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15. Abstract

Objective

The NDDOT is interested in identifying the maintenance practices for thermal cracking in asphalt pavements in states and provinces with similar climates to North Dakota. It is hoped that this information could be used for the development of a manual of "Best Management Practices" for NDDOT.

Scope

The researchers surveyed more than 20 states with similar climates as North Dakota and reviewed the states' specifications, research reports, and journal papers on maintenance of thermal cracks in asphalt pavements.

Summary

Based upon findings from the study and guidance from the Project Advisory Committee, the following recommendations were submitted:

- States surveyed indicate that rubberized asphalt, low modulus rubberized asphalt, asphalt emulsion, asphalt rubber, and polymer modified liquid asphalts are commonly used.
- A distinction exists between crack sealing and crack filling, and the material used depends on the operation.
- The use of cutback asphalts either has been discontinued or has not been part of surveyed states practices.

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Asphalt Pavement Thermal Crack Maintenance Best Management Practices: Survey and Literature Review

NDDOT Project Number: NDSU 2013-01
SPR-R034(009)

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FEDERAL HIGHWAY ADMINISTRATION
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EVALUATION	CONSTRUCTION PROBLEMS	PERFORMANCE
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APPLICATION	1 ADOPTED AS PRIMARY STD. 2 PERMITTED ALTERNATIVE 3 ADOPTED CONDITIONALLY 320	4 X PENDING 5 REJECTED 6 NOT CONSTRUCTED *(Explain in remarks if 3, 4, 5, or 6 is checked)*
REMARKS	321 This research will identify processes and/or materials that have been successfully and unsuccessfully used for maintenance of thermally cracked asphalt pavements on highway systems with climates similar to North Dakota. Research findings will be used to compare the successful BMPs of the surveyed agencies with current NDDOT maintenance practices. 700	

Form FHWA 1461

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ACKNOWLEDGEMENT

The research team at North Dakota State University would like to acknowledge the help and support of North Dakota Department of Transportation in conducting research.

EXECUTIVE SUMMARY

The primary objective of this study was to investigate the maintenance practices for thermal cracking in asphalt pavements of states and provinces with similar climates to North Dakota for the ultimate goal of assembling a best management practices policy for the NDDOT.

Based on the literature findings, hot pour crack or joint sealer is the preferred category of crack maintenance materials among all states and provinces. Fiberized and rubberized sealants are commonly used. Generally, sealant applications are only permitted when the air temperature is 40°F or higher. Routing of existing cracks is the most common practice for crack preparation; however states do not have uniform criteria for when to rout or not rout. Generally, cracks should not be routed to a width larger than 3/4 inch and cracks larger than 3/4 inch are commonly filled without routing. Cracks smaller than 1/2 inch are typically routed to either 1/2 inch or 5/8 inch. All states and provinces require the routed or unrouted cracks to be cleaned and dried prior to application of maintenance materials with compressed air or hot-air lance. The hot air lance is preferred for enhanced cleaning and warming of the crack channel for increased bonding. Configurations of the final sealed/filled crack vary greatly between states and provinces.

The most common specifications used for material acceptance are ASTM D 6690 or AASHTO M 324 (Types, I, II, III, and IV), and ASTM D 5329. Materials must meet the requirements of one or both of these testing criteria in 15 of the 26 states/provinces reviewed. It should be noted, ASTM D 6690 and AASHTO M 324 have 4 types, and states/provinces may not utilize all types of materials.

The terminology for crack sealing and crack filling are not uniformly agreed in the literature and across states/provinces surveyed. The literature definition of each term is featured in section 1.1 of this report, with the primary difference being the maintenance approach of working and non-working cracks (further defined in Chapter 2). The in-field practice was established through an overview of the specifications, follow-up questions, and a second round of follow-up questions for select states. The terminology is often not distinguished, or used interchangeably as shown in 6 of the 8 responses of the second set of follow-ups. Generally, states/provinces that have separate criteria for sealing and filling use the crack size as the differentiating factor. Larger cracks are filled with the treatment material after cleaning the existing crack. Smaller cracks are subjected to routing/sawing and cleaning before being sealed to a finishing configuration. This was supported by the 2 remaining selected surveyed states, as well as the terminology used in the state/province specifications. The responses of second round follow-up questions for the selected states are provided in Table 4.18.

Based on survey analysis, the treatment procedures of cracks are oriented towards crack sealing with rout and seal preparations and overband of cracks. The least used operation chosen was crack pour. The preferred time for crack maintenance operations is spring and fall, followed by summer, and then winter. The most used crack preparation approaches are compressed air, followed by hot air lance. Routing of cracks is more common among states/provinces, while sawing of cracks was chosen by a limited number of states/provinces. Very few states/provinces have no crack preparation methods. Based on the responses of the states/provinces with regards to their experience with crack sealing products, it can be implied that most states/provinces are not utilizing cutback asphalt products. 59% of the state/province respondents have used cutback asphalt but are no longer using it, whereas the rest of the states (41%) have never used it before. Based on the survey results, 52% of the respondents currently use rubberized asphalt, 45% currently use low modulus rubberized asphalt, 39% currently use asphalt emulsion, 36% currently use asphalt

rubber, and 32% currently use polymer modified liquid asphalt; as illustrated in section 4.7 of the survey analysis. It is recommended that these material types be considered in the order presented, and according to product availability.

For the specific products used by the NDDOT; MC-3000 cutback asphalt, 40% of the states/provinces respondents have used this product before but are no longer using it, while the rest of states/provinces respondents (60%) have never used it before. 20% of the respondents are currently using Elastoflex 52 (crumb rubber modified asphalt), and 20% of the respondents are currently using Elastoflex 71 (polymer modified asphalt sealant). Thus, Elastoflex 52 or Elastoflex 71 may be used, while it is recommended not to use MC-3000.

1. INTRODUCTION

The North Dakota Department of Transportation (NDDOT) maintains more than 8,500 roadway miles on the Interstate, National Highway, and State Systems. The vast majority of those highway miles are asphalt pavements. The properties of asphalt pavement allow it to expand and contract with fluctuations in the material temperature. However, extreme cold temperatures can cause asphalt pavements to contract to a point that exceed the material's elastic capabilities, resulting in thermally cracked pavements. If these cracks are left untreated, the asphalt layer, granular base, and lower soil layers are susceptible to damage from water that infiltrates the crack. Water can "strip" the asphalt binder from the sides of the crack, weakening the pavement structure. Water can also increase the moisture content of the granular base and subgrade soils, thereby weakening the foundation layers. Both situations can lead to depressed cracks, decreased ride quality, and a shortened pavement life.

The NDDOT has not identified a single "best management practice" (BMP) to be used statewide. It is presumed that other processes and/or materials may be in use by states and provinces with similar highway systems and climatic conditions. The NDDOT desires to identify the successful BMPs of northern tier states and provinces as a means to increase its understanding of effective pavement preservation techniques that could be put to use on the NDDOT highway system. This research will identify processes and/or materials that have been successfully and unsuccessfully used for maintenance of thermally cracked asphalt pavements on highway systems with climates similar to North Dakota. Research findings will be used to compare the successful BMPs of the surveyed agencies with current NDDOT maintenance practices. If applicable, additional BMPs may be found that could add to the NDDOT pavement preservation toolbox. A BMP recommendation for crack maintenance will be provided for the districts in the NDDOT based on research findings. If appropriate, research findings may be used to conduct field evaluations of other successful BMPs.

The scope of work for this research is to obtain BMP information from agency experts through e-mail surveys. The agencies to obtain BMP information are Departments of Transportation (or equivalent) from the following states and provinces; Alberta, British Colombia, Colorado, Idaho, Illinois, Indiana, Iowa, Kansas, Maine, Manitoba, Michigan, Minnesota, Missouri, Montana, Nebraska, Nevada, New Hampshire, New York State, Ohio, Ontario, Oregon, Pennsylvania, Saskatchewan, South Dakota, Utah, Vermont, Washington State, Wisconsin, and Wyoming.

To achieve the aforementioned goals, information and data were collected through a literature review and a multi-phase survey. Literature review of national studies, state reports, and research publications focused on knowledge and research of thermal cracking mechanisms, current crack maintenance materials and practices, and state/province crack maintenance specifications was formalized. The literature review is presented in Chapter 2 of this report. Existing BMP guidelines for states/provinces featured in the survey were reviewed to determine the components of best management practices, and the specific practices that are successfully implemented across cold-weather states. An overview of the components of BMP guidelines is presented in Chapter 3 and a summary of state/province BMPs are presented in Appendix B. Survey questions were developed based on preliminary research of national studies and practices for thermal cracking maintenance. The survey was sent to representatives of the 29 state/province DOTs by e-mail. The NDDOT provided a list of the representatives, generally consisting of the heads of maintenance or materials divisions of state/province DOTs. Representatives were contacted by phone and e-mail on a regular basis to ensure maximum completion of the survey. Follow-up questions were sent by e-mail for the purpose of clarifying terminology, practices, and other information that was unclear or unusual among the responding states/provinces. The survey question form is presented in

Appendix A, and survey responses and analysis are presented in Chapter 4. Additionally, a section on the terminology used in this report is presented in section 1.1 to define specific terms and phrases that vary between states/provinces. The final recommendations of this research consider the findings of the literature, current state/province specifications and BMPs, and survey results. The report summary and final recommendations are presented in Chapter 5.

1.1. Terminology

- **Backer Rod**: A compressible material that is placed in joints or cracks before applying sealant to prevent bonding of the sealant on the bottom of the joint, control sealant depth, and prevent sagging of the sealant [1].
- **Band-Aid**: An overband configuration where material is shaped/finished to desired dimensions [2].
- **Blotting**: The application of material to a freshly sealed crack to prevent the occurrence of tracking or pulling due to traffic loading.
- **Capped (crack capping)**: An overband configuration where material is not shaped or finished. The material is allowed to level over the crack channel itself [2].
- **Cleaning (crack cleaning)**: Removal of debris and loose material from an existing crack or crack channel using a hot air lance or compressed air to blow out the debris in the crack [3].
- **Crack channel**: The crack cavity as defined by either the original (uncut) crack or cut crack [2].
- **Crack Filling:** The placement of materials into non-working cracks to substantially reduce the infiltration of water and to reinforce the adjacent pavement. Non-working crack refers to horizontal and/or vertical movements less than 0.1 inch (2.5 mm). Non-working cracks typically include mostly longitudinal, diagonal cracks and some block cracks. Such cracks do not move much due to the close spacing between the edges. Crack filling is therefore simply filling the cracks that do not show significant movement [4, 5, 6, 7]. Simple overbands are usually used with filling operations [6, 7]. Crack filling involves placing the filling material and spreading it out over and into the crack(s) with a squeegee. Squeegees are typically U or V shaped to push the material and concentrate it over the crack [6, 7]. Crack filling materials may be hot applied rubber or polymer asphalts, or cold applied emulsion-based products. The emulsion products assist with forming a good adhesive bond with the crack wall and additives such as Styrene Butadiene Rubber (SBR) latex ensure that the material can endure some degree of movement. In some cases, hot applied fiber modified asphalt binders may be used [8, 9]. For short-term crack-fill performance (1 to 3 years) in pavements with nonworking cracks (less than 0.1 inch (2.5 mm) of horizontal crack movement) and low to moderate traffic levels, asphalt cement should be placed in flush-fill configuration [10, 11, 12, 13]. For long-term crack-fill performance (between 5 and 8 years) under the above conditions, an asphalt rubber or rubberized asphalt may be placed in either a flush-fill or overband configuration, or a fiberized asphalt may be placed in an overband configuration [10, 11, 12, 13].
- **Crack Sealing:** The placement of specialized materials either above or into working cracks using unique configurations to prevent the intrusion of water and other incompressibles into the pavement cracks. Working cracks refers to horizontal and/or vertical crack movements greater than 0.1 inch (2.5 mm). Transverse cracks are a good example of working cracks; however, some longitudinal cracks may also meet the movement criterion [4]. Crack sealing involves thorough crack preparation followed by the placement of a high-quality material in a specific configuration [5, 6,

