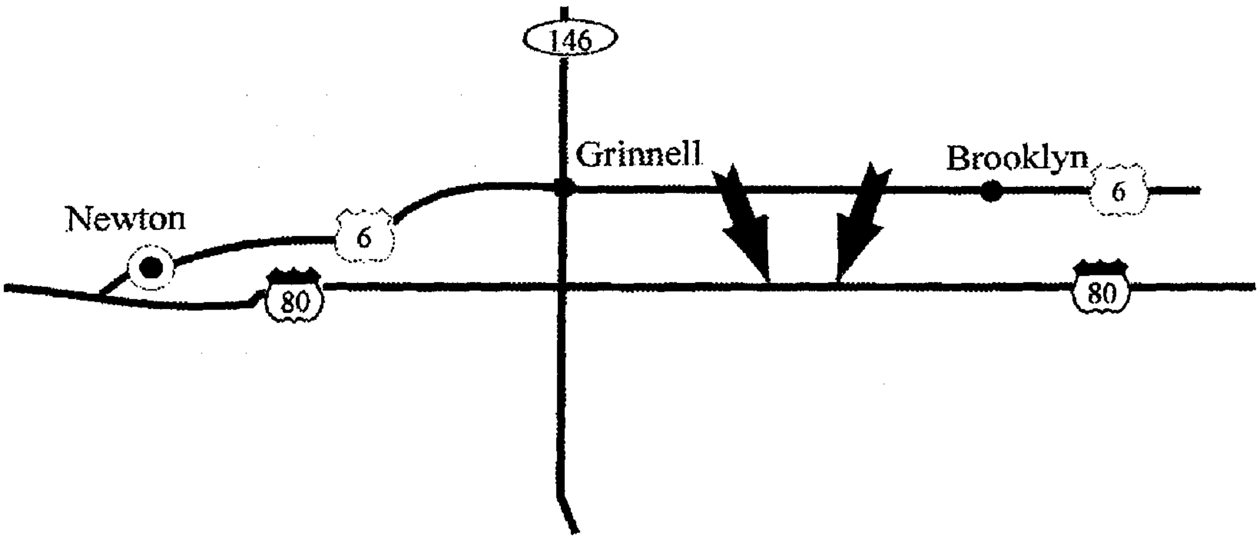


Figure 5. Grinnell, Iowa joint reseal test site.

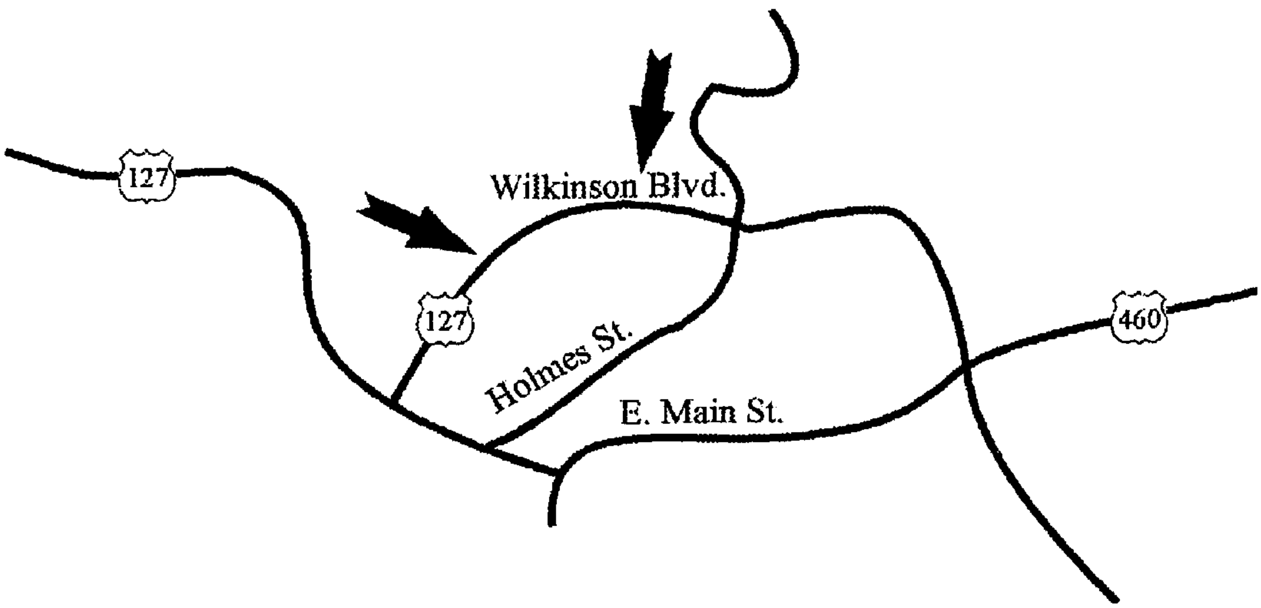


Figure 6. Frankfort, Kentucky joint reseal test site.

I-77, Columbia, South Carolina

In the wet-nonfreeze climatic region, the joint reseal site was located in the outside northbound lane of I-77, north of Columbia, South Carolina (MP 38.0 to MP 39.9). Its location is marked on figure 7. Originally built in 1981, the pavement was constructed using 254 mm of JPC over a 152-mm lean concrete base and a 152-mm cement-treated stone subbase. Joints were sawed perpendicular to the roadway on a staggered spacing of 5.8 to 7.6 m. The original sealant, a non-sag silicone sealant, was still in the joint and performing very well. The pavement remains in excellent condition and carries more than 19,400 vpd (1993) in both directions, with a high percentage of trucks. Spalls 25 to 76 mm wide were present on more than one-third of the joints about 0.6 m from the outside lane edge. These spalls appeared to have resulted from a wheel rim or other sharp, heavy object dragging along the pavement. The minimum air temperature experienced by the pavement since test site installation was -11°C on January 16, 1994.

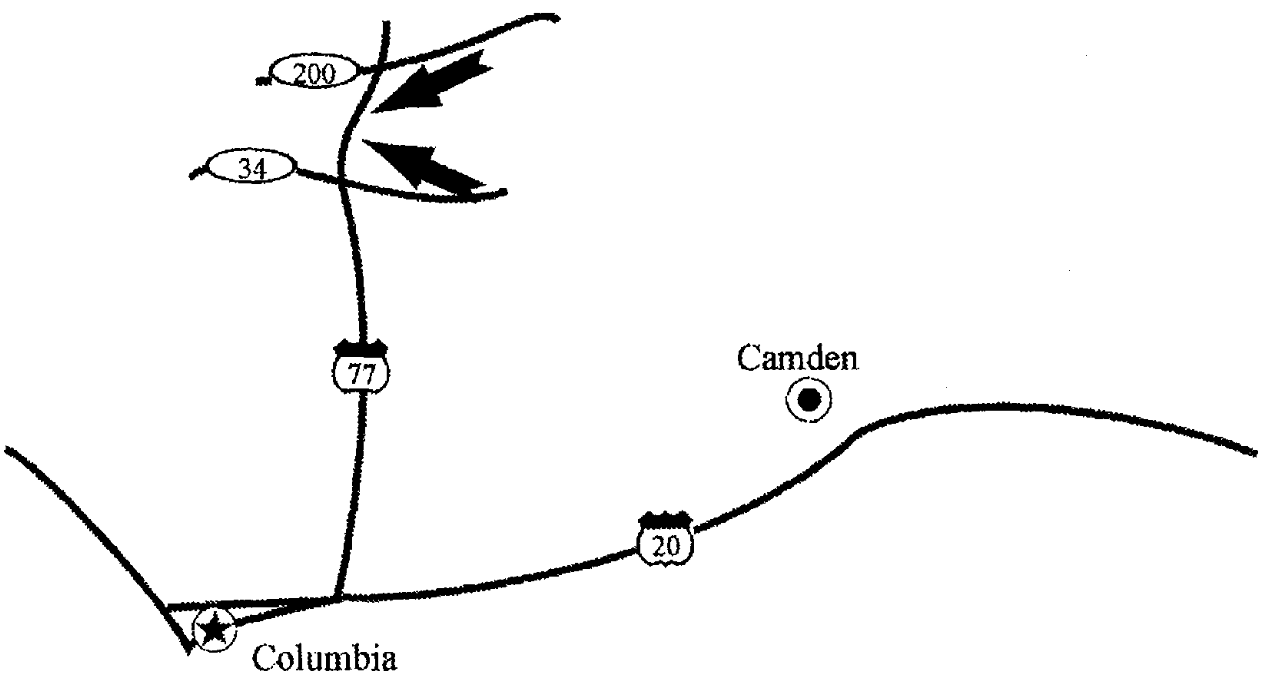


Figure 7. Columbia, South Carolina joint reseal test site.

CHAPTER 2. TEST SITE INSTALLATIONS

The installation of the five joint resealing test sites began in April 1991 and continued through June 1991. Installation of the test sites was regulated and monitored by the project team, together with representatives from the sealant manufacturers and a consultant with expertise in joint sealing. This chapter presents an overview of the installation planning process, along with material costs, productivity rates, equipment requirements, problems that were encountered during installation, and comments on the materials and procedures used.

Test Site Arrangements

To install the test sites, four preparatory steps were taken. First, the test site locations were selected based on the appropriateness of each potential site and the interest of corresponding State agencies to participate in the study. Secondly, the material requirements for each site were determined. Thirdly, the materials were purchased and shipped to the appropriate State maintenance yards. And, lastly, the labor and equipment resources of each participating State agency were ascertained. These steps are discussed in further detail below.

Test Site Selection

Using the criteria described in the SHRP H-106 *Experimental Design and Research Plan (EDRP)*, 5 pavement sections were chosen to serve as test sites from the 28 potential pavements identified through preliminary site visits (Evans et al., 1991). The selected sites were previously described in chapter 1.

Computation of Material Quantities

Estimates of the rubberized asphalt sealant quantities required for each test site were made assuming 60 joints per site, with each joint having dimensions of 13 by 13 mm. The appropriate quantity of each silicone sealant was based on 20 joints per site, with each joint having dimensions of 13 by 6 mm. Initially, a wastage factor of 25 percent was used in planning for material purchase; however, at the suggestion of the manufacturers of rubberized asphalt sealants, the wastage factor was increased to provide enough sealant for flushing the melter–applicator so that the melter–applicator could function properly. This additional sealant was also expected to reduce the possibility of overheating the sealant.

Manufacturers' literature provides an estimate of the coverage rate for each material in the recessed configuration. These rates are included in table 3. For a typical rubberized asphalt sealant, these figures indicated that about 45.4 kg of each rubberized asphalt sealant would be required to seal 60 recessed joints at each test site. However, the overband configuration, which was used on two-thirds of the joints, required additional sealant. Although the coverage rates in table 3 are much less than those experienced in the installation of these test sites, they are likely to

Table 3. Sealant material and coverage costs.

Sealant Material	Material Cost ($/kg)	Coverage (kg/100 m)	Coverage Cost ($/100 lin m)
Crafco RS 221	0.90	42.7	38.43
Crafco RS 231	1.23	39.4	48.46
Crafco RS-SL	6.15	23.3	143.30
Koch 9005	0.51	40.4	20.60
Koch 9030	0.77	37.1	28.57
Koch 9050	2.64	37.7	99.53
Meadows Hi-Spec	0.64	41.3	26.43
Meadows Sof-Seal	1.06	37.4	39.64
Dow 888	5.46[a]	38.7	211.30
Dow 888-SL	6.15[a]	25.3	155.60
Mobay 960	6.72[a]	31.5	211.68
Mobay 960-SL	7.40[a]	25.6	189.44
16-mm backer rod	$0.11/lin m		11.00

[a] Cost based on 208-L drums.

be closer to those encountered in large-scale joint resealing. The backer rod used at the test sites was approved by each sealant manufacturer, and the quantities ordered were slightly greater than those required.

Material Purchase and Shipping

Sealant materials were purchased from the manufacturers in amounts corresponding to the estimated requirements. Each material used at all five sites was from the same production batch. Costs of materials were set by the manufacturers at the January 1991 typical cost and are listed in table 3. Shipping costs for rubberized asphalt sealants ranged from $0.11 to $0.57/kg. All sealant materials were ordered in the first week of March 1991, and by the third week of March, all sealants had been shipped to the test site locations.

Assessment and Coordination of Resources

In late January and early February 1991, an individualized copy of the *EDRP* was sent to each State coordinator and to the foreman of the crew scheduled to install the test site. The purpose of the summary was to determine the availability of resources at each test site and to inform the participating State agency of the scope and requirements of the installation procedures. These summaries included lists of materials, detailed descriptions of the preparation and installation procedures to be followed, and maps showing the location of each section of the test site. They also contained a specific list of the equipment and manpower to be provided by the State and of the equipment and supervision provided by the SHRP H-106 contractor. A tentative construction schedule and construction guidelines were also included.

Labor

Based on discussions with consultants and State workers, the manpower requirements were estimated at nine persons. Four of the participating State agencies indicated the ability to acquire manpower from neighboring maintenance crews on days when additional workers were needed. During construction, the average number of laborers actually used for sawing and airblasting was five; for joint preparation and sealant installation the average was eight.

Equipment

As was specified in the *EDRP*, the minimum equipment requirements for construction of each test site included the following:

- Traffic control equipment (attenuator, signs, cones, placement truck).
- A 165-kBtu/h water-cooled concrete saw with tandem diamond-tipped blades 254 to 356 mm in diameter or greater.
- A water truck with a positive pump carrying at least 2,271 L of water.
- A joint plow equipped with a rectangular, not tapered, blade attached to a tractor or other powered vehicle that provides positive control of up-and-down and side-to-side motion.
- Sandblasting equipment, including an air compressor that provides clean, dry air at more than 621 kPa.
- An air compressor, hose, and wand with a shutoff valve that can supply clean, dry air at more than 621 kPa.
- Conventional double-boiler, oil-jacketed melter–applicator, with a capacity of at least 379 L, equipped with a mechanical agitator and separate temperature controls and thermometers for both the oil and melting vat.
- Air-powered, cartridge dispensing caulking guns with a continuous compressed air supply of at least 310 kPa.

The quality and availability of equipment at each test site varied significantly, yet the required equipment (apart from the joint plow) was procured in time for its required use.

Productivity Estimation

Prior to test site construction, it was estimated that about 20 h would be required to saw 240 joints, and during that time, the joint plowing (80 joints) could be completed. One week was allowed at most sites for layout, sawing, plowing, gauge plug installation, and joint dimension and fault measurement. This schedule allowed the wet-sawed joints to dry over the weekend.

Based on a projected average of less than 3 min per joint, it was estimated that hot-applied sealant could be placed in at least 160 joints per 8-h day. Plans were made to seal 120 joints daily using two hot-applied sealants. If this schedule were adhered to, installation of the rubberized asphalt sealant at each test site could be completed in 2 working days.

The sandblasting operation was assumed to be the slowest cleaning procedure, and the request was made that States provide two sandblasting units and crews. Only one State was able to comply. It was estimated that 140 joints could be cleaned per 8-h day using a sandblasting crew of two persons. This would allow for the installation of two rubberized asphalt sealants. As will be shown later, these estimates were close to the installation productivity rates actually experienced.

Outside Consultants and Manufacturers' Representatives

Because it was considered critical that sealants be placed correctly and in accordance with manufacturers' recommendations, representatives of each participating sealant manufacturer were requested to observe and participate in the installation of their materials. On the whole, interest among the manufacturers was high and all sent representatives to at least one site. Manufacturers who had representatives attend installation at each test site are listed in table 4. An expert in joint seal installation also attended the first installation in South Carolina. He offered advice on quality control, coordination of manpower and equipment, and evaluation of sealant performance.

Installation Process

The installation process required first that the joints be chosen and marked. Preparations were then made for pavement evaluation, and sealants were installed according to manufacturers' recommendations.

Layout

The design of the experiment called for construction of 20 joints of each appropriate material–configuration. Locations for each test section at every test site were randomly selected prior to installation. Maps of the test site were prepared to assist the installation crews in determining the appropriate preparation methods and materials to be installed. At the onset of installation, joints at the test site were inspected for possible use, selected, and marked for inclusion. The dates and number of working days required for layout and construction at each site are shown in table 5.

Table 4. Manufacturers' representatives present at test site installation.

Test Site	Crafco, Inc.	Dow Corning	Koch Materials	Mobay	W. R. Meadows
Arizona	YES		YES		YES
South Carolina	YES	YES	YES		
Colorado	YES		YES	YES	YES
Iowa	YES	YES	YES		
Kentucky	YES		YES		

Table 5. Schedule of test site construction.

Test Site Location	Layout/Construction Dates	Total Working Days Layout/Construction
I-17 Phoenix, AZ	April 1 through 12, 1991	8
I-77 Columbia, SC	April 22 through 28, 1991	6
I-25 Ft. Collins, CO	April 29 through May 10, 1991	10
I-80 Grinnell, IA	May 20 through June 6, 1991	8
U.S. 127 Frankfort, KY	June 10 through July 1, 1991	10

Joint Selection

Several joints at each test site contained spalls greater than 25.4 mm long that might affect localized sealant performance. These joints were not used in the experiment and, as time allowed, they were prepared and sealed together with adjacent joints. Many joints at the Arizona test site were spalled and were wider than the design width of 13 mm. These joints were not included in the experiment. Within the test site in Iowa, 97 percent of the available joints were used; in Colorado, 94 percent; in Kentucky, 77 percent; in South Carolina, 67 percent; and in Arizona, 45 percent.

Marking of Test Sections

On the shoulder adjacent to the test site, a 152-mm-wide strip of highway marking tape was placed before the first joint of each test section. The numbers of the adjacent test sections were painted on the shoulder on both sides of the marking tape, as were the material and configuration to be used. This reduced the confusion during installation when crews were required to prepare only certain test sections.

Preparation

After layout of the test site was completed, preparation began for installation of the joint sealants. Gauge plugs were installed on both sides of the joints, and measurements were taken of the joint width and gauge plug separation. Measurements of the level of faulting at each joint were also recorded. Joints were refaced with a concrete saw, or sealant was removed with a joint plow. Sandblasting, airblasting, and backer rod installation began immediately prior to sealant installation.

Gauge Plug Installation

Studying the relative opening movement of each joint required the installation of stationary markers on opposite sides of the joints. Gauge plugs were installed on the last eight joints of each test section prior to sealant installation while the sawing operation was in progress. The initial gage plugs were 9.5-mm rod couplers with screws in each end. Holes were drilled in the concrete 51 mm from each joint edge and 457 mm from the shoulder–pavement interface. The gauge plugs were then set in the holes with epoxy cement.

This process proved to be time-consuming, and the original gauge plugs were replaced with 35-mm Parker-Kalon® (P-K) nails that were epoxied into predrilled, countersunk holes at the specified locations. To provide positive positioning for the center points of the caliper, small indentations were formed in the center of each nail head using a center punch. Installed P-K nails are shown in figure 8.

Measurement of Faulting and Joint Dimensions

The initial faulting condition at each pavement joint of each test site was determined using a digital readout fault-measuring device developed at the Georgia Department of Transportation (DOT). Two readings were recorded at each joint at 305 to 508 mm from the inside shoulder edge. Figure 9 shows the fault measurement device in use. Deeply tined or milled pavement caused minor problems with the precision of the fault measurements; however, the readings indicated that no significant faulting was present.

After the epoxy holding the gauge plugs had a chance to dry, measurements were taken using a digital caliper between the plug centers at each joint, as well as measurements of the width of the joint between the gauge plugs. While these gauge plug readings were taken, climatic conditions and pavement temperatures were obtained on an hourly basis to allow study of correlations between joint movement and air and pavement temperatures. Judging from repetitive testing of joint measurement, the accuracy of the measurements was to 0.254 mm.

Joint Preparation

The original experimental design called for three configurations to be used for the installation of each rubberized asphalt sealant. These three techniques are described as the standard recessed, the saw-and-overband, and the plow-and-overband configurations, and the basic steps for their completion are listed below. The properties of the silicone sealants required that they be installed in the standard recessed configuration 1 only.

- Standard recessed (configuration 1).
  - Saw the joint reservoir to achieve clean sawed faces on both walls.
  - Sandblast the dry vertical joint walls.
  - Airblast the sealant reservoir.
  - Place backer rod in the joint reservoir.
  - Install sealant in the standard recessed configuration.

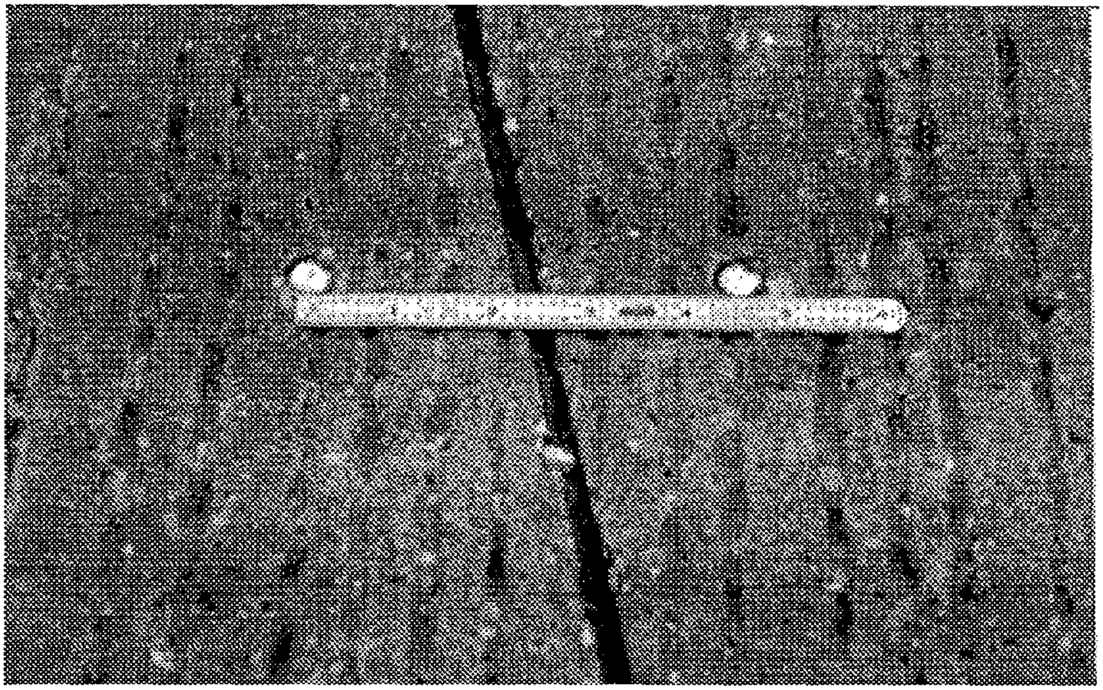


Figure 8. Installed gauge plugs.

Figure 9. Fault measurement.

- Saw and overband (configuration 2).
  - Saw the joint reservoir to achieve clean, sawed faces on both walls.
  - Sandblast the dry vertical joint walls and adjacent pavement surface.
  - Airblast the sealant reservoir and adjacent pavement surface.
  - Place backer rod in the joint reservoir.
  - Install sealant in overband configuration.

- Plow and overband (configuration 3).
  - Plow the sealant from the existing joint.
  - Airblast the reservoir and adjacent pavement surface.
  - Place backer rod in the joint reservoir.
  - Install sealant in the overband configuration.

Due to unforeseen circumstances, a fourth configuration replaced the third configuration at the Arizona and Colorado sites. These circumstances are discussed later in the joint plowing section. The fourth configuration, designated as the saw-and-flush fill, employs all of the steps of the standard recessed configuration, but the sealant reservoir is filled to the surface instead of recessed 6.4 mm.

Joints for configurations 1, 2, and 4 at each test site were sawed using 165-kBtu/h water-cooled, diamond-bladed concrete saws. The design width of joint sawing was 12.7 mm and the design depth was 44.5 mm. Shown in figure 10 is the saw used at the Iowa test site. Several joints at the north end of replicate 2 at the Arizona site were dry-sawed using 46-kBtu/h crack saws.

The joint plowing operation was considered to be the quickest and easiest method of joint preparation. It was noted, however, that joint plowing on a 3.7-m lane of a road that carries traffic in the adjacent lane is difficult. Difficulty is increased further when sharp side slopes, guard rails, or curbs are present on the adjacent shoulder. A small percentage of joints were too shallow to allow sealant and backer rod placement, making the plowing operation insufficient to meet the design requirements.

Joints for configuration 3 were plowed in South Carolina, Iowa, and Kentucky. An 8-year-old silicone joint seal in excellent condition was removed in South Carolina, a 6-year-old failed silicone sealant was removed in Iowa, and a failed asphalt-based sealant of unknown age was removed in Kentucky. The plowing operation in Iowa is shown in figure 11.

At the Arizona site, at least half of the joints required for plowing were sawed between the time of layout (February) and the installation (April). This was required because steel inserts had to be removed from the joints. It was discovered during the plowing operation that about half of the remaining joints to be plowed were less than 13 mm deep, making it impossible to install backer rod beneath the sealant. The third configuration was, therefore, replaced by a fourth configuration that involved sawing and flush-filling the joints.

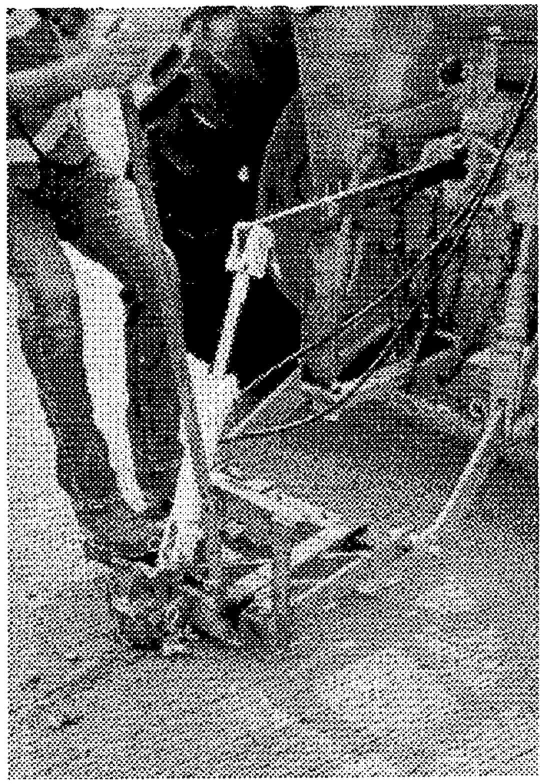


Figure 10. Joint plowing operation.

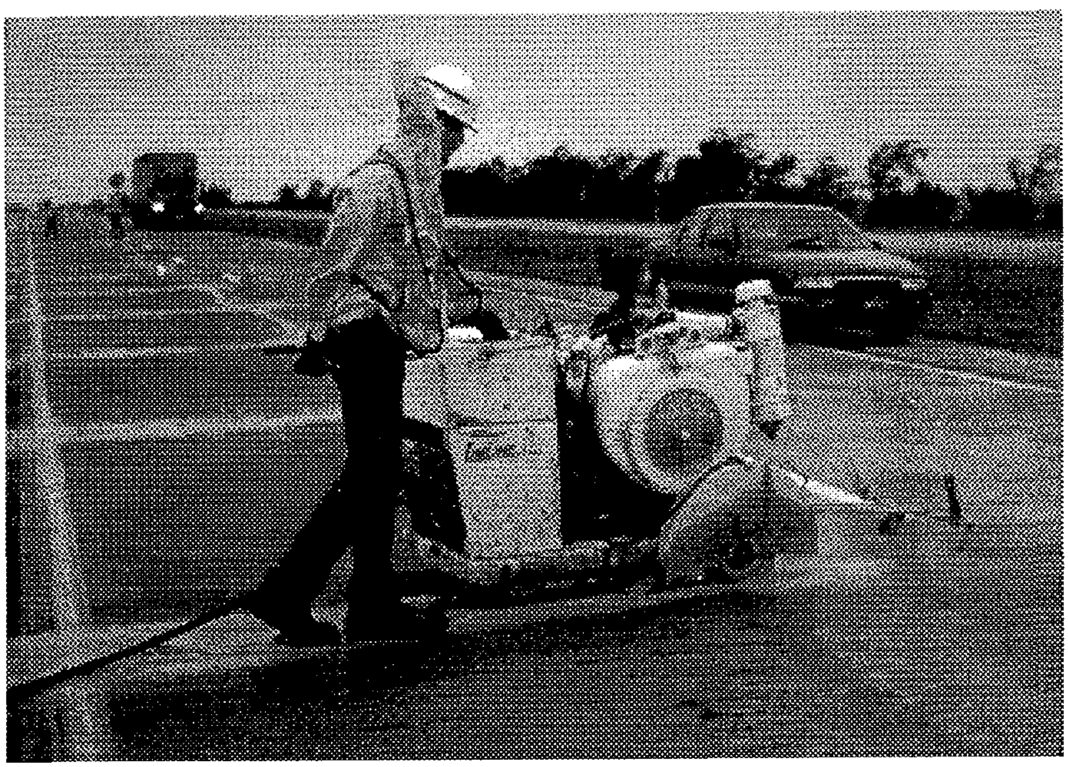


Figure 11. Joint-sawing operation.

Plowing at the Colorado site was attempted and also discontinued in favor of the fourth configuration. There were two reasons for this decision. First, the joint plow available at the site could not be stabilized so that the plow blade would effectively scrape the sides of the joint. Second, the sealant present in the joints was a polyvinyl chloride (PVC) coal-tar material that was less than 5 years old and was expected to react with the sealants used in the experiment, forming a softened region at their interface.

When the sawed joints had been blown out with compressed air and had dried, the inside edges of the joints for configurations 1, 2, and 4 were thoroughly sandblasted. At the South Carolina, Colorado, and Kentucky sites, the sandblast nozzle was held by the operator at a distance of 51 to 152 mm from the joint face and at an angle of 60 to 80 degrees from the plane of the pavement surface. Attached to the sandblast hose and nozzle at the Arizona site was a 1.5-m length of angle iron, as shown in figure 12. The tip of the angle iron had been ground to a point so it could fit into the joint, allowing the nozzle to be dragged at the desired angle and distance from the joint face.

A more elaborate method of sandblasting was used at the Iowa site. A stainless steel plate was attached to a handle. The hose and nozzle were fixed to the plate and handle at the desired angle and position, and the guide was pulled through each joint held in position by a centering pin in the steel plate. Two sandblast units were used for this operation, one for each joint face. This sandblast apparatus is shown in figure 13.

Not only were the sawed joints that were to be overbanded sandblasted along each joint wall, but the adjacent surface to 25 mm from the joint edge was also sandblasted. In most cases, this work was conducted freehand by the operator, but a guide was used at the Iowa test site for about half of the overbanded joints.

Airblasting, shown in figure 14, was accomplished using an air compressor with the cleanest, driest airstream available. After the sandblasting operation had progressed at least 10 joints ahead, the sand and dust in the joints were removed by airblasting the reservoir. Sand and dust from the sawing and the sandblasting operations were also blown from the pavement surface to the adjacent shoulder or gutter. When the airblasting operation had progressed at least five joints ahead, a crew of two or three persons installed backer rod in the joints to be sealed. An adjustable backer rod placement roller was used to recess the rod to the required depths. Typically, backer rod was cut slightly longer than the length of the joint, and one end of the rod was placed in the joint at the lane edge nearest the shoulder. Then, the person unrolling the backer rod would move to the opposite end of the joint and slightly stretch the backer rod as it was recessed, thus easing the rolling procedure. This is shown in figure 15. When the rolling was nearly complete, the backer rod was cut to the exact length required for providing a tight seal, and the entire length was rolled a second time.

Several widths of backer rod were required because of widened areas and narrow unsawed joint widths. To improve this installation process, the necessary rolls of backer rod were mounted in the back of an available truck and unrolled as needed for each joint. If sealant installation was delayed more than about 50 min, the joint was cleaned with an additional low-pressure airstream.

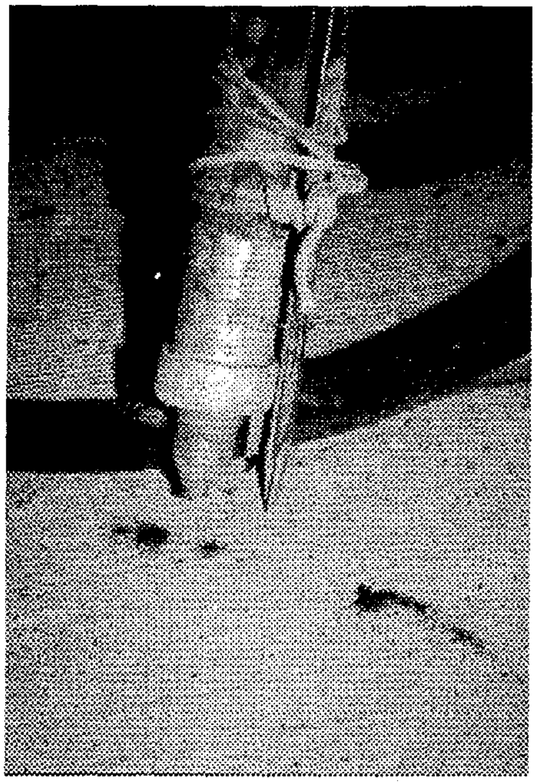


Figure 12. Arizona sandblasting nozzle.

Figure 13. Sandblasting operation.

Figure 14. Airblasting operation.

Figure 15. Backer rod installation.

The Arizona site, in particular, presented logistical problems for preparation and installation. Due to the high traffic volume, the subcontractor's workmen were only allowed on the pavement between 9:00 p.m. and 3:30 a.m. As a result, preparation and installation were hurried in an effort to install two rubberized asphalt sealants per night. The road was equipped with streetlights, but it was learned on the first night that the main contractor was putting in additional lights and he required that the lights remain off during most of the preparation and installation process. Additional portable lights were brought in the next night, but it was difficult to find the test section locations and to monitor the sawing and cleaning operations.

Installation

The order of placement for the various sealants and configurations described in the *EDRP* was generally followed in the field installation (Evans et al., 1991). A summary of the number of joints sealed at each site using the selected materials and procedures is shown in table 6.

One significant change from the initial experimental design was the replacement of the configuration 3 overbanded joints in Arizona and Colorado with a fourth configuration, the flush-fill method. Also, since the primer for Koch 9005 could not be supplied in time for installation at the site in Iowa, those test sections were replaced with Dow Corning 888 and Dow Corning 888-SL silicone with primer. A test section for Koch 9005 with primer was installed at the Kentucky site.

Materials

The joint sealing materials installed at the test sites were those recommended in the SHRP H-105 final report (Smith et al., 1990). These included several rubberized asphalt sealants and silicone sealants. At the request of the participating State agencies, additional silicone and polysulfide sealants were installed for further evaluation.

Rubberized Asphalt

Rubberized asphalt sealants having ASTM D 3407 penetrations between 75 and 85 dmm were installed using the preparation methods and configurations described in the preceding section. Koch 9005 was placed in 60 joints at each site to serve as the control material. In addition, Meadows Hi-Spec and Crafco RS 221 were installed at the Arizona site, replacing Koch 9030 and Meadows Sof-Seal. The configurations and number of joints sealed with each material are shown in table 6.

Each rubberized asphalt sealant material is packaged in 22.7-kg blocks for easy placement in a melter–applicator. The recommended pouring temperature for the rubberized asphalt sealants varies from 188 to 199°C, and the maximum safe heating temperature ranges from 199 to 210°C. Sealant and heating oil temperatures were monitored carefully during installation to ensure that overheating of the sealants did not occur. In many cases, representatives from the sealant manufacturers were present to monitor and assist in the installation.

Table 6. Summary of materials and procedures used for joint seal installation.

Sealant Material	Config. - Prep. [a]	Phoenix, AZ	Columbia, SC	Ft. Collins, CO	Grinnell, IA	Frankfort, KY
Crafco RS 221	1	20 [b]				
	2	20				
	4	20				
Crafco RS 231	1	20	20	20	20	20
	2	20	20	20	20	20
	3		20		20	20
	4	20		20		
Koch 9005	1	20	20	20	20	20
	2	20	20	20	20	20
	3		20		20	20
	4	20		20		
Koch 9030	1		20	20	20	20
	2		20	20	20	20
	3		20		20	20
	4			20		
Meadows Hi-Spec	1	20 [b]				
	2	20				
	4	20				
Meadows Sof-Seal	1		20	20	20	20
	2		20	20	20	20
	3		20		20	20
	4			20		
Dow 888	1	20	20	20	20	20
Dow 888-SL	1	20	20	20	20	20
Mobay 960-SL	1	20	20	20	20	20
Mobay 960	1				20	
Crafco 903-SL	1	20				
Koch 9050	1			20		10
Dow 888 w/ Primer	1				10	
Dow 888-SL w/ Primer	1				10	
Koch 9005 w/ Primer	1					10

[a] Configuration 1: Saw and recessed; Configuration 2: Saw and overband; Configuration 3: Plow and overband; Configuration 4: Saw and flush-fill.

[b] Number of joints installed at the site.

As might be expected when inexperienced workmen attempt to install sealant for the first time, some difficulties were encountered during installation. On occasion, depending on the coordination of the person installing the recessed sealant and the type of sealant wand, the sealant was installed too thinly or too thickly in the reservoir. If the sealant was less than about 6.4 mm thick, a second layer of sealant was added immediately after initial installation to obtain the desired sealant thickness. Occasionally, due to inadequate backer rod installation, sealant would flow through gaps in the backer rod and leave a sunken area of sealant. This problem was addressed by tighter monitoring of backer rod installation.

Bubbles were noted in the sealant material at several of the sites. It was initially assumed that these were the result of moisture in or below the pavement, even though the pavement appeared dry and it had not rained for the previous 24 h. Some bubbles were also determined to be the result of air entrained in the sealant by the agitator in the melter–applicator. When this was noted, additional sealant was added to the heating chamber and the motion of the agitator was reduced or reversed.

At the Colorado site, it was noted that severe bubbling was occurring in the first joint using Koch 9005. On the assumption that moisture was the problem, installation was halted. Returning to the site the next day, the same problem was encountered. Further investigation revealed that the backer rod used in that joint was defective and was melting and producing bubbles when heated sealant was placed over it. The backer rod was 22-mm HBR-XL, closed-cell, expanded polyethylene. Since 16-mm backer rod was required for 75 percent of the joints at the site and the 16-mm rod from the same manufacturer was not melting, the remainder of the joints were sealed. Where large-diameter backer rod was required, a thin first layer was applied over the 22-mm rod, followed by another layer to reach the required depth. This significantly reduced the bubbling problem. Suitable large-diameter backer rod was provided by the manufacturer for use at the remaining sites.

Traffic was not allowed on the joints sealed using rubberized asphalt for at least 60 min. That time could have been reduced to about 15 min, if the conditions had so required.

Low-Modulus Rubberized Asphalt

Low-modulus rubberized asphalt sealant materials have a greater working range with respect to low-temperature extensibility and resistance to high-temperature softening. Penetrations of the materials installed at the sites vary from 110 to 140 dmm. Recommended pouring temperatures range from 188 to 199°C, and the maximum safe heating temperatures vary from 199 to 210°C.

The same preparations and installation procedures used for the rubberized asphalt sealants were used with the low-modulus sealants: Crafco RS 231, Meadows Sof-Seal, and Koch 9030. The locations, configurations, and number of joints sealed with each material are listed in table 6. Some bubbling was noted at each test site, and the above-mentioned procedures were used to reduce this bubbling. Some sealant was also lost through gaps at the backer rod ends. At most sites, the thick consistency of the Crafco RS 231 eliminated this problem for that material.

Again, no traffic was allowed on the low-modulus sealant joints until they had cured at least an hour. This time could have been reduced to less than 15 min, if necessary.

Silicone

Two self-leveling silicone sealants and one non-self-leveling silicone sealant were installed at the five test sites. In addition, two more silicone sealants were added to the Arizona and Iowa sites. The configuration, location, and number of sealed joints are shown for each silicone sealant in table 7. The preparation for each sealant included resawing the joint, sandblasting, airblasting, and installing backer rod. A reticulated, closed-cell backer rod of extruded polyolefin foam was used to support the sealant and to create the lower bound of the sealant reservoir. Air-powered cartridge applicators were used to place the sealant in the joints. Each silicone was recessed 3.2 to 6.4 mm and installed with thicknesses varying from 6.4 to 9.5 mm.

During installation, it was noted that several bubbles were forming in the Mobay 960-SL silicone sealant. Some air was typically forced into the sealant by the cartridge applicator as it ran out of sealant. Since about three 325-mL cartridges were used for each joint, this may have caused some of the bubbling. The other silicone sealants did not show problems with bubbling in any significant amount.

The self-leveling silicone sealant flows in the joint reservoir in a manner similar to the hot-applied sealants. As a result, in a few places where gaps existed between the backer rod and the sidewall or at the ends of joints, the sealant tended to flow around the rod, leaving areas of thin sealant. This was addressed by more tightly controlling the backer rod installation.

Due to time limitations, traffic was allowed on one silicone sealant within 30 min of installation at the Arizona site. This resulted in fine sand particles adhering to the sealant surface. However, no performance problems are expected. In most cases, about 1 h was needed before allowing traffic on the non-self-leveling sealants and about 90 min was required for the self-leveling sealants to form a protective skin.

Polysulfide

A one-part, moisture-cured, self-leveling polysulfide was installed at the Colorado and Kentucky sites. Preparation included sawing, sandblasting, airblasting, and inserting backer rod. Sealant was installed about 13 mm thick and recessed about 3.2 mm.

No problems were noted during installation, and the skin-over time in Colorado was about 15 to 25 min. In Kentucky, the sealant had not skinned over after more than an hour. Traffic allowed on the pavement after about 60 min did track some of the high sealant onto the pavement surface, but a new skin was formed, and adhesion loss did not occur.

<u>Equipment</u>

Equipment for construction of the test sites was, in most cases, readily available to the State crews or contractors, although some modifications were made for the equipment to perform satisfactorily. Some State agencies, however, could not obtain the required equipment, and the project was required to provide the necessary items:

- Crafco 378.5-L melter–applicator for use in Colorado.
- Cleasby 378.5-L melter–applicator for use in Colorado.
- Joint plow for use in Colorado, Iowa, and Kentucky.

In most States, 165-kBtu/h, water-cooled concrete saws made by Cimline or Target were used to reface the joints. It was noted at the Iowa site that the type and thickness of blade can affect production significantly. Several blades were warped at that site because blades of insufficient thickness were used. Using these blades significantly slowed the operation.

A joint plow fabricated in Granite City, Illinois, was used to remove sealant from the joints in Colorado, Iowa, and Kentucky. This plow was attached to the three-point hitch of highway department tractors. A rectangular bit with a carbide tip was attached to the plow and pulled through the joint, making two passes and removing the bulk of the old sealant material.

Problems were encountered in Colorado with keeping the plow frame rigidly mounted to the tractor. Rigid mounting was required so that the blade could be pushed firmly against the joint edge while cleaning. Keeping the tractor in line with the skewed joints was also difficult. Spalling resulted when the tractor was misaligned. Also, since the plow was mounted on the rear of the tractor, the operator found it difficult to drive the tractor and watch the plow. Guardrails near the shoulder, elevated curbs, and shoulder dropoffs also caused difficulty for the plowing operators.

Clemco 272-kg sandblast machines were used at all sites except Colorado, where a shop-made blasting apparatus was employed. Typically, one pass was made to clean each joint face. It was discovered that the sandblasting operation does a poor job of removing old sealant from the joint face. This was especially true of silicone sealants and other sealants that still retained some resiliency. The sand rebounded off the sealant, and continued blasting typically left gouges in the concrete around the periphery of the old sealant. As a result, workers with hand-held knives removed the majority of any sealant material that remained from the sawing operation before final sandblasting. Visual inspection of the joints after sandblasting was completed on an intermittent basis to ensure the effectiveness of the operation.

Air compressors of varying vintages were used for test site installation. Prior to use at the site, air from each compressor was blown onto the pavement and onto a nearby tire. If any signs of oil or moisture were left on the pavement or the tire after this test, the compressor was rejected. Several compressors were rejected during this testing and were upgraded by adding oil and water traps. In some cases, older compressors were used since they did not have systems that add lubricating oil to the airstream.

Melter–applicators manufactured by BearCat, Crafco, Steppes, Cleasby, and Cimline were used for hot-poured sealant application. These varied in capacity from 379 to 1,136 L. The time required for initial heating of sealant for use in the project was 1 to 1.5 h for the smaller melters and about 2.5 h for the 1,136-L applicators. Melters with auger-type agitators seemed to require slightly more time in heating than did those equipped with full-sweep agitators.

The squeegees used for overbanding the hot-applied sealants were made from 356-mm industrial floor squeegees formed into a U shape. The back dimension of the squeegees was 89 mm, and a 2- by 34-mm notch was cut from the rubber insert in the back of the squeegees to promote the formation of the overband on the pavement surface. The squeegee was pushed or pulled, as required by the adjacent traffic patterns and worker preferences.

Procedures

Hot-applied, rubberized asphalt sealants were installed using configuration 1 according to manufacturers' recommendations, filling from the bottom up and keeping the sealant surface 3.2 to 6.4 mm below the pavement surface. Application in South Carolina is shown in figure 16. Using the configuration 4 method, the sealant was placed from the bottom up to just even with the pavement surface. Flush-filled, hot-applied sealant is shown in figure 17. The average sealant thickness was 13 mm.

Approved oil-jacketed melter–applicators of various types were used to install sealant at the test sites. Sealants were applied at temperatures within the manufacturers' recommended ranges, and careful attention was paid to keeping the sealant temperature below the safe heating

Figure 16. Recessed sealant installation.

Figure 17. Installed flush-filled sealant.

temperature at all times. To reduce the possibility of contamination, before using any melter–applicator, all sealant was drained from the kettle and 45 to 68 kg of fresh sealant was heated, circulated through the pump and hose, and completely drained. After flushing, 136 to 182 kg of sealant was placed in the heating chamber and heated.

During heating and application, correlations were made between the sealant temperature measured using calibrated, hand-held thermometers and temperatures indicated by the thermometers on the melter–applicators. Samples of each hot-applied sealant were retained after installation for possible laboratory testing.

Hot-applied sealants were installed using the overbanded configurations according to manufacturers' recommendations, filling from the bottom up and slightly overfilling the joints. The average sealant thickness was 13 mm for configuration 2 and 9.5 mm for configuration 3. A squeegee followed the applicator wand at a distance of 152 to 610 mm, striking off the surface and leaving an overband about 2 mm thick and 34 mm wide, with a total wipe zone width of about 89 mm. The overband installation process is shown in figure 18, and a recently installed overband is shown in figure 19. Traffic was kept off the sealant until it had sufficiently cooled.

Figure 18. Overbanded sealant installation.

Figure 19. Installed overbanded sealant.

Silicone and polysulfide sealants were installed using air-powered cartridge applicators, according to manufacturers' recommendations, as shown in figure 20. The non-self-leveling silicone sealants were tooled to a maximum recess of about 6.4 mm using folded pieces of oversized backer rod. This left a thickness of about 9.5 mm. Tooling was completed within 1 min of sealant installation. The self-leveling silicone sealants were installed 9.5 mm thick to about 6.4 mm below the pavement surface.

Some bubbles were noticed in the Mobay Baysilone 960-SL sealant as it was placed. Spot-checks of sealant thickness were made during installation by inserting a metal ruler through the fresh sealant to the top of the backer rod. Traffic was not generally allowed onto the sealant until it had cured at least an hour. Production rates for silicone and hot-applied sealants are shown in table 7.

Productivity and Cost Data

Project staff were present at each site during preparation and installation to direct and monitor the operations. Journals of installation were kept for each site, and production rate information for preparation operations was recorded on sheets similar to figures B-1 through B-5 in appendix B. Average production rates for each procedure are listed in table 7.

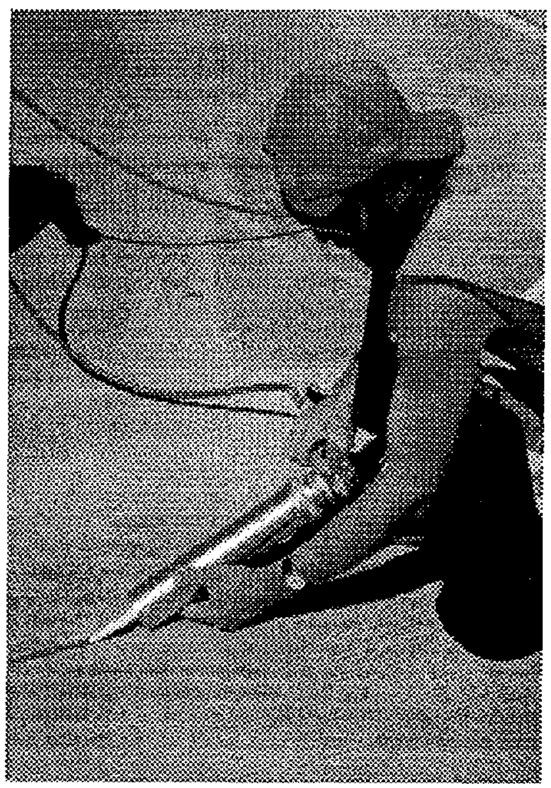


Figure 20. Silicone sealant installation.

