Evaluation of Low Temperature Properties of Asphalt Crack Sealants Using the Direct Tension Tester

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ABSTRACT

It is critical to identify the low temperature properties of different asphalt crack sealants to achieve long lasting performance. The current test methods, as outlined in ASTM International D5329, do not provide an effective way to correlate field performance to test results. The Direct Tension Tester (DTT) is a Superpave instrument designed to study the low temperature properties of asphalt binders. The DTT consists of elongating asphalt binders and studying its failure mechanisms. In this study, the DTT is used to study the thermally induced stress for different asphalt crack sealants when the temperature decreases from 5°C to -30°C. Both hot and cold-applied asphalt crack sealants are included in this study. Similar to the Thermal Stress Retained Specimen Test (TSRST), with the ends of specimen restrained, the tensile stress due to thermal contraction of different asphalt sealants is plotted versus temperature. Results indicate that the thermal stress can be used to differentiate the bonding capability for different asphalt crack sealants. The tensile stress and strain at -29°C for different asphalt crack sealants are also measured. The comparison shows that the DTT can be used to classify asphalt crack sealant based on their low temperature property.

RÉSUMÉ

Il est critique d'identifier les propriétés de différents scellements bitumineux de fissures pour obtenir une performance qui dure longtemps. Les méthodes d'essais courantes, telles que résumées dans l'ASTM International D5329, ne procurent pas un moyen efficace de corréler la performance en chantier avec les résultats d'essai. L'appareil de traction directe (ATD) est un instrument Superpave conçu pour étudier les propriétés à basse température des liants bitumineux. L'ATD fait l'étirement des liants bitumineux et étudie leurs mécanismes de rupture. Dans cette étude, l'ADT est utilisé pour étudier la contrainte thermique induite dans divers scellements bitumineux de fissures quand la température décroît de 5°C à -30°C. Les bouche-fissures bitumineux à froid et à chaud sont tous deux inclus dans cette étude. Comme dans l'essai de retrait thermique empêché (ERTE), avec les bouts de l'échantillon retenus, la contrainte due à la contraction thermique de divers bouche-fissures bitumineux est tracée en fonction de la température. Les résultats montrent que la contrainte thermique peut être utilisée pour différencier la capacité d'adhérence de divers bouche-fissures bitumineux. La contrainte de tension et la déformation à -29°C de divers bouche-fissures sont aussi mesurées. La comparaison montre que l'ATD peut être employé pour classifier les bouche-fissures selon leurs propriétés à basse température.

1.0 INTRODUCTION

To prevent underlying pavement structure from water penetration, crack sealing is one of the main practices used to prevent pavement deterioration. Properly applied crack sealant prevents further pavement degradation and prolongs pavement life [1-3]. Among the different materials used in crack sealing and filling, asphalt crack sealant is one of the most common materials. Based on the temperature of application, there are hot-poured (applied) and cold-poured (applied) asphalt crack sealants. Both types of asphalt crack sealants are highly modified with polymers and other additives. Asphalt crack sealants have been successfully applied in warm climates with desirable durability [4, 5]. However, asphalt crack sealants often suffer from cohesive or adhesive failures in cold harsh climates when exposed to many freeze-thaw cycles [6]. The causes of these failures are usually divided into major categories: sealant properties and installation factors [7, 8]. Sealant properties are intrinsic factors related to chemical composition and rheological behaviour, such as adhesion, ageing, viscosity, viscoelasticity, and cohesive strength. Installation factors are extrinsic criteria related to crack sealant application, such as crack preparation and cleaning, weather conditions, and joint design. For adhesive failure, the interaction between the crack surface and the sealant is the key issue. Both sealant properties and installation factors have significant contributions to the failure mechanism. Cohesive failure happens away from the interface. The sealant properties are the key factors. When the tensile strength on the sealant exceeds its cohesive strength, the sealant will crack in the middle [7]. To prevent these failures and achieve long-lasting performance, it is critical to properly identify the low temperature properties of different asphalt crack sealants.

