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Thresholds Identification and Field Validation of the Performance Based Guidelines for the Selection of Hot-Poured Crack Sealants

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ABSTRACT

Hot-poured bituminous crack sealing has been widely accepted as a routine preventative maintenance practice, and with proper installation, it is expected to extend the pavement service life three to five years. However, the current specifications for the selection of crack sealants correlate poorly with field performance; hence, a set of new testing methods, which are based on sealant rheological/ mechanical properties, were developed recently. Measuring the mechanical properties of crack sealant at low temperatures is one of the criteria introduced as part of the developed performance-based guidelines. The main purpose of this study was to identify and validate the low temperature selection thresholds for the newly developed performance based guideline for selecting hot-poured bituminous crack sealants. In this study, selection criteria for crack sealant bending beam rheometer (CSBBR) and crack sealant direct tension tester (CSDTT) tests are identified. Two performance parameters for CSBBR test are used for the selection criteria: stiffness at 240s and Average Creep Rate (ACR). Both parameters were identified by comparing laboratory testing results with known sealant field performance, obtained from a long-term study in Canada. The selection criterion for the CSDTT test is extendibility, which is based on field values reported in the literature. The recommended selection criteria were used to predict the field performance of 12 sealants evaluated by the National Transportation Product Evaluation Program (NTPEP). The results show good correlation between the proposed selection thresholds and NTPEP field sealant performance.

Keywords: Crack sealant, Low temperature, thresholds, CSBBR, CSDTT

INTRODUCTION

For a material to provide acceptable performance as a hot-poured bituminous-based crack sealant, it must resist adhesion, degradation, and cohesion failures in the range of service of temperature at which it is expected to be used. In addition, the material should be easily and effectively installed, and able to resist degradation from the surrounding environment. Because of their chemical complexity, crack sealant specifications have been developed around physical property tests that are thought relevant to their performance. The current crack sealant specification system, found in ASTM D5329 and AASHTO M173, focuses on utilizing simple empirical tests such as cone penetration and softening point to measure the ability of the material to resist cohesive failures. Although the viscoelastic behavior of crack sealants is too complicated to be described by simple empirical parameters, the used consistency tests have served well over the years for specifying crack sealants and to ensure the consistency of sealant properties (*1*).

As a result of increasing traffic, axle loading, and tire pressure, a new range of highly-modified crack sealants have been introduced that can have quite complex behavior compared to traditional sealant materials. The implementation of the current specification system on these new classes of crack sealant materials revealed that the used consistency tests do not adequately describe the linear viscoelastic properties that are needed to relate physical properties to performance, to relate sealant chemistry to performance, and to develop a performance-related crack sealant specification system. In addition, results of these tests were found to correlate poorly with field performance. While some sealants provided superior field performance, they were ranked equally to low performance sealants. The poor prediction of sealant performance using the current specification system has been widely reported in the literature (*2, 3, 4*). In summary, characterization of hot-poured crack sealants using the current specification system does not ensure adequate or reflect actual field performance. Hence, an improved sealant specification and selection system is urgently needed.

The key to improving sealant durability is to develop effective performance guidelines for selection and application of sealants. This study makes use of the well-established methods and equipment originally developed during the five-year Strategic Highway Research Program (SHRP) as part of the Performance Grade (PG) system for asphalt binders. Because the equipment utilized in the PG system are already owned by various pavement and State transportation agencies, it makes it an attractive and economical choice to be adopted in this research project. However, because of the high flexibility of crack sealants and the large deformation experienced under loading, it was found that the original bending beam rheometer (BBR) and direct tension tester (DTT) are not suitable to test crack sealant material. Therefore, in order to use the equipment developed by SHRP, some modifications were necessary to allow for testing hot-poured sealants (*5, 6*).

In addition, a unique feature of the SuperPave™ binder specification system is that the specified criteria of fundamental rheological properties of asphalt binder remain constant, but the temperature at which the criteria must be met changes for the various PG grades. The tests are performed at temperatures that are encountered by in-service pavements. The similar idea of establishing selection threshold for crack sealant was also adopted for crack sealant bending beam rheometer (CSBBR) test which has a specified criterion over the various sealant service temperatures. However, for crack sealant direct tensile tester (CSDTT) test, the selection criteria are varied with various sealants in service temperatures. This is due to the various loading mechanisms between sealant and asphalt binder in the field. Therefore, this paper presents the sealant low temperature selection thresholds and preliminary validation of these selection thresholds using CSBBR and CSDTT tests.

