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Michael A. Lacasse¹ and J-F. Masson¹

Developing a Performance-Based Joint Sealant Specification for Airport PCC Pavements

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Abstract: Despite recent progress to develop a performance-based specification for bituminous sealants applied to asphalt concrete (AC) roadways and runways, a performance-based specification for cold-applied joint sealants for Portland cement concrete (PCC) aprons, taxiways, and parking areas has yet to be mapped and developed. Unique in-service conditions exist on these PCC pavements, where sealants are not only exposed to climatic effects and heavy traffic loads, but also to jet fuel and de-icing fluids. Installation and maintenance conditions are also unique in that it is often necessary to install or replace joint sealants at night or in a very short time so that aircraft traffic disruption is avoided. Hence, special consideration must be provided to ascertain that joint sealants are effective and durable. Recent studies on joint and crack sealants used on airport pavements that experience cold climates indicate that current specifications do not necessarily allow for the selection of durable sealants and that sealant failure can be rapid. To address the issue of premature failure, and in an effort to extend joint sealant service life, the elements of a performance-based specification for cold applied joint sealants for PCC airport pavements is reviewed. The benefits of such a specification include the selection of joint sealants for specific local needs, reduced airport pavement maintenance costs, and extended airport PCC pavement service life.

Keywords: airport, concrete pavement, joint sealing, maintenance, performance, sealants, specification

¹ Senior Research Officers, National Research Council Canada, Institute for Research in Construction, 1200 Montreal Road, Building M20, Ottawa, ON, Canada K1A 0R6

1. Introduction

For airports, the expected service life of well-sealed and well-maintained PCC taxiways, aprons and parking areas may achieve 30 or more years [1]. Unfortunately, it is not uncommon for the service life to be reduced, in part due to joint sealant failures. Failed sealants allow the ingress of fluids and incompressible debris in the joints, which can lead to frost heave, sub-grade settlement followed by slab corner cracking or disintegration of the slab longitudinal edges, in addition to the contamination of underground soil and water by the fluid.

Ideally, a joint sealant would not need replacement until the repair or reconstruction of the PCC pavement. Hence, it would last more than 30 years. Recent studies on joint sealants used on airport pavements that experience cold climates and exposure to jet fuel or de-icing liquids indicate that sealant performance may extend beyond 10 years, but that premature failure is not uncommon [1, 2, 3]. Generally, early failure is typically due to improper sealant installation, whereas later failures may result from improper sealant selection and aging [4].

Notwithstanding recent developments towards a performance-based specifications for bituminous sealants applied to asphalt concrete (AC) pavements [5, 6, 7, 8] and the seminal works of Evans and Romine [9], and that of Lynch et al. on joint sealants for PCC pavements [3, 10], [11], performance-based joint sealant specifications for PCC taxiways, aprons, and parking areas have yet to be delineated and developed.

In an effort to promote the development of such a specification, this paper provides a review of the factors that affect joint sealant performance, defines the key elements of the specification, and highlights the benefits of a performance based specification for the selection of durable joint sealants for use in airports.

2. In-Service Conditions and Requirements

Durability in an airport setting requires that joint sealants be able to sustain horizontal and vertical loads without cohesive or adhesive failure. These loads respectively arise from temperature driven cyclic opening and closing of joints, and from slow aircraft traffic. The ability of a joint sealant to sustain these loads varies according to its temperature-dependant stiffness and stress relaxation behaviors, along with its resistance to aging upon exposure to freezing and thawing, sunlight, rain, jet fuels or deicing fluids, alone or in combination.

Of particular importance to sealant performance is the ability of a sealant to strongly adhere to PCC. Adhesion depends on sealant viscosity and chemistry, and sealant installation [12], which in an airport setting is particularly challenging. It is often necessary to install or replace joint sealants during summer nights or within a few hours so that aircraft traffic disruption is avoided [1]. Hence, time for cleaning and preparing a joint for sealing and resealing can be very short, with the effect that resealed joints often fail in areas where old sealant remained [13]. The sealant also needs to skin or cure quickly, before the pavement is back in service. In the end, it is extremely difficult to find a joint sealant that meets all the requirements for service in an airport located in a Nordic region. A summary of the requirements is found in Table 1.