- 7]. Crack sealant materials are rubberized products that have the ability to seal the crack and flex with the pavement's movement. They are used for active cracks that continue to extend both in size and severity with time and the ravages of the traffic and weather. Crack sealants have excellent adhesive and cohesive properties. In other words they firmly adhere to the walls of the cracks and do not tear or split when the cracks widen [4]. Reservoirs are generally associated with sealing operations [6, 7]. In a sealing operation, sealant is placed either flush with the surface or slightly recessed within a cut reservoir. The purpose of the reservoir is to create room for enough material to be applied, create a desirable sealant shape, and provide a uniform surface for the sealant to adhere to. The sealant also may be recessed to prevent plow and traffic damage [6, 7]. For sealing working cracks, the preferred sealant is usually elastomeric. This means the sealant has a low modulus of elasticity and will stretch easily and to high elongations (usually around 10 times its non-strained dimensions) without fracture. Such sealants also recover over time to close to their original dimensions [8, 9]. For short-term crack-seal performance (between 1 and 3 years) in pavements with ordinary working cracks 0.1- 0.2 inch (2.5-5 mm) of horizontal crack movement) and moderate traffic levels, a standard rubberized asphalt should be placed in a simple Band-Aid configuration [10, 11, 12, 13]. For medium-term crack-seal performance (between 3 and 5 years) under the above conditions, either a standard rubberized asphalt may be placed in a recessed Band-Aid configuration or a modified rubberized asphalt may be placed in a simple Band-Aid configuration [10, 11, 12, 13]. For long-term crack-seal performance (between 5 and 8 years) under the above conditions, a modified rubberized asphalt sealant should be installed in either a standard or shallow recessed Band-Aid configuration [10, 11, 12, 13].

- **Crack reservoir**: A uniform crack channel resulting from cutting operations. Generally rectangular in shape [2].
- **Flush Fill**: Crack filling method where fill material is forced into a crack and is struck flush with the pavement surface [14].
- **Hot air lance**: A preparation device that uses heated compressed air to clean, dry, and warm cracks prior to sealing [1].
- **Incompressible**: Material, such as sand, stone, and dirt, that resists the compression of a closing crack channel [2].
- **Melting Kettle**: A device used to heat sealing materials to working temperatures in the field.
- **Non-working Cracks**: cracks that experience relatively little horizontal and/or vertical movement as a result of temperature change or traffic loading. As a general rule, movement less than 0.1 inch (2.5 mm) [2].
- **Overband**: A type of finish in which material is allowed to completely cover crack channel by extending onto the pavement surface. Overbands consist of Band-Aid and capped configurations [2].
- **Routing**: Crack preparation method involving the use of pavement router to create a reservoir centered over existing cracks [3].
- **Sawing**: Crack preparation method involving the use of a pavement saw to create transverse joints at regular intervals along a newly placed pavement [3].
- **Squeegee**: A device used to apply sealant in an overbanding configuration or remove excess sealing material from the sealed crack.
- **Working Cracks**: Cracks that experience considerable horizontal and/or vertical movement as a result of temperature change or traffic loading. In general, movement greater than or equal to 0.1 inch (2.5 mm) [2].

2. LITERATURE REVIEW

The effect of material factors of asphalt concrete (AC) mixtures on low temperature cracking is reasonably well understood [16]. The temperature susceptibility of the asphalt cement has been found to be a deterministic factor for performance [16]. Pavements in cold regions are subjected to thermal and traffic loading, where pavement temperatures can range between -50°C in the winter to +50°C in the summer. The pavement distresses related to temperature are thermal cracking and rutting [16]. It is suggested that the thermal cracking in cold regions occurs by two distress mechanisms [16, 17, 18, 19]. The first mechanism is related to the transverse cracks that may be caused by the overall contraction of the entire pavement structure and/or underlying subgrade. As a result, cracks extend through the entire pavement structure and into the subgrade. Cracks can also extend across the pavement surface into the shoulder and be several centimeters wide. The thermal contraction of soil (in the base, subbase, and/or subgrade) is primarily responsible for such types of transverse cracks rather than the AC surface layer. Such transverse cracks can even occur in unpaved roads at intervals of 39.4 to 295.3 feet (12 to 90m) and depths extending to 6.6 feet (2m) [16, 17]. The second mechanism responsible for low temperature cracking in AC relates to the volumetric contraction that occurs as the material experiences a temperature drop. Provided that a material is unrestrained, it tends to shorten as the temperature falls. However, if such material is restrained, resembling the case of AC in a pavement structure, the development of thermal stress can produce cracking when the stress equals the tensile strength of the material [16]. During warm weather, AC can be considered to act as a viscoelastic material. Thus, the developed thermal stresses due to temperature drop in a warm temperature range can be dissipated through stress relaxation. Unfortunately, this doesn't apply to cold weather where the AC behaves as an elastic material. The thermal stresses are not dissipated and cracking can occur [16].

Low temperature cracking of AC pavements represents a serious problem in the northern United States, Canada, and other cold regions. Severe cracking has been reported in areas where the freezing index, a measure of the combined duration and magnitude of below freezing temperatures occurring during any given freezing season, is equal to or greater than 13,330°C-hours, based on air freezing indices [20]. It has been reported that low temperature cracking can even occur in areas where the freezing index is as low as 8665°C-hours [16, 21]. Generally, low temperature cracking has a primarily pattern that is transverse to the direction of traffic and is fairly regularly spaced at intervals of 98.4 to 196.9 feet (30 to 60m) for new pavements and less than 16.4 feet (5m) for older pavements [16]. Longitudinal cracking may also occur if the transverse crack spacing is less than the width of the pavement, leading to the development of a block pattern. However, thermal cracking occurring wholly in the AC surface layer represents a more serious problem than the transverse cracking caused by the overall contraction of the pavement structure and subgrade [16, 18]. The presence of cracks that are restricted to the AC surface layer enable ingress of water, which increases the rate of stripping and allows pumping of a fine granular base course [16]. In addition, reduction of the bearing capacity of the pavement system may occur, thereby leading to premature failure. Upward lipping at the crack edge can also occur as a result of water entering in the crack during the winter that may lead to the formation of an ice lens below the crack. Also, localized thawing of the base can occur due to the entering of de-icing solutions into the crack that may cause a depression around the crack [16].

2.1. Mechanism of low temperature cracking

As the temperature drops to an extremely cold level, tensile stresses induce the formation of low temperature cracking due to the pavement's tendency to contract. The development of tensile stresses in AC pavements occurs as a result of the friction between the pavement and the base course layer that resists the contraction. A microcrack would develop at the edge and surface of the pavement if the tensile stress induced in the pavement equals the strength of the AC mix. The crack would eventually penetrate the full depth and across the AC layer under repeated temperature cycles or the occurrence of colder temperatures. According to field observations, it has been shown that the cracks start at the surface and progress down through the entire pavement [16, 22]. Provided that the coefficient of contraction of the stabilized layer is greater than that of the AC layer, it may be possible for a thermal crack to reflect up through the AC layer from an underlying stabilized layer [16, 19].

2.2. Factors Influencing Low Temperature Cracking in AC Pavements

Factors influencing low-temperature cracking in AC pavements can be categorized as (1) material, (2) environmental, and (3) pavement structure geometry [16].

2.2.1. Material Factors

Several material factors can affect the thermal behavior of asphalt-aggregate mixtures. These factors include asphalt cement, aggregate type and gradation, asphalt cement content, and air-void content [16]:

Asphalt cement

The single most important factor affecting the severity of low-temperature cracking in an AC mix is the temperature-stiffness relationship of the asphalt. The most important considerations are the stiffness or consistency (i.e., viscosity or penetration) at a cold temperatures and the temperature susceptibility (i.e., the range in consistency with temperature). Lower viscosity (or penetration) grades or lower temperature performance graded materials will have a reduced rate of increasing stiffness with decreasing temperature. This results in a lower potential for low-temperature cracking [16]. It has been found that the addition of polymer to liquid or heated asphalt generally improves field performance because it imparts flexibility to the asphalt [15].

Aggregate type and gradation

Aggregates that have high abrasion resistance, low freeze-thaw loss, and low absorption show improved resistance to transverse cracking. Little variation in low-temperature strength is associated with aggregates that possess these characteristics. The low-temperature strength is reduced through absorptive aggregates because the asphalt cement remaining in the mix for bonding is less than it would be in a mix with a non-absorptive aggregate. Little influence on low-temperature strength can be related to the gradation of the aggregate used in the mix, provided that the mix is designed to provide reasonable resistance to rutting [16].

Asphalt cement content

No significant influence on a mix's low-temperature cracking performance has been reported when changes in asphalt cement content occur within a reasonable range of optimum. Increasing asphalt content increases the coefficient of thermal contraction and decreases the stiffness. This leads to equilibrium between the thermal stress developing and the stress that developed before the asphalt cement content was changed [16].

Air-void content

The degree of compaction and related air void content and permeability do not significantly influence the low-temperature cracking characteristics of the mix [16].

2.2.2. Environmental Factors

Several environmental factors can affect low-temperature cracking. These factors include the following [16]:

Temperature

It was reported that, for a given mix, as the pavement surface temperature is reduced, the incidence of thermal cracking is increased. The ambient air temperature and wind speed both affect the pavement surface temperature. The majority of low-temperature cracking occurs when the temperature decreases to a level below the glass transition temperature and is maintained at this level [16].

Rate of cooling

A faster rate of cooling will result in greater tendency for thermal cracking [16].

Pavement age

The incidence of thermal cracking is associated with older pavement. This occurs as a result of the increasing stiffness of aging asphalt cements. The aging characteristics of a mix may be affected by the air void content. In addition, as the pavement's service life increases, the probability of more extreme low-temperatures occurring will increases [16].

2.2.3. Pavement Structure Geometry

Several pavement structure geometry factors can affect thermal cracking response. These factors include pavement width, pavement thickness, coefficient of friction between the AC layer and base course, subgrade types, and construction flaws [16]:

Pavement width

It has been suggested through field investigations that thermal cracks are more closely spaced in narrow pavements than in wide pavements. Initial crack spacing for secondary roads of 24 feet (7.3m) width is approximately 98.4 feet (30m). As the pavement ages, secondary and tertiary cracks develop and the differences in crack spacing are not apparent [16].