Table 7. Productivity rates, labor, and equipment requirements.

Procedure	Persons Required	Equipment Required	Time per 10 Joints, minutes
Wet saw	2	65-hp saw, water truck	20 to 60
Airblast or waterwash	2	Air compressor or water sprayer, truck	15 to 20
Plow	2	Powered joint plow	20 to 40
Sandblast (recessed)	2	Sandblaster, air compressor, truck	15 to 30
Sandblast (overband)	2	Sandblaster, air compressor, truck	20 to 45
Airblast	2	Air compressor, truck	10 to 15
Backer rod installation	2	Installation tool, optional truck	10 to 15
Recessed hot-pour installation	2	Approved melter–applicator	10 to 15
Overbanded hot-pour installation	3	Approved melter–applicator, squeegee	10 to 15
Tooled silicone installation	2	Silicone pump or air compressor and cartridge applicator, tooling apparatus	40 to 50
Self-leveling silicone installation	3	Silicone pump or air compressor and cartridge applicator	30 to 40

Production rates for each operation, material, and configuration are listed for each site in table B-1 of appendix B. For this project, the average amount of labor required for one joint to be sawed, initially airblasted, sandblasted, airblasted, and have backer rod and sealant installed in a recessed configuration was about 25 person-minutes, not including startup time and sealant heating time.

Costs of sealant materials and shipping used in this project were previously listed in table 3. Shipping costs for the silicone sealants were paid by the manufacturer. The cost of shipping the rubberized asphalt sealant materials ranged from 19 to 83 percent of the per-kilogram sealant cost. This productivity and cost information can be used, together with field performance results, to determine the cost-effectiveness of each material. A method for determining cost-effectiveness is shown in appendix E, along with sample calculations.

Documentation

To effectively document and evaluate joint movement, pavement condition, installation techniques, and rates, seven information sheets were completed during installation. These installation forms were contained in the SHRP H-106 *Evaluation and Analysis Plan (EAP)* and are illustrated in appendix B (Evans et al., 1992). Among the data collected were the following:

- Climatic conditions.
- Pavement condition.

- Pavement temperatures.
- Initial joint dimensions.
- Gauge plug separations.
- Joint faulting.
- Temperatures of hot-applied sealants.
- Production rates.
- Labor requirements.

Photo documentation was made of each installation procedure, and representative photos of each material and configuration were taken at the test sites.

Comments

Several items should be mentioned in a reflective analysis of the installation of the joint resealing test sites. Among these are items pertaining to the sealant removal and cleaning operations and to the control of material placement.

Various problems were encountered in the joint plowing operation. Some were related to the original reservoir depth, some to the old sealant material, and some to the difficulties inherent in a rear-mounted plowing system. The speed of the plowing operation was comparable to that of the sawing operation; however, the quality of cleaning was far less. If a maneuverable plow with positive horizontal and vertical control were available, this might increase the advantages of the joint plow. Also, if the plowed joint were in such condition that the remaining sealant could be removed by sandblasting, the plowing operation could compete with sawing and sealing since it leaves a dry joint and does not significantly widen the joint. Good engineering judgment should be applied when choosing to use a joint plow, taking into account such variables as existing joint dimensions, condition of the existing sealant, and effectiveness of sandblasting.

Due to the inability to effectively plow joints at the Arizona and Colorado sites, the third configuration could not be used with the hot-applied sealants at those sites. This reduced the comprehensiveness of the factorial design, not allowing comparison of sealant performance in the third configuration in those regions. It also reduced the effectiveness of performance analysis across climatic regions.

In most cases, the resealing of joints in concrete pavements requires working with traffic in the adjacent lane. This sets up a situation in which sand and dirt in the adjacent lane can be blown into the joint reservoir in the period between cleaning and sealant placement. In the installation of the test sites, this problem was reduced by blowing sand and dirt from the joint reservoir and the pavement surface onto the nearest shoulder, using compressed air. If curbs are present or the prevailing winds are contrary, joints can be contaminated quickly by blowing debris. Perhaps it should be specified that a waterless street sweeper/vacuum be used to remove dirt from the pavement in conjunction with the sandblasting and the airblasting operations.

Night construction makes good quality joint resealing even more difficult to obtain. Adequate lighting needs to be available for all operations, including the inspection process. Time constraints make it tempting to cut corners in preparation thoroughness and installation quality. If the sealant is not preheated, there is motivation to heat the sealant quickly, possibly resulting in overheating. Additional inspection personnel may be necessary to maintain installation quality.

Finally, the rubberized asphalt, hot-applied sealants are very sensitive to overheating and to extended heating. Although overheating of materials was not noted during installation, it is very tempting to speed the heating operation by raising the oil temperature to more than 260°C, thereby inducing localized overheating of the sealant material. Sufficient monitoring of the sealant temperatures should be conducted to ensure that the sealant does not exceed the safe heating temperature at any time.

CHAPTER 3. MATERIAL TESTING

In addition to the data collected during installation of the joint resealing materials, laboratory testing was performed on the primary sealant materials. Initial tests were run to confirm the compliance of each sealant to the manufacturer's specifications as well as to the ASTM D 3405 specifications for the hot-applied materials.

The materials also underwent supplemental testing following test site installation. The purpose of this additional testing was to compare the laboratory-defined material properties of each material with the sealant's performance at the controlled test sites. Supplemental test procedures were conducted using tests that were expected to correlate well with such performance properties as adhesion loss, overband wear, stone intrusion, cohesive failure, and spalling of the joint walls.

To ensure that the materials tested were representative of the material at each site, the silicone and hot-applied sealant materials installed at all five sites were each selected from a single production batch. Suitably sized samples of each silicone sealant and rubberized asphalt material were obtained from the South Carolina and Colorado sites, respectively, and shipped to two approved laboratories for testing.

Laboratory Tests Performed

Several of the initial tests were performance-based tests. These included ASTM D 3407 penetration, flow, bond, and resilience tests for rubberized asphalt materials, as well as ASTM D 412 tensile stress and elongation tests for silicone sealants. Additional initial tests were used to measure general sealant material properties, such as the specific gravity, extrusion rate, and tack-free time.

Supplemental performance tests were selected to investigate specific sealant performance properties, such as adhesive strength, cohesion strength, flexibility, durability, resilience, and resistance to weathering. The effects of extreme temperature on some of these properties were also investigated. These tests and any modifications made to them were described in the *EAP* (Evans et al., 1992). Two tests that were performed on all nine sealants were the ASTM D 412 tensile test (figure 21) and the ASTM D 3583 immersed bond strength test (figure 22). The tensile test was performed on all sealant materials under temperature conditions ranging from -18 to 60°C. Tensile test results were also obtained for the silicone sealants after the specimens had undergone 504 h of ASTM G 23 weathering.

Most of the tests originally described in the *EAP* were completed successfully; however, due to procedural or equipment problems, two tests required additional modification or could not be run. Table 8 lists the supplemental laboratory tests used in the experimental design, the properties sought in the testing, and comments about the testing procedures. Results of these tests have been collected and are listed in the following section and in appendix C.

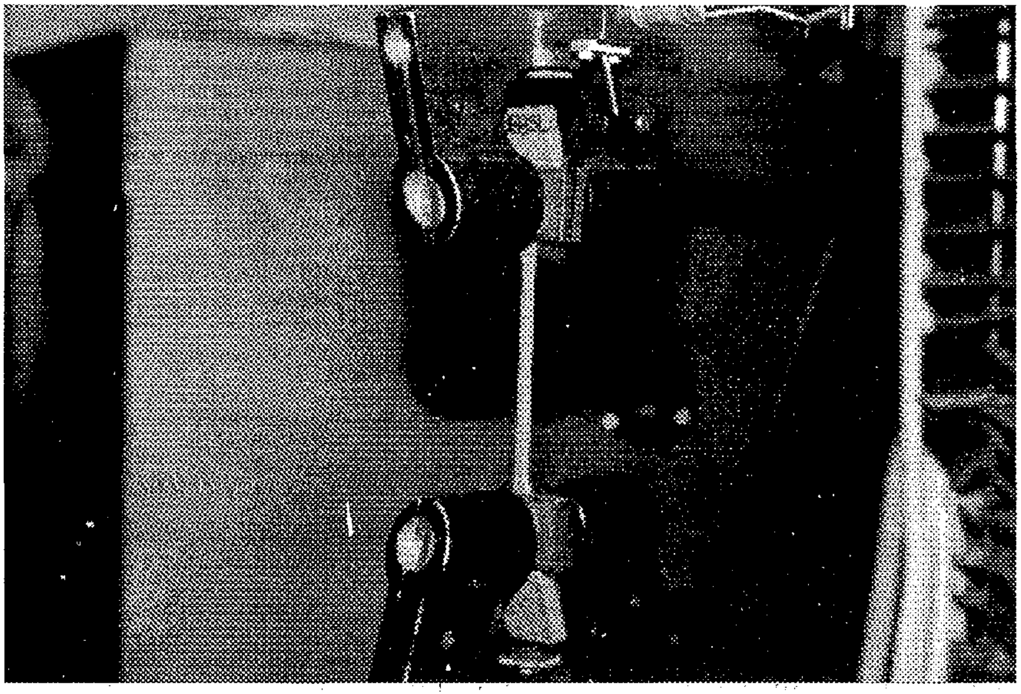


Figure 21. ASTM D 412 tensile testing.

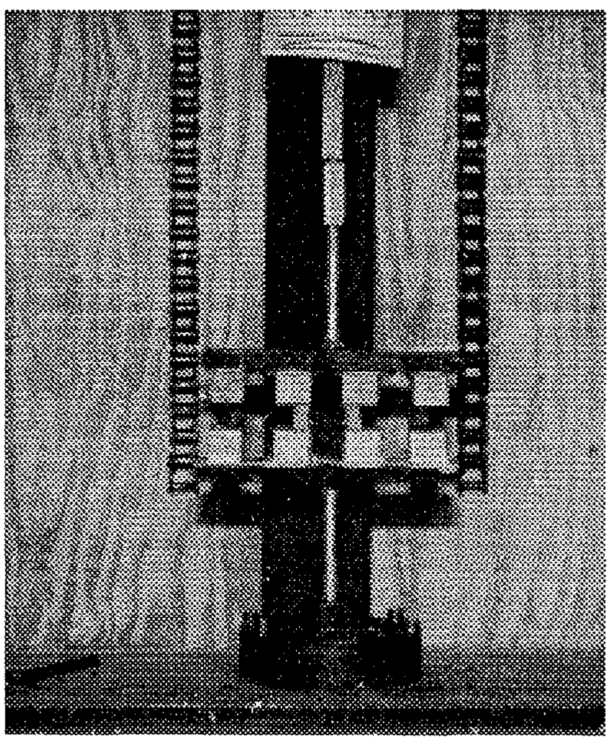


Figure 22. ASTM D 3583 tensile adhesion testing.

Table 8. Target properties and modifications of supplemental performance tests.

Test	Procedure	Pertinent Properties	Material	General Comments
Softening Point	ASTM D 36	High-temperature tracking potential	Rubberized Asphalt	No modifications.
Cone Penetration, -17.8°C	ASTM D 3407	Low-temperature flexibility	Rubberized Asphalt	Conducted at -18°C.
Cold Bend	Utah Spec.	Cohesion	Rubberized Asphalt	Conducted at 18°C.
Force Ductility	ASTM D 113 & Utah Spec.	Flexibility	Rubberized Asphalt, Silicone	Ductility test run at 4°C.
Tensile Adhesion	ASTM D 3583	Adhesion/cohesion	Rubberized Asphalt, Silicone	Standard test run at 24°C, soaked and unsoaked PCC blocks.
Modulus: -17.8°C -3.9°C 23.9°C 60.0°C	ASTM D 412	Flexibility	Silicone	Conducted at a separation rate of 51 mm/min instead of 508 mm/min. Originally designed for -18, 24, and 60°C. High temp. replaced with 4°C due to material softening.
Modulus after Artificial Weathering, 504 h	ASTM G 23 ASTM D 412	Durability/flexibility	Rubberized Asphalt	Completed on silicone only at 24°C. Asphalt-based sealants deformed during weathering phase.
Track Abrasion	ASTM D 3910	Durability	Silicone	Test discontinued due to migration and pull-up problems.
Cyclic Adhesion/Cohesion	ASTM C 719	Adhesion/cohesion		Performed at 24°C. Cycling 50% compression to 100% extension.

Laboratory Test Results

The rubberized sealant materials used in this study contain different amounts of asphalt and other additives, such as polymers, rubbers, and filler materials, blended and linked in a manner that results in some variation in the outcome of laboratory testing. Results of the initial laboratory tests on the hot-applied and the low-modulus hot-applied sealants are shown in tables 9 and 10. Typically, two or three replicates of each test were performed, and the results of each replicate, as well as the average for each test, are shown in these tables. Table 9 also contains the limits set by the ASTM D 3405 specification for comparison. For the low-modulus hot-applied sealants, several States have developed specifications for assistance in screening and quality control. The specifications used in Minnesota, Michigan, and Iowa are shown in table 10 for comparison.

Table 9. Results of initial laboratory tests on hot-applied sealants.

Test Description	ASTM Test Method	ASTM D 3405-78 Specification Limits	Crafco RS 221	Meadows Hi-Spec	Koch 9005
Penetration at 25°C, 150 gm, 5 s, dmm	D 3407-78	≤ 90	75.5	63.5	82.0
Flow at 60°C, mm	D 3407-78	≤ 3.0 mm	0	0	1
Bond at -29°C, 3 cycles, 50% extension	D 3407-78	3 cycles	Pass	Pass	Pass
Resilience at 25°C, %	D 3407-78	≥ 60%	65.3	63.7	70.3
Specific gravity at 15.6°C	D 3407-78		1.180	1.112	1.068

Table 10. Results of initial laboratory tests on low-modulus hot-applied sealants.

Test Description	ASTM Test Method	Typical Specifications			Crafco RS 231	Meadows Sof-Seal	Koch 9030
		MN	MI	IA			
Penetration at 25°C, 150 gm, 5 s, dmm	D 3407-78	110 to 150	110 to 150	90 to 150	75.3	137	114.5
Flow at 60°C, mm	D 3407-78	≤ 3	≤ 3	≤ 3	0	0	0
Bond at -29°C, 3 cycles, 100% extension	D 3407-78	3 cycles	3 cycles	3 cycles @ 200%	Pass	Pass	Pass
Resilience at 25°C, %	D 3407-78	≥ 60	≥ 60	≥ 60	70.7	69.7	83.7
Specific gravity at 16°C	D 3407-78				1.128	1.078	1.101

One non-self-leveling silicone sealant, Dow Corning 888, was tested, and the results of the initial tests, along with the current Georgia DOT specification, are shown in table 11. The Georgia specifications for shore A hardness and skin-over time are included, although these are not the same tests that were used in the H-106 laboratory testing program.

Two self-leveling silicone sealants, Dow Corning 888-SL and Mobay Baysilone 960-SL, were also tested, and the results of the initial tests are compared with Georgia specification 83306-B in table 12. Summaries of the results of supplemental tests performed on silicone and hot-applied sealants are shown in tables C-1 through C-7 in appendix C.

Table 11. Results of initial laboratory tests on non-self-leveling silicone sealants.

Test Description [a]	ASTM Test Method	Typical Specification GA 83306-A [b]	Dow 888
Tack-free time at 25°C, 50% relative humidity, min	C 679-87	Skin-over ≤ 90	65
Durometer hardness, shore 00, 25°C	D 2240-86	Shore A 10 to 25	70
Flow at 50°C, mm	D 2202-88		6.4
Extrusion rate, gm/min	C 603-83	≥ 75	81.8
Ultimate elongation, 25°C, %	D 412-87 die C		1950
Tensile stress at 150% elongation, 25°C, kPa	D 412-87 die C	≤ 310	234

[a] Cured 21 days at 25°C, 50% relative humidity.
[b] Cured 28 days at 25°C, 50% relative humidity.

Table 12. Results of initial laboratory tests on self-leveling silicone sealants.

Test Description [a]	ASTM Test Method	Typical Specifications GA 83306-B [b]	Dow 888-SL	Mobay 960-SL
Tack-free time at 25°C, 50% relative humidity, min	C 679-87	Skin-over ≤ 90	150	240
Durometer hardness, shore 00, 25°C	D 2240-86	40-80	59	50
Extrusion rate, 25°C, gm/min	C 603-83	> 90	180	300
Ultimate elongation, 25°C, %	D 412-87 die C		2150	647
Tensile stress at 150% elongation, 25°C, kPa	D 412-87 die C	< 276	114	172

[a] Cured 21 days at 25°C, 50% relative humidity.
[b] Cured 28 days at 25°C, 50% relative humidity.

CHAPTER 4. FIELD PERFORMANCE

Ten evaluations of the performance of the experimental joint seals were completed at approximately 1, 5, 9, 12, 18, 30, 42, 56, 68, and 82 months after installation. The lanes in which each test site was installed were closed down, and a detailed 1- to 2-day evaluation of the conditions of the sealants and surrounding concrete was performed. This chapter describes the types of performance data collected over the 82-month monitoring period and presents a summary of the field performance observations following the tenth and final evaluation.

Performance Data Collection

Toward the goal of collecting the required performance data efficiently, consistently, and completely, a standard joint seal evaluation form (see appendix D) was prepared and duplicated for each joint at each test site. The tabular form included data cells for recording the following types of sealant system distress data on a foot-by-foot basis:

- Partial-depth adhesion loss (approach and leave side).
- Full-depth adhesion loss (approach and leave side).
- Partial-depth spalling (approach and leave side).
- Full-depth spalling (approach and leave side).
- Overband wear (approach and leave side).
- Stone intrusion.
- Partial-depth cohesion loss.
- Full-depth cohesion loss.

Most of the distresses represented a reduction in a seal's ability to perform its main function—to keep water from infiltrating the joint. These distresses include partial-depth adhesion and cohesion loss, partial-depth spalling, overband wear, and stone intrusion. The other distresses, full-depth adhesion and cohesion loss and full-depth spalling, signified a seal's inability to perform its function. These distresses were termed "failure distresses." The total amount of failure distress observed in a seal formed the primary basis for performance comparisons.

Other types of data collected in the field evaluations included climatic conditions (e.g., air temperatures, precipitation), joint gauge plug measurements, and faulting measurements. Data from two in-place sealant tests were also recorded. The nondestructive coin test was performed regularly on each sealant product to give a general indication of the material's resilience. The test procedure consists of inserting a quarter half-way into the sealant and measuring the amount it is ejected after a 1-min period. Full ejection of the quarter indicates a very resilient material, one capable of keeping incompressible materials from penetrating into the joint. The destructive pull-out test was periodically conducted to indicate material flexibility and adhesiveness. In this test, a 50-mm segment of sealant is cut along the joint sidewalls and at one end. It is then grabbed at 25 mm and pulled straight up at a constant, gradual rate. If the sealant continues to pull from the joint with limited stretching, then the bond is inadequate. If it doesn't pull from the joint, the amount that it stretches before rupture is measured to determine how extensible or flexible it is.

Field Performance Results

After 82 months of service, the predominant failure type at all joint reseal sites was adhesion failure, with sliver spall and cohesive failure having also occurred in slight, but varying, amounts. Figure 23, from I-25 in Colorado, shows typical full-depth adhesion loss. Partial-depth adhesion distress, shown in figure 24, typically ranged in depth from 3.2 mm to 60 percent of the sealant thickness, with an average depth of about half the sealant thickness. Spall-related failure, shown in figure 25, occurred predominantly in the colder States of Iowa and Colorado. Typically, in these States, partial-depth spalls occurred as frequently as full-depth spalls. Reduction in the thickness of the overbanded sealant material, as shown in figure 26, occurred in all seals.

The overall effectiveness levels (i.e., percentage of joint seal length not failed) recorded in the 1997-1998 round of test site inspections are shown in table 13. Types of failure contributing to the overall effectiveness were full-depth adhesion, cohesion, and spall distress. It should be noted that no statistical difference may exist between seals having different effectiveness levels. Statistical analysis of these results is described in chapter 5.

As seen in table 13, several materials were still performing well at the time of the final inspection, with a few having developed less than 5 percent overall failure. However, a significant amount of failure had developed in some materials, with 43 of 82 treatments (i.e., material–configuration combinations in individual States) exhibiting more than 25 percent overall failure. This was an increase from 30 treatments in the 1996-1997 field inspection round, and it indicates that the functional lives of several treatments were nearing an end. According to the seal performance rating categories developed by Belangie and Anderson (1985) and shown in table 14, 20 of the material–configuration combinations in the test sites reached a failed rating (more than 50 percent failure) in the 1997-1998 surveys. This was up from 14 in 1996-1997.

As seen in figure 27, a comparison by State of the overall performance of the primary seals indicates that the effectiveness has continued to decrease now that the seals have weathered six to seven winters and seven summers. Moreover, the seals at South Carolina and Colorado were not performing as well as those at other sites. A primary reason for the large amount of failure at the South Carolina site was the excessive adhesion failure in the configuration 3 joints. In these joints, unfailed silicone sealant was incompletely removed by the available plowing equipment. The silicone that remained on the joint walls inhibited bonding of the new hot-applied sealants and led to significant adhesion loss. The failure at the Colorado site was possibly due to the large amount of joint movement and the rapid temperature changes that occur as storm fronts cross the mountains into the plains. This test site is situated just east of the foothills of the Colorado Rocky Mountains. Another possible reason for the large Colorado site failure was the low quality of the available sandblasting equipment.

Using the database of performance data from this joint seal study, summary reports were derived. Abbreviations were selected for each material and configuration to simplify reporting. These are listed in tables 15 and 16. An example yearly summary table for survival of joint seal effectiveness at the test site on I-25 in Colorado is shown in table 17.

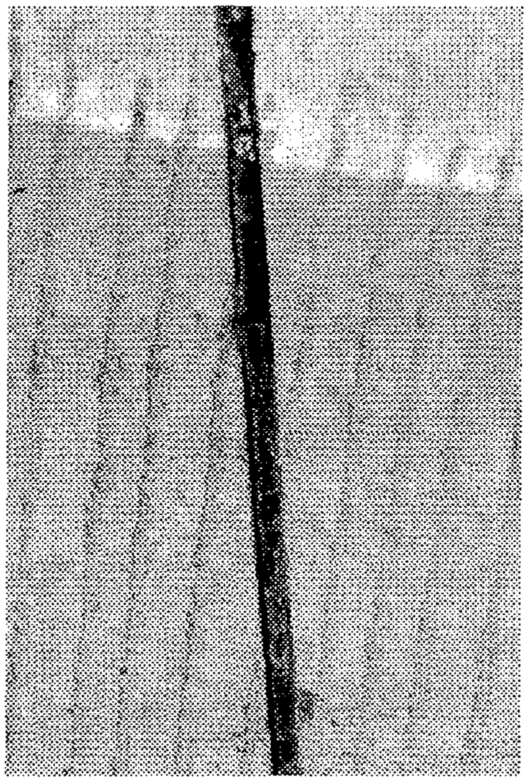


Figure 23. Full-depth adhesion failure.

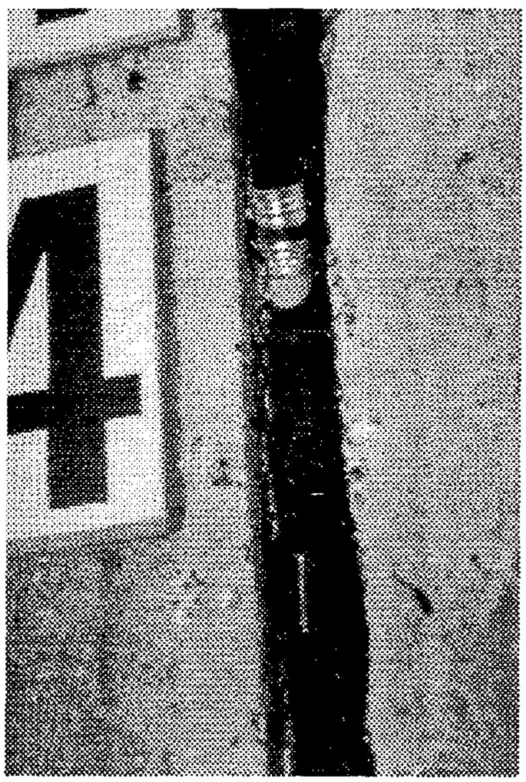


Figure 24. Partial-depth adhesion loss.

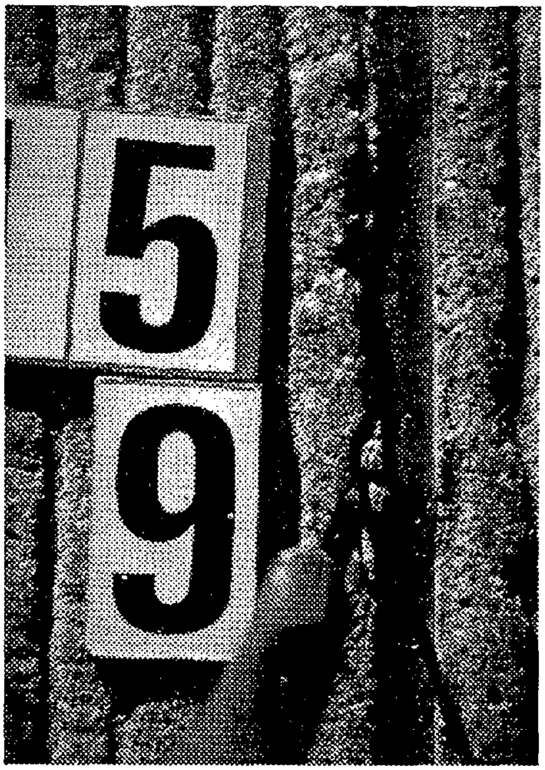


Figure 25. Full-depth spall failure.

Figure 26. Overband wear.

Table 13. Overall effectiveness levels of various treatments following 1997-1998 field inspection round.

Sealant Material	Config-uration	Total Joints	Overall Effectiveness, percent joint length				
			Arizona	Colorado	Iowa	Kentucky	South Carolina
Koch 9005	1	97	80	55	78	93	58
	2	97	87	47	79	97	86
	3	59			92	98	49
	4	38	50	63			
Crafco RS 231	1	98	40	66	63	78	74
	2	96	92	55	85	85	91
	3	59			80	97	71
	4	38	64	60			
Meadows Sof-Seal	1	76		9	20	49	46
	2	75		14	36	59	35
	3	59			59	89	26
	4	19		17			
Koch 9030	1	76		13	43	59	31
	2	73		9	53	62	52
	3	58			60	88	10
	4	19		12			
Meadows Hi-Spec	1	19	37				
	2	20	64				
	4	20	61				
Crafco RS 221	1	20	57				
	2	20	86				
	4	20	71				
Dow 888	1	93	99.7	88	86	97	99
Dow 888-SL	1	97	98	83	86	98	99
Mobay 960-SL	1	98	99	77	51	80	97
Mobay 960	1	18			89		
Crafco 903-SL	1	19	98				
Koch 9050	1	29		15		85	
Dow 888 w/ primer	1	10			89		
Dow 888-SL w/ primer	1	9			87		
Koch 9005 w/ primer	1	10				96	

Table 14. Seal performance rating (Belangie and Anderson, 1985).

Rating	Effectiveness Level, %	Number of Treatments
Very good	90 to 100	17
Good	80 to 89.9	18
Fair	65 to 79.9	8
Poor	50 to 64.9	19
Very poor (failed)	0 to 49.9	20

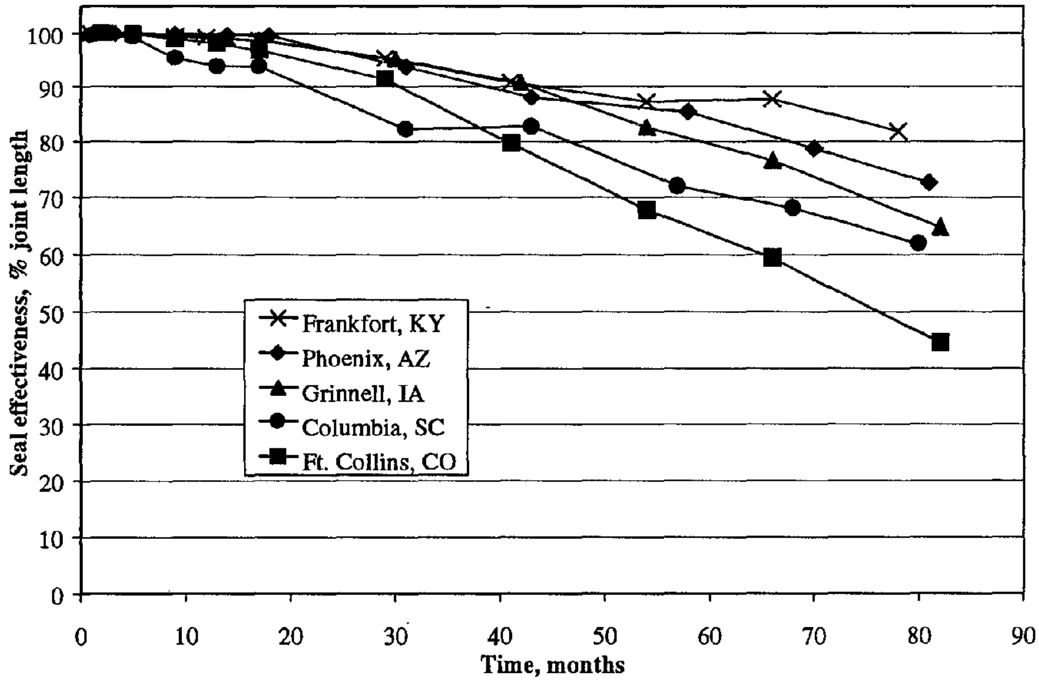


Figure 27. Overall performance of primary seals at each test site.

Table 15. Sealant names and material codes.

Material Code	Manufacturer	Sealant Name	Sealant Type	Abbreviation
1	Crafco	RS 221	Rubberized asphalt	C-221
2	Crafco	RS 231	Low-modulus rubberized asphalt	C-231
3	Koch	9005	Rubberized asphalt	K-9005
4	Koch	9030	Low-modulus rubberized asphalt	K-9030
5	Meadows	Hi-Spec	Rubberized asphalt	M-HS
6	Meadows	Sof-Seal	Low-modulus rubberized asphalt	M-SS
7	Dow	888	Silicone	888
8	Dow	888-SL	Self-leveling silicone	888-SL
9	Mobay	960-SL	Self-leveling silicone	960-SL
A	Mobay	960	Silicone	960
B	Crafco	RS 903-SL	Self-leveling silicone	RS-SL
C	Koch	9050	1-part polysulfide	K-9050
D [a]	Dow	888	Silicone	888-Prm
E [a]	Dow	888-SL	Self-leveling silicone	888-SL/Pr
F [a]	Koch	9005	Rubberized asphalt	K-9005 Prime

[a] Joint walls for these material codes were primed.

Table 16. Configurations (preparation methods) and their abbreviations.

Configuration Number	Preparation Method	Abbreviation
1	Saw, sandblast, airblast, install recessed	S&R
2	Saw, sandblast, airblast, install overbanded	S&O
3	Plow, airblast, install overbanded	P&O
4	Saw, sandblast, airblast, install flush with surface	S&F

Table 17. Seal effectiveness summary for Colorado I-25 site.

Material	Config-uration	Repli-cate	Partial-Depth Adhesiveness, % joint length	Full-Depth Adhesiveness, % joint length	Full-Depth Cohesiveness, % joint length	Partial-Depth Spall Adequacy, % joint length	Full-Depth Spall Adequacy, % joint length	Overall Effectiveness, % joint length
C-231	1	1	80.2	79.9	99.6	90.9	93.5	73.0
C-231	1	2	46.7	79.3	88.2	90.7	92.7	60.2
		avg	62.5	79.6	93.6	90.8	93.1	66.3
C-231	2	1	88.2	60.9	100.0	93.0	90.3	51.2
C-231	2	2	65.6	66.6	100.0	94.9	92.6	59.2
		avg	76.3	63.9	100.0	94.0	91.5	55.4
C-231	4	1	86.7	60.2	100.0	89.1	93.9	54.1
C-231	4	2	76.7	73.6	99.7	93.9	91.9	65.3
		avg	81.2	67.6	99.8	91.7	92.8	60.3
K-9005	1	1	78.5	78.0	70.8	93.0	96.9	45.7
K-9005	1	2	94.0	83.7	83.3	96.8	96.5	63.5
		avg	86.7	81.0	77.3	95.0	96.7	55.0
K-9005	2	1	99.2	84.4	61.6	96.2	98.8	44.8
K-9005	2	2	100.0	79.8	70.6	96.3	99.0	49.4
		avg	99.6	82.0	66.3	96.3	98.9	47.3
K-9005	4	1	98.0	98.6	63.8	95.4	98.2	60.6
K-9005	4	2	100.0	99.4	67.9	93.4	97.3	64.6
		avg	99.0	99.0	66.0	94.4	97.7	62.7
K-9030	1	1	62.7	20.1	100.0	91.9	91.8	11.9
K-9030	1	2	65.1	20.3	100.0	94.9	93.4	13.7
		avg	64.0	20.2	100.0	93.5	92.7	12.9
K-9030	2	1	68.7	15.7	100.0	91.4	92.6	8.3
K-9030	2	2	58.3	18.3	100.0	95.8	92.0	10.3
		avg	63.2	17.1	100.0	93.7	92.3	9.4
K-9030	4	1	75.2	9.3	99.8	95.0	92.4	1.5
K-9030	4	2	76.1	30.6	99.8	93.5	90.3	20.7
		avg	75.7	20.5	99.8	94.2	91.3	11.6
M-SS	1	1	58.0	17.5	100.0	88.1	92.1	9.6
M-SS	1	2	67.4	15.3	99.9	94.3	93.1	8.3
		avg	63.0	16.4	99.9	91.4	92.6	8.9

Table 17. Seal effectiveness summary for Colorado I-25 site (continued).

Material	Config-uration	Repli-cate	Partial-Depth Adhesiveness, % joint length	Full-Depth Adhesiveness, % joint length	Full-Depth Cohesiveness, % joint length	Partial-Depth Spall Adequacy, % joint length	Full-Depth Spall Adequacy, % joint length	Overall Effectiveness, % joint length
M-SS	2	1	75.2	23.5	99.2	84.6	83.3	5.9
M-SS	2	2	69.8	39.2	95.5	92.1	86.5	21.2
		avg	72.4	31.8	97.2	88.5	85.0	14.0
M-SS	4	1	82.3	29.0	98.2	91.4	86.3	13.5
M-SS	4	2	81.9	36.6	99.0	94.0	85.0	20.6
		avg	82.1	33.0	98.6	92.7	85.6	17.2
888	1	1	98.8	97.7	100.0	83.1	87.6	85.3
888	1	2	99.9	99.4	99.9	86.3	90.1	89.4
		avg	99.3	98.6	100.0	84.8	88.9	87.5
888-SL	1	1	98.5	96.1	100.0	88.6	88.6	84.6
888-SL	1	2	99.3	95.2	100.0	92.8	87.0	82.2
		avg	98.9	95.6	100.0	90.8	87.8	83.4
960-SL	1	1	96.7	89.3	100.0	87.8	85.0	74.3
960-SL	1	2	97.2	97.8	100.0	89.2	82.0	79.9
		avg	97.0	93.8	100.0	88.5	83.4	77.2
K-9050	1	1	100.0	29.0	90.8	94.8	94.7	14.5
K-9050	1	2	97.8	47.6	80.5	95.6	88.0	16.0
		avg	98.9	38.8	85.4	95.2	91.2	15.3

Unshaded rows in this table represent a summation for each treatment replicate—10 joints prepared with the same materials and preparation procedures. Shaded rows are an average of the percent joint length effectiveness for both replicates of a treatment. The remaining performance summary tables for each site and distress are included in appendix D. Summaries of the full-depth adhesion, cohesion, and spall failures after 82 months for each site, material, and installation method are shown in figures 28 through 32.

Differences in the performances of the silicone and hot-applied sealants increased significantly as traffic and climatic cycling took a toll. These differences became more evident after the third winter, as figure 33 illustrates. Because not all sealants were installed at every site, using figure 33 for direct performance comparison is not recommended. For example, the secondary sealants (Crafco 221 and Meadows Hi-Spec) were installed at only one site. Table 1 in chapter 1 provides a list of the sealants installed at each location. The performance characteristics of each material in configuration 1 at individual test sites are shown in figures D-2 through D-6 in appendix D.

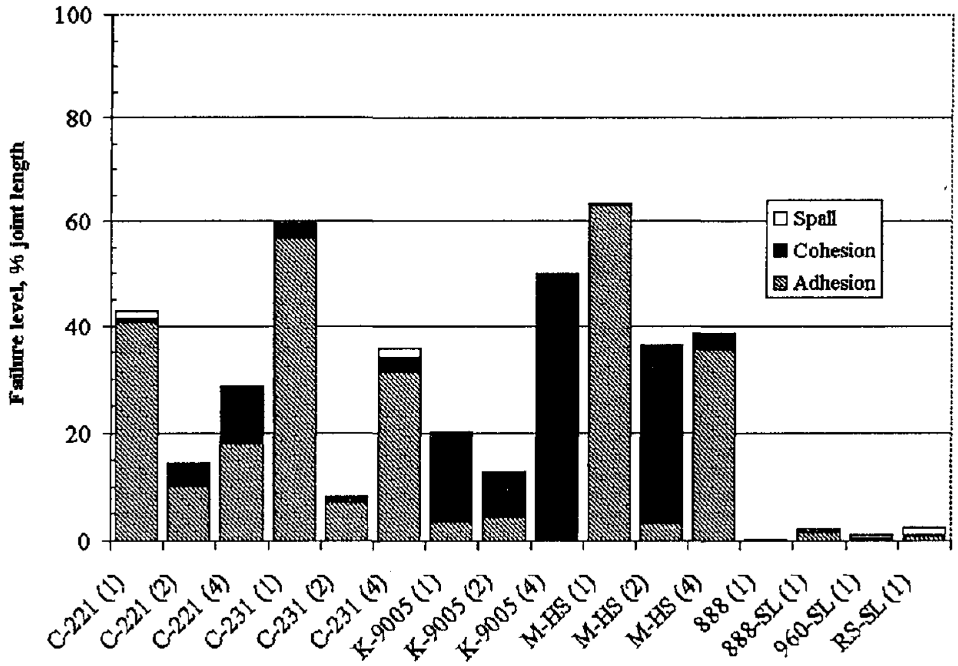


Figure 28. Overall failure at Arizona I-17 site after 81 months.

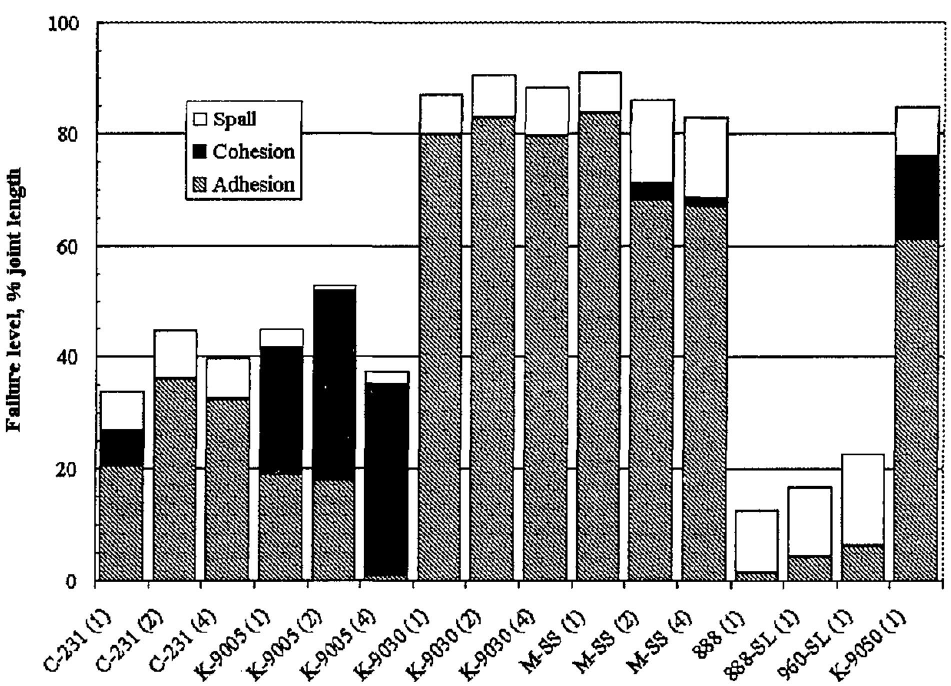


Figure 29. Overall failure at Colorado I-25 site after 81 months.

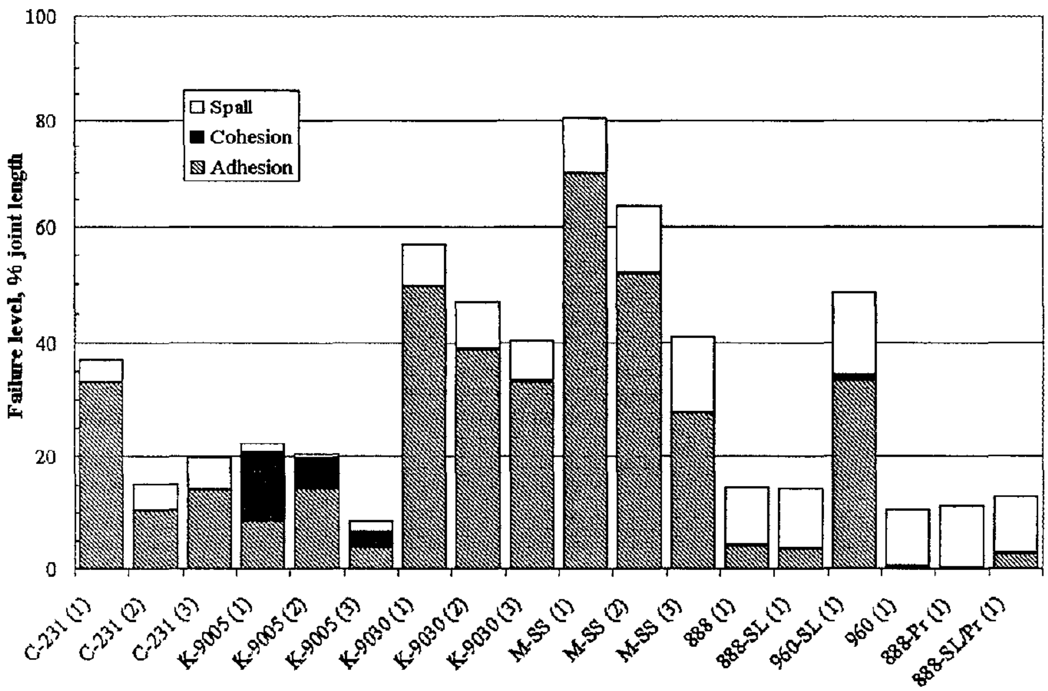


Figure 30. Overall failure at Iowa I-80 site after 82 months.

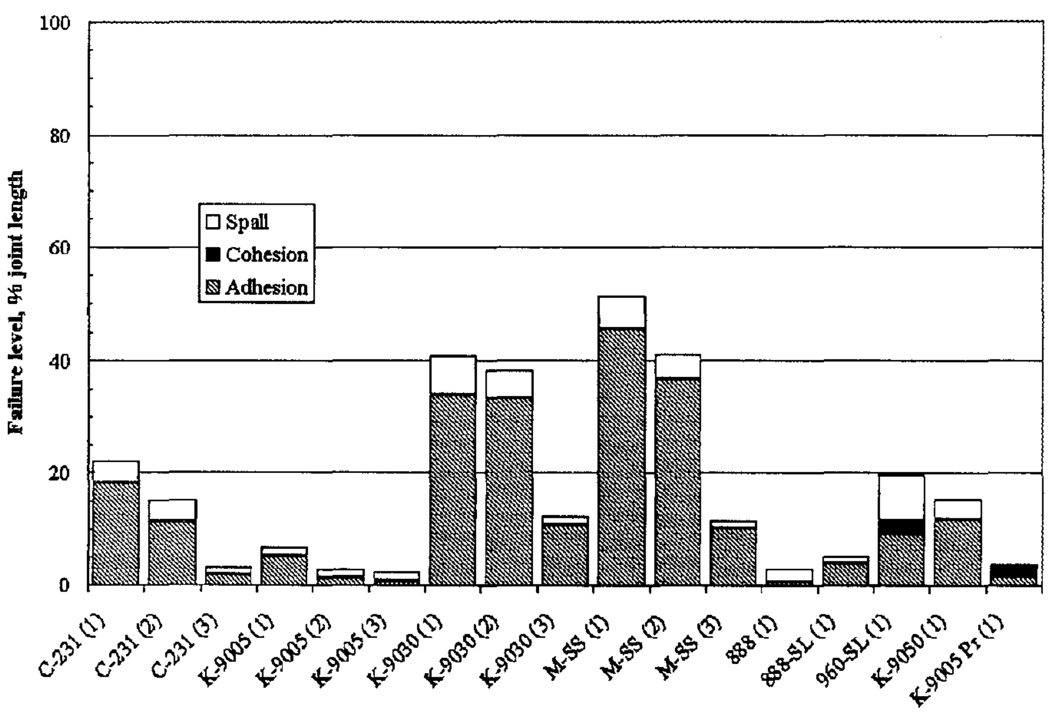


Figure 31. Overall failure at Kentucky U.S. 127 site after 78 months.

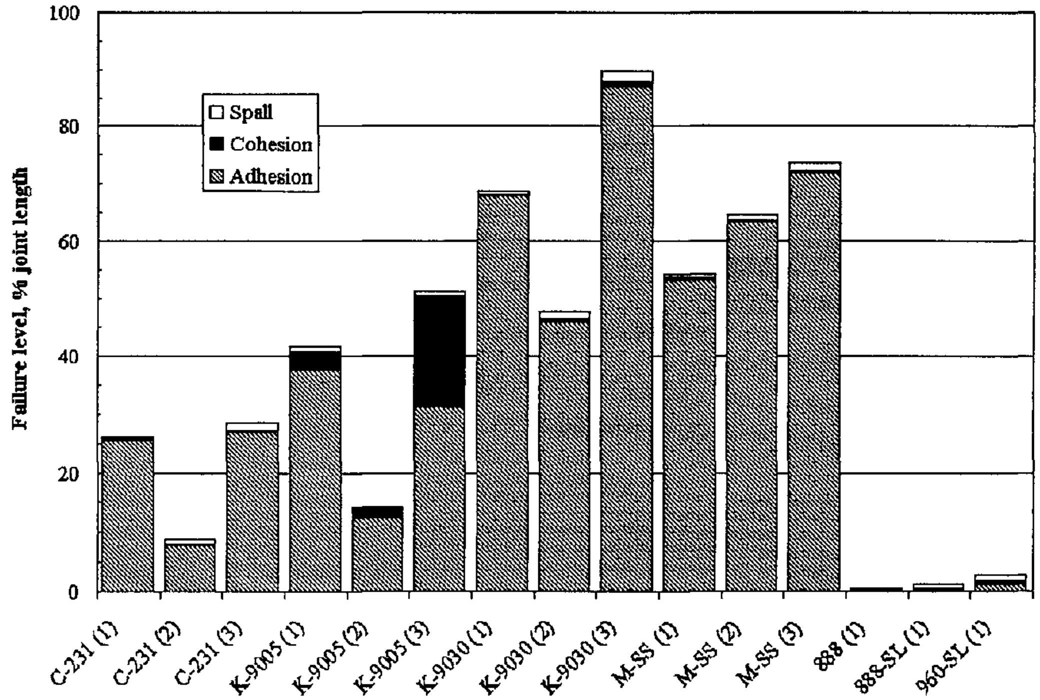


Figure 32. Overall failure at South Carolina site after 80 months.