OBJECTIVES

The objective of this paper is to identify the selection criteria of hot-poured crack sealant at low temperature using CSBBR and CSDTT tests. Two performance parameters for CSBBR test are used for the selection criteria: stiffness at 240s and Average Creep Rate (ACR). Both parameters were identified by comparing laboratory testing results with known sealant field performance obtained from a long-term study in Canada (*7*). The selection criterion for the CSDTT test is extendibility, which is based on field values reported in the literature. The recommended selection criteria were used to predict the field performance of 12 sealants evaluated with the National Transportation Product Evaluation Program (NTPEP). The sealants were installed in Minneapolis and St. Paul, Minnesota.

SEALANT MATERIALS

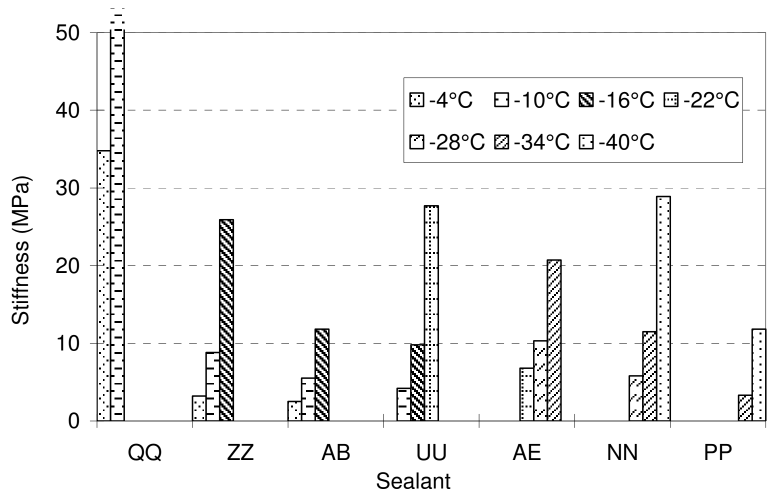
Fifteen laboratory-tested sealants —designated as PP, BB, AD, WW, AE, NN, MM, UU, DD, EE, VV, AB, QQ, YY, and ZZ— five Montreal field sealants—designated A, B, E, G, and J — and 12 NTPEP field sealants with varying chemical compositions were evaluated. The laboratory-tested sealants were obtained from various North American manufactures and were used to investigate the mechanical behavior of crack sealant. The laboratory-tested sealants represent a wide array of rheological behaviors, and thus, they are expected to perform in various environments with a low-temperature range of -4°C to -40°C. Variations in the rheological properties can be attributed to various factors, including the source of the origin crude, the refining and modification process, and the content of polymer, filler, and additives. There is no field performance data available for the 15 laboratory-tested sealants. The five Montreal field sealants were installed in the early 1990s in Montreal, Canada; they have detail performance records and used to establish the sealant selection criteria.

Twelve types of crack sealants produced by seven manufactures were used in the study. Sealants were installed in the U.S. Highway 169, at Delaware Avenue, between Belle Plaine and Jordan, southwest of Minneapolis and St. Paul, in Minnesota. The sealants were installed on September 14, 2005. The pavement condition was rated as “good” at the time of construction. Some transverse cracks existed, but there were few longitudinal cracks. All cracks were prepared by cutting a reservoir for the sealant using a router. Sealant installation was completed between 10:00 a.m. and 4:00 p.m. Ambient temperature ranged from 61 to 75 °F.