Pavement thickness

In general, lower incidence of thermal cracking has been recorded for thicker AC layer pavements. In a study made Burgess et al., it was fond that increasing the thickness of the AC from 3.9 inch to 12 inch (10cm to 25cm) resulted in one-half the cracking frequency when all other variables were consistent [16, 23].

Coefficient of friction between the AC layer and base course

It was found that the existence of a prime coat on an untreated aggregate base course layer reduces the incidence of low-temperature cracking. This result was attributed to the fact that an AC layer is "perfectly" bonded to the underlying granular base with a reduced thermal contraction coefficient (because the granular base has a lower thermal contraction coefficient than the AC). The gradation of the base course, particularly the percentage of material finer than the No. 200 sieve, may have a minor influence on the incidence of low-temperature cracking [16].

Subgrade type

The frequency of low-temperature cracking is usually greater for pavements on sand subgrades than on cohesive subgrades [16].

Construction flaws

Steel roller compaction of asphalt layers at high temperatures and low mix stiffness creates transverse flaws. As the pavement cools, cracks may be initiated at these flaws, often spaced closer than the width of a lane [16].

2.3. General Maintenance Practices Overview

Increasing budget constraints require that states and local agencies perform more work with less money. Historically, the emphasis of local highway departments has been on building new roads, but the new focus is on maintaining and preserving existing pavement surfaces. This shift has resulted in three types of pavement maintenance operations [3]:

2.3.1. Preventative Maintenance

A preventive maintenance program is a systematic approach to using a series of preventive maintenance treatments over time. A single treatment will improve the quality of the pavement surface and extend the pavement life, but the true benefits of pavement maintenance are realized when there is a consistent schedule for performing the preventive maintenance. An effective pavement preservation program integrates many preventive maintenance strategies and rehabilitation treatments. The goal of such a program is to extend pavement life and enhance system-wide performance in a cost-effective and efficient way. Studies show that preventive maintenance is six to ten times more cost-effective than a “do nothing” maintenance strategy [3]. Benefits of pavement preservation include improved customer service and substantial life cycle cost savings; treatments are especially cost-effective when applied early in the life of a pavement. In addition, by extending the life of a pavement section until it can be rehabilitated, preventive maintenance allows an agency to even out its maintenance budget from year to year, which otherwise can vary greatly. Preventive maintenance activities can include conventional treatments such as crack sealing, chip sealing, fog sealing, rut filling, and thin overlays. They can also include emerging technologies; such as ultra-thin wearing courses, very thin overlays, and microsurfacing applications. Aside from crack treatments, all of these treatments leave the pavement with a new wearing surface. Preventive maintenance is generally planned and cyclical in nature. Its intent is to repair early pavement deterioration, delay pavement failures, and reduce the need for corrective maintenance and service activities. Although this type of maintenance is not performed to improve the load-carrying capacity of a pavement, it extends the pavement useful life and level of service [3].

2.3.2. Corrective Maintenance

Corrective maintenance is performed to improve or extend the functional life of a pavement. It is a strategy of surface treatments and operations intended to retard progressive failures, and reduce the need for routine maintenance and service activities [3]. Corrective maintenance differs from preventive maintenance primarily in cost and timing. While preventive maintenance is performed when the pavement is still in good condition, corrective maintenance is performed when the pavement is in need of repair, and is therefore more costly. Delaying maintenance allows increased occurrence of pavement defects and increased severity, resulting in more extensive and expensive work. Consequently, the life cycle costs of the pavement will be considerably increased when corrective maintenance is performed. Corrective maintenance is much more reactive than preventive maintenance, and is performed to correct a specific pavement or area of distress. Activities include structural overlays, mill and overlays, pothole repair, patching, and crack repair [3].

2.3.3. Emergency Maintenance

This maintenance activity may be performed during an emergency situation, such as when a blowout or severe pothole must be repaired immediately, generally for safety reasons or to allow for traffic to use the roadway. Emergency maintenance also describes those treatments that hold the surface together until a more extensive rehabilitation or reconstruction treatment can be accomplished. When emergency maintenance is needed, some of the typical considerations for choosing a treatment method are no longer important. Cost may be the least important consideration after safety and time of application are considered. Materials that may not be acceptable when used in preventive or corrective maintenance activities, for cost or long-term performance reasons, may be highly acceptable when used in an emergency situation [3].

2.4. Types of Maintenance Treatments

Crack repair with sealing: A localized treatment method used to prevent water and debris from entering a crack, which might include routing to clean the entire crack and to create a reservoir to hold the sealant. It is only effective for a few years and must be repeated. However, this treatment is very effective at prolonging the pavement life. This method includes the following three crack repair methods [3]:

- Clean and seal: Used on all types of cracks, it involves using a hot air lance or compressed air to blow out the debris in the crack, then filling with a sealant.
- Saw and seal: Involves using a pavement saw to create transverse joints at regular intervals along a newly placed pavement, then filling with a sealant.
- Rout and seal: Used on transverse and longitudinal cracks. Involves using a pavement saw or router to create a reservoir centered over existing cracks, then filling with a sealant.

Crack filling: Differs from crack sealing mainly in the preparation given to the crack prior to treatment and the type of sealant used. Crack filling is most often reserved for more worn pavements with wider, more random cracking [3].

Full-depth crack repair: A localized treatment to repair cracks that are too deteriorated to benefit from sealing.

Fog seal: An application of diluted emulsion to enrich the pavement surface and delay raveling and oxidation. It is considered a temporary treatment [3].

Seal coat: Used to waterproof the surface, seal small cracks, reduce oxidation of the pavement surface, and improve friction [3].

Double chip seal: An application of two single seal coats. The second coat is placed immediately after the first. This treatment waterproofs the surface, seals small cracks, reduces oxidation of the pavement surface, and improves friction [3].

Slurry seal: A mixture of fine aggregate, asphalt emulsion, water, and mineral filler, used when the primary problem is excessive oxidation and hardening of the existing surface. Slurry seals are used to retard surface raveling, seal minor cracks, and improve surface friction [3].

Microsurfacing: Commonly referred to as a polymer-modified slurry seal; however, the major difference is that the curing process for microsurfacing is a chemically controlled process, versus the thermal process used by slurry seals and chip seals. Also may be used to fill ruts [3].

Thin hot-mix overlays: Includes dense, open, and gap-graded mixes that improve; ride quality, reduce oxidation of the pavement surface, provide surface drainage and friction, and correct surface irregularities [3].
Pothole patching: Includes using cold and hot asphalt mixtures, spray injection methods, and slurry and microsurfacing materials, to repair distress and improve ride quality [3].

2.5. Required Properties for a Crack Sealant to Thermal Cracks

Due to the moving nature of working thermal cracks, a suitable crack sealant must be capable of [23]:

- Remaining adhered to the walls of the crack
- Elongating to the maximum opening of the crack and recovering to the original dimensions without rupture
- Expanding and contracting over a range of service temperatures without rupture or delamination from the crack walls
- Resisting abrasion and damage caused by traffic.

2.6. Thermal Cracking Construction Processes

2.6.1. Crack Evaluation and Assessment for Crack Maintenance

The formation of cracks in asphalt pavements will occur with normal traffic and time, but the severity and occurrence is not predictable by any single common method. Generally and historically, crack treatments are used as a means to slow the rate of deterioration of pavements and prevent water from entering the lower pavement layers [3, 24, 25]. Decisions for the correct maintenance measures and crack treatments are determined by predictive measures based on previous experience or the current state of the pavement. The severity and occurrence of cracking is done through evaluation of the pavement.

2.6.2. Maintenance Method Determination

Maintenance planning and design may involve advance scheduling of maintenance techniques according to pavement management systems (PMS). A PMS is “an established, documented procedure treating many or all of the pavement management activities listed in a systematic and coordinated manner” [26, 27]. Determination of the proper techniques for a PMS or repairing a specific distress may require experience or rational decision making. Hicks et al. lists cost, reliability, availability of contractors, environment, and other factors such as availability of materials and time of year placement as the key components for PMS decision making [27]. Many studies have isolated cost and cost-effectiveness as the main concern, where a balance between cost and performance will often determine the final material or method selected [24, 25, 27].

Hicks et al. investigated the cost compared to the expected life of several treatments used for preventative maintenance. Using present serviceability index (PSI) as the performance gauge, the researchers concluded that the cost-effectiveness of the treatments varied based on the specific distresses in the road. The performance of rout and seal treatments and rout and fill treatments were effective in longitudinal and transverse cracking distresses, but mixed results were seen with other treatments [27]. Hand et al. presented a literature review and a limited survey regarding cost-effectiveness of crack and joint sealing after the Wisconsin Department of Transportation implemented a “no-seal” policy in 1990 [25]. The basis of this research was that crack sealing is historically accepted as a maintenance practice, but may not be cost-effective due to research findings. The results of the study concluded that crack sealing practices will retard the deterioration of asphalt pavements, but treatments may only be cost-effective in certain climates or when there is little structural damage to the pavement. Selection of the material will vary with the specific road, but identifying the proper material or technique for cracking will often be determined by the severity and density of cracking [28].

After assessing maintenance needs and determining the different materials that may be used, the selection of the specific material or product should be based on the desired properties needed for the maintenance. Short preparation time, quick and easy application, short cure time, adhesiveness, cohesiveness, resistance to softening and flow, flexibility, elasticity, resistance to aging and weathering, and abrasion resistance are the most desirable properties to consider according to the FHWA [15].

The selection process for Mn/DOT relies on cost effectiveness. Decisions are made based on three questions; 1) Does the treatment enhance pavement performance? 2) Is the treatment cost-beneficial? 3) What is the best treatment method used? Determination of the best treatment is generally based on the pavement type, crack conditions, extent of distress, roadway use and level of traffic, climate and environmental factors, traffic loading, cost of treatment, expected life, availability of qualified staff and contractors, availability of quality materials, time of year of placement, facility downtime, pavement noise, and surface friction. Cracking treatments depend on the severity, edge deterioration, and frequency of cracks [3, 24].

2.7. Cost-Effectiveness Analysis

Cost-effectiveness is often the preferred method of determining which materials and procedures to use [29]. Cuelho et al. made a cost effectiveness study on crack sealing materials for the Montana DOT [29]. The study involved the construction of four experimental test sites within larger crack sealing projects. These sites include combinations of eleven sealant materials and six sealing techniques. Ten sealants were hot poured materials and one was cold pour material. Table 2.1 and 2.2 illustrate the hot and cold pour crack sealing materials used and their properties, respectively. The crack sealing technique included both non-routed and routed methods. Non-routed methods consisted of the Simple Band-Aid and Capped configurations. The Band-Aid configuration used a V-shaped or U-shaped squeegee to spread the sealant, and the capped configuration was accomplished by overfilling the crack slightly and allowing the excess sealant to settle. Routed methods included a “square” reservoir and a “shallow” reservoir. Square reservoirs were filled using three techniques: Flush, Recessed, or Band-Aid. This combination provided six crack sealing techniques; a) simple band aid (BA), b) capped (C), c) square reservoir and flush (SQ-F), d) square reservoir and recessed (SQ-R), e) square reservoir and band aid (SQ-BA) ,and f) shallow reservoir and flush (SH-F). In the aforementioned study, monitoring of the test sites included visual inspections (for all of the sites), and nondestructive structural readings and surface distress identification. An estimate of the useful life of each crack sealing method has been determined from these investigations. Two methods were employed to estimate crack sealing performance: Method A and Method B. The simplest method (Method A) used the forecasted life of a particular material/technique combination to estimate performance. For this method it is assumed that the crack sealant performance decays linearly over time. The minimum acceptable level of service of crack sealing (condition = 50 percent) is defined by the water’s ability to penetrate 50 percent of the sealed crack’s length [29].

