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# Analysis of Bituminous Crack Sealants by Physico-Chemical Methods and its Relationship to Field Performance

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#### ABSTRACT

Bituminous crack sealants were analyzed by viscometry, fluorescence microscopy, infrared spectroscopy, thermogravimetry, modulated differential scanning calorimetry and low temperature tensile testing. The results indicate that sealants are blends of bitumen, oil, copolymer and filler. Upon blending, these components produce a three phase system that consists of a polymer-modified bitumen (PMB) matrix, a filler, and a filler-PMB interface. Spectroscopy and microscopy indicate that the PMB phase is rich in styrene-butadiene type copolymer, that the filler is recycled rubber, sometimes mixed with calcium carbonate, and that the interface depends on the filler and the oil content in the sealant. The physico-chemical methods were used to predict the short- and medium-term performance of sealant mixtures. The short-term performance predicted from viscometry and microscopy correlated well with the 1-year field performance of the sealants. Sealants showed two glass transition temperatures (Tg's), and a reasonable correlation was also found between the low temperature Tg and medium-term performance in a wet-freeze climate. However, because Tg measurements do not account for stress relaxation and aging effects, correlation was not perfect.

#### **INTRODUCTION**

Bituminous sealants have been used to seal pavement cracks and joints for more than 60 years (1). They reduce the ingress of water into the pavement structure and help reduce the rate of pavement degradation. However, it was

not until the 1960's, after the pioneering work of Tons on sealant mechanics (2), that sealants showed significant benefits and allowed for extending the service life of roadways where they were applied. Recent work with sophisticated numerical models and finite element analysis demonstrates the great advances in this field (*3-5*). Notwithstanding these advances, sealant performance has levelled, and it is not uncommon that sealants fail prematurely despite acceptable installations (*1,6*).

To make any significant improvements on current performance, a better understanding of the relationship between sealant microstructure, composition, and properties is required. To this end, five physico-chemical methods of analysis were used to characterize hot-poured bituminous sealants : viscometry, fluorescence microscopy, infrared spectroscopy (IR), thermogravimetry, and modulated differential scanning calorimetry (MDSC). Low temperature tensile testing was also performed. Viscometry provides an indication of sealant flow during installation, and flow relates to early adhesion (7). Microscopy was used to quantify the filler content, assess its dispersion, and measure the particle size distribution. Infrared spectroscopy was used to identify the polymer and filler, and to measure polymer concentration. Thermogravimetry was used to measure oil content. MDSC was used to determine the glass transition temperature ( $T_g$ ). From these measurements the relative short- and medium-term cold temperature performance of the different bituminous crack sealants was predicted with reasonable accuracy.

#### EXPERIMENTAL

#### Materials

Sealants were selected from an intitial set of twelve bituminous hot-pour materials from eight different producers (8). Based on infrared spectroscopy, all sealants had the same generic composition, which consisted of a styrenebutadienetype copolymer, a base bitumen binder, and a filler. These twelve sealants were used in previous field (6) and laboratory studies (10). For this study, four sealants from different producers, labeled A, E, H and M, were selected for further investigation, based on their 4-year field performance in Montreal, Canada, which experiences a wet-freeze climate with temperature lows of -30 to -40 °C. Sealant A performed poorly, sealants E and H performed well, and sealant M had an average performance. The selected sealants are thus representative of the family of bituminous hot-pour used on roadways. All sealants were purported to meet ASTM D3405. Standard test results were published earlier (6). For product characterization, 300-500 g of as-received (virgin) sealant was heated to 185 °C and slowly stirred for 30 min before being molded into bars of  $2 \times 2 \times 30 \text{ cm}^3$ . These bars were stored several weeks at room temperature before analysis.

#### Viscometry

Sealant viscosity was measured using a Bohlin Visco-88-BV viscometer after the sealants had been slowly stirred for 30 min in a closed vessel while the temperature was kept constant at  $185 \pm 1$  °C. The viscometer was equipped with a cylindrical spindle. Measurements were taken at a low shear rate of 3.43 Hz in a container large enough to prevent edge effects. Each reported viscosity reading was a 10-s time-averaged value.

