Joint Sealant Field Performance – Ten Year Evaluation

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ABSTRACT

In 1989, the US Army Engineer Research and Development Center and Crafco, Incorporated initiated a research effort to develop improved materials and processes for sealing and resealing joints in Portland cement concrete (PCC) pavements. The objectives of the research were to develop specification limits for improved field performance of hot-applied, jet-fuel-resistant (JFR) and non-jet-fuel-resistant (non-JFR) sealants and obtain field data to determine the field performance of different sealants and installation configurations.

The research effort was divided into two phases, a laboratory and a field phase. The laboratory phase focused on identifying ideal properties that a hot-applied non-JFR and hot-applied JFR sealant should possess, evaluating commercially available sealants to determine if they exhibited those properties, and developing improved hot-applied materials that would exhibit as many of those properties as feasible.

The field phase was initiated in June 1991 at Fairchild Air Force Base near Spokane, WA. The focus of this effort was to determine the field performance of field molded sealants (including improved materials versus commercially available sealants), and if field performance could be improved by changing the sealant installation geometry. Thirteen different field-molded sealants were installed and their field performance monitored at different times over a 10-year period. The evaluations indicated that two of the hot-applied, asphalt-based sealants, four of the silicone-based sealants, and one of the coal tar-based sealants had live expectancies of greater than 10 years. The improved JFR and non-JFR sealants exhibited better field performance than the standard hot-applied sealants included in the evaluation.

INTRODUCTION

In 1989, the Geotechnical and Structures Laboratory, U.S. Army Engineer Research and Development Center, and Crafco Incorporated initiated a research investigation under the auspices of the Construction Productivity Advancement Research (CPAR) program. The objectives or the research program were:

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 that would minimize the bubbling tendencies associated with hot-applied sealants and improve the sealant's adhesion to Portland cement concrete (PCC).
3. Develop field data to determine realistic field performance of different sealant types and application methods (flush-fill versus recessed application of 3.2 mm (1/8 in) to 6.4 mm (1/4 in)).

A two-phase research program was conducted to accomplish the objectives. Phase I was a laboratory investigation [1] that focused on improving the performance characteristics of hot-applied pavement joint sealants. Phase II was the field evaluation [2] to validate the findings of the laboratory investigation.

Summary of the Laboratory Investigation

A summary of the laboratory phase is presented here for completeness. The laboratory study was used to identify the ideal properties of hot-applied sealants, evaluate commercially available sealants to determine specification conformance, and to determine to what level they exhibit the properties identified as "ideal." Laboratory formulation studies were also conducted to develop sealants that would exhibit more of the ideal properties than the commercially available sealants. The conclusions concerning the commercially available hot-applied JFR sealants used in the laboratory study included [1]:

1. They conformed to the requirements of Federal Specification SS-S-1614A [3] (the specification used by the Department of Defense for sealants that will be used in fuel spillage areas).
2. They were capable of passing low temperature bond testing at -18^{o}C (0^{o}F) but not at -29^{o}C (-20^{o}F) indicating that they stiffen with a decrease in temperature.
3. They exhibited significant surface hardening when subjected to forced-draft oven aging at 70^{o}C (158^{o}C) similar to the hardening exhibited by sealants in the field.
4. They had lower values of flow than the Federal Specification SS-S-1614A requirement, i.e., the maximum specification value was much higher than the sealants exhibited.
5. The physical properties of the sealants changed with length of time exposed to heating, i.e., the sealants become more brittle and could exhibit premature failure as a result of prolonged heating.
6. The laboratory development work revealed that it was possible to produce hot-applied JFR sealants that exhibited better low temperature and aging properties than the current Federal Specification SS-S-1614A sealants as indicated by laboratory testing.
7. Specification limits for an improved hot-applied JFR sealant were developed and a trial production batch was produced for use in the field evaluation. Specification details are found in reference 1.

The conclusions concerning the hot-applied non-JFR sealants included the following:

1. Materials manufactured to meet the specification requirements of Federal Specification SS-S-1401C [4] were not capable of passing bond testing at 200 percent extension at -29^{o}C (-20^{o}C) while "low-modulus" ASTM D3405 [5] type materials were capable of passing this bond testing.
2. The flow and resilience properties of the "low-modulus" or "improved" sealant were similar to the Federal Specification SS-S-1401C materials, but the sealants did exhibit different adhesion and modulus characteristics.
3. The physical properties of the sealants did change with varying heating times again indicating that sealants could become brittle and prematurely fail if improperly heated.
4. Specification limits for an improved hot-applied non-JFR sealant were developed and a trial production batch was produced for use in the field evaluation. Specification details are found in reference 1.