TABLE 1 — *Joint sealant performance requirements* (adapted from [14]).

-
- Adheres to joint faces without internal rupturing when subjected to joint movements due to climatic and aircraft loads.
 - Resistant to moisture and weathering.
 - Resistant to jet-fuel or de-icing fluids.
 - Rejects intrusions of incompressible materials or can withstand the effects of intrusion.
 - Can be installed within hours.
 - Economical to install and replace.
-

3. Sealant Specifications and Standard Tests

Current sealant specifications have been developed to provide some measure of durability when sealants are exposed to climatic effects, de-icing fluids or jet fuels. Table 2 shows the relationship between the current specifications and the pavement and sealant types. There are a number of specifications, some of which apply only to sealants for PCC joints, others to both PCC joints and AC cracks. In the case of PCC joint sealants for use in an airport setting, the situation can be confusing. Four specifications can be used to select hot-applied jet fuel resistant (JFR) sealants, and two specifications for non-JFR sealants. Military airports in the USA use Federal Specifications (FS), but it is not obvious which specification civilian airports located in North American should be using.

TABLE 2 — *Sealant specifications for PCC joints in airport settings*

Pavement	JFR ¹		Non-JFR	
	Hot-applied	Cold-applied	Hot-applied	Cold-applied
PCC	ASTM ² D3569 ASTM D1854		ASTM D3406	ASTM D5893
PCC or AC	ASTM D3581 FS-SS-S-1614A ³	FS-SS-S-200E	ASTM D6690	

¹Jet Fuel Resistant;

²American Society for Testing and Materials;

³Federal Specification (FS).

The tests for the various specifications are listed in Table 3. All the specifications for the JFR sealants call for the same basic tests and requirements and the ASTM Specification for Joint Sealant (Hot Applied, Elastomeric-Type) for Portland Cement Concrete Pavements (D3569) encompasses the other specifications. As such, the ASTM D3569 is apparently more demanding in part due to an aging test. From a users perspective, however, the specifications for hot-applied JFR sealants are nearly identical. In principle, ASTM D3569 applies to *elastomeric* sealants, and the ASTM Specification for Jet-Fuel-Resistant Concrete Joint Sealer, Hot-Applied Elastic Type (D1854) and ASTM Specification for Join Sealant, Hot-Applied, Jet-Fuel Resistant Type, for Portland Cement Concrete and Tar-Concrete Pavements (D3581) to *asphaltic* sealants. The difference is mostly semantic as in practice asphaltic sealants do contain an elastomer [15], elastomeric sealants can contain tar (see below), and ASTM D3569 excludes many tests applied to truly elastomeric sealants, e.g. as

exist in the ASTM Specification for Cold Applied, Single Component, Chemically Curing Silicone Joint Sealant for Portland Cement Concrete Pavements (D5893), and as shown in Table 3.

The difference between the specifications for hot-applied non-JFR sealants, i.e. the ASTM Specification for Joint Sealant, Hot-Applied, Elastomeric-Type, for Portland Cement Concrete Pavements (D3406) and the ASTM Specification for Joint and Crack Sealants, Hot Applied, for Concrete and Asphalt Pavements (D6690), is also of interest. Four sealant types are specified in ASTM D6690:

- Type I: moderate climate (low temperature extension to 50% at –18 °C, formerly ASTM D1190)
- Type II: most climates (low temperature extension to 50% at –29 °C, formerly ASTM D3405)
- Type III: most climates (same requirements as Type II, but with an additional water-immersed bond test, formerly Federal specification FS-SS0S-1401C)
- Type IV: climates with very low temperatures (low temperature extension to 200% at –29 °C)