#### **Fluorescence microscopy**

Sealant bulk morphology was exposed by shaving a 5 cm<sup>2</sup> surface with a cryo-microtome capable of planing the sample at -70°C. To observe the morphology, a light microscope equipped with quartz optics and a mercury lamp that produced UV light of 354 nm was used. On top of the microscope was a low-light, high-sensitivity, color CCD camera (Dage-MTI Inc., model DC330E). The imaging system had an automated stage that allowed the acquisition of twenty-five ~1 cm<sup>2</sup> fields that were compiled into a 5 cm<sup>2</sup> composite image of the entire sealant surface. Image acquisition was short, typically a few seconds per field, so that the sealant surface did not melt due to the heat created by UV-light. Individual micrographs were captured at 50x magnification (Figure 1-3).

#### Infrared spectroscopy

Analysis was performed in transmission. For qualitative analysis, sealant films were cast from trichloroethylene solutions onto potassium bromide crystal disks. Quantitative sealant analysis was performed with a 1.25 mm solution cell with 5% (w:v) sealant solutions in carbon disulfide. Although carbon disulfide must be handled with care because of its toxicity and flammability, this solvent was chosen because of its lack of absorbance below 1400 cm<sup>-1</sup> and its ability to dissolve bitumen and polymers in sealants equally well. Fifty scans were coadded on a Bomem MB100 spectrometer operated at a resolution of 4 cm<sup>-1</sup>. The concentration of SB-type copolymer concentration in the sealant was measured as described by Masson et al. (*12*).

#### Thermogravimetry

The relative amount of volatile material in each sealant was obtained from the mass loss upon heating in a Dupont 951 Thermogravimetric Analyzer. Airflow in the sample cell was maintained at a rate of 100 ml/min during measurements. Fifteen to twenty milligrams of each sealant was heated at a rate of 50 °C/min from 25 °C to 185 °C and held isothermally for 3 h.

#### Modulated differential scanning calorimetry (MDSC)

MDSC was performed with a TA Instrument 2910 MDSC. About 25 mg of sample was sealed in an aluminium pan. The sample heat capacity was measured under helium delivered at a rate of 50 mL/min. Liquid nitrogen was used to cool the sample. The heat capacity was measured by cooling the sample from 150 to -100 °C at a rate of 3 °C /min with a modulation of ±0.47 °C. The resulting heat capacity curve, which is simpler than the heating curve (*13*), was used to measure Tg. For improved clarity, the derivatives of the heat capacity cooling curves are reported. Other details of MDSC analysis on bituminous materials can be found elsewhere (*11*).

#### **Tensile elongation**

Tensile elongation-at-break was obtained with an Instron model 1122 Universal Testing Machine. The standard specification ASTM D638 was adapted for use with crack sealants. Samples 2.5 mm wide and 2-3 mm thick were cut using die M-III. All samples were conditioned for 24 h at -37 °C prior to testing. The test temperature of -37°C was maintained with the use of a box cooled with liquid nitrogen. Samples were strained at a rate of 50 mm/min.

#### RESULTS

Sealant viscosity ( $\eta$ ) is affected by temperature and heating time (9). Table 1 shows the viscosity of each sealant after 30 min of heating at 185 °C. The range of values is significant, as sealants with  $\eta < 10$  Pa•s are self-leveling and sealants with  $\eta > 30$  Pa•s are difficult to pour.

The microstructure of sealants is revealed by fluorescence microscopy. With UV light, as with white light, bitumen is black and shows few features under the microscope. In contrast, when bitumen is mixed with a polymer to produce a polymer modified bitumen (PMB), bitumen swells the polymer to produce a polymer-rich phase and a bitumen-rich phase. The polymer-rich phase shows green-yellow fluorescence while the bitumen-rich phase

remains dark. In a PMB with a compatible polymer-bitumen pair where the polymer content is below 5% by weight, the fluorescent phase is dispersed in the continuous bitumen matrix. In contrast, when the polymer content exceeds about 5% by weight, the fluorescent phase is continuous (Figure 1).