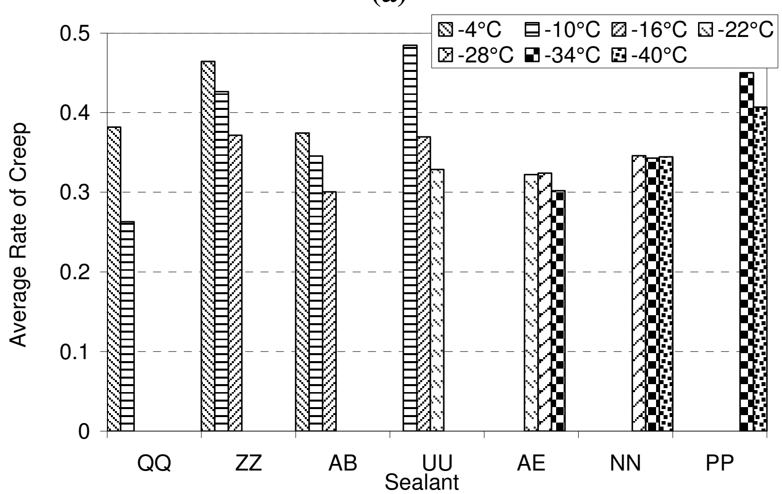
SEALANT LOW TEMPERATURE TESTS

Crack Sealant Bending Beam Rheometer (CSBBR) Test

The bending beam rheometer (BBR) is used in most pavement laboratories nowadays to measure binder stiffness at low temperature. A modified BBR test, a crack sealant bending beam rheometer (CSBBR), was introduced to measure the flexural creep of crack sealants at temperatures as low as -40°C. The development of this procedure is described in detail in a supporting document (*8*). Two performance parameters were suggested for use in the specification: stiffness at 240s and average creep rate (see Figure 1) [*9*].



(a)



(b)

FIGURE 1 (a) Stiffness at 240s and (b) Average creep rate at various testing temperatures for various sealants

Crack Sealant Direct Tension Tester (CSDTT) Test

When the temperature drops in the winter or at night, the pavement will contract and will induce an opening of the crack. In the summer or daytime, the temperature increases, and therefore, the pavement will expand and the crack will close. The crack opening distance during the temperature cycle varies from 10 to 90% strain. Therefore, to investigate whether a sealant can survive in a particular set of service conditions, the SuperPave^{TM} DTT was considered and modified for crack sealants. The development of CSDTT is described in detail elsewhere (*10*). The extendibility of the sealant was measured and used as a performance parameter (see Figure 2). Extendibility was found to be an appropriate criterion for identifying sealants and distinguishing between various sealant types. In addition, it is worth noting that several sealants in Figure 2 show extendibility of 90% without failure. The DT device housed in most laboratories can only extend the material up to 92%. Therefore, it was determined to conduct the test only up to 90% of strain, even if the specimen does not fail.

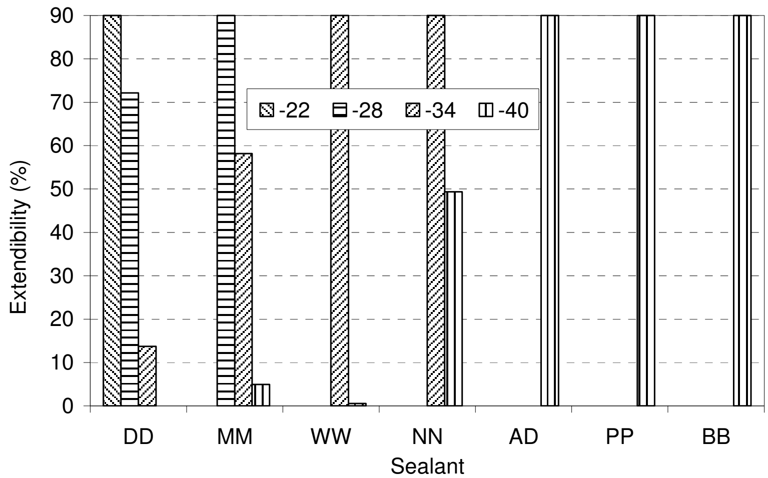


FIGURE 2 Extendibility of various sealants at -22, -28, -34, and -40°C

MONTREAL FIELD PERFORMANCE

Five sealants (A, B, E, G, and J) installed in Montreal in the fall of 1990 were used in this study to identify the crack sealant performance criteria for CSBBR test. The ASTM D6690 Type II test results of the five sealants are reported in Table 1(a) [*7*]. Field samples were collected during visual surveys at the first and ninth years after installation. Masson (*11*) noted that the sealants were not always installed at the recommended pouring temperature and that the air temperature and weather conditions varied [see Table 1(b)]. Hence, installation conditions need to be considered when sealant laboratory testing results are correlated to their corresponding sealant field performance.

The first and second performance surveys of the installed sealants were obtained after three and six months of installation, and the lowest temperatures were -5°C and -35°C, respectively. The short-term performance was most affected by installation conditions and sealant characteristics. The performance of the five sealants is presented in Table 1(c). For example, sealant G had 3% of the installed length de-bonded and less than 1% pull-out after one year. The de-bonding is identified as sealant loses adhesion to the crack wall, and the pull-out is identified as sealant is completely absent from the crack. After the first winter, the de-bonding percentage of sealant G increased to 24%, and the pull-out percentage increased to 3%.

