Evaluation of Joint and Crack Sealants Based on

Cyclic Loading and Rheological Properties

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Abstract

Sealing pavement joints and cracks is one of the essential pavement maintenance practices to protect subsurface layers from the ingress of moisture and debris. The expected life of a sealant is affected by several factors. In-service temperature range can be considered the most important factor. Using inappropriate crack sealant reduces its expected life which leads to reducing pavement design life. Development of a reliable characterization method for crack sealants has been a challenging process in the last decade. Currently, field studies are the most reliable method to evaluate sealants performance in cold climates which is not a cost-effective method. This research discusses two laboratory tests that were used for characterizing the performance of hot-pour sealants in cold climates. A cyclic tension and compression test -30^{o}C was used for testing the cohesion strength of sealants and the adhesion strength between sealants and pavement. Dynamic Shear Rheometer (DSR) test was used for characterizing the rheological properties of sealant at temperature range of +5^{o}C to +64^{o}C. The results of a two years field study were used to verify the reliability of these methods. These laboratory methods can replace costly and time-consuming field studies, and provide the ability to test and evaluate the performance of new sealing materials as they become available in market.

Introduction

Joint and crack sealants are used for protecting pavement structure from moisture, and prevent the retention of incompressible materials in joints [5]. Sealing materials have been improved during the last decades due to the availability of new materials that could have better sealing performance. Having good selection criteria based on laboratory evaluation can decrease the uncertainty about sealant field performance and the suitability of sealant to site climate. Current ASTM tests for sealants are empirically-based tests and do not reflect the field performance of sealants. Field studies are the most reliable alternative for ASTM tests to evaluate sealants performance, which is not a cost-effective method. Several laboratory evaluation methods have been proposed to evaluate sealant performance by testing the parameters that could affect filed performance at different temperatures. These parameters could be the mechanical properties of sealant, adhesion to different pavement materials, or chemical composition of sealant.

Sealant is considered failed if it can not perform its function probably, which is protecting pavement from the ingress of moisture and debris. Sealant failures can be classified to two types: cohesion failure, and adhesion failure. Cohesion failure occurs when the cohesion between sealant particles can not withstand the external stresses applied on it and sealant cracks or rupture. Adhesion failure occurs when the bond between sealant and crack surface is not sufficient enough to resist stresses due to pavement shrinkage. There are a lot of sealant properties that may affect the type of failure, for example: stiffness, ability to dissipate tensile stress, and sealant viscosity at installation temperature [9].

Zanzotto [12] developed two tests for evaluating adhesion strength and stress relaxation for sealants at low temperatures. Adhesion strength was tested by pulling a cylindrical sealant sample away from a concrete block at a rate of 10 mm/min. Stress relaxation for sealants was evaluated by applying 50% strain on a cylindrical sample at a rate of 1 mm/min. and measuring the corresponding stress for one hour. The results of these tests were used together with the results of filed evaluation studies conducted using the same sealants to develop threshold values for sealant selection.

Al-Qadi et al. [1] used a cyclic shear and constant horizontal deformations to evaluate the performance of rigid pavement joint sealants. The horizontal deformation was used for simulating temperature loading, while the cyclic shear was used for simulating traffic loading. Worms and Shalaby [11] evaluated hot-poured sealants using a cyclic tension and compression test at three temperatures: -30^{o}C, 0^{o}C, and +30^{o}C.

Masson [8] stated that sealant rheology relates to sealant stiffness and stress relaxation. Rheological properties of sealants can be evaluated at low temperature using the bending beam rheometer test (BBR). Al-Qadi et al. [2] doubled the thickness of the BBR sample, so that the BBR test could be conducted for soft sealants. This modified sample size was used for evaluating eight hot-pour sealants [3]. Creep stiffness and creep rate were used for ranking sealants and represent stiffness and stress relaxation ability at low temperature.

Lynch and Janssen [6] characterized the viscoelastic properties of silicone sealants by using DSR test. DSR test were conducted for six silicone sealants at temperatures ranging from -30^{o}C to +50^{o}C in 10^{o}C increments and at different frequencies. The DSR data, complex shear modulus (G^*) and phase angle (δ), were used to construct master curves at selected temperatures.

Masson et al. [10] measured the viscosity of bituminous hot-pour sealants using a Bohlin Visco-88-BV viscometer at installation temperatures. Sealant were stirred for 30 minutes in a closed vessel before testing and the temperature was maintained constant at 185 ± 1^o C. Results showed that sealants with viscosity less that 10 Pa.s were self levelling and expected to have good adhesion, while sealants with viscosity greater that 30 Pa.s were difficult to pour and expected to have poor adhesion. A good agreement was found between sealant viscosity and the filed performance of sealant after one year.