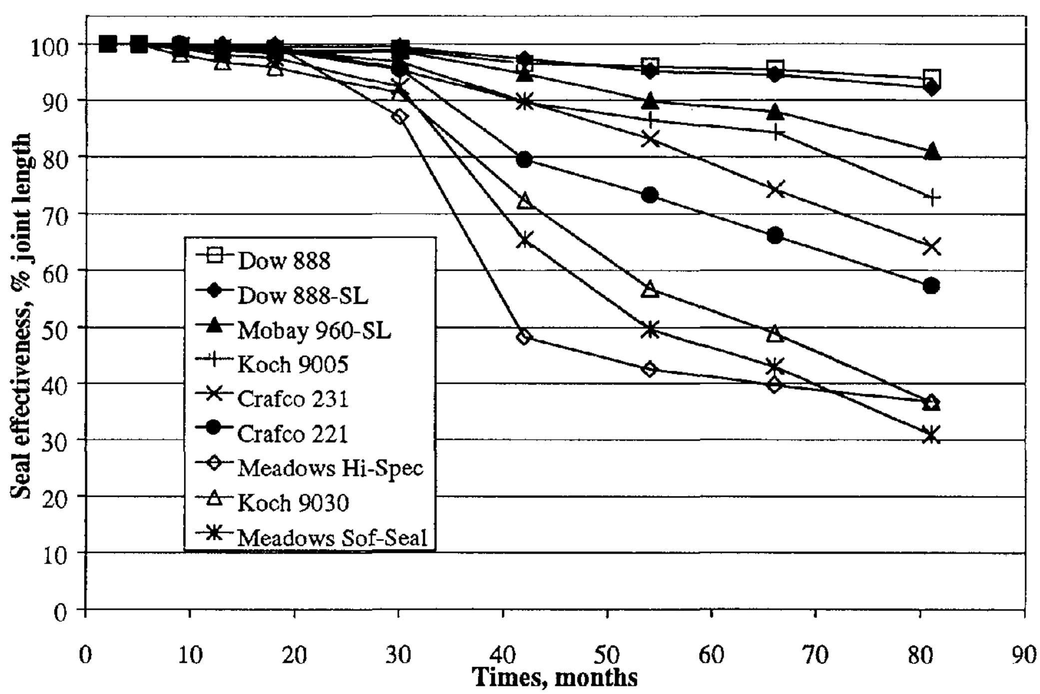


Figure 33. Overall effectiveness of configuration 1 sealants from all sites.

Some performance differences between the standard rubberized asphalt (ASTM D 3405), the low-modulus rubberized asphalt (low-modulus ASTM D 3405), and the silicone sealant materials became evident. The standard rubberized asphalt sealants tended to become sticky at high temperatures and stiff at low temperatures. This led to some embedment of stones in these materials and occasional cohesion failure as the stiffened sealant is stretched beyond its tensile limit. Some of these materials seemed to have a self-healing tendency, whereby the summer season tended to soften the sealant and promoted readherence to the joint edge. The average overall amount of adhesion and cohesion failure for these sealants was 15.8 and 12.2 percent, respectively. Following the final inspection, adhesion failure tended to be highest in the recessed configuration 1 and least in the overbanded configuration 2.

The low-modulus ASTM D 3405 sealants were generally soft and resilient over a range of temperatures, and they resisted stone intrusion well. When overbanded 3 mm thick, the materials were typically completely worn away by traffic after 18 months, with one exception. Crafco RS 231 sealant resisted traffic wear more than the other low-modulus sealants, but it was generally worn from most sites by the time of evaluation 7 (approximately 42 months).

Although the low-modulus sealants were soft under cold conditions, they generally developed more adhesion failure than the standard rubberized asphalt sealants. Again, the exception was the Crafco RS 231 low-modulus sealant. Cohesion failure was minimal for this type of sealant—less than 0.5 percent. The average amount of adhesion failure for the low-modulus sealants was 41.7 percent, up from 31.7 percent in the 1996-1997 field inspection round. Overall failure was generally highest in the sawed/recessed configuration 1 and the sawed/flush-filled configuration 4.

An average of 10.5 percent overall failure developed in the self-leveling and non-self-leveling silicone sealant materials at all sites. The joints in which these materials were installed were prepared in the same manner as the joints sealed using recessed hot-applied sealants. However, the silicone sealant overall adhesion failure rate was only 4.2 percent, and partial-depth adhesion loss was less than 1 percent. The only material that began to exhibit adhesion and cohesion failure was the Mobay 960-SL silicone, which has been taken off the market. At the Iowa site, samples of this sealant partially or completely split from the bottom upward. Spall formation accounted for 6.0 percent of the overall silicone failures. These spalls were typically less than 25 mm long and less than 9 mm wide and were commonly found in the wheelpaths.

Comparison of the ASTM D 3405 sealant performance differences, when installed in different configurations, revealed some interesting trends. The performance characteristics of the standard and low-modulus ASTM D 3405 materials are shown in figures D-2 through D-6 in appendix D. Overall failure was more pronounced in the sawed/recessed and sawed/flush-filled configurations (configurations 1 and 4), averaging 41 and 33 percent, respectively. More than 91 percent of the failures in all configurations were related to adhesion or cohesion. Full-depth adhesion loss was greater in recessed sealants than in overbanded and flush-filled sealants at the same site by 2.7 and 1.7 times, respectively. These trends indicated that the recessed configuration may not provide the best adhesion performance when compared with other installation methods.

Joint Movement

Concrete pavements shrink in cold temperatures, causing the joint widths to increase and the joint seal to be stretched in the reservoir. To estimate the joint movement experienced by the sealant materials at the five sites, joint widths were measured at extreme summer and winter temperatures, as well as at the sealant installation temperature. Using the average coefficient of thermal expansion backcalculated from air temperatures and from the joint width data, the maximum extension at each joint was computed at the coldest recorded air temperature since installation.

As shown in table 18, the variability in movement from joint to joint was great at each site. The Arizona site experienced the least movement, as expected, because of its short joint spacing and the small difference between installation temperature and the minimum temperature. The Colorado site experienced the largest average computed joint movement.

Table 18. Computed maximum joint movement.

Test Site	Joint Spacing, m	Average Air Temperature During Installation, °C	Min. Air Temperature Since Installation, °C	Average of Maximum Computed Joint Opening, %	Standard Deviation of Maximum Computed Joint Opening, %	Computed Joint Opening Range, %
Phoenix, AZ	4.6	18.3	0	4.2	5.4	0 to 33.8
Ft. Collins, CO	3.7 to 4.6	15.6	-28.4	22.2	9.9	1.3 to 72.5
Grinnell, IA	6.1	28.3	-32.3	9.4	6.2	0.4 to 57.7
Frankfort, KY	9.1 to 15.2	31.7	-23.3	16.6	11.5	0.2 to 62.1
Columbia, SC	5.8 to 7.6	23.9	-10.5	12.7	9.2	0 to 76.2

CHAPTER 5. DATA ANALYSIS

The primary objective of this project was to determine which materials and procedures provided the longest-lasting joint seal performance. Once the performance characteristics of the various joint seal treatments were determined, then the cost-effectiveness of each material and procedure could be computed. A supplemental goal of the project was to determine which laboratory tests and properties relate well with field performance. Such knowledge would assist maintenance planners in specifying and using high-quality materials.

Variations in failure rates since installation resulted in a wide range of treatment failure levels (between 9 and 99 percent of the total joint length) at the time of the final round of field inspections. Consequently, some significant differences in performance became evident. The following sections outline the methodology used in determining statistical differences in joint seal performance and present the results of statistical analysis with regard to field performance and laboratory testing. A comparative analysis of the performance properties of each treatment is also presented and discussed.

Statistical Methodology

The joint resealing experiment was designed for a randomized block design analysis with two factors—treatments and position along the joint. Two replicates of 10 joints sealed using unique treatments (i.e., combinations of one material and one preparation method) comprised the blocks for analysis of performance at each site. To complete a statistical analysis of the joint seals, a statistical comparison was made of the distresses, failures, and laboratory test results between each of these treatments periodically and over time. An additional analysis of the time to 75 percent effectiveness was also conducted.

Analysis of field and laboratory performance data was performed using SAS® statistical software release 6.12. Prior to statistical analysis, performance data were compiled in spreadsheets, verified, and converted to American Standard Code for Information Interchange (ASCII) format. SAS® command files were prepared for each analysis, instructing the program how to read the ASCII data, what types of statistical analysis to perform, and what form of output was desired.

For the analysis of treatment performance, the SAS® General Linear Models (GLM) procedure with the multivariate analysis of variance (MANOVA) option was used. This procedure used the mean distress values and variability associated with each distress or failure to determine if the performance of one or more of the treatments was statistically different at a determined confidence level. If the analysis of variance indicated that performance differences existed, a Tukey's Studentized Range (HSD) analysis of ordered means was completed to rank the treatments that performed differently. The SAS® CONTRAST options and multiple paired t-tests were used to determine if sealant performance in different configurations was statistically different. In addition, the SAS® PROC CORR function was used to study relationships between field performance and sealant material laboratory test results.

Analysis of Variance

Analysis of variance yields a probability rating between 0 and 1 that the values of each distress are the same for each replicate, treatment, and position. For example, if there is no significant difference at one site between the adhesion failure of all treatments, the rating would be near 1. If, however, a significant difference exists between one or more of the treatments, the rating would be near 0. The ratings are based on a Type IV mean square, with Replicate*Treatment as an error term. For this analysis, probability ratings of 0.05, corresponding to a 95 percent confidence level, were used to indicate the existence of significant differences.

Results of the analysis of variance of treatments for the five sites are presented in table 19. As the probability ratings indicate, one or more treatments at all sites exhibited a statistically significant difference in partial- and full-depth adhesion loss and partial-depth sliver spall failure. The amount of full-depth spalls and full-depth cohesion failure in each treatment was significantly different at only three of the five sites. The indication is that full-depth spalls and cohesive failure are not largely a function of material type or installation method at the remaining two sites. Overall failure, which includes full-depth adhesion, cohesion, and spall failure, was significantly different between two or more treatments for all sites except Arizona.

When the MANOVA analysis indicates a significant difference in one or more of the treatments, further analysis can be conducted to determine which treatments are performing differently. The Tukey's studentized range analysis of the SAS® GLM procedure was used to rank each treatment by similar performance. Tukey analysis orders the mean distress values for each treatment in descending order and groups treatments that are performing statistically the same. Table 20 is an example of the means and grouping for each treatment at the Colorado test site, as ranked by the amount of full-depth adhesion failure. This example, shown graphically in figure 31, indicates that the amount of full-depth adhesion loss was not significantly different for treatments 1, 2, 3, and 4. There was also no significant difference in the adhesion failure of treatments 5, 6, and 7; 8 and 9; 10,11, and 12; and 13, 14, 15, and 16. Statistically, the treatments in grouping 1 exhibited less adhesion failure than the remaining groupings, and the treatments in grouping 5 have developed more distress than those in the other groupings.

Table 19. Probability ratings from analysis of variance for 1997-1998 treatment performance.

Distress	Arizona	Colorado	Iowa	Kentucky	South Carolina
Partial-depth adhesion loss	0.0001 ✓	0.0001 ✓	0.0172 ✓	0.0091 ✓	0.0121 ✓
Full-depth adhesion loss	0.0027 ✓	0.0001 ✓	0.0003 ✓	0.0001 ✓	0.0006 ✓
Full-depth cohesion failure	0.5537	0.0014 ✓	0.0031 ✓	0.1031	0.0451 ✓
Partial-depth spall distress	0.0004 ✓	0.0001 ✓	0.0001 ✓	0.0004 ✓	0.0010 ✓
Full-depth spall distress	0.0001 ✓	0.0001 ✓	0.0001 ✓	0.6627	0.6545
Overall failure	0.1420	0.0001 ✓	0.0001 ✓	0.0077 ✓	0.0011 ✓

✓ Indicates a significant difference.

Table 20. Illustration of Tukey groupings for Colorado full-depth adhesion failure.

Treatment	Material	Configuration	Mean (%)	Groupings				
1	Koch 9005	4	1.0	1				
2	Dow 888	1	1.4	1				
3	Dow 888-SL	1	4.4	1				
4	Mobay 960-SL	1	6.2	1				
5	Koch 9005	2	18.0		2			
6	Koch 9005	1	19.0		2			
7	Crafco RS 231	1	20.4		2			
8	Crafco RS 231	4	32.4			3		
9	Crafco RS 231	2	36.1			3		
10	Koch 9050	1	61.2				4	
11	Sof Seal	4	67.0				4	
12	Sof Seal	2	68.2				4	
13	Koch 9030	4	79.5					5
14	Koch 9030	1	79.8					5
15	Koch 9030	2	82.9					5
16	Sof Seal	1	83.6					5

Analysis of service life was conducted using the same SAS GLM procedure with the MANOVA option. The time at which each joint reached 75 percent effectiveness was used as the performance measure, and HSD analysis allowed for comparison of effectiveness differences between treatments. Results of these analysis methods are presented in the following sections.

Field Performance Analyses

Analyses of field performance were made between materials, between preparation and installation methods, between States, over time, and along the length of the joint. In the discussions that follow, the materials are referred to by their names or by a number or a letter, as listed previously in table 15, and configuration or installation methods are designated by the numbers or letters listed previously in table 16. Figure 2 in chapter 1 illustrates the methods and profile of each configuration.

Comparison of Materials and Preparation Methods

Comparison of material performance can be based on full-depth seal system failure or non-failure distresses. The definition of full-depth seal system failure used in this report is a seal system that allows unrestricted infiltration of moisture or incompressible material below the joint seal. The distresses observed in this study that met the above system failure criteria were full-depth adhesion, spall, and cohesion failures. Non-failure distresses observed at the test sites included overband wear, partial-depth adhesion loss, and partial-depth spall distress.

The results of the MANOVA analyses of overall failure indicate that a significant difference in performance occurred between at least one material–configuration combination and the remaining combinations in four test sites. This allows HSD comparison of the univariate means to determine the ranking of performance between materials and configurations. Results of the HSD comparisons between materials for 82-month overall failure at each test site are shown in figures 34 through 38. Results of the HSD comparisons between materials regarding full-depth adhesion failure are illustrated in figures D-7 through D-11 of appendix D.

Overall Performance

In comparing the 82-month overall performance of materials in each configuration, it is clear that there were statistically evident performance differences at all sites but Arizona. As table D-1 in appendix D indicates, overall failure at the Arizona site varied greatly between replicates. Typically, joint seals in replicate 2 developed much more failure than those in replicate 1. There was little difference in the traffic levels and pavement condition between these replicates, making differences in installation conditions a possible cause for the variation.

Numerically, the Dow 888 and Dow 888-SL silicone sealants and the Crafco RS 231 and Koch 9005 hot-applied sealants showed the best overall performance. Crafco RS 903-SL silicone also performed well. Materials that did not perform as well were the Meadows Sof-Seal and Koch 9030 ASTM D 3405 sealants. Although these sealants are low-modulus, very soft sealant materials, their adhesive properties appear to have been reduced by the addition of polymers and rubbers. Mobay's 960-SL silicone, which is no longer commercially available, developed cohesion and adhesion problems at the Iowa and Kentucky sites, reducing its overall performance.

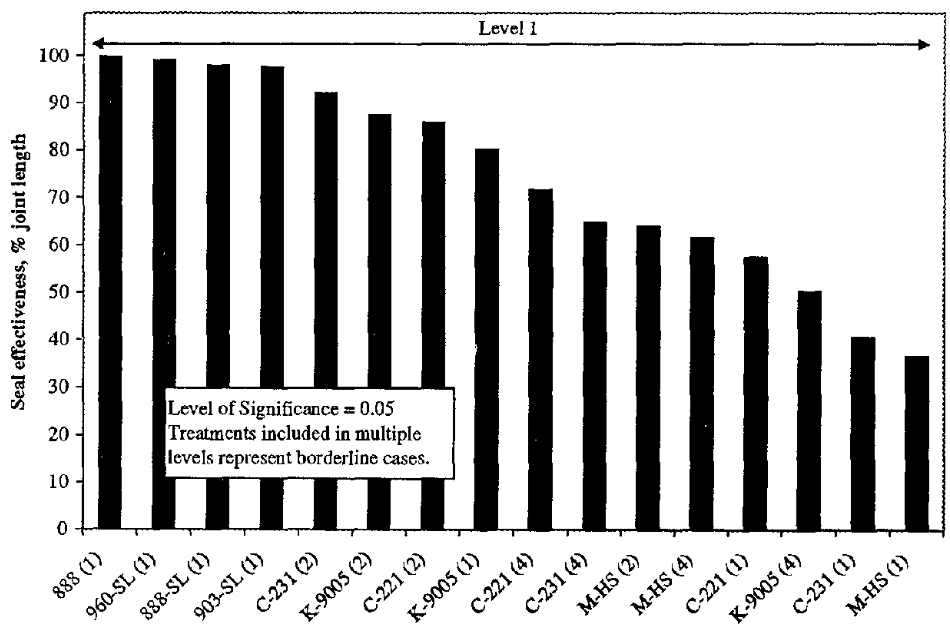


Figure 34. Overall effectiveness groupings for Arizona I-17 site.

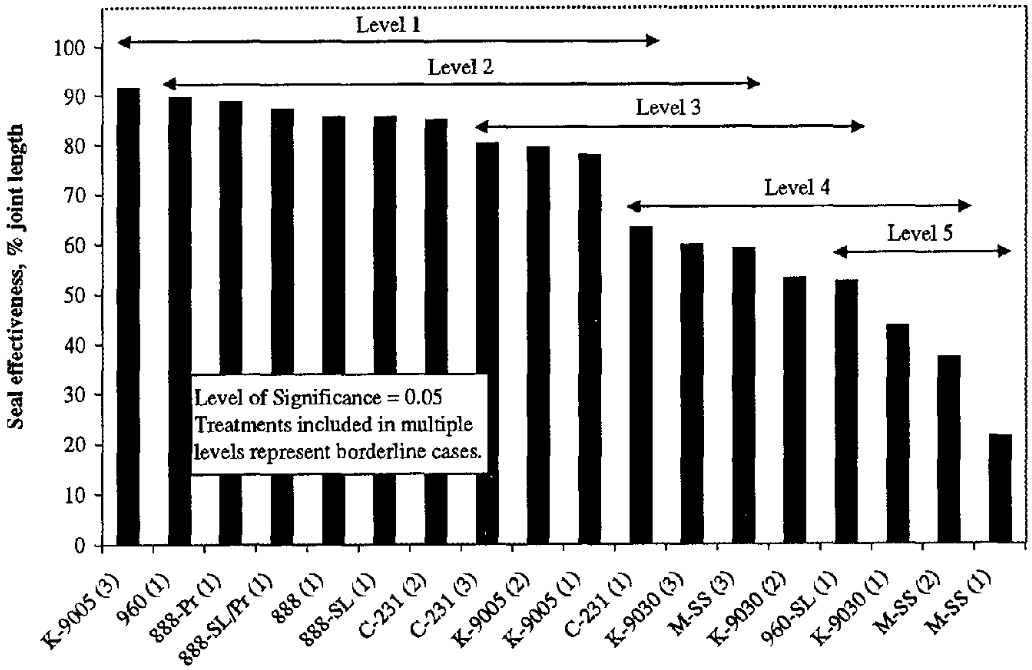


Figure 35. Overall effectiveness groupings for Iowa I-80 site.

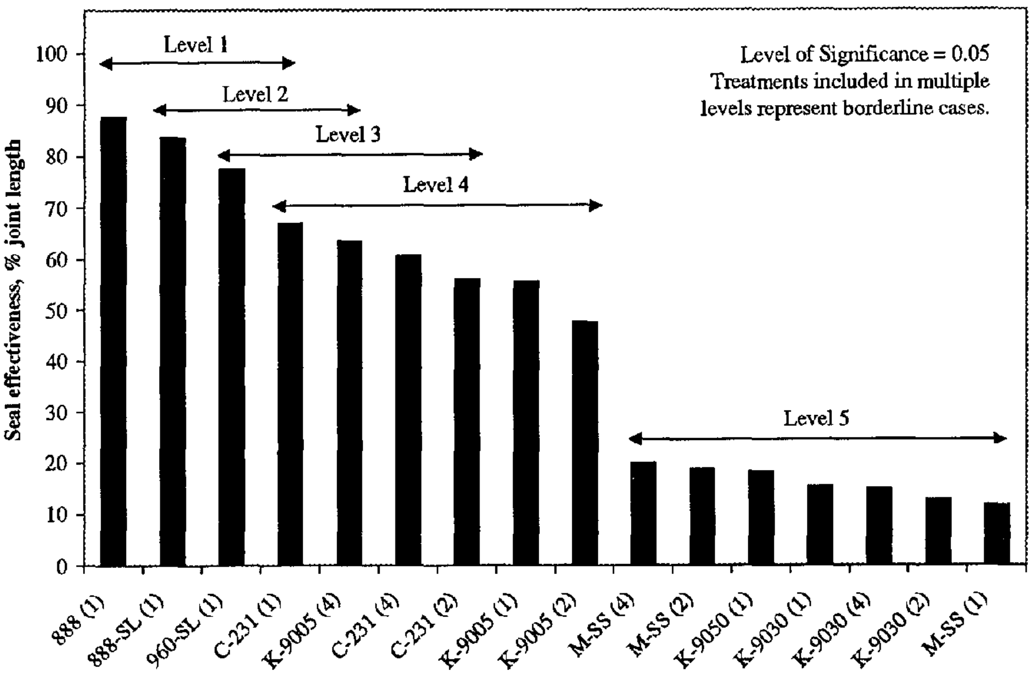


Figure 36. Overall effectiveness groupings for Colorado I-25 site.

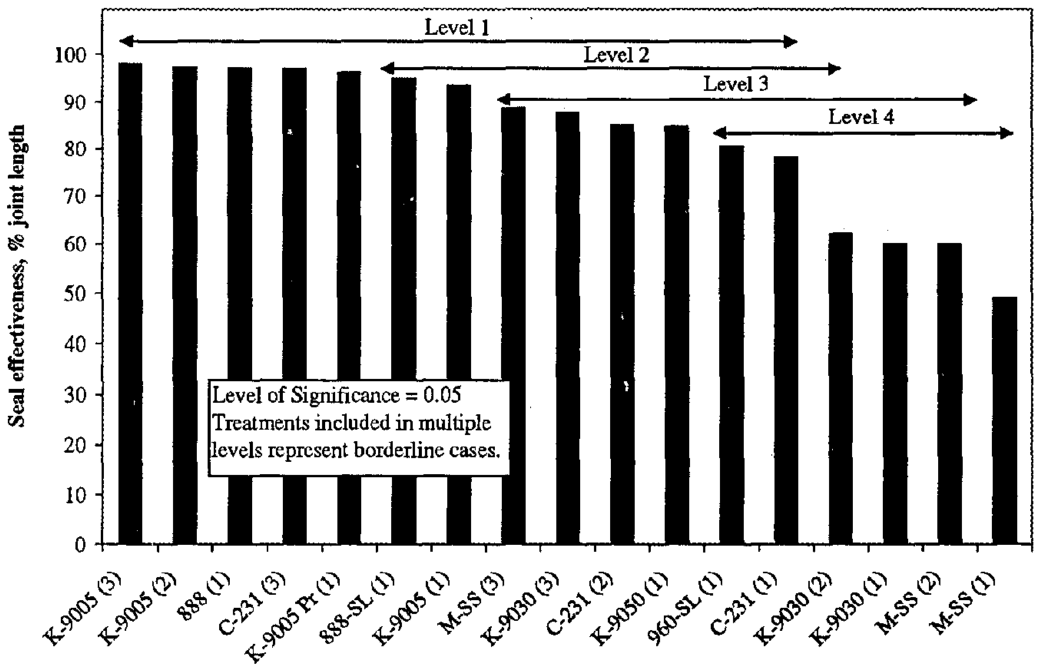


Figure 37. Overall effectiveness groupings for Kentucky U.S. 127 site.

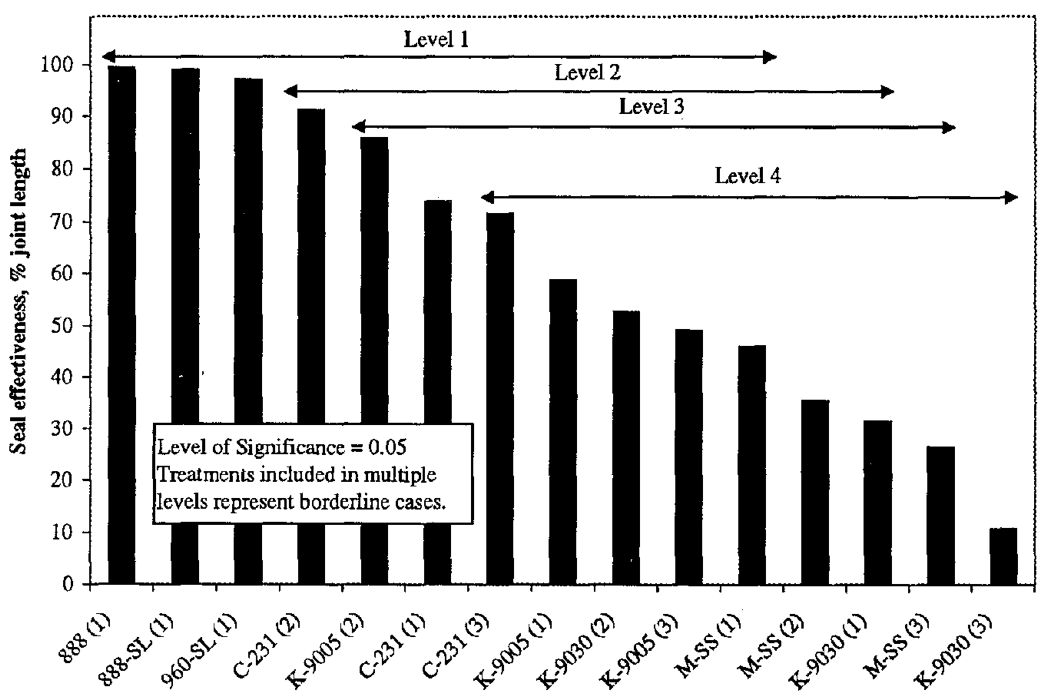


Figure 38. Overall effectiveness groupings for South Carolina I-77 site.

The self-leveling polysulfide sealant failed completely at the Colorado site, yet maintained better than 75 percent effectiveness at the Kentucky site. Different formulations were used at these two sites.

Statistically, the currently available silicone sealants provided better overall performance in the recessed configuration. Crafco's RS 231 developed more overall failure than silicone sealants, but remained statistically no different from the Dow silicone sealants at four sites. Koch 9005 also was not statistically different from the silicone sealants at three sites in terms of allowing moisture to penetrate the seal. It should be noted that the Koch 9005 was very soft and sticky at times and permitted a large amount of stone intrusion. This material also became stiff in cold conditions and was noted to fail in cohesion during the winter and melt together in the summer months.

Full-Depth Adhesion

Similar statistical comparisons were possible for full-depth adhesion loss at the five sites, as noted in figures D-7 through D-11. At the Arizona test site, adhesion failure in configuration 1 joints was the same for the silicone sealants and Koch 9005. The remaining three sealants contained more adhesion failure. Silicone sealants at the remaining sites also contained the least adhesion loss. Koch 9005 adhesion failure in configuration 1 was also statistically the same as silicone sealants at two sites. Meadows Sof-Seal and Koch 9030 in configuration 1 resisted adhesion failure the least of the installed sealants. Koch 9050 polysulfide at the Colorado site also developed more adhesion failure than most other sealants in configuration 1.

In configurations 2, 3, and 4, the Crafco RS 231 and Koch 9005 developed statistically less adhesion failure than the other hot-applied sealants at four sites. At the Arizona site, Koch 9005 in configuration 4 showed very little adhesion failure, but it exhibited nearly 50 percent cohesive failure. The full-depth adhesion performance in configuration 2 at the Colorado site was significantly different between materials, with performance decreasing from Koch 9005 to Crafco RS 231, to Koch 9030 to Meadows Sof-Seal.

Full-Depth Spalls

Since sealant installation, full-depth sliver spalls developed along 8.7 percent of the total joint length at the Colorado site and along 7.9 percent of the joint length at the Iowa site. These percentages for the Kentucky, South Carolina, and Arizona site were 3.2, 1.1, and 0.6 percent, respectively. Failure resulting from spalls accounted for a large amount of total seal failure at the colder sites. Understanding the mechanism for this failure and developing methods for reducing spall formation could be a very cost-effective proposition.

Nearly twice as much new full-depth spall failure was noted in the silicone sealants at the Iowa site (11.8 percent), compared with the hot-applied sealants in configuration 1 at the same site (6.5 percent). This ratio is about 1.7 for the silicone sealants at the Colorado site (13.3:8.0). The larger amount of spalling developed in the silicone sealants may, in part, be traced to the stress developed when the sealant is elongated. As shown in tables C-4 and C-6, the stress in silicone sealants installed at the Iowa and Colorado sites is 1.4 to 6.2 times greater than that in rubberized asphalt sealants when stretched to 150 percent of their original length. The bond strength between the silicone sealant and the concrete may have been better than the tensile strength of the concrete. Therefore, in conjunction with cold-weather elongation and traffic loads, more new spalls may have developed along the joints containing silicone sealants.

This theory does not hold up well for spall failure in silicone sealants. In both the Iowa and Colorado sites, joints sealed with Mobay 960-SL with low stress (95 kPa) developed 1.4 times the amount of spalls as the Dow 888-SL (109 kPa) and the Dow 888 (256 kPa). Another possible reason for the larger amount of spall development in silicone-sealed joints is the stress-softening characteristics of hot-applied sealants. Stresses in extended hot-applied sealant samples reportedly decrease over time, whereas stresses in silicone sealants remain essentially the same. Combined with shear stresses from multiple traffic loads, the extended higher level of stress in silicone sealants may have produced additional spall failure.

Joints primed and sealed with a non-self-leveling Dow Corning 888 silicone at the Iowa site developed no more partial- and full-depth spalls than unprimed joints sealed with Dow Corning 888. Priming joints sealed with a self-leveling Dow Corning 888-SL silicone sealant also showed no significant difference in partial- and full-depth spall development from unprimed joints sealed with the same material.

Full-Depth Cohesion Failure

Compared with the low-modulus ASTM D 3405 and the silicone sealants, cohesive failure developed in statistically larger amounts in the standard ASTM D 3405 hot-applied sealant materials at the Arizona, Colorado, and Iowa sites. For unknown reasons, cohesive failure typically developed in much larger amounts in replicate 2 of the Arizona site. The resulting high treatment variability led to no statistical difference in cohesion failure between any materials at this site. At the Colorado site, large amounts of cohesive failure developed in the Koch 9005 in all configurations. Average cohesive failure for configurations 1, 2, and 4 was 22.7, 33.7, and 34.0 percent, respectively. Statistically, however, there was no difference in cohesive failure levels between these configurations. Cohesive failure at the Iowa site also developed in the Koch 9005 in configurations 1 and 2 at statistically greater levels than the other sealants.

<u>Relationship Between Performance and Position Along Joint</u>

The effect of tire contact and traffic loads on adhesion loss and spall distress was studied, and the results indicate that spalling occurs more frequently in the wheelpaths. Only minor differences in adhesion performance as a function of the distance from the shoulder edge were noted, and these differences did not correlate well with the wheelpath positions. The relationship between distance from the shoulder edge and spall failure is shown in figure 39. Failure rates are shown in this figure for each of the twelve 0.3-m increments from the longitudinal shoulder edge.

Statistical analysis of variance of the full-depth spalling indicates that, at all but the Arizona site, a difference existed in spall development, depending on its position in the lane. For example, at the Iowa site, more full-depth spalls developed at positions 2, 3, 4, 10, and 11 (the wheelpaths) and more partial-depth spalls developed at positions 2, 3, 4, 9, 10, and 11. At the Colorado site,

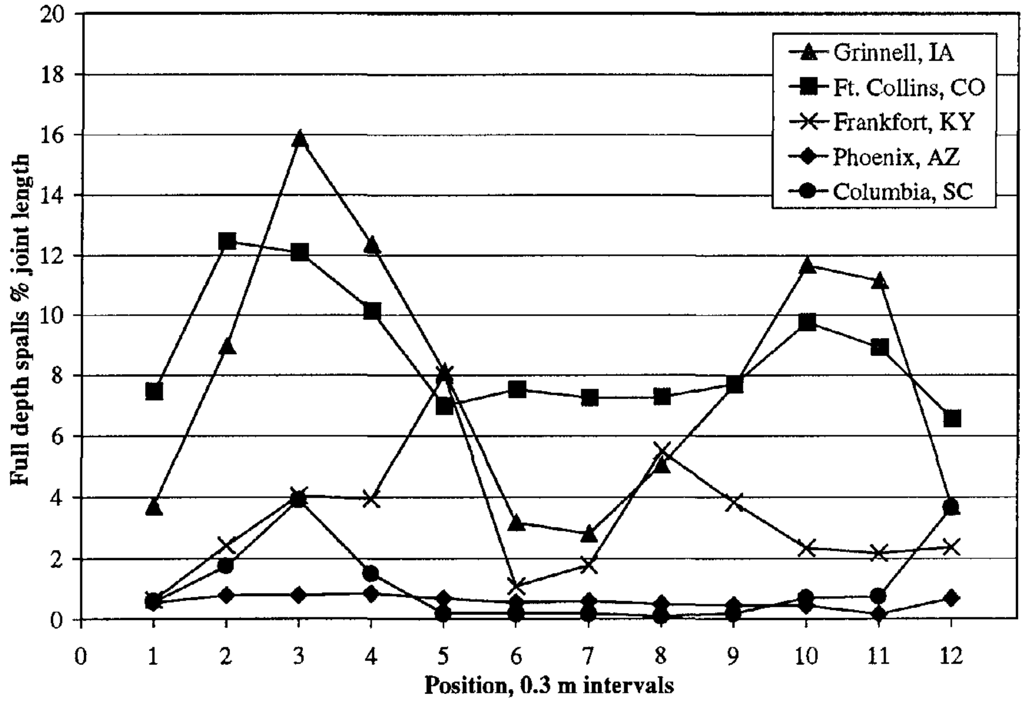


Figure 39. New full-depth spalls vs. distance from shoulder.

more partial- and full-depth spalls occurred at positions 2, 3, and 10. Sliver spalls were also prominent in the wheelpaths at the Kentucky site and were statistically greater in the wheelpaths at the Arizona site. Spalls at positions 3 and 12 in the wheelpath at the South Carolina site were a result of pavement damage from a dragging object and from normal pavement deterioration.

The effect of sliver spalls on joint seal performance at some sites is evident from figure 39. Water and debris entered the pavement system along more than 10 percent of the length at several positions through spalled joint edges. Research into the causes of this spalling (e.g., sawing methods) and methods to reduce its occurrence (e.g., beveled joint edges) appears warranted.

Comparison of Performance Between States

When making sealant performance comparisons between test sites, several variables enter into the analysis. Many of these variables are difficult to quantify and tend to confound the analysis. Among these variables are the climatic conditions and the design and properties of the pavement surface, base, and subgrade, including the type and strength of aggregate and mortar.

Preparation variables, such as the type and quality of sandblasting and airblasting, the presence of traffic adjacent to the work zone, whether the installation was during the day or night, the condition and type of the old sealant to be plowed from the joints, and the amount of wind and airborne dust particles present during installation, also enter the analysis. Each of these preparation variables was controlled to the best of the contractor's ability by using only oil- and moisture-free air compressors, training workers as necessary, inspecting sandblasted and airblasted joints for cleanliness and ordering additional cleaning as necessary, bringing in additional lighting where needed, removing sandblasting particles from the adjacent pavement surface as well as from the joint reservoir, and requiring additional low-pressure air cleaning of joints containing backer rod if dust had accumulated in them prior to sealant installation. Nevertheless, some additional variation was present and must be noted when making performance comparisons.

A comparison of the overall failure for recessed joint sealants between States was previously provided in figure 27. One thing that stands out was the excellent adhesion performance of the silicone sealants in every State. Only slight adhesion loss in silicone sealants was noted at each test site, with the majority of the distress initiated by partial-depth spalling. As sliver spalls develop, traffic pulls and shears the silicone from the spalled joint surface. In many cases, the movement of the sliver spall, still attached to the silicone seal, causes the silicone to tear from the adjacent joint sidewalls.

As shown previously in figures 29 and 30, full-depth spall failure was much more prevalent at the Colorado and Iowa sites. These sites are in cold climatic regions where joints experience large opening widths at the same time that sealant materials are colder and stiffer. Spalling at the Iowa site was generally greater than at the Colorado site, possibly because of differences in aggregate and mortar strength or a difference in the amount of moisture present.

Comparison of Installation Methods

Statistical comparison of the differences in performance of the installed hot-applied sealants in the different configurations was completed for each test site. T-tests comparing the means and standard deviations of overall failure for the different configurations at each site were completed using a pooled variance from each site. These pooled variances ranged from 245 at the Kentucky site to 587 at the South Carolina site, illustrating the range in variability among the sites.

Table 21 illustrates the mean percentage of hot-applied sealant failure along the joint length for each configuration. The failure rates are recorded in the same column for each State if there

Table 21. Statistical comparison of hot-applied sealant failures by configuration.

	Average Hot-Applied Seal Failure, % joint length														
	Arizona			Colorado			Iowa			Kentucky			S. Carolina		
Config.	1[a]	2	3	1	2	3	1	2	3	1	2	3	1	2	3
1			46.3	64.2					49.5			29.4		47.7	
2	18.0					68.5		36.6			22.8		33.8		
3							27.4			7.2					60.8
4		38.0		62.3											

[a] 1 = best, 3 = worst

was no significant difference in the material performance between configurations. In recent years, the relationship of effectiveness level between the configurations at each site has typically remained the same, as figures 40 through 44 indicate.

It is evident that the type of configuration makes a significant difference in the amount of overall failure for the hot-applied sealants at all sites. Materials in configuration 2 (sawed/overbanded) performed better than those in configuration 1 (sawed/recessed) at all sites, except for a slight difference in Colorado. Sealant dimensions and preparation procedures were the same for configurations 1 and 2. The only difference was the sandblasting of the adjacent surface and controlled width overband installation. This indicates that, when these hot-applied sealants are overbanded, the extra sawing and sandblasting effort and the increased bonding area result in better overall performance.

Interestingly, the overbanded materials were generally worn from the pavement wheelpath surfaces before 9 to 18 months for all hot-applied sealants except Crafco RS 231 (24 to 36 months). In lower volume roadways, overbanded sealants are not expected to wear away as quickly, further improving their performance. Although there was a statistical difference in configuration 2 performance, the results of a life-cycle cost comparison of the different installation methods must be used to determine if the extra effort associated with overbanding is cost-effective (see the "Cost-Effectiveness Analysis" section later in this chapter).

Surprisingly, configuration 3 (plow and overband) showed the least overall failure at the Iowa and Kentucky sites. About 75 to 85 percent of the original seal material was completely removed from the joint walls at these sites. Seal materials at these sites were generally poorly bonded to the joint walls below the seal surface, but the seals remained bonded to the pavement surface and traffic reduced the sealant weathering. The result was a watertight seal at the seal surface, with underlying adhesion loss at the two sites where the plowing operation was most effective. Configuration 3 seal effectiveness in the 82-month Iowa site evaluation was 73 percent.

The South Carolina site developed much more failure in configuration 3 joints, as can be seen in figure 44. This failure was due to the silicone sealant that remained on the joint walls at the South Carolina site after the plowing operation. The plowing equipment used for installation was nearly ineffective at this site, resulting in less than 25 percent of the joint face being effectively cleaned. As a result, within a year of installation, seal effectiveness in the plowed joints at the South Carolina site was less than 85 percent. In the most recent evaluation, configuration 3 seal effectiveness was 39 percent. It can be concluded that when effective joint plowing is used, seal performance can be as good or better than when using standard installation practices. Since the plow equipment was not as effective as currently available state-of-the-art equipment and only airblast cleaning methods were used, improved performance can be expected using joint plows that are more than 95 percent effective in combination with sandblasting and airblasting.

Sealants installed using the sawed/flush-filled configuration 4 slightly outperformed seals in configuration 1 joints at the Arizona site and provided no statistical improvement over configuration 1 joints at the Colorado site. Flush-filled sealant joints were filled to the top as

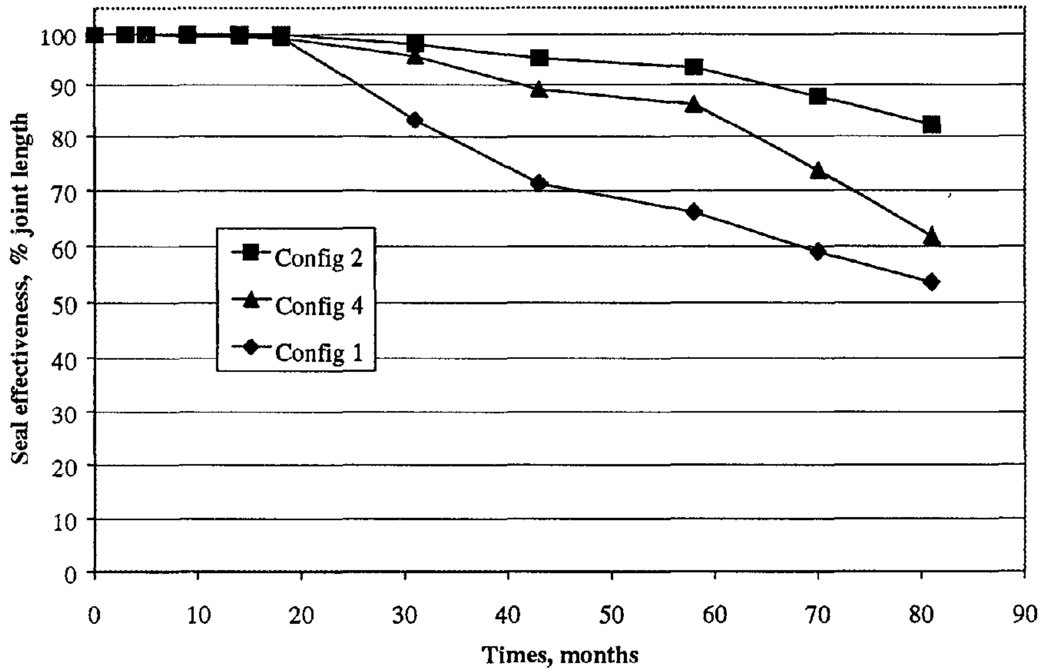


Figure 40. Overall configuration effectiveness for Arizona I-15.

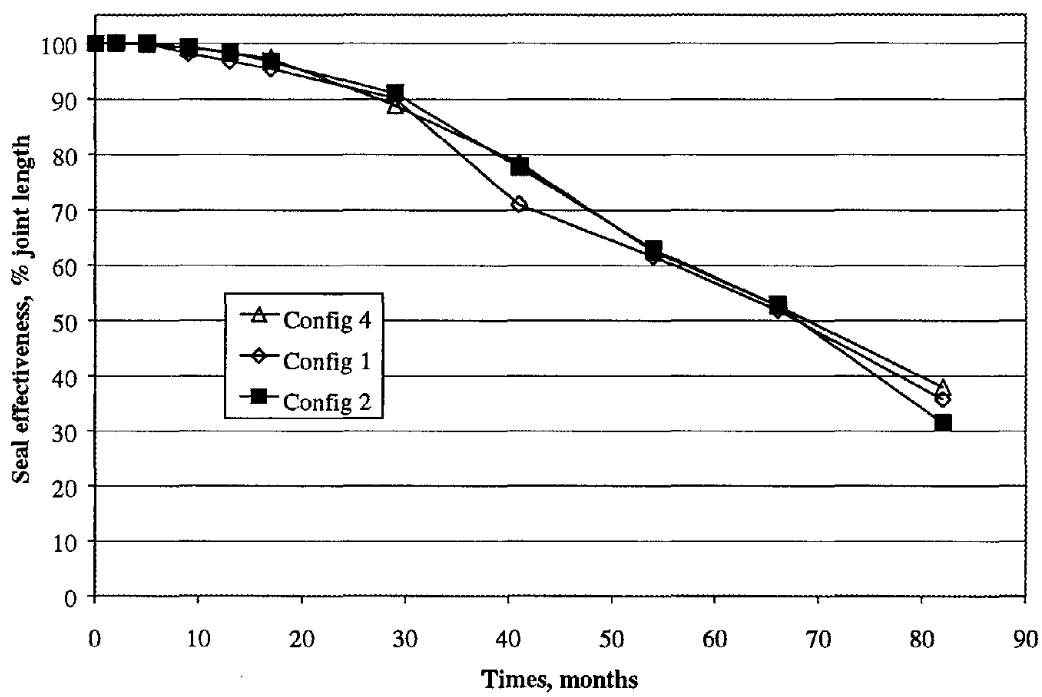


Figure 41. Overall configuration effectiveness for Colorado I-25 site.

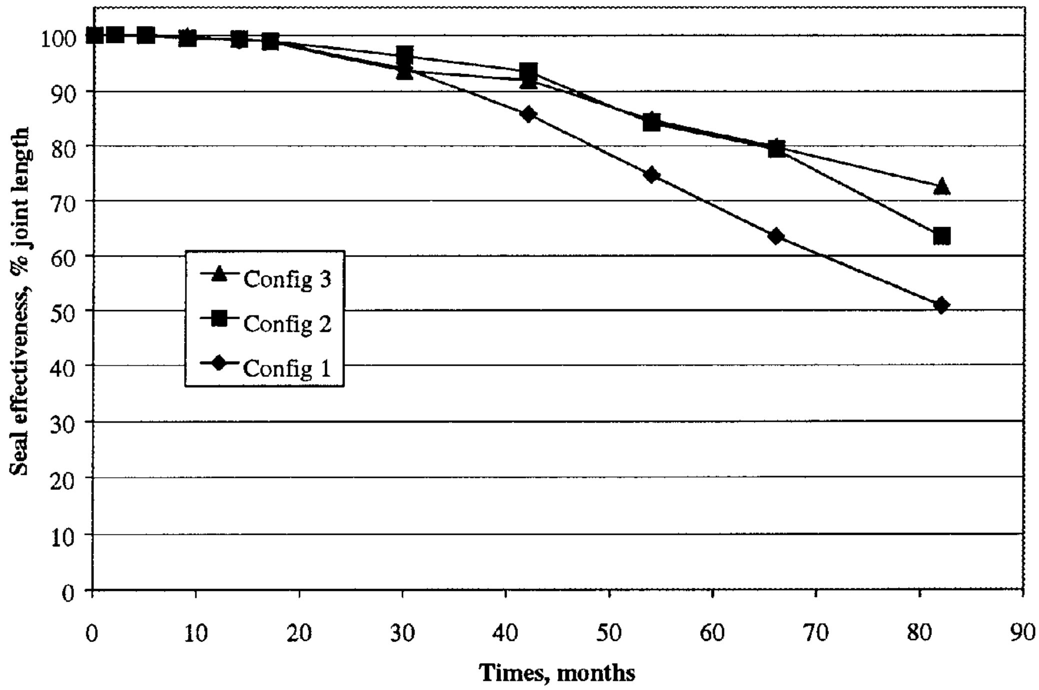


Figure 42. Overall configuration effectiveness for Iowa I-80 site.

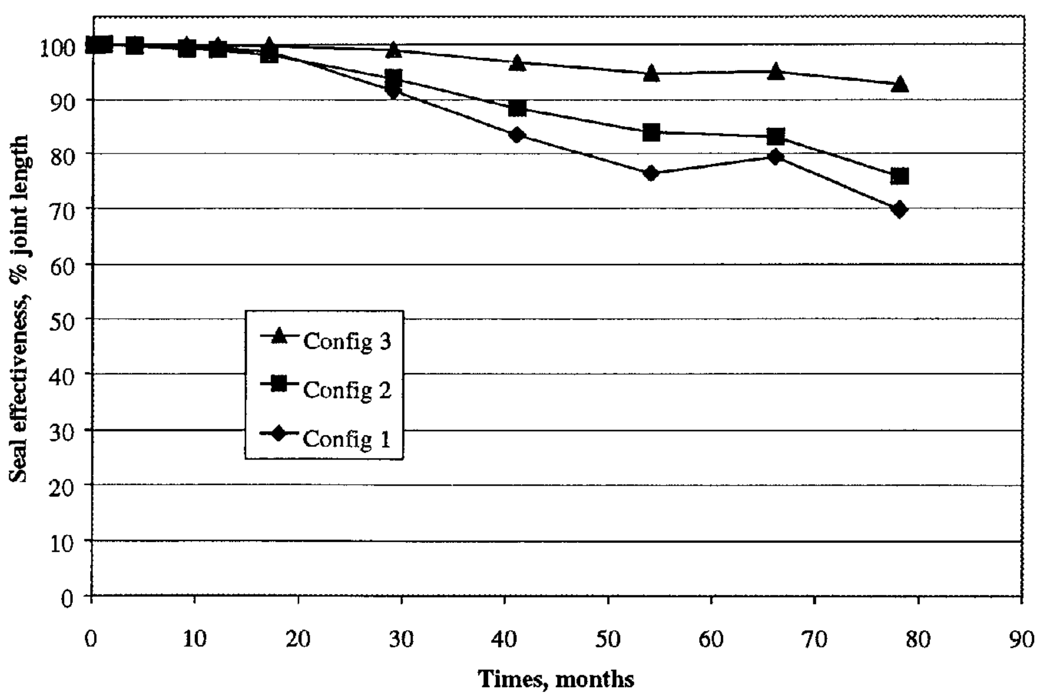


Figure 43. Overall configuration effectiveness for Kentucky U.S. 127 site.