TABLE 3 — *Test methods for specifications given in Table 2*

Tests	JFR					Non-JFR		
	D3569	D1854	D3581	1614A	200E	D3406	D6690	D5893
Artificial weathering	x				x	x		x
Bond, non-immersed	x	x	x	x	x	x	x	x
Bond, fuel-immersed	x	x	x	x	x			
Bond, water-immersed	x	x	x	x	x	x	x ^a	x
Bond, oven-aged								x
Penetration, non-immersed	x	x	x	x		x	x	
Penetration, fuel-immersed	x	x	x	x				
Flexibility	x					x		
Flow	x	x	x	x	x	x	x	x
Resilience	x				x	x	x	
Resilience, oven-aged	x				x	x	x ^a	x
Solubility (weight loss)	x	x	x	x	x			
Tensile adhesion	x					x		
<i>Exclusive to cold-applied sealants</i>								
Extrusion rate								x
Tack-free time					x			x
Tensile strength					x			x
Hardness					x			x
Heat aging								x
Flame resistance					x			

^a Type III sealants only

The ASTM D 3406 covers the Type I sealant from ASTM D6690, with the addition that sealants are weathered one week by artificial sunlight exposure. Interestingly, ASTM D6690 only requires the aging of Type III sealants, and by means of one week of oven aging. In general, ASTM D6690 is a much broader based specification than ASTM D3406 or those that have been withdrawn, i.e. ASTM Specification for Concrete Joint Sealer, Hot-Applied Elastic Type (D1190), ASTM Specification for Joint Sealants, Hot-Applied, for Concrete and Asphalt Pavements (D3405), and U.S. Federal specification SS0S-1401C.

The greatest differences between the specifications listed in Table 2 are between cold- and hot-applied sealants. ASTM D5893 treats of silicone-based sealants whereas the U.S. Federal specification for Joint Sealants, Two Component, Jet-Blast-Resistant, Cold-Applied, for Portland Cement Concrete Pavement (FS-SS-S-200E) treats of two-component sealants, these typically being polysulfides or polyurethane modified tars. Both specifications require tests related to installation, namely, tack-free time and extrusion rate, in addition to tests typically applied to elastomers in general, namely, tensile modulus and hardness (Table 3). Interestingly, FS-SS-S-200E is used in the United States, mostly on military airports, but no specification for cold applied JFR sealants has official jurisdiction in Canada given that the Canadian Government Standards Board (CGSB) withdrew the CGSB specification for two-component cold-tar sealants cold-applied JFR sealants (CAN/CGSB 19.20 M87).

From Tables 2 and 3, it is deduced that the basis for the various specification tests was not developed from an end-use or sealant user perspective, but from a material suppliers perspective, asphalt- and polymer-based sealants being respectively characterized by methods common to asphalt or polymer materials, the exception being ASTM D3569 (for elastomeric hot-applied sealants), which lacks the tests associated to typical elastomers, but this goes back to the semantic issue discussed earlier. This perspective is reinforced by the lack of an aging test to mimic field aging and weathering, and the lack of a method to assess the movement capability of the sealant although some measure of movement capability may be gleaned from both the bond and the tensile tests. The ASTM Test Method for Adhesion and Cohesion of Elastomeric Joint Sealants Under Cyclic Movement (C719) could be applied for such a purpose, but the test results do not invariably permit assessing the expected field performance. The correlation between these properties and field performance is of the utmost importance and it is useful to review some of this work.

4. Studies on Laboratory Standards

A full-scale investigation of sealant performance and methods for resealing joints in PCC pavements was carried out under the sponsorship of the U.S. Strategic Highways Research Program in 1991 [9]. More than 1600 joints at five sites across the US were sealed with one of four installation methods and twelve sealants, including asphalt-, silicone- and polysulfide-based sealants. The sites were deemed representative of the four climate regions of the United States, of which three might apply to Canada. Both laboratory analysis of the sealant properties and evaluation of their respective field performance were conducted over a three-year period. One of the objectives of the research was to determine the extent to which field performance correlated to standard laboratory tests, specifically ASTM Standard Test Methods for Joint Sealants, Hot-Poured, for Concrete and Asphalt Pavements (D3407) and ASTM Test Method for Vulcanized Rubber and Thermoplastic Elastomers—Tension (D412) (for cold applied materials). It was found that field performance and standard test results

were not correlated, but that some test results were weakly correlated to adhesion loss. Interestingly, although the mode of sealant failure was noted, the possible reasons for the failures were not identified.