Table 2. 1 Properties for hot-pour materials as advertised on manufacturer data sheets [29].

Material	Cone penetration 0.003 inch (0.1 mm)	Modified cone penetration 0.003 inch (0.1 mm)	Flow inch (mm)	Resilience	Bond (pass 3 cycles)	Softening Point (°C)	Recommended Application Temp. (°C)
Crafco221	90 max	no data	0.11 (3) max	60%	-29°C. 50%	no data	190
Crafco 231	90 to 150	no data	0.11 (3) max	60%	-29°C. 200%	no data	190
Crafco 299	110 to 160	40 min.	0.39 (10) max	25 to 50%	-29-C. 200%	no data	190
Crafco 516	50 to 80	no data	no data	30%	no data	77 min.	190
Crafco 522	100 to 150	25 min.	0.39 (10) max	30 to 60%	-29°C. 200%	no data	190
Deery101 ELT	100 to 150	25 min.	0.39 (10) max	30 to 60%	-29°C. 200%	no data	190
Deery 1101	150 max	no data	0.11 (3) max	60%	-29°C. 200%	85 min.	190
Maxwell 60	150 max	no data	0.11 (3) max	60%	-18°C. 100*.	88 min.	190 to 205
Maxwell 71	90 to 150	no data	0.11 (3) max	no data	-29°C. 200%	77 min.	190 to 205
Maxwell 72	100 to 150	25 min.	0.39 (10) max	30 to 60%	-29°C. 200%	no data	190 to 205
Cone penetration (ASTM D 3405. D 5329): non immersed at 25°C (77°F). 150 g moving mass. 5 s							
Modified cone penetration (modified ASTM D 5329): non immersed at -18°C (0°F). 150 g moving mass. 5 s							
Flow (ASTM D 3405, D 5329): 60°C (140°F). specimen at 75 degrees from horizontal for 5 h							
Resilience (ASTM D 3405, D 5329) 25°C (75°F):0.670 in. diameter sphere. 75 g moving mass. 20s recovery							
Bond (ASTM D 3405, D 5329):non-immersed, at-29°C (-20°F), percentage is extension from initial width of 1/4 in.							
Softening Point (ASTM D 36):ring and ball apparatus, temperature rise of 5°C (9°F) per minute							

Table 2. 2 Properties for cold-pour materials as advertised on manufacturer data sheets [29].

Material	Saybolt Furol Viscosity at 77°F (s)	Tests on Residue			
		Kinematic Viscosity at 275°F (cSt)	Kinematic Viscosity at 140°F (cSt)	Asphaltene Content %	Polymer Content W%
Witco CRF-MP	30 to 120	90 min.	7,000 to 12,000	9.5 max.	3.5 min
Sayboll Furol Viscosity - ASTM D244					
Kinematic Viscosity - ASTM D2170					
AsphalteneContent-ASTMD2007					
Polymer Content - Infrared Method (non-standardized test by Witco, Inc.)					

Field measurements conducted as part of this study were used to determine, and in some cases estimate, the time at which various crack sealant material/techniques combinations would reach this condition. Method B was created because the exponential portion of the forecasting technique used to estimate useful life of crack sealing was sensitive to fluctuations in the distress data. As such, this method used measured performance conditions collected from test sites at specific time intervals. As in Method A, Method B defines the minimum acceptable level of service of crack sealing to be when its condition = 50 percent, i.e., when water is able to penetrate 50 percent of the sealed crack's length. This method provides a more accurate estimate of the effectiveness of crack sealing material/technique combinations since it considers real performance values over time rather than an estimated performance derived from estimates of useful life. The effectiveness of the material/technique combinations was determined using both methodologies. The effectiveness was divided by the average installation cost to determine cost-effectiveness as illustrated in Table 2.3 [29].

Table 2. 3 Individual rankings of specific material/technique combinations based on their cost-effectiveness [29].

Rank	**Material/Technique Combination**	
	Method A	**Method B**
1	Crafco 522, SQ-F	Crafco 522, BA
2	Crafco 522, SH-F	Crafco 231, BA
3	Crafco 522, SQ-BA	Maxwell 72, SH-F
4	Crafco 231, SH-F	Maxwell 71 , SH-F
5	Crafco 231, SQ-F	Crafco 231 , SQ-BA
6	Maxwell 72, SH-F	Crafco 522, SH-F
7	Maxwell 71, SH-F	Crafco 231, SH-F
8	Maxwell 71, SQ-F	Crafco 522, SQ-BA
9	Crafco 231, SQ-BA	Maxwell 72, SQ-F
10	Crafco 522, BA	Crafco 522, SQ-F

2.8. Maintenance Scheduling

Planning and scheduling of preventative maintenance measures are usually planned and cyclic to delay pavement failures and reduce the need for more extreme maintenance in the future. Timing and selection of the proper techniques can extend the service life of the road and improve cost effectiveness [3]. It is common practice to utilize network-level analysis and decision trees to determine the needs of pavements and where to appropriately spend money. Mn/DOT provides a condensed version of their decision tree in the 2009 *Preventive Maintenance Best Management Practices of Hot Mix Asphalt Pavements* report. Here, a simple question and answer flow chart starts with the occurrence of a distress, the severity, and the proper action for repair [24]. Mn/DOT *Best Practices Handbook on Asphalt Pavement Maintenance* includes a section on improved planning, which allows districts to assess needs based on Mn/DOT's PMS. The plan identifies pavement sections that would benefit from preventative maintenance, recommendations for maintenance methods, PMS optimization, and provides a pavement preservation plan. The key to the planning process is the optimization, which provides annual information including; selection of the roads most in need, road life expectancy, and the specific treatment based on distresses [3]. Ideally, scheduling of roads can be done through the use of a performance model that can predict the current or future occurrence of cracking in roadways [24]. However, due to the large amount of variables involved (traffic, climate factors, different distresses, etc…); there is no standard performance model available.

2.9. Pavement Performance Prediction Modeling

Scheduling accuracy can be improved through modeling prediction curves for the performance of the road, which can be specifically tailored to individual distresses like thermal cracking. Many studies have sought to accurately quantify cracking behavior in asphalt pavements using a variety of methods. Easa et al. have presented a reliability-based model based on thermal cracking distresses observed in Canada and the Northern United

States [29]. The reliability calculations were based on several measureable pavement properties including coefficient of thermal contraction, pavement temperature, penetration and softening point, penetration index, binder stiffness, mixture stiffness, and pavement stresses. The model incorporates two forms of failure modes for thermal cracking, which are low-temperature cracking and thermal-fatigue cracking. The combination of both failure modes, along with the technological improvements to reliability-based modeling methods, was shown to have consistency in simulation, where older models had variability. Shen and Kirkner studied the effects of stress redistribution and localized damage of cracks in a semianalytical model for thermal cracking [30, 31]. This approach uses the multi-scale nature of cracking through analysis of the formation of the crack and the stresses applied while considering the viscoelastic properties and inhomogeneity of asphalt concrete. The model derived in this study was consistent with field observations and can generate cracking predictions of the entire pavement structure. Bouldin et al. research involved bending beam rheometer (BBR) and direct tension tests (DDT) to build a prediction model for low-temperature cracking performance of asphalt binders in the field. The researchers utilized a mechanistic model and validated correlations with test sections and data from Alberta and Canada [32]. Timm and Voller studied the influence of input parameters on a spacing model for thermal cracks. Utilizing the unbound granular base as a Mohr-Coulomb material, the adjusted model was found to reasonably predict crack spacing [33].

2.10. Pavement Field Assessments

Field condition surveys and non-destructive testing provide a rational approach to determining the proper maintenance strategy [3]. Rating systems are the most common way to assess the road and prioritize the need for maintenance. Mn/DOT uses three indices for rating pavements; Present Serviceability Index (PSR), Surface Rating (SR), and Pavement Quality Index (PQI); with surface rating as the preferred method [3, 24]. Mn/DOT also refers to Pavement Condition Index (PCI) as one of the most popular rating systems, although it is not the primary choice in Minnesota.

A very common method for monitoring the status of a pavement is through annual inspection using a specially equipped vehicle. For Mn/DOT, the collection van is used to monitor roughness and rutting yearly, but the condition surveys are compiled every other year [24]. Crack data can be collected using digital imaging equipment, but the resolution of the images is not sufficient to identify the initial formation of cracks.

More specialized equipment can be used for increased detection of cracks. In a study linking the effects of thermal cracking to roughness, researches used the Automated Laser Profile System (ALPS) to map cracks across the target area. This equipment is typically used to measure rutting and has been used in Minnesota (MnROAD) since 2002. However, distresses like faulting, curling, warping, lane shoulder drop-off, and cracking can be more closely evaluated with this system. The equipment is placed parallel to the traffic direction and a laser mounted on a rolling plate scans the surface. The collected data was compared to IRI (International Roughness Index) for examined road sections. Results showed that more severe cracks resulted in increased roughness [34].

2.11. Thermal Cracking Maintenance Specifications and Practice Guidelines

Due to the factors that influence the occurrence of thermal cracks; including climate, traffic, and mix design; and the many different materials and methods available to maintain cracks, most agencies develop unique maintenance policies. However, national studies, such as the FHWA's *Sealing and Filling Cracks in Asphalt Pavements* have provided valuable research and recommendations as a basis for effective maintenance programs. Included in the aforementioned FHWA report is an overview of test road sites in Texas, Washington, Iowa, Kansas, and Ontario that were treated with a variety of crack treatments over a 6.5-year period. Weathering, pull-outs, overband wear, tracking, extrusion, stone intrusion, adhesion loss, cohesive loss as a result of tensile/shear forces, cohesive loss as a result of bubbling, and edge deterioration served as evaluation parameters. 15 different treatment methods, 8 installation methods, and 7 preparation procedures were used in various combinations across the 5 sites. The results of the study lead to basic recommendations from the FHWA. With ordinary working cracks and moderate traffic; simple Band-Aid configuration should be used with standard rubberized asphalt for short-term (1-3 years) maintenance, simple Band-Aid configuration with modified rubberized asphalt or recessed Band-Aid configuration with standard rubberized asphalt should be used for medium-term (3-5 years) crack maintenance, and modified rubberized asphalt in standard or shallow recessed Band-Aid configuration for long-term (5-8 years) crack maintenance. With nonworking cracks and low to moderate traffic; short-term crack maintenance should utilize asphalt cement in a flush-fill configuration. Under the same traffic levels and the same type of cracks, long term treatments should be treated with asphalt rubber or rubberized asphalt in flush-fill or overband configuration, or fiberized asphalt in an overband configuration. The final recommendation focused on the importance of quality control in all crack sealing and filling practices [14].

