Joint Resealing Project at Fairchild Air Force Base, Washington

Twenty-One-Year Field Performance

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In 1989, the U.S. Army Engineer Research and Development Center and Crafco, Inc., initiated a research effort to develop improved materials and processes for sealing joints in portland cement concrete pavements. Objectives were to develop specifications for improved hot-applied, jet fuel–resistant (JFR) and non–jet fuel–resistant (non-JFR) sealants and to determine the impact of installation configuration on field performance. The laboratory phase identified desired sealant properties, evaluated sealants for those properties, and developed sealants with improved low-temperature and aging properties. The field phase was installed in June 1991 at Fairchild Air Force Base, Washington, to determine performance of developed sealants compared with standard sealants and to determine whether performance could be improved by changing installation geometry. Thirteen sealants were installed. The field study documented installation and evaluations at 6 and 12 months. After study completion, the installations were monitored several additional times. Detailed papers were prepared after 5 and 10 years. At 10 years, some sealants had greater than a 10-year life. In 2011, the installations reached 20 years of age. The JFR sections had been replaced, and non-JFR sections were still intact and were evaluated in April 2012. Results of the 21-year evaluation are presented. One silicone sealant and the improved non-JFR sealant achieved a 21-year life. Results also show that the flush-fill installation geometry increased life of the hot-applied asphalt sealants by more than 50% compared with the standard recessed configuration and should be considered for joint sealant installations.

In 1989, the Geotechnical and Structures Laboratory, U.S. Army Engineer Research and Development Center, and Crafco, Inc., initiated a research investigation under the auspices of the Construction Productivity Advancement Research program. Objectives of the research program were to

1. Improve performance characteristics of hot-applied, jet fuel–resistant (JFR) and non–jet fuel–resistant (non-JFR) sealants or develop new materials to achieve the desired performance,
2. Develop a primer system to minimize bubbling tendencies associated with hot-applied sealants and improve the sealant's adhesion to portland cement concrete, and
3. Collect field data to determine realistic field performance of different sealant types and application methods [flush-fill versus recessed application of 3.2 to 6.4 mm (⅛ to ¼ in.)].

A two-phase research program was conducted. Phase I was a laboratory investigation that focused on improving the performance characteristics of hot-applied pavement joint sealants (*1*). Phase II was the field evaluation to validate findings of the laboratory investigation (*2*). Phase II included field evaluations at 6 and 12 months. Field test sections were evaluated four more times within the last 10 years after installation. Detailed papers were prepared on the 5-year (*3*) and 10-year (*4*) evaluations. Ten-year results showed that some of the sealants could perform satisfactorily for greater than 10 years.

In 2011, 20 years after installation, a final field evaluation was planned, if the test sections were still in place. On September 21, 2011, the base was visited to view the sections. The JFR sections had been resealed, but the non-JFR sections were still mostly in place. In some areas, several of the concrete slabs had been replaced, and joints resealed, but original sections could still be identified and were mostly intact. Therefore, the final evaluation was planned for early spring 2102 to coincide with the time of year when the 10-year evaluation was conducted. This paper reviews results of the initial laboratory and field studies and the 10-year performance results; presents results of the 21-year evaluation; and provides conclusions on joint sealant performance, installation geometry, and life expectancy.

SUMMARY OF LABORATORY INVESTIGATION

The laboratory study was used to identify desired properties of hot-applied sealants, evaluate commercially available sealants to determine specification conformance, and identify performance limits in laboratory tests. Laboratory formulation studies were conducted to develop sealants that would exhibit improved field performance properties. Conclusions from the laboratory study included the following (*1*):

1. In general, sealants conform to the specification requirements for which they were designed.
2. Sealants did not pass bond testing at lower temperatures than required by specifications.
3. Sealant properties were altered during extended heating.
4. JFR sealants experienced significant surface hardening during aging.

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5. Specification limits for improved versions of JFR and non-JFR sealants with better low temperature properties and aging resistance were developed.

6. Trial production batches of improved JFR and non-JFR sealants were produced for the field evaluation phase.

FIELD TEST SECTION LAYOUT, JOINT PREPARATION, AND SEALANT INSTALLATION

Fairchild Air Force Base (AFB), Spokane, Washington, was selected for the field evaluations. Fairchild AFB experiences an average daily temperature during January of −4°C (25°F), with average lows of −7°C (19°F) and extreme low temperatures of −34°C (−30°F). Therefore, the low temperature capabilities of the sealants would be tested. The average daily temperature during August is approximately 21°C (70°F), with the average high of 29°C (84°F). Extreme high temperatures of up to 42°C (108°F) have been recorded, and that ensured that the high temperature characteristics of the sealants would also be evaluated. With the use of FHWA LTPPBIND (*5*), the air temperature range at Fairchild is 34.2°C to −21.1°C (94°F to −6°F), and the 98% confidence climate grade for asphalt paving is PG 58-28, very typical of many moderately cold areas of the United States.