However, the current crack sealant specification in ASTM International (ASTM) D6690 [9] and test methods outlined in ASTM D5329 [10] do not provide an efficient way to correlate field performance with physical properties [7, 8]. Bond test in these specifications has only a grade of pass or fail, which does not rank the performance of the same type of crack sealants in a clear manner. Furthermore, these specifications focus on average climate conditions and do not specifically address cold climate conditions [6]. There is a need to develop performance-based test criteria that measures the response of the crack sealant to the stress caused by low temperatures. Penetration and viscosity have been used as a guideline to select low-temperature crack sealants however, both properties do not consistently correlate to low-temperature performance [2, 7]. Masson and colleagues have identified that the physico-chemical properties of asphalt sealant can be used to correlate their field performance. Furthermore, they have recommended using the rheological properties of the asphalt crack sealants as a basis for developing a performance-based specification [11-13].

Superpave™ (Superpave) specification developed by the Strategic Highway Research Program (SHRP) has successfully related rheological properties of asphalt binders to their field performance [14]. Crack sealant manufacturers have used Performance Graded (PG) grading system to differentiate the performance limits for different hot-poured asphalt crack sealants. Researchers have attempted to use the Superpave equipment, such as the Bending Beam Rheometer (BBR), to study the low temperature properties of different asphalt crack sealant [8]. The Direct Tension Tester (DTT) is a Superpave equipment designed to study the low temperature failure properties of asphalt binders [15]. This test consists of elongating specimens of an asphalt binder and studying their failure mechanism. These properties can be used as criteria to select an asphalt crack sealant based on their mechanical response to low temperature. The other low temperature test method that has been used to evaluate failure properties of asphalt crack sealants is the Thermal Stress Retained Specimen Test (TSRST) [16, 17]. This method evaluates the low temperature cracking susceptibility of asphalt paving mixtures. The ends of the specimens are restrained and as the temperature drops, thermal tensile stresses build up until the specimen fractures. Following the same TSRST mechanism, the DTT can be used to monitor the thermally induced tensile stress building up inside the asphalt at different low temperatures, which can be used as an indicator for the sealant's effectiveness.

In this study, the DTT is used to study the thermally induced stress build-up for different asphalt crack sealants when the temperature decreases from 5°C to -30°C. Both hot applied and cold-applied asphalt crack sealants are included in this study. Similar to the TSRST [16], with the ends of the specimen restrained, the tensile stress due to thermal contraction of different asphalt sealants is plotted versus temperature. Results indicate the thermal stress can be used to differentiate the bonding capability of different asphalt crack sealants. The tensile stress and strain at -29°C for different asphalt crack sealants are also measured. These properties are correlated to the bond test results and used to rank the performance of different sealants. The comparison shows that the DTT can be used to classify asphalt crack sealant based on their low temperature behaviour.

2.0 EXPERIMENTAL DESIGN

2.1 Materials

2.1.1 Asphalt

To evaluate the effect of asphalt softness on the low temperature properties, several different penetration range asphalts were selected: 200/300, 120/150, 80/100, 40/60, and 10/30. The penetration values for these asphalts are listed in Table 1.

Table 1. Penetration Values of Different Asphalt

Penetration Range	10/30	40/60	80/100	120/150	200/300
Penetration at 25°C	25	44	90	122	265

To evaluate the effect of polymer, 80/100 penetration range asphalt was selected as the base and modified with a Styrene-Butadiene-Styrene (SBS) radial copolymer. The percentages of polymer content are: one, two, and four percent.

2.1.2 Crack Sealants

Both hot-pour and cold-pour asphalt sealants were selected in this study (Table 2). The hot-poured crack sealants were coded as SH1 to SH6, and SC1 and SC2 were two cold-poured sealants.