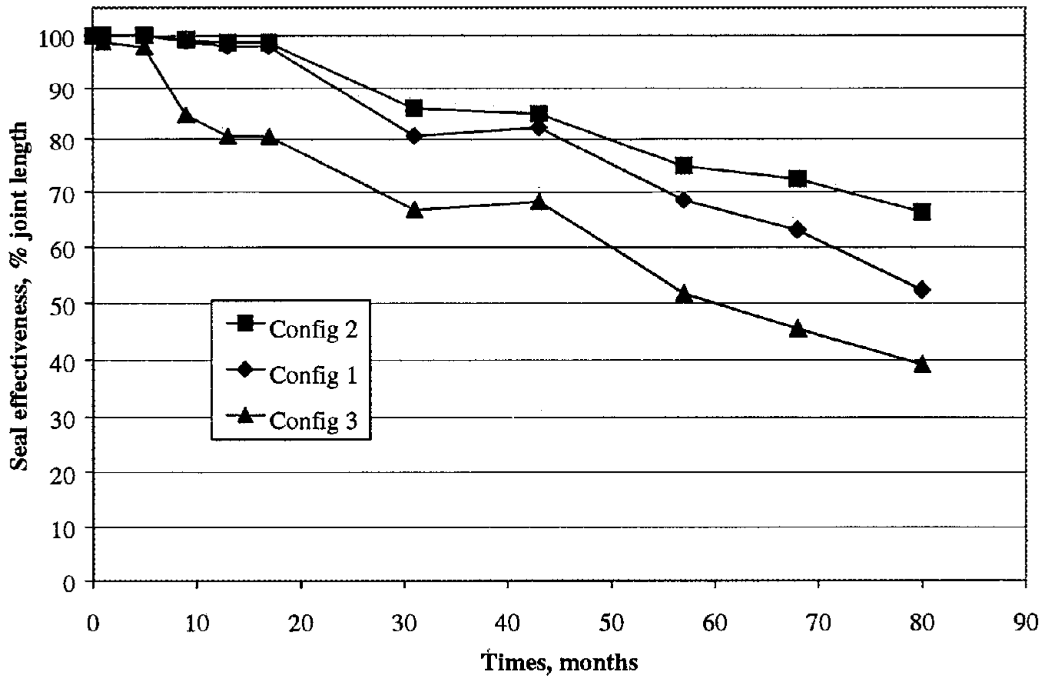


Figure 44. Overall configuration effectiveness for South Carolina I-77 site.

nearly as the applicator operator was able. In more than 50 percent of the joints, the sealant surface was below the pavement surface. As a result, increased weathering occurred along these joints where the sealant was not exposed to traffic. Improved performance could be obtained if the joints were overfilled at installation and a flat squeegee was used to strike off the sealant flush with the pavement surface. This would provide increased bonding surface and an intimate bond at the surface-sealant interface.

Comparison of Service Life

In addition to the statistical evaluation of overall seal performance at a point in time and the graphical performance evaluation, it is important to include in the analysis the time at which resealing becomes necessary for each sealant material–configuration combination. Such a service life comparison was possible in this study because of the high level of failures and different failure trends that developed in several test sections.

To conduct a service-life analysis, it is necessary to define a failure level. Because the percentage of seal failure at which States consider a joint seal to be failed varies with the pavement type, budget level, engineering preferences, and other factors, agencies can select the service life that best suits their needs. This analysis examined joint seal performance based on a 75 percent overall effectiveness level for each joint. A joint with overall effectiveness greater than or equal to 75 percent was classified as surviving, whereas one with overall effectiveness of less than 75 percent was classified as failing. For example, if 4 out of 10 joints in a test section have failed along greater than 25 percent of the joint length, then the percentage of joint seal survival is 60 percent.

In completing this analysis, a third-order equation was computed for the overall survival of each joint in the test sites. Correlation coefficients (r^2) for these equations averaged 0.91. The time at which these equations predicted a 75 percent effectiveness level was then computed. Nearly 50 percent of the joints had reached the 75 percent effectiveness level at the time of the 1997-1998 evaluation, allowing for interpolation of the service life. All remaining joint performance equations were extrapolated, limited by a maximum allowable time of 200 months.

Standard SAS® GLM procedures with the MANOVA option were used to evaluate the mean service life for each treatment, accounting for the associated variability. Using the Tukey studentized range analysis of the SAS® GLM procedure, the 75 percent effectiveness-based service lives of all treatments at a site were ranked and grouped according to similar performance.

Results of the service-life analysis of variance indicate that there was sufficient difference in service life at the test sites to differentiate between the performance of the seal treatments over time. For all sites, the average service lives for each material–configuration treatment are shown in table 22. Figures 45 through 49 illustrate, for each site, the time to 75 percent seal effectiveness and the performance rankings of all joint seal treatments. The mean and standard deviation range are also shown in these figures. Treatments at the same level were determined to not be significantly different according to the statistical test results. As seen in the point-in-time Tukey rankings, the silicone materials performed better over time in the sawed/recessed configuration 1 than with the hot-applied sealants, with the exceptions of Crafco RS 231 and Koch 9005 at a majority of the test sites.

A large amount of variability in the Arizona sealant service life for each joint, shown in figure 45, allowed only one conclusion to be drawn. Dow 888 had a statistically longer service life than Meadows Hi-Spec at this site. Service lives at the Colorado site (figure 46) were greatest for silicone materials and least for low-modulus ASTM D 3405 sealants. The Crafco RS 231 service life was on par with the Mobay 960-SL silicone, and Koch 9005 was slightly below these sealants.

A similar pattern was experienced at the Iowa site (figure 47). Low-modulus ASTM D 3405 sealants Meadows Sof Seal and Koch 9030 had the shortest service lives, and most silicone sealants exhibited the longest lives. An exception to the silicones was the Mobay 960-SL silicone that had recently failed in adhesion from the bottom upward. Crafco RS 231 (configuration 2) and Koch 9005 (configuration 3) exhibited the same service life characteristics as the good-quality silicone sealants, although none had reached the 75 percent effectiveness level.

Extreme variability in the joint seal service life at the Kentucky site also did not allow statistical conclusions to be drawn. Dow silicone sealants had the longest service lives, whereas the shortest service lives were experienced by the Meadows Sof Seal and the Koch 9030. Finally, the silicone and the Crafco RS 231 (configuration 2) sealants at the South Carolina site exhibited the longest service lives (figure 49). The remaining materials and configurations had average joint seal service lives of less than 7.5 years.

Table 22. Time after installation at which 75 percent effectiveness was reached.

Scalant Material	Config-uration	Time at Which 75% Effectiveness Level Was Reached, months [a]					
		Arizona	Colorado	Iowa	Kentucky	South Carolina	Average
Koch 9005	1	116	66	94	156	63	99
	2	112	66	91	191	90	110
	3			148	182	49	126
	4	105	61				83
Crafco RS 231	1	52	80	76	86	92	77
	2	135	69	118	108	138	114
	3			103	155	80	113
	4	83	72				78
Meadows Sof-Seal	1		34	40	39	55	42
	2		40	51	64	46	50
	3			57	161	31	83
	4		43				43
Koch 9030	1		31	50	60	41	46
	2		32	63	50	58	51
	3			59	143	15	72
	4		37				37
Meadows Hi-Spec	1	43					43
	2	94					94
	4	76					76
Crafco RS 221	1	65					65
	2	105					105
	4	117					117
Dow 888	1	198	145	130	186	178	167
Dow 888-SL	1	183	110	125	164	186	154
Mobay 960-SL	1	194	93	65	115	168	127
Mobay 960	1			143			143
Crafco 903-SL	1	194					194
Koch 9050	1		19		136		78
Dow 888 w/ primer	1			151			151
Dow 888-SL w/ primer	1			143			143
Koch 9005 w/ primer	1				173		173

[a] Times greater than 82 months are extrapolated to a maximum of 200 months.

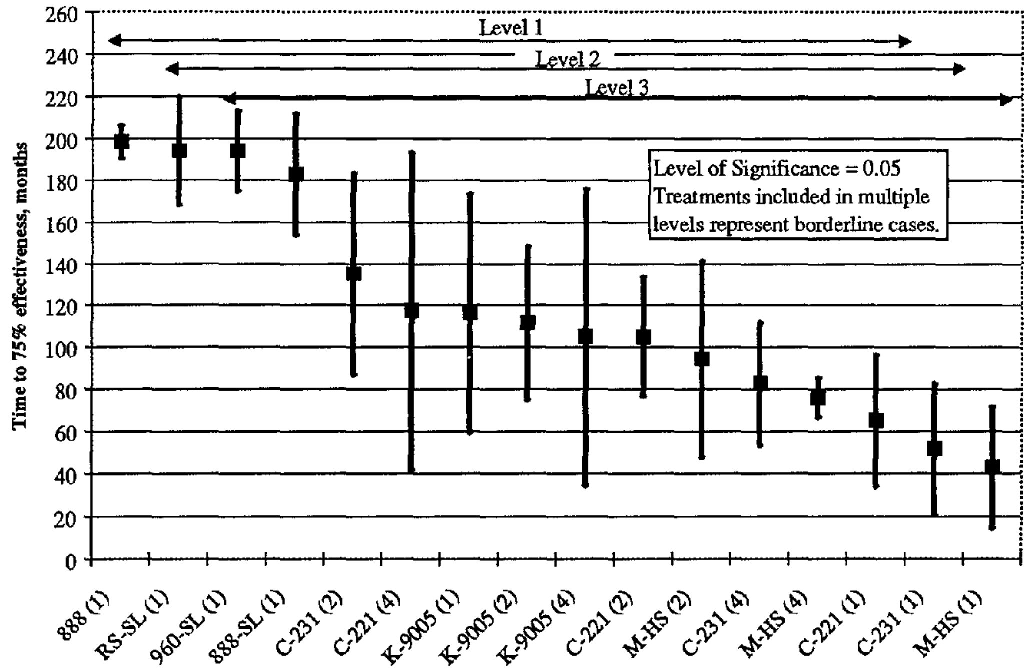


Figure 45. Service-life ranking for overall effectiveness at Arizona I-17 site.

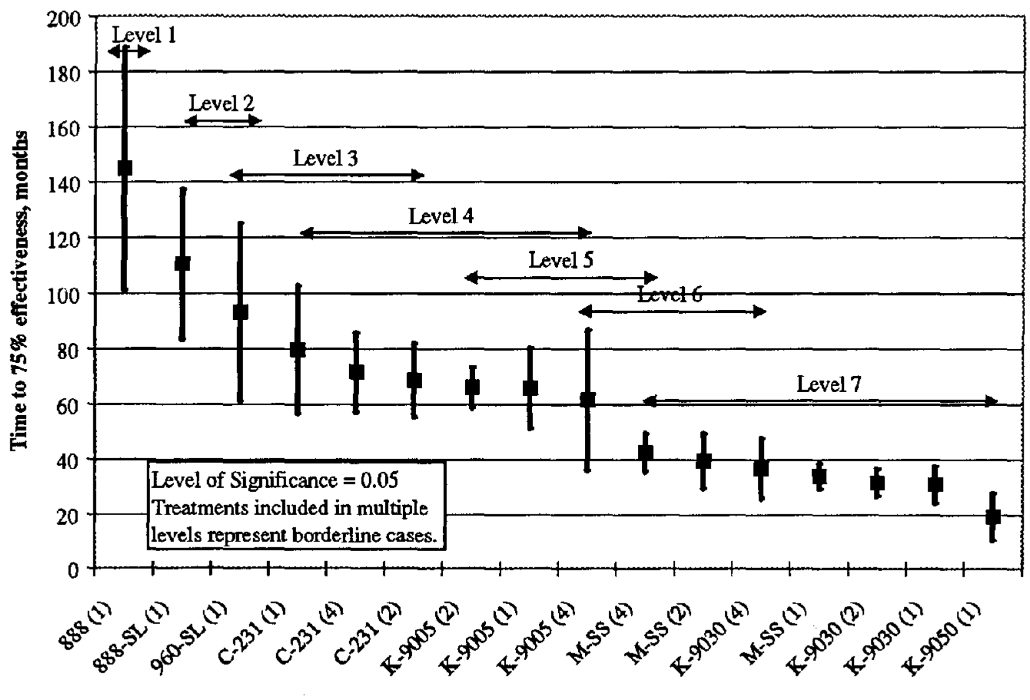


Figure 46. Service-life ranking for overall effectiveness at Colorado I-25 site.

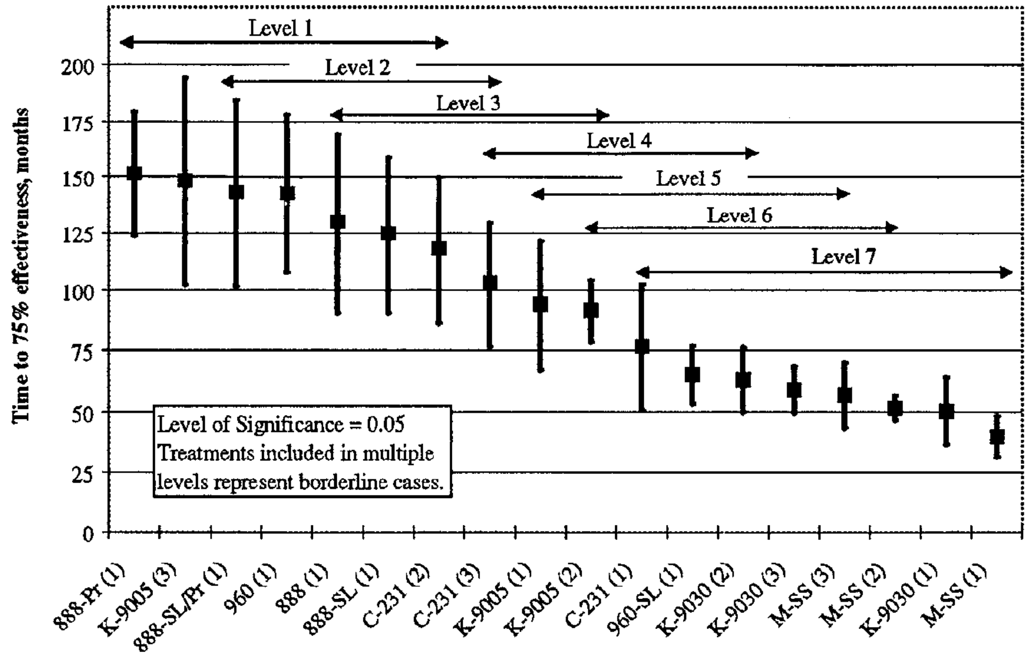


Figure 47. Service-life ranking for overall effectiveness at Iowa I-80 site.

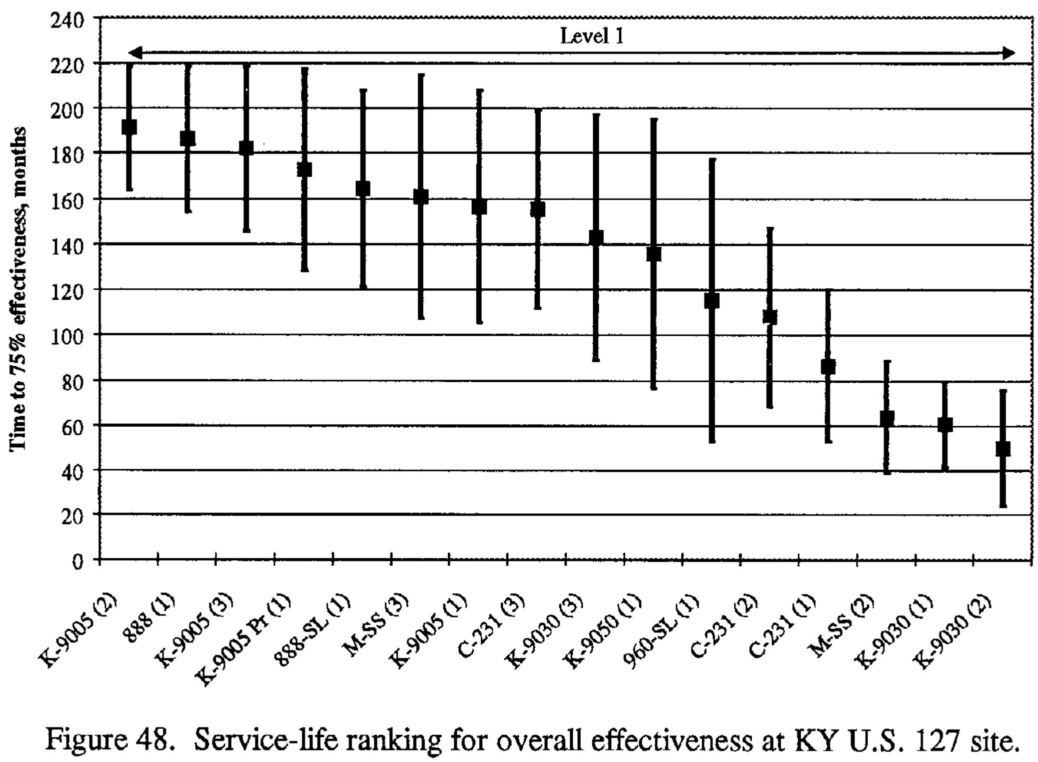


Figure 48. Service-life ranking for overall effectiveness at KY U.S. 127 site.

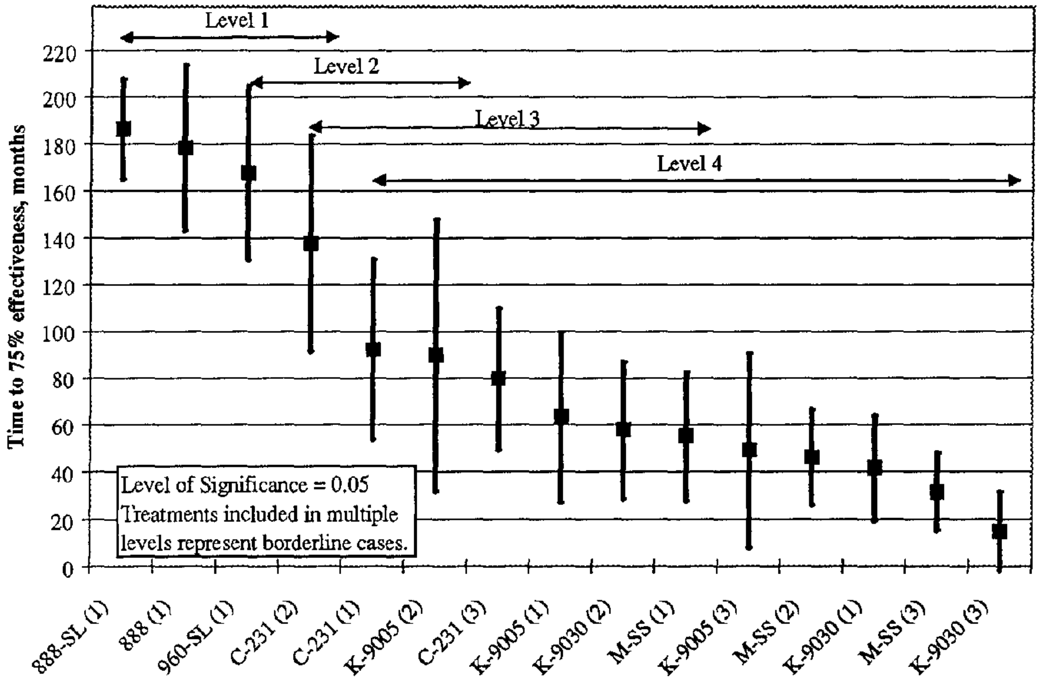


Figure 49. Service-life ranking for overall effectiveness at South Carolina I-77 site.

Cost-Effectiveness Analysis

Because the effectiveness level of approximately half of the joints deteriorated to below 75 percent of the joint length, it was possible to complete a preliminary cost analysis using production data presented in the 1993 SHRP H-106 *Joint Seal Repair* final report (Evans et al., 1993b) and performance results from the preceding service-life analysis. An effectiveness level of 75 percent was used for this analysis. The methods used for completing this cost-effectiveness analysis were described in the SHRP H-106 *Concrete Pavement Repair Manual of Practice* (Evans et al., 1993a) and summarized below.

To complete a cost-effectiveness study, several factors must be determined or estimated. These include the production rates, labor rates, equipment costs, material amounts and costs, and the estimated service life of the joint seal treatment. Based on information collected in the SHRP H-106 study, tables 23, 24, and 25 present the estimated production, labor, and equipment inputs used in this analysis. For this evaluation, labor and equipment rates were set at the same level for all treatments at all sites, although these rates can vary greatly from State to State. Table 22 previously listed the interpolated and extrapolated time after installation that each joint seal treatment developed failure along 25 percent of the joint length. Extrapolated values were obtained by projecting the third-order deterioration curve to the 75 percent effectiveness level for each joint. A maximum extrapolated value of 200 months was selected to reduce the uncertainty of the extrapolation process.

Table 23. Estimated production and labor rates.

Work Item	Production or Labor Rate
Plowing rate, m/h	160
Sawing rate, m/h	84
Airblasting rate, m/h	152
Sandblasting rate, m/h	114
Backer rod installation rate, m/h	165
Sealant installation rate, m/h	165
Standard labor rates, $/day	$120
Supervisor labor rate, $/day	$200

Table 24. Estimated material costs.

Sealant Material	Material Cost
Crafco RS 221, $/kg	$0.90
Crafco RS 231, $/kg	1.23
Koch 9005, $/kg	0.51
Koch 9030, $/kg	0.77
Meadows Hi-Spec, $/kg	0.64
Meadows Sof-Seal, $/kg	1.06
Dow 888, $/kg	5.46
Dow 888-SL, $/kg	6.14
Mobay Baysilone 960-SL, $/kg	6.71
Backer rod, $/m	0.11
Blasting sand, $/kg	0.11

Table 25. Estimated equipment cost and crew size.

Installation Process	Equipment Cost, $/day	Crew Size
Traffic control	$450	1
Joint plowing	150	2
Joint sawing	450 (2 saws)	2
Initial airblasting	175	2
Sandblasting	200	2
Final airblasting	175	2
Backer rod installation	10	2
Sealant installation	200	2

Material coverage rates for each sealant material were determined using the methods described in the *EDRP*, based on a 12.7-mm joint width and a sealant depth recommended by the manufacturer. A coverage rate for sandblasting was estimated at 0.3 kg/m for standard recessed joints and 0.45 kg/m for overbanded sealant installation. Twenty percent and 5 percent wastage factors were applied to the sealant materials and backer rod, respectively.

Results of the cost-effectiveness analysis indicate substantial differences in the average annual costs of different material–configuration treatments, as shown in table 26. The range of annual costs among the treatments at each site varied from $0.16 to $1.48/m, which illustrates the importance of selecting the proper materials and installation procedures for joint resealing. When the annual costs of each treatment at the five sites were averaged, as shown in the right column of table 26, the costs ranged from $0.22/m for Dow 888 in configuration 1 to $0.69/m for Koch 9030 in configuration 3.

Comparing the five sealants that were placed in configuration 1 at each of the five sites, it can be seen in table 26 that the most cost-effective sealants were the Dow 888 and Dow 888-SL silicones ($0.22 and $0.24/m, respectively). On a broader level, cost-effective seals were also provided by Mobay 960-SL and Crafco RS 231 (in most configurations). The average annual cost of silicone seals placed in configuration 1 was $0.25/m, whereas the average cost for hot-applied sealants in the same configuration was almost twice as much ($0.48/m). The indication, therefore, is that given the same preparation and installation procedures, the silicone sealants were more cost-effective than the hot-applied sealants.

Table 26. Annual treatment cost based on 75 percent effectiveness service life.

Sealant Material	Configuration	Average Annual Cost Based on Service Life Corresponding to 75% Effectiveness, $/linear m of joint					
		Arizona	Colorado	Iowa	Kentucky	South Carolina	Average
Koch 9005	1	$0.25	$0.39	$0.29	$0.20	$0.41	$0.31
	2	$0.27	$0.41	$0.31	$0.18	$0.32	$0.30
	3			$0.19	$0.16	$0.48	$0.28
	4	$0.27	$0.42				$0.35
Crafco RS 231	1	$0.50	$0.34	$0.35	$0.32	$0.30	$0.36
	2	$0.23	$0.40	$0.26	$0.28	$0.23	$0.28
	3			$0.25	$0.19	$0.31	$0.25
	4	$0.33	$0.37				$0.35
Meadows Sof-Seal	1		$0.74	$0.63	$0.65	$0.48	$0.63
	2		$0.67	$0.53	$0.44	$0.59	$0.56
	3			$0.43	$0.18	$0.75	$0.45
	4		$0.59				$0.59
Koch 9030	1		$0.79	$0.51	$0.43	$0.61	$0.59
	2		$0.81	$0.44	$0.54	$0.47	$0.57
	3			$0.41	$0.20	$1.48	$0.70
	4		$0.67				$0.67
Meadows Hi-Spec	1	$0.58					$0.58
	2	$0.31					$0.31
	4	$0.35					$0.35
Crafco RS 221	1	$0.40					$0.40
	2	$0.28					$0.28
	4	$0.25					$0.25
Dow 888	1	$0.20	$0.24	$0.26	$0.20	$0.21	$0.22
Dow 888-SL	1	$0.20	$0.30	$0.27	$0.22	$0.20	$0.24
Mobay 960-SL	1	$0.19	$0.34	$0.45	$0.28	$0.21	$0.29
Mobay 960	1			$0.24			$0.24
Crafco 903-SL	1	$0.20					$0.20
Koch 9050	1		$1.47		$0.26		$0.86
Dow 888 w/ primer	1			$0.25			$0.25
Dow 888-SL w/ primer	1			$0.26			$0.26
Koch 9005 w/ primer	1				$0.20		$0.20

Among the hot-applied sealants evaluated in this study, the average annual cost was least when they were installed in the sawed/overbanded configuration 2 ($0.38/m) and greatest when installed in the sawed/recessed configuration 1 ($0.48/m). Average costs for materials in configurations 3 and 4 were $0.42 and $0.43/m, respectively. This leads to the conclusion that the extra expense associated with proper overband preparation and installation is worth the effort, in terms of life-cycle cost.

Laboratory Test–Field Performance Correlation Analysis

The average laboratory test properties of the six hot-applied and three primary silicone sealant materials were statistically compared with the average field performance properties for these materials at all five sites using the SAS® PROC CORR statistical package. Separate analyses were completed for hot-applied sealants in configurations 1 and 2. Another analysis was completed using the average performance ratings for both configurations 1 and 2. Silicone sealants were reviewed separately from hot-applied materials. Field performance properties and the laboratory tests that were compared are listed in table 27. The results of these comparisons are shown using combined performance results from hot-applied sealants in configurations 1 and 2. Comparison results for hot-applied sealant configurations 1 and 2 are shown separately in tables D-26 and D-27 of appendix D. Silicone analysis results are shown in table D-28.

Several correlations were anticipated in the design of the experiment, based on previous specifications and performance. These comparisons are unshaded in the table, and unanticipated correlations are shaded. If the relationships between laboratory test results and field performance indicators were found to be significant at a 95 percent level of significance ($\alpha = 0.05$), the Pearson correlation coefficient, r, for each comparison was listed in bold in table 33. Correlation coefficients were listed in normal font if their significance was between 90 and 95 percent. Where a coefficient is near 1.000, the laboratory results and the field performance were highly related. A coefficient near 0 indicates a lack of correlation. The sign of the coefficient designates whether the relationship between laboratory test results and field performance was direct (+) or inverse (-).

Three material properties are required by the ASTM D 3405 joint sealant specifications—cone penetration (25°C), flow (60°C), and resilience (25°C). Cone penetrations at -17.8 and 25°C held moderately strong inverse correlations with partial-depth spall formation at the test sites. As the amount of penetration increased, the amount of partial-depth spall distress decreased. This result was primarily affected by the minimal spalling occurring in the Arizona site—the only site where Crafco RS 221 and Meadows Hi-Spec were installed. Both of these materials had lower cone penetrations at both temperatures than did the other hot-applied sealants. Koch 9005 also had a relatively low penetration. Flow also appeared to be strongly related to cohesion failure in configuration 1 and mildly related to 75 percent service life. Resilience test results did not correlate well with the performance properties identified in this analysis.

Stress at 150 percent elongation (3.9°C) correlated well with total failure and service life for hot-applied sealants in configurations 1 and 2. Materials that had higher stress levels exhibited smaller failure amounts after 82 months and longer service lives. Contrary to normally

Table 27. Selected laboratory test–field performance correlation results (configurations 1 and 2).

Test Parameter	ASTM Test Number	Pearson Correlation Coefficients for Field Distresses						
		Partial-Depth Adhesion	Full-Depth Adhesion	Partial-Depth Spall	Full-Depth Spall	Full-Depth Cohesion	Overall Failure	Service Life
Ultimate strength, -17.8 °C	D 412							
Ultimate strength, 3.9 °C	D 412	**-0.9018**				**0.8848**		
Ultimate strength, 23.0 °C	D 412							
Stress at 150%, -17.8 °C	D 412			**-0.8674**	-0.7436			
Stress at 150%, 3.9 °C	D 412						**-0.8863**	**0.9111**
Stress at 150%, 23.0 °C	D 412							
Ultimate elongation, -17.8 °C	D 412							
Ultimate elongation, 3.9 °C	D 412							
Ultimate elongation, 23.0 °C	D 412							
Adhesion/coh., immersed	D 3583	-0.8114	**-0.9284**		-0.8150	0.8561	-0.8711	**0.9305**
Adhesion/coh., non-immersed	D 3583	**-0.8792**	**-0.8662**		-0.7816		-0.7823	
Cone penetration, -17.8 °C	D 3407			**0.9071**				
Cone penetration, 25 °C	D 3407			**0.9438**	**0.8563**	-0.7664		
Flow, 60 °C	D 3407	-0.8111						
Resilience, 25 °C	D 3407							
Softening point	D 36							
Brookfield viscosity	D 4402							
Specific gravity, 15.6 °C	D 3407							
Density, 25 °C	D 1475							
Maximum elongation	D 113		-0.7759				**-0.8501**	**0.8561**
Maximum engineering stress	D 113							
Maximum true strain	D 113							
Asphalt modulus	D 113			-0.7335				
Polymer modulus	D 113							
Engineering area	D 113							
True area	D 113							

Notes: Level of significance (α) for bolded Pearson coefficients is 0.05. Non-bolded α is 0.10. Shaded cells indicate no significant correlation is expected.

understood relationships, sealants in this project with higher stresses at 150 percent exhibited less failure. The fact that the good-performing Crafco RS 231 and Koch 9005 sealants developed stresses 2 to 3 times that of the poorer performing Koch 9030 and Meadows Sof-Seal led to this inverse relationship.

Other noteworthy relationships included the D 412 ultimate strength test performed at 3.9°C and the D 3583 immersed adhesion/cohesion test. When the ultimate strength in cool testing conditions increased, the amount of adhesion loss decreased and cohesion failure increased. Low-modulus ASTM D 3405 sealants from Meadows and Koch tended to fail in adhesion in the ASTM D 3583 extension test at lower percentages of elongation than the Crafco RS 231 and Koch 9005 sealants. As a result, there was an inverse relationship between ASTM D 3583 maximum elongations and full- and partial-depth adhesion failure. Also, the correlation of ASTM D 3583 maximum elongations with cohesion loss indicates that as maximum elongations increased, full-depth cohesion failure increased. This resulted primarily because the Koch 9005 sealant was the only material that exhibited a significant amount of cohesive failure and because it had the largest maximum elongation. As a result of the several good correlations between ASTM D 3583 results and seal failure levels, the overall failure and service-life ratings were also closely related with the D 3583 test results.

Because failure levels were much greater in hot-applied sealants than in silicone sealants, laboratory correlations for silicone sealants were conducted separately. The small silicone failure rates did not allow for much significant correlation between material properties and performance history. The exceptions were the moderate direct relationships between non-immersed ASTM D 3583 extension limits and adhesion failure and full-depth spall formation. Tensile adhesion elongation values were largest for the Mobay 960-SL silicone sealant, which also exhibited the largest amount of adhesion and cohesion failure of the silicone materials. As a result, a direct relationship between the test and this material property was observed. The Mobay 960-SL silicone failed the ASTM C 719 test after only 1 cycle, whereas the other primary silicone sealants performed well for all 10 cycles. Although this test is time-consuming, it indicated well the adhesive tendencies of the silicone sealants.

As additional failures develop in the silicone sealants, more reliable, and possibly more significant, correlations could become evident. However, current correlations indicate that, with regard to adhesion loss, the ASTM D 3583 test (23°C) for tensile adhesive properties is a good indicator of hot-applied and silicone seal performance. Also, overall seal failure and 75 percent service life currently relate well with the ASTM D 113 maximum elongation and the ASTM D 3583 tensile adhesion tests. These two tests are time-consuming, but could be useful in performance-based seal material selection and approval.

CHAPTER 6. SUMMARY OF FINDINGS AND RECOMMENDATIONS

The SHRP H-106 experiment and subsequent FHWA *LTM* project represent the most extensive pavement surface study ever conducted. In the joint seal portion of the study alone, more than 1,600 joints were resealed using 31 distinct treatment types (combinations of material and placement methods) at 5 test sites. Several of the treatment types were applied at more than 1 site, resulting in a total of 82 treatments in 4 distinct climatic zones.

The intent of the joint reseal experiment was to improve the state of the art in sealing and resealing joints in concrete pavements using head-to-head performance comparisons of materials and preparation methods. The potential benefits of the study—more cost-effective maintenance operations, less exposure of highway workers to adjacent traffic, and fewer maintenance delays for the traveling public—make it very timely in these days of increased demand for effective maintenance procedures.

The details of the test sites constructed as part of the H-106 joint reseal study were provided in chapters 1 and 2 of this report. An in-depth discussion of the results of several laboratory tests performed on the experimental materials was provided in chapter 3. Complete documentation of the field performance information collected in the study was given in chapter 4, and the results of various data analyses designed to distinguish treatment performance and cost-effectiveness were presented in chapter 5.

This chapter summarizes the major findings and observations of the joint reseal study. These findings are divided into general findings and specific findings about materials and methods. Also contained in this chapter are various recommendations concerning joint resealing operations that could be useful to highway maintenance administrators, practitioners, and researchers.

Findings

General

- Over the 7-year evaluation period, a significant amount of overall seal failure developed at the five test sites. At the time of the final evaluation, only 21 percent of the treatments developed 10 percent or less failure along the length of their joints. Approximately 52 percent of the treatments exhibited at least 25 percent failure and nearly 25 percent of the treatments showed failure over more than 50 percent of their joint length.

- With respect to climate, much higher amounts of partial- and full-depth spalling generally occurred in colder regions in joints containing silicone sealant than in joints containing standard, recessed rubberized asphalt sealant. Joints filled with silicone and hot-applied sealants at the dry-freeze site and the northern wet-freeze site averaged 10.4 and 9.1

percent partial- and full-depth spalling of the joint length, whereas joints in the warmer regions averaged 3.8 and 2.0 percent partial- and full-depth spall failure.

- With respect to the cost-effectiveness of placement methods, the average annual cost of sawed/overbanded sealants was \$0.10/m less than the average annual cost of sawed/recessed sealants. Compared with plowed/overbanded and sawed/flush-filled sealants, the average cost of sawed/overbanded sealants was about \$0.05/m less. The extra expense associated with proper overband preparation and installation appears to be worth the effort, in terms of life-cycle cost.

- With respect to the cost-effectiveness of materials, the average annual costs for the Dow 888 and Dow 888-SL were the least, based on comparisons using the sawed/recessed configuration 1. Cost-effective seals were also provided by Mobay 960-SL and Crafco RS 231 (in most configurations). The average annual cost of silicone seals placed in configuration 1 was \$0.25/m, whereas the average annual cost of ASTM D 3405 hot-applied seals placed in the same configuration was \$0.48/m. This indicates that when the same installation methods are used, the evaluated silicone sealants can be more cost-effective than the evaluated hot-applied sealants.

- Correlation analyses of laboratory test results and field performance data provided the following key observations:

  - The ASTM D 3583 test at 23°C correlated well with adhesion failure in both the hot-applied and silicone sealants used in the study.
  - Overall seal failure and estimated service life both related well with the ASTM D 113 maximum elongation and the ASTM D 3583 tensile adhesion test for hot-applied sealants. Both of these tests are time-consuming, but could improve current performance-based seal material selection processes.

Materials

- Partial-depth adhesion loss—The silicone sealants that currently remain on the market developed significantly less partial-depth adhesion failure than the rubberized asphalt sealants. When installed in identically prepared joints using the standard, recessed configuration, the silicone sealants averaged less than 1 percent partial-depth adhesion loss, the standard ASTM D 3405 rubberized asphalt sealants averaged 15 percent adhesion loss, and the low-modulus ASTM D 3405 sealants averaged 41 percent adhesion loss, across all sites.

- Full-depth adhesion failure—In the recessed configuration, currently available silicone materials statistically outperformed all hot-applied sealants at three sites. Although Koch 9005 exhibited the same full-depth adhesiveness at two sites in this configuration, the remaining hot-applied sealants developed statistically more adhesion failure than the silicone sealants at all sites. In configurations 2, 3, and 4, Koch 9005 and Crafco RS 231 developed statistically less adhesion failure than the remaining low-modulus ASTM D 3405 sealants.

- Full-depth sliver spall failure—Sliver palls developed along 7.8 percent of the Iowa site length and along 8.7 percent of the Colorado site. Relatively little sliver spalling occurred at the remaining sites. At the Iowa and Colorado sites, the greatest amount of spalling in the recessed configuration occurred in the self-leveling Mobay 960-SL and the tooled Dow 888 silicone joints. A statistically smaller number of spalls developed in joints sealed using recessed Crafco RS 231, Koch 9005, and Koch 9030 sealants. Spall development in self-leveling sealants was not significantly different from tooled sealants at these sites.

- Overall seal system failure—Among sealants placed in the sawed/recessed configuration 1, the silicone sealants provided the best performance. Crafco RS 231, with more overall failure, statistically performed no different from the currently available silicone sealants at four sites. Koch 9005 statistically was no different from the silicone sealants at three sites.

Configurations

- Recessed versus overbanded seals—ASTM D 3405 sealants installed in the sawed/overbanded configuration 2 performed statistically better in overall effectiveness than the same sealants placed in the sawed/recessed configuration 1 at all sites except the Colorado site. Sawed/overbanded (configuration 2) rubberized asphalt sealants developed overall failure along 36 percent of their joint length, whereas these sealants installed in a recessed configuration exhibited 47 percent failure.

- Recessed versus flush-filled seals—Flush-filled ASTM D 3405 sealants installed at the Arizona site developed statistically less overall failure than the recessed seals. Many of these seals were installed close to the surface and remained exposed to traffic-kneading effects. At the Colorado site, flush-filled sealants (many of which were not exposed to traffic) showed the same effectiveness as recessed sealants.

- Sawed versus plowed joints—Hot-applied sealants installed in the plowed/overbanded configuration 3 at the Iowa and Kentucky sites developed statistically less overall failure than the same sealants installed in the sawed/overbanded configuration 2 at these sites. Average failure rates at these sites were 17 percent for plowed/overbanded joint seals and 30 percent for sawed/overbanded joint seals. Plowing effectiveness for these sites was about 75 to 85 percent. However, at the South Carolina site, where plowing effectiveness was less than 25 percent, plowed joint seals were statistically the least effective.

- Primed joint seals—Based on 60 joint seals at the Iowa site, no significant differences in sealant adhesion failure, spall failure, and overall failure were found to exist among primed and unprimed joints containing the same silicone sealant. The same was true at the Kentucky site, where joints primed and filled with Koch 9005 performed statistically the same as unprimed joints in adhesion, spall, and overall failure. The levels of overall failure on these materials were less than 15 percent, mostly related to spalls; therefore, it is possible that adhesion failure differences may become evident in the future.

Recommendations

Recommendations are provided below for both the designer/operator of joint resealing projects and the planner/researcher for joint resealing policies.

Joint Sealing Operations

All joint sealing recommendations are based on available performance data and on experience with test site installation.

- Cost-effectiveness analysis indicates that the currently available silicone sealants used in this study should be used for long-term resealing projects. These currently available silicones include Dow 888 and Crafco RS 903-SL. Dow 888-SL, Mobay 960, and Mobay 960-SL have all been discontinued and are no longer available.

- For resealing projects that are designed to be overlaid or replaced in less than 6 years, good-performing hot-applied sealants, such as Crafco RS 231 and Koch 9005, should be used.

- The practice of overbanding hot-applied sealants using a squeegee notched 3 mm by 35 mm showed better results than recessed and flush-filled joint seals, and is therefore recommended, especially for low-volume roadways.

- Effective plowing of sealant from joints resulted in good hot-applied sealant performance at two H-106 test sites. When edge spalling can be restricted and joint plowing is more than 95 percent effective, joint plowing can be used with limited confidence. The effectiveness is expected to increase if sandblasting and airblasting are completed prior to seal installation.

- Sandblasting of each joint face was used at all sites in the H-106 study, with good results, especially with silicone sealants. Also, a jig for maintaining the sandblast nozzle at the proper angle and distance was used at the Iowa site. The practice of a single sandblast pass along the center of a joint should be avoided, in deference to dual passes. Jigs or other methods of reducing operator fatigue and ensuring that the sandblast nozzle is properly positioned are also recommended.

- Occasionally, self-leveling silicone sealants were installed high enough in the joint to be exposed to traffic wear. In most cases, partial- and sometimes full-depth adhesion loss occurred at these locations. Nozzles or tooling devices should be used to ensure that silicone sealant is installed from the bottom of the joint and that it is not exposed to traffic.

- In material acceptance testing of hot-applied sealants, the ASTM D 3583 tensile adhesion test and the ASTM D 113 maximum elongation test should be used as indicators of field performance.

- Performance-based acceptance testing of silicone sealants should include the non-immersed ASTM D 3583 tensile adhesion test.

Education and Research

The SHRP H-106 project has taken steps toward improving the state of the practice of resealing joints in concrete pavements. Recommendations for actions in research and education that may lead to further progress in joint resealing are as follows:

- Continue monitoring selected repair sites. The average failure rates for silicone sealants (except Mobay 960-SL) at the Arizona, Colorado, Iowa, Kentucky, and South Carolina sites were 98.6, 85.5, 87.0, 97.5, and 99.0 percent, respectively. Crafco RS 231 and Koch 9005 have maintained effective seals in at least one configuration along at least 85 percent of the joint length at four sites. The above high effectiveness levels make it difficult to project 75 percent effectiveness service lives for these materials. Cost-effectiveness computation accuracy for these materials can be greatly increased with selective monitoring of these materials at intervals of 2 or more years.

- Set up regional testing centers for continued testing. Although the SHRP H-105 project attempted to identify those materials and procedures that had the most performance potential, many materials were not tested under SHRP H-106, and new materials are continually being produced. In addition to evaluating new materials, this would allow the controlled study of new equipment, such as modern joint plows, automated backer rod insertion tools, sandblasting nozzles and guides, hydro-blasting equipment, and improved installation wands and tooling devices. Also, methods for installation, joint cleanliness quantification, and moisture detection could be developed and analyzed.

- Transfer the technology. The information gathered under the SHRP H-106 program can be put to its best use when it reaches the most people on the decision-making, supervisory, and installation levels of joint resealing. Therefore, continued incorporation of its results into technology transfer programs is essential.

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APPENDIX A. TEST SITE LAYOUTS

The SHRP H-106 joint reseal test sites were laid out in two replicates, generally end to end. Each replicate contained test sections consisting of 10 joints resealed using 1 of each sealant material–preparation method combination. The order of material placement at each test site was chosen randomly. Tables A-1 and A-2 list the materials and placement methods used at each site in the order that they were installed along the roadway.

Table A-1. Layout of test sections at the Arizona and Colorado test sites.

Test Section	Sealant Material (Configuration)	
	I-17 Phoenix, Arizona	I-25 Ft. Collins, Colorado
1	Crafco RS 231 (4)	Koch 9005 (1)
2	Dow 888-SL silicone (1)	Meadows Sof-Seal (2)
3	Koch 9005 (1)	Crafco RS 231 (4)
4	Dow 888 silicone (1)	Crafco RS 231 (2)
5	Crafco RS 221 (2)	Koch 9030 (1)
6	Mobay Baysilone 960-SL (1)	Meadows Sof-Seal (1)
7	Meadows Hi-Spec (1)	Koch 9005 (4)
8	Crafco RS 231 (1)	Crafco RS 231 (1)
9	Meadows Hi-Spec (4)	Koch 9030 (2)
10	Crafco RS 221 (1)	Dow 888 silicone (1)
11	Koch 9005 (2)	Koch 9005 (2)
12	Crafco RS 221 (4)	Mobay Baysilone 960-SL (1)
13	Koch 9005 (4)	Koch 9030 (4)
14	Crafco RS 231 (2)	Meadows Sof-Seal (4)
15	Meadows Hi-Spec (2)	Dow 888-SL silicone (1)
16	Crafco 903-SL silicone (1)	Koch 9050 polysulfide (1)

Table A-2. Layout of test sections at the Iowa, Kentucky, and South Carolina test sites.

Test Section	Sealant Material (Configuration)		
	I-80 Grinnell, Iowa	U.S. 127 Frankfort, Kentucky	I-77 Fairfield, South Carolina
1	Koch 9005 (1)	Koch 9005 (1)	Koch 9005 (1)
2	Meadows Sof-Seal (2)	Meadows Sof-Seal (2)	Meadows Sof-Seal (2)
3	Crafco RS 231 (3)	Crafco RS 231 (2)	Crafco RS 231 (3)
4	Dow 888-SL/888 w/ primer	Koch 9030 (1)	Crafco RS 231 (2)
5	Crafco RS 231 (2)	Crafco RS 231 (3)	Koch 9030 (1)
6	Koch 9030 (1)	Meadows Sof-Seal (1)	Meadows Sof-Seal (1)
7	Meadows Sof-Seal (1)	Crafco RS 231 (1)	Koch 9005 (3)
8	Koch 9005 (3)	Koch 9005 (3)	Crafco RS 231 (1)
9	Crafco RS 231 (1)	Koch 9030 (2)	Koch 9030 (2)
10	Koch 9030 (2)	Dow 888 silicone (1)	Dow 888 silicone (1)
11	Dow 888 silicone (1)	Koch 9005 (2)	Koch 9005 (2)
12	Koch 9005 (2)	Mobay 960-SL silicone (1)	Mobay 960-SL silicone (1)
13	Mobay 960-SL silicone (1)	Koch 9030 (3)	Koch 9030 (3)
14	Koch 9030 (3)	Meadows Sof-Seal (3)	Meadows Sof-Seal (3)
15	Meadows Sof-Seal (3)	Dow 888-SL silicone (1)	Dow 888-SL silicone (1)
16	Dow 888-SL silicone (1)	Koch 9005 w/ primer (1)	
17	Mobay Baysilone 960 (1)	Koch 9050 polysulfide (1)	

APPENDIX B. INSTALLATION DATA

During installation of the test sites, several items were documented, including the production rates of each operation, climatic conditions, width of joints, faulting of joints, and sealant temperature. This appendix contains examples of the data sheets used for collection of this information. These are included in figures B-1 through B-5. Summaries of the documented installation items are included in tables B-1 through B-4.