Crack sealants are much like PMBs with a continuous polymer-rich matrix, but they also contain dispersed recycled rubber particles (Figure 2). Both the recycled rubber particles and the bitumen-rich phase remain dark. It is possible to separate the bitumen and the recycled rubber based on size and shape. For example, Figure 3 shows an image of sealant E with each grain size range colored differently. From such images, quantitative information can be obtained. In sealant E, bitumen shows as a very fine dispersion of  $30 \,\mu\text{m}$  (red) and  $75 \,\mu\text{m}$  (green) particles of irregular shape. In contrast, recycled rubber shows as oval or round particles with sizes of  $300 \,\mu\text{m}$  (pink) or larger (blue). Most of the recycled rubber particles are of similar size. Sealant M has more particles, the size is somewhat larger, and the particles are angular. The particles in sealants A and H are also angular, but much larger than those in sealants E and M. The surface area of the recycled rubber particles increase in the order E<M<A<H (Table 1). The micrographs also show that the yellow-green background intensity increases in the order A<M<H<E. It is noteworthy that sealant H has a smeared texture and that the micrograph appears out of focus. This is a result of microtoming a sealant that had not become completely rigid even at  $-70 \,^{\circ}$ C, the microtome planing temperature.

The polymer in the sealant cannot be identified by microscopy although its presence is obvious. In principle, the PMB matrix of a sealant can be obtained from many bitumen-polymer combinations, but in practice, few polymers are used. Common polymers are block copolymers like styrene-butadiene (SB) or styrene-butadiene-styrene (SBS), random copolymers like styrene-butadiene rubber (SBR), and polyolefin-based polymers like ethylene vinyl acetate (EVA). Infrared spectroscopy is best suited to identify the polymer in a sealant. Characteristic absorption frequencies in the IR spectrum can be identified and matched to those for known polymers. Table 2 provides absorbance frequencies characteristic of EVA, SBR, and SBS in addition to those for bitumen and two common inorganic fillers, calcium carbonate (CaCO<sub>3</sub>) and silica (SiO<sub>2</sub>). Figures 4 and 5 show the infrared spectra of sealants A, E, M and H.

A comparison of Table 2 and Figures 4 and 5 indicates that all sealants contain an SB or SBS copolymer, with typical absorbances at 966 and 699 cm<sup>-1</sup>. These copolymers have an infrared spectrum almost identical to that for

SBR. The only difference is the additionnal absorbance of SB(S) at 745 cm<sup>-1</sup> (Table 2). Sealant A also shows absorbances characteristic of calcium carbonate (Figure 5). Table 1 shows the concentration of SB(S) in sealants A, E, M and H, as measured by infrared spectroscopy (*10*). As indicated in the experimental section, all twelve sealants of the original lot had the same generic composition , which include SB(S). Copolymer concentrations for other sealants are found in reference (*10*).

The IR spectra in Figure 4 also shows that sealant H contains an SB-type copolymer somewhat different from that in other sealants. In sealant H the absorbance ratios for the styrene unit at 699 cm<sup>-1</sup> and butadiene unit at 966 cm<sup>-1</sup> is 0.88, but in the other sealants it is 0.75. Based on a calibration curve obtained from SB(S) copolymer of known composition (not shown), it is estimated that the S/B ratio is 28/72 for the copolymer in sealant H, and 25/75 for the copolymers in the other sealants. As indicated earlier, the micrograph for sealant H is also the only one to show strings and smearing of the surface, which suggest the presence of a lower molecular weight copolymer in sealant H than in the other sealants. The copolymer may be a low molecular weight SBS triblock or an SB diblock (*14*).

Both microscopy and IR provide an indication of copolymer content, but IR is quantitative, whereas microscopy is qualitative. The micrographs of sealants indicate that they contain more than 5% SB(S) copolymer, the intensity of the fluorescence being proportional to the polymer concentration, as indicated by IR spectroscopy. Based on the correlation between fluorescence and polymer concentration, it is estimated that sealant H contains about 15% copolymer.

Oils may be added to sealants during formulation to increase sealant flexibility and enhance the compatibility of SB(S) and recycled rubber with bitumen. The amount of oil added can be measured by thermogravimetry as a loss of weight when the sealant is maintained at 185 °C. Figure 6 shows the weight loss of each sealant over 3 h. The oil content increases in the order A $\approx$ H<M<E.

A relative comparison of sealant behavior at low temperatures can be obtained by measuring tensile elongation at break according to ASTM D638 (Table 1). Another indication of low temperature behavior is obtained by MDSC. This method is used to identify the Tg regions of crack sealants. All four sealants show two Tg regions, as shown by the large trough below 0 °C and the shallow peak between 20-120°C. The former is an indication of the temperature at which the sealant becomes rigid. The latter is an indication of the temperature at which the sealant flows. The low temperature Tg of the sealants increases in the order E < M < A < H, whereas the high temperature Tg is fixed with a centre at 60-70 °C. Figure 8 shows the MDSC curves for typical sealant raw materials : bitumen, SBS, recycled rubber, and oil.