Field Section Layout, Joint Preparation, and Sealant Installation

Fairchild Air Force Base (AFB), Spokane, Washington was selected as the field evaluation site. 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. Conversely, the average daily temperature during August is approximately 21°C (70°F) with the average high being 29°C (84°F). Extreme high temperatures of up to 42°C (108°F) have been recorded which ensured the high temperature characteristics of the sealants would also be evaluated. The sealants used for the field evaluation included those from the laboratory investigation and several commercially available sealants. The materials installed during the field investigation are listed in Table 1.

The field test section was divided into two areas. The non-JFR sealants were installed in Area 1 and the 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. Since the initial installation, the usage 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 currently not in use. The sealants in both areas were exposed to limited traffic during the 10-year period; therefore, environmental effects were the predominant means of deterioration or degradation.

The concrete slabs in the test areas were 7.6 m (25 ft) by 7.6 m (25 ft) by 40.6 cm (16 in) and were doweled. At the time of sealant installation, the slabs were approximately 35 years old. Most joints contained old sealant that had experienced significant adhesion failure. The age of the existing sealant was not known. Two replicates or sections of each sealant and application configuration were installed with 107 linear m (350 linear ft) of sealant in each section. The section numbers and application variables are included in Table 1.

The existing sealant was removed using a water-cooled concrete saw. The resurfaced joints were approximately 19 mm (3/4 in) wide and sufficiently deep to accept a backer rod material and maintain the appropriate shape factor for the sealant. The joints were flushed using high-pressure water equipment to remove the debris left by the sawing operation. Once the joints had dried, they were sandblasted and then cleaned using compressed air. Any joint that was not sealed the same day it was sandblasted was re-cleaned using compressed air just prior to sealing. Additional details on joint preparation, existing pavement conditions, and sealant installation can be found in reference 2.

FIELD PERFORMANCE EVALUATIONS

Field performance evaluations were conducted over a 10-year period. The evaluations were conducted at six, 12, 22, 58, 86, and 117 months. The evaluations were conducted by visually inspecting the sealant in each joint for adhesion and cohesion failures, fuel damage, debris retention, bubbling, and surface cracking. The amount of defect for the section was measured and reported as a percent defect. The percent defect was subdivided into five categories:

1. 0 percent – no failure
2. 1 to 10 percent – few failures
3. 11 to 50 percent – frequent failures
4. 51 to 99 percent – extensive failures
5. 100 percent – complete failure

Initially, each of the type of defect was noted as a percentage and listed as no, few, frequent, etc. In subsequent evaluations, the criteria were changed such that full depth failures, adhesive and cohesive, were combined into a single defect. This change was made to reflect the fact that realistically it does not matter to users if the sealant has adhesion or cohesion, the sealant is not performing as designed.

Six-Month Evaluation

The six-month evaluation was conducted on January 22, 1992. During the survey, ambient temperature ranged from -4°C to 2°C (25°F to 35°F). The overall performance of the sealants after six months was very good. The most common defect noted in the non-JFR and JFR hot-applied materials was bubbling. Many of the hot-applied sealants had experienced surface bubbling during installation and the bubbling appeared to increase in size and quantity during the initial six months. A small amount of adhesion failure (less than one percent) was noted in some sealants. Additionally, some of the adhesive failures in the “flush-fill” geometry sealants appeared to have been caused by snow plowing.

12-Month Evaluation.

The 12-month evaluation was conducted on July 27, 1992 with temperatures ranging from 20°C to 24°C (68°F to 75°F). As in the six-month survey, the primary defect noted was bubbling in the non-JFR and JFR hot-applied sealants. There was a significant amount of bubbling in the hot-applied sealants but it did not appear to adversely impact the performance of the sealant.

Overall, adhesion failures had increased slightly between the six-month and 12-month evaluations but they still averaged less than one percent. Many of the adhesion failures appeared to initiate in areas where old joint sealant had not been removed during joint preparation. Minor partial depth adhesion loss was noted in many of the hot-applied sealants. The hot-applied sealants were beginning to peel away from the joint face to a depth of approximately 1.6 mm (1/16 in) to 3.2 mm (1/8 in). These areas were not classified as adhesion failures because the failures were not full depth.