SHRP H-106 Installation Monitoring Form

Site:	Material:				Replicate:	Config:	Test Section:	
AZ (04)	1	C-221	A	M-960	1	1	1	11
SC (45)	2	C-231	B	C-RS-SL	2	2	2	12
CO (08)	3	K-9005	C	K-9050	3	3	3	13
IA (19)	4	K-9030	D	D-888-P			4	14
KY (21)	5	M-HS	E	D-888-SL-P			5	15
	6	M-SS	F	K-9005-P			6	16
	7	D-888					7	17
	8	D-888-SL					8	
	9	M-960-SL					9	
							10	

Site Id No: _ _ J _ _ _ _ ** **
1 2 3 4 5 6 7 8 9

INSTALLATION - PREPARATION:

Operations	Beginning		Ending	
	Date	Time	Date	Time
Sawing	*5/22/91*	*10:10*		*11:00*
Plowing				
Sandblast #1	*6/6/91*	*8:12*		*8:22*
Sandblast #2				
Airblast #1	*5/22/91*	*12:26*		*12:42*
Airblast #2	*6/6/91*	*8:33*		*8:53*

INSTALLATION - SEALANT PLACEMENT:

Installation Operations	Beginning		Ending	
	Date	Time	Date	Time
Primer				
Backer Rod	*6/6/91*	*8:55*		*9:12*
Sealant	*6/6/91*	*9:15*		*10:00*

Figure B-1. Field installation data form.

Installation and Evaluation Climatic Conditions

This form is to be completed by the H-106 contractor during both installation and evaluation. Readings will be taken at 60-min (± 5-min) time intervals. The method for obtaining the readings is explained in the Evaluation and Analysis Plan.[2]

Date: *5/8/91* **Inspector:** *ARR* **Site:** **AZ SC CO IA KY**

Time	Air Temperature (°F)	Relative Humidity (%)	Percent Clouds (%)	Pavement Surface Temp (°F)	Pavement Center Temp (°F)	Pavement Base Temp (°F)
6:00 am/pm						
7:00						
8:00	*62.8*	*50*	*10*	*51.2*	*51.9*	*53.6*
9:00	*59.0*	*64*	*5*	*57.5*	*55.5*	*55.9*
10:00	*68.5*	*42*	*5*	*65.3*	*61.3*	*58.2*
11:00	*68.8*	*46*	*5*	*68.7*	*64.2*	*60.6*
12:00	*70.8*	*35*	*5*	*74.6*	*70.3*	*65.6*
1:00	*75.6*	*29*	*5*	*78.2*	*72.5*	*68.5*
2:00	*79.7*	*27*	*5*	*82.0*	*75.9*	*71.4*
3:00	*80.2*	*27*	*10*	*85.1*	*78.4*	*74.3*
4:00	*82.1*	*27*	*10*	*88.1*	*82.4*	*78.2*
5:00	*84.0*	*26*	*5*	*86.7*	*82.5*	*78.9*
6:00	*83.5*	*27*	*10*	*85.4*	*82.7*	*80.4*
7:00						
8:00						

°C = (°F-32) x 5/9

Figure B-2. Climatic conditions data collection form.

Installation Joint Width Form

Site: **AZ** **SC** **CO** **IA** **KY**

Replicate: **1** **2**

Test Section Number: **1** **2** **3** **4** **5** **6** **7** **8**

9 **10** **11** **12** **13** **14** **15** **16** **17**

Inspector: ______

Site Identification Number _ _ J _ _ _ _ _ _ * *

JOINT MOVEMENT EVALUATION:

Joint Number	Date (mm/dd/yy)	Time (begin/end)	Joint Depth (in)	Joint Width (in)	Gauge Plug Width (in)
1	*6/13/91*	*9:22 AM*	*2.72*	*0.439*	*4.472*
2			*2.25*	*0.467*	*4.386*
3			*2.31*	*0.439*	*4.623*
4			*2.19*	*0.548*	*4.727*
5			*2.35*	*0.598*	*4.515*
6			*2.68*	*0.498*	*4.504*
7			*2.00*	*0.379*	*4.641*
8			*2.04*	*0.497*	*4.631*
9			*1.88*	*0.446*	*4.597*
10		*9:30 AM*	*2.30*	*0.547*	*4.543*

1 in = 25.4 mm

Figure B-3. Joint width data collection form.

Joint Faulting Data Collection Form

GENERAL INFORMATION:

Site: **AZ** **SC** **CO** **IA** **KY**

Replicate: **1** **2**

Test Section Number: **1** **2** **3** **4** **5** **6** **7** **8**

9 **10** **11** **12** **13** **14** **15** **16** **17**

Inspector: _______

Site Identification Number _ _ J _ _ _ _ _ * *

JOINT FAULTING EVALUATION:

Joint Number	Station Number	Date (mm/dd/yy)	Time (begin/end)	Fault Measurement (0.05 in)	
				Outside [a]	Inside [b]
1	101+80	*7/23/91*	*10:25 AM*	*0*	*0*
2	102+26			*0*	*1*
3	103+46			*0*	*0*
4	103+61			*0*	*0*
5	13+76			*0*	*0*
6	103+91			*0*	*0*
7	104+06			*0*	*0*
8	104+21			*0*	*0*
9	104+36			*0*	*0*
10	104+66		*10:30 AM*	*0*	*0*

[a] Positioned 406 mm (16 in) from the outside shoulder joint
[b] Positioned 508 mm (20 in) from the outside shoulder joint

Figure B-4. Joint faulting data collection form.

Sealant Temperature Data Collection Sheet

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 60-min (± 5-min) time intervals. One form will be completed for each sealant material and for each day. Temperatures will be reported in degrees Fahrenheit. Nozzle readings are optional if the air temperature is greater than 60°F.

Date: *6/5/91* Kettle Type: *Crafco*

Kettle Tender: *Steve* Kettle Size (gal): *200*

Sealant Material:
1.) Crafco RoadSaver 221
2.) Crafco RoadSaver 231
3.) Koch 9005
4.) Koch 9030
5.) Meadows Hi-Spec
6.) Meadows Sof-Seal

Begin Heating Time: *6:00 AM*

Time Product at Application Temperature: *7:45 AM*

Time	Heating Oil Gauge Temp (°F)	M/A Sealant Gauge Temp. (°F)	Recirculation Gauge Temp (°F)	Measured M/A Sealant Temp (°F)	Nozzle Temp (°F)
6:00 am/pm					
7:00					
8:00					
9:00					
10:00	*360*	*360*	*345*	*355*	*355*
11:00	*445*	*380*	*375*	*375*	*375*
12:00	*370*	*380*	*365*	*375*	*370*
1:00	*450*	*390*	*345*	*380*	*355*
2:00	*375*	*390*	*385*	*380*	*380*
3:00					
4:00					
5:00					

Figure B-5. Sealant temperature data collection form.

Table B-1. Time required for joint sealant installation operations.

Operation	Config	Arizona I-17	Colorado I-25	Iowa I-80	Kentucky U.S. 127	S Carolina I-77	Average (min/jt)
Sawing	1, 2, 4	2:39	5:26	4:50	4:55	2:37	4:05
Plowing	3			1:45	1:23	2:02	1:43
Sandblasting	1	1:19	2:00	1:12	3:11	1:41	1:53
	2	2:19	3:08	2:23	4:46	2:33	3:02
	4	1:16	2:54				2:05
Airblasting	1	1:25	1:50	1:31	2:19	1:27	1:42
	2	1:42	2:07	1:05	2:06	1:21	1:40
	3			0:58	0:47	1:22	1:02
	4	1:22	1:28				1:25
Backer Rod Installation	1	2:03	1:58	1:27	1:57	1:25	1:46
	2	1:34	2:17	1:02	1:42	1:36	1:38
	3			1:04	1:56	1:31	1:30
	4	2:09	1:59				2:04
Sealant Installation	1 HP	1:07	1:14	1:06	1:52	1:18	1:19
	1 Sil	4:30	3:19	3:39	3:45	5:30	4:09
	2	1:08	1:23	1:16	1:57	1:18	1:24
	3			1:16	1:23	1:17	1:19
	4	1:08	1:25				1:17

Table B-2. Average air temperature during sealant installation.

Material	Config.	Average Air Temperature (°C)				
		I-17 Arizona	I-25 Colorado	I-80 Iowa	U.S. 127 Kentucky	I-77 S. Carolina
Crafco 221	1	21.4				
	2	19.3				
	4	21.6				
Crafco 231	1	23.7	16.7	29.8	32.5	25.8
	2	18.4	17.6	29.6	30.6	23.8
	3			28.8	31.6	23.9
	4	19.3	16.6			
Koch 9005	1	19.3	12.2	25.7	29.9	22.1
	2	21.6	13.8	26.7	31.3	23.7
	3			28.3	32.5	23.6
	4	21.6	15.4			
Koch 9030	1		12.8	29.4	31.3	23.7
	2		16.4	26.5	33.1	23.3
	3			29.4	30.7	21.2
	4		18.2			
Meadows Hi-Spec	1	19.4				
	2	21.7				
	4	19.6				
Meadows Sof-Seal	1		15.3	29.6	32.2	25.3
	2		12.2	28.5	30.3	24.1
	3			29.4	30.9	25.1
	4		13.7			
Dow 888	1	19.3	14.2	27.0	33.4	25.2
Dow 888-SL	1	19.3	19.1	28.3	31.9	21.9
Mobay 960-SL	1	19.3	18.3	27.3	31.3	23.9
Mobay 960	1			28.6		
Crafco 903-SL	1	20.6				
Koch 9050	1		18.7		29.3	

Table B-3. Average joint width during sealant installation.

Material	Config.	Average Joint Width (mm)				
		I-17 Arizona	I-25 Colorado	I-80 Iowa	U.S. 127 Kentucky	I-77 S. Carolina
Crafco 221	1	12.9				
	2	12.8				
	4	13.7				
Crafco 231	1	12.4	13.8	12.8	12.2	13.3
	2	12.3	13.9	13.3	11.7	13.8
	3			7.9	6.4	9.8
	4	11.0	14.4			
Koch 9005	1	11.3	13.6	11.6	11.9	13.2
	2	12.8	14.5	11.9	11.6	13.1
	3			6.9	6.5	9.3
	4	13.2	13.7			
Koch 9030	1		13.6	12.5	11.7	14.4
	2		13.8	12.5	11.7	14.7
	3			7.1	6.8	9.5
	4		14.4			
Meadows Hi-Spec	1	13.1				
	2	12.5				
	4	14.6				
Meadows Sof-Seal	1		13.9	12.0	12.1	14.2
	2		14.9	11.7	12.0	12.8
	3			7.1	6.7	9.1
	4		14.0			
Dow 888	1	13.0	14.3	11.9	11.5	14.6
Dow 888-SL	1	11.5	14.5	11.9	11.5	14.4
Mobay 960-SL	1	13.0	14.4	12.2	12.0	13.0
Mobay 960	1			11.8		
Crafco 903-SL	1	12.7				
Koch 9050	1		14.4		NA	

NA=Not available.

Table B-4. Average joint faulting at the time of sealant installation.

Material	Config.	Average Joint Faulting (mm) [Resolution = 1.3 mm]				
		I-17 Arizona	I-25 Colorado	I-80 Iowa	U.S. 127 Kentucky	I-77 S. Carolina
Crafco 221	1	0.00				
	2	-0.25				
	4	-0.25				
Crafco 231	1	-0.25	0.00	0.00	0.00	0.00
	2	-0.25	-0.25	0.00	0.00	0.00
	3			0.00	0.00	0.00
	4	-0.25	0.00			
Koch 9005	1	-0.25	0.00	0.00	-0.25	0.00
	2	-0.25	0.00	0.00	0.00	0.00
	3			0.00	-0.25	0.00
	4	0.00	0.00			
Koch 9030	1		0.00	0.00	0.00	0.00
	2		0.00	0.00	-0.25	0.00
	3			0.00	0.00	0.00
	4		0.00			
Meadows Hi-Spec	1	-0.25				
	2	0.00				
	4	-0.25				
Meadows Sof-Seal	1		-0.25	0.00	-0.25	0.00
	2		0.00	0.00	-0.25	0.00
	3			0.00	-0.50	0.00
	4		0.00			
Dow 888	1	-0.25	0.00	0.00	-0.25	0.00
Dow 888-SL	1	-0.25	0.00	0.00	-0.25	0.00
Mobay 960-SL	1	-0.25	-0.25	0.00	0.00	0.00
Mobay 960	1			0.00		
Crafco 903-SL	1	-0.25				
Koch 9050	1		0.00		NA	

NA=Not available.

APPENDIX C. MATERIAL TESTING DATA

Laboratory tests were conducted on six hot-applied rubberized asphalt sealants and on three silicone sealants to ensure the characteristics of the sealant used in the project, as well as to allow comparison of field performance with laboratory results. The results of the initial quality assurance laboratory tests were previously listed in tables 8 through 12 in chapter 3. Results of the supplemental tests completed on the nine sealants are listed in tables C-1 through C-7.

Table C-1. Results of supplemental lab tests on hot-applied joint sealants.

Material Test	ASTM Test Method	Crafco RS 231	Meadow Sof-Seal	Koch 9030	Meadow Hi-Spec	Crafco RS 221	Koch 9005
Softening point, °C	D 36	87.8	86.1	92.2	85.6	88.9	83.3
		88.3	87.2	92.8	85.6	89.4	84.4
Brookfield viscosity, cPs	D 4402	2350	2500	1300	3550	4800	525
		2300	2550	1250	3925	5200	550
Ductility, %	D 113	81	52	30	45	71	59
		70	46	31	43	60	74
Cold bend (-18°C)	Utah Spec.	Pass	Pass	Pass	Pass	Pass	Pass
		Pass	Pass	Pass	Pass	Pass	Pass
Cone penetration (at -18°C), dmm	D 3407	73	82	60	15	9	57
		75	81	60	15	7	57

Table C-2. Force-ductility test results for hot-applied joint sealants.

Material Test	ASTM Spec.	Crafco RS 231	Meadow Sof-Seal	Koch 9030	Meadows Hi-Spec	Crafco RS 221	Koch 9005
Maximum elongation, mm	D 113	810	520	300	450	710	590
		700	460	310	430	600	740
	Average	**755**	**490**	**305**	**440**	**655**	**665**
Maximum load, N	D 113	12.0	9.3	20.5	23.1	16.9	11.1
		12.9	7.1	19.1	22.7	19.1	10.2
	Average	**12.5**	**8.2**	**19.8**	**22.9**	**18.0**	**10.7**
Maximum engineering stress, kPa	D 113	120.0	93.1	203.4	229.6	168.2	109.6
		129.6	71.0	191.7	228.2	191.0	100.7
	Average	**124.8**	**82.1**	**197.6**	**228.9**	**179.6**	**105.2**
Maximum engineering strain, mm/mm	D 113	27.0	17.3	19.7	15.0	23.7	10.0
		23.4	15.3	24.7	14.3	20.0	10.3
	Average	**25.2**	**16.3**	**22.2**	**14.7**	**21.9**	**10.2**
Maximum true stress, kPa	D 113	3224.8	1643.8	4028.7	3519.2	3401.3	1110.1
		3046.2	1132.8	4691.4	3313.0	3585.4	1108.0
	Average	**3,135.5**	**1,388.3**	**4,360.1**	**3,416.1**	**3,493.4**	**1,109.1**
Maximum true strain, mm/mm	D 113	3.3	2.9	3.0	2.8	3.2	2.4
		3.2	2.8	3.2	2.7	3.0	2.4
	Average	**3.3**	**2.9**	**3.1**	**2.8**	**3.1**	**2.4**
Area under engineering curve, kPa	D 113	224.8	139.3	415.1	361.3	448.9	104.8
		192.4	100.0	444.7	353.0	428.2	101.4
	Average	**208.6**	**119.7**	**429.9**	**357.2**	**438.6**	**103.1**
Area under true curve, kPa	D 113	1450.8	901.2	2678.0	2331.9	2900.0	679.2
		1243.2	644.7	2871.8	2279.5	2767.0	653.0
	Average	**1,347.0**	**773.0**	**2,774.9**	**2,305.7**	**2,833.5**	**666.1**

Table C-3. Results of tensile adhesion tests on hot-applied joint sealants.

Test	ASTM Test Method	Crafco RS 221	Meadows Hi-Spec	Koch 9005	Crafco RS 231	Meadows Sof-Seal	Koch 9030
24°C, Non-immersed							
Maximum elongation, mm	D 3583	106.7	85.1	111.3	91.4	78.2	47.0
		117.6	93.5	109.2	71.1	78.2	69.3
		74.4	89.7	124.5	80.8	60.5	51.6
Average		**99.6**	**89.4**	**115.0**	**81.1**	**72.3**	**56.0**
Percent elongation, %	D 3583	840	670	876	720	615	370
		926	736	860	560	615	546
		586	706	980	636	475	406
Average		**784**	**704**	**905**	**639**	**568**	**441**
Type of failure	D 3583	Adhesion	Adhesion	Adhesion	Adhesion	Adhesion	Adhesion
		Adhesion	Adhesion	Adhesion	Adhesion	Adhesion	Adhesion
		Adhesion	Adhesion	Adhesion	Adhesion	Adhesion	Adhesion
24°C, Immersed							
Maximum elongation, mm	D 3583	76.2	N/C [a]	104.9	74.4	30.5	22.4
		68.6	N/C	100.3	74.4	45.7	19.1
		60.5	N/C	101.1	57.1	44.5	27.4
Average		**68.4**	**N/C**	**102.1**	**68.6**	**40.2**	**23.0**
Percent elongation, %	D 3583	600	N/C	826	585	240	176
		540	N/C	790	585	360	150
		476	N/C	796	450	350	216
Average		**539**	**N/C**	**804**	**540**	**317**	**181**
Type of failure	D 3583	Adhesion	N/C	Adhesion	Adhesion	Adhesion	Adhesion
		Adhesion	N/C	Adhesion	Adhesion	Adhesion	Adhesion
		Adhesion	N/C	Adhesion	Adhesion	Adhesion	Adhesion

[a] Test not completed.

Table C-4. Tensile stress at 150 percent elongation—hot-applied sealants.

Material Tests	ASTM Test Method	Crafco RS 231	Meadows Sof-Seal	Koch 9030	Crafco RS 221	Meadows Hi-Spec	Koch 9005
Tensile stress at 150% elongation at -18°C, kPa	D 412	NA [a]	39.3	56.5	134.5	135.8	63.4
		NA [a]	43.4	44.8	141.3	115.1	72.4
	Average	**NA [a]**	**41.4**	**50.7**	**137.9**	**125.5**	**67.9**
Tensile stress at 150% elongation at 4°C, kPa	D 412	188.9	47.6	24.1	101.4	NA [b]	145.5
		175.8	25.5	40.7	99.3	NA [b]	121.4
	Average	**182.4**	**36.6**	**32.4**	**100.4**	**NA [b]**	**133.5**
Tensile stress at 150% elongation at 23°C, kPa	D 412	12.4	27.6	28.3	19.3	76.5	35.2
		9.0	34.5	32.4	20.0	60.7	35.9
	Average	**10.7**	**31.1**	**30.4**	**19.7**	**68.6**	**35.6**

NA=Not available.

[a] Failed in cohesion before reaching 150% elongation.

[b] Test not completed.

Table C-5. Results of ultimate elongation tests for silicone joint sealants.

Material Tests	ASTM Spec.	Dow 888	Dow 888-SL	Mobay 960-SL
Ultimate elongation at -18°C, %	D 412	1242	1962	689
		2021	2511	719
		1806	2566	782
	Average	1690	2346	730
Ultimate elongation at 25°C, %	D 412	1840	2290	630
		1950	2040	660
		2060	2120	650
	Average	1950	2150	647
Ultimate elongation at 60°C, %	D 412	1156	1457	670
		1297	1661	580
		1304	1554	480
	Average	1252	1557	577
Ultimate elongation at 25°C, after 504 h weathering, %	D 412	791	1103	359
		727	1081	355
		755	1172	422
	Average	758	1119	379

Table C-6. Tensile stress at 150 percent elongation—silicone sealants.

Material Tests	ASTM Spec.	Dow 888	Dow 888-SL	Mobay 960-SL
Tensile stress at 150% elongation at -18°C, kPa	D 412	198.6	112.4	105.5
		277.2	108.3	96.5
		291.0	105.5	82.7
	Average	**255.6**	**108.7**	**94.9**
Tensile stress at 150% elongation at 25°C, kPa	D 412	222.7	117.9	175.8
		235.1	113.8	166.2
		245.5	110.3	172.4
	Average	**234.4**	**114.0**	**171.5**
Tensile stress at 150% elongation at 60°C, kPa	D 412	251.7	91.7	58.6
		239.3	90.3	51.0
		229.6	87.6	46.2
	Average	**240.2**	**89.9**	**51.9**
Tensile stress at 150% elongation at 25°C after 504 h weathering, kPa	D 412	281.3	112.4	98.6
		273.0	123.4	102.7
		267.5	120.0	96.5
	Average	**273.9**	**118.6**	**99.3**

Table C-7. Results of supplemental performance tests for silicone sealants.

Material Tests	ASTM Spec.	Dow 888	Dow 888-SL	Mobay 960-SL
Cyclic adhesion/cohesion test, 23°C, -50% to +100% cycling	C 719	5% adh. fail., 10 cycles	Slight deform., bbls., 10 cycles	Adh. failure, 1 cycle
		5% coh. fail., 10 cycles	Slight deform., 10 cycles	Adh. failure, 1 cycle
Tensile adhesion at 23°C (non-immersed), % elongation	D 3583	333.3	382.7	625.0
		241.8	194.6	371.3
		223.8	251.0	440.6
	Average	266.3	276.1	479.0
Tensile adhesion at 23°C (immersed), % elongation	D 3583	277.2	255.6	436.8
		227.2	377.4	462.6
		588.2	224.8	601.8
	Average	364.2	285.9	500.4
Density at 25°C, gm/mL	D 1475	1.501	1.356	1.128

APPENDIX D. FIELD PERFORMANCE

A wealth of performance data was collected during the 10 field evaluations conducted since test site installation. The data were stored in spreadsheets and in the SHRP H-106 database, and summaries of the field performance are contained in this appendix. Joint width and joint faulting data were collected during subsequent evaluations using the forms contained in appendix B. Results of visual inspections of each joint on a foot-by-foot basis were recorded on forms similar to figure D-1. Tables D-1 through D-25 list summaries of the adhesion, spall, and cohesion sealant distress for each replicate (10 joints) at the 5 test sites. An explanation of the values in this table was previously provided in chapter 4. To assist in visualizing trends in the data, summary graphs have been prepared and are presented in figures D-2 through D-10. Laboratory test versus field performance statistics are listed in tables D-26 through D-28.

LTPP Long-Term Monitoring Site Evaluation Form

Joint ID	Pos.	Adhesion loss, in						Tensile failure, in		Band wear, in		Overall adh/coh failure, in
		Partial left	Partial right	Partial overall	Full left	Full right	Full overall	Partial	Full	Thickness		
										Low	High	
04J421401	1											
04J421401	2	2	2	3								
04J421401	3	4	5	9								
04J421401	4				3	5	5	2	1			6
04J421401	5											
04J421401	6											
04J421401	7											
04J421401	8											
04J421401	9											
04J421401	10				3	2	5					5
04J421401	11											
04J421401	12											

Joint ID	Psn	Sliver spall distress, in						PCC edge failure, in			Single stones, #	Overall system failure, in
		Partial left	Partial right	Partial overall	Full left	Full right	Full overall	Full left	Full right	Full overall		
04J421401	1							11		11	1	
04J421401	2		1	1							1	
04J421401	3		1	1								
04J421401	4											6
04J421401	5		1	1							1	
04J421401	6											
04J421401	7		1	1		1	1					1
04J421401	8											
04J421401	9		1	1							1	
04J421401	10											5
04J421401	11											
04J421401	12										3	

1 in = 25.4 mm

Figure D-1. Site evaluation data collection form.

Table D-1. Summary of distress survival at Arizona I-17 site.

Material	Config.	Rep.	Partial-depth Adhesion Survival, % edge length	Full-depth Adhesion Survival, % joint length	Full-depth Cohesion Survival, % joint length	Partial-depth Spall Survival, % joint length	Full-depth Spall Survival, % joint length	Overall Survival, % joint length
C-221	1	1	75.3	70.6	99.6	98.5	99.0	69.2
C-221	1	2	68.2	48.0	99.4	97.4	98.1	45.4
		avg	71.7	59.2	99.5	98.0	98.5	57.2
C-221	2	1	96.5	93.2	96.5	99.7	99.9	89.7
C-221	2	2	95.5	86.5	95.6	99.4	99.7	81.7
		avg	96.0	89.8	96.0	99.5	99.8	85.7
C-221	4	1	97.4	99.2	99.7	98.8	99.7	98.6
C-221	4	2	95.1	65.0	79.9	98.2	99.5	44.4
		avg	96.3	82.1	89.8	98.5	99.6	71.5
C-231	1	1	27.0	74.9	97.4	95.6	99.2	71.4
C-231	1	2	64.3	12.5	98.1	97.8	99.4	9.9
		avg	45.9	43.3	97.7	96.7	99.3	40.3
C-231	2	1	90.9	93.9	99.1	99.6	100.0	93.0
C-231	2	2	93.1	92.1	99.5	98.3	99.2	90.8
		avg	92.0	93.0	99.3	99.0	99.6	91.9
C-231	4	1	61.2	74.4	97.2	96.8	98.2	69.8
C-231	4	2	66.5	63.2	97.9	96.8	97.9	59.0
		avg	63.9	68.8	97.5	96.8	98.0	64.4
K-9005	1	1	98.9	93.1	71.8	99.2	99.9	64.8
K-9005	1	2	99.8	99.6	95.6	99.4	99.8	95.0
		avg	99.3	96.4	83.7	99.3	99.8	79.9
K-9005	2	1	98.8	90.7	97.1	99.7	100.0	87.9
K-9005	2	2	100.0	99.9	86.4	99.7	100.0	86.3
		avg	99.4	95.6	91.5	99.7	100.0	87.1
K-9005	4	1	99.8	99.6	99.4	99.5	99.8	98.8
K-9005	4	2	100.0	100.0	6.4	99.5	99.9	6.3
		avg	99.9	99.8	50.4	99.5	99.9	50.1
M-HS	1	1	59.0	51.2	99.7	98.5	99.8	50.8
M-HS	1	2	87.0	21.0	99.9	98.5	99.9	20.8
		avg	72.3	36.9	99.8	98.5	99.9	36.6

Table D-1. Summary of distress survival at Arizona I-17 site (continued).

Material	Config.	Rep.	Partial-depth Adhesion Survival, % edge length	Full-depth Adhesion Survival, % joint length	Full-depth Cohesion Survival, % joint length	Partial-depth Spall Survival, % joint length	Full-depth Spall Survival, % joint length	Overall Survival, % joint length
M-HS	2	1	69.1	93.2	97.6	99.2	99.9	90.8
M-HS	2	2	100.0	100.0	36.9	99.8	99.7	36.6
		avg	84.5	96.6	67.3	99.5	99.8	63.7
M-HS	4	1	93.6	57.1	98.8	98.1	99.4	55.3
M-HS	4	2	71.4	72.1	95.8	97.9	99.4	67.4
		avg	82.5	64.6	97.3	98.0	99.4	61.3
888	1	1	100.0	100.0	100.0	98.4	99.9	99.9
888	1	2	99.9	100.0	100.0	95.5	99.5	99.5
		avg	99.9	100.0	100.0	96.9	99.7	99.7
888-SL	1	1	99.8	99.6	100.0	98.4	99.2	98.9
888-SL	1	2	92.9	97.2	100.0	96.3	99.4	96.6
		avg	96.3	98.4	100.0	97.3	99.3	97.7
960-SL	1	1	98.3	99.6	99.8	96.4	99.3	98.7
960-SL	1	2	99.9	100.0	100.0	94.8	99.3	99.3
		avg	99.1	99.8	99.9	95.6	99.3	99.0
903-SL	1	1	100.0	99.9	100.0	94.6	98.8	98.7
903-SL	1	2	99.8	98.3	100.0	94.8	98.1	96.5
		avg	99.9	99.1	100.0	94.7	98.4	97.5

Table D-2. Overall survival over time at Arizona I-17 site.

Material	Config.	Rep. #	Overall Survival Over Time, percent joint length										
			0	2	5	9	14	18	31	43	58	70	81
C-221	1	1	100.0	100.0	100.0	100.0	100.0	100.0	97.2	85.6	79.9	74.4	69.4
		2	100.0	99.9	99.9	99.9	99.9	99.9	87.6	72.8	66.5	58.3	45.4
		Avg.	100.0	99.9	99.9	99.9	99.9	99.9	92.4	79.2	73.2	66.3	57.4
C-221	2	1	100.0	100.0	100.0	100.0	100.0	100.0	99.1	98.8	97.6	94.8	89.7
		2	100.0	99.7	99.7	99.7	99.7	99.7	98.5	95.6	90.9	85.8	81.7
		Avg.	100.0	99.9	99.9	99.9	99.9	99.9	98.8	97.2	94.3	90.3	85.7
C-221	4	1	100.0	100.0	100.0	100.0	100.0	100.0	100.0	99.8	99.4	99.0	98.6
		2	100.0	99.9	99.9	99.3	99.3	97.5	84.1	73.4	67.6	54.1	44.4
		Avg.	100.0	99.9	99.9	99.7	99.7	98.8	92.0	86.6	83.5	76.6	71.5
C-231	1	1	100.0	100.0	99.6	98.7	98.3	97.9	92.8	92.4	88.1	79.5	72.0
		2	100.0	100.0	100.0	98.5	99.3	99.3	54.0	36.1	26.7	14.0	9.9
		Avg.	100.0	100.0	99.8	98.6	98.8	98.6	73.4	64.2	57.4	46.7	41.0
C-231	2	1	100.0	100.0	100.0	100.0	100.0	100.0	99.4	99.1	98.4	94.9	93.0
		2	100.0	100.0	100.0	100.0	100.0	100.0	96.0	93.3	91.6	89.0	90.8
		Avg.	100.0	100.0	100.0	100.0	100.0	100.0	97.7	96.2	95.0	91.9	91.9
C-231	4	1	100.0	100.0	100.0	99.9	99.9	99.9	98.5	96.6	94.5	85.9	69.6
		2	100.0	100.0	100.0	98.5	97.9	97.9	97.8	96.3	90.7	76.5	59.5
		Avg.	100.0	100.0	100.0	99.2	98.9	98.9	98.2	96.4	92.6	81.2	64.5
K-9005	1	1	100.0	100.0	100.0	100.0	100.0	100.0	89.4	86.2	85.4	74.5	64.8
		2	100.0	100.0	100.0	100.0	100.0	99.8	98.0	99.3	97.2	94.1	95.0
		Avg.	100.0	100.0	100.0	100.0	100.0	99.9	93.7	92.7	91.3	84.3	79.9
K-9005	2	1	100.0	100.0	100.0	100.0	100.0	100.0	99.7	99.1	98.3	95.9	89.1
		2	100.0	100.0	100.0	100.0	100.0	100.0	100.0	99.7	99.7	91.2	86.3
		Avg.	100.0	100.0	100.0	100.0	100.0	100.0	99.9	99.4	99.0	93.5	87.7
K-9005	4	1	100.0	100.0	100.0	100.0	100.0	100.0	99.8	100.0	99.8	99.4	98.9
		2	100.0	99.6	99.6	99.2	99.2	98.8	89.4	54.8	51.5	10.2	6.3
		Avg.	100.0	99.8	99.8	99.6	99.6	99.4	94.6	77.4	75.6	54.8	52.6
M-HS	1	1	100.0	99.8	99.8	99.8	99.8	99.8	88.8	69.0	62.4	58.6	50.8
		2	100.0	100.0	100.0	100.0	100.0	100.0	59.3	27.6	22.6	26.3	28.3
		Avg.	100.0	99.9	99.9	99.9	99.9	99.9	74.1	48.3	42.5	42.5	39.5
M-HS	2	1	100.0	100.0	100.0	99.9	99.9	99.9	99.5	98.8	96.9	95.9	90.8
		2	100.0	100.0	100.0	100.0	100.0	100.0	92.5	76.5	73.0	54.0	36.6
		Avg.	100.0	100.0	100.0	100.0	100.0	100.0	96.0	87.6	85.0	74.9	63.7
M-HS	4	1	100.0	100.0	100.0	100.0	100.0	100.0	98.3	95.1	92.7	79.3	55.3
		2	100.0	99.9	99.9	99.9	99.9	99.9	99.9	97.6	94.7	88.8	67.4
		Avg.	100.0	100.0	100.0	100.0	100.0	100.0	99.1	96.4	93.7	84.1	61.3
888	1	1	100.0	100.0	100.0	100.0	100.0	100.0	99.8	99.7	99.7	99.9	99.9
		2	100.0	100.0	100.0	100.0	100.0	100.0	100.0	99.9	99.7	99.6	99.5
		Avg.	100.0	100.0	100.0	100.0	100.0	100.0	99.9	99.8	99.7	99.7	99.7
888-SL	1	1	100.0	100.0	100.0	100.0	100.0	100.0	99.8	99.4	99.0	99.1	98.9
		2	100.0	100.0	100.0	99.9	100.0	100.0	99.9	99.6	98.1	97.6	96.6
		Avg.	100.0	100.0	100.0	100.0	100.0	100.0	99.8	99.5	98.5	98.3	97.7
960-SL	1	1	100.0	100.0	100.0	100.0	100.0	100.0	100.0	98.8	99.4	99.2	98.7
		2	100.0	100.0	100.0	100.0	100.0	100.0	99.9	99.8	99.5	99.5	99.3
		Avg.	100.0	100.0	100.0	100.0	100.0	100.0	100.0	99.3	99.4	99.4	99.0
RS-SL	1	1	100.0	100.0	100.0	100.0	100.0	100.0	99.7	98.5	97.9	97.7	97.8
		2	100.0	100.0	100.0	100.0	100.0	100.0	100.0	99.1	98.4	98.3	96.5
		Avg.	100.0	100.0	100.0	100.0	100.0	100.0	99.9	98.8	98.2	98.0	97.1

Table D-3. Adhesion survival at Arizona I-17 site.

Material	Config.	Rep. #	Adhesion Survival Over Time, percent joint length										
			0	2	5	9	14	18	31	43	58	70	81
C-221	1	1	100.0	100.0	100.0	100.0	100.0	100.0	98.4	86.7	81.2	75.7	70.8
		2	100.0	100.0	100.0	100.0	100.0	100.0	87.9	74.8	68.5	60.5	48.0
		Avg.	100.0	100.0	100.0	100.0	100.0	100.0	93.2	80.7	74.8	68.1	59.4
C-221	2	1	100.0	100.0	100.0	100.0	100.0	100.0	99.9	99.9	98.6	96.2	93.2
		2	100.0	99.7	99.7	99.7	99.7	99.7	99.0	97.9	94.4	90.1	86.5
		Avg.	100.0	99.9	99.9	99.9	99.9	99.9	99.5	98.9	96.5	93.2	89.8
C-221	4	1	100.0	100.0	100.0	100.0	100.0	100.0	100.0	99.9	99.7	99.4	99.2
		2	100.0	100.0	100.0	99.4	99.4	97.6	84.3	75.5	71.2	66.5	65.0
		Avg.	100.0	100.0	100.0	99.7	99.7	98.8	92.2	87.7	85.5	83.0	82.1
C-231	1	1	100.0	100.0	99.6	98.7	98.3	97.9	94.6	95.2	91.2	82.7	75.4
		2	100.0	100.0	100.0	98.5	99.3	99.3	54.4	37.1	28.3	16.5	12.5
		Avg.	100.0	100.0	99.8	98.6	98.8	98.6	74.5	66.1	59.8	49.6	43.9
C-231	2	1	100.0	100.0	100.0	100.0	100.0	100.0	100.0	99.9	99.2	95.9	93.9
		2	100.0	100.0	100.0	100.0	100.0	100.0	98.9	98.0	95.1	92.5	92.1
		Avg.	100.0	100.0	100.0	100.0	100.0	100.0	99.4	98.9	97.2	94.2	93.0
C-231	4	1	100.0	100.0	100.0	99.9	99.9	99.9	98.8	97.9	96.3	89.4	74.3
		2	100.0	100.0	100.0	98.5	97.9	97.9	98.1	96.9	91.8	79.0	63.9
		Avg.	100.0	100.0	100.0	99.2	98.9	98.9	98.5	97.4	94.1	84.2	69.1
K-9005	1	1	100.0	100.0	100.0	100.0	100.0	100.0	94.0	91.7	90.9	93.0	93.1
		2	100.0	100.0	100.0	100.0	100.0	99.8	98.1	99.5	97.8	98.4	99.6
		Avg.	100.0	100.0	100.0	100.0	100.0	99.9	96.0	95.6	94.4	95.7	96.4
K-9005	2	1	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	99.9	98.7	91.7
		2	100.0	100.0	100.0	100.0	100.0	100.0	100.0	99.7	99.8	100.0	99.9
		Avg.	100.0	100.0	100.0	100.0	100.0	100.0	100.0	99.9	99.8	99.3	95.8
K-9005	4	1	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	99.9	99.7
		2	100.0	100.0	100.0	99.7	99.7	99.2	92.4	99.8	87.8	100.0	100.0
		Avg.	100.0	100.0	100.0	99.8	99.8	99.6	96.2	99.9	93.9	99.9	99.8
M-HS	1	1	100.0	100.0	100.0	100.0	100.0	100.0	89.4	69.9	63.3	59.1	51.3
		2	100.0	100.0	100.0	100.0	100.0	100.0	59.5	27.8	23.0	26.9	28.9
		Avg.	100.0	100.0	100.0	100.0	100.0	100.0	74.5	48.9	43.2	43.0	40.1
M-HS	2	1	100.0	100.0	100.0	99.9	99.9	99.9	99.9	99.8	98.4	98.2	93.2
		2	100.0	100.0	100.0	100.0	100.0	100.0	99.9	98.8	98.3	100.0	100.0
		Avg.	100.0	100.0	100.0	100.0	100.0	100.0	99.9	99.3	98.3	99.1	96.6
M-HS	4	1	100.0	100.0	100.0	100.0	100.0	100.0	98.3	96.4	94.3	81.0	57.1
		2	100.0	100.0	100.0	100.0	100.0	100.0	100.0	98.1	96.2	90.8	72.1
		Avg.	100.0	100.0	100.0	100.0	100.0	100.0	99.2	97.3	95.2	85.9	64.6
888	1	1	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
		2	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
		Avg.	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
888-SL	1	1	100.0	100.0	100.0	100.0	100.0	100.0	100.0	99.9	99.8	99.8	99.7
		2	100.0	100.0	100.0	99.9	100.0	100.0	100.0	99.9	98.5	98.1	97.2
		Avg.	100.0	100.0	100.0	100.0	100.0	100.0	100.0	99.9	99.2	99.0	98.4
960-SL	1	1	100.0	100.0	100.0	100.0	100.0	100.0	100.0	99.7	99.7	99.6	99.6
		2	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	99.9	100.0	100.0
		Avg.	100.0	100.0	100.0	100.0	100.0	100.0	100.0	99.9	99.8	99.8	99.8
RS-SL	1	1	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	99.9	99.9	99.9
		2	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	98.3
		Avg.	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	99.1

Table D-4. Cohesion survival at Arizona I-17 site.

Material	Config.	Rep. #	Cohesion Survival Over Time, percent joint length										
			0	2	5	9	14	18	31	43	58	70	81
C-221	1	1	100.0	100.0	100.0	100.0	100.0	100.0	99.7	99.7	99.6	99.6	99.6
		2	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	99.9	99.7	99.4
		Avg.	100.0	100.0	100.0	100.0	100.0	100.0	99.9	99.8	99.7	99.6	99.5
C-221	2	1	100.0	100.0	100.0	100.0	100.0	100.0	99.2	98.9	99.0	98.6	96.5
		2	100.0	100.0	100.0	100.0	100.0	100.0	99.5	97.8	96.6	95.9	95.6
		Avg.	100.0	100.0	100.0	100.0	100.0	100.0	99.3	98.3	97.8	97.3	96.0
C-221	4	1	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	99.9	99.8	99.7
		2	100.0	100.0	100.0	100.0	100.0	100.0	99.9	98.3	96.8	88.0	79.9
		Avg.	100.0	100.0	100.0	100.0	100.0	100.0	99.9	99.2	98.3	93.9	89.8
C-231	1	1	100.0	100.0	100.0	100.0	100.0	100.0	98.5	98.4	97.6	97.5	97.4
		2	100.0	100.0	100.0	100.0	100.0	100.0	99.7	99.4	99.0	98.2	98.1
		Avg.	100.0	100.0	100.0	100.0	100.0	100.0	99.1	98.9	98.3	97.8	97.7
C-231	2	1	100.0	100.0	100.0	100.0	100.0	100.0	99.4	99.2	99.2	99.1	99.1
		2	100.0	100.0	100.0	100.0	100.0	100.0	97.2	95.8	97.2	97.2	99.5
		Avg.	100.0	100.0	100.0	100.0	100.0	100.0	98.3	97.5	98.2	98.1	99.3
C-231	4	1	100.0	100.0	100.0	100.0	100.0	100.0	100.0	99.4	99.2	98.3	97.1
		2	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	99.7	99.7	97.8
		Avg.	100.0	100.0	100.0	100.0	100.0	100.0	100.0	99.7	99.4	99.0	97.5
K-9005	1	1	100.0	100.0	100.0	100.0	100.0	100.0	95.3	94.5	94.6	81.6	71.8
		2	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	99.5	95.9	95.6
		Avg.	100.0	100.0	100.0	100.0	100.0	100.0	97.7	97.3	97.0	88.8	83.7
K-9005	2	1	100.0	100.0	100.0	100.0	100.0	100.0	99.7	99.1	98.4	97.2	97.4
		2	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	99.9	91.2	86.3
		Avg.	100.0	100.0	100.0	100.0	100.0	100.0	99.9	99.5	99.2	94.2	91.9
K-9005	4	1	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	99.9	99.7	99.4
		2	100.0	100.0	100.0	100.0	100.0	100.0	97.1	55.1	63.7	10.3	6.4
		Avg.	100.0	100.0	100.0	100.0	100.0	100.0	98.5	77.5	81.8	55.0	52.9
M-HS	1	1	100.0	100.0	100.0	100.0	100.0	100.0	99.5	99.3	99.3	99.7	99.7
		2	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	99.9	99.9	99.9
		Avg.	100.0	100.0	100.0	100.0	100.0	100.0	99.8	99.7	99.6	99.8	99.8
M-HS	2	1	100.0	100.0	100.0	100.0	100.0	100.0	99.7	99.0	98.6	97.8	97.6
		2	100.0	100.0	100.0	100.0	100.0	100.0	92.8	77.8	74.9	54.2	36.9
		Avg.	100.0	100.0	100.0	100.0	100.0	100.0	96.3	88.4	86.8	76.0	67.3
M-HS	4	1	100.0	100.0	100.0	100.0	100.0	100.0	100.0	99.0	99.0	98.8	98.8
		2	100.0	100.0	100.0	100.0	100.0	100.0	100.0	99.8	99.0	98.6	95.8
		Avg.	100.0	100.0	100.0	100.0	100.0	100.0	100.0	99.4	99.0	98.7	97.3
888	1	1	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
		2	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
		Avg.	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
888-SL	1	1	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
		2	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
		Avg.	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
960-SL	1	1	100.0	100.0	100.0	100.0	100.0	100.0	100.0	99.9	100.0	100.0	99.8
		2	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
		Avg.	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	99.9
RS-SL	1	1	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
		2	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
		Avg.	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0

Table D-5. Spall survival over time at Arizona I-17 site.

Material	Config.	Rep. #	Spall Survival Over Time, percent joint length										
			0	2	5	9	14	18	31	43	58	70	81
C-221	1	1	100.0	100.0	100.0	100.0	100.0	100.0	99.0	99.3	99.2	99.2	99.0
		2	100.0	99.9	99.9	99.9	99.9	99.9	99.7	98.0	98.1	98.1	98.1
		Avg.	100.0	99.9	99.9	99.9	99.9	99.9	99.4	98.6	98.6	98.6	98.5
C-221	2	1	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	99.9
		2	100.0	100.0	100.0	100.0	100.0	100.0	99.9	99.9	99.9	99.8	99.7
		Avg.	100.0	100.0	100.0	100.0	100.0	100.0	100.0	99.9	99.9	99.9	99.8
C-221	4	1	100.0	100.0	100.0	100.0	100.0	100.0	100.0	99.9	99.9	99.9	99.7
		2	100.0	99.9	99.9	99.9	99.9	99.9	99.9	99.6	99.6	99.6	99.5
		Avg.	100.0	99.9	99.9	99.9	99.9	99.9	100.0	99.7	99.7	99.7	99.6
C-231	1	1	100.0	100.0	100.0	100.0	100.0	100.0	99.7	98.8	99.4	99.3	99.2
		2	100.0	100.0	100.0	100.0	100.0	100.0	99.9	99.6	99.4	99.4	99.4
		Avg.	100.0	100.0	100.0	100.0	100.0	100.0	99.8	99.2	99.4	99.3	99.3
C-231	2	1	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
		2	100.0	100.0	100.0	100.0	100.0	100.0	100.0	99.6	99.2	99.2	99.2
		Avg.	100.0	100.0	100.0	100.0	100.0	100.0	100.0	99.8	99.6	99.6	99.6
C-231	4	1	100.0	100.0	100.0	100.0	100.0	100.0	99.7	99.2	99.0	98.2	98.2
		2	100.0	100.0	100.0	100.0	100.0	100.0	99.7	99.3	99.2	97.8	97.8
		Avg.	100.0	100.0	100.0	100.0	100.0	100.0	99.7	99.3	99.1	98.0	98.0
K-9005	1	1	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	99.9	99.9	99.9
		2	100.0	100.0	100.0	100.0	100.0	100.0	99.9	99.8	99.8	99.8	99.8
		Avg.	100.0	100.0	100.0	100.0	100.0	100.0	100.0	99.9	99.9	99.9	99.8
K-9005	2	1	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
		2	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
		Avg.	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
K-9005	4	1	100.0	100.0	100.0	100.0	100.0	100.0	99.8	100.0	99.9	99.9	99.8
		2	100.0	99.6	99.6	99.6	99.6	99.6	99.9	99.9	99.9	99.9	99.9
		Avg.	100.0	99.8	99.8	99.8	99.8	99.8	99.9	100.0	99.9	99.9	99.9
M-HS	1	1	100.0	99.8	99.8	99.8	99.8	99.8	99.9	99.8	99.8	99.8	99.8
		2	100.0	100.0	100.0	100.0	100.0	100.0	99.8	99.8	99.8	99.4	99.4
		Avg.	100.0	99.9	99.9	99.9	99.9	99.9	99.8	99.8	99.8	99.6	99.6
M-HS	2	1	100.0	100.0	100.0	100.0	100.0	100.0	99.9	99.9	99.9	99.9	99.9
		2	100.0	100.0	100.0	100.0	100.0	100.0	99.9	99.9	99.8	99.7	99.7
		Avg.	100.0	100.0	100.0	100.0	100.0	100.0	99.9	99.9	99.9	99.8	99.8
M-HS	4	1	100.0	100.0	100.0	100.0	100.0	100.0	99.9	99.8	99.4	99.4	99.4
		2	100.0	99.9	99.9	99.9	99.9	99.9	99.9	99.7	99.4	99.4	99.4
		Avg.	100.0	100.0	100.0	100.0	100.0	100.0	99.9	99.7	99.4	99.4	99.4
888	1	1	100.0	100.0	100.0	100.0	100.0	100.0	99.8	99.7	99.7	99.9	99.9
		2	100.0	100.0	100.0	100.0	100.0	100.0	100.0	99.9	99.7	99.6	99.5
		Avg.	100.0	100.0	100.0	100.0	100.0	100.0	99.9	99.8	99.7	99.7	99.7
888-SL	1	1	100.0	100.0	100.0	100.0	100.0	100.0	99.8	99.4	99.2	99.3	99.2
		2	100.0	100.0	100.0	100.0	100.0	100.0	99.9	99.7	99.5	99.4	99.4
		Avg.	100.0	100.0	100.0	100.0	100.0	100.0	99.8	99.5	99.4	99.4	99.3
960-SL	1	1	100.0	100.0	100.0	100.0	100.0	100.0	100.0	99.2	99.7	99.7	99.3
		2	100.0	100.0	100.0	100.0	100.0	100.0	99.9	99.8	99.6	99.5	99.3
		Avg.	100.0	100.0	100.0	100.0	100.0	100.0	100.0	99.5	99.7	99.6	99.3
RS-SL	1	1	100.0	100.0	100.0	100.0	100.0	100.0	99.7	98.5	98.0	97.8	97.8
		2	100.0	100.0	100.0	100.0	100.0	100.0	100.0	99.1	98.4	98.3	98.1
		Avg.	100.0	100.0	100.0	100.0	100.0	100.0	99.9	98.8	98.2	98.1	98.0

Table D-6. Summary of distress survival at Colorado I-25 site.