#### DISCUSSION

Disregarding early failure due to poor cleaning of routed cracks before sealant application, sealant performance is governed by a combination of adhesive, bulk and aging properties. These properties make for a 3-stage sealant performance (6). The first stage, which is governed by adhesion, includes the first winter. In this stage, sealants fail adhesively because a weak sealant/asphalt concrete (AC) interface is strained by the opening of cracks due to pavement contraction. If adhesion is initially good and sealant bulk characteristics are such that the sealant is flexible in winter, then the sealant joint retains its integrity and failure rates are low (2<sup>nd</sup> stage). This stage continues until sealant starts to fail again, because of increased stiffness due to weathering (3<sup>rd</sup> stage). If early adhesion is poor, the 2<sup>nd</sup> stage is absent and failure keeps increasing until the 3<sup>rd</sup> stage. Results of the previous physico-chemical analyses help us understand the sealant related parameters that govern performance in the 1<sup>st</sup> and 2<sup>nd</sup> stage.

#### Early sealant adhesion

Low sealant viscosity during installation at 170-200 °C promotes adhesion as it facilitates the penetration of the sealant into the irregular AC surface and helps reduce interfacial voids that lead to early failure (7). Low sealant viscosity should thus enhance early sealant performance. In this respect, the self-levelling sealants E and H show much better performance than sealant A, which flows poorly during application (*15*) and shows poor aggregate wetting (7). The high viscosity of sealant A is likely due to its 50% recycled rubber content by volume, as seen by microscopy, coupled with a large concentration of CaCO<sub>3</sub>, as indicated by its strong absorbance in the IR spectrum. Calcium carbonate is not easily seen by fluorescence microscopy. However, after its presence is revealed by IR spectoscopy, it can be recognized as a faint white dispersion and some white agglomerates in the micrograph (Figure 2). High loadings of calcium carbonate not only affect sealant viscosity, it can also introduce interfacial defects by preventing the flow of the sealant PMB phase into the AC surface irregularities and microvoids, thus reducing adhesion (7). Recycled rubber particles may have the same effect if not swollen with oil. Swollen recycled rubber

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particles are elastic and develop adhesive properties. The degree of swelling and adhesiveness depends on the size of the particles and the amount of oil available for swelling (16,17). Fully swollen particles are 3 to 5 times their original volume (13).

The shape of the recycled rubber particles in the sealants may be an indication of their contribution to elasticity and adhesion. A swollen particle is expected to have smooth edges whereas an unswollen particle is more angular. Sealants A and H contain angular particles in excess of 500  $\mu$ m. Their angularity indicates that they are not swollen, and consequently they may not contribute much to adhesion. In contrast, sealants E and M contain small particles in the 75-300  $\mu$ m range, and it may be expected that the recycled rubber in both of these sealants would be well swollen. However, only sealant E contains oval shaped particles that indicate swelling, which is likely facilitated by the high oil content in this sealant (13%). The small particles in sealant M likely retained their angularity because of the low oil content in the sealant (3%).

The first stage of sealant performance (short-term performance) being governed by adhesion, with adhesion being affected by sealant viscosity and filler content, it may be possible to anticipate short-term performance based viscosity and filler content (Table 3). On this basis, the performance is expected to increase in the order A< M  $\approx$  H <E. The order of performance measured after 1 winter in the field was A<H<M<E (*6*). Thus anticipated short-term performance correlates well with actual performance. The difference may be attributed to the sealant bulk properties.

#### **Sealant Bulk Properties**

To discuss bulk properties, it is convenient to consider a sealant as a three-phase system; the filler, the PMB matrix and the interface between them. In summer temperatures, fillers reduce abrasion wear due to tires and increase the resistance to tracking (the flow of sealant due to traffic). In winter, fillers increase bitumen stiffness proportionally to filler content (*18*). Hence, it is expected that sealant stiffness will increase progressively as the filler goes from swollen recycled rubber < non-swollen recycled rubber < inorganic filler.

In winter, when cracks open and the sealant is strained, the filler-PMB interface is expected to be critical to sealant integrity. It is likely that the capability of the filler to transfer the tensile load to the surrounding PMB matrix prevents the fracture of the filler-PMB interface and limits damage to the internal structure of the sealant.