The field test section was divided into two areas: Non-JFR sealants were installed in Area 1, and JFR sealants were installed in Area 2. At the time of sealant installation, Area 1 was used primarily as a taxiway through a parking apron, and Area 2 was a parking apron for trainer aircraft. Within each area, concrete age, condition, joint spacing and width, and pavement use were consistent for all of the installed sealants. Since the initial installation, use of the pavement areas has changed. A portion of Area 1 is now used as a parking apron for refueling aircraft, and Area 2 is not in use. Sealants in both areas were exposed to limited traffic; therefore, environmental and maintenance effects are the predominant means of degradation.

The concrete slabs were 7.6 m (25 ft) by 7.6 m (25 ft) by 40.6 cm (16 in.) thick, and the joints were doweled. During sealant installation, the slabs were approximately 35 years old. Most joints contained old unidentified sealant that exhibited significant adhesion failure. Two randomized replicates or sections of each sealant and application configuration were installed, with 107 linear m (350 linear ft) of sealant in each section. The sealants installed, section numbers, and application variables are shown in Table 1.

The existing sealant was removed using a water-cooled concrete saw. The resurfaced joints were approximately 19 mm (¾ in.) wide and sufficiently deep to accept a backer rod material to maintain the appropriate sealant shape factor. The joints were flushed using high-pressure water equipment to remove debris left by the sawing operation. Once the joints dried, they were sandblasted and then cleaned by using compressed air. Any joint that was not sealed the same day that it was sandblasted was recleaned with compressed air just before sealing. Additional details on joint preparation, existing pavement conditions, and sealant installation can be found in Lynch et al. (*2*).

PREVIOUS FIELD PERFORMANCE EVALUATIONS

Previous evaluations were conducted at 6, 12, 22, 58, 86, and 117 months. Details of these evaluations are found elsewhere (*2–4*). Evaluations were conducted by visual inspection of the sealant in each joint for adhesion and cohesion failures, spalling, fuel damage, debris retention, bubbling, and surface cracking. Initially, each type of defect was noted as a percentage and listed as no, few, frequent, and so on. In later evaluations, criteria were changed so that full-depth adhesive and cohesive failures were combined into a single determination of percent length that would allow water infiltration. These criteria are consistent with procedures developed during the SHRP H-106 project (*6*) and with National Transportation Product Evaluation Program (NTPEP) joint sealant evaluation procedures from AASHTO. Summaries of the 58-, 86-, and 117-month evaluation results are shown in Table 2. Conclusions from the 10-year (117-month) evaluation are as follows:

1. Some JFR and non-JFR sealants exhibited life expectancies of greater than 10 years. The improved JFR sealant had a life of greater than 10 years. In the non-JFR area, two hot-applied, asphalt-based sealants and four silicone sealants had life expectancies of greater than 10 years.
2. There was no major performance difference between hot-applied asphalt sealants installed with the flush-fill or those installed with recessed configuration.
3. The improved hot-applied JFR and non-JFR sealants developed and installed during this project had better performance than the standard sealants specified by the military.
4. Bubbling of hot-applied sealants did not seem to adversely affect overall sealant performance.
5. Some asphalt-based and silicone sealants exhibited similar field performance, but failure mechanisms were different. Asphalt-based sealants generally failed in adhesion, while silicone sealants generally failed from spalling.

INSPECTION RESULTS AT 243 MONTHS

On September 21, 2011, the test installations were visited and briefly inspected to determine whether an in-depth evaluation would be appropriate. Area 2, the JFR sealant test area, had been resealed with silicone sealant several years ago; therefore, no further information on the JFR test sections could be obtained beyond the 10-year results. Several slabs in Area 1, the non-JFR area, had been replaced in the last 10 years because of slab deterioration and during construction of a pipeline through the area. Joints at the edges of all replaced slabs were resealed with silicone. Of the original 336 joint lengths in the 24 test section areas, 62 had been replaced, leaving 81.5% of the original joints remaining. A quick visual evaluation of joint sealant condition was performed. Estimated failures ranged from 25% to 75% for the different sealants and installation configurations. It was determined that sufficient materials remained to perform a detailed evaluation.