Table 2. Crack Sealants Properties

Sealant	Penetration at 25°C	Bond Test	Pass/Fail
SH1	66	-29C 50% Extension	Pass
SH2	127	-29C 200% Extension	Pass
SH3	40	-29C 50% Extension	Pass
SH4	79	-29C 200% Extension	Pass
SH5	29	-18C 50% Extension	Pass
SH6	19	-18C 50% Extension	Fail
SC1	55	N/A	N/A
SC2	86	N/A	N/A

SH1 and SH3 conformed to the requirements of ASTM D6690 Type II. SH2 was an extra low modulus, low resilience crack sealant for various low temperature applications. SH4 conformed to the requirements of ASTM D6690 Type III. SH5 met the specification of ASTM D6690 Type I, while SH6 failed the bond test. Both SH5 and SH6 had high viscosity and were design for hot to moderate climates. SC1 and SC2 were cold-poured crack sealant designed for moderate and cold climates.

2.2 Experiment

2.2.1 Sample Preparation

Hot-poured crack sealants were heated until fluid to pour in the oven at the manufacturer recommended pour temperatures. The samples were poured into preheated DTT molds at cooled at ambient temperature for 24±4 hrs for conditioning. Asphalt samples were also conditioned for 24±4 hrs before testing.

For cold-poured sealants, the samples were poured into the molds at ambient temperature and cured for 24±4 hrs. The specimens were then cured in a 60°C oven for 12±2 hrs. Finally, the sample was cooled at ambient temperature for 2 hrs before testing.

2.2.2 DTT Testing (Simulating TSRST)

The temperature of the DTT was set at 5°C. The specimen was conditioned in the bath for 60±10 minutes. The specimen was then mounted on the loading pins of the load frame. A load of 1±0.2 newton (N) was preloaded on the specimen. The bath was then changed to cool from 5°C to -30°C. The load was zeroed. During the cooling period, the DTT was not started. The temperature of the bath and the stress reading were recorded every 2 minutes though the cooling process.

2.2.3 DTT Testing (Failure Stress and Strain)

The failure stress and strain of the samples were tested at -29°C after 60±10 minutes conditioning. For samples that did not break the maximum stress value was recorded.

3.0 RESULTS AND DISCUSSIONS

3.1 Effect of Asphalt Softness (Penetration)

As temperature decreases from 5°C to -30°C, asphalts with different penetration ranges show different thermal stress build-up (Figure 1). At the same temperature, lower penetration or harder asphalt has a higher thermal stress value compared to the higher penetration or softer asphalts. At -30°C, the 10/30 asphalt has a thermal stress value close to 1 MPa, while 200/300 asphalt has a stress less than 0.2 MPa. The rate of thermal stress build-up increases as the penetration range decreases. The failure stress and strain values for these asphalts at -29°C are listed in Table 3. Although the failure stresses of these asphalts do not show significant difference, the failure strain increases as the asphalt becomes softer. The failure strains are less than one percent for all of these asphalts, which indicates that these asphalts are brittle at extreme low temperatures. To increase the elasticity at low temperature, polymer modification is needed.

To obtain a relative measure of the resistance for asphalt to low temperature induced stress failure, the Thermal Stress Index (I_T) is introduced.

$$I_T = \frac{\sigma_T}{\sigma_F} \times 100 \quad (1)$$

where: σ_T is the thermal stress measured at -29°C
σ_F is the failure stress measured at -29°C

I_T is a positive constant with a value from 0 to 100. A higher I_T value means the material is more likely to crack at low temperature. From the data in Table 3, as the penetration of the asphalt increases, I_T decreases. the 200/300 asphalt has the lowest I_T value, which means this asphalt is more thermal crack resistant than other asphalts at low temperatures.