2.12. Thermal Cracking maintenance Assessments and Quality Assurance

For application of crack maintenance materials, many states provide a manual for the crews or contractors to have in the field to ensure completion of tasks and adherence to proper procedure. Nebraska, for example, provides a manual with a specific checklist for quality control. This checklist is an outlined step-by-step list of tasks that includes information on; climatic conditions, routing, material preparation, cleaning of cracks and routs, sealant application, overbanding of sealant, and sealant [1].

Long-term performance of crack treatment materials will show the longevity and durability of the selected treatments, as well as provide insight to the selection process. Masson et al. conducted a study on twelve bituminous hot-pour sealants in cold urban conditions over a four year period [35]. Each material was subjected to the ASTM D3405 specification, with only 5 materials passing all requirements; 11 of the 12 should have met or exceeded the specification. Installation of the twelve sealants was conducted by the same contractor and under the same preparation procedure of routing, cleaning, and heat treating. Sealant performance was evaluated on the basis of pull-out and debonding. Materials were applied in autumn with assessments occurring after three, seven, eighteen, thirty-two, and forty-four months of service (most assessments occurred during the spring). To compare the performance of materials while considering the two performance criteria, a performance index was used that accounted for the percentage of debonding length and the percent of pull-out length. Sealant performance varied tremendously between products in the study. Sealant source, rout size, and rout orientation were found to affect the performance of the materials. Another conclusion of this study was materials that passed the ASTM D3405 specification performed within "averagely," while the materials that failed the specification generally performed the best or the worst [35]. As a result, the researchers determined that a performance-based specification is required.

2.13. Laboratory Assessments

The FHWA manual lists several material types and the available specifications for testing the materials. Generally, the manufacturer will provide the testing standards to which the material was processed or made, along with any quality assurance testing used for sampling. Each batch of material received by the DOT should be subjected to sample testing, as deemed necessary. ASTM and AASHTO standards are generally used, with exceptions for state-modifications or federal-modifications [2].

Quality assurance is an important piece of a pavement management system, and testing ensures that the received materials will perform in the field. Fundamental standardized testing, combined with the experience with tested materials, will provide the DOT with an indication of material performance, expected service life, and can indicate which materials should or should not be used in future applications. It is not uncommon for DOTs to use modifications to standardized tests for extreme conditions or for materials that are highly specialized. For example, cone penetration may be modified for different states to account for required performance for tracking concerns, softness, or for temperature extremes. Details of state/province specifications and material acceptance testing are provided in section 2.10 of this report.

Other research works have investigated testing set-ups that will correlate lab testing directly to field performance of crack maintenance materials as a way to enhance testing standards like ASTM or AASHTO standards. For example, Al-Qadi et al. used a modified BBR test to subject sealant materials to a known and repeatable testing method that can be related to field performance. The results of the test produced consistent data with stiffness, creep rate, and energy dissipation ratio as the main parameters for comparison. [36].

2.14. Crack Maintenance Specifications and Practices for States and Provinces

2.14.1. Alberta

Alberta allows for the use of cold pour rubber filled bituminous emulsified pavement crack sealant conforming to EC-101 specifications and hot pour bituminous pavement crack sealant conforming to HC-200 specification. Five manufacturers are permitted for the cold pour technology (M&M Asphalt, Ace Asphalt & Maintenance Ltd., McAsphalt Industries Limited, Pounder Emulsions Limited, and Elsro Construction Products) and two manufacturers are permitted for the hot pour technology (Husky Oil Marketing Company and Elsro Construction Products). Quality assurance for cold pour technologies are tested for uniformity (EC-101), viscosity (ASTM D 562), solids content (ASTM D 244), and rate of curing (EC-101). Hot pour technologies are tested for softening point (ASTM D 36), penetration at 25°C (ASTM D 5), and viscosity (ASTM D 2170). The contractor shall supply quality control testing from the manufacturer to the consultant for each crack seal batch. Blotter materials; including screened sand with a maximum top size of 0.078 inch (2 mm), cement, or fly ash, shall be supplied by the contractor when necessary [37].

All work shall be performed during daylight hours, with visibility of 2296.5ft (700 m) or more, in dry conditions (no snow or rain), and when the atmospheric temperature is above 0°C. All cracks measuring 0.19 inch (5 mm) and greater shall be sealed. Cracks and adjacent pavement surface are to be clean prior to application. Sealant materials are to be prepared and applied under the manufacturer’s recommendations. Cracks are to be flush filled with sealant and an overband of approximately 0.98 inch (25 mm) should be applied beyond the edge of the crack. Excess sealant shall be removed immediately with a squeegee from the road center to the shoulder 3.1 mile (5 km) lots are subject to material sampling and inspection by the Department [37].

2.14.2. British Colombia

British Colombia’s crack sealant materials consist of rubberized asphaltic and/or elasticized asphalt sealants Passing the requirements of ASTM D 6690, sand, and dust cover. ASTM accordance is not mandatory for the Lower Mainland, Vancouver Island, or the Sunshine Coast. Special provisions specify that the contractor use a Rubberized or High Float Emulsified Asphalt HF15OS or equivalent. The ministry representative shall select random samples of sealant for testing from each lot. Sand shall be tested under ASTM C 117, be grade to specifications, approved by the Ministry Representative, and shall be required for pavements using High Float Emulsified Asphalt. Dust cover including Portland cement, talc, lime, or other materials approved by the Representative, shall be used on rubberized or elasticized sealants [38].

Cracks sealing shall only be performed in conditions where temperatures are at least 10°C and where pavement surfaces, road base, and cracks are dry. Cracks measuring 0.62 inch (16 mm) or less shall be routed to 0.62 inch (16 mm) wide and form a vertical-walled reservoir 0.74-0.98 inch (19-25 mm) deep. Routing shall be performed so pavements are not broken or torn out. Routing shall not be performed on pavements where spalling or fractures will occur. Rout reservoirs should be cleaned with a hot air lance. Sealant shall be applied from the bottom of the reservoir to the surface level with overfill. Excess material shall be struck from the road surface to leave an even spread between 0.98 inch (25 mm) to 1.57 inch (40 mm) on either side of the crack [38].

Rubberized and elasticized sealants shall be used on pavements less than 10 years old and where the majority of cracks are less than 0.98 inch (25 mm) wide. These sealants shall be applied to cracks routed to a uniform depth and width, and where cracks having a width of 0.62 inch (16 mm); which do not require routing. High Float Emulsified Asphalts where cracks have depressions or lipping, or where the majority of cracks measure over 0.98 inch (25 mm) wide. These cracks should be cleaned, immediately filled, and sanded [38].

2.14.3. Colorado

Colorado specification for joint and crack sealing states that only pre-blended, pre-reacted, and prepackaged materials that conform to ASTM D 6690 Type I or Type II may be used. All materials used must be from CDOT's Approved Products List. Materials shall not be mixed, and must come directly from the manufacturer's sealed container. Preparation, application, and all testing shall adhere to the manufacturer's recommendations [39].

Cracks between 1/8 inch and 1 inch are to be filled with sealant. Loose and foreign matter shall be cleared from the crack to a depth of approximately twice the width of the crack. A hot compressed air lance should be used to clean and dry the crack, and warm the adjacent asphalt for a better seal. The crack should be filled with the selected crack sealant and excess sealant should be leveled off with a squeegee, shoe attachment on the applicator, or other means specified by the engineer. Excess material should be a maximum of 3 inch wide and shall not exceed a depth of 1/16 inch. Sealant application should occur when the air temperature and pavement temperature are both at least 40°F and rising. Any material that is pulled out or picked up after application will be replaced at the expense of the contractor. Blotter material that is approved by the engineer should be provided by the contractor and may be placed at the contractor's expense to prevent tracking or pull out [39].

2.14.4. Illinois

Illinois DOT Specifications Section 451 on crack sealing for hot-mix asphalt pavement specifies hot-poured joint sealer consistent with Illinois DOT specification 1050.02 for crack sealing of HMA pavements. The specification states sealant materials shall be according to ASTM 6690, Type II. Generally, only primary longitudinal and transverse working cracks are to be maintained unless otherwise directed by the engineer [40].

Cracks are to be routed as neatly as possible to approximately 3/4-in wide by 3/4-in deep to provide a 1:1 depth to width ratio. The routed crack should be cleaned of debris and dust immediately ahead of sealer placement with the use of a power brush/blower or compressed air at a minimum of 90 psi. Sealant should be prepared in accordance with the manufacturer's recommendations and all applications should occur when the air temperature in the shade is 40°F or higher in the shade. Cracks should be slightly over filled and squeegeed to apply an approximately 2 inch "Band-Aid" that is flush with the pavement. To prevent tracking, sealants may be dusted with fine sand, Portland cement, or mineral filler if specified by the engineer. Sealants should be allowed to cure prior to exposure to traffic [40].

2.14.5. Indiana

Indiana uses asphalt binder, asphalt emulsion, fine aggregates, and joint sealing materials for sealing of cracks [41]. The asphalt binder may only be graded to PG 64-22, but may be blended with styrene butadiene rubber (SBR). Asphalt emulsions for use in crack sealing may be AE-90, AE-90S, or AE-150 as listed in Indiana specification 902.01b. AE-90 is a "medium breaking, low-penetration, high asphalt content type" emulsion used for sealing and other maintenance [42]. AE-90S is a "rapid setting, anionic type emulsion" used for seal coatings [42]. AE-150 is a "medium breaking, moderately soft penetration type" emulsion [42]. Joint sealing materials are hot pour that must be in accordance with AASHTO M 324, Type II with testing through ASTM D 5329. Joint sealing materials may be used for crack sealing if the manufacturer's recommendations are followed [42].

Indiana distinguishes between filling and sealing practices. All sealing and filing practices shall not occur when the ambient air temperature is below 40°F or under other unsuitable conditions, unless specified by the engineer. For crack filling, crack preparation consists of routing cracks to a maximum of 3/4 inch wide and minimum 3/4 inch depth with a routing machine that is capable of cutting a uniform shape. Routing will occur when specified for the cracks requiring maintenance. Cracks or routed cracks should be filled with hot pour joint sealant to within 1/4 inch of the surface in accordance with the manufacturer's recommendations. For sealing practices, cracks should be cleaned with compressed air at a pressure of at least 100 psi, or cleaned "by other suitable means" [41]. Sealing material should be placed using a "V" shaped wand tip and cracks should be completely filled or overbanded. Overbanding should not exceed 5 inches unless needed. Cracks shall be covered with sufficient fine aggregate to prevent tacking and all excess should be removed [41]. Acceptance of the work performed is dependent on the engineer's opinion of performance of work, consistent with Indiana DOTs Conformance with Plans and Specifications. Current crack maintenance practices have been refined as a result of the findings of *Evaluation of the Implementation of Hot Pour Sealants and Equipment for Crack Sealing in Indiana* [43].