EVALUATION AT 250 MONTHS

Evaluation was planned for late March, coinciding with the timing of the 10-year evaluation. However, scheduling conflicts required the evaluation to be performed on April 23 and 24, 2012. Throughout this project history, there has been consistency of personnel. The same individuals who conducted the initial project research and who were involved with installation of the test sections also performed the previous field evaluations and the 250-month evaluation. Temperatures during the evaluation ranged from 13°C (55°F) in the mornings to approximately 27°C (80°F) in the afternoons. Weather conditions

TABLE 1 Sealants, Sections, and Installation Configurations

Area	Sections	Sealant	Configuration	Type of Sealant
1	1 and 18	Crafco Roadsaver 222	3.2- to 6.4-mm recess	Hot-applied rubberized asphalt sealant manufactured to meet requirements of FS SS-S-1401C
1	2 and 19	Crafco Roadsaver 222	Flush with the pavement surface and overband	
1	3 and 20	Crafco Roadsaver 222	3.2- to 6.4-mm recess and all joints were primed	
1	4 and 21	Crafco Improved Non-JFR	3.2- to 6.4-mm recess	Hot-applied rubberized asphalt sealant that has a lower modulus than FS SS-S-1401C sealants and improved low-temperature bond and adhesion properties
1	5 and 22	Crafco Improved Non-JFR	Flush with the pavement surface and overband	
1	6 and 23	Crafco Improved Non-JFR	3.2- to 6.4-mm recess and all joints were primed	
1	7 and 24	Crafco Silicone SL	Sealant installed according to manufacturer's guidance	Cold-applied, single-component, self-leveling silicone sealant manufactured to meet requirements of ASTM D5893 Type SL
1	8 and 16	Mobay Silicone 960	Sealant installed according to manufacturer's guidance	Cold-applied, single-component, non-sag silicone sealant (no longer available)
1	9 and 15	Mobay Silicone 960 SL	Sealant installed according to manufacturer's guidance	Cold-applied, single-component, self-leveling silicone sealant (no longer available)
1	10 and 17	Koch Product 9005	Sealant installed according to manufacturer's guidance; selected joints were primed	Hot-applied rubberized asphalt sealant manufactured to meet requirements of FS SS-S-1401C (no longer available)
1	11 and 14	Dow Corning 902 RCS	Sealant installed according to manufacturer's guidance	Two-component, self-leveling, cold-applied silicone sealant
1	12 and 13	Dow Corning 890 SL	Sealant installed according to manufacturer's guidance	Cold-applied, single-component, self-leveling, low-modulus silicone sealant that meets requirements of ASTM D5893 Type SL
2	1 and 6	Crafco Superseal 1614A	Sealant installed according to manufacturer's guidance	Hot-applied, polymer-modified, tar-based material manufactured to meet requirements of FS SS-S-1614A (no longer available)
2	2 and 7	Crafco Improved JFR	Sealant installed according to manufacturer's guidance	Hot-applied, polymer-modified, tar-based material that has a lower modulus than FS SS-S-1614A and improved low-temperature bond properties and improved long-term aging characteristics (no longer available)
2	3 and 9	Koch Product 9050 SL	Sealant installed according to manufacturer's guidance	Single-component, cold-applied, polysulfide-based material (no longer available)
2	4 and 10	Koch Product 9020	Sealant installed according to manufacturer's guidance	Two-component, cold-applied, polysulfide-based material manufactured to meet requirements of FS SS-S-200E (no longer available)
2	5 and 8	Koch Product 9012	Sealant installed according to manufacturer's guidance; selected joints were primed	Hot-applied, polymer-modified, tar-based material manufactured to meet requirements of FS SS-S-1614A and ASTM D3569 (no longer available)

were partly cloudy to sunny. To minimize impact on base operations, products that were no longer commercially available or that had exceeded their service life of 75% effectiveness (25% maximum failure) at the time of the 10-year evaluation were not evaluated. Three of the original eight non-JFR sealants installed in test Area 1 are no longer manufactured. The five non-JFR sealants that are still manufactured were evaluated at 250 months. Additionally, the September 2011 visual evaluation and 10-year results indicated that the use of primer did not influence sealant bubbling; therefore, these sections were also not evaluated. The following were evaluated:

Sections	*Sealant*	*Type*
1-1 and 1-18	Crafco Roadsaver 222	Recess
1-2 and 1-19	Crafco Roadsaver 222	Flush
1-4 and 1-21	Crafco Improved Non-JFR	Recess
1-5 and 1-22	Crafco Improved Non-JFR	Flush
1-7 and 1-24	Crafco Silicone SL	Recess
1-11 and 1-14	Dow Corning 902 RCS Silicone	Recess
1-12 and 1-13	Dow Corning 890 SL Silicone	Recess