In 1996, after longitudinal cracking of PCC joint edges was observed following installations of silicone-based sealants, Transport Canada assessed the mechanical properties and physical characteristics of six joint sealants, including two silicone cold-pours; one, tar modified, polyurethane two-component cold-pour; and three bitumen-based sealants. Mechanical test conducted at -10 and -30 °C to evaluate the low-temperature performance and rheological characteristics showed that the stress relaxation at -30 °C was far superior in silicones than in hot-applied sealants after a 50% extension. Hot applied sealants became rigid and brittle in low temperatures and easily debonded from concrete. The work suggested that rheological characteristics would be useful in the assessment of field performance. Incidentally, it was later found that PCC edge cracking was related to the application of silicone sealants to the joints prior to sufficient curing of the PCC [16].

In 1988, the U.S. Army Waterways Experiment Station (WES) undertook a two-part investigation of field molded joint sealants [14, 17]. The investigation consisted of a laboratory evaluation and a field performance survey, with the main objective being to determine the field performance of field-molded joint sealants manufactured to meet federal specifications. One-third of the sealants were found not to conform to specification, but conformance specification did not ensure adequate field performance [18]. This situation was said to arise from the discrepancy between laboratory and field conditions, and the inability of the standard specification to account for joint preparation and sealant installation.

Lynch et al. [10, 11] followed with another laboratory and field evaluation of joint sealants, the basis of the study being the problems associated with the sealing and re-sealing of joints identified in the first study [18]. This follow-up study was partly intended to improve the characteristics of sealant produced by Crafcro Inc. for later field trials in Spokane, Washington, where temperature highs and lows are respectively -28°C and 58°C . Thirteen sealants were installed, including two specially formulated sealants. Table 4 shows the sealant types and base. All the sealants performed satisfactorily after one year, although cold-applied products appeared to perform better than the hot applied [10,11]. In 2002, Lynch et al. [3] reported on the ten-year field performance of these thirteen sealants (Table 4). The estimated life of several sealants extended up to and beyond 10 years, but a relatively short life was also evident for either cold or hot-applied products.

Comparison between cold and hot-applied products suggests that respective performance over a ten-year period is essentially the same. Their mode of failure is different, however, as silicone-based sealants with estimated life expectancies greater than 10 years failed primarily due to spalling of the substrate, whereas adhesion loss was the main mode of failure in hot-applied products [3].

5. Performance-Based Specification for Joint Sealants

Irrespective of the fact that sealants may meet a specification, a most significant test will be one that brings about failure, as it is known to occur in the field, if any. The key to identifying such a test method is to review survey results of field failures knowing the conditions to which the products have been subjected to between installation and failure

times. This is not straightforward, however, as there is a need to define failure and to quantify the parameters thought to cause failure.

A performance-based material specification is helpful as long as a sealant is applied onto a clean substrate and that installation requirements are followed, a subject discussed by Lynch [18]. After the material is installed correctly, the sealants are exposed to various loads and aging elements as discussed earlier. Interestingly, for joints along airport PCC pavements, little or no information is available on the expected amount of loads that take effect in service. Consequently, the typical loads that should be applied during a standard test remain undetermined, as much as the effect of the aging elements on the sealant.

TABLE 4 — *Ten-year field performance of joints sealants* (adapted from [3]).