A long-term sealant performance survey was conducted four years after installation [see Table 1(c)]. The long-term performance was mainly affected by the sealant weathering and stiffening. A performance index (PI) was suggested based on the level of de-bonding and pull-out. The PI is calculated as follows (*7*):

$$PI = 100-(D+nP) \quad (1)$$

where,

PI = sealant performance index;
D = percent de-bonded length of the sealant;
P = percent pull-out length; and
n = an integral that accounts for the effect of pull-out over de-bonding on performance

TABLE 1 (a) Montreal Sealant Standard Test Results; (b) Field Sealant Installations; (c) Short- and Long-Term Sealant Performance (Failure Lengths, %) [7]

(a)

Sealant	Penetration (<90 dmm)*, †	Flow (<3 mm)*	Resilience (>60%)*	Bond (3 cycles)*
A	86	0.5	57	No
B	68	0.5	64	Yes
E‡	104	1	73	Yes
G	50	0.5	51	No
J	66	6	48	Yes

*ASTM D3405 requirements.
†1 dmm = 0.1 mm.

(b)

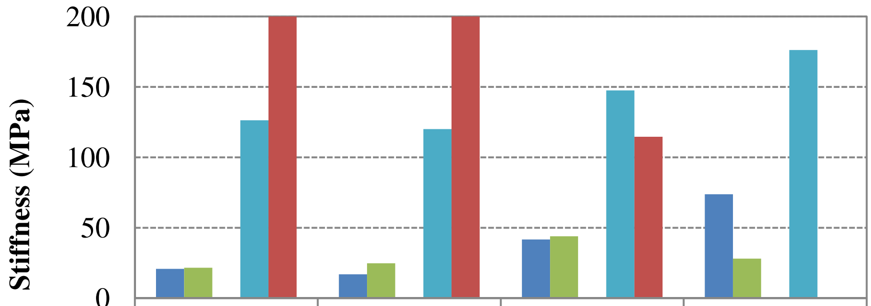
Sealant	Temperature (°C)		Air Temperature at Start of Installation (°C)
	Recommended	Measured	
A	190-205	205	Overcast and -6
B	170-200	215	--
E	185-195	195	Overcast and 7
G	170-180	175	Overcast and 7
J	185-195	--	Overcast and 3

(c)

Sealant	Before First Winter		After First Winter		After Four Years		Performance Index after Four Years
	De-bonding	Pull-out	De-bonding	Pull-out	De-bonding	Pull-out	
A	1	<1	12	9	11	14	33
B	5	<1	5	<1	22	1	74
E	1	<1	11	1	20	2	72
G	3	<1	24	3	36	14	8
J	1	<1	8	6	13	12	39

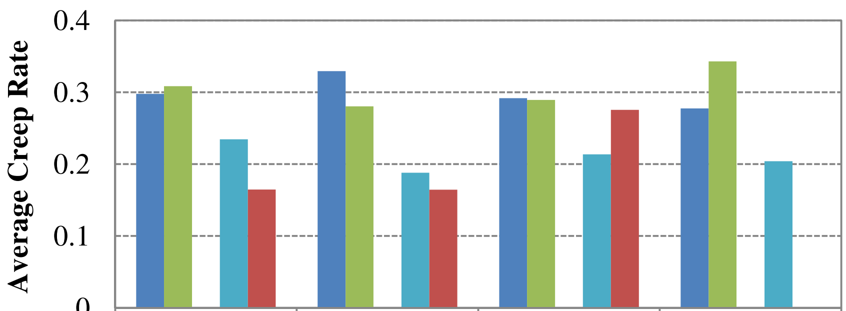
The n value was assigned as four in the Masson's study (*7*). The suggested value was based on the assumption of that a loss of one meter of sealant might allow the intrusion of water, sand, and stone into the pavement, which could damage the pavement during its expansion and contraction (*12*). This damage is more critical than de-bonding over the same length. A higher PI value is indicative of better sealant performance. For example, the PI for sealant A was 33 and the performance was classified as "poor," while sealant E had a PI of 72 and a performance classification of "good."

The five Montreal sealants were subsequently tested in the laboratory. According to the LTTPBind, the low temperature PG of binder with 98% reliability in the region is -40°C, so all sealants were tested at -34°C (6°C higher than the temperature grade). Sealants were tested at four conditions: virgin (before installation), after accelerated weathering (vacuum oven aging), after one, three, five, and nine years of field weathering. Figure 3 and Figure 4 present the CSBBR and CSDTT test results for the five Montreal sealants.