Experimental Program

Eight hot-pour sealants are included in this study. Two sealants are classified as type I and the remaining as type IV according to ASTM standards D6690 [4]. Table 1 shows the tested sealants and the results of penetration, bond, and resilience tests conducted for these sealants. Two laboratory tests were adopted for characterizing sealants performance: cyclic tension and compression test at -30^{o}C, and DSR test at temperatures from +5^{o}C to +64^{o}C. Cyclic tension and compression test simulates thermal loading cycles, while, DSR test characterize the rheological properties of sealants.

Table 1: Properties of Tested Sealants

Sealant	Type	Penetration (1/10 mm)	Bond test [a]	Resilience (%)
Z	I	67	Pass	82
Y	I	95	Pass	67
X	IV	95	Pass	83
W	IV	115	Pass	68
V	IV	148	Pass	71
U	IV	116	Pass	54
T	IV	115	Pass	53
S	IV	121	Pass	72

[a] Bond test conducted at temperature -18°C for type I sealants and -29°C for type IV

Cyclic Tension and Compression

The sealant specimen consists of a sealant strip with 10 mm thickness placed between two concrete blocks with cross-section 50mmx75mm and height 50mm. the aggregate used in the preparation of concrete blocks is a mix of granite and river gravel. A curing time is allowed for concrete to reach a minimum strength 30MPa after 28 days. Each two blocks are poured together as one piece and saw-cut after curing to simulate the actual pavement joint surface. Four anchor bolts are placed in each block to mount the specimen on the loading fixture. Each two blocks are clamped together to form a gap of 50mm width, 50mm length, and 10mm thickness. Sealants are heated to the pouring temperatures recommended by the manufacturer and poured in the gap between the two concrete blocks. Figure 1 shows the specimen of cyclic tension and compression test.

The sealant specimen is subjected to sinusoidal axial tensile and compressive deformation with amplitude 2mm and frequency 0.003 Hz at -30°C. Liquid nitrogen is used for reaching the desired temperature. Each sealant sample is subjected to 25 loading cycles. The test is stopped when complete debonding between the sealant and the concrete block occurs or when 85% drop of tensile load is reached.

Four sealants (Z, Y, X, and U) experienced adhesion failure; two of them (Z and X) showed complete debonding between sealant and concrete block. The percent load drop was directly calculated from the initial and final loads, which were measured from cyclic test, as indicated in equations 1 and 2.

$$\%LoadDropTension\ (LDT) = \frac{Initial\ Tensile\ Load - Final\ Tensile\ Load}{Initial\ Tensile\ Load} * 100 \quad \textbf{(1)}$$

$$\%LoadDropCompression\ (LDC) = \frac{Initial\ Compressive\ Load - Final\ Compressive\ Load}{Initial\ Compressive\ Load} * 100 \quad \textbf{(2)}$$

High percent load drop can be due to failure of sealant, or soften of sealant due to cyclic load. To distinguish between the two cases, another factor should be calculated "Percent Load Drop Ratio" which is the ratio between the percent load drop in tension and compression, as indicated in equation 3.

$$Load\ Drop\ Ratio\,(LDR) = \frac{\%\,Load\ Drop\ Tension\,(LDT)}{\%\,Load\ Drop\ Compression\,(LDC)} \quad \textbf{(3)}$$

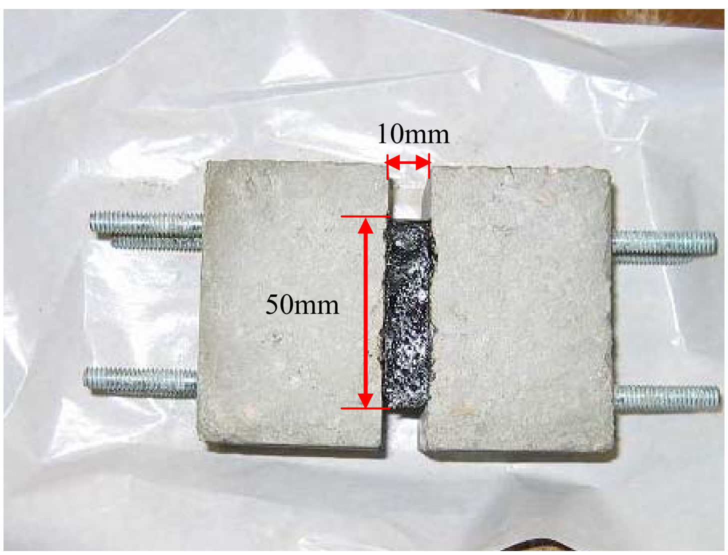

FIGURE 1: Sealant Specimen for Cyclic Tension and Compression Test

Sealant dimensions are 50 mm width, 50 mm length, and 10 mm thickness.