All of the sealants were performing satisfactorily at the 12-month evaluation. However, the cold-applied, single- and two-component sealants appeared to be performing better than the hot-applied sealants.

22-Month Evaluation

The 22-month evaluation was conducted on March 25, 1993 with temperatures ranging from 10°C to 13°C (50°F to 55°F). During this evaluation, some differences in sealants began to be noticed. The overall condition of the non-JFR sealants in Area 1 appeared to be similar to the 12-month evaluation. There was still a significant amount of bubbling but it did not appear to have worsened from the previous evaluation. The hot-applied sealants continued to exhibited partial depth adhesive loss. The Mobay 960SL material also exhibited partial depth adhesive loss. The other silicone sealants did not exhibit any adhesive, cohesive, or spalling defects.

In Area 2, the Crafco Superseal 1614A sealant exhibited significant amounts of adhesive and cohesive failures. The sealant appeared to be hardening from the top and bottom surfaces of the sealant. The other JFR sealants were performing satisfactorily with limited or no adhesive or cohesive defects.

58-Month Evaluation

The 58-month evaluation was conducted on April 12, 1996. Temperatures ranged from 4°C to 7°C (40°F to 45°F) during the evaluation. During this evaluation, significant differences began to become apparent. There were two sealants, Crafco Superseal 1614A and Koch Product 9005, which had greater than 50 percent adhesion loss. On government projects, 25 to 50 percent adhesion or cohesion loss would be considered failure, i.e., the sealant should be replaced. The silicone materials and the “improved” JFR and non-JFR materials appeared to be performing the best at 58 months, but in general, the overall performance of the sealants remain satisfactory. Table 2 provides the 58-month evaluation summary for the sealants.

86-Month Evaluation

The 86-month evaluation was completed on August 2, 1998 with temperatures ranging from 21°C to 27°C (70°F to 80°F). There seemed to be a decrease in the amount of adhesive failure in the hot-applied sealants except for the Crafco Superseal 1614A, Koch Product 9012, and Koch Product 9050SL. These materials exhibited an increase in adhesion loss. The most probable reason for the apparent improvement or decrease in adhesion loss of the hot-applied sealants is the ambient temperature. This was the first time since the 12-month evaluation that the evaluation was conducted during the summer. Ambient temperatures were higher than during the previous evaluations, the joints were narrower, and the sealants were softer. This could have created a “healing effect” of the sealants. Also, the sealant could have begun to degrade, reverting back to a liquid state, which would have given the appearance of healing due to softening of the thermoplastic, hot applied sealants. For example, the average failure noted for Roadsaver 222 decreased from 12 percent to 1 percent and Koch Product 9005 decreased from 50 percent to 25 percent. The silicone sealants continued to exhibit less than 1 percent failures, including Mobay 960 SL, which decreased from 10 percent to 1 percent. The improved JFR and non-JFR sealants were performing well with less than 1 percent failures. At this evaluation, four sealants had reached 25 percent failure – Crafco Superseal 1614A, Koch Product 9005, Koch Product 9050 SL, and Koch Product 9012. Using the 25 to 50 percent reseal “rule,” these materials should be replaced. Table 3 provides the 86-month evaluation summary for the sealants.

117-Month Evaluation

The 117-month evaluation was conducted on March 26, 2001 with temperatures ranging from 4°C to 7°C (39°F to 45°F). During this evaluation, it was noticed that several of the slabs in and around Area 1 had been replaced and the joints surrounding the test sections had been resealed. Some of the test section sealants had been removed as a result of these activities. The sealant that had been replaced was subtracted from the individual test sections and was not included in the percent failure calculations. For example, the original test section for each sealant was 107 linear meters. In Area 1, Section 1, approximately 30 linear meters of sealant had been replaced. Therefore, the total linear meters of sealant used for the percentage failure calculations for that section was 77 linear meters. Some sealants had become damaged by pavement marking removal and by snow plowing. Even though the failure was mechanically induced, it was included in the failure. The reason the mechanically induced failure was included in the total is because it is one that resulted from normal pavement maintenance activities and the sealant would need to be replaced. Table 4 provides the 117-month evaluation summary.

The field performance evaluation indicated that the Crafco Improved Non-JFR sealant was the only sealant that was rated as “Few” failures (less than 11 percent). This sealant had an average of 8 percent failures in the recessed and the flush fill configurations. Thirteen of the sealants were rated as having “Frequent” failures (11 to 50 percent). One sealant, Koch Product 950SL, was rated as having “Extensive” failures (greater than 50 percent) and one sealant, Crafco Superseal 1614, had 100 percent failure.