2.14.6. Iowa

Iowa does not have a crack maintenance program for asphalt pavements. Iowa DOT published a report on low modulus hot pour joint sealant in 1990 covering the use of Seatlight No. 2486 experimental low modulus sealant. Cracks were sawed or routed to be 1/2 to 3/4 inch wide, sandblasted, cleaned by air compressor, and sealed. In addition to low modulus sealant, a conventional sealant was used for comparison. Both sealant types performed well for the first two years of the study, but the low modulus sealant lost adhesion after 2.5 years and the conventional sealant failed after 3 years. Low modulus sealant continued to perform better than the conventional sealant after failure; however the improvement was not sufficient enough to warrant a recommendation to switch to low modulus sealants [44].

2.14.7. Kansas

The Kansas Department of Transportation (KDOT) allows the use of 2 general categories of crack sealing materials; hot type joint compound and fiber-reinforced asphalt [45]. The Kansas specification for hot sealing compounds lists 8 requirements for any material provided by a KDOT qualified manufacture. The sealant must be a "homogeneous blend of elastomers and other plasticizers and agents" that will seal cracks from water intrusion while maintaining flexibility and adhesion from 0°F-140°F. The materials must have a twelve-hour pot life, materials may not be mixed if from different manufacturers, and the materials must be properly labeled in storage. Bond, flow, resilience, and penetration properties must adhere to the KDOT Spec. 1501.2 and ASTM D 5329 sections 9, 8, 12, and 6 respectively. Penetration testing has additional variations [46]. Fiber-reinforced asphalt shall consist of PG 64-22 binder and polypropylene fibers consistent with KDOT's Type D certification. The material mixture is also subject to visual inspection prior to use [47].

Cracks shall only be sealed if the crack is between 1/8 inch and 2 inches wide. Cracks are to be routed to size according to Kansas Spec. 835.3c; cracks between 1/8 and 1/2 inch wide should be routed to follow the existing crack, cracks between 1/8 to 3/8 inches should be routed with a 5/8 inch head, cracks between 3/8 and 1/2 inch should be routed with a 3/4 inch router head, and cracks larger than 1/2 inch do not require routing. Loose material is to be removed from the surface. Cracks are to be cleaned and dried with heat lance without burning the existing pavement. Un-routed cracks between 1/8 and 1/2 inch shall be filled with hot type joint seal and cracks wider than 1/2 inch shall be filled with fiber-reinforced asphalt. Cracks should be filled enough to leave a slight recess below the pavement surface [45].

2.14.8. Manitoba

Manitoba allows for hot-applied and cold-applied crack sealants Hot-applied technologies must meet the low modulus specification for Type IV sealants (ASTM D6690) and tested under ASTM D5329 for cone penetration, flow, bond, resilience, and asphalt compatibility. Additionally, the sealant must comply with extended heating at poring temperature. Hot-applied sealants are prohibited if self-leveling or flow or track at high pavement temperatures. Cold-applied sealants must perform below -29°C, and are prohibited if self-leveling or track at high pavement temperatures. All sealants must be pre-approved and placed on the Department's Products Standards List through material submission and testing by the Department [48].

Application procedures will be performed under Departments standards. Cracks are to be routed to a width to depth ratio of 3:1. Routed cracks should be cleaned and dried by hot air lance. Routed cracks shall be overfilled and squeegeed to leave a sealant film of 0.39 inch (10 mm) or less on both sides of the rout reservoir. Sealed crack approval will be based on bond failure and tensile failure. Loss of bond on one face, loss of bond on two faces, complete loss of bond, and tensile stress failure of sealants shall not exceed a combined 7% in total length after the first winter or 10% after 2 winters [48].

2.14.9. Michigan

Michigan (Michigan DOT, MDOT) utilizes four materials for crack maintenance; hot poured joint sealant, asphalt binder, polyester fibers, and asphalt rubber products on the MDOT Qualified Product List. Hot Pour sealants shall be used with saw or rout and seal practice. Hot pour sealants must meet ASTM D 6690, Type II requirements with state-specific variations for bond, penetration, sand, and length of time for reporting results. Overbanding applications can consist of either of two alternative material combinations. First, a combination asphalt binder (PG 64-22 or PG 58-22 for roads south and north of Michigan Highway 46, respectively), 5% by weight of qualified asphalt rubber, and 5% by weight of polyester fibers. Polyester fibers must adhere to ASTM D 3937, ASTM D 2256, ASTM D 1577, and additional state variations. The second overbanding method will consist of an asphalt rubber on the Qualified Product List [49].

Equipment used in the preparation and application of crack maintenance includes a compressed air system, melter applicator, and application wand. The compressed air system must produce 150cfm (cubic feet per minute) flow of continuous air flow at a minimum of 100 psi. The system must be equipped to remove moisture and oil from the air supply. The melter applicator must have a boiler kettle with pressure pump, hose, applicator wand, shut off control on the hose, mechanical agitator in the kettle, monitoring thermometers, and thermostatic controls that regulate up to 425°F. The application wand must have a V-shaped or U-shaped squeegee or a round application head with a concave underside [49].

Crack treatment applications may only occur when the air temperature is between 45 and 85°F. All cracks should be cleaned and dried with compressed air to remove deleterious material, vegetation, and loose dirt no more than 10 minutes prior to the application of fills or sealants. Saw or rout and seal practices should occur with cracks no larger than 1 1/4 inch wide on working cracks. Working cracks, as defined by MDOT, are "cracks that experience considerable horizontal or vertical movement, at least 1/8 inch, as a result of temperature or traffic loading" [44]. Sawing or routing should create a reservoir of 7.5 cubic inches per foot of the cracks to create a depth-to-width ratio of 1:1. The reservoir walls should be vertical with a flat bottom. Sealant should be placed to flush or within 1/8 inch of the pavement surface [49].

Non-working cracks should be treated with overbanding methods using fill materials. Non-working cracks, as defined by MDOT, are "cracks that experience relatively little horizontal or vertical movement, less than 1/8 inch, as a result of temperature change or traffic loading" [49]. Overband application should occur on only clean and dry cracks. The overband should be 4 inch wide and between 1/8 and 3/16 inch; however the overband may be up to 6 inch with the prior written consent of the engineer for coverage of multiple cracks. MDOT overbanding practices vary depending on other maintenance practices that may follow the crack treatments. Stand-alone overband crack fill is used for cracks less than 1 1/4 inch wide when no other surface treatments are required. Cracks that are less than 1 1/4 inch wide should be filled prior to micro surfacing. For chip seal preparation, cracks that are greater than 1/8 inch wide or 3 feet long should be filled, and cracks with varying widths with portions greater than 1/8 inch should be sealed. For paver placed surfaced seals, cracks between 1/4 and 1 1/4 inch should be filled. Visible cracks less than 1 1/4 inch should be filled prior to application of HMA ultra-thin overlays [49].

Quality control planning shall be conducted between the engineer and the contractor during a pre-production meeting. All operations and practices should follow the plan until completion of the work. The engineer will note any deficiencies in the work during a scheduled inspection and contractors must correct all work the engineer identifies as unacceptable [49].

2.14.10. Minnesota

Minnesota DOT (Mn/DOT) Materials Lab Supplemental Specifications for Construction 2014 Edition lists 3 sealing materials for use in crack sealing applications in bituminous pavements; hot-poured, crumb rubber type crack sealer; hot-poured, elastic type joint and crack sealer; and hot-poured extra low modulus, elastic type joint and crack sealer [50].

Hot-poured, crumb rubber type crack seal materials are required to; be on the Approved Products List, consist of manufacturer-blended asphalt and crumb rubber, not separate or settle when melted, and maintain uniform consistency suitable for filling cracks. These materials must meet the requirements of ASTM D 6690, Type I with modifications after one cycle of heating, cooling, and reheating at the manufacturer's maximum recommended temperatures. ASTM D 6690 modifications include recycled rubber mass, bond testing, resilience, and softening point. Samples of the material are required to meet the requirements of ASTM D 5329, with the exception of using sawed asphalt HMA blocks for the bond test [50].

Hot-poured, elastic type joint and crack sealer are required to; be listed on the Approved/Qualified Products List, be composed of fully chemically reacted polymeric materials to a homogenous blend, not separate or settle when melted, and maintain uniform consistency suitable for sealing cracks without holes. Sealants shall meet the requirements of ASTM D 6690, Type II with modifications to cone, bond testing, 1 inch Mandrel Bend , and resilience . Testing of sampled material shall meet the requirements of ASTM D 5329 [50].

Hot-poured extra low modulus, elastic type joint and crack sealers are required to; be listed on the Mn/DOT Approved Products List, be composed of fully chemically reacted polymeric materials to a homogenous blend, not separate or settle when melted, and maintain uniform consistency suitable for sealing cracks without holes or discontinuities. Sealants shall meet the requirements of ASTM D 6690, Type IV. Material sampling will be conducted by the materials engineer and shall meet the requirements of ASTM D 5329 with modifications to cone penetration and resilience [50].

Mn/DOT's "*Recommended Practices for Crack Sealing HMA Pavement"* describe crack sealing practices using the previously listed materials. Hot-poured, crumb rubber type crack sealer are recommended for crack filling applications. Hot-poured, elastic type joint and crack sealer is recommended for clean and seal methods and rout and seal methods where the rout reservoir is required to be wider. Hot-poured extra low modulus, elastic type joint and crack sealer is recommended for transverse rout and seal applications and for agencies that perform saw and seal methods [51].

2.14.11. Missouri

Missouri DOT does not have a crack maintenance program, but specifications for crack sealing of asphalt pavements consist of routing, heat lancing, and sealing practices. Hot pour elastomeric sealant conforming to ASTM D 6690 Type II with modifications to cone penetration, flow, bond, and resilience shall be used. For material acceptance, the contractor must submit material certification or laboratory testing to the engineer that the material passes all requirements. The router must be capable of following random cracks, have a cutter head clutch, be capable of adjusting widths and depths, and must be equipped with a carbide-tipped vertical-sided bit. The heat lance must be a hot compressed-air lance capable of producing air up to 2500°F and shall have separate valves to control propane, burner air, and lance air. The hot-applied sealant applicator shall be a self-contained double boiler with onboard automatic heat control, provide constant and vigorous agitation to the material, and be equipped with a hose and wand capable of delivering the material from the tank to the crack [52].

Sealants may not be applied when the ambient and air temperatures are below 40°F and conditions are not foggy or rainy. Cracks of width 1/4 to 1 1/4 inch shall be routed to remove at least 1/8 inch from each sidewall of the crack, and with a minimum and maximum width of 1/2 inch and 1 1/2 inch, respectively. Larger cracks will be repaired in accordance to plans of the engineer. Cracks shall be cleaned of dust, deleterious material, old sealant, incompressible material, and organic material (vegetation must be removed and the crack shall be treated with herbicide). All cracks should be dried and heated by hot compressed-air lance no more than 10 minutes prior to sealant application. Heating and sealing equipment should not be more than 50 feet apart during operation and crack sidewalls should not be burned or overheated. Sealant shall be applied from the bottom of the reservoir to the top in a uniform manner. Cracks should be filled flush to the surface with excess removed by squeegee. The sealant cap may not exceed 1/16 inch above the surface and no wider than 2 inch beyond the sidewall. Over banding should be minimized and final settlement of the sealant may not exceed 3/8 inch below the pavement surface. All operations must have close conformity to specifications as determined by field measurements of completed work [52].