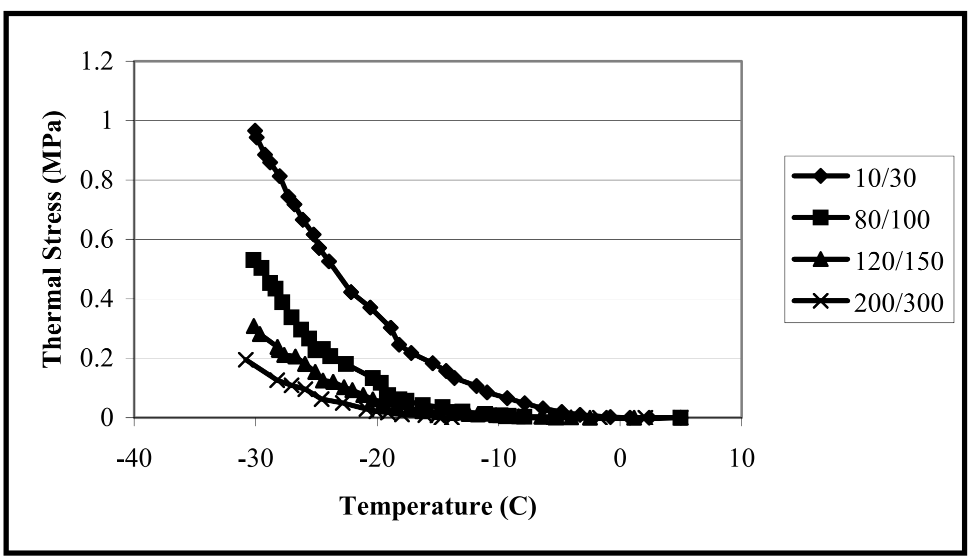

Figure 1. Thermal Stress versus Temperature (Asphalts with Different Penetration Range)

Table 3. Stresses for Asphalts with Different Penetration Range

	200/300	120/150	80/100	10/30
Thermal Stress (MPa)	0.15	0.25	0.47	0.87
Failure Stress (MPa)	2.44	2.24	2.99	1.62
Failure Strain (%)	0.388	0.232	0.213	0.144
Thermal Stress Index (I_T)	6.1	11.2	15.7	53.7

3.2 Effect of Polymer Modification

The effect of polymer modification on thermal stresses is shown in Figure 2 and Table 4. The addition of polymer decreases the thermal stress at -30°C and slows down the rate of thermal stress build-up. The penetration of the blend decreases, while both failure stress and strain increase, as polymer content increases. The thermal stress index decreases with the addition of polymer. The addition of polymer increases the elasticity of asphalt and provides a higher modulus while improving its stress relaxation. The Polymer Modified Asphalt (PMA) is more flexible than neat asphalt at low temperature. The data also indicates that penetration may be misleading when it is used to correlate PMA low temperature performance.