Within the “Frequent” failures or defects group, five of the sealants/configurations were borderline. On the low end or almost in the “Few” category was the Crafco Roadsaver 222 flush fill (11 percent), Dow Corning 902 RCS (14 percent), Crafco Roadsaver 222 with primed joints (15 percent), and the Crafco Silicone SL sealant (16 percent or 13 percent if the mechanical damage was omitted). On the upper end or close to the “Extensive” category was Koch Product 9012 with a rating of 48 percent. The remaining sealants in this category had loss ratings that ranged from 17 percent to 35 percent (Crafco Roadsaver 222 recessed – 17 percent, Mobay 960 non-sag – 20 percent, Mobay 960 SL – 23 percent, Crafco Improved JFR – 22 percent, Dow 890SL – 28 percent, Crafco Improved non-JFR (primed joints with sealant recessed) – 33 percent, Koch Product 9005 – 30 percent, and Koch Product 9020 – 35 percent).

Comparing the sealant configurations (flush fill with small over band versus recessed) indicated that the flush fill geometry performed slightly better with an average 10 percent failure versus 13 percent for the recessed configuration. These results appear to be more of a function of the sealant than the geometry since the Improved non-JFR sealant exhibited the same performance in both configurations.

Separating the sealants into generic categories idicated that on average the silicone materials and the asphalt-based materials performed similarly at 20 percent versus 18 percent respectively. For this comparison, only the Crafco Roadsaver 222 and Crafco Improved non-JFR in the recessed configuration were included in the asphalt-based sealant average because that it the geometry recommended on military projects. If the other geometry sections are included, the asphalt-based average decreases to 15 percent. The coal tar-based and polysulfide-based materials performed significantly worse with ratings of 57 percent and 44 percent failures respectively. There was a wide variability of results within the coal tar-based sealants with the Crafco Improved JFR sealant performing significantly better than the other JFR materials.

Elongation tests were conducted during the 117-month evaluation in addition to the adhesive and cohesive loss measurements. Table 5 provides a summary of the elongation results. The elongation test was conducted by cutting along both joint faces to create a section of sealant that was approximately 76 mm long. A 25.4 mm section was then marked on the sealant and the sealant was pulled perpendicular to the pavement surface until it broke or began to loss adhesion. The amount of elongation of the 25.4 mm section was measured. Figure 1 provides an illustration of an elongation test being conducted.

Typically, it would be expected that sealants that exhibit higher elongations would also exhibit better field performance and those that had lower elongations would exhibit poorer performance. If one sealant can be stretched longer than another then it should be able to better withstand joint movements. For example, the Mobay 960 non-sag material exhibited an overall failure of approximately 20 percent as compared to the Crafco Improved JFR material that exhibited an overall failure of approximately 22 percent. One could realistically expect that the amount of elongation for these two materials would be similar, but they are not (50 percent elongation and 250 percent respectively). The elongation for the Koch Product 9005 could not be measured because the material was gooey or putty-like. The gooey consistency indicates that the sealant has degraded. This degradation could also explain why the sealant had a high percentage of recorded failure at the 58-month evaluation and then seem to improve during the later evaluations. The polymers in the material began to degrade and the sealant flowed back onto the joint faces.

Elongation is a function of modulus and modulus is a function of the material, rate of loading, and temperature. The impact of material is demonstrated by comparing silicone and asphalt-based or coal tar-based sealants. The modulus and elongation properties of silicone-based sealants are very stable over a wide temperature range, while, modulus and elongation of asphalt- or tar-based, hot-applied sealants are highly affected by temperature changes and rate of loading. The values collected during this evaluation can provide an indication of how the individual sealants have changed over time, but a complete curve of elongation versus temperature would be required to help determine how the performance is impacted. The elongation values will be helpful in future performance evaluations of the sealants

Perhaps one of the most interesting findings from this limited study is the fact that the asphalt-based sealants appear to be performing as well as the silicone-based sealants. There are several issues that may have skewed the results; the amount of sealant that had been replaced by removing slabs and resealing, the use of only the asphalt-based materials installed in the recessed geometry were used in the comparisons, the fact that the area is routinely swept so that debris retention is not a problem, and the minimum volume of traffic on the pavement sections.