The strength of the interface depends on the interaction between the filler and the PMB matrix, as it is the case with other filled systems (*17*). Swelling is a sign of favorable interactions (*19*), hence sealants with swollen recycled rubber particles ought to have a stronger interface, less likely to be damaged by tensile stresses, than a sealant with non-swollen recycled rubber particles, in accordance with the greater tensile elongation at break of sealant E over that of sealant M. Both products have small particles, but the extent of swelling is different. As for inorganic fillers (CaCO<sub>3</sub>, SiO<sub>2</sub>), they are highly polar and bond poorly to non-polar matrices, e.g. bitumen (*20*). Hence, it is expected that the calcium carbonate-PMB matrix will be weaker and more likely to fail than the recycled rubber-PMB interface.

The properties of the PMB matrix are possibly the most important factors that control sealant performance, with Tg being a key factor. Unmodified bitumens have Tg's centered between 0 and -40 °C (*21*), and a Tg region that extends about 20 °C on either side of the centre (Figure 8). Hence, when temperature drops below freezing, bitumen hardens and becomes subject to fracture. Physico-chemical measurements have shown that sealants contain oil, SB(S), and recycled rubber, all of which have Tg's below bitumen (Figure 8). Consequently, when bitumen is blended with these components, the Tg of the blend is below that of bitumen, and the resulting sealant has reduced low temperature susceptibility. There is a good correlation between Tg and recycled rubber content ( $R^2 = 0.84$ ), but this is likely coincidental because the correlation disregards the type of recycled rubber particles, the extent of their swelling, and the oil and SB(S) contents, all of which affect Tg. The glass transition temperature of a sealant is thus a complex function of its components.

Notwithstanding the lack of understanding of the parameters that govern sealant Tg's, there is a correlation between Tg and performance. Low Tg's indicate sealants with low hardening temperatures, as evidenced by the elongation at break of sealant E at -37 °C (a Canadian winter low). Based on Tg's, the expected order of sealant performance is H<A<M<E. The ranking obtained after 4 years in the field is A<M<E≤H (6). The ranking is as expected with the exception of Sealant H, wich performed much better than expected. This discrepancy may be due to the lower molecular weight copolymer in sealant H. Low molecular weights lead to greater stress relaxation (22), which may have helped reduce failure.

Performance thus seems to be governed by sealant stiffness and stress relaxation, just as it is the case for hot-mix asphalt binders (23). Tg measurements via DSC can help assess sealant performance, but because it is a static

method, it is not infallible. These measurements fail to capture the effect of strain and strain rate, which affect stress relaxation, and stress transfer across the filler-PMB interface. A larger perspective of the effect of temperature, stress and low temperature relaxation on sealants may be obtained by rheological methods.

#### CONCLUSION

Hot-pour bituminous crack sealants used on roadways have the same generic composition. Four typical sealants were selected for characterization based on a range of performance in a wet-freeze climate. This characterization included low temperature tensile testing, viscometry, fluorescence microscopy, infrared spectroscopy, thermogravimetry, and modulated differential scanning calorimetry. This study illustrates the usefulness of these methods to determine specific sealant composition and properties.

Hot-pour crack sealants used on roadways consist of a polymermodified bitumen (PMB) phase in which a filler is dispersed. The polymer is of the styrene-butadiene type (SBS or SB). The four sealants investigated in detail contained 5-18 wt % SB(S), 3-13 wt. % oil, and 10-50 vol. % recycled rubber. Calcium carbonate was also identified as a filler in one sealant. This mixture of raw materials produced sealants with two glass transition temperatures (Tg's). The low temperature Tg, centered between –35 and –70 °C, was product dependent, but the high temperature Tg, centered at about 60 °C, showed little product dependence.

The physico-chemical properties of crack sealants were related to crack sealant performance. Viscosity and filler content affect adhesion, which governs short-term performance; low viscosity and low filler contents enhance the bonding of sealant to asphalt concrete (AC), whereas high viscosity and high filler contents introduce interfacial defects that can become loci of failure at the sealant-AC interface. Hence, the short-term performance predicted from viscometry and filler content as obtained from microscopy correlated well with the 1-year field performance of the sealants in a wet-freeze climate.

A reasonable correlation was also found between the low temperature Tg and 4-year performance in wet-freeze climate, but little correlation was found between Tg and composition. The Tg provided a comparative ranking of sealant 4-year performance, but the method needs refinement because Tg measurements do not reflect the strain and stress relaxation that occur when a sealant is in the field.