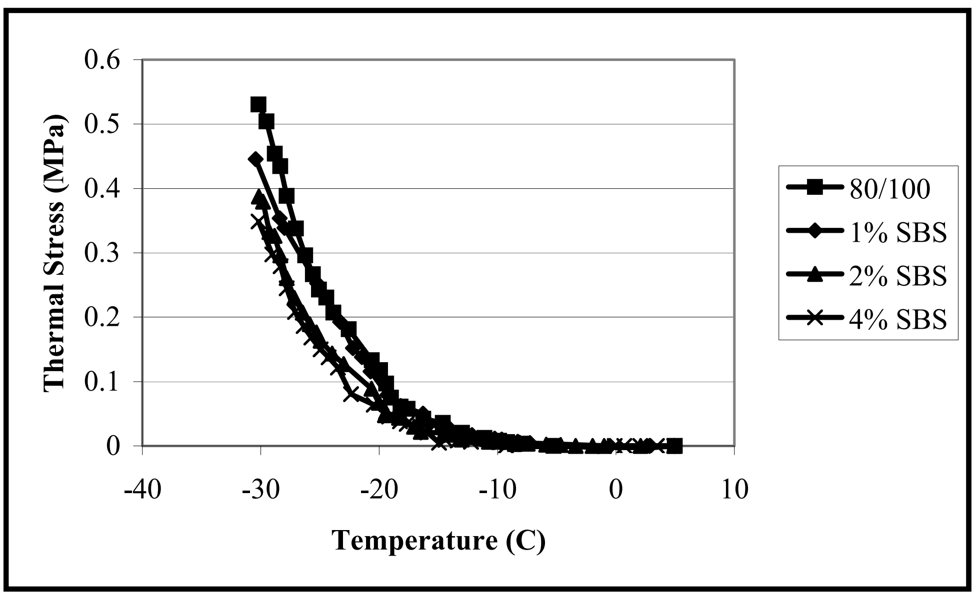

Figure 2. Thermal Stress versus Temperature (80/100 with Different Polymer Content)

Table 4. Stresses for Asphalts with Different Polymer Content

	80/100	1% SBS	2% SBS	4% SBS
Penetration at 25C	90	83	76	62
Thermal Stress (MPa)	0.47	0.40	0.33	0.29
Failure Stress (MPa)	2.99	3.82	4.43	6.63
Failure Strain (%)	0.213	0.391	0.626	1.101
Thermal Stress Index (I_T)	15.7	10.5	7.4	4.4

Note: SBS = Styrene-Butadiene-Styrene

3.3 Evaluation of Different Hot-Poured Crack Sealants

Figure 3 and 4 show the thermal stress build-up for different hot-poured crack sealants. Low-temperature crack sealants have much lower thermal stress than high temperature crack sealants. SH6, which failed the bond test, has the highest thermal stress level (close to 0.7 MPa at -30°C). SH5, with a thermal stress less than 0.2 MPa at -30°C, passes the -18° C bond test. SH1 to SH4, pass the bond test at -29°C, and have thermal stresses less than 0.1 MPa. SH1 and SH3 have relatively higher thermal stress values compared to SH2 and SH4. The extra low modulus SH2 shows almost no thermal stress build-up through the cooling process. Both SH1 and SH3 pass the bond test at -29°C with 50 percent extension, while SH2 and 4 passes with 200 percent extension. The results indicate that the thermal stress might be used to differentiate the low temperature performances of crack sealants with same bond test results.

Crack sealants SH1 to SH5 did not break during the failure strain/stress test (Table 5). SH6 breaks at a low strain level. SH2 and SH4 show lower stresses compared to SH1 and SH3. SH5 and SH6 have higher I_T values than the other low temperature crack sealants. The differences in I_T between SH2 and SH4, and SH1 and SH3 can be used to rank the relative performance of the same type of crack sealants. Further research and field evaluation are needed to relate the thermal stress index to the performance of the crack sealant.