	Virgin	Oven Aged	1 yr W	9 yr W
Sealant A	21	17	42	74
Sealant B	22	25	44	28
Sealant E				
Sealant G	126	120	148	176
Sealant J	602	521	115	

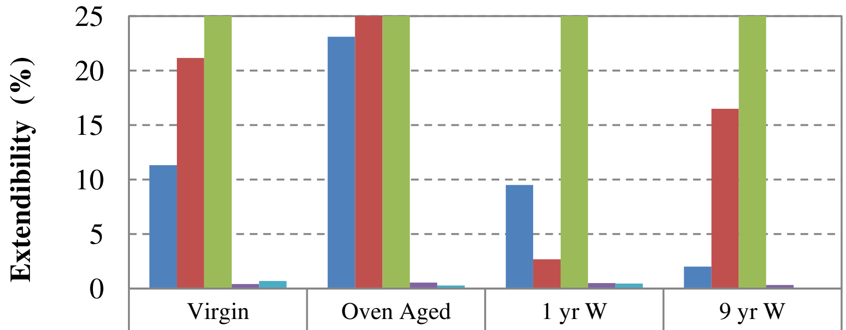
(a)



	Virgin	Oven Aged	1 yr W	9 yr W
Sealant A	0.30	0.33	0.29	0.28
Sealant B	0.31	0.28	0.29	0.34
Sealant E				
Sealant G	0.23	0.19	0.21	0.20
Sealant J	0.16	0.16	0.28	

(b)

FIGURE 3 (a) Stiffness at 240s and (b) Average creep rate of Montreal field sealants



	Virgin	Oven Aged	1 yr W	9 yr W
Sealant A	11.3	23.1	9.5	2.0
Sealant B	21.2	92.7	2.7	16.5
Sealant E	93.0	94.4	92.5	93.5
Sealant G	0.4	0.5	0.5	0.3
Sealant J	0.7	0.3	0.4	

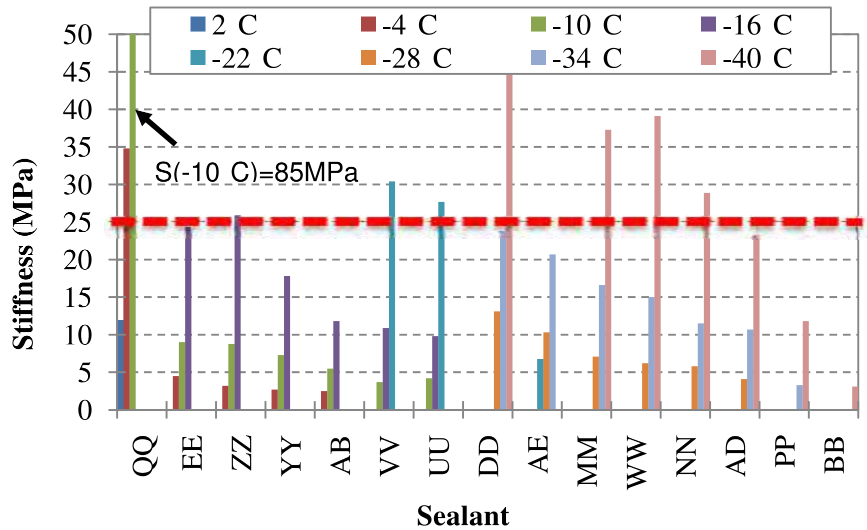
FIGURE 4 Extendibility of Montreal field sealants

The results presented in Figure 3 and Figure 4 show that in general, vacuum-oven-aged sealants exhibit a softer behavior (lower stiffness value) in the CSBBR test compared to 1- and 9-year field weathered sealant and higher extendibility in the CSDTT test. For sealant A, the Montreal field-aged sealant showed stiffening compared to the virgin sealant. However, vacuum-oven-aged sealant A showed slight softening. For sealants B and G, vacuum-oven-aged and the Montreal field-aged sealants showed similar stiffening with aging. For sealant J, vacuum-oven-aged results show softening compared to the virgin sealant, and a similar trend was observed for the Montreal field-aged samples.