Evaluation Procedures

Individual 7.6-m (25-ft)-long joint segments were identified as either transverse or longitudinal, with a number designation. Each section had six transverse joint segments labeled T1 through T6, and eight longitudinal joint segments labeled L1 through L8. During the evaluation, data for each individual joint segment were determined and recorded. The evaluation method followed the field evaluation observations procedures contained in the Standard Practice for NTPEP Evaluation of PCC Pavement Joint Sealant Material. Procedures were to

1. Inspect the test section to verify presence of correct material and joint segments to evaluate.
2. Lay out a 7.6-m (25-ft)-long tape measure along each joint section.
3. Inspect visually and probe the sealant with a thin dull knife to determine the length of failures where water will bypass the sealant through either complete adhesion or cohesion failure. Record the

TABLE 2 Summary of Field Performance at 58, 86, and 117 Months

Sealant	Installation Method[a]	Section Numbers[b]	58-Month Performance: Failure Types[c]	58-Month Performance: Average Total Failure[d] (%)	86-Month Performance: Failure Types[c]	86-Month Performance: Average Total Failure[d] (%)	117-Month Performance: Failure Types[c]	117-Month Performance: Average Total Failure[e] (%)
Crafco Roadsaver 222	Recess	1/1, 1/18	A	13	A	1	A	17
Crafco Roadsaver 222	Flush	1/2, 1/19	A	15	A	1	A	11
Crafco Roadsaver 222	Recess, primed	1/3, 1/20	A	8	A	1	A	15
Crafco Improved Non-JFR	Recess	1/4, 1/21	A	<1	A	<1	A	8
Crafco Improved Non-JFR	Flush	1/5, 1/22	A	<1	A	<1	A	8
Crafco Improved Non-JFR	Recess, primed	1/6, 1/23	A	6	A	3	A	33
Crafco Silicone SL	Recess	1/24, 1/7	A	<1	A	<1	A, S	16[f]
Koch Product 9005	Recess	1/10, 1/17	A	50	A	25	A	30
Mobay 960 SL	Recess	1/15, 1/9	A	10	A	1	A, C, S	23
Dow Corning 902 RCS	Recess	1/14, 1/11	A, C	<1	A, C	<1	A, S	14
Dow Corning 890 SL	Recess	1/13, 1/12	A, C	<1	A, C	<1	A, S	28
Mobay 960	Recess	1/16, 1/8	A	<1	A	<1	A, S	20
Crafco Superseal 1614A	Recess	2/1, 2/6	A, C	>50	A, C	75	A, C	100
Crafco Improved JFR	Recess	2/2, 2/7	A	<1	A	<1	A	22
Koch Product 9050 SL	Recess	2/3, 2/9	A, C	12	A, C	25	A, C	53
Koch Product 9012	Primed	2/5, 2/8	A, C	9	A, C	25	A, C	48
Koch Product 9020	Recess	2/4, 2/10	A	8	A	8	A	35

[a]Installation method refers to the final sealant configuration. Recess = sealant recessed 3 to 7 mm below the pavement surface; flush = sealant filled flush with the pavement surface with an overband; primed = all or some of the joints in the section were primed with a primer.
[b]Section numbers refer to the location of the sealant. For example, 1/1 refers to Area 1 (non-JFR area), section 1; 2/5 refers to Area 2 (JFR area) section 5, etc.
[c]Failure types: A = adhesion; C = cohesion; S = spalling.
[d]Some sealant material had been replaced by accident during a reseal project or as a result of slab replacement. The total length of the test section was reduced and the amount of failure is a percentage of the new length.
[e]Average total failure is the average amount of the sealant sections that would allow water to penetrate the joint.
[f]Some of the adhesion loss was a result of grinding and snowplow damage.

location and length of full-depth adhesion failures, cohesion failures, missing or damaged sealant, concrete spalling failures, and notes for each joint.

4. Calculate the percentage of joint length allowing water infiltration with the following equation:

$$\%L = \left(\frac{L_f}{L_{\text{tot}}}\right) \times 100\%$$

where

$\%L$ = percentage of length of joint allowing water infiltration,
L_f = length of joint allowing water infiltration, and
L_{tot} = total length of joint evaluated.