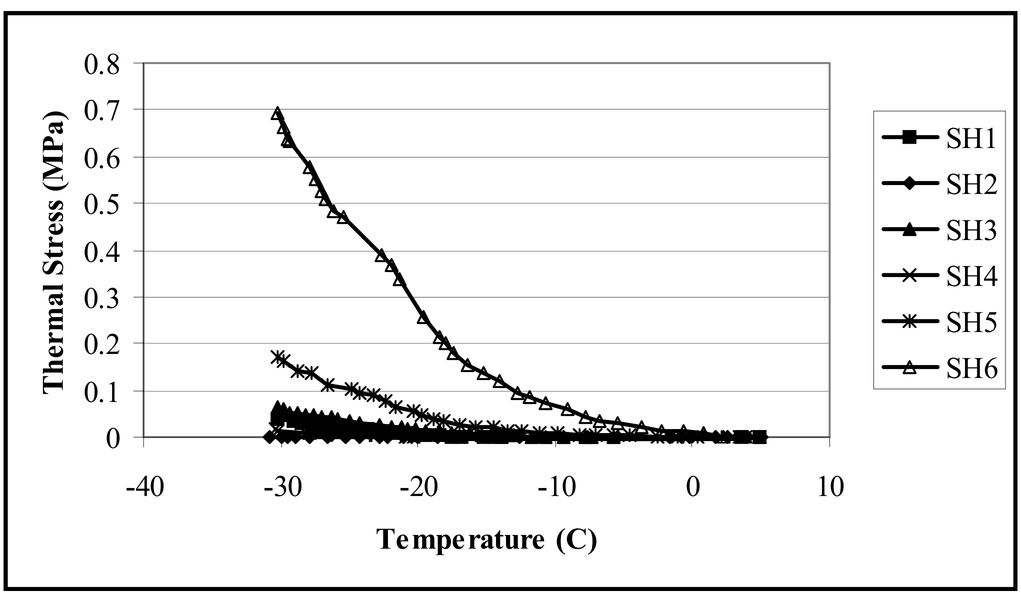

Figure 3. Thermal Stress versus Temperature (Hot-Poured Crack Sealants)

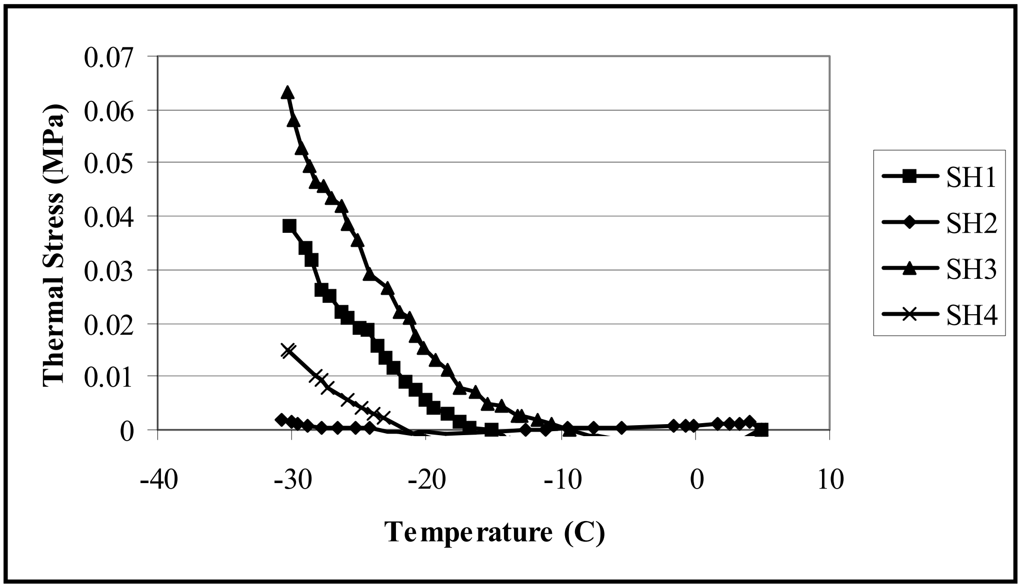

Figure 4. Thermal Stress versus Temperature (Hot-Poured Low Temperature Crack Sealants)

Table 5. Stresses for Hot-Poured Crack Sealants

	SH1	SH2	SH3	SH4	SH5	SH6
Thermal Stress (MPa)	0.035	0.0009	0.0505	0.012	0.15	0.6
Failure/Max. Stress (MPa)	1.86	0.225	1.48	0.69	1.2	2.37
Failure Strain (%)	Not broken	Not broken	Not broken	Not broken	Not broken	0.384
Thermal Stress Index (I_T)	1.9	0.4	3.4	1.7	12.5	25.3

3.4 Evaluation of Different Cold-Poured Crack Sealants

Thermal stress build-up and the thermal stress index can also be used to differentiate the performance of cold-poured crack sealants (Figure 5 and Table 6). Both SC1 and SC2 are designed for similar climate, but they show significant differences in thermal stresses. SC2 has a higher failure stress and lower thermal stress, resulting in a low I_T value. This indicates that SC2 is much more stable in low temperature climates.