Product information			Percent failure after yrs in service		Estimated life
Type	Name	Base	5 y	10 y	years
Cold applied	Crafco Roadsaver	Silicone	<1	16	> 10
	Mobay 960 ^a	Silicone	1	20	> 10
	Mobay 960-SL ^a	Silicone	10	23	10
	Dow Corning 902 RCS	Silicone	2	14	> 10
	Dow Corning 890 SL	Silicone	1	28	10
	Koch 9050 SL ^a	Polysulfide	22	53	5
	Koch 9020*	Polysulfide	8	35	8
Hot-applied	Crafco 222	Rubberized asphalt	13	17	> 10
	Crafco improved	Rubberized asphalt	< 1	8	> 10
	Crafco JFR	Polymer modified tar	> 50	100	2
	Crafco JFR improved	Polymer modified tar	1	22	> 10
	Koch 9005	Rubberized asphalt	50	30	3
	Koch 9012 ^a	Polymer modified tar	2	48	6

^a Products no longer available

Existing specifications for sealants are descriptive, in that test methods are indirectly related to sealant durability. As a consequence, standard test results correlated weakly to field performance [4, 18]. In contrast, a performance-based specification is highly correlated to sealant performance because laboratory tests are designed to reproduce field effects [5, 7]. Performance guidelines for hot-pour crack sealants are currently being developed [8], based on an approach already discussed [6, 8].

The requirements of a performance-based specification for joint sealants are not much different from those for crack sealants. It requires the assessment of the response of the sealant-PCC pavement system to its environment, with the following elements of importance:

- Effect of joint preparation on the adhesion and performance of the sealant
- Sealant stiffness and stress relaxation behavior
- Limiting tensile stress that the sealant –PCC interface can sustain
- Weathering rate and mechanism for joint sealant
- Effect of weathering on performance
- Effect of jet fuels and deicing fluids on performance

Figure 1 shows the interrelation of the issues that must be resolved to develop a joint sealant performance-based specification. The outgrowth of a performance-based specification is a series of test procedures that relate physical properties of the sealant-pavement system to critical distress mechanisms and field performance.

FIGURE 1 — *Inter-relationship between elements required to develop a performance-based specification* (adapted from [5]).

A performance-based specification can be developed in two concurrent phases (Table 5). One phase aims to determine installation and the in-service conditions, the other to establish performance-based laboratory tests that simulate in-service conditions. The outgrowth of this approach consist of up-dated installation guidelines, including the state of practice as compared to the state of the art; accelerated aging and performance-based test procedures for hot or cold-applied, non- and jet-fuel resistant sealants; and performance guidelines for the selection of joint sealants

There are several benefits to the use of performance-based guidelines for the selection of joint sealants for use on PCC airport pavements:

- Selection of sealants based on specific local climate
- Extended sealant durability, fewer sealant replacements over lifetime of pavement
- Scheduling of joint re-sealing becomes easier as sealant service life is more accurately predicted
- Decreased maintenance costs due to:
 - Greater efficiency in the application of joint sealants due to improved joint sealant installation techniques
 - Extended joint service life
 - Increased avoidance of costly disruptions of airport services related to early sealant replacement
- Extended service life for runways, aprons, taxiways, and parking areas

TABLE 5 — *A two-phase approach to develop performance-based guidelines for PCC joint sealants used in airports.*

<i>Phase 1 - Field work</i>	<i>Phase 2 - Laboratory work</i>
<ul style="list-style-type: none"> • Monitor the installation of jet-fuel and non-jet fuel resistant sealants, including hot- and cold-applied products • Assess sealant performance in representative climatic zones (e.g. Canada's coastal and Great Lakes areas) • Identify failure mechanisms over 5- to 10-years • Collect sealants to determine changes in material characteristics 	<ul style="list-style-type: none"> • Measure sealant rheological properties • Determine sealants aging rate and mechanism of deterioration • Develop an accelerated aging method that mimics in-service aging • Correlate sealant aging and rheology to field performance • Establish performance-criteria for performance-based tests

6. Summary

Current specifications for joint sealant selection and installation lack performance data for various sealant types, including information on their resistance to weathering and exposures to jet-fuels, de-icing chemicals, or cold temperature cycling. A systematic and combined laboratory and field program would help establish a basis for guidelines on sealant selection and installation. It would also permit the selection of sealants for very cold climates based on specific local needs and would help extend joint sealant durability. In turn, this is expected to reduce airport pavement maintenance costs, help optimize the management of crack sealant programs and extend PCC airport pavement service life.

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