During compilation and analysis of the field data, it was determined that several adjustments should be considered in reporting the failure data. Some isolated areas of the test sections were damaged by wire snow broom and mechanical stripe removal operations, causing very obvious cutting damage to portions of the sealant. Additionally, there were isolated areas that had been subjected to fuel or oil exposure that affected sealant properties. These damaged and contaminated areas were recorded as damaged. Also, lengths of sealant were missing in some sections that had been cut out during previous evaluations for sampling and testing. These lengths were recorded as missing. According to the NTPEP procedure, lengths where joint edge spalling consisting of breaking, chipping, or fraying of the joint edges occurs are not to be counted as adhesion failures. Length and location of joint spalling were recorded, so that failure amounts could be calculated both with and without these failures. Considering these factors, it was decided to calculate three sets of failure results, labeled as overall, total, and net. Overall results include all recorded failures such as full-depth adhesion, cohesion, spalling, and damaged and missing lengths (this would be consistent with the 10-year evaluation). Total results exclude damaged and missing lengths from both failed length and evaluated length, and they give the best indication of overall sealant and joint surface performance. Net results exclude damaged and missing lengths, and spalling failures from both failed length and evaluated length, to give the best indication of sealant-only performance. Initially, failure amounts for each of the two test section replicates were to be determined and then averaged. However, during data analysis, it was noted that in some sections, the evaluated joint lengths were reduced significantly because of slab replacement. Some sections had as little as 30.5 m (100 ft) of sealant remaining, compared with the original 107 m (350 ft). Different lengths skewed results toward sections with lower lengths. To eliminate this situation, joint lengths and failures from both replicate sections were combined and calculated as a single set of results. Table 3 lists the total joint lengths evaluated and percentages of damaged, missing, and spalled, along with full-depth adhesion and cohesion failures. Overall, total, and net failure amounts for the 250-month evaluation are shown in Table 4.

Determinations of Sealant Life

Sealant life has been previously determined as the time when sealant failure reaches 25%, that is, 75% of the sealant length effectively

TABLE 3 Evaluation Results at 250 Months

Sealant	Installation	Sections	Evaluated Length (m)	Damaged (%)	Missing (%)	Spalled (%)	Cohesion (%)	Adhesion (%)
Crafco Roadsaver 222	Recess	1-1, 1-18	105	0.0	0.0	0.5	0.3	70.9
	Flush	1-2, 1-19	182	0.0	0.0	2.4	0.1	29.8
Crafco Improved Non-JFR	Recess	1-4, 1-21	180	3.4	0.1	2.3	0.0	49.0
	Flush	1-5, 1-22	194	2.8	0.0	3.1	0.1	9.4
Crafco Silicone SL	Recess	1-7, 1-24	149	3.0	3.0	12.4	0.1	4.2
Dow Corning 902 RCS	Recess	1-11, 1-14	157	8.5	1.4	13.2	0.6	14.0
Dow Corning 890 SL	Recess	1-12, 1-13	182	0.4	2.0	13.8	1.9	18.0

TABLE 4 Overall, Total, and Net Failure at 250 Months

Sealant	Installation	Sections	Failure Overall[a] (%)	Failure Total[b] (%)	Failure Net[c] (%)
Crafco Roadsaver 222	Recess	1-1, 1-18	71.7	71.70	71.5
	Flush	1-2, 1-19	32.3	32.3	30.6
Crafco Improved Non-JFR	Recess	1-4, 1-21	55.1	53.5	52.4
	Flush	1-5, 1-22	15.4	13.0	10.1
Crafco Silicone SL	Recess	1-7, 1-24	22.8	17.9	5.4
Dow Corning 902 RCS	Recess	1-11, 1-14	37.8	31.0	19.0
Dow Corning 890 SL	Recess	1-12, 1-13	36.1	34.5	23.8

[a]Overall failure includes all failures: spalling, missing, damaged, cohesion, and adhesion.
[b]Total failure excludes missing and damaged lengths.
[c]Net failure excludes missing, damaged, and spalling lengths.

prevents water intrusion (*6*). This criterion was used along with the total failure results in Table 4 to determine life of the sealants. If total failure at 250 months exceeded 25%, the time to reach 25% failure was estimated with linear interpolation between the 10- and 21-year results. Estimated sealant lives are shown in Table 5.

Evaluations of Sealant Property

The field elongation of the sealants was evaluated, and sections of sealant were removed for property testing in the laboratory. Table 6 shows results of field elongation tests performed at 250 months and the elongations obtained at 117 months. Table 7 shows properties of the hot-applied asphalt sealants removed from the test sections at 250 months, along with original properties when installed. Table 8 shows properties of silicone sealants removed from the pavement at 250 months, along with original properties when installed. Results in Table 8 were obtained from cured sealants from the test sections; exact sample preparation procedures could not be followed, and that may influence results.