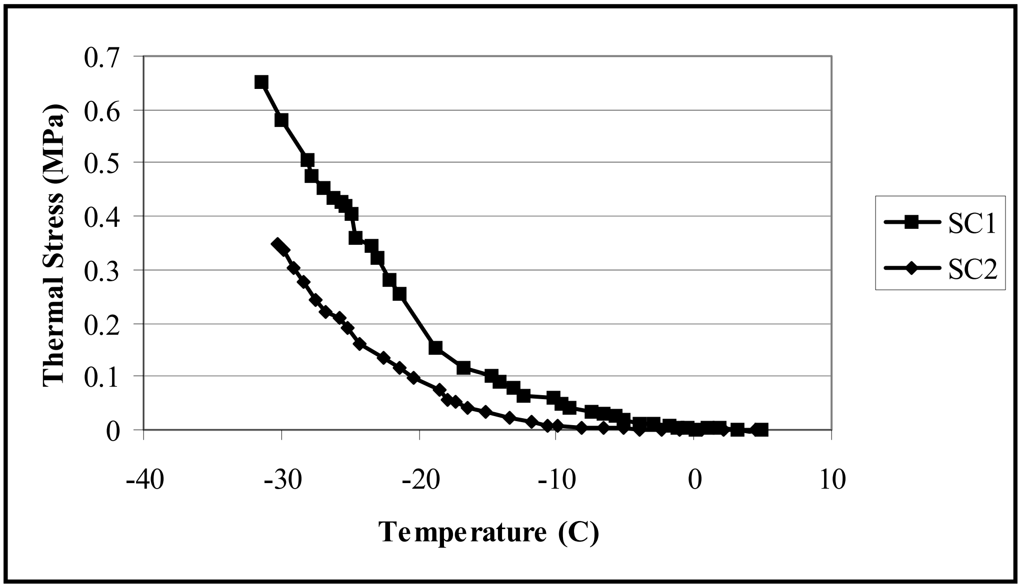

Figure 5. Thermal Stress versus Temperature (Cold-Poured Crack Sealants)

Table 6. Stresses for Cold-Poured Crack Sealants

	SC1	SC2
Thermal Stress (MPa)	0.54	0.30
Failure Stress (MPa)	1.47	5.34
Failure Strain (%)	0.148	1.86
Thermal Stress Index (I_T)	36.7	5.6

4.0 SUMMARY OF FINDINGS

1. DTT can be used to measure and rank the low temperature performance of crack sealants.
2. Thermal Stress Index (I_T) and thermal induced stress values can be used to differentiate the same type of crack sealants (hot-poured and cold-poured).
3. Asphalts with higher penetration have lower thermally induced stress and is more thermally crack resistant than asphalts with a lower penetration.
4. Polymer modification improves the elasticity of the asphalt and provides durability at low temperatures.
5. Penetration may not correctly reflect the low temperature performance of polymer modified asphalts.
6. Good low temperature performance crack sealants have low thermally induced stress and low thermal stress index values.

REFERENCES

1. Chong GJ. "Rout and Seal Cracks in Flexible Pavement – A Cost-effective Preventive Maintenance Procedure", Transportation Research Record No. 1268, Transportation Research Board, National Research Council, National Academies, Washington, D.C., 8-16 (1990).

2. Masson JF. "Sealing Cracks in Asphalt Concrete Pavements", Construction Technology Update, 49, 4-7 (June 01, 2001).

3. Smith KL, Romine AR. "Materials and Procedures for Sealing and Filling Cracks in Asphalt-Surfaced Pavements", Publication FHWA-RD-99-147, Federal Highway Administration, Department of Transportation, McLean, Virginia (1999).