Material	Config.	Rep.	Partial-depth Adhesion Survival, % edge length	Full-depth Adhesion Survival, % joint length	Full-depth Cohesion Survival, % joint length	Partial-depth Spall Survival, % joint length	Full-depth Spall Survival, % joint length	Overall Survival, % joint length
C-231	1	1	80.2	79.9	99.6	90.9	93.5	73.0
C-231	1	2	46.7	79.3	88.2	90.7	92.7	60.2
		avg	62.5	79.6	93.6	90.8	93.1	66.3
C-231	2	1	88.2	60.9	100.0	93.0	90.3	51.2
C-231	2	2	65.6	66.6	100.0	94.9	92.6	59.2
		avg	76.3	63.9	100.0	94.0	91.5	55.4
C-231	4	1	86.7	60.2	100.0	89.1	93.9	54.1
C-231	4	2	76.7	73.6	99.7	93.9	91.9	65.3
		avg	81.2	67.6	99.8	91.7	92.8	60.3
K-9005	1	1	78.5	78.0	70.8	93.0	96.9	45.7
K-9005	1	2	94.0	83.7	83.3	96.8	96.5	63.5
		avg	86.7	81.0	77.3	95.0	96.7	55.0
K-9005	2	1	99.2	84.4	61.6	96.2	98.8	44.8
K-9005	2	2	100.0	79.8	70.6	96.3	99.0	49.4
		avg	99.6	82.0	66.3	96.3	98.9	47.3
K-9005	4	1	98.0	98.6	63.8	95.4	98.2	60.6
K-9005	4	2	100.0	99.4	67.9	93.4	97.3	64.6
		avg	99.0	99.0	66.0	94.4	97.7	62.7
K-9030	1	1	62.7	20.1	100.0	91.9	91.8	11.9
K-9030	1	2	65.1	20.3	100.0	94.9	93.4	13.7
		avg	64.0	20.2	100.0	93.5	92.7	12.9
K-9030	2	1	68.7	15.7	100.0	91.4	92.6	8.3
K-9030	2	2	58.3	18.3	100.0	95.8	92.0	10.3
		avg	63.2	17.1	100.0	93.7	92.3	9.4
K-9030	4	1	75.2	9.3	99.8	95.0	92.4	1.5
K-9030	4	2	76.1	30.6	99.8	93.5	90.3	20.7
		avg	75.7	20.5	99.8	94.2	91.3	11.6

Table D-6. Summary of distress survival at Colorado I-25 site (continued).

Material	Config.	Rep.	Partial-depth Adhesion Survival, % edge length	Full-depth Adhesion Survival, % joint length	Full-depth Cohesion Survival, % joint length	Partial-depth Spall Survival, % joint length	Full-depth Spall Survival, % joint length	Overall Survival, % joint length
M-SS	1	1	58.0	17.5	100.0	88.1	92.1	9.6
M-SS	1	2	67.4	15.3	99.9	94.3	93.1	8.3
		avg	63.0	16.4	99.9	91.4	92.6	8.9
M-SS	2	1	75.2	23.5	99.2	84.6	83.3	5.9
M-SS	2	2	69.8	39.2	95.5	92.1	86.5	21.2
		avg	72.4	31.8	97.2	88.5	85.0	14.0
M-SS	4	1	82.3	29.0	98.2	91.4	86.3	13.5
M-SS	4	2	81.9	36.6	99.0	94.0	85.0	20.6
		avg	82.1	33.0	98.6	92.7	85.6	17.2
888	1	1	98.8	97.7	100.0	83.1	87.6	85.3
888	1	2	99.9	99.4	99.9	86.3	90.1	89.4
		avg	99.3	98.6	100.0	84.8	88.9	87.5
888-SL	1	1	98.5	96.1	100.0	88.6	88.6	84.6
888-SL	1	2	99.3	95.2	100.0	92.8	87.0	82.2
		avg	98.9	95.6	100.0	90.8	87.8	83.4
960-SL	1	1	96.7	89.3	100.0	87.8	85.0	74.3
960-SL	1	2	97.2	97.8	100.0	89.2	82.0	79.9
		avg	97.0	93.8	100.0	88.5	83.4	77.2
K-9050	1	1	100.0	29.0	90.8	94.8	94.7	14.5
K-9050	1	2	97.8	47.6	80.5	95.6	88.0	16.0
		avg	98.9	38.8	85.4	95.2	91.2	15.3

Table D-7. Overall survival at Colorado I-25 site.

Material	Config.	Rep. #	Overall Survival Over Time, percent joint length										
			0	2	5	9	13	17	30	42	54	66	82
C-231	1	1	100.0	99.9	99.9	99.5	98.8	98.7	98.1	94.4	86.2	84.7	75.7
		2	100.0	100.0	99.9	99.2	98.8	97.9	97.4	93.8	85.6	75.5	60.2
		Avg.	100.0	99.9	99.9	99.4	98.8	98.3	97.7	94.1	85.9	80.1	68.0
C-231	2	1	100.0	100.0	100.0	99.4	98.3	97.4	94.8	88.3	81.0	76.7	56.0
		2	100.0	100.0	100.0	99.4	99.4	98.8	97.2	96.9	89.5	77.4	59.2
		Avg.	100.0	100.0	100.0	99.4	98.9	98.1	96.0	92.6	85.3	77.0	57.6
C-231	4	1	100.0	99.8	99.8	99.0	98.7	98.4	97.2	92.7	84.0	75.8	62.9
		2	100.0	100.0	100.0	99.9	99.5	99.5	99.0	97.7	89.4	79.5	65.3
		Avg.	100.0	99.9	99.9	99.5	99.1	99.0	98.1	95.2	86.7	77.7	64.1
K-9005	1	1	100.0	99.9	99.9	97.6	97.6	94.6	86.9	62.6	85.3	87.6	51.1
		2	100.0	99.9	99.9	99.8	99.8	99.8	98.8	94.6	84.1	81.5	63.5
		Avg.	100.0	99.9	99.9	98.7	98.7	97.2	92.9	78.6	84.7	84.5	57.3
K-9005	2	1	100.0	100.0	100.0	99.9	99.9	99.8	97.4	89.2	85.8	81.2	50.3
		2	100.0	100.0	100.0	99.9	99.4	99.6	99.6	97.1	86.5	81.1	49.4
		Avg.	100.0	100.0	100.0	99.9	99.7	99.7	98.5	93.1	86.1	81.1	49.9
K-9005	4	1	100.0	100.0	100.0	99.7	99.2	99.4	80.6	76.8	72.3	73.4	64.6
		2	100.0	100.0	100.0	99.9	99.9	97.3	96.9	82.2	79.4	72.6	64.6
		Avg.	100.0	100.0	100.0	99.8	99.5	98.4	88.8	79.5	75.9	73.0	64.6
K-9030	1	1	100.0	99.9	99.9	94.9	91.6	87.6	78.5	55.8	38.8	36.9	20.7
		2	100.0	100.0	99.5	96.3	94.0	92.1	82.1	58.5	35.8	24.0	13.8
		Avg.	100.0	100.0	99.7	95.6	92.8	89.9	80.3	57.2	37.3	30.4	17.2
K-9030	2	1	100.0	100.0	100.0	98.9	96.3	94.5	84.6	54.6	36.9	35.4	17.5
		2	100.0	100.0	100.0	99.0	97.6	90.9	76.0	54.7	32.5	19.6	10.3
		Avg.	100.0	100.0	100.0	98.9	96.9	92.7	80.3	54.6	34.7	27.5	13.9
K-9030	4	1	100.0	100.0	99.8	98.3	95.6	93.6	78.1	46.9	19.5	15.6	11.4
		2	100.0	99.7	99.4	98.1	97.2	94.0	91.0	74.4	53.0	44.2	20.7
		Avg.	100.0	99.8	99.6	98.2	96.4	93.8	84.5	60.7	36.3	29.9	16.0
M-SS	1	1	100.0	100.0	100.0	98.9	96.8	96.3	93.5	46.5	32.4	32.3	18.6
		2	100.0	100.0	99.9	99.4	97.6	96.0	87.2	61.3	42.2	12.2	8.3
		Avg.	100.0	100.0	99.9	99.1	97.2	96.1	90.3	53.9	37.3	22.3	13.5
M-SS	2	1	100.0	99.9	99.9	97.8	96.7	94.9	87.4	59.4	36.2	29.9	15.3
		2	100.0	100.0	100.0	99.4	99.2	97.2	94.5	81.7	53.9	40.0	21.2
		Avg.	100.0	100.0	100.0	98.6	98.0	96.1	90.9	70.5	45.0	34.9	18.3
M-SS	4	1	100.0	100.0	99.9	99.3	98.3	97.3	95.8	74.9	45.1	35.8	22.2
		2	100.0	99.9	99.7	98.3	98.3	96.5	92.4	82.4	55.1	44.0	20.6
		Avg.	100.0	99.9	99.8	98.8	98.3	96.9	94.1	78.6	50.1	39.9	21.4
888	1	1	100.0	100.0	100.0	99.2	99.2	99.1	98.1	93.2	90.4	89.9	86.7
		2	100.0	100.0	100.0	99.1	98.4	98.3	98.0	96.5	92.6	91.2	89.4
		Avg.	100.0	100.0	100.0	99.2	98.8	98.7	98.0	94.9	91.5	90.6	88.1
888-SL	1	1	100.0	100.0	99.9	99.5	99.2	99.0	98.3	97.3	91.4	89.0	86.2
		2	100.0	100.0	99.9	99.8	99.5	99.0	96.3	90.6	88.4	86.8	82.2
		Avg.	100.0	100.0	99.9	99.7	99.3	99.0	97.3	93.9	89.9	87.9	84.2
960-SL	1	1	100.0	100.0	100.0	99.7	99.7	99.5	98.3	96.3	86.3	82.4	76.9
		2	100.0	99.9	99.9	99.3	97.6	96.0	93.1	91.7	84.7	82.7	79.9
		Avg.	100.0	99.9	99.9	99.5	98.6	97.7	95.7	94.0	85.5	82.6	78.4
K-9050	1	1	100.0	100.0	99.2	92.4	80.3	61.9	48.8	36.2	33.1	27.6	23.1
		2	100.0	100.0	100.0	99.2	96.7	77.1	56.5	40.3	36.1	27.3	16.0
		Avg.	100.0	100.0	99.6	95.8	88.5	69.5	52.6	38.3	34.6	27.5	19.5

Table D-8. Adhesion survival at Colorado I-25 site.

Material	Config.	Rep. #	Adhesion Survival Over Time, percent joint length										
			0	2	5	9	13	17	30	42	54	66	82
C-231	1	1	100.0	100.0	100.0	100.0	99.6	99.6	99.5	97.4	90.8	89.5	81.9
		2	100.0	100.0	99.9	99.7	99.5	99.0	99.0	97.3	90.3	81.9	79.3
		Avg.	100.0	100.0	100.0	99.9	99.5	99.3	99.3	97.3	90.6	85.7	80.6
C-231	2	1	100.0	100.0	100.0	100.0	99.9	99.9	99.1	93.5	88.8	84.7	64.8
		2	100.0	100.0	100.0	99.8	99.9	99.9	99.8	99.6	95.2	84.0	66.6
		Avg.	100.0	100.0	100.0	99.9	99.9	99.9	99.4	96.6	92.0	84.3	65.7
C-231	4	1	100.0	100.0	100.0	100.0	100.0	99.8	99.0	95.3	87.6	80.0	68.1
		2	100.0	100.0	100.0	99.9	100.0	100.0	100.0	99.5	95.0	86.5	73.6
		Avg.	100.0	100.0	100.0	100.0	100.0	99.9	99.5	97.4	91.3	83.3	70.9
K-9005	1	1	100.0	100.0	100.0	98.5	98.5	95.5	89.3	99.7	89.7	91.5	80.2
		2	100.0	100.0	100.0	100.0	100.0	100.0	99.0	99.4	94.4	94.8	83.8
		Avg.	100.0	100.0	100.0	99.2	99.2	97.7	94.2	99.5	92.0	93.1	82.0
K-9005	2	1	100.0	100.0	100.0	100.0	100.0	100.0	97.7	100.0	99.9	99.2	86.0
		2	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	97.5	97.9	79.8
		Avg.	100.0	100.0	100.0	100.0	100.0	100.0	98.9	100.0	98.7	98.6	82.9
K-9005	4	1	100.0	100.0	100.0	99.8	99.7	99.7	81.2	98.8	97.4	98.2	98.8
		2	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	99.2	99.4
		Avg.	100.0	100.0	100.0	99.9	99.9	99.9	90.6	99.4	98.7	98.7	99.1
K-9030	1	1	100.0	99.9	99.9	95.7	93.3	90.5	84.5	61.3	45.4	43.5	28.1
		2	100.0	100.0	99.5	96.7	94.9	93.1	84.5	61.3	40.8	29.2	20.3
		Avg.	100.0	100.0	99.7	96.2	94.1	91.8	84.5	61.3	43.1	36.4	24.2
K-9030	2	1	100.0	100.0	100.0	99.5	97.8	96.8	88.9	60.3	43.3	41.4	24.2
		2	100.0	100.0	100.0	99.2	98.3	92.4	79.4	58.5	39.2	27.3	18.3
		Avg.	100.0	100.0	100.0	99.4	98.1	94.6	84.1	59.4	41.3	34.3	21.3
K-9030	4	1	100.0	100.0	100.0	99.0	96.5	95.3	81.2	50.0	23.5	22.0	18.4
		2	100.0	100.0	99.9	99.4	98.4	97.3	95.2	80.4	60.6	53.5	30.6
		Avg.	100.0	100.0	99.9	99.2	97.5	96.3	88.2	65.2	42.0	37.8	24.5
M-SS	1	1	100.0	100.0	100.0	99.4	98.3	98.1	96.7	51.4	38.8	37.9	25.8
		2	100.0	100.0	99.9	99.7	98.1	96.5	88.5	64.0	47.2	18.3	15.3
		Avg.	100.0	100.0	99.9	99.5	98.2	97.3	92.6	57.7	43.0	28.1	20.6
M-SS	2	1	100.0	100.0	100.0	99.7	99.5	97.8	93.1	67.5	50.4	43.8	31.2
		2	100.0	100.0	100.0	99.5	99.9	99.6	98.5	86.9	67.8	56.4	39.2
		Avg.	100.0	100.0	100.0	99.6	99.7	98.7	95.8	77.2	59.1	50.1	35.2
M-SS	4	1	100.0	100.0	100.0	100.0	99.6	98.8	97.6	78.4	51.7	47.6	36.1
		2	100.0	100.0	99.9	99.9	99.7	99.5	96.8	92.8	66.8	58.0	36.6
		Avg.	100.0	100.0	99.9	99.9	99.7	99.2	97.2	85.6	59.2	52.8	36.4
888	1	1	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	97.9
		2	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	99.4
		Avg.	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	98.6
888-SL	1	1	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	99.7	98.2	96.5
		2	100.0	100.0	100.0	100.0	100.0	100.0	100.0	99.6	99.7	99.0	95.2
		Avg.	100.0	100.0	100.0	100.0	100.0	100.0	100.0	99.8	99.7	98.6	95.8
960-SL	1	1	100.0	100.0	100.0	99.9	99.9	99.9	99.9	99.5	96.9	95.1	90.3
		2	100.0	100.0	100.0	100.0	100.0	100.0	100.0	99.9	99.9	99.3	97.8
		Avg.	100.0	100.0	100.0	99.9	99.9	99.9	99.9	99.7	98.4	97.2	94.1
K-9050	1	1	100.0	100.0	99.2	92.7	80.6	62.3	50.4	38.7	38.3	37.3	36.1
		2	100.0	100.0	100.0	99.4	97.3	78.3	60.5	49.6	49.9	47.1	47.6
		Avg.	100.0	100.0	99.6	96.0	89.0	70.3	55.5	44.1	44.1	42.2	41.8

Table D-9. Cohesion survival at Colorado I-25 site.

Material	Config.	Rep. #	Cohesion Survival Over Time, percent joint length										
			0	2	5	9	13	17	30	42	54	66	82
C-231	1	1	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	99.8	99.4	99.7
		2	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	88.2
		Avg.	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	99.9	99.7	93.9
C-231	2	1	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
		2	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
		Avg.	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
C-231	4	1	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
		2	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	99.7	99.7
		Avg.	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	99.9	99.9
K-9005	1	1	100.0	100.0	100.0	100.0	100.0	100.0	100.0	66.4	99.2	99.1	73.7
		2	100.0	100.0	100.0	100.0	100.0	100.0	100.0	96.5	91.5	89.0	83.3
		Avg.	100.0	100.0	100.0	100.0	100.0	100.0	100.0	81.4	95.3	94.1	78.5
K-9005	2	1	100.0	100.0	100.0	100.0	100.0	100.0	100.0	89.5	86.3	82.8	65.4
		2	100.0	100.0	100.0	100.0	100.0	99.9	99.9	97.3	89.4	84.0	70.6
		Avg.	100.0	100.0	100.0	100.0	100.0	100.0	100.0	93.4	87.8	83.4	68.0
K-9005	4	1	100.0	100.0	100.0	100.0	100.0	100.0	100.0	79.5	76.8	76.7	67.4
		2	100.0	100.0	100.0	100.0	100.0	97.5	97.5	83.1	81.3	75.4	67.9
		Avg.	100.0	100.0	100.0	100.0	100.0	98.8	98.8	81.3	79.1	76.1	67.7
K-9030	1	1	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
		2	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
		Avg.	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
K-9030	2	1	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
		2	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
		Avg.	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
K-9030	4	1	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	99.9
		2	100.0	100.0	100.0	100.0	100.0	100.0	100.0	99.9	99.9	99.8	99.8
		Avg.	100.0	100.0	100.0	100.0	100.0	100.0	100.0	99.9	99.9	99.9	99.8
M-SS	1	1	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
		2	100.0	100.0	100.0	100.0	100.0	100.0	100.0	99.9	99.9	99.9	99.9
		Avg.	100.0	100.0	100.0	100.0	100.0	100.0	100.0	99.9	99.9	99.9	99.9
M-SS	2	1	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	99.6	99.6	99.2
		2	100.0	100.0	100.0	100.0	99.6	99.6	99.6	100.0	96.1	96.0	95.5
		Avg.	100.0	100.0	100.0	100.0	99.8	99.8	99.8	100.0	97.8	97.8	97.4
M-SS	4	1	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	98.4
		2	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	99.0
		Avg.	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	98.7
888	1	1	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
		2	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	99.9
		Avg.	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
888-SL	1	1	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
		2	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
		Avg.	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
960-SL	1	1	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
		2	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
		Avg.	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
K-9050	1	1	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	98.0	94.4	91.7
		2	100.0	100.0	100.0	100.0	100.0	100.0	100.0	99.6	95.7	91.3	80.5
		Avg.	100.0	100.0	100.0	100.0	100.0	100.0	100.0	99.8	96.8	92.8	86.1

Table D-10. Spall survival at Colorado I-25 site.

Material	Config.	Rep. #	Spall Survival Over Time, percent joint length										
			0	2	5	9	13	17	30	42	54	66	82
C-231	1	1	100.0	99.9	99.9	99.5	99.2	99.1	98.6	97.0	95.6	95.7	94.2
		2	100.0	100.0	100.0	99.5	99.3	98.9	98.3	96.5	95.3	93.6	92.7
		Avg.	100.0	99.9	99.9	99.5	99.2	99.0	98.5	96.7	95.4	94.7	93.4
C-231	2	1	100.0	100.0	100.0	99.4	98.3	97.5	95.7	94.7	92.3	92.0	91.3
		2	100.0	100.0	100.0	99.7	99.5	98.8	97.4	97.4	94.3	93.4	92.6
		Avg.	100.0	100.0	100.0	99.5	98.9	98.2	96.5	96.0	93.3	92.7	91.9
C-231	4	1	100.0	99.8	99.8	99.0	98.7	98.6	98.3	97.4	96.3	95.8	94.8
		2	100.0	100.0	100.0	100.0	99.5	99.5	99.0	98.2	94.4	93.3	91.9
		Avg.	100.0	99.9	99.9	99.5	99.1	99.1	98.6	97.8	95.4	94.5	93.4
K-9005	1	1	100.0	99.9	99.9	99.1	99.1	99.1	97.6	96.6	96.4	97.0	97.2
		2	100.0	99.9	99.9	99.8	99.8	99.8	99.8	98.7	98.3	97.6	96.5
		Avg.	100.0	99.9	99.9	99.4	99.4	99.4	98.7	97.6	97.3	97.3	96.8
K-9005	2	1	100.0	100.0	100.0	99.9	99.9	99.8	99.7	99.7	99.6	99.2	99.0
		2	100.0	100.0	100.0	99.9	99.4	99.7	99.7	99.8	99.6	99.2	99.0
		Avg.	100.0	100.0	100.0	99.9	99.7	99.7	99.7	99.7	99.6	99.2	99.0
K-9005	4	1	100.0	100.0	100.0	99.9	99.4	99.7	99.4	98.5	98.1	98.5	98.4
		2	100.0	100.0	100.0	99.9	99.9	99.8	99.4	99.0	98.1	98.0	97.3
		Avg.	100.0	100.0	100.0	99.9	99.7	99.8	99.4	98.8	98.1	98.2	97.8
K-9030	1	1	100.0	100.0	100.0	99.2	98.3	97.2	94.0	94.4	93.4	93.3	92.6
		2	100.0	100.0	100.0	99.5	99.1	99.0	97.6	97.2	95.1	94.7	93.4
		Avg.	100.0	100.0	100.0	99.4	98.7	98.1	95.8	95.8	94.2	94.0	93.0
K-9030	2	1	100.0	100.0	100.0	99.4	98.4	97.7	95.7	94.2	93.6	94.0	93.3
		2	100.0	100.0	100.0	99.7	99.3	98.5	96.7	96.1	93.3	92.3	92.0
		Avg.	100.0	100.0	100.0	99.5	98.9	98.1	96.2	95.2	93.4	93.2	92.7
K-9030	4	1	100.0	100.0	99.8	99.2	99.1	98.3	96.9	96.9	96.0	93.6	93.1
		2	100.0	99.7	99.6	98.7	98.8	96.7	95.8	94.2	92.5	90.8	90.3
		Avg.	100.0	99.8	99.7	99.0	98.9	97.5	96.4	95.5	94.3	92.2	91.7
M-SS	1	1	100.0	100.0	100.0	99.5	98.5	98.3	96.7	95.1	93.6	94.4	92.8
		2	100.0	100.0	100.0	99.7	99.5	99.4	98.7	97.4	95.1	94.0	93.1
		Avg.	100.0	100.0	100.0	99.6	99.0	98.9	97.7	96.3	94.4	94.2	93.0
M-SS	2	1	100.0	99.9	99.9	98.2	97.2	97.2	94.3	91.9	86.2	86.5	84.9
		2	100.0	100.0	100.0	99.9	99.7	98.1	96.4	94.7	90.0	87.6	86.5
		Avg.	100.0	100.0	100.0	99.0	98.5	97.6	95.3	93.3	88.1	87.1	85.7
M-SS	4	1	100.0	100.0	99.9	99.3	98.8	98.5	98.1	96.5	93.5	88.3	87.6
		2	100.0	99.9	99.9	98.4	98.5	97.0	95.6	89.6	88.3	86.0	85.0
		Avg.	100.0	99.9	99.9	98.9	98.6	97.7	96.9	93.0	90.9	87.2	86.3
888	1	1	100.0	100.0	100.0	99.2	99.2	99.1	98.1	93.2	90.4	89.9	88.8
		2	100.0	100.0	100.0	99.1	98.4	98.3	98.0	96.5	92.6	91.2	90.1
		Avg.	100.0	100.0	100.0	99.2	98.8	98.7	98.0	94.9	91.5	90.6	89.5
888-SL	1	1	100.0	100.0	99.9	99.5	99.2	99.0	98.3	97.3	91.7	90.8	89.7
		2	100.0	100.0	99.9	99.8	99.5	99.0	96.3	91.0	88.8	87.8	87.0
		Avg.	100.0	100.0	99.9	99.7	99.3	99.0	97.3	94.1	90.2	89.3	88.4
960-SL	1	1	100.0	100.0	100.0	99.8	99.9	99.7	98.4	96.8	89.4	87.3	86.5
		2	100.0	99.9	99.9	99.3	97.6	96.0	93.1	91.8	84.9	83.4	82.0
		Avg.	100.0	99.9	99.9	99.5	98.7	97.8	95.7	94.3	87.1	85.3	84.3
K-9050	1	1	100.0	100.0	100.0	99.7	99.7	99.7	98.3	97.5	96.9	96.0	95.2
		2	100.0	100.0	100.0	99.9	99.4	98.8	96.0	91.2	90.6	88.9	88.0
		Avg.	100.0	100.0	100.0	99.8	99.5	99.2	97.2	94.3	93.7	92.4	91.6

Table D-11. Summary of distress survival at Iowa I-80 site.

Material	Config.	Rep.	Partial-depth Adhesion Survival, % edge length	Full-depth Adhesion Survival, % joint length	Full-depth Cohesion Survival, % joint length	Partial-depth Spall Survival, % joint length	Full-depth Spall Survival, % joint length	Overall Survival, % joint length
C-231	1	1	73.0	66.2	100.0	88.7	96.6	62.8
C-231	1	2	56.2	67.4	99.9	91.3	95.9	63.2
		avg	64.2	66.8	100.0	90.1	96.2	63.0
C-231	2	1	96.9	85.6	100.0	92.4	96.1	81.6
C-231	2	2	98.2	93.3	100.0	95.6	94.7	88.0
		avg	97.6	89.6	100.0	94.0	95.4	85.0
C-231	3	1	99.0	80.5	100.0	93.4	94.8	75.3
C-231	3	2	99.7	90.9	100.0	96.1	93.7	84.6
		avg	99.4	86.0	100.0	94.8	94.2	80.2
K-9005	1	1	93.0	89.9	84.1	96.6	97.5	71.5
K-9005	1	2	96.7	92.7	90.8	98.2	99.0	82.5
		avg	95.0	91.5	87.8	97.5	98.3	77.6
K-9005	2	1	99.5	93.2	89.7	96.0	99.2	82.1
K-9005	2	2	100.0	79.1	99.0	96.5	98.9	77.0
		avg	99.8	85.8	94.6	96.2	99.0	79.4
K-9005	3	1	96.8	95.2	95.7	95.4	99.2	90.1
K-9005	3	2	99.6	97.4	98.6	92.8	96.8	92.8
		avg	98.3	96.3	97.2	94.0	98.0	91.5
K-9030	1	1	78.1	54.6	100.0	90.8	91.6	46.2
K-9030	1	2	91.9	46.5	100.0	92.4	93.7	40.2
		avg	85.4	50.4	100.0	91.7	92.7	43.1
K-9030	2	1	84.7	51.9	100.0	93.3	91.0	42.9
K-9030	2	2	88.6	69.4	99.9	95.1	92.6	62.0
		avg	86.8	61.1	100.0	94.2	91.8	53.0
K-9030	3	1	99.8	67.8	99.8	96.4	95.0	62.6
K-9030	3	2	99.2	65.8	100.0	97.3	91.2	57.1
		avg	99.5	66.8	99.9	96.9	93.0	59.7

Table D-11. Summary of distress survival at Iowa I-80 site (continued).

Material	Config.	Rep.	Partial-depth Adhesion Survival, % edge length	Full-depth Adhesion Survival, % joint length	Full-depth Cohesion Survival, % joint length	Partial-depth Spall Survival, % joint length	Full-depth Spall Survival, % joint length	Overall Survival, % joint length
M-SS	1	1	63.3	35.4	100.0	89.0	90.4	25.8
M-SS	1	2	95.5	25.4	100.0	87.2	88.8	14.2
		avg	80.3	30.2	100.0	88.0	89.5	19.7
M-SS	2	1	94.3	35.0	99.9	92.7	88.3	23.3
M-SS	2	2	77.1	60.1	99.9	92.8	87.8	47.8
		avg	85.2	48.2	99.9	92.8	88.0	36.2
M-SS	3	1	99.8	63.2	99.9	95.8	88.7	51.8
M-SS	3	2	99.2	80.6	100.0	97.0	84.9	65.5
		avg	99.5	72.3	100.0	96.5	86.7	59.0
888	1	1	99.8	93.9	100.0	83.0	89.2	83.1
888	1	2	100.0	97.6	100.0	84.1	90.1	87.7
		avg	99.9	95.9	100.0	83.6	89.7	85.5
888-SL	1	1	99.9	94.7	100.0	93.3	88.9	83.6
888-SL	1	2	100.0	98.1	100.0	90.6	89.4	87.5
		avg	100.0	96.5	100.0	91.8	89.2	85.6
960-SL	1	1	99.9	55.3	99.0	93.4	84.4	38.7
960-SL	1	2	100.0	76.3	99.7	92.0	86.8	62.8
		avg	100.0	66.4	99.3	92.7	85.7	51.4
960	1	1	99.9	99.4	100.0	78.0	90.0	89.4
960	1	2	100.0	99.9	100.0	80.5	89.7	89.6
		avg	100.0	99.7	100.0	79.4	89.9	89.5
888-Pr	1	1	100.0	99.7	100.0	81.5	89.0	88.7
888-SL/Pr	1	1	99.7	97.2	100.0	89.7	90.0	87.2

Table D-12. Overall survival at Iowa I-80 site.

Material	Config.	Rep. #	Overall Survival Over Time, percent joint length										
			0	2	5	8	14	17	30	42	54	66	82
C-231	1	1	100.0	100.0	100.0	99.9	99.9	99.9	99.2	98.3	89.2	77.0	62.9
		2	100.0	99.9	99.9	99.7	99.1	98.8	98.7	95.9	91.4	73.1	63.2
		Avg.	100.0	100.0	100.0	99.8	99.5	99.3	98.9	97.1	90.3	75.1	63.1
C-231	2	1	100.0	100.0	100.0	99.9	99.5	99.4	99.2	95.6	93.1	91.8	82.7
		2	100.0	100.0	100.0	100.0	99.8	99.7	99.7	98.9	94.7	93.7	88.0
		Avg.	100.0	100.0	100.0	99.9	99.7	99.6	99.4	97.2	93.9	92.7	85.3
C-231	3	1	100.0	100.0	100.0	99.9	99.9	99.9	97.2	94.7	89.8	85.6	77.2
		2	100.0	100.0	100.0	99.8	100.0	100.0	97.0	97.8	92.1	90.5	84.6
		Avg.	100.0	100.0	100.0	99.9	99.9	99.9	97.1	96.2	90.9	88.1	80.9
K-9005	1	1	100.0	100.0	100.0	91.8	99.5	99.2	90.8	96.6	93.1	79.6	75.5
		2	100.0	100.0	100.0	100.0	99.9	99.9	99.4	99.2	97.8	95.3	82.5
		Avg.	100.0	100.0	100.0	95.9	99.7	99.5	95.1	97.9	95.4	87.5	79.0
K-9005	2	1	100.0	100.0	100.0	100.0	100.0	100.0	94.9	99.9	92.6	90.8	82.7
		2	100.0	100.0	100.0	100.0	100.0	99.7	99.2	99.1	98.4	97.8	77.0
		Avg.	100.0	100.0	100.0	100.0	100.0	99.9	97.0	99.5	95.5	94.3	79.9
K-9005	3	1	100.0	100.0	100.0	99.7	99.7	99.8	99.1	99.4	98.8	91.4	90.6
		2	100.0	100.0	100.0	100.0	99.7	99.7	98.4	98.5	96.6	95.8	92.8
		Avg.	100.0	100.0	100.0	99.8	99.7	99.7	98.8	98.9	97.7	93.6	91.7
K-9030	1	1	100.0	100.0	100.0	99.9	99.9	99.9	94.9	84.9	72.2	64.0	48.3
		2	100.0	100.0	100.0	99.6	99.2	99.2	96.7	74.2	57.8	51.2	40.2
		Avg.	100.0	100.0	100.0	99.8	99.5	99.6	95.8	79.5	65.0	57.6	44.2
K-9030	2	1	100.0	100.0	100.0	96.7	96.7	96.5	89.8	84.1	71.6	65.1	47.1
		2	100.0	100.0	100.0	100.0	99.9	97.2	96.9	96.6	88.4	84.0	62.0
		Avg.	100.0	100.0	100.0	98.3	98.3	96.8	93.4	90.3	80.0	74.6	54.5
K-9030	3	1	100.0	100.0	100.0	99.3	97.4	96.7	84.9	88.1	73.5	68.4	64.1
		2	100.0	100.0	100.0	100.0	99.4	97.2	88.7	88.8	80.2	72.4	57.1
		Avg.	100.0	100.0	100.0	99.7	98.4	97.0	86.8	88.4	76.8	70.4	60.6
M-SS	1	1	100.0	100.0	100.0	97.9	96.6	96.7	84.1	77.6	63.6	45.3	27.2
		2	100.0	100.0	100.0	99.6	98.4	97.2	89.0	60.1	39.3	27.6	14.2
		Avg.	100.0	100.0	100.0	98.8	97.5	96.9	86.5	68.8	51.5	36.5	20.7
M-SS	2	1	100.0	100.0	100.0	99.4	99.6	99.9	95.3	83.7	65.3	48.1	23.6
		2	100.0	100.0	99.5	98.9	98.7	98.6	96.0	87.5	71.2	62.5	47.8
		Avg.	100.0	100.0	99.8	99.1	99.1	99.2	95.7	85.6	68.2	55.3	35.7
M-SS	3	1	100.0	100.0	100.0	99.4	98.5	98.2	85.8	80.6	68.8	62.2	54.7
		2	100.0	100.0	100.0	100.0	99.0	98.8	97.3	86.6	80.6	75.6	65.5
		Avg.	100.0	100.0	100.0	99.7	98.8	98.5	91.6	83.6	74.7	68.9	60.1
888	1	1	100.0	100.0	99.9	98.3	98.4	98.5	97.8	92.5	90.3	88.8	83.8
		2	100.0	100.0	100.0	100.0	99.9	99.5	99.5	98.3	92.4	91.9	87.7
		Avg.	100.0	100.0	100.0	99.2	99.1	99.0	98.6	95.4	91.3	90.4	85.7
888-SL	1	1	100.0	100.0	100.0	97.6	97.6	97.6	96.8	94.4	91.4	89.3	83.4
		2	100.0	100.0	100.0	100.0	99.5	99.4	99.2	95.0	92.1	91.6	87.5
		Avg.	100.0	100.0	100.0	98.8	98.5	98.5	98.0	94.7	91.7	90.5	85.5
960-SL	1	1	100.0	100.0	99.8	95.4	95.0	94.8	91.5	81.5	72.8	66.5	39.9
		2	100.0	100.0	100.0	99.5	99.4	98.0	95.6	93.6	84.2	82.0	62.8
		Avg.	100.0	100.0	99.9	97.5	97.2	96.4	93.6	87.5	78.5	74.2	51.3
960	1	1	100.0	100.0	100.0	98.9	98.8	98.8	98.3	95.3	94.3	92.4	90.5
		2	100.0	100.0	100.0	99.2	99.4	99.2	99.2	96.9	94.0	93.5	89.6
		Avg.	100.0	100.0	100.0	99.0	99.1	99.0	98.8	96.1	94.1	92.9	90.0
888-Pr	1	1	100.0	100.0	100.0	99.2	99.2	99.2	99.0	97.3	91.4	91.3	88.8
888-SL/Pr	1	1	100.0	100.0	100.0	99.5	99.6	99.6	99.6	94.9	90.5	90.3	87.3

Table D-13. Adhesion survival at Iowa I-80 site.

Material	Config.	Rep. #	Adhesion Survival Over Time, percent joint length										
			0	2	5	8	14	17	30	42	54	66	82
C-231	1	1	100.0	100.0	100.0	100.0	100.0	100.0	99.4	100.0	91.3	79.2	66.0
		2	100.0	100.0	100.0	99.9	99.4	99.4	99.2	97.2	94.6	76.4	67.4
		Avg.	100.0	100.0	100.0	100.0	99.7	99.7	99.3	98.6	92.9	77.8	66.7
C-231	2	1	100.0	100.0	100.0	100.0	99.7	99.7	99.4	98.3	96.4	95.3	86.7
		2	100.0	100.0	100.0	100.0	99.9	99.9	99.9	99.8	98.5	97.4	93.3
		Avg.	100.0	100.0	100.0	100.0	99.8	99.8	99.7	99.1	97.4	96.4	90.0
C-231	3	1	100.0	100.0	100.0	99.9	99.9	99.9	97.2	97.1	93.1	89.1	81.9
		2	100.0	100.0	100.0	100.0	100.0	100.0	97.1	98.4	97.0	95.8	90.9
		Avg.	100.0	100.0	100.0	100.0	99.9	99.9	97.2	97.7	95.1	92.4	86.4
K-9005	1	1	100.0	100.0	100.0	91.8	100.0	99.7	92.9	100.0	97.7	95.8	90.6
		2	100.0	100.0	100.0	100.0	100.0	100.0	100.0	99.9	99.0	97.9	92.7
		Avg.	100.0	100.0	100.0	95.9	100.0	99.9	96.5	99.9	98.4	96.9	91.7
K-9005	2	1	100.0	100.0	100.0	100.0	100.0	100.0	99.9	100.0	99.2	99.1	93.6
		2	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	99.8	79.1
		Avg.	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	99.6	99.4	86.4
K-9005	3	1	100.0	100.0	100.0	100.0	100.0	100.0	99.9	100.0	100.0	96.4	95.6
		2	100.0	100.0	100.0	100.0	99.9	99.9	100.0	100.0	99.9	99.3	97.4
		Avg.	100.0	100.0	100.0	100.0	99.9	99.9	99.9	100.0	99.9	97.8	96.5
K-9030	1	1	100.0	100.0	100.0	100.0	100.0	100.0	95.5	89.9	78.1	71.0	56.0
		2	100.0	100.0	100.0	100.0	99.9	99.9	97.6	76.2	63.3	56.9	46.5
		Avg.	100.0	100.0	100.0	100.0	99.9	99.9	96.6	83.0	70.7	64.0	51.3
K-9030	2	1	100.0	100.0	100.0	99.6	99.2	99.0	93.1	90.2	78.4	73.4	55.7
		2	100.0	100.0	100.0	100.0	100.0	99.9	99.9	99.4	95.1	91.0	69.4
		Avg.	100.0	100.0	100.0	99.8	99.6	99.5	96.5	94.8	86.7	82.2	62.6
K-9030	3	1	100.0	100.0	100.0	99.9	98.2	97.6	86.1	90.4	76.9	73.1	69.0
		2	100.0	100.0	100.0	100.0	99.7	98.5	90.5	91.9	86.3	79.7	65.8
		Avg.	100.0	100.0	100.0	100.0	98.9	98.1	88.3	91.1	81.6	76.4	67.4
M-SS	1	1	100.0	100.0	100.0	98.5	97.5	97.6	85.4	82.9	69.4	54.0	36.5
		2	100.0	100.0	100.0	100.0	99.0	97.7	91.5	65.0	49.6	38.6	25.4
		Avg.	100.0	100.0	100.0	99.3	98.2	97.7	88.4	74.0	59.5	46.3	30.9
M-SS	2	1	100.0	100.0	100.0	99.9	100.0	100.0	95.6	91.8	75.1	59.4	35.3
		2	100.0	100.0	100.0	100.0	99.8	99.7	97.8	90.9	82.3	73.9	60.1
		Avg.	100.0	100.0	100.0	100.0	99.9	99.9	96.7	91.4	78.7	66.6	47.7
M-SS	3	1	100.0	100.0	100.0	100.0	99.4	98.8	87.3	86.5	76.2	72.5	65.6
		2	100.0	100.0	100.0	100.0	100.0	100.0	99.2	96.9	93.6	89.5	80.6
		Avg.	100.0	100.0	100.0	100.0	99.7	99.4	93.3	91.7	84.9	81.0	73.1
888	1	1	100.0	100.0	100.0	100.0	100.0	100.0	100.0	99.9	99.2	98.8	94.5
		2	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	99.7	99.5	97.6
		Avg.	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	99.4	99.2	96.1
888-SL	1	1	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	95.2
		2	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	98.1
		Avg.	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	96.6
960-SL	1	1	100.0	100.0	100.0	99.7	99.3	99.1	96.3	90.0	85.6	81.3	56.1
		2	100.0	100.0	100.0	99.8	99.7	99.7	97.9	98.3	94.4	93.1	76.3
		Avg.	100.0	100.0	100.0	99.7	99.5	99.4	97.1	94.1	90.0	87.2	66.2
960	1	1	100.0	100.0	100.0	100.0	99.8	99.8	99.8	99.5	99.9	99.9	99.5
		2	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	99.9
		Avg.	100.0	100.0	100.0	100.0	99.9	99.9	99.9	99.8	100.0	100.0	99.7
888-Pr	1	1	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	99.7
888-SL/Pr	1	1	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	99.4	99.4	97.2

Table D-14. Cohesion survival at Iowa I-80 site.

Material	Config.	Rep. #	Cohesion Survival Over Time, percent joint length										
			0	2	5	8	14	17	30	42	54	66	82
C-231	1	1	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
		2	100.0	100.0	100.0	100.0	100.0	100.0	100.0	99.9	99.9	99.9	99.9
		Avg.	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
C-231	2	1	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
		2	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
		Avg.	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
C-231	3	1	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
		2	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
		Avg.	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
K-9005	1	1	100.0	100.0	100.0	100.0	100.0	100.0	99.1	98.3	97.5	85.9	87.2
		2	100.0	100.0	100.0	100.0	100.0	100.0	99.5	100.0	99.7	98.3	90.8
		Avg.	100.0	100.0	100.0	100.0	100.0	100.0	99.3	99.1	98.6	92.1	89.0
K-9005	2	1	100.0	100.0	100.0	100.0	100.0	100.0	94.9	100.0	94.2	92.4	90.1
		2	100.0	100.0	100.0	100.0	100.0	100.0	99.5	99.2	99.3	99.0	99.0
		Avg.	100.0	100.0	100.0	100.0	100.0	100.0	97.2	99.6	96.7	95.7	94.5
K-9005	3	1	100.0	100.0	100.0	100.0	100.0	100.0	99.4	100.0	99.7	96.0	96.0
		2	100.0	100.0	100.0	100.0	100.0	100.0	98.6	99.4	99.1	98.8	98.6
		Avg.	100.0	100.0	100.0	100.0	100.0	100.0	99.0	99.7	99.4	97.4	97.3
K-9030	1	1	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
		2	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
		Avg.	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
K-9030	2	1	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
		2	100.0	100.0	100.0	100.0	100.0	100.0	100.0	99.9	99.9	99.9	99.9
		Avg.	100.0	100.0	100.0	100.0	100.0	100.0	100.0	99.9	100.0	100.0	100.0
K-9030	3	1	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	99.8	99.8
		2	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
		Avg.	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	99.9	99.9
M-SS	1	1	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
		2	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
		Avg.	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
M-SS	2	1	100.0	100.0	100.0	100.0	100.0	100.0	99.9	99.9	99.9	99.9	99.9
		2	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	99.9	99.9	99.9
		Avg.	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	99.9	99.9	99.9
M-SS	3	1	100.0	100.0	100.0	100.0	100.0	100.0	100.0	99.9	99.9	99.9	99.9
		2	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
		Avg.	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
888	1	1	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
		2	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
		Avg.	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
888-SL	1	1	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
		2	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
		Avg.	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
960-SL	1	1	100.0	100.0	100.0	100.0	100.0	100.0	100.0	99.9	99.9	99.9	99.1
		2	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	99.7
		Avg.	100.0	100.0	100.0	100.0	100.0	100.0	100.0	99.9	100.0	99.9	99.4
960	1	1	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
		2	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
		Avg.	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
888-Pr	1	1	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
888-SL/Pr	1	1	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0

Table D-15. Spall survival at Iowa I-80 site.

Material	Config.	Rep. #	Spall Survival Over Time, percent joint length										
			0	2	5	8	14	17	30	42	54	66	82
C-231	1	1	100.0	100.0	100.0	99.9	99.9	99.9	99.8	98.3	97.9	97.8	96.9
		2	100.0	99.9	99.9	99.8	99.7	99.3	99.4	98.8	96.9	96.8	95.9
		Avg.	100.0	100.0	100.0	99.9	99.8	99.6	99.6	98.5	97.4	97.3	96.4
C-231	2	1	100.0	100.0	100.0	99.9	99.9	99.8	99.8	97.2	96.7	96.5	96.0
		2	100.0	100.0	100.0	100.0	99.9	99.8	99.7	99.1	96.2	96.3	94.7
		Avg.	100.0	100.0	100.0	99.9	99.9	99.8	99.8	98.2	96.4	96.4	95.3
C-231	3	1	100.0	100.0	100.0	100.0	100.0	100.0	100.0	97.6	96.7	96.5	95.3
		2	100.0	100.0	100.0	99.8	100.0	100.0	99.9	99.4	95.1	94.7	93.7
		Avg.	100.0	100.0	100.0	99.9	100.0	100.0	100.0	98.5	95.9	95.6	94.5
K-9005	1	1	100.0	100.0	100.0	100.0	99.5	99.5	98.8	98.3	97.8	97.8	97.6
		2	100.0	100.0	100.0	100.0	99.9	99.9	99.9	99.4	99.1	99.1	99.0
		Avg.	100.0	100.0	100.0	100.0	99.7	99.7	99.3	98.9	98.5	98.5	98.3
K-9005	2	1	100.0	100.0	100.0	100.0	100.0	100.0	100.0	99.9	99.2	99.2	99.0
		2	100.0	100.0	100.0	100.0	100.0	99.7	99.7	99.9	99.1	99.0	98.9
		Avg.	100.0	100.0	100.0	100.0	100.0	99.9	99.9	99.9	99.2	99.1	99.0
K-9005	3	1	100.0	100.0	100.0	99.7	99.7	99.8	99.8	99.4	99.1	99.0	99.0
		2	100.0	100.0	100.0	100.0	99.9	99.8	99.8	99.1	97.6	97.6	96.8
		Avg.	100.0	100.0	100.0	99.8	99.8	99.8	99.8	99.2	98.4	98.3	97.9
K-9030	1	1	100.0	100.0	100.0	99.9	99.9	99.9	99.4	95.0	94.0	92.9	92.3
		2	100.0	100.0	100.0	99.6	99.4	99.4	99.1	98.1	94.4	94.3	93.7
		Avg.	100.0	100.0	100.0	99.8	99.6	99.7	99.2	96.5	94.2	93.6	93.0
K-9030	2	1	100.0	100.0	100.0	97.1	97.6	97.5	96.7	93.9	93.2	91.7	91.4
		2	100.0	100.0	100.0	100.0	99.9	97.2	97.0	97.4	93.4	93.1	92.6
		Avg.	100.0	100.0	100.0	98.5	98.7	97.4	96.9	95.6	93.3	92.4	92.0
K-9030	3	1	100.0	100.0	100.0	99.4	99.2	99.2	98.8	97.6	96.6	95.6	95.3
		2	100.0	100.0	100.0	100.0	99.7	98.7	98.2	96.9	93.9	92.8	91.3
		Avg.	100.0	100.0	100.0	99.7	99.4	98.9	98.5	97.3	95.2	94.2	93.3
M-SS	1	1	100.0	100.0	100.0	99.4	99.1	99.0	98.7	94.7	94.2	91.3	90.8
		2	100.0	100.0	100.0	99.6	99.4	99.4	97.5	95.1	89.7	89.0	88.8
		Avg.	100.0	100.0	100.0	99.5	99.3	99.2	98.1	94.9	92.0	90.1	89.8
M-SS	2	1	100.0	100.0	100.0	99.4	99.6	99.9	99.8	91.9	90.2	88.8	88.4
		2	100.0	100.0	99.5	98.9	98.9	98.9	98.3	96.6	89.0	88.7	87.8
		Avg.	100.0	100.0	99.8	99.2	99.2	99.4	99.0	94.3	89.6	88.8	88.1
M-SS	3	1	100.0	100.0	100.0	99.4	99.1	99.4	98.5	94.2	92.6	89.7	89.1
		2	100.0	100.0	100.0	100.0	99.0	98.8	98.1	89.7	86.9	86.1	84.9
		Avg.	100.0	100.0	100.0	99.7	99.0	99.1	98.3	91.9	89.8	87.9	87.0
888	1	1	100.0	100.0	99.9	98.3	98.4	98.5	97.8	92.6	91.1	90.0	89.2
		2	100.0	100.0	100.0	100.0	99.9	99.5	99.5	98.3	92.7	92.4	90.1
		Avg.	100.0	100.0	100.0	99.2	99.1	99.0	98.6	95.4	91.9	91.2	89.7
888-SL	1	1	100.0	100.0	100.0	97.6	97.6	97.6	96.8	94.4	91.4	89.3	88.2
		2	100.0	100.0	100.0	100.0	99.5	99.4	99.2	95.0	92.1	91.6	89.4
		Avg.	100.0	100.0	100.0	98.8	98.5	98.5	98.0	94.7	91.7	90.5	88.8
960-SL	1	1	100.0	100.0	99.8	95.8	95.7	95.7	95.2	91.6	87.2	85.3	84.7
		2	100.0	100.0	100.0	99.7	99.7	98.3	97.7	95.3	89.8	88.9	86.8
		Avg.	100.0	100.0	99.9	97.7	97.7	97.0	96.5	93.5	88.5	87.1	85.7
960	1	1	100.0	100.0	100.0	98.9	99.0	99.0	98.5	95.8	94.4	92.4	91.0
		2	100.0	100.0	100.0	99.2	99.4	99.2	99.2	96.9	94.0	93.5	89.7
		Avg.	100.0	100.0	100.0	99.0	99.2	99.1	98.9	96.4	94.2	93.0	90.3
888-Pr	1	1	100.0	100.0	100.0	99.2	99.2	99.2	99.0	97.3	91.4	91.3	89.0
888-SL/Pr	1	1	100.0	100.0	100.0	99.5	99.6	99.6	99.6	94.9	91.0	90.9	90.1

Table D-16. Summary of distress survival at Kentucky U.S. 127 site.