TABLE 5 Estimated Sealant Life to 75% Effectiveness

Sealant	Installation	Life (years)
Crafco Roadsaver 222	Recess	11.4
	Flush	18.4
Crafco Improved Non-JFR	Recess	13.8
	Flush	>21
Crafco Silicone SL	Recess	>21
Dow Corning 902 RCS	Recess	16.9
Dow Corning 890 SL	Recess	10

SEALANT FIELD PERFORMANCE AND PROPERTIES

Crafco Roadsaver 222

Sealant Field Performance

In the standard recessed geometry, Roadsaver 222 exhibited total failure of 71.7% at 250 months. There was 0.5% joint spalling, and no missing or damaged sealant. Full-depth adhesion failure was

TABLE 6 Comparison of Field Sealant Elongations at 117 and 250 Months

Sealant	117 Months (%)	250 Months (%)
Crafco Roadsaver 222	300 C	150 C
Crafco Improved Non-JFR	600 C	300 C
Crafco Silicone SL	300 C	300 C
Dow Corning 902 RCS	600 C	1,000 A
Dow Corning 890 SL	600 A	600 C

NOTE: C = cohesive break; A = adhesion loss.
SOURCE: Field elongation procedure contained in Smith et al. (*6*).

TABLE 7 Properties of 21-Year-Old Field-Aged, Hot-Applied Sealants Compared with Original Results

	Crafco Roadsaver 222		Crafco Improved Non-JFR	
Property	Original[a]	250 Months[b]	Original	250 Months
Cone penetration, 25°C (77°F)[c] (mm)	7.8	4.0	12.7	7.5
Flow, 60°C (140°F) (mm)	0.5	0.0	0.0	0.0
Resilience, 25°C (77°F) (mm)				
Unaged (%)	73	53	73	57
Aged (%)	64	NT	67	NT
Bond, −29°C (−20°F), 50%	Pass 3	Fail 1	NT	Pass 3
Bond, −29°C (−20°F), 100%	NT	NT	NT	Pass 3
Bond, −29°C (−20°F), 200%	NT	NT	Pass 3	Pass 2
Bond, −7°C (20°F), 50%	NT	Fail 1	NT	NT
Static adhesion	NT	NT	Pass	Pass
Compatibility	Pass	Pass	Pass	Pass
Brookfield viscosity, 204°C (400°F) (cp)	NT	2,100	NT	2,000
Ring and ball softening point (°C)	NT	95.5	NT	96

NOTE: NT = not tested.
[a]Original results from Lynch et al. (*2*).
[b]250-month results obtained from melting samples of sealant removed from the joints.
[c]Test procedures contained in Lynch et al. (*1*).

70.9%, and cohesive failure was 0.3%. The flush-fill configuration exhibited total failure of 32.3% at 250 months. There was no missing or damaged sealant, 2.4% spalled joints, 0.1% cohesive failure, and 29.8% full-depth adhesive failure. Sealant life based on 25% failure was estimated to be 11.4 years with recess fill and 18.4 years with flush-fill. Flush-fill installation geometry resulted in a 61% increase in estimated sealant life compared with the recess fill. Throughout the test sections, there was a significant amount of partial-depth adhesion failure, up to approximately 12 mm (0.5 in.) deep. Some sealant in the recessed sections was not recessed the required amount, that is, it was closer to a flush-fill application. These areas had less full-depth adhesion failure than where sealant was recessed as planned.

Sealant Properties

Field elongation was 150% at 250 months, compared with 300% at 10 years. During the 11-year period, the sealant aged and lost 50% field elongation. Laboratory test results in Table 7 show that the 21 years of field aging produced a decrease in penetration from 7.8 mm to 4.0 mm (49%), resilience decreased from 73% to 53% (27%), and the sealant did not pass the original bond test at −29°C (−20°F). Additionally, bond testing was attempted at −7°C (20°F) using 50% extension, and the sealant did not pass. Flow test results at 60°C (140°F) showed 0.0 mm compared with the original 0.5 mm, indicating less flow at high temperatures. The sealant softening point was 95.5°C (204°F), which meets requirements of ASTM D6690 of an 80°C (176°F) minimum. Sealant viscosity at application temperature 204°C (400°F) is 2,100 cp, indicating easily pourable application characteristics. The sealant surface exhibited bubbling in both flush-fill and recess installation configurations. Aging or oxidation at the sealant surface was higher than the inside portions of the samples, as indicated by hardness of the material.