A value of *LDR* close to one indicates that the sealant material is flexible at low temperature and has the ability to dissipate load in tension and compression, so it can resist adhesion failure. A high value of *LDR* (close to two or higher) indicates that the sealant material is stiff and that an adhesion failure may have occurred (if *%LDT* is high). An intermediate value of *LDR* indicates that the sealant material has intermediate stiffness, so it has the ability to dissipate load and can resist the penetration of incompressible debris.

The severe loading condition that may cause adhesion failure occurs at low temperature. Table 2 shows *%LDT, %LDC,* and *LDR* at temperature -30^{o}C, where these values represent the worst loading condition. Sealants that experienced adhesion failure (Z, Y, X, and U) have *%LDT* higher than 75% and *LDR* higher than 1.75. While, other sealants have *%LDT* ranges from 45.88% to 68% and *LDR* ranges from 1.08 to 1.60.

Table 2: Percent Load Drop and LDR at Temperature -30°C

Sealant	*% LDT*	*% LDC*	*LDR*
Z	87.62 [1]	34.24	2.56
Y	87.14 [1]	48.23	1.81
X	88.38 [1]	42.56	2.08
W	53.37	40.80	1.31
V	45.88	42.67	1.08
U	79.97 [1]	43.79	1.83
T	61.34	38.60	1.59
S	67.92	48.25	1.41

[1] Adhesion Failure Noted

Dynamic Shear Rheometer (DSR)

DSR test was conducted at temperature range of +5^{o}C to +64^{o}C using Bohlin DSR equipment shown in Figure 2. All tests were conducted with the 25 mm diameter sample with a gap of 1.0 mm. A sinusoidal strain was applied to sealant specimen with frequency 1.5 Hz. The strain amplitude was selected to be 2% for test temperatures from +5^{o}C to +40^{o}C and 4% for temperatures from +46^{o}C to +64^{o}C. These strain amplitudes were selected such that all the tested sealants satisfy the linearity conditions proposed by Marasteanu and Anderson [7] for DSR test.

Figure 3 shows an example of the results of the pilot tests conducted to select the appropriate strain amplitudes.