Considering the issues listed above, the ones that can be evaluated with the available data are the first two. Adding or deleting questionable test sections addresses the first two issues. The results of this did not change the results by more than one or two percentage points. Therefore it can be stated that given the conditions of these test section with respect to joint preparation, joint size, age of concrete, climate, and traffic volume, that in general, the asphalt-based sealants performed as well as the silicone-based materials.

Although the overall performance rating was similar, the two different types of sealant did exhibit different failure modes. The primary mode of failure associated with the asphalt-based sealant sections was adhesive loss. The sealant lost bond with the concrete joint face thus allowing water to penetrate the pavement structure as shown in Figure 2. The primary failure mode associated with the silicone-based sealant sections was also adhesive loss. However, the failure was not a true adhesive loss, instead the sealant appeared to create spalling of the concrete as shown in Figure 3. Based on these two failure modes, it would appear for this application that the asphalt-based materials would be more desirable because the silicone materials appear to be pulling the concrete apart.

INDIVIDUAL SEALANT PERFORMANCE RESULTS

During the 10-year service life of the sealants installed at Fairchild AFB, all of the products experienced various types of failures and decreases in performance. Also, during this time period, five of the thirteen sealants have been discontinued, and the two experimental sealants have become commercially available.

A value of 75 percent effectiveness (25 percent failure) has been used in recent sealant field performance studies to indicate the effective life of sealant material [5,6]. This criterion is used to indicate life of sealants for this project. Following are discussions of the condition of sealants, life expectancy, and effects of installation conditions and other factors on performance.

Crafco Roadsaver 222

In the standard recessed geometry, Roadsaver 222 exhibited 13 percent failure at 5 years, and 17 percent at ten years. The flush fill/overband configuration showed slightly improved performance with failures of 15 percent at 5 years, and 11 percent at ten years. Throughout the evaluation period, the sealant developed partial depth adhesion loss that ranged up to approximately 6 mm (1/4 in) deep. It was noted that less partial depth adhesion loss developed in the flush filled joints than in the recessed joints. Bubbling formed in the sealant during installation. It did not appear that bubbling reduced sealant performance with the sealant remaining elastic and resilient at 10 years. Elongation was 300 percent with the sealant remaining adhered to the joint sidewall at break. This material is performing satisfactorily at 10 years.

Crafco Improved Non-JFR

This sealant showed the lowest average failure level of all products in the project. In the standard recessed configuration, failure was less than 1 percent at 5 years, and 8 percent at 10 years. The flush fill/overband configuration showed the same average results. The primed joints; however, did not perform as well with 6 percent failure at 5 years and 33 percent at 10 years. Bubbles formed during installation of this sealant, and they did not appear to reduce performance.

The sealant has remained elastic and resilient. Elongation was 600 percent with a cohesive break during the test indicating that the sealant was adhering well to the joint. The primary mode of failure for this sealant was adhesion loss. No cohesive failures or joint spalling developed during the evaluation period. Partial depth adhesion loss was present with lesser amounts in the flush filled sections versus the recessed sections. Life expectancy of this sealant at this project is greater than 10 years. The sealant is showing improved performance compared to the other FS SS-S-1401C sealants installed on the project.

The improved non-JFR specification developed during the project requires bond performance evaluation of 200 percent extension at -29C (-20F), compared to the standard requirement of 50 percent at the same temperature, thus producing sealant with increased low temperature elongation properties. These improved properties are resulting in better sealant performance. Sealants meeting the improved non-JFR specification are now available and are being used by several state agencies, and ASTM is incorporated this type of sealant into a specification.

Crafco Silicone SL

This sealant showed less than 1 percent failure at 5 years and an average of 16 percent at 10 years. The primary failure mode was spalling of the concrete joints resulting in edge separations. No cohesive failures (except where mechanically abraded) were observed. Some partial depth adhesion loss was noted. Elongation testing produced a result of 300 percent with the sealant remaining adhered to the joint sidewall at break. The sealant remained elastic and resilient. This sealant is performing very well after 10 years of service.

Koch Product 9005

The Koch Product 9005 exhibited 50 percent failure at 5 years, and 30 percent at 10 years. At first look, this seems somewhat contradictory; however, failures were rated at 25 percent at 86 months. This sealant experienced loss of elastic properties as it aged and appeared to re-heal at warmer temperatures, thus causing a fluctuation in reported failure levels. The primary failure mode was adhesion loss. Partial depth adhesion loss was present to depths of up to 6 mm (1/4 in) deep. No cohesive splits were observed. Bubbling was present in the sealant, but it did not appear to reduce performance. When installed, the sealant was elastic and resilient; however, after 10 years of aging, it had a putty-like consistency in the joint. Life expectancy of this sealant at this project was approximately 3 to 4 years.