4. Rajagopal A, Minkarah IA, Green R, Morse AA. "Effectiveness of Crack Sealing on Pavement Serviceability & Life", Report FHWA/OH-2003-009, Ohio Department of Transportation, Columbus, Ohio, (2003).

5. Yildirim Y, Qatan A, Kennedy WT. "Performance Evaluation of Hot- and Cold-pour Crack Sealing Treatments on Asphalt Surfaced Pavements", Report FHWA/TX-03-4061-2, Texas Department of Transportation, Austin, Texas, (2002).

6. Masson JF, Collins P, Légaré PP. "Performance of Pavement Crack Sealants in Cold Urban Conditions", Canadian Journal of Civil Engineering, 26, (4), 395-401 (August 01, 1999).

7. Masson JF. "Bituminous Sealants for Pavement Joints and Cracks: Building the Basis for a Performance-Based Specification", Rilem Symposium on Durability of Building and Construction Sealants, 315-328, Fort Lauderdale, (February 02, 2000).

8. Al-Qidi IL, Loulizi A, Aref S, Masson JF, McGhee KM. "Modification of Bending Beam Rheometer Specimen for Low Temperature Evaluation of Bituminous Crack Sealants", Transportation Research Board, 84th Annual Meeting, Washington D.C. (2005).

9. ASTM International (ASTM) D6690. "Standard Specification for Joint and Crack Sealants, Hot-Applied, for Concrete and Asphalt Pavements", Annual Book for ASTM Standards, Road and Paving Materials; Vehicle-Pavement Systems, 04.03, West Conshohocken, Pennsylvania (2003).

10. ASTM International (ASTM) D5329. "Standard Test Methods for Sealants and Fillers, Hot-Applied, for Joints and Cracks in Asphaltic and Portland Cement Concrete Pavements", Annual Book for ASTM Standards, Road and Paving Materials; Vehicle-Pavement Systems, 04.03, West Conshohocken, Pennsylvania (2003).

11. Masson JF, Collins P, Margeson JC, Polomark GM. "Analysis of Bituminous Crack Sealants by Physico-chemical Methods and its Relationship to Field Performance", Transportation Research Record No. 1795, Transportation Research Board, National Research Council, National Academies, Washington, D.C., 33-39 (2001).

12. Lacasse MA, Masson JF. "Developing a Performance-based Joint Sealant Specification for Airport PCC Pavements", in Wolf, AT. (Editor), Durability of Building and Construction Sealants and

Adhesives, STP 1453, ASTM International (ASTM), West Conshohocken, Pennsylvania, 346-354, (2004).

13. Masson JF, Collins P, Bundalo-Perc S, Woods JR, Al-Qadi I. "Variations in the Composition and Rheology of Bituminous Crack Sealants for Pavement Maintenance", Transportation Research Board, 84th Annual Meeting, Washington, D.C. (2005).

14. Anderson DA, Christensen DW, Bahia HU, Dongré R, Sharma MG, Antle CE, Button J. "Binder Characterization and Evaluation Volume 3: Physical Characterization", Report SHRP-A-369, Federal Highway Administration, Department of Transportation, McLean, Virginia (1994).

15. Dongré R, Sharma MG, Anderson DA. "Characterization of Failure Properties of Asphalt Binders", in Hardin, JC. (Editor) Physical Properties of Asphalt Cement Binders, STP 1241, ASTM International (ASTM), West Conshohocken, Pennsylvania, 117-136 (1995).

16. Carter S, Ksaibati K, Huntington G. "Field and Laboratory Evaluations of Hot-poured Thermoelastic Bituminous Crack Sealing of Asphalt Pavements", Transportation Research Board, 84th Annual Meeting, Washington, D.C. (2005).

17. American Association of State Highway and Transportation Officials (AASHTO) TP10. "Standard Test Method for Thermal Stress Restrained Specimen Tensile Strength", AASHTO Provisional Standards 2000 Edition, Washington, D.C. (2000).