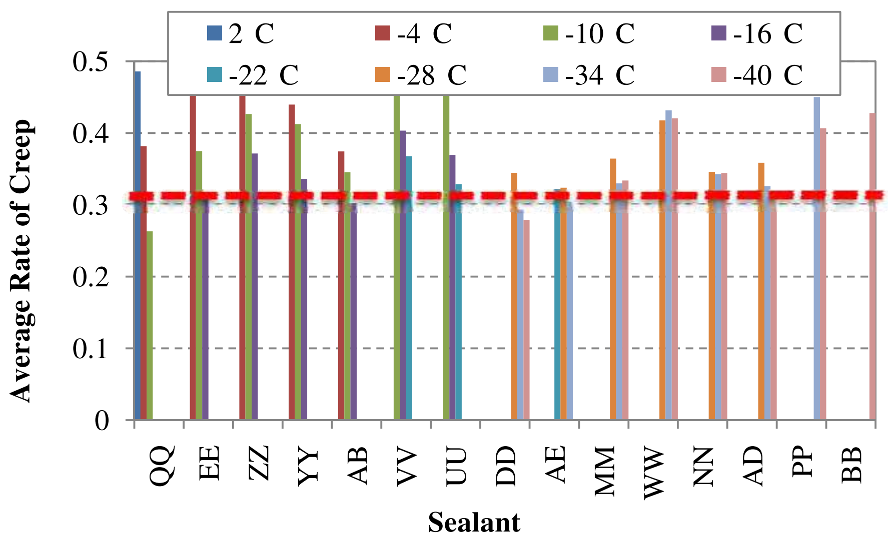
This variation between vacuum-oven-aged and field-aged of some sealants could be due to the fact that the samples obtained from the field had a high content of fine particles. Although significant effort was spent to remove the fine particles, complete removal might not have been achieved. In addition, a limited amount of material was collected from the field, so sealant samples were used for more than one test. Multiple heating and cooling cycles might have contributed to sealant softening. It is recommended that a comprehensive field survey and testing of field-aged sealant be conducted.

SEALANT TESTS PARAMETER THRESHOLDS SELECTION

An expert group of representatives from 26 transportation agencies and manufacturers discussed the most appropriate approach given the limited field data from Montreal and the rationale to identify selection thresholds for CSBBR and CSDTT tests. For the CSBBR test, two performance parameter thresholds were identified: stiffness at 240s and average creep ratio (ACR). Sealant B and sealant E performed the best in the Montreal study. The stiffness at 240s of sealant B varied from 22MPa at an un-aged state to 44MPa after one year of field weathering. For sealant E, the material was too soft for the procedure to accurately evaluate. The ACR for sealant B varied from 0.28 to 0.34mm/mm/s. The expert group recommended the use of 25MPa for the stiffness at 240s and 0.31mm/mm/s for the ACR as preliminary selection criteria. The recommended selection criteria were applied to the 15 laboratory-tested sealants, as shown in Figure 5. Most of the sealants pass the threshold at two testing temperatures, with the exception of the very stiff sealant, QQ.



(a)



(b)

FIGURE 5 (a) Stiffness at 240s and (b) Average creep rate of 15 laboratory-tested sealants

Researchers have shown that the maximum crack opening distance in the field can be as high as 90% of the original crack width (*13, 14, 15*). The factors that affect crack opening include pavement type, pavement location, crack configurations, and, most importantly, pavement temperature. A pavement crack in the northern region of the North America is generally subjected to larger crack opening distance. On the other hand, the pavement in the southern region is generally subjected to only a few days of subzero temperature. Given these environmental differences, the expert group suggested the selection criteria of the sealants based on in-service temperature and corresponding extendibility, as shown in Table 2. After the proposed selection thresholds were applied to the 15 laboratory-tested sealants (Figure 6), only three sealants did not pass the criterion under the testing conditions.

TABLE 2 Threshold for Extendibility at Various Lowest Pavement Service Temperatures

Temperature (°C)	-4	-10	-16	-22	-28	-34	-40
Extendibility (%)	10	25	40	55	70	85	85+