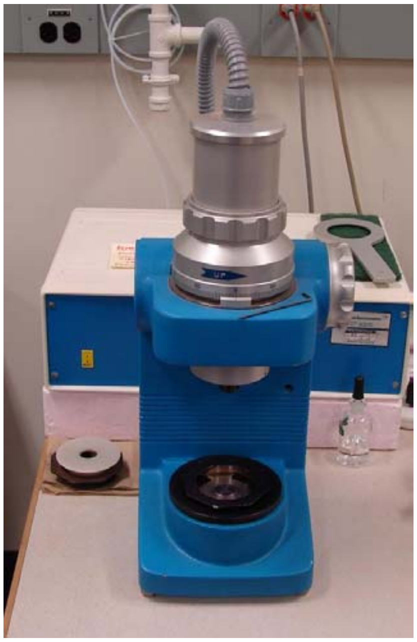

FIGURE 2: DSR Testing Equipment

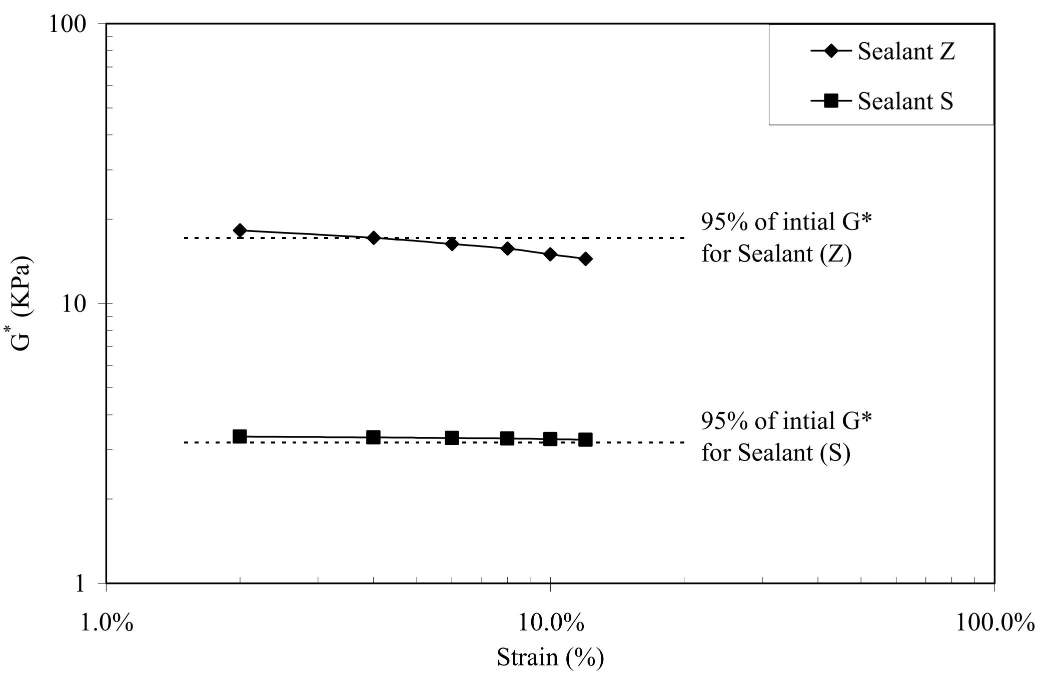

FIGURE 3: Linearity Check for Sealants (Z) and (S) at +64°C

Ten minutes were allowed for the equilibrium of specimen temperature before starting test. At each test temperature, the sealant specimen was subjected to ten conditioning cycles followed by another ten cycles for obtaining test results. At temperatures from +5°C to +16°C, the 2% strain could not be achieved for some stiff sealants (Z, Y, and X), where the DSR equipment limit the stress that can be applied to the 25 mm specimen to 3228 Pa.

Figure 4 and Table 3 show the complex shear modulus (G^*) obtained from the DSR test. At temperature +5°C, sealants Z and Y have G^* higher than 1200 KPa, while, sealants S, T and V have G^* less than 200 KPa. The measured phase angles for the tested sealants ranged from 25 to 55 degrees and they were not sensitive to test temperature in the range of +5°C to +64°C.