2.14.12. Montana

Montana has three basic materials for crack sealing projects; crack sealant, backer rods, and blotter material. The use of sealants meeting the requirements of ASTM D 5167 and the following additional testing requirements of modified ASTM D 5329; cone penetration, flow, resilience , bond, recommended pour temperature of 380°F, safe heating temperature of 410°F, and pass asphalt compatibility. A 30-pound sealant material sample shall be submitted to the Helena Materials Bureau for testing prior to acceptance of the sealant lot. Backer rods meeting ASTM D 5249, Type 1 shall be used for cracks 1 1/2 inch or larger. Toilet paper is utilized for blotter material. A 30-pound sample of the sealant in its original packaging must be submitted at least 20 days prior to application to the Helena Materials Bureau for lot testing [53].

Cracks will be routed under the following guidelines; all existing cracks between 1/8 inch and 1 inch, all longitudinal cracks shall be routed to ¾ inch walls and ¾ inch wide flat bottom reservoir, and transverse cracks shall be routed to 1/2 inch walls and 1 1/2 inch wide bottom reservoir. Routing will only be permitted on dry roadways when the temperature is 35°F or above. All cracks must be dry and free of loose material prior to sealant application. If a backer rod is needed, it shall be installed in the crack prior to application of sealant. Sealant shall be applied when the road surface temperature is between 35 and 120°F and within 72 hours of routing. Sealant should fill the routed reservoir flush to the pavement surface using a pressure type applicator. Blotter material should be place on all sealed cracks. [53].

2.14.13. Nebraska

Nebraska has a pavement maintenance manual that overviews the general practices of the Nebraska Department of Roads (NDOR) for the purposes of pavement preservation. General practices consist of crack sealing within 2 years of an overlay and cracks 1/4 inch or wider must be sealed prior to other treatments (like seal coats). Cracks must be routed and cleaned prior to sealing, and hot-air lance should be used if the presence of moisture is suspected. In general, sealing materials for cracks that are 1 inch wide or less should be ASTM D 5078-90 sealants. NDOR currently uses Crafco AR-2 Type 1 and Type 2 rubberized asphalts and Crafco 231 low-modulus rubberized asphalts. In addition, in some instances PG 58-28 asphalt may be used [54].

Sealant materials in Nebraska consist of a mixture of pavement grade asphalt, vulcanized recycled rubber, and polymer modifiers. Vulcanized recycled rubber should be between 10 and 15% of the total product by weight, and free of wire, fabric, and other contaminating materials. 100% of the rubber shall pass the No. 8 sieve and a maximum of 5% passing the No. 200 sieve. The sealant should be heated and sampled in accordance with ASTM D 5078 and pass ASTM D 5329 testing standards. Additionally, materials must meet bitumen content requirements (ASTM D-4) of 60% minimum. Material acceptance will be based on certificate of compliance provided by the supplier and one sample per lot will be sent to the NDOR Materials and Research Division for additional compliance testing under ASTM D 5078 [54].

Cracks of widths 3/8 inch or less shall be routed to 1/2 inch wide by 3/4 to 1 inch deep to form a reservoir. The reservoir should be cleaned with compressed air to remove dust, dirt, loose material, and moisture to provide a clean and dry crack. Cracks that are wider than 3/8 inch shall be cleaned through the full-depth of the crack by sandblasting, brushing, or air-blowing to remove dust, dirt, loose material, and moisture. Incompressible material at the base of the crack should be removed by gouging or plowing, if needed. The sidewalls of cracks should be warmed with a hot air lance prior to sealant application. All cracks must be cleaned and dried before application and the engineer will inspect prepared cracks left unsealed at the beginning of each working day. Sealant should be applied by filling the crack from the bottom up with a pressure type applicator and a nozzle fitting the crack. The crack should be overfilled and squeegeed to leave a level seal between 2 and 4 inches over the crack [55].

2.14.14. New Hampshire

New Hampshire allows for the use of Type II hot-poured crack sealants and low modulus Type IV hot-poured crack sealant outlined by AASHTO M 324 (ASTM D 6690) and their Qualified Products List. Accepted Type II products include Flex a Fill 9005 and Road Saver 201 from Crafco, Inc.; Crack-Rite HP3405 by Dalton Enterprises, Inc; and Hi-Spec by W.R. Meadows. Type II materials must meet AASHTO M324 or ASTM D6690 requirements if no overlay is to be used. Acceptable Type IV low modulus products include Road Saver 231 from Crafco, Inc; Deery 101 by Deery Brand (Crafco, Inc); and BERAM 195 Low Modulus by McAsphalt Industries. If the materials will have an overlay applied, low modulus materials conforming to AASHTO M 324 or ASTM D6690 shall be used [56].

Engineers shall approve all equipment used for preparation and application of sealants; including air compressors, melting kettles, hand pouring pots, routers, hot-air lances, and wand applicators. Air compressors shall be portable and capable of 100cfm flow and no less than 90psi at the nozzle. Melting kettles shall be portable, indirect-fired double boilers with; suitable heat transfer materials shall meet a flash point of 530°F between the inner and outer shells of the kettle, have an agitator capable of continuous stirring (non-rocking type), and be equipped with thermostatic controls calibrated between 200°F and 550°F. Hand pouring pots must have mobile carriages, rubber shoes, and flow control valves. Routers shall have multi-blade rotary cutter head types. Hot-air lances shall be approved propane burner and compressed air types with capability of cleaning and drying cracks without allowing flames to reach the pavement. Wand applicators shall be connected to the tank by a hose capable of controlling flow and have a bypass device to allow flow back to the tank after the nozzle is shut off [56].

Crack routing to 3/4 inch (plus/minus 1/8 inch) and 5/8 inch deep in a rectangular shape shall be implemented for cracks between 1/8 inch and 3/4 inch, unless otherwise directed. Cracks greater than 3/4 inch shall not be routed. All dirt, foreign material, and loose edges shall be cleaned by hot-air lance from each crack. Hot air-lance cleaning shall not be performed when the crack or pavement is wet, or when the ambient air temperature is below 50°F. Hot poured sealant shall be prepared and maintained by manufacturer’s recommendations and applied using hand pouring pots or wand applicators within 2-minutes of hot-air lancing. Cracks shall be filled to 1/16 to 1/8 inch below the surface, left slightly concave, and shall bond tightly to the pavement. Flush filling, overbanding, or overfilling will not be accepted, and any non-bonding seals shall be removed and redone. All work shall be completed in a neat manner and cracks shall not be subject to traffic until the sealant has had proper time to cool [56].

2.14.15. New York State

New York State DOT specifications state that cracks less than 1/4 inch wide do not require cleaning or sealing. Cracks between 1/4 inch and 1 inch should be cleaned of all dirt and loose material by compressed air stream of at least 80psi. Cleaning should be done to a depth of at least twice the width of the crack by applying compressed air 1 inch above the pavement surface. Existing crack seal material is not required to be removed prior to new application. Asphalt filler should be used to fill the crack to a level below the surface to allow for expansion. The seal should be blotted with fine aggregate if required. Cracks exceeding 1 inch should be filled with asphalt shim or an approved cold, plant-mixed stockpile patching material [57].

Materials in the New York State DOT specifications for crack sealing include asphalt filler and asphalt shim. Asphalt fillers, categorized as miscellaneous asphalt cements in

NYSDOT Specifications shall be homogeneous, free from water, and should not foam at 350°F. Additional testing for quality assurance includes AASHTO T 47, 48, 49, 51, and 53. Asphalt shim materials must be submitted to the Regional Materials Engineer and follow the general limits of NYSDOT Specification Table 401-1, Type 5. Mix should contain 7.0-9.5% PG64-22 or PG70-22 (depending on location in the state) asphalt by weight, and have a mixing and placing temperature range of 250-325°F [57].

New York State DOT's Comprehensive Pavement Design Manual outlines the sealing process for the state. Seals are expected to last two years, and should not be scheduled within 1 year of an overlay or within three months of quick-set slurry or micro-surfacing. Routing and sealing should only occur in well-defined cracks. Cracks should be cleaned by high-pressure air blasting between routing and sealing. Excess seal should be squeegeed to leave a film that is 0.039 inch (1 mm) thick or less and 1.96 inch (50 mm) wide or less. Treatment should only occur if the remaining life of the pavement exceeds five years. Sealing should only occur when the weather is dry, air and pavement temperature are in the middle of the annual temperature ranges, air temperature must be greater than 5°C above the dew point, and spring and fall applications are preferred. Seals must meet the requirements of ASTM D 3405 [58].

2.14.16. Ohio

Ohio allows the use of Type I, II, III, and IV crack sealant materials as long as the materials and the manufacturer are provided on the Qualified Products List from ODOT. Type I crack sealant must conform to ASTM D 6690, but Type I is used primarily for Portland cement concrete joints. Type II and Type III crack sealants must comply with ASTM D 1577 for denier, ASTM D 3937 for crimps, ASTM D 2256 for tensile strength, and other criteria specific to the manufactured materials if the material is to be mixed by the DOT. Prepackaged Type II crack sealants are permitted if materials fulfill the previously listed ASTM standards, as well as all manufacturer recommendations. Type IV crack sealants must contain no recycled fibers and have a minimum of 2% fibers. Type IV binders must also meet testing requirements for cone penetration, flow, resilience, ductility, bond, impact, and compression recovery; while the fibers must meet the requirements for Type II polyester fiber [59].

Type I sealants must be heated with a double boiler melter or kettle and by indirect heat. The kettle or melter must have positive temperature control of the oil bath between the inner and outer shells, and a mixing vat with recirculating pumps and mechanical agitation. Types II, III, and IV sealants will require a double boiler kettle or melter, capable of supplying indirect heat, with separate thermometers for the mixing vat and the fluid between the inner and outer shells. The vat should be equipped with 2 inch minimum recirculating pump and a full sweep type agitator [59].

Cracks shall be prepared and filled at the direction of the engineer only when the pavement surface is not visibly damp or when the temperature is below 45°F. For cracks where sawing is specified, all cracks shall be sawed to between 3/4 inch and 7/8 inch wide, and between 7/8 inch and 1inch deep. All slivers of asphalt remaining that do not provide a 1inch wide shall be removed by hand tools or a chipping hammer. Sawed cracks should be sand blasted on both sidewalls for texture and to remove contamination. A backer rod shall be inserted into the sawed crack if the cracking is deeper than 3/8 inch below the bottom of the reservoir. For cracks where routing is specified, all cracks less than 3/4 inch wide shall be routed to 3/4 inch wide and 1inch deep. All dust, dirt, moisture, vegetation, and other foreign matter should be removed from the prepared crack [59].

Types I and IV sealants require an applicator wand capable of positive sealant flow shut off and continuous feeding of sealant through nozzles shaped to penetrate cracks. Types

II and III sealants require applicator wands capable of sealant flow shut off and nozzles capable of filling cracks. Portable air compressors used for cleaning shall be required to produce 100psi at the nozzle. Water cleaning equipment must be capable of 2000psi water delivery from the nozzle. Mechanical and power driven routers and saws must be capable of cutting without causing excessive damage or spalling to the pavement. Saw blades should be no larger than 8 inch diameter and should be diamond blades [59].