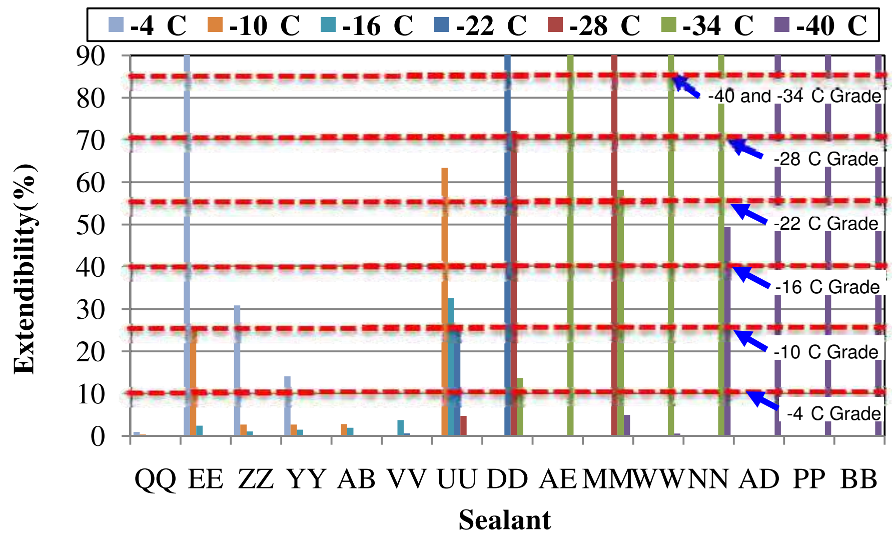


FIGURE 6 Extendibility of 15 laboratory-tested sealants

THRESHOLD VALIDATION USING NTPEP FIELD STUDY RESULTS

In 2005, the NTPEP conducted a program to study the installation and field crack sealing materials. Minnesota served as the host state and the Minnesota DOT (MNDOT) was responsible for locating the site for the installation, coordinating supplier participation, overseeing the experimental installation, and providing traffic control for the experimental installation as well as for the 2006 field evaluation. Using the selected sealant thresholds for the CSBBR and CSDTT parameters, the field performance of several sealants installed in Minnesota was used to validate the proposed low temperature selection criteria for crack sealants. The laboratory evaluations of the tested sealants were conducted at the MNDOT laboratory as well as at the Advanced Transportation Research and Engineering Laboratory (ATREL) of the University of Illinois at Urbana-Champaign.

Field Survey Results

Visual inspection was performed by the MNDOT staff during winter months. Two evaluations were scheduled and carried out during early October 2006 and mid-February 2008. Two distress evaluations were reported for each testing site: the percent length of adhesion /cohesion /infiltration and the present of stone/debris retention. The sealants showed evident signs of distress during cold weather when compared to the performance in the summer.

Adhesion and cohesion failures were determined through visual inspection. The percent length of adhesion/cohesion/infiltration is used to evaluate water infiltration. The percentage of cracks that would allow water infiltration, measured as the percentage of the overall crack length where water could bypass the sealant and enter the crack either through complete adhesion or cohesion failure, was determined by the following equation:

$$\%L = \frac{L_f}{L_{total}} \tag{2}$$

where,

%L = Percent length of the crack allowing water infiltration;
L_f = Total length of the crack sealant field evaluation section allowing the Infiltration of water (inches);
L_{total} = Total length of the crack sealant field evaluation section (inches).

The present of stone/debris retention was rated as follows:

- No debris retention: No stones or debris are stuck to the top of the sealant or embedded on the surface of the sealant/ HMA interface.
- Low Severity: Occasional stones and/or debris are stuck to the top of the sealant, or debris is embedded on the surface of the sealant/HMA interface.
- Medium Severity: Stones or debris are stuck to the sealant and some debris is deeply embedded in the sealant, or material is embedded between the sealant and the crack face, but does not enter the crack below the sealant.
- High Severity: A large quantity of stones and debris are stuck and deeply embedded in the sealant, or filling the crack, or a considerable amount of debris is embedded between the sealant and the crack face and entering the crack below the sealant.

The results of the field inspection and the associated performance index (PI), which was based on the level of adhesion/cohesion/infiltration, were calculated using the method presented by Masson (*7*). The results are presented in Table 3. It is worth noting that the NTPEP study did not separate the percentage de-bonding and pullout failure. Therefore, the calculated PI values are generally higher than those of the Montreal study. In this study, a PI value greater than 70 was defined as good performance (passed the standard). In general, all of the sealants performed satisfactorily during the first winter. Obvious distresses were observed during the second inspection, which was performed 29 months after installation. Only three sealants showed a PI less than 70% (Roadsaver 515MN, D-3405, and Beram 3060 LM).

Laboratory Test Results

Sealants were tested in the laboratory in accordance with the crack sealant performance grade specifications and ASTM specification D6690 type II material. Table 4(a) shows the results of two low temperature tests developed in this study. In addition, results of ASTM D6690 are also shown in Table 4(b). According to the results of the low temperature tests of crack sealants presented in this study, nine sealants were graded as “pass.” The three sealants graded as “fail” were D-3405, Beram 3060LM, and Elastoflex 63LM.