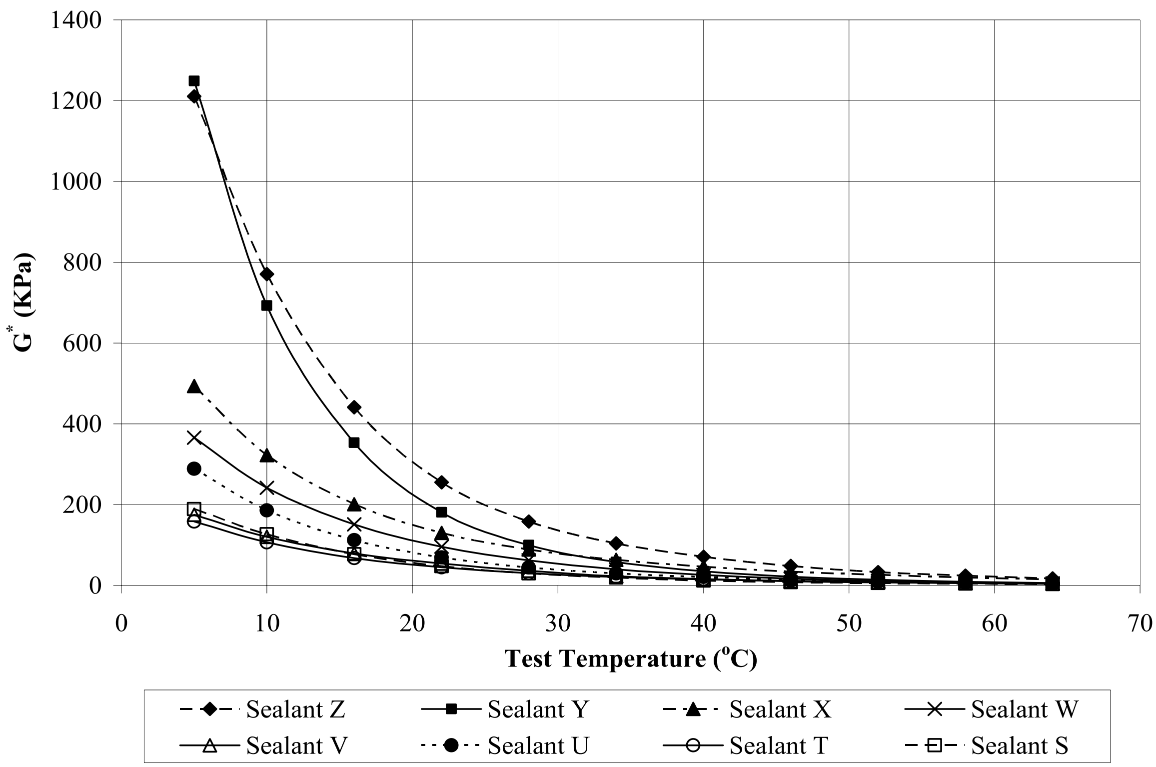

FIGURE 4: Complex Shear Modulus (G^*)-Temperature Curve

TABLE 3: Complex Shear Modulus (G*) for Tested Sealants

Sealant	G^* (KPa)		
	+5°C	+34°C	+64°C
Z	1211	104	17.1
Y	1249	58.0	6.1
X	494	63.4	15.1
W	365.8	40.3	5.2
V	175.1	23.0	4.2
U	288.8	30.1	5.3
T	158.1	20.9	4.0
S	189.4	19.3	3.3

Field Evaluation of Tested Sealant

The eight hot-pour sealants evaluated in this study were applied to longitudinal and transverse cracks of a test section located in a major highway near Winnipeg, MB. The sealed cracks were inspected after each winter for a period of two years. The lengths of sealants failures were measured and the rate of failure was calculated for each sealant.
Table 4 shows the rate of failure calculated for transverse cracks only after two years of sealants application. Sealant Z showed the highest failure rate (70%), while, Sealant S showed the lowest failure rate (2%).

Sealant Evaluation Criteria

LDR at -30^{o}C and G^* at +5^{o}C were selected to characterize sealant performance at low temperature. *LDR* reflects the sealant ability to dissipate tensile and compressive stresses from cyclic loading. A sealant with a low *LDR* at -30^{o}C and G^* at +5^{o}C is expected to has a less adhesion failures and better field performance.

Table 4 shows the ranking of the tested sealant according to *LDR* at -30^{o}C and G^* at +5^{o}C. Sealants were ranked from 1 to 8, where, 1 corresponds to excellent performance and 8 corresponds to very poor performance. A good agreement was found between the two laboratory evaluation criteria. Also, a good agreement was found between the field evaluation and laboratory evaluation in defining sealants with poor performance.

TABLE 4: Ranking of Tested Sealants According to Field and Laboratory Evaluation

Sealant	Rate of Sealant Failures (%)	Field Evaluation	Laboratory Evaluation	
			LDR at -30°C	G^* at +5°C
Z	70	8	8	7
Y	57	6	5	8
X	65	7	7	6
W	30	3	2	5
V	32	4	1	2
U	36	5	6	4
T	29	2	4	1
S	2	1	3	3

Summary and Conclusions

The laboratory performance of eight hot-pour sealants were evaluated with two tests: cyclic tension and compression test at -30°C, and DSR test at temperatures from +5°C to +64°C. The cyclic tension and compression test evaluate the adhesion strength between sealant and concrete blocks and the sealant ability to dissipate stresses from cyclic loading. The sealant ability to dissipate stresses was evaluated based on the ratio between the percent of load drop in tension and compression (*LDR*).

The DSR test was conducted at temperatures ranging from +5°C to +64°C to characterize the stiffness of sealant. Pilot tests were conducted to select the appropriate strain level for conducting tests. The strain level was selected to maintain the sealant behaviour in the linear viscoelastic region. Complex shear modulus and phase angle were recorded at different test temperatures. Phase angle was not sensitive to test temperature in the range of +5°C to +64°C.

The failure rates obtained from a two years field evaluation of the tested sealants were compared to the laboratory evaluation criteria. Two laboratory evaluation criteria were selected: load drop ratio (*LDR*) and complex shear modulus at +5^{o}C. Tested Sealants were ranked from 1 to 8 according to the field and laboratory evaluation criteria, where, 1 corresponds to excellent performance and 8 corresponds to very poor performance. A good agreement was found between the two laboratory evaluation criteria. Also, a good agreement was found between field evaluation and laboratory evaluation criteria for sealants with poor performance. The method presented can be used for distinguishing poor performing sealants, however, additional laboratory evaluation criteria are required to distinguish between sealants with fair to excellent performance.

Acknowledgement

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