Crafco Improved Non-JFR

Sealant Field Performance

In the standard recessed geometry, total failure was determined to be 53.5% at 250 months. There was 2.3% joint spalling, no cohesive failure, and 3.4% missing and damaged sealant. Primary failure

TABLE 8 Properties of 21-Year-Old Field-Aged Silicone Sealants Compared with Original Results

	Crafco Silicone SL		Dow Corning 902 RCS		Dow Corning 890 SL	
Property	Original[a]	250 Months[b]	Original	250 Months	Original	250 Months
Elongation[c] (%)	825	450	NT	1,000	1,600	980
Shore hardness 00	63	70	NT	55	50	40

[a]Original results from Lynch et al. (*2*).
[b]Test results at 250 months determined on cut and trimmed samples removed from project joints.
[c]Test procedures contained in Lynch et al. (*2*).

was full-depth adhesion loss at 49.0%. In flush-fill geometry, total failure was 13.0% at 250 months, with 3.1% spalling, 2.8% missing and damaged sealant, 9.4% full-depth adhesion loss, and 0.1% cohesive failure. Sealant life in the recessed configuration was estimated to be 13.8 years, and greater than 21 years for flush-fill geometry. Flush-fill geometry exhibited greater than a 52% increase in estimated sealant life versus recessed geometry. There was a significant amount of partial-depth adhesion failure in the sections, measuring up to approximately 12 mm (0.5 in.) deep. The primary mode of failure for this sealant was adhesion loss. In flush-filled sections, there were fewer partial-depth adhesion failures than in recessed sections. The sealant is showing improved performance compared with the standard FS-SS-S-1401C sealants installed on the project.

Sealant Properties

Field elongation at 250 months was 300% compared with 600% at 10 years, a 50% loss of elongation over the 11-year period. Laboratory test results show that the 21 years of field aging decreased the penetration from 12.7 mm to 7.5 mm (41%) and decreased resilience from 73% to 57% (22%). The sealant passed two cycles of the original 200% extension bond test at −29°C (−20°F) and three cycles when tested at 100% extension at −29°C (−20°F). Bond results indicate that the sealant had aged some and was not as extensible at low temperature as when originally installed, but it was still capable of high extension at low temperature. Flow testing at 60°C (140°F) showed the same 0.0 mm result as did the original sealant. The sealant softening point was 96.1°C (205°F), which meets ASTM D6690 requirements of an 80°C (176°F) minimum. Viscosity at the application temperature of 204°C (400°F) was 2,000 cp, which indicates easily pourable application characteristics. The sealant surface exhibited bubbling in both recess and flush-installation configurations. The sealant surface was aged and harder than the inside portions were. The sealant has remained elastic and resilient. The improved non-JFR specification developed during the project requires bond performance evaluation of 200% extension at −29°C (−20°F), compared with the standard requirement of 50% at the same temperature, thus producing sealant with increased low temperature elongation properties. Sealants meeting the improved non-JFR specification are used by several state agencies in colder climates, and ASTM has incorporated this type of sealant into the D6690 Type IV specification. Figure 1 shows the 21-year-old sealant in the flush-fill installation.

Crafco Silicone SL

Sealant Field Performance

This sealant exhibited 17.9% total failure at 250 months, compared with 16% at 10 years. There was 12.4% joint spalling, 3.0% missing sealant, 3.0% damaged sealant, 0.1% cohesion loss, and 4.2% full-depth adhesion loss. The 10-year data included the mechanically damaged sealant lengths. Adding back in the damaged lengths produces a failure amount at 250 months of 20.2% for best comparison to the 10 year results. Using total results, which includes spalling, sealant life is estimated to be greater than 21 years. The primary failure mode was spalling of the concrete joints, resulting in edge separations. Some partial-depth adhesion loss up to approximately 3 mm (⅛ in.) deep was noted.

FIGURE 1 Sample of 21-year-old Crafco Improved Non-JFR sealant.

Sealant Properties

The field elongation testing result was 300% at 250 months, the same as at 10 years. The sealant did not experience loss of field elongation in the last 11 years. The sealant had a smooth surface and remains elastic and resilient. Laboratory test results in Table 8 show that the 21 years of field aging produced an elongation of 450%, a decrease of 45% from original results. Shore 00 hardness increased from 63 to 70. Results indicate that the sealant lost some extension during the first 10 years, and it has since retained similar extensibility over the last 11 years. The sealant remains flexible and extensible. Figure 2 shows a view of the 21-year-old sealant.

Dow Corning 902 RCS

Sealant Field Performance

The total failure at 250 months was 31.0%, compared with 14% at 10 years. There was 13.2% joint spalling, 1.4% missing sealant, 8.5% damaged sealant, 0.6% cohesion failure, and 14.0% full-depth adhesion failure. The primary failure modes were spalling and full-depth adhesion loss. Some partial-depth adhesion loss was present

FIGURE 2 Sample of 21-year-old Crafco Silicone SL sealant.

to a depth of approximately 3 mm (⅛ in.) deep. Sealant life is estimated to be 16.9 years. There was some cohesive failure in the sealant, primarily where the sealant was installed too thin over the backer rod. This was also noted in the 10-year evaluation.