According to the ASTM specifications, three sealants were predicted to pass (3405, D-3405, and Beram 195) and nine sealants were predicted to fail. If one compares the ASTM specification prediction to the field performance survey, only three predictions were correct (Meadows 3405, Roadsaver 515MN, and Beram 3060LM). On the other hand, using the proposed test corresponding parameters, their thresholds correlate well with sealant field performance. It has to be noted that the results are based on sealants installed at one climatic region. To further validate the proposed tests and the selection thresholds, performance data of sealants installed at various climatic regions are needed.

TABLE 3 Sealant Field Inspections Results and Performance Index

Distress	Inspection	Adhesion/Cohesion/ Infiltration (%)	Stone/Debris Retention	Performance Index
Deery 101ELT	1st winter	0	No	100
	2nd winter	7	No	93
Deery 3723	1st winter	0	No	100
	2nd winter	24	No	76
Meadows 3405-M	1st winter	0	No	100
	2nd winter	9	No	91
Meadows 3405	1st winter	0	No	100
	2nd winter	22	No	78
Roadsaver 522	1st winter	0	No	100
	2nd winter	9	No	91
Roadsaver 515MN	1st winter	0	No	100
	2nd winter	38	No	62
Dura-Fill 3405	1st winter	0	No	100
	2nd winter	21	No	79
Dura-Fill 3725	1st winter	0	No	100
	2nd winter	24	No	76
Right Pointe D-3405	1st winter	0	No	100
	2nd winter	40	No	60
Beram 195	1st winter	0	No	100
	2nd winter	29	No	71
Beram 3060 LM	1st winter	0	No	100
	2nd winter	38	No	62
Elastoflex 63LM	1st winter	0	No	100
	2nd winter	27	No	73

TABLE 4 Laboratory Test Results of NTPEP Sealants

(a)

Standard	Crack Sealant Performance Grade			Result
Criteria	S 240	ACR	.	
	<25 MPa	>0.31mm/mm/s	>85%	
Temp (^{o}C)	-34	-34	-34	
Deery 101ELT	5	0.44	>90	Pass
Deery 3723	7	0.45	>90	Pass
Meadows 3405-M	6	0.38	>85	Pass
Meadows 3405	23	0.37	>85	Pass
Roadsaver 522	6	0.4	--	Pass
Roadsaver 515MN	13	0.43	>85	Pass
Dura-Fill 3405	12	0.39	>85	Pass
Dura-Fill 3725	8	0.34	--	Pass
Right Pointe D-3405	17	0.38	26	Fail
Beram 195	16	0.33	>85	Pass
Beram 3060 LM	13	0.37	2.47	Fail
Elastoflex 63LM	26	0.33	2.36	Fail

(b)

Standard	ASTM D6609 Type II				Result
Criteria	Cone Penetration	Flow	Resilience	Bond	
	(<90 dmm)*, †	(<3 mm)*	(>60%)*	(3 cycles)*	
Temp (C)	25°C	60°C	25°C	-29°C	
Deery 101ELT	103	2	55	P	Fail
Deery 3723	87	3	58	P	Fail
Meadows 3405-M	131	1	59	P	Fail
Meadows 3405	86	0	62	P	Pass
Roadsaver 522	90	5	49	P	Fail
Roadsaver 515MN	64	2	52	P	Fail
Dura-Fill 3405	79	2	57	P	Fail
Dura-Fill 3725	109	0	52	P	Fail
Right Pointe D-3405	73	0	73	P	Pass
Beram 195	76	0	60	P	Pass
Beram 3060 LM	112	1	47	P	Fail
Elastoflex 63LM	103	0	56	P	Fail

SUMMARY AND CONCLUSIONS

The parameter thresholds for low temperature sealant selection criteria, using the CSBBR and CSDTT tests, were identified using field data from Montreal. The study recommends stiffness at 240s of 25MPa and ACR of 0.31mm/mm/s for CSBBR test results and extendibility criterion for the CSDTT test results to be used at the lowest pavement in-service temperatures. The selection criteria were used with 12 field sealants, used in the NTPEP study, for validation. The result shows good correlation between low temperature performance grade sealant specification and field performance. This study clearly shows the validity of the proposed tests and selection criteria for hot-poured crack sealants at low temperature.

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