Material	Config.	Rep.	Partial-depth Adhesion Survival, %	Full-depth Adhesion Survival, % joint length	Full-depth Cohesion Survival, % joint length	Partial-depth Spall Survival, % joint length	Full-depth Spall Survival, % joint length	Overall Survival, % joint length
C-231	1	1	81.0	79.1	100.0	93.7	99.0	78.1
C-231	1	2	67.5	84.7	99.9	93.2	93.0	77.5
		avg	74.2	81.9	99.9	93.4	96.0	77.8
C-231	2	1	97.1	93.5	99.7	97.3	99.2	92.4
C-231	2	2	90.4	85.0	100.0	98.3	93.7	78.7
		avg	93.4	88.8	99.9	97.9	96.1	84.8
C-231	3	1	98.1	98.5	100.0	98.1	100.0	98.5
C-231	3	2	99.2	97.9	99.9	98.7	97.5	95.3
		avg	98.6	98.2	100.0	98.4	98.7	96.9
K-9005	1	1	74.4	97.9	100.0	94.2	98.8	96.7
K-9005	1	2	94.9	91.9	99.7	97.1	98.4	89.9
		avg	84.7	94.9	99.8	95.7	98.6	93.3
K-9005	2	1	95.2	98.8	99.7	98.1	99.2	97.6
K-9005	2	2	87.6	98.9	99.9	98.2	98.3	97.0
		avg	91.4	98.9	99.8	98.1	98.7	97.3
K-9005	3	1	99.2	99.9	99.9	99.0	99.2	99.0
K-9005	3	2	98.9	98.7	99.7	99.3	98.1	96.5
		avg	99.1	99.3	99.8	99.2	98.6	97.7
K-9030	1	1	20.7	66.2	100.0	94.7	98.3	64.5
K-9030	1	2	63.5	66.0	100.0	96.0	89.0	55.0
		avg	44.5	66.1	100.0	95.4	93.1	59.2
K-9030	2	1	86.4	69.9	100.0	98.1	99.4	69.3
K-9030	2	2	87.3	63.7	99.9	94.8	91.4	55.0
		avg	86.9	66.6	100.0	96.3	95.1	61.7
K-9030	3	1	97.9	83.3	99.8	96.4	98.0	81.1
K-9030	3	2	96.6	94.9	99.9	99.4	99.0	93.7
		avg	97.2	89.4	99.8	98.0	98.5	87.8

Table D-16. Summary of distress survival at Kentucky U.S. 127 site (continued).

Material	Config.	Rep.	Partial-depth Adhesion Survival, % edge length	Full-depth Adhesion Survival, % joint length	Full-depth Cohesion Survival, % joint length	Partial-depth Spall Survival, % joint length	Full-depth Spall Survival, % joint length	Overall Survival, % joint length
M-SS	1	1	64.5	51.7	100.0	90.1	96.5	48.3
M-SS	1	2	57.5	56.7	100.0	93.1	92.2	49.0
		avg	60.6	54.5	100.0	91.7	94.1	48.6
M-SS	2	1	84.1	65.5	99.8	96.5	96.8	62.1
M-SS	2	2	69.1	60.9	100.0	95.5	94.9	55.7
		avg	77.0	63.3	99.9	96.0	95.9	59.1
M-SS	3	1	98.5	83.0	100.0	97.4	98.6	81.6
M-SS	3	2	98.4	96.9	100.0	99.2	98.7	95.6
		avg	98.4	89.9	100.0	98.3	98.6	88.6
888	1	1	100.0	99.9	100.0	84.5	96.7	96.5
888	1	2	99.7	98.6	100.0	90.3	99.4	98.1
		avg	99.9	99.4	100.0	86.4	97.6	97.0
888-SL	1	1	99.9	92.9	100.0	93.3	97.7	90.6
888-SL	1	2	100.0	99.6	100.0	96.7	100.0	99.6
		avg	100.0	96.1	100.0	94.9	98.8	94.9
960-SL	1	1	100.0	88.2	95.5	96.3	84.1	67.8
960-SL	1	2	99.7	93.4	99.8	96.7	99.7	92.8
		avg	99.9	90.8	97.6	96.5	91.9	80.3
K-9050	1	1	96.7	88.3	100.0	96.0	96.3	84.6
K-9005 Pr	1	1	94.4	98.5	98.4	99.8	99.3	96.2

Table D-17. Overall survival at Kentucky U.S. 127 site.

Material	Config.	Rep. #	Overall Survival Over Time, percent joint length										
			0	1	5	9	12	17	29	41	54	66	78
C-231	1	1	100.0	100.0	100.0	99.9	99.9	99.3	97.8	90.1	87.4	82.6	78.1
		2	100.0	100.0	100.0	99.6	99.6	99.6	98.4	97.6	90.3	88.1	77.5
		Avg.	100.0	100.0	100.0	99.7	99.7	99.4	98.1	93.8	88.9	85.3	77.8
C-231	2	1	100.0	100.0	100.0	100.0	99.8	99.2	98.0	95.6	94.7	91.3	89.5
		2	100.0	100.0	100.0	100.0	100.0	100.0	99.9	98.0	94.8	92.1	78.7
		Avg.	100.0	100.0	100.0	100.0	99.9	99.6	98.9	96.8	94.7	91.7	84.1
C-231	3	1	100.0	100.0	99.9	99.9	99.9	99.9	99.4	98.9	99.1	98.8	98.5
		2	100.0	100.0	100.0	100.0	100.0	100.0	100.0	99.7	99.4	99.2	95.3
		Avg.	100.0	100.0	100.0	100.0	100.0	100.0	99.7	99.3	99.2	99.0	96.9
K-9005	1	1	100.0	100.0	100.0	99.8	99.8	99.5	99.2	95.5	89.6	96.2	96.7
		2	100.0	99.9	99.8	99.7	99.7	99.5	98.8	98.4	96.5	98.3	89.9
		Avg.	100.0	100.0	99.9	99.7	99.7	99.5	99.0	96.9	93.0	97.3	93.3
K-9005	2	1	100.0	100.0	100.0	100.0	100.0	100.0	98.9	98.5	98.0	97.7	97.6
		2	100.0	100.0	100.0	100.0	100.0	100.0	99.4	97.0	98.3	96.1	97.0
		Avg.	100.0	100.0	100.0	100.0	100.0	100.0	99.1	97.8	98.2	96.9	97.3
K-9005	3	1	100.0	100.0	100.0	100.0	100.0	99.9	99.0	98.8	98.7	99.0	99.0
		2	100.0	100.0	100.0	100.0	100.0	99.9	99.9	99.0	96.5	99.4	96.5
		Avg.	100.0	100.0	100.0	100.0	100.0	99.9	99.5	98.9	97.6	99.2	97.7
K-9030	1	1	100.0	99.9	99.7	99.4	98.6	97.2	86.0	79.2	75.6	66.2	59.1
		2	100.0	100.0	100.0	99.6	99.4	99.1	89.8	80.3	68.6	76.0	55.0
		Avg.	100.0	99.9	99.9	99.5	99.0	98.1	87.9	79.8	72.1	71.1	57.0
K-9030	2	1	100.0	100.0	99.0	97.2	96.8	93.1	80.9	79.0	72.2	80.1	78.5
		2	100.0	100.0	99.4	98.3	98.3	98.2	89.2	80.7	67.8	68.3	59.5
		Avg.	100.0	100.0	99.2	97.8	97.6	95.6	85.1	79.8	70.0	74.2	69.0
K-9030	3	1	100.0	100.0	99.7	99.7	99.5	99.2	99.2	96.2	86.9	86.5	83.0
		2	100.0	100.0	99.8	99.9	99.9	99.8	99.5	97.3	96.5	94.0	93.8
		Avg.	100.0	100.0	99.7	99.8	99.7	99.5	99.3	96.7	91.7	90.2	88.4
M-SS	1	1	100.0	100.0	99.3	99.1	98.5	97.4	84.0	63.2	50.9	51.3	49.0
		2	100.0	100.0	100.0	99.9	99.6	98.9	78.0	62.7	51.3	76.0	49.0
		Avg.	100.0	100.0	99.7	99.5	99.0	98.2	81.0	63.0	51.1	63.6	49.0
M-SS	2	1	100.0	100.0	99.9	99.6	97.8	95.8	90.3	76.6	70.7	67.7	65.2
		2	100.0	100.0	99.9	99.8	99.8	99.5	97.4	91.3	88.8	86.2	64.6
		Avg.	100.0	100.0	99.9	99.7	98.8	97.6	93.9	83.9	79.7	76.9	64.9
M-SS	3	1	100.0	100.0	100.0	99.4	99.4	99.4	94.7	88.5	86.3	88.8	81.6
		2	100.0	100.0	100.0	99.9	99.9	99.9	100.0	95.8	95.8	95.6	95.6
		Avg.	100.0	100.0	100.0	99.7	99.7	99.7	97.4	92.2	91.0	92.2	88.6
888	1	1	100.0	100.0	100.0	98.2	98.0	98.0	97.5	97.4	96.7	96.5	96.5
		2	100.0	100.0	100.0	99.2	95.5	95.5	89.6	97.2	96.3	96.8	96.5
		Avg.	100.0	100.0	100.0	98.7	96.7	96.7	93.5	97.3	96.5	96.6	96.5
888-SL	1	1	100.0	100.0	100.0	99.6	99.6	99.5	99.6	98.8	94.0	93.4	90.6
		2	100.0	100.0	100.0	100.0	100.0	100.0	99.9	99.6	99.7	99.7	99.7
		Avg.	100.0	100.0	100.0	99.8	99.8	99.8	99.7	99.2	96.9	96.6	95.1
960-SL	1	1	100.0	100.0	100.0	97.9	97.8	97.5	96.0	90.4	75.3	71.4	67.8
		2	100.0	100.0	99.8	99.8	99.8	99.8	99.4	96.7	94.6	94.6	92.8
		Avg.	100.0	100.0	99.9	98.9	98.8	98.6	97.7	93.5	85.0	83.0	80.3
K-9050	1	1	100.0	100.0	100.0	100.0	100.0	100.0	99.9	99.4	88.8	85.3	84.6
K-9005/Pr	1	1	100.0	100.0	100.0	99.9	99.9	99.9	99.2	96.3	91.5	94.7	96.2

Table D-18. Adhesion survival at Kentucky U.S. 127 site.

Material	Config.	Rep. #	Adhesion Survival Over Time, percent joint length										
			0	1	5	9	12	17	29	41	54	66	78
C-231	1	1	100.0	100.0	100.0	100.0	100.0	100.0	99.0	94.5	87.7	82.8	79.1
		2	100.0	100.0	100.0	100.0	100.0	100.0	99.2	99.4	92.2	90.5	84.7
		Avg.	100.0	100.0	100.0	100.0	100.0	100.0	99.1	97.0	90.0	86.7	81.9
C-231	2	1	100.0	100.0	100.0	100.0	99.8	99.8	99.0	97.8	95.6	93.6	91.9
		2	100.0	100.0	100.0	100.0	100.0	100.0	99.9	98.5	95.5	92.8	85.0
		Avg.	100.0	100.0	100.0	100.0	99.9	99.9	99.4	98.2	95.6	93.2	88.4
C-231	3	1	100.0	100.0	99.9	99.9	99.9	99.9	99.4	99.0	99.2	98.8	98.5
		2	100.0	100.0	100.0	100.0	100.0	100.0	100.0	99.7	99.4	99.2	97.9
		Avg.	100.0	100.0	100.0	100.0	100.0	100.0	99.7	99.3	99.3	99.0	98.2
K-9005	1	1	100.0	100.0	100.0	100.0	100.0	99.9	99.6	96.6	90.7	97.4	97.9
		2	100.0	100.0	100.0	100.0	100.0	99.9	99.8	98.8	97.1	98.8	91.9
		Avg.	100.0	100.0	100.0	100.0	100.0	99.9	99.7	97.7	93.9	98.1	94.9
K-9005	2	1	100.0	100.0	100.0	100.0	100.0	100.0	100.0	99.8	99.0	98.9	98.8
		2	100.0	100.0	100.0	100.0	100.0	100.0	99.4	97.9	98.7	98.0	98.9
		Avg.	100.0	100.0	100.0	100.0	100.0	100.0	99.7	98.9	98.8	98.4	98.9
K-9005	3	1	100.0	100.0	100.0	100.0	100.0	100.0	100.0	99.9	99.7	99.9	99.9
		2	100.0	100.0	100.0	100.0	100.0	100.0	100.0	99.9	96.9	99.7	98.8
		Avg.	100.0	100.0	100.0	100.0	100.0	100.0	100.0	99.9	98.3	99.8	99.3
K-9030	1	1	100.0	100.0	99.9	99.7	99.0	97.5	86.9	83.9	78.3	67.6	60.5
		2	100.0	100.0	100.0	99.7	99.5	99.5	94.0	85.1	72.9	80.3	66.0
		Avg.	100.0	100.0	100.0	99.7	99.2	98.5	90.4	84.5	75.6	73.9	63.3
K-9030	2	1	100.0	100.0	99.0	97.9	97.5	93.1	81.5	79.9	72.6	80.6	79.0
		2	100.0	100.0	99.4	98.5	98.5	98.5	91.6	83.1	71.0	71.7	66.6
		Avg.	100.0	100.0	99.2	98.2	98.0	95.8	86.5	81.5	71.8	76.1	72.8
K-9030	3	1	100.0	100.0	99.7	99.7	99.5	99.5	99.4	96.7	87.5	87.5	85.0
		2	100.0	100.0	99.8	99.9	99.9	99.8	99.7	97.7	97.0	95.1	94.9
		Avg.	100.0	100.0	99.7	99.8	99.7	99.7	99.6	97.2	92.3	91.3	90.0
M-SS	1	1	100.0	100.0	99.3	99.1	98.5	97.7	85.5	72.2	53.8	54.2	51.9
		2	100.0	100.0	100.0	99.9	99.6	99.0	79.5	65.8	54.6	79.3	56.7
		Avg.	100.0	100.0	99.7	99.5	99.0	98.3	82.5	69.0	54.2	66.7	54.3
M-SS	2	1	100.0	100.0	99.9	99.7	97.8	96.7	93.5	84.7	73.4	70.3	68.3
		2	100.0	100.0	100.0	99.9	99.9	99.9	98.8	94.0	90.6	88.1	68.7
		Avg.	100.0	100.0	99.9	99.8	98.9	98.3	96.2	89.4	82.0	79.2	68.5
M-SS	3	1	100.0	100.0	100.0	99.7	99.7	99.7	95.1	89.7	87.2	89.4	83.0
		2	100.0	100.0	100.0	99.9	99.9	99.9	100.0	96.9	96.9	96.9	96.9
		Avg.	100.0	100.0	100.0	99.8	99.8	99.8	97.5	93.3	92.0	93.2	89.9
888	1	1	100.0	100.0	100.0	100.0	100.0	100.0	100.0	99.9	99.9	99.8	99.9
		2	100.0	100.0	100.0	100.0	99.9	99.9	100.0	99.6	97.7	98.5	98.1
		Avg.	100.0	100.0	100.0	100.0	99.9	99.9	100.0	99.7	98.8	99.1	99.0
888-SL	1	1	100.0	100.0	100.0	100.0	100.0	100.0	100.0	99.4	94.8	94.2	92.9
		2	100.0	100.0	100.0	100.0	100.0	100.0	99.9	99.7	99.7	99.7	99.7
		Avg.	100.0	100.0	100.0	100.0	100.0	100.0	100.0	99.6	97.3	96.9	96.3
960-SL	1	1	100.0	100.0	100.0	100.0	99.9	99.7	98.7	95.8	92.4	89.9	88.2
		2	100.0	100.0	100.0	100.0	100.0	100.0	99.7	96.9	95.1	95.1	93.4
		Avg.	100.0	100.0	100.0	100.0	100.0	99.9	99.2	96.4	93.8	92.5	90.8
K-9050	1	1	100.0	100.0	100.0	100.0	100.0	100.0	99.9	99.4	92.4	89.0	88.3
K-9005/Pr	1	1	100.0	100.0	100.0	100.0	100.0	100.0	100.0	97.6	93.4	96.9	98.5

Table D-19. Cohesion survival at Kentucky U.S. 127 site.

Material	Config.	Rep. #	Cohesion Survival Over Time, percent joint length										
			0	1	5	9	12	17	29	41	54	66	78
C-231	1	1	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
		2	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	99.9	99.9
		Avg.	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	99.9	99.9
C-231	2	1	100.0	100.0	100.0	100.0	100.0	100.0	100.0	99.9	99.8	99.7	99.7
		2	100.0	100.0	100.0	100.0	100.0	100.0	100.0	99.9	100.0	100.0	100.0
		Avg.	100.0	100.0	100.0	100.0	100.0	100.0	100.0	99.9	99.9	99.9	99.9
C-231	3	1	100.0	100.0	100.0	100.0	100.0	100.0	100.0	99.9	99.9	100.0	100.0
		2	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	99.9	99.9
		Avg.	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
K-9005	1	1	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
		2	100.0	100.0	100.0	100.0	100.0	100.0	99.4	99.9	99.8	99.8	99.7
		Avg.	100.0	100.0	100.0	100.0	100.0	100.0	99.7	99.9	99.9	99.9	99.8
K-9005	2	1	100.0	100.0	100.0	100.0	100.0	100.0	99.1	99.5	99.6	99.7	99.7
		2	100.0	100.0	100.0	100.0	100.0	100.0	99.9	99.7	99.8	99.9	99.9
		Avg.	100.0	100.0	100.0	100.0	100.0	100.0	99.5	99.6	99.7	99.8	99.8
K-9005	3	1	100.0	100.0	100.0	100.0	100.0	100.0	99.9	99.7	99.8	99.9	99.9
		2	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	99.5	99.7	99.7
		Avg.	100.0	100.0	100.0	100.0	100.0	100.0	100.0	99.9	99.7	99.8	99.8
K-9030	1	1	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
		2	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
		Avg.	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
K-9030	2	1	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
		2	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	99.9
		Avg.	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
K-9030	3	1	100.0	100.0	100.0	100.0	100.0	100.0	100.0	99.9	99.8	99.8	99.8
		2	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	99.9	99.8	99.9
		Avg.	100.0	100.0	100.0	100.0	100.0	100.0	100.0	99.9	99.8	99.8	99.8
M-SS	1	1	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
		2	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
		Avg.	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
M-SS	2	1	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	99.9	99.9
		2	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
		Avg.	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	99.9
M-SS	3	1	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
		2	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
		Avg.	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
888	1	1	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
		2	100.0	100.0	100.0	100.0	100.0	100.0	100.0	99.9	99.9	99.9	99.9
		Avg.	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	99.9	99.9
888-SL	1	1	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
		2	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
		Avg.	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
960-SL	1	1	100.0	100.0	100.0	100.0	100.0	100.0	99.7	97.0	96.7	96.0	95.5
		2	100.0	100.0	100.0	100.0	100.0	100.0	100.0	99.9	99.9	99.9	99.8
		Avg.	100.0	100.0	100.0	100.0	100.0	100.0	99.8	98.4	98.3	98.0	97.6
K-9050	1	1	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
K-9005/Pr	1	1	100.0	100.0	100.0	100.0	100.0	100.0	99.2	98.7	98.8	98.4	98.4

Table D-20. Spall survival at Kentucky U.S. 127 site.

Material	Config.	Rep. #	Spall Survival Over Time, percent joint length										
			0	1	5	9	12	17	29	41	54	66	78
C-231	1	1	100.0	100.0	100.0	99.9	99.9	99.3	98.8	95.6	99.7	99.7	99.0
		2	100.0	100.0	100.0	99.6	99.6	99.6	99.2	98.1	98.1	97.7	93.0
		Avg.	100.0	100.0	100.0	99.7	99.7	99.4	99.0	96.8	98.9	98.7	96.0
C-231	2	1	100.0	100.0	100.0	100.0	100.0	99.4	99.0	97.8	99.2	97.9	97.9
		2	100.0	100.0	100.0	100.0	100.0	100.0	100.0	99.6	99.3	99.3	93.7
		Avg.	100.0	100.0	100.0	100.0	100.0	99.7	99.5	98.7	99.3	98.6	95.8
C-231	3	1	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
		2	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	97.5
		Avg.	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	98.8
K-9005	1	1	100.0	100.0	100.0	99.8	99.8	99.7	99.7	98.9	98.9	98.8	98.8
		2	100.0	99.9	99.8	99.7	99.7	99.6	99.6	99.7	99.6	99.7	98.4
		Avg.	100.0	100.0	99.9	99.7	99.7	99.6	99.6	99.3	99.2	99.3	98.6
K-9005	2	1	100.0	100.0	100.0	100.0	100.0	100.0	99.8	99.2	99.4	99.2	99.2
		2	100.0	100.0	100.0	100.0	100.0	100.0	100.0	99.4	99.9	98.3	98.3
		Avg.	100.0	100.0	100.0	100.0	100.0	100.0	99.9	99.3	99.7	98.7	98.7
K-9005	3	1	100.0	100.0	100.0	100.0	100.0	99.9	99.1	99.2	99.2	99.2	99.2
		2	100.0	100.0	100.0	100.0	100.0	99.9	99.9	99.2	100.0	100.0	98.1
		Avg.	100.0	100.0	100.0	100.0	100.0	99.9	99.5	99.2	99.6	99.6	98.6
K-9030	1	1	100.0	99.9	99.8	99.8	99.7	99.7	99.1	95.3	97.2	98.6	98.6
		2	100.0	100.0	100.0	99.9	99.9	99.6	95.8	95.2	95.7	95.7	89.0
		Avg.	100.0	99.9	99.9	99.9	99.8	99.6	97.5	95.2	96.5	97.2	93.8
K-9030	2	1	100.0	100.0	100.0	99.3	99.3	100.0	99.4	99.0	99.6	99.6	99.6
		2	100.0	100.0	100.0	99.8	99.8	99.7	97.6	97.6	96.8	96.7	93.0
		Avg.	100.0	100.0	100.0	99.5	99.5	99.8	98.5	98.3	98.2	98.1	96.3
K-9030	3	1	100.0	100.0	100.0	100.0	100.0	99.7	99.7	99.6	99.6	99.2	98.2
		2	100.0	100.0	100.0	100.0	100.0	100.0	99.8	99.6	99.7	99.1	99.0
		Avg.	100.0	100.0	100.0	100.0	100.0	99.9	99.8	99.6	99.6	99.2	98.6
M-SS	1	1	100.0	100.0	100.0	100.0	100.0	99.7	98.5	91.0	97.1	97.1	97.1
		2	100.0	100.0	100.0	100.0	100.0	99.9	98.5	96.9	96.7	96.7	92.2
		Avg.	100.0	100.0	100.0	100.0	100.0	99.8	98.5	93.9	96.9	96.9	94.7
M-SS	2	1	100.0	100.0	100.0	99.9	99.9	99.0	96.7	91.9	97.3	97.5	97.1
		2	100.0	100.0	99.9	99.9	99.9	99.7	98.6	97.2	98.1	98.1	95.9
		Avg.	100.0	100.0	99.9	99.9	99.9	99.3	97.7	94.5	97.7	97.8	96.5
M-SS	3	1	100.0	100.0	100.0	99.7	99.7	99.7	99.7	98.8	99.1	99.3	98.6
		2	100.0	100.0	100.0	100.0	100.0	100.0	100.0	98.9	98.9	98.7	98.7
		Avg.	100.0	100.0	100.0	99.9	99.9	99.9	99.8	98.9	99.0	99.0	98.6
888	1	1	100.0	100.0	100.0	98.2	98.0	98.0	97.5	97.5	96.9	96.7	96.7
		2	100.0	100.0	100.0	99.2	95.6	95.6	89.6	97.6	98.7	98.5	98.5
		Avg.	100.0	100.0	100.0	98.7	96.8	96.8	93.5	97.6	97.8	97.6	97.6
888-SL	1	1	100.0	100.0	100.0	99.6	99.6	99.5	99.6	99.4	99.2	99.2	97.7
		2	100.0	100.0	100.0	100.0	100.0	100.0	99.9	99.9	100.0	100.0	100.0
		Avg.	100.0	100.0	100.0	99.8	99.8	99.8	99.8	99.6	99.6	99.6	98.9
960-SL	1	1	100.0	100.0	100.0	97.9	97.9	97.8	97.7	97.6	86.3	85.5	84.1
		2	100.0	100.0	99.8	99.8	99.8	99.8	99.8	99.9	99.7	99.7	99.7
		Avg.	100.0	100.0	99.9	98.9	98.9	98.8	98.8	98.7	93.0	92.6	91.9
K-9050	1	1	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	96.3	96.3	96.3
K-9005/Pr	1	1	100.0	100.0	100.0	99.9	99.9	99.9	100.0	100.0	99.3	99.3	99.3

Table D-21. Summary of distress survival at South Carolina I-77 site.

Material	Config.	Rep.	Partial-depth Adhesion Survival, % edge length	Full-depth Adhesion Survival, % joint length	Full-depth Cohesion Survival, % joint length	Partial-depth Spall Survival, % joint length	Full-depth Spall Survival, % joint length	Overall Survival, % joint length
C-231	1	1	28.1	78.5	99.9	98.3	99.4	77.8
C-231	1	2	57.8	70.4	100.0	98.3	99.4	69.8
		avg	43.0	74.4	100.0	98.3	99.4	73.8
C-231	2	1	72.9	93.1	100.0	98.7	99.3	92.4
C-231	2	2	65.6	91.1	100.0	98.3	98.7	89.8
		avg	69.3	92.1	100.0	98.5	99.0	91.1
C-231	3	1	84.3	57.1	99.9	97.8	98.5	55.5
C-231	3	2	81.9	89.2	100.0	96.7	98.3	87.5
		avg	83.1	73.1	100.0	97.3	98.4	71.5
K-9005	1	1	86.6	79.0	99.7	99.7	99.0	77.7
K-9005	1	2	83.7	45.9	94.2	99.2	98.7	38.9
		avg	85.1	62.4	97.0	99.5	98.9	58.3
K-9005	2	1	82.8	90.6	98.1	99.3	99.2	87.8
K-9005	2	2	85.1	84.4	99.6	98.6	99.5	83.5
		avg	84.0	87.5	98.9	99.0	99.3	85.7
K-9005	3	1	93.6	73.4	95.1	98.3	99.3	67.8
K-9005	3	2	99.9	64.1	66.7	96.9	99.1	29.9
		avg	96.8	68.7	80.9	97.6	99.2	48.8
K-9030	1	1	60.4	43.5	99.9	99.2	99.2	42.6
K-9030	1	2	65.2	20.6	100.0	98.3	99.0	19.7
		avg	62.8	32.1	99.9	98.7	99.1	31.1
K-9030	2	1	90.3	73.8	100.0	97.6	98.0	71.8
K-9030	2	2	91.7	34.4	99.4	98.5	99.2	33.0
		avg	91.0	54.1	99.7	98.1	98.6	52.4
K-9030	3	1	99.4	15.3	100.0	96.9	97.6	12.9
K-9030	3	2	97.8	10.3	98.8	96.8	98.5	7.6
		avg	98.6	12.8	99.4	96.8	98.0	10.3

Table D-21. Summary of distress survival at South Carolina I-77 site (continued).

Material	Config.	Rep.	Partial-depth Adhesion Survival, % edge length	Full-depth Adhesion Survival, % joint length	Full-depth Cohesion Survival, % joint length	Partial-depth Spall Survival, % joint length	Full-depth Spall Survival, % joint length	Overall Survival, % joint length
M-SS	1	1	33.2	68.5	100.0	99.0	99.3	67.8
M-SS	1	2	74.1	25.1	99.7	99.4	99.1	23.9
		avg	53.6	46.8	99.8	99.2	99.2	45.9
M-SS	2	1	70.7	44.9	99.8	98.7	99.3	44.0
M-SS	2	2	68.1	28.4	99.9	98.8	98.6	26.9
		avg	69.4	36.7	99.9	98.8	99.0	35.5
M-SS	3	1	81.6	29.3	100.0	95.9	97.8	27.1
M-SS	3	2	94.5	26.9	99.7	96.2	98.8	25.5
		avg	88.1	28.1	99.9	96.0	98.3	26.3
888	1	1	99.8	100.0	100.0	96.2	99.4	99.4
888	1	2	100.0	100.0	100.0	94.7	99.2	99.2
		avg	99.9	100.0	100.0	95.5	99.3	99.3
888-SL	1	1	100.0	99.8	100.0	98.3	99.4	99.2
888-SL	1	2	100.0	99.6	100.0	97.4	98.8	98.4
		avg	100.0	99.7	100.0	97.8	99.1	98.8
960-SL	1	1	98.9	99.6	99.7	96.9	99.0	98.3
960-SL	1	2	100.0	98.1	99.6	98.6	98.3	96.0
		avg	99.4	98.9	99.6	97.8	98.7	97.2

Table D-22. Overall survival at South Carolina I-77 site.

Material	Config.	Rep. #	Overall Effectiveness (%) Over Time, months										
			0	1	5	9	13	17	31	43	57	68	80
C-231	1	1	100.0	100.0	100.0	100.0	100.0	100.0	100.0	98.8	91.6	83.1	77.8
		2	100.0	100.0	100.0	100.0	100.0	100.0	99.9	99.9	95.1	89.6	69.8
		Avg.	100.0	100.0	100.0	100.0	100.0	100.0	99.9	99.3	93.3	86.3	73.8
C-231	2	1	100.0	100.0	100.0	100.0	100.0	100.0	99.9	99.9	97.0	94.2	92.4
		2	100.0	100.0	100.0	100.0	100.0	100.0	97.7	98.5	96.8	94.4	89.8
		Avg.	100.0	100.0	100.0	100.0	100.0	100.0	98.8	99.2	96.9	94.3	91.1
C-231	3	1	100.0	98.0	97.8	94.4	91.0	91.0	86.4	88.2	75.3	67.4	55.5
		2	100.0	99.7	99.7	99.7	98.3	98.3	97.2	99.0	97.7	96.7	87.5
		Avg.	100.0	98.9	98.8	97.0	94.7	94.7	91.8	93.6	86.5	82.0	71.5
K-9005	1	1	100.0	100.0	99.9	99.2	98.4	98.4	86.3	89.9	84.9	84.7	77.7
		2	100.0	100.0	100.0	97.7	97.1	97.1	67.4	71.5	46.9	53.8	38.9
		Avg.	100.0	100.0	100.0	98.4	97.7	97.7	76.8	80.7	65.9	69.2	58.3
K-9005	2	1	100.0	100.0	100.0	100.0	99.6	99.6	99.2	97.3	92.7	89.5	87.8
		2	100.0	100.0	100.0	100.0	99.9	99.9	75.0	77.3	51.0	77.4	83.5
		Avg.	100.0	100.0	100.0	100.0	99.8	99.8	87.1	87.3	71.9	83.5	85.7
K-9005	3	1	100.0	99.8	99.4	77.5	76.9	76.9	74.2	83.1	66.2	68.9	67.8
		2	100.0	100.0	100.0	84.7	84.7	84.7	65.3	80.6	45.7	30.6	29.9
		Avg.	100.0	99.9	99.7	81.1	80.8	80.8	69.8	81.8	55.9	49.7	48.8
K-9030	1	1	100.0	100.0	100.0	97.5	97.7	97.7	58.3	78.1	71.7	52.8	42.6
		2	100.0	100.0	100.0	97.4	93.1	93.1	73.2	66.3	38.5	32.6	19.7
		Avg.	100.0	100.0	100.0	97.4	95.4	95.4	65.7	72.2	55.1	42.7	31.1
K-9030	2	1	100.0	100.0	100.0	98.6	98.7	98.7	94.7	90.7	84.9	78.0	71.8
		2	100.0	100.0	100.0	96.6	93.8	93.8	72.2	64.8	46.0	36.5	33.0
		Avg.	100.0	100.0	100.0	97.6	96.2	96.2	83.5	77.7	65.5	57.2	52.4
K-9030	3	1	100.0	100.0	96.3	77.4	66.2	66.2	46.9	44.7	27.1	17.9	12.9
		2	100.0	92.7	89.8	52.3	50.1	50.1	28.4	31.1	12.0	9.7	7.6
		Avg.	100.0	96.4	93.0	64.9	58.1	58.1	37.7	37.9	19.5	13.8	10.3
M-SS	1	1	100.0	100.0	100.0	99.9	99.9	99.9	96.6	91.9	81.1	74.0	67.8
		2	100.0	100.0	100.0	99.2	97.6	97.6	63.8	61.1	37.6	33.5	23.9
		Avg.	100.0	100.0	100.0	99.5	98.8	98.8	80.2	76.5	59.3	53.8	45.9
M-SS	2	1	100.0	100.0	100.0	99.9	99.0	99.0	87.7	80.8	71.7	58.5	44.0
		2	100.0	100.0	100.0	99.3	97.6	97.6	60.8	67.6	58.8	50.3	26.9
		Avg.	100.0	100.0	100.0	99.6	98.3	98.3	74.3	74.2	65.2	54.4	35.5
M-SS	3	1	100.0	100.0	100.0	97.7	92.8	92.8	78.9	66.7	53.2	44.1	27.1
		2	100.0	100.0	100.0	85.8	84.0	84.0	56.4	49.2	36.0	28.5	25.5
		Avg.	100.0	100.0	100.0	91.7	88.4	88.4	67.6	58.0	44.6	36.3	26.3
888	1	1	100.0	100.0	100.0	99.9	97.4	97.4	99.9	99.7	99.7	99.5	99.4
		2	100.0	100.0	100.0	100.0	99.5	99.5	99.5	99.5	99.7	99.6	99.2
		Avg.	100.0	100.0	100.0	100.0	98.5	98.5	99.7	99.6	99.7	99.5	99.3
888-SL	1	1	100.0	100.0	100.0	100.0	100.0	100.0	99.2	99.2	99.2	99.5	99.2
		2	100.0	100.0	100.0	100.0	99.5	99.5	98.7	99.0	98.6	98.8	98.4
		Avg.	100.0	100.0	100.0	100.0	99.8	99.8	99.0	99.1	98.9	99.1	98.8
960-SL	1	1	100.0	100.0	100.0	100.0	99.5	99.5	99.5	99.5	98.9	99.2	98.3
		2	100.0	100.0	100.0	99.9	98.8	98.8	98.7	98.7	98.1	97.5	96.0
		Avg.	100.0	100.0	100.0	99.9	99.2	99.2	99.1	99.1	98.5	98.3	97.2

Table D-23. Adhesion survival at South Carolina I-77 site.

Material	Config.	Rep. #	Spall Survival Over Time, percent joint length										
			0	1	5	9	13	17	31	43	57	68	80
C-231	1	1	100.0	100.0	100.0	100.0	100.0	100.0	100.0	99.9	93.8	83.7	78.5
		2	100.0	100.0	100.0	100.0	100.0	100.0	99.9	99.9	95.2	89.8	70.4
		Avg.	100.0	100.0	100.0	100.0	100.0	100.0	100.0	99.9	94.5	86.7	74.4
C-231	2	1	100.0	100.0	100.0	100.0	100.0	100.0	99.9	100.0	97.2	94.7	93.1
		2	100.0	100.0	100.0	100.0	100.0	100.0	99.2	100.0	98.1	95.4	91.1
		Avg.	100.0	100.0	100.0	100.0	100.0	100.0	99.5	100.0	97.7	95.1	92.1
C-231	3	1	100.0	98.1	98.0	94.7	91.3	91.3	86.6	88.5	76.0	68.7	57.1
		2	100.0	99.7	99.7	99.7	99.7	99.7	98.6	99.8	98.9	97.8	89.2
		Avg.	100.0	98.9	98.9	97.2	95.5	95.5	92.6	94.2	87.4	83.3	73.1
K-9005	1	1	100.0	100.0	100.0	99.3	98.6	98.6	86.5	90.3	85.5	85.6	79.0
		2	100.0	100.0	100.0	97.7	97.7	97.7	68.1	73.2	49.2	57.2	45.9
		Avg.	100.0	100.0	100.0	98.5	98.2	98.2	77.3	81.7	67.4	71.4	62.4
K-9005	2	1	100.0	100.0	100.0	100.0	100.0	100.0	100.0	99.5	95.9	92.0	90.6
		2	100.0	100.0	100.0	100.0	100.0	100.0	75.2	77.8	51.7	78.1	84.4
		Avg.	100.0	100.0	100.0	100.0	100.0	100.0	87.6	88.6	73.8	85.1	87.5
K-9005	3	1	100.0	99.8	99.4	77.5	77.0	77.0	76.7	87.2	71.3	74.3	73.4
		2	100.0	100.0	100.0	84.8	84.8	84.8	74.7	96.7	64.2	64.4	64.1
		Avg.	100.0	99.9	99.7	81.1	80.9	80.9	75.7	91.9	67.7	69.4	68.8
K-9030	1	1	100.0	100.0	100.0	97.5	97.7	97.7	58.3	78.3	71.9	53.7	43.5
		2	100.0	100.0	100.0	97.4	93.1	93.1	74.2	67.7	39.9	33.5	20.6
		Avg.	100.0	100.0	100.0	97.4	95.4	95.4	66.3	73.0	55.9	43.6	32.1
K-9030	2	1	100.0	100.0	100.0	98.6	98.7	98.7	95.4	91.6	85.8	79.7	73.8
		2	100.0	100.0	100.0	96.6	94.4	94.4	73.1	65.8	47.4	37.6	34.4
		Avg.	100.0	100.0	100.0	97.6	96.5	96.5	84.2	78.7	66.6	58.6	54.1
K-9030	3	1	100.0	100.0	96.3	77.4	66.2	66.2	47.4	45.6	28.1	19.9	15.3
		2	100.0	92.7	89.8	52.3	51.0	51.0	30.0	32.6	14.9	12.4	10.3
		Avg.	100.0	96.4	93.0	64.9	58.6	58.6	38.7	39.1	21.5	16.1	12.8
M-SS	1	1	100.0	100.0	100.0	99.9	99.9	99.9	96.6	91.9	81.1	74.7	68.5
		2	100.0	100.0	100.0	99.2	98.1	98.1	64.4	62.0	38.6	34.5	25.1
		Avg.	100.0	100.0	100.0	99.5	99.0	99.0	80.5	76.9	59.9	54.6	46.8
M-SS	2	1	100.0	100.0	100.0	99.9	99.0	99.0	87.8	81.1	72.0	59.4	44.9
		2	100.0	100.0	100.0	99.3	97.6	97.6	61.1	67.9	59.7	51.5	28.4
		Avg.	100.0	100.0	100.0	99.6	98.3	98.3	74.5	74.5	65.9	55.5	36.7
M-SS	3	1	100.0	100.0	100.0	97.7	92.8	92.8	79.4	67.6	54.1	45.8	29.3
		2	100.0	100.0	100.0	85.8	84.0	84.0	56.9	50.3	37.7	30.4	26.9
		Avg.	100.0	100.0	100.0	91.8	88.4	88.4	68.2	59.0	45.9	38.1	28.1
888	1	1	100.0	100.0	100.0	100.0	98.1	98.1	100.0	100.0	100.0	100.0	100.0
		2	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
		Avg.	100.0	100.0	100.0	100.0	99.1	99.1	100.0	100.0	100.0	100.0	100.0
888-SL	1	1	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	99.8
		2	100.0	100.0	100.0	100.0	100.0	100.0	99.6	99.8	99.8	99.6	99.6
		Avg.	100.0	100.0	100.0	100.0	100.0	100.0	99.8	99.9	99.9	99.8	99.7
960-SL	1	1	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	99.5	99.7	99.6
		2	100.0	100.0	100.0	99.9	99.9	99.9	99.9	100.0	99.4	98.6	98.1
		Avg.	100.0	100.0	100.0	99.9	99.9	99.9	99.9	100.0	99.4	99.1	98.9

Table D-24. Cohesion survival at South Carolina I-77 site.

Material	Config.	Rep. #	Cohesion Survival Over Time, percent joint length										
			0	1	5	9	13	17	31	43	57	68	80
C-231	1	1	100.0	100.0	100.0	100.0	100.0	100.0	100.0	99.9	99.9	99.9	99.9
		2	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
		Avg.	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
C-231	2	1	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
		2	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
		Avg.	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
C-231	3	1	100.0	100.0	100.0	100.0	100.0	100.0	100.0	99.9	99.9	99.9	99.9
		2	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
		Avg.	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
K-9005	1	1	100.0	100.0	100.0	100.0	100.0	100.0	100.0	99.9	99.9	100.0	99.7
		2	100.0	100.0	100.0	100.0	100.0	100.0	100.0	99.0	98.5	97.4	94.2
		Avg.	100.0	100.0	100.0	100.0	100.0	100.0	100.0	99.4	99.2	98.7	97.0
K-9005	2	1	100.0	100.0	100.0	100.0	100.0	100.0	99.6	98.6	98.0	98.1	98.1
		2	100.0	100.0	100.0	100.0	100.0	100.0	100.0	99.9	99.7	99.6	99.6
		Avg.	100.0	100.0	100.0	100.0	100.0	100.0	99.8	99.2	98.8	98.9	98.9
K-9005	3	1	100.0	100.0	100.0	100.0	100.0	100.0	97.7	96.3	95.3	95.1	95.1
		2	100.0	100.0	100.0	100.0	100.0	100.0	90.9	84.0	81.6	66.7	66.7
		Avg.	100.0	100.0	100.0	100.0	100.0	100.0	94.3	90.1	88.4	80.9	80.9
K-9030	1	1	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	99.9	99.9	99.9
		2	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
		Avg.	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	99.9	99.9
K-9030	2	1	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
		2	100.0	100.0	100.0	100.0	100.0	100.0	99.9	99.9	99.6	99.5	99.4
		Avg.	100.0	100.0	100.0	100.0	100.0	100.0	100.0	99.9	99.8	99.8	99.7
K-9030	3	1	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
		2	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	98.9	98.8	98.8
		Avg.	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	99.4	99.4	99.4
M-SS	1	1	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
		2	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	99.9	99.7	99.7
		Avg.	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	99.9	99.9	99.8
M-SS	2	1	100.0	100.0	100.0	100.0	100.0	100.0	100.0	99.8	99.8	99.8	99.8
		2	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	99.9
		Avg.	100.0	100.0	100.0	100.0	100.0	100.0	100.0	99.9	99.9	99.9	99.9
M-SS	3	1	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
		2	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	99.9	99.9	99.7
		Avg.	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	99.9	99.9	99.9
888	1	1	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
		2	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
		Avg.	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
888-SL	1	1	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
		2	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
		Avg.	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
960-SL	1	1	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	99.9	99.9	99.7
		2	100.0	100.0	100.0	100.0	100.0	100.0	100.0	99.9	99.9	99.9	99.6
		Avg.	100.0	100.0	100.0	100.0	100.0	100.0	100.0	99.9	99.9	99.9	99.6

Table D-25. Spall survival at South Carolina I-77 site.