All crack sealing operations shall take place within 250 feet of the cleaning operation. Only cracks that are wide enough to permit entry of sealant or showing signs of spalling or raveling shall be sealed. Cracks larger than 1 inch or having 4 inch or greater cavities shall not be sealed unless otherwise specified. Types I and IV sealants shall be placed by filling the crack from the bottom of the reservoir up to 1/16 inch above the pavement surface. A "V" shaped or "U" shape squeegee, or similar hand tool, shall be used to smooth the excess overfill sealant. The work will not be accepted if the overband exceeds 2 inches wide. Types II and III sealants shall be applied by filling the crack and leaves a band width within 2 to 4 inches on the surface, and the work will not be accepted if the band thickness is greater than 3/16 inch. All work is subject to the engineer's approval [59].

2.14.17. Ontario

Ontario specifications allow the use of hot poured rubberized asphalt joint sealing compound consistent with Ontario Provincial Standard Specification (OPSS) 1212 [60]. Sealant materials shall be in accordance with ASTM D 6690-01, ASTM D 5329, and ASTM D 5 [60]. Sealant compound shall be melted slowly using a double boiler heating kettle with a built-in agitator and thermometers to measure the sealing compound temperature and the heat transfer fluid. The sealant should be lump-free, free-flowing, and at temperature range recommended by the manufacturer. Cracks of width up to 0.78 inch (20 mm), excluding alligator or map cracking, shall be routed as specified in the contract for work. Cracks larger than 0.78 inch (20 mm) do not require routing. Cracks and routed cracks shall be cleaned and dried using a hot air lance to ensure all moisture, debris, and loose material is removed. Sealant application shall be placed immediately after cleaning by way of a manual pouring cone from the kettle spigot or by a house connected to the heating kettle. Pavements being prepared for an immediate HMA overlay shall have cracks sealed 0.15-0.23 inch (4-6 mm) below the pavement surface. Other pavements require the sealant to be no more than 0.03 inch (1 mm) below the surface after the sealant has cooled. Sealants that will be subjected to immediate traffic shall be dusted by Portland cement or an alternative material. During placement of the sealant, the material may be sampled for quality control [61].

2.14.18. Oregon

Oregon allows the use of any materials that are intended for sealing cracks in asphalt pavements that conform to the requirements of ASTM D 6690. All equipment used in sealing application shall meet the manufacturer's recommendations. Mixing and heating of sealant material shall follow manufacturer's recommendations and be between 280 to 400°F, with the use of an indirect heat double boiler with a mechanically operated agitator with thermostatic temperature control [62].

All sealing operations shall be in accordance with the manufacturer's recommendations. The cracks should be dry and cleaned of loose and foreign matter with the use of hot air lance. Cracks should be sealed from the bottom upward, leaving the surface of the sealant flush to 3/16 inch below the pavement surface. A "V" shaped squeegee should be used to flush the sealant in the crack and excess material should not exceed 1 1/2 inches from the crack. Cleaning sand should be placed over the finished seal, with excess swept away. Application should occur when the ambient and pavement temperatures are at least 45°F and rising [62].

2.14.19. Pennsylvania

Pennsylvania has a specification section for polymer modified asphalt joint and crack sealing prior to the application of an overlay. Asphalt cement class AC-20 may be combined with reclaimed granulated rubber (RGR) at a proportion of 2 pounds RGR per gallon of AC-20 asphalt. Additional materials that may be used are asphalt rubber sealing compound and rubberized joint sealing material. The AC-20 asphalt and granulated rubber should be mixed in an oil-jacketed double wall kettle with indirect heating, an agitator, and a 2 inch pump. Materials should be heated and agitated for 30 minutes at a range of 350-380°F.Premixed materials shall be prepared according to the manufacturer's recommendations [63].

Cracks and an area of 4 to 6 inch on both sides of cracks should be clean, dry, and free of loose material with the use of air blasting prior to application of sealant. Compressed air of at least 100psi or a hot air lance may be used for air blasting. Crack sealing applies for cracks between 1/8 and 1 inch wide. Cracks larger than 1 inch should be filled with bituminous wearing course (Bituminous Wearing Course FJ-1) as defined in section 422.2 of the Pennsylvania DOT Specifications [63].

Polymer modified asphalt sealants shall be applied to prepared cracks using a V-shaped asphalt squeegee wand. Sealing may only be applied air temperature is between 40 and 90°F, but lower temperatures may be waived if the engineer determines that the hot air lance can sufficiently warm the crack for proper adhesion. Sealant should be level with the pavement surface with no more than 1/8 inch buildup [63].

2.14.20. Saskatchewan

Saskatchewan specifies the use of hot poured rubber asphalt sealant for all work. Sealant should be prepared through slow heating under the manufacturer's recommendations with a double boiler type heating kettle capable of indirect heat. The kettle should be equipped with thermostatic controls for the product, built in automatic agitator, and thermometers for the sealant and the heat transfer fluid within the kettle. Material shall be sampled randomly from each lot, and tested at the frequency directed by the engineer under ASTM D 3405 and ASTM D 3407 standards [64].

Cracks should be routed to a width of 1.18 inch (30 mm) and a depth of 0.59 inch (15 mm). Severely fatigue-block area cracking, centerline cracks not on curves, cracks less than 0.078 inch (2 mm) wide, and cracks larger than 0.98 inch (25 mm) shall not be sealed unless directed by the engineer. The routed cracks should be cleaned of loose material and dried by hot compressed air to the point where the pavement is darkened, but not burned. Sealant application shall be performed by hose and wand at the manufacturer's recommended temperatures, unless otherwise directed by the engineer. Sealant shall be applied at the bottom of the routed crack and filled to a level specified by the project plans. Full acceptance of the end product shall have no surface defects, meet the designated acceptance limits, have rout under filling not exceeding 0.19 inch (5 mm), and rout cross sections of sublots shall show both sides of the crack are routed, the rout width exceeds 0.98 inch (25 mm), and the rout depth exceeds 0.51 inch (13 mm). End product rejection shall occur if there are surface defects or if the lot meets rejection criteria [64].

2.14.21. South Dakota

South Dakota allows the use of sealants conforming to ASTM D 3405 with modifications to penetration, bond, extension, and unit weight. Acceptable materials must pass these testing requirements and are found at SDDOT's Approved Products List. All sealant handling and preparation operations must adhere to the manufacturer's recommendations [65].

Routing equipment must be capable of cutting reservoirs to specified dimensions, be mechanical, and power drive. The use of crack plowing equipment is not permitted. Routing with a star bit type is not allowed when the ambient air temperature is below 55°F. Cracks under the width of 3/4 inch shall be routed to a width of 3/4 inch and cracks larger than 3/4 inch are not routed. Routed cracks should have vertical walls and a flat-bottomed reservoir. All cracks shall be cleaned, dried, and free of loose material and debris by compressed air. The air compressor must be capable of producing at least 125cfm flow and be equipped with a nozzle measuring to a maximum of 3/4 inch [65].

Cracks 3/8 inch or greater in width shall be filled with a blocking medium prior to seal placement. The blocking material must be inert, compressible, and compatible with the sealant. Application of sealant should overfill the crack and excess sealant should be squeegeed with a U-shape device and leave a film on the road surface between 1 and 3 inches. Blotting material shall be placed on intersections, super elevated curves, grades greater than 4 percent, roads where traffic is allowed to cross the sealant before it is track free status, or when specified. Routing and sealing practices may only occur between May 1 and October 15 during daylight hours [65].

2.14.22. Utah

Utah Department of Transportation (UDOT) requires sealants to ASTM D 5329, Section 14 for asphalt compatibility. Testing for materials shall consist of AASHTO T 51 for ductility, AASHTO T 300 (a) for force-ductility, ASTM D 3405 (b) for tensile-adhesion (UDOT modified), ASTM D 4402 for viscosity; and ASTM D 5329 for flow, cone penetration, resilience, and bond. Additionally, UDOT has a modified test for cold temperature flexibility, UDOT method 967, which requires that no cracks appear in the sealant. The use of backer rods may be used for cracks exceeding 2 inches deep and 1/2 inch wide. The backer rod must be compatible with the sealant. Cracks are to be dried and free of loose material by the use of hot compressed air [66, 67].

2.14.23. Vermont

Vermont Agency of Transportation (VTrans) crack sealing practices use hot poured joint sealer in accordance with AASHTO M 324 [68, 69]. Sealers shall be hot-applied, single component, low-modulus, elastic sealants that allow 200% elongation at temperatures as low as -20°F in a typical application configuration [58]. Material preparation shall follow the recommendations of the manufacturer and approved by the engineer. Sealing materials shall be heated using an indirectly fired double boiler melting kettle that is portable. The Kettle must come equipped with heat transfer fluid with a flashpoint of 531°F or higher, an agitator the can continuously agitate the sealer by stirring or gear pump circulation, and thermostatic controls between 200°F and 550°F [68].

Cracks will be prepared through routing or sawing using a rotary impact type cutter or a diamond-blade crack saw that is capable of creating the proper specified crack reservoir. Cracks measuring between 1/8 inch and 3/4 inch in width shall be routed to a 3/4 inch by 3/4 inch square reservoir. Any cracks measuring greater than 3/4 inch wide will only be prepared at the engineer’s direction. All cracks designated for sealing shall be routed or sawed to the directed sizes. Routed or sawed cracks shall be cleared of loose pavement, vegetation, sand, dust, and other debris with the use of a hot air lance capable of blowing clean air and drying cracks. The hot air lance must be a propane gas and compressed air burner operating at 3000°F and providing a velocity of 3000ft/s [68].

Crack sealing applications are only permitted when the ambient air temperature of 40-104°F and pavement temperature 50-140°F, or the engineer may adjust temperature restrictions when it is in the public’s interest. Prepared cracks shall be heated prior to sealant application with a hot air lance. Routed cracks shall be fully filled with sealer material using an application wand capable of controlling flow through and insulated or heated hose. Excess material should be removed to leave a film no greater than 1/16 inch thick and 1 1/2 inch wide. Specifications state, “Optimally, the pavement aggregate should be visible through the film band” [68].

2.14.24. Washington State

Washington State DOT (WSDOT) does not have a crack maintenance program. WSDOT’s specifications list rubberized asphalt as the only crack sealing material allowed. The sealant should meet the requirements of their 9-04.2(1) specification for hot poured joint sealant, with the exception of bond. The specification requires that materials meet AASHTO M 324 Type IV, with exceptions for cone penetration and minimum Cleveland Open Cup Flash Point of AASHTO T 48. All sealants should be sampled by ASTM D 5167 standards and tested in accordance with ASTM D 5329 [70]. WSDOT conducted a study in 1992 on crack sealing effectiveness. Results were inconclusive to determine crack sealing was effective enough to justify costs, in terms of longer pavement life and smoother pavements [71].

2.14.25. Wyoming

Wyoming uses hot-poured elastic sealant in accordance with AASHTO M 324 Type I Wyoming Modified (WY Modified) or AASHTO M 324 Type IV WY Modified sealants. Wyoming modifications include the following test alterations; cone penetration of 90 maximum for Type I, and minimum and maximum of 90 and 150, respectively, for Type IV. Maximum