In a previous study, it was not possible to segregate the best from the worst sealants for a wet-freeze climate based on the empirical ASTM D3405. This study shows that parameters specific to interfacial and fundamental sealant bulk properties can be used to predict short- and medium-term behavior. Obviously, the study of four bituminous hot-pour sealants by physico-chemical means does not provide a comprehensive nor standard method of selecting such sealants for long-term performance. However, it does indicates that a better method of assessing sealant modulus and relaxation at high and low temperatures is needed for these materials and that the change in rheological properties with aging must be considered, if long-term performance predictions of sealants are to be made.

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**TABLE 1** Sealant Characteristics

 TABLE 2 Infrared Absorbances for Sealant Raw Materials Useful for Identification

 TABLE 3 Adhesion Characteristics and Anticipated Short-term Performance of

 Bituminous Sealants

#### **Figure captions**

FIGURE 1 Fluorescence Micrographs of a PMB with 6% SBS by Weight.

FIGURE 2 Fluorescence Micrographs of Bituminous Crack Sealants A, E, H, and M.

FIGURE 3 False Color Micrographs of Crack Sealant E for Analysis and Quantification.

FIGURE 4 IR Spectrum of Sealants M, E and H Between 600 and 1100 cm-1. The Absorbances at 966 and 699 cm<sup>-1</sup> Arise From the SB(S) Copolymer.

FIGURE 5 IR Spectrum of Sealant A Between 600 and 1700 cm<sup>-1</sup>. The Spectrum of Sealant H Serves As Reference. The Absorbances at 714, 876 and 1420 cm<sup>-1</sup> Arise From Calcium Carbonate.

FIGURE 6 Loss of Oil Over Time for Sealants Maintained 3h at 185 °C.

FIGURE 7 Glass Transition Temperature Regions in Sealants Shown by Downward Peaks on the Derivative of the Heat Capacity Curve Obtained Upon Cooling by means of MDSC.

FIGURE 8 Glass Transition Temperature Regions for Sealant Raw Materials as obtained by MDSC.

# **TABLE 1 Sealant Characteristics**

A 70	Е 9	H 5	M 19
70	9	5	19
70	9	5	19
25	700	n.d.	6
-48	-70	-35	-60
3	13	7	3
40	10	50	30
5	18	~15**	6
	25 -48 3 40 5	25 700 -48 -70 3 13 40 10 5 18	25 700 n.d. -48 -70 -35 3 13 7 40 10 50 5 18 ~15**

n.d., not determined; \* from IR spectroscopy; \*\* from microscopy

Compound	Abs. $(cm^{-1})$	Origin		
EVA	1737	C = O stretching		
	1242	C–O stretching		
SBR	966	6 C–H out of plane (oop) bending of trans-alkene		
	911	C-H oop bending of terminal-alkene		
	760, 699	C-H oop bending in monoalkylated aromatics		
SBS*	745	C-H oop bending in monoalkylated aromatics		
Bitumen	1030	S = O stretching		
	874	C-H oop bending in 1,2,4-substituted aromatics		
	814	C-H oop bending in 1,2,4-, and 1,4- substituted aromatics		
	746	C-H oop bending in 1,2- substituted aromatics		
	722	rocking of $(CH_2)_n$ , $n > 4$		
CaCO <sub>3</sub>	714	$CO_3^-$		
	876	$CO_3^-$ oop bending		
	1420	CO <sub>3</sub> <sup>-</sup> stretching		
SiO <sub>2</sub>	3748	Free O–H stretch		
	3660	Bonded O–H stretch		
	1230-1045	Si–O–Si skeleton stretch		

### TABLE 2 Infrared Absorbances for Sealant Raw Materials Useful for Identification

\*SBS shows the same bands as SBR in addition to that at 745 cm  $^{\text{-1}}$ 

# TABLE 3. Adhesion Characteristics and Anticipated Short-term Performance of

## **Bituminous Sealants**

Sealant	Characteristic	Anticipated Adhesion	Field Rank After 1-year
Е	Low Viscosity, Low Filler Content	Good (1)	1
Н	Low viscosity, High Filler Content	Good-Fair (2)	3
М	Medium-Low Viscosity, Medium Filler Content	Fair (3)	2
А	High Viscosity, High Filler Content	Poor (4)	4







Figure 2.







Figure 4.

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Figure 5.



Figure 6.



Figure 7.



Figure 8.