Sealant Properties

The field elongation test result was 1,000%, compared with 600% at 10 years. Laboratory test results for the 21-year-aged sealant show an elongation of 1,000%, with no original results for comparison. Shore 00 hardness was 55, with no original results for comparison. Since original test results were not available, it is not known to what degree the sealant properties may have changed over time. The sealant had a slightly wrinkled appearing surface and had remained elastic and extensible over 21 years.

Dow Corning 890 SL

Sealant Field Performance

This sealant exhibited 34.5% total failure at 250 months, compared with 28% at 10 years. There was 13.8% joint spalling, 2.0% missing sealant, 0.4% damaged sealant, 1.9% cohesive failure, and 18.0% full-depth adhesion failure. Sealant life was previously reported to be 10 years. The main failure types were spalling and adhesion loss. A small amount of cohesive splitting occurred where the sealant was installed too thin. Partial-depth adhesion failures up to 3 mm (⅛ in.) deep were present.

Sealant Properties

The field elongation test result was 600%, which is the same as the 10-year result, indicating that the sealant did not experience loss of elongation properties in the last 11 years. Laboratory test results for the 21-year-aged sealant showed elongation of 980% compared with the original 1,600%, a 43% decrease. Shore 00 hardness was 40 compared with the original reported 50, indicating some softening of the sealant. Results indicate that the sealant lost some elongation during the first 10 years, and it had retained similar extensibility over the last 11 years. The sealant had a wrinkled appearing surface and remained flexible and extensible. Figure 3 shows a view of the 21-year-old sealant.

FIGURE 3 Sample of 21-year-old Dow Corning 890 SL sealant.

CONCLUSIONS

Field performance and laboratory evaluations performed during this project and subsequent evaluations over 21 years led to several conclusions about joint sealant life, installation, and sealant properties:

1. A silicone sealant and a low-modulus, hot-applied asphalt sealant installed with flush-fill geometry exhibited a performance life greater than 21 years on this project.
2. With the hot-applied asphalt sealants, flush-fill installation geometry produced greater than a 50% increase in sealant life compared with the standard recess fill.
3. Sealant life for hot-applied asphalt sealants is influenced by both sealant properties and installation configuration. For sealants on the project, installation configuration seems to have had a greater long-term effect on sealant life than did sealant properties.
4. The improved non-JFR sealant developed and evaluated during this project exhibited a longer lifespan than did sealants manufactured to the requirements of FS-SS-S-1401C.
5. Silicone sealants produced six times more joint spalling than did hot-applied asphalt sealants.
6. Hot-applied asphalt sealants aged to a greater degree than did silicone sealants.
7. There does not seem to be a correlation between silicone sealant extension ranging from 450% to 1,000% and silicone sealant life.

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REFERENCES

1. Lynch, L. N., D. W. White, and J. Chehovits. *Improved Materials and Processes for Sealing and Resealing Joints in Portland Cement Concrete Pavements—Laboratory Evaluation.* Technical report CPAR-GL-93-1. U.S. Army Engineer Waterways Experiment Station, Vicksburg, Miss., 1993.
2. Lynch, L. N., D. W. White, and J. Chehovits. *Improved Materials and Processes for Sealing and Resealing Joints in Portland Cement Concrete Pavements—Field Evaluation.* Technical report CPAR-GL-93-2. U.S. Army Engineer Waterways Experiment Station, Vicksburg, Miss., 1993.
3. Lynch, L. N., J. G. Chehovits, and L. A. Erickson. A Five Year Field Performance of Joint Sealants at Fairchild Air Force Base. *Proc., Pavement Crack and Joint Sealers for Rigid and Flexible Pavements Conference,* Vicksburg, Miss., U.S. Army Corps of Engineers, Vicksburg, Miss., 1997, pp. 87–107.
4. Lynch, L. N., J. G. Chehovits, and D. G. Luders. Ten-Year Field Performance Review of Joint Resealing Project. In *Transportation Research Record: Journal of the Transportation Research Board, No. 1795,* Transportation Research Board of the National Academies, Washington, D.C., 2002, pp. 40–48.
5. LTPPBIND Version 2.1. Turner–Fairbank Highway Research Center, FHWA, U.S. Department of Transportation, 1998.
6. Smith, K. L., M. A. Pozsgay, L. D. Evans, and A. R. Romine. *LTPP Pavement Maintenance Materials: SHRP Joint Reseal Experiment.* Final report. FHWA-RD-99-142. FHWA, U.S. Department of Transportation, 1999.

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