Mobay 960 SL

This silicone sealant had 10 percent failure at 5 years and 23 percent at 10 years. The primary failure type present was joint spalling with some adhesion loss. In several areas, cohesive splits were present. Partial depth adhesion loss up to 3mm (1/8 in) deep was present throughout. The sealant was elastic and resilient, but had an elongation of 50 percent to break while remaining adhered to the joint sidewall. This was the lowest field elongation of the silicone sealants tested Life expectancy of this sealant is approximately 10 years at this project.

Dow Corning 902 RCS

This sealant exhibited 2 percent failure at 5 years, and 14 percent at 10 years. The primary failure type was joint spalling, as it was with the other silicones. A small amount of cohesive splitting was observed where the sealant was installed too thin on top of the backer rod. Partial depth adhesion loss up to 3mm (1/8 in) deep was present. The sealant was elastic and resilient with an elongation of 600 percent while remaining adhered to the joint sidewall at break. Expected life at this project is greater than 10 years.

Dow Corning 890 SL

Failures at 5 years averaged 1 percent and increased to 28 percent at 10 years. The main failure type was spalling and related adhesive separations. A small amount of cohesive splitting occurred where sealant was installed too thin. Partial depth adhesion failures up to 3mm (1/8 in) deep were present. The sealant was elastic and resilient. The field elongation test yielded a result of 600 percent with loss of adhesion to the joint sidewall when that elongation was reached. Expected life at this project is approximately 10 years.

Mobay 960

This sealant had 1 percent failure at 5 years and 20 percent at 10 years. As with the other silicones, the main failure types were spalling and related adhesion loss. No cohesive loss was present. Partial depth adhesion loss up to 3 mm (1/8 in) deep was present. The sealant was elastic and resilient, but along with the Mobay 960 SL had the lowest elongation (50 percent) of the silicone sealants. Life expectancy at this project is greater than 10 years.

Crafco Superseal 1614A

This sealant began showing approximately 30 percent adhesive and cohesive failures at the 22-month evaluation. Some bubbling formed during sealant installation. During subsequent evaluations, the observed failures increased to 50 percent at 5 years and 100 percent at 10 years. The small amount of sealant remaining in the joint was brittle with no elongation capabilities. Life expectancy at this project was approximately 2 years.

Crafco Improved JFR Sealant

At the 5-year evaluation, this sealant had less than 1 percent failure, and at 10 years, 22 percent failure. Primary failure type was adhesion loss. Some partial depth adhesion loss up to 3mm (1/8 in) in depth was noted. It remained elastic and resilient with an elongation of 250 percent. The sealant broke cohesively at that elongation. Minor bubbling that was present did not appear to decrease performance. The improvements in low temperature bond requirements and aging characteristics incorporated into the sealant specification developed during this project resulted in significantly improved performance as compared to typical SS-S-1614A specification type products. Life expectancy at this project was greater than 10 years, which was the best of the JFR materials, installed.

Koch Product 9050 SL

This sealant had 22 percent failure at 5 years, and 53 percent at 10 years. The sealant experienced both adhesion and cohesion failures. No bubbling was noted. Partial depth adhesion loss was also present up to 6 mm (1/4 in) deep. The sealant was stiff, but remained elastic and resilient. The surface of the sealant showed a cracking pattern throughout. Elongation result was 150 percent with the sealant remaining adhered to the joint sidewall at break. Life expectancy at this project was approximately 5 years.

Koch Product 9012

This sealant had 21 percent failure at 5 years and 48 percent at 10 years. The sealant exhibited adhesion and cohesion failures. Partial depth adhesion loss up to 3 mm (1/8 in) was present. Some bubbling formed during sealant installation. The sealant was stiff and slightly elastic. Elongation testing produced a result of 75 percent with the sealant remaining adhered to the joint sidewall at break. Life expectancy at this project was approximately 6 years.

Koch Product 9020

This sealant had 8 percent failure at 5 years and 35 percent at 10 years. Adhesive separations were the main failure type. No bubbling was observed. Partial depth adhesion loss was present ranging from 3 mm to 6mm (1/8 in to 1/4 in) deep. The sealant was stiff but remained elastic and resilient. Elongation was 200 percent with a cohesive break at that elongation. Life expectancy at this project was approximately 8 years.