Material	Config.	Rep. #	Spall Survival Over Time, percent joint length										
			0	1	5	9	13	17	31	43	57	68	80
C-231	1	1	100.0	100.0	100.0	100.0	100.0	100.0	100.0	99.0	97.8	99.4	99.4
		2	100.0	100.0	100.0	100.0	100.0	100.0	99.9	99.9	99.9	99.8	99.4
		Avg.	100.0	100.0	100.0	100.0	100.0	100.0	100.0	99.5	98.9	99.6	99.4
C-231	2	1	100.0	100.0	100.0	100.0	100.0	100.0	100.0	99.9	99.8	99.4	99.3
		2	100.0	100.0	100.0	100.0	100.0	100.0	98.5	98.5	98.7	99.0	98.7
		Avg.	100.0	100.0	100.0	100.0	100.0	100.0	99.3	99.2	99.2	99.2	99.0
C-231	3	1	100.0	99.9	99.9	99.8	99.8	99.8	99.8	99.7	99.4	98.8	98.5
		2	100.0	100.0	100.0	100.0	98.7	98.7	98.6	99.2	98.8	98.8	98.3
		Avg.	100.0	99.9	99.9	99.9	99.2	99.2	99.2	99.5	99.1	98.8	98.4
K-9005	1	1	100.0	100.0	99.9	99.9	99.8	99.8	99.7	99.7	99.5	99.0	99.0
		2	100.0	100.0	100.0	100.0	99.4	99.4	99.4	99.4	99.2	99.2	98.8
		Avg.	100.0	100.0	100.0	99.9	99.6	99.6	99.5	99.5	99.3	99.1	98.9
K-9005	2	1	100.0	100.0	100.0	100.0	99.6	99.6	99.6	99.2	98.8	99.4	99.2
		2	100.0	100.0	100.0	100.0	99.9	99.9	99.8	99.7	99.7	99.7	99.5
		Avg.	100.0	100.0	100.0	100.0	99.8	99.8	99.7	99.4	99.3	99.5	99.3
K-9005	3	1	100.0	100.0	100.0	100.0	99.9	99.9	99.7	99.7	99.7	99.4	99.3
		2	100.0	100.0	100.0	99.9	99.9	99.9	99.8	99.8	99.9	99.4	99.1
		Avg.	100.0	100.0	100.0	100.0	99.9	99.9	99.8	99.8	99.8	99.4	99.2
K-9030	1	1	100.0	100.0	100.0	100.0	100.0	100.0	99.9	99.8	99.9	99.2	99.2
		2	100.0	100.0	100.0	100.0	100.0	100.0	99.0	98.5	98.5	99.0	99.0
		Avg.	100.0	100.0	100.0	100.0	100.0	100.0	99.4	99.2	99.2	99.1	99.1
K-9030	2	1	100.0	100.0	100.0	100.0	100.0	100.0	99.3	99.1	99.1	98.3	98.0
		2	100.0	100.0	100.0	100.0	99.4	99.4	99.2	99.1	99.1	99.3	99.2
		Avg.	100.0	100.0	100.0	100.0	99.7	99.7	99.3	99.1	99.1	98.8	98.6
K-9030	3	1	100.0	100.0	100.0	100.0	100.0	100.0	99.5	99.1	99.0	98.0	97.6
		2	100.0	100.0	100.0	100.0	99.0	99.0	98.4	98.5	98.3	98.6	98.5
		Avg.	100.0	100.0	100.0	100.0	99.5	99.5	99.0	98.8	98.6	98.3	98.0
M-SS	1	1	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	99.4	99.3
		2	100.0	100.0	100.0	100.0	99.5	99.5	99.4	99.1	99.1	99.3	99.1
		Avg.	100.0	100.0	100.0	100.0	99.8	99.8	99.7	99.5	99.5	99.3	99.2
M-SS	2	1	100.0	100.0	100.0	100.0	99.9	99.9	99.9	99.9	99.9	99.4	99.3
		2	100.0	100.0	100.0	100.0	100.0	100.0	99.7	99.7	99.0	98.8	98.6
		Avg.	100.0	100.0	100.0	100.0	100.0	100.0	99.8	99.8	99.4	99.1	99.0
M-SS	3	1	100.0	100.0	100.0	100.0	100.0	100.0	99.4	99.1	99.1	98.3	97.8
		2	100.0	100.0	100.0	99.9	99.9	99.9	99.5	98.9	98.5	98.3	98.8
		Avg.	100.0	100.0	100.0	100.0	100.0	100.0	99.5	99.0	98.8	98.3	98.3
888	1	1	100.0	100.0	100.0	99.9	99.3	99.3	99.9	99.7	99.7	99.5	99.4
		2	100.0	100.0	100.0	100.0	99.5	99.5	99.5	99.5	99.7	99.6	99.2
		Avg.	100.0	100.0	100.0	100.0	99.4	99.4	99.7	99.6	99.7	99.5	99.3
888-SL	1	1	100.0	100.0	100.0	100.0	100.0	100.0	99.2	99.2	99.2	99.5	99.4
		2	100.0	100.0	100.0	100.0	99.5	99.5	99.1	99.2	98.8	99.2	98.8
		Avg.	100.0	100.0	100.0	100.0	99.8	99.8	99.2	99.2	99.0	99.3	99.1
960-SL	1	1	100.0	100.0	100.0	100.0	99.5	99.5	99.5	99.5	99.5	99.7	99.0
		2	100.0	100.0	100.0	100.0	99.0	99.0	98.8	98.8	98.8	99.0	98.3
		Avg.	100.0	100.0	100.0	100.0	99.2	99.2	99.2	99.2	99.2	99.3	98.7

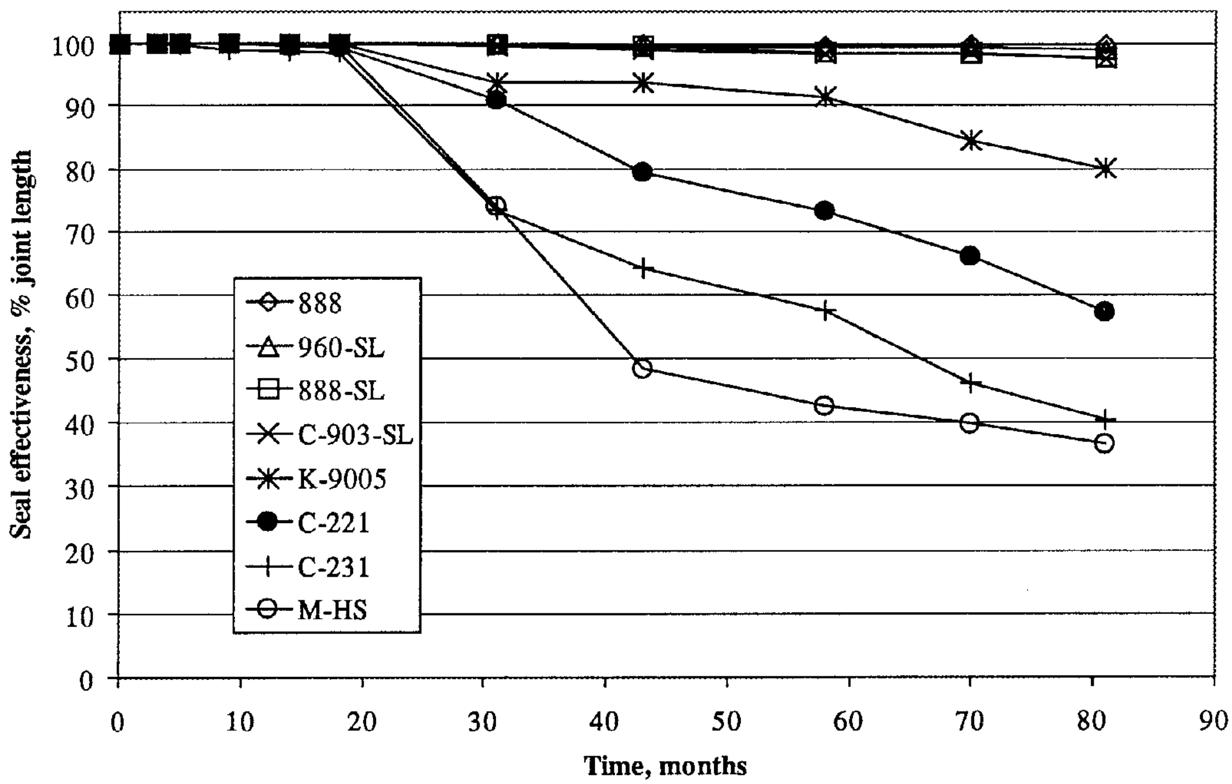

Figure D-2. Overall performance for Arizona I-17 configuration 1 seals.

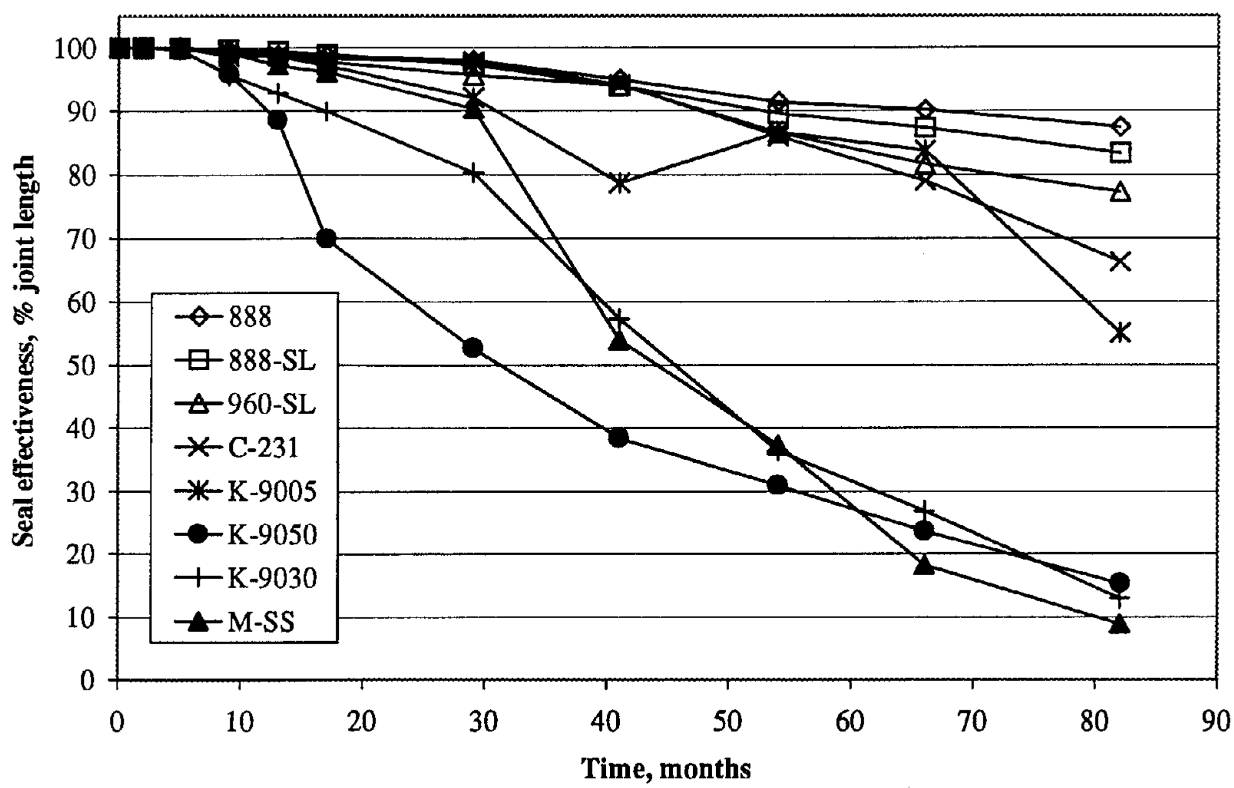

Figure D-3. Overall performance for Colorado I-25 configuration 1 seals.

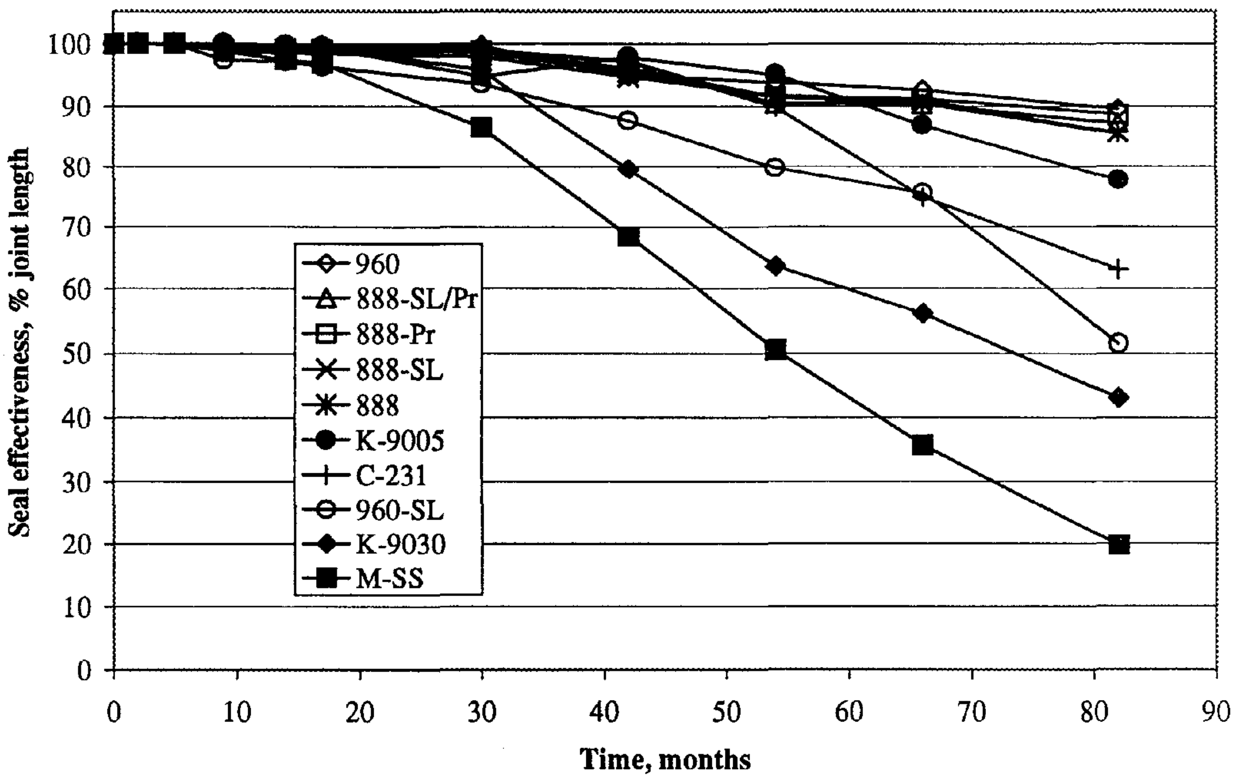

Figure D-4. Overall performance for Iowa I-80 configuration 1 seals.

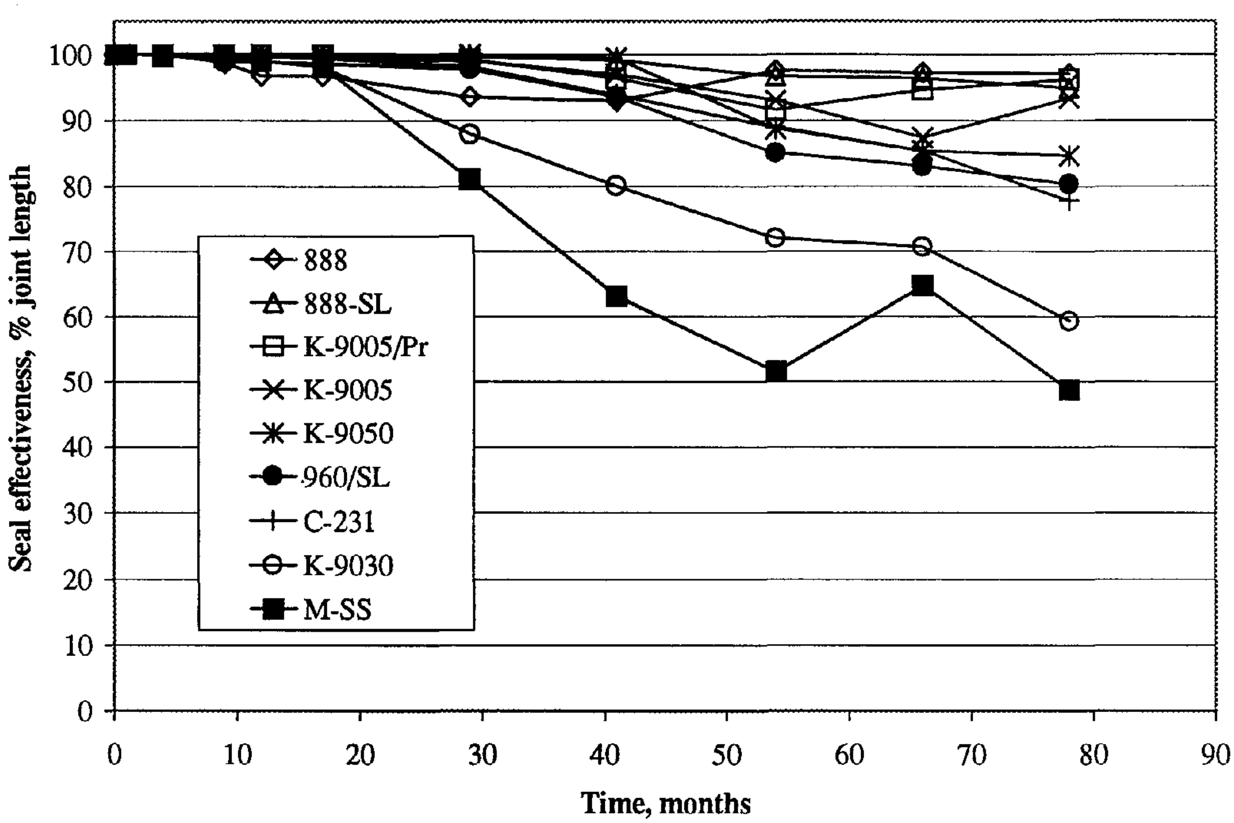

Figure D-5. Overall performance for Kentucky U.S. 127 configuration 1 seals.

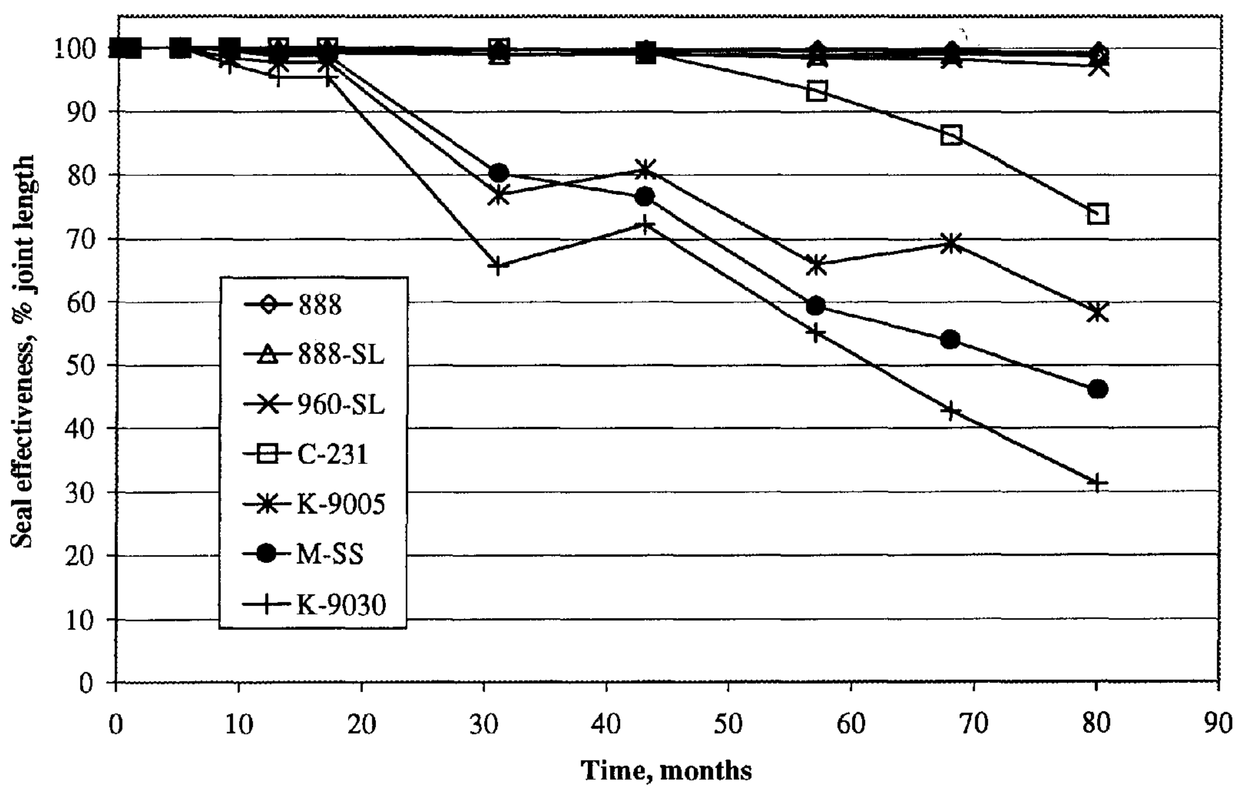

Figure D-6. Overall performance for South Carolina I-77 configuration 1 seals.

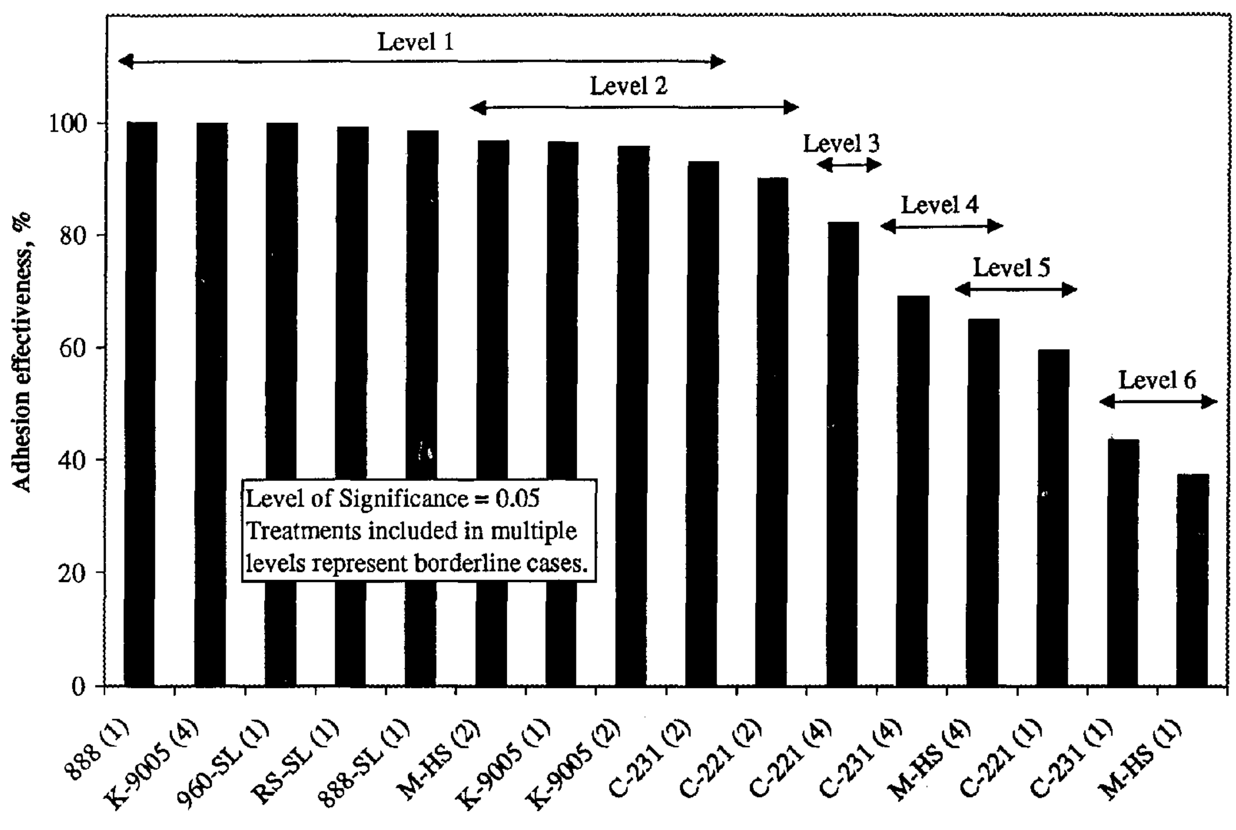

Figure D-7. Adhesion performance Tukey ranking for Arizona I-17 seals.

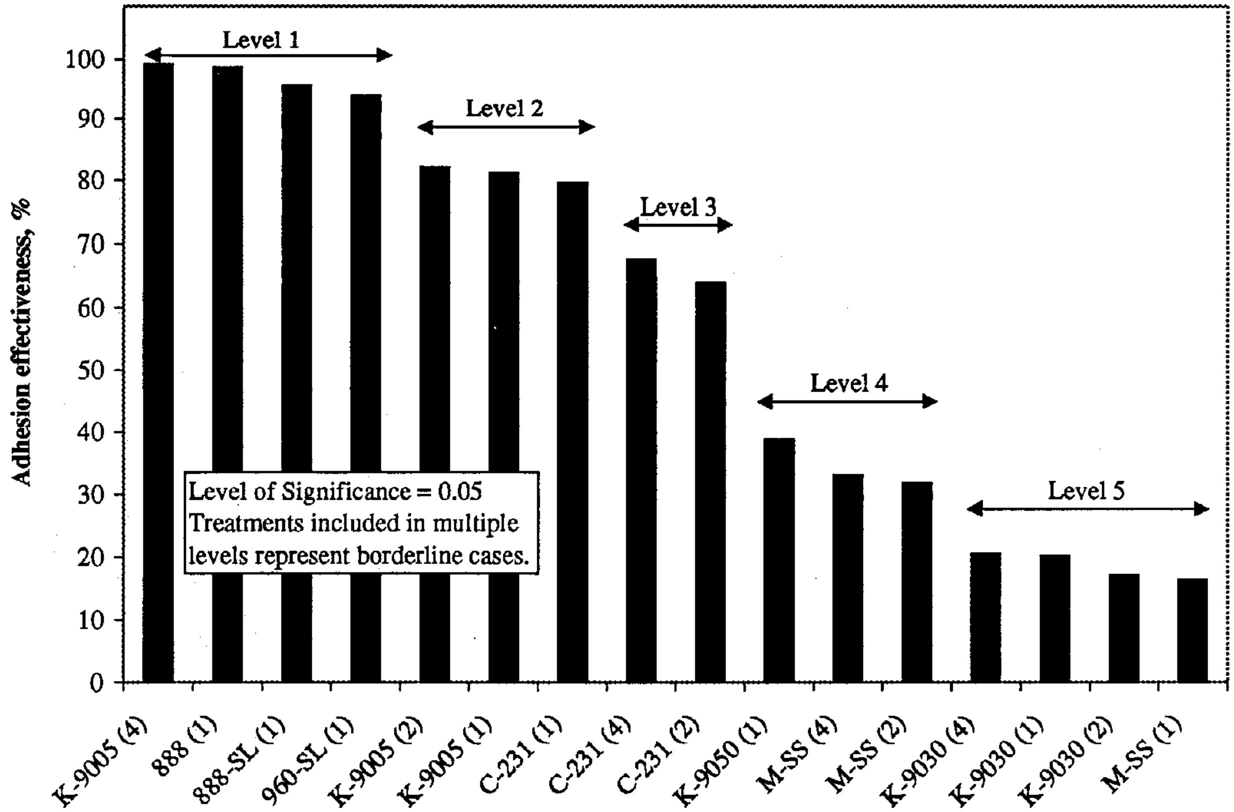

Figure D-8. Adhesion performance Tukey ranking for Colorado I-25 seals.

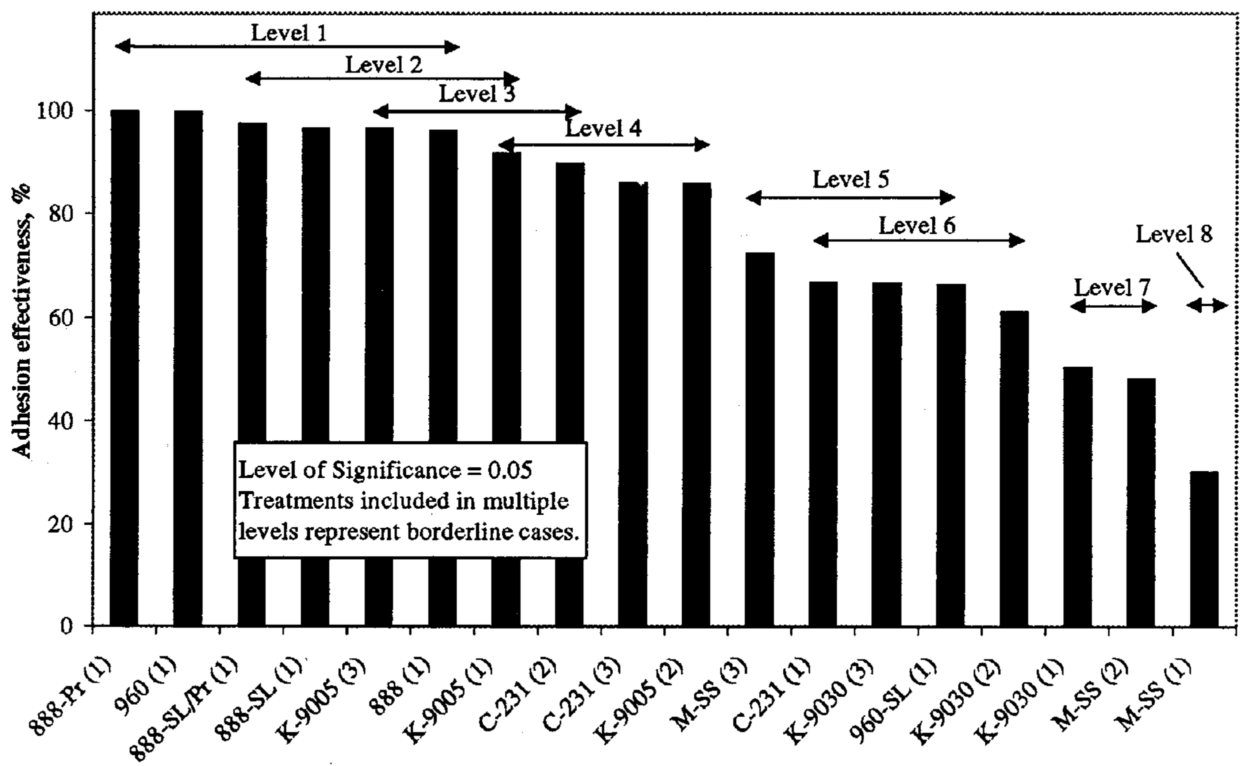

Figure D-9. Adhesion performance Tukey ranking for Iowa I-80 seals.

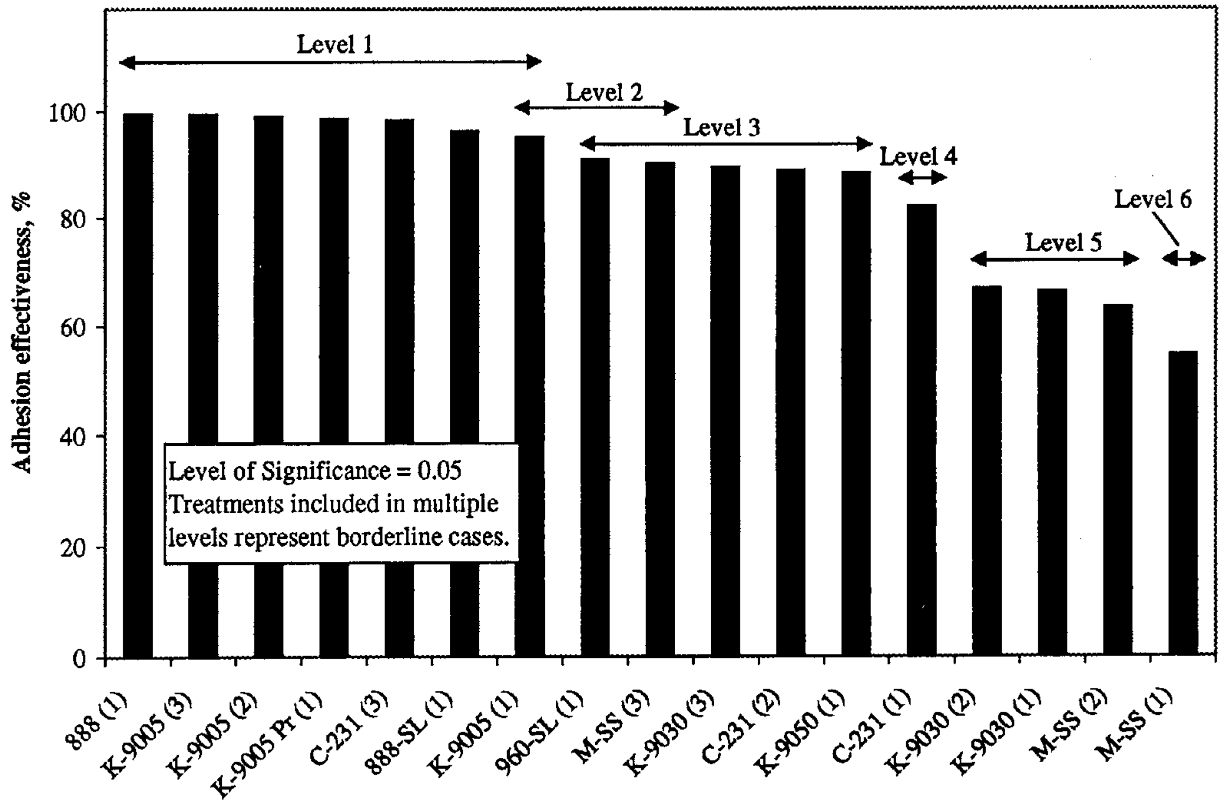

Figure D-10. Adhesion performance Tukey ranking for Kentucky U.S. 127 seals.

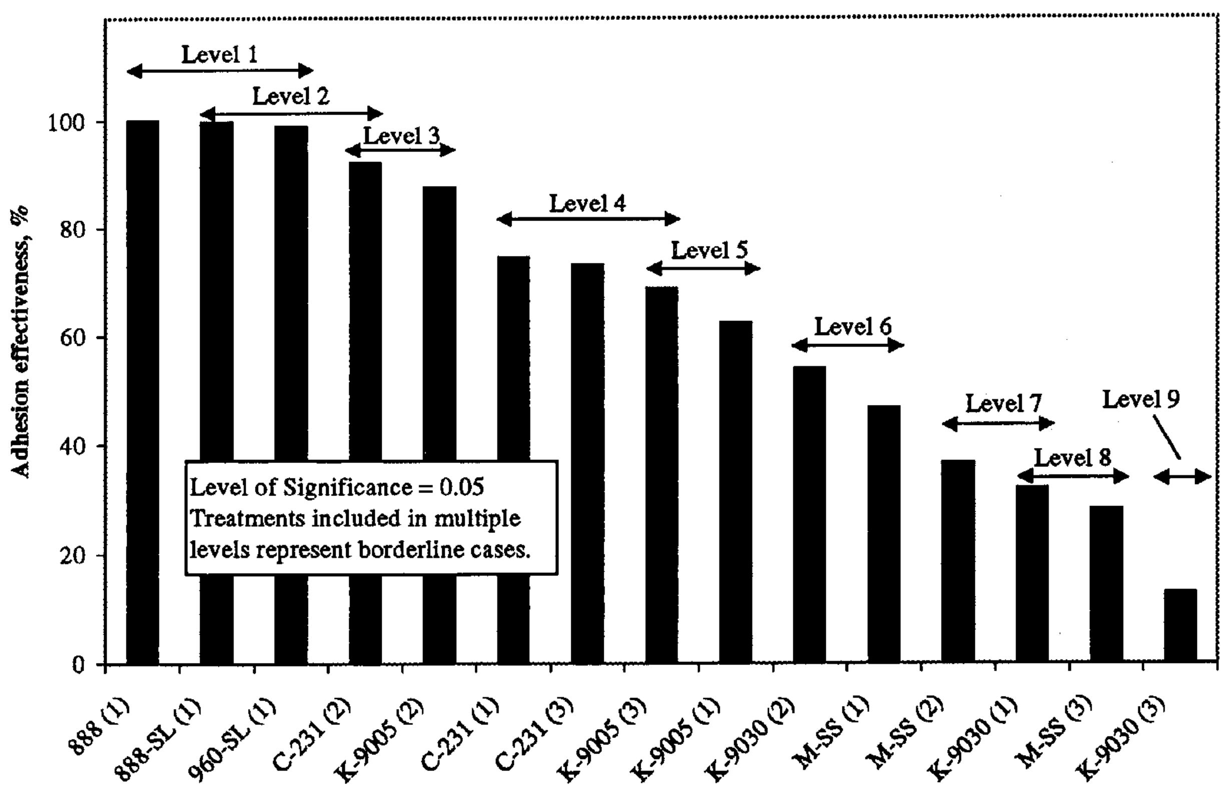

Figure D-11. Adhesion performance Tukey ranking for South Carolina I-77 seals.

Table D-26. Selected hot-applied laboratory test–field performance correlation results for configuration 1.

Test Parameter	ASTM Number	Pearson Correlation Coefficients for Field Distresses						
		Partial Adhesion	Full Adhesion	Partial Spall	Full Spall	Full Cohesion	Total Failure	75% Life
Ultimate strength, -17.8 °C	D 412							
Ultimate strength, 3.9°C	D 412	**-0.9303**						
Ultimate strength, 23.0°C	D 412							
Stress at 150%, -17.8°C	D 412		0.1454					
Stress at 150%, 3.9°C	D 412		-0.8383					0.8140
Stress at 150%, 23.0°C	D 412							
Ultimate elongation, -17.8°C	D 412							
Ultimate elongation, 3.9°C	D 412							
Ultimate elongation, 23.0°C	D 412							
Adhesion/coh., immersed	D 3583		**-0.9407**		-0.8720		**-0.9225**	**0.9488**
Adhesion/coh., non-immersed	D 3583	-0.7883					-0.7414	0.7392
Cone penetration, -17.8°C	D 3407			**0.890**	0.7628			
Cone penetration, 25°C	D 3407			**0.980**	0.8308			
Flow, 60°C	D 3407	**-0.8788**				**0.9884**		0.7919
Resilience, 25°C	D 3407							
Softening point	D 36							
Brookfield viscosity	D 4402							
Specific gravity, 15.6°C	D 3407							
Density, 23°C								
Maximum elongation	D 113		-0.7836				**-0.8361**	0.7702
Maximum engineering stress	D 113							
Maximum true strain	D 113	**0.9093**				-0.7568		
Asphalt modulus	D 113			-				
Polymer modulus	D 113	0.7342						
Engineering area	D 113							
True area	D 113							

Level of significance (α) for bolded Pearson coefficients is 0.05. Non-bolded α is 0.10.
Shaded cells indicate that no significant correlation is expected.

Table D-27. Selected hot-applied laboratory test–field performance correlation results for configuration 2.

Test Parameter	ASTM Number	Pearson Correlation Coefficients for Field Distresses						
		Partial Adhesion	Full Adhesion	Partial Spall	Full Spall	Full Cohesion	Total Failure	75% Life
Ultimate strength, -17.8 °C	D 412							
Ultimate strength, 3.9°C	D 412					**0.9527**		
Ultimate strength, 23.0°C	D 412					-0.7694		
Stress at 150%, -17.8°C	D 412			**-0.8369**	-0.7496			
Stress at 150%, 3.9°C	D 412		-0.8510				-0.8534	**0.9299**
Stress at 150%, 23.0°C	D 412					**0.9120**		
Ultimate elongation, -17.8°C	D 412							
Ultimate elongation, 3.9°C	D 412							
Ultimate elongation, 23.0°C	D 412							
Adhesion/coh., immersed	D 3583		-0.8673			0.8396		0.8654
Adhesion/coh., non-immersed	D 3583	**-0.8153**	-0.7895		-0.7711		-0.7675	
Cone penetration, -17.8°C	D 3407			**0.8964**	0.8063			
Cone penetration, 25°C	D 3407			**0.8731**		-0.7368		
Flow, 60°C	D 3407							
Resilience, 25°C	D 3407							
Softening point	D 36							
Brookfield viscosity	D 4402							
Specific gravity, 15.6°C	D 3407							
Density, 23°C								
Maximum elongation	D 113						-0.8087	**0.8235**
Maximum engineering stress	D 113							
Maximum true strain	D 113							
Asphalt modulus	D 113							
Polymer modulus	D 113							
Engineering area	D 113							
True area	D 113							

Level of significance (α) for bolded Pearson coefficients is 0.05. Non-bolded α is 0.10.
Shaded cells indicate that no significant correlation is expected.

Table D-28. Selected silicone laboratory test–field performance correlation results.

Test Parameter	ASTM No.	Pearson Correlation Coefficients for Field Distresses						
		Partial Adhesion	Full Adhesion	Partial Spall	Full Spall	Full Cohesion	Overall Failure	75% Life
Ultimate strength, -17.8 °C	D 412							
Ultimate strength, 23.0°C	D 412							
Ultimate strength, 60°C	D 412							
Stress at 150%, -17.8°C	D 412	-0.9923		0.9906				
Stress at 150%, 23.0°C	D 412							
Stress at 150%, 60°C	D 412							
Ultimate elongation, -17.8°C	D 412							
Ultimate elongation, 23.0°C	D 412					-0.9939		
Ultimate elongation, 23.0 °C, weathered	D 412							
Ultimate elongation, 60°C	D 412							
Adhesion/coh., immersed	D 3583							
Adhesion/coh., non-immersed	D 3583		0.9926		**0.9999**		0.9966	

Level of significance (α) for bold Pearson coefficients is 0.05. For unbolded coefficients, α is 0.10.
Shaded cells indicate that no significant correlation is expected.

APPENDIX E. COST-EFFECTIVENESS

Choosing maintenance materials and methods that provide the most effective balance of performance and cost is becoming increasingly important to maintenance planners. Described in this appendix is the information required to compare the cost-effectiveness of joint seal materials and installation procedures. Tables to assist in the calculations are included, along with a set of example calculations. Steps for determining the cost-effectiveness of methods and materials for resealing joints in PCC pavements include:

1. Determining the amounts and costs of materials needed.
2. Estimating the labor needs and costs.
3. Determining the equipment requirements and costs.
4. Estimating the effective lifetime of each resealing option.
5. Calculating the average annual cost for each method under consideration.

Material and Shipping Costs

Material costs for sealant, backer rod, blasting abrasive, primer, and other required materials can be obtained from local suppliers or manufacturers. Shipping costs can be up to 40 percent or more of the material costs, depending on the amount of material purchased and the required shipping distance. Overall material and shipping costs can be estimated using table E-2. The sealant coverage rates in table E-3 can be estimated by using the following equation or by consulting manufacturers' literature.

$$CR = 0.001\,(WF)(ST)(W)(T) \tag{E-1}$$

where:

CR = Sealant coverage rate, liters/meter.
WF = Waste factor (WF = 1.2 for 20 percent waste).
ST = Surface type constant (tooled surface: ST = 1.1; non-tooled surface: ST = 1.0).
W = Joint width, mm.
T = Thickness of sealant, mm.

By multiplying the material cost, the coverage rate, and the length of the joint to be resealed, the total cost for each material and the overall material cost can be estimated.

Labor Costs

Total labor costs can be estimated by entering into table E-3 the wages for each worker, the number of workers required for each operation, and the expected time necessary to complete each operation. The test site installation production rates listed in table E-1 should be helpful in determining labor requirements. However, in addition to wage rates, labor costs are greatly influenced by crew productivity and the need for night work or extra traffic control. Therefore, local conditions should be considered when estimating production rates.

Table E-1. Production rates.

Resealing Operation	Number of Workers	Average Production Rates (hours / kilometer)
Joint plowing	2	6 to 9
Joint resawing	1	11 to 22
Sandblasting	2	4.5 to 12
Final airblasting	2	4.5 to 12
Backer rod installation	2	3 to 9
Sealant installation	2	4.5 to 7.5

Equipment Costs

The cost of equipment will be affected by the availability of adequate equipment and the need for equipment rental. The amount of time that each piece of equipment is required also greatly influences equipment costs. By completing table E-4 and multiplying the daily equipment costs by the number of pieces of equipment required and by the number of days the equipment is needed, the cost of resealing equipment can be estimated. Production rates should be based on local experience, although the rates shown on table E-1 may be used to obtain rough estimates.

User Delay Costs

Although difficult to determine, there is the cost of delay to roadway users during the time that joints are cleaned and resealed. This delay cost should be included in cost-effectiveness calculations if the options being evaluated require significantly different amounts of lane closure. Experienced traffic engineers or agency guidelines should be consulted in defining the cost of delay.

Cost-Effectiveness Comparisons

After the material, labor, equipment, and user costs have been determined, the worksheet in table E-5 can be used to determine the annual cost of each resealing option. The expected rate of inflation and the estimated lifetime of each material–placement method option are required inputs for the worksheet. By comparing the average annual cost of various materials and repair procedures, the most cost-effective resealing option can be determined. A sample cost-effectiveness comparison is included in the following section.

Table E-2. Material and shipping costs.

Material, unit	Material Cost ($/unit)	Coverage Rate (ft/unit)	Length Required (linear meters)	Total Cost ($/material)
	a	b	c	a x b x c
Sealant, L				
Backer rod, m				
Blasting sand, kg				
Primer, L				
Total Material Cost:				

1 gal = 3.785 L; 1 ft = 0.305 m; 1 lb = 0.454 kg

Table E-3. Labor costs.

Crew Labor	Wages ($/day)	Number in Crew	Days Required	Total Cost, $
	d	e	f	d x e x f
Supervisor				
Traffic control				
Plowing				
Sawing				
Initial airblast				
Sandblast				
Final airblast				
Backer rod				
Sealant installation				
Total Labor Cost:				

Table E-4. Equipment costs.

Equipment	Daily Cost	Number of Units	Number of Days	Total Cost, $
	g	h	i	g x h x i
Traffic control				
Joint plow				
Concrete saw				
Air compressor				
Sandblast equip.				
Installation Equip.				
Other trucks				
Total Equipment Cost:				

Table E-5. Cost-effectiveness worksheet.

Cost Item	Source	Total Cost ($)		Eq. Code
		Option 1	Option 2	
Materials and shipping	Table E-2			
Labor	Table E-3			
Equipment	Table E-4			
User delay				
Total Resealing Cost ($)				A
Project length (linear kilometers)				B
Average cost ($/linear kilometer)	A x B			C
Estimated lifetime of joint seal (years)				D
Rate of inflation				E
Average Annual Cost ($/lane-mi [$/lane-km])	Equation E-2			

$$\textit{Average Annual Cost} = C\left[\frac{(E)\left[(1+E)^{p}\right]}{(1+E)^{p}-1}\right] \quad \text{(E-2)}$$

Sample Cost-Effectiveness Calculations

An engineer has decided to compare the cost-effectiveness of two sealant materials, a silicone and a rubberized asphalt, for a 4.0-km resealing project containing 6.1 linear km of joints. The preparation methods and labor and installation rates are nearly the same for each material and are listed in table E-6. Based on local experience and manufacturers' recommendations, information relative to each material has been compiled in table E-7. Using this information, coverage rates can be computed, and material, equipment, and labor costs can be estimated, as shown in tables E-8, E-9, and E-10. Sample equipment cost and cost-effectiveness calculations are given in tables E-11 and E-12.

Table E-6. Production and labor rates.

Operation / Operator	Production and Labor Rates
Joint plowing	160 m/h
Joint resawing	84 m/h
Airblasting	152 m/h
Sandblasting (with overband)	114 m/h (84 m/h)
Backer rod installation	165 m/h
Sealant installation	165 m/h
Labor	$120 / day
Maintenance supervisor	$200 / day

Table E-7. Sealant material information.

	Option 1	Option 2
Material type	Self-leveling silicone	Rubberized asphalt
Shape factor (W:T)	2:1	1:1
Joint width (W)	13 mm	13 mm
Sealant thickness (T)	6.5 mm	13 mm
Primer required	None	None
Estimated lifetime	13 years	8 years
Wastage factor (WF)	1.2	1.2
Surface type constant (ST)	1	1

The sealant coverage rate for option 1 is calculated in the following equation:

$$CR = 0.001\,(1.2)(1.0)(12.7)(6.4) = 0.097536 \qquad \text{(E-3)}$$

where:

CR = Coverage rate, L/m.
WF = Wastage factor = 1.2.
ST = Surface type constant = 1.0.
W = Joint width = 12.7 mm.
T = Thickness of sealant = 6.4 mm.

Since the recommended shape factor for option 2 is 1:1, the required sealant thickness is 12.7 mm, resulting in a coverage rate of 0.19507 L/m.

Table E-8. Option 1 material and shipping costs.

Material, unit	Material/Shipping Cost ($/unit)	Coverage Rate (unit/m)	Length Required (m)	Total Cost ($/material)
	a	b	c	a x b x c
Sealant, L	7.40	0.097536	6,100	4,403
Backer rod, m	0.011	1.05	6,100	70
Blasting sand, kg	0.11	0.30	6,100	201
Primer, L	-0-	-0-	-0-	0
Total Material Cost:				4,674

Table E-9. Option 2 material and shipping costs.

Material, unit	Material/Shipping Cost ($/unit)	Coverage Rate (unit/m)	Length Required (m)	Total Cost ($/material)
	a	b	c	a x b x c
Sealant, L	1.45	0.19507	6,100	1,729
Backer rod, m	0.011	1.05	6,100	70
Blasting sand, kg	0.11	0.30	6,100	201
Primer, L	-0-	-0-	-0-	0
Total Material Cost:				2,000

Table E-10. Labor costs for options 1 and 2.

Crew Labor	Wages ($/day)	Number in Crew	Days Required	Total Cost, $
	d	e	f	d x e x f
Supervisor	200	1	14	2,800
Traffic control	120	1	14	1,680
Plowing	120	2	5	1,200
Sawing	120	1	3.5	420
Initial airblast	120	2	3.5	840
Sandblast	120	2	6	1,440
Final airblast	120	2	3.5	840
Backer rod	120	2	4.6	1,104
Sealant installation	120	2	4.6	1,104
Total Labor Cost:				11,428

Table E-11. Sample equipment costs.

Equipment	Daily Cost	Number of Units	Number of Days	Total Cost, $
	g	h	i	g x h x i
Traffic control	450	1	14.0	6,300
Joint plow	150	1	5.0	750
Concrete saw	225	2	3.5	1,575
Air compressor	175	1	7.5	1,125
Sandblast equipment (including compressor)	200	1	6.0	1,200
Installation equipment	200	1	4.6	920
Other trucks	100	2	14.0	2,800
Total Equipment Cost:				14,670

Table E-12. Sample cost-effectiveness calculations

Cost Item	Source	Total Cost ($)		Eq. Code
		Option 1	Option 2	
Materials and shipping	Tables E-8, E-9	4,674	2,000	
Labor	Table E-10	11,428	11,428	
Equipment	Table E-11	14,670	14,670	
User delay		2,250	2,250	
Total Resealing Cost ($)		33,022	30,348	A
Project length (linear meters)		6,100	6,100	B
Average reseal cost ($/linear meter)	A / B	5.41	4.98	C
Estimated lifetime of joint seal (years)		13 years	8 years	D
Rate of inflation		0.05	0.05	E
Average Annual Cost ($/linear meter)	Equation E-2	**$0.58/lin. m**	**$0.77/lin. m**	

$$\textit{Option 1 Avg. Annual Cost} = \$5.43\left[\frac{(0.05)\left[(1+0.05)^{13}\right]}{(1+0.05)^{13}-1}\right] = \$0.58 \tag{E-4}$$

$$\textit{Option 2 Avg. Annual Cost} = \$4.99\left[\frac{(0.05)\left[(1+0.05)^{8}\right]}{(1+0.05)^{8}-1}\right] = \$0.77 \tag{E-5}$$

Results of this hypothetical engineer's analysis show that, although the material cost of option 2 is less than option 1, the higher expected lifetime of option 1 results in option 1 having a smaller average annual cost per linear meter. This type of analysis allows a planner to compare resealing materials and methods on an even basis and to choose the most cost-effective option.