CONCLUSIONS

The 10-year performance evaluation of the joint sealants has lead to several conclusions, some of which were not entirely expected. The conclusions are:

1. Sealant Life Expectancy – In both the JFR and non-JFR test sections, sealants were installed that produced life expectancies of greater than 10 years. In the non-JFR portion of the project two hot-applied asphalt based-sealants and 4 silicone-based sealants had life expectancies of greater than 10 years. In the JFR portion of the project, the hot-applied coal tar-based sealant that was developed during the lab phase was the only sealant to have a life expectancy of greater than 10 years.
2. Sealant Installation Configuration – The objective was to determine if a flush-fill geometry with a 25 to 50 mm overband would provide better field performance versus the traditional recess geometry. The answer appears to be material dependent if there is any benefit at all. Two sealants were used in this portion of the evaluation. The Crafco Roadsaver 222 in the flush-fill geometry did have fewer adhesive failures (approximately 5 percent) than the Crafco Roadsaver 222 in the recessed geometry. The Crafco Improved non-JFR sealant performed identically in both the flush-fill geometry and the recessed geometry. It should be noted that the overbanding used on both sealants was damaged early in the evaluations probably by snowplowing activities and that less partial depth adhesive loss was noted with the overband geometry.
3. Low-Modulus Hot-Applied Sealants – The hypothesis was that low-modulus hot-applied sealants would perform better in cold climates than the sealants currently required on military projects, i.e., those manufactured to meet the requirements of Federal Specification SS-S-1401C and Federal Specification SS-S-1614A. This hypothesis was proven to be correct as demonstrated by the field performance of the two "improved" sealants versus the commercially available SS-S-1401C and SS-S-1614A sealants used in the evaluation.
4. Bubbling of Hot-Applied Sealants – Bubbling of pavement joint sealants has long been considered a field performance issue particularly with hot-applied sealants. A primer system was developed during this project to minimize the bubbling tendencies of the hot-applied sealants. The primer appeared to minimize bubbling initially; however, in the long term, bubbling was not reduced. Perhaps a more important finding from the 10-year evaluation is that the bubbling of the hot-applied sealants did not have an adverse impact on the overall sealant performance.
5. What is the best sealant – Once a person gets past whether or not sealing is a good thing and decides that it is, the next question is generally what sealant is best. That question is very difficult to answer because it depends on the climate, the pavement structure, the size and shape of the joint or crack, the type and volume of

traffic, the future use of the pavement, etc. From this study, it would appear that for pavements exposed to jet fuel spillage, the “improved” JFR sealant would provide the best performance (life expectancy greater than 10 years). The best sealant for pavements not exposed to jet fuel spillage, based on this study would be the “improved” non-JFR sealant (life expectancy of greater than 10 years). Two silicones also had a life expectancy of greater than 10 years, the Dow 902 RCS and Crafco SL Silicone. The fact that, on average the asphalt-based sealants and the silicone-based sealants performed similarly was interesting. The failure mechanism between the sealant types was different. The primary failure mode of the silicone sealants was spalling and for the asphalt-based sealants it was adhesion loss. This finding demonstrates that proper joint preparation is critical for satisfactory field performance.

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TABLE 1 Sealants And Installation Configurations

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

TABLE 2 58-Month Performance Summary

Sealant	**Installation Method**[a]	**Section Numbers**[b]	**Failure Types**[c]	**Average Total Failure**[e]
Crafco Roadsaver 222	Recess	1/1, 1/18	A	13%
Crafco Roadsaver 222	Flush	1/2, 1/19	A	15%
Crafco Roadsaver 222	Recess/Primed	1/3, 1/20	A	8%
Crafco Improved Non-JFR	Recess	1/4, 1/21	A	< 1%
Crafco Improved Non-JFR	Flush	1/5, 1/22	A	< 1%
Crafco Improved Non-JFR	Recess/Primed	1/6, 1/23	A	6%
Crafco Silicone SL	Recess	1/24, 1/7	A	< 1%
Koch Product 9005	Recess	1/10, 1/17	A	50%
Mobay 960 SL	Recess	1/15, 1/9	A	10%
Dow 902 RCS	Recess	1/14, 1/11	A, C	< 1%
Dow 890 SL	Recess	1/13, 1/12	A, C	< 1%
Mobay 960	Recess	1/16, 1/8	A	< 1%
Crafco Superseal 1614A	Recess	2/1, 2/6	A, C	> 50%
Crafco Improved JFR	Recess	2/2, 2/7	A	< 1%
Koch Product 9050 SL	Recess	2/3, 2/9	A, C	12%
Koch Product 9012	Primed	2/5, 2/8	A, C	9%
Koch Product 9020	Recess	2/4, 2/10	A	8%

Notes:
[a] Installation method refers to the final sealant configuration. Recess – sealant recessed 3 to 7 mm below the pavement surface, Flush – sealant was 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 (the non-JFR area) and section 1, 2/5 refers to area 2 (the JFR area) section 5, etc.
[c] Failure types are A – adhesion, C – cohesion, S – spalling.
[d] Average total failure is the average amount of the sealant sections that would allow water to penetrate the joint.

TABLE 3 86-Month Performance Summary

Sealant	**Installation Method**[a]	**Section Numbers**[b]	**Failure Types**[c]	**Average Total Failure**[e]
Crafco Roadsaver 222	Recess	1/1, 1/18	A	1%
Crafco Roadsaver 222	Flush	1/2, 1/19	A	1%
Crafco Roadsaver 222	Recess/Primed	1/3, 1/20	A	1%
Crafco Improved Non-JFR	Recess	1/4, 1/21	A	< 1%
Crafco Improved Non-JFR	Flush	1/5, 1/22	A	< 1%
Crafco Improved Non-JFR	Recess/Primed	1/6, 1/23	A	3%
Crafco Silicone SL	Recess	1/24, 1/7	A	< 1%
Koch Product 9005	Recess	1/10, 1/17	A	25%
Mobay 960 SL	Recess	1/15, 1/9	A	1%
Dow 902 RCS	Recess	1/14, 1/11	A, C	< 1%
Dow 890 SL	Recess	1/13, 1/12	A, C	< 1%
Mobay 960	Recess	1/16, 1/8	A	< 1%
Crafco Superseal 1614A	Recess	2/1, 2/6	A, C	75%
Crafco Improved JFR	Recess	2/2, 2/7	A	< 1%
Koch Product 9050 SL	Recess	2/3, 2/9	A, C	25%
Koch Product 9012	Primed	2/5, 2/8	A, C	25%
Koch Product 9020	Recess	2/4, 2/10	A	8%

Notes:
[a] Installation method refers to the final sealant configuration. Recess – sealant recessed 3 to 7 mm below the pavement surface, Flush – sealant was 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 (the non-JFR area) and section 1, 2/5 refers to area 2 (the JFR area) section 5, etc.
[c] Failure types are A – adhesion, C – cohesion, S – spalling.
[d] Average total failure is the average amount of the sealant sections that would allow water to penetrate the joint.

TABLE 4 117-Month Performance Summary

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

Notes:
[a] Installation method refers to the final sealant configuration. Recess – sealant recessed 3 to 7 mm below the pavement surface, Flush – sealant was 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 (the non-JFR area) and section 1, 2/5 refers to area 2 (the JFR area) section 5, etc.
[c] Failure types are A – adhesion, C – cohesion, S – spalling.
[d] Average total failure is the average amount of the sealant sections that would allow water to penetrate the joint.
[e] 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.
[f] Some of the adhesion loss was a result of grinding and snowplow damage.

TABLE 5 Sealant elongation at 117 months

Sealant	Percent Elongation	Failure Type[a]
Crafco Roadsaver 222	300%	Cohesive break
Crafco Improved Non-JFR	600%	Cohesive break
Crafco Silicone SL	300%	Cohesive break
Koch Product 9005	0	Material “gooey” could not conduct test
Mobay 960 SL	50%	Cohesive break
Dow 902 RCS	600%	Cohesive break
Dow 890 SL	600%	Adhesive loss
Mobay 960	50%	Cohesive break
Crafco Superseal 1614A	0	No material remaining in joints.
Crafco Improved JFR	250%	Cohesive break
Koch Product 9050 SL	150%	Cohesive break
Koch Product 9012	75%	Cohesive break
Koch Product 9020	200%	Cohesive break

Notes:
[a] Failure type refers to how the sealant failed at the end of the elongation test. Cohesive break means that the sealant broke at the elongation listed. Adhesive loss means that the sealant began pulling away from the joint face at the elongation listed.

FIGURE 1 Conducting an Elongation Test

FIGURE 2 Adhesive Failure of The Asphalt-Based Sealant

FIGURE 3 Spalling Associated With The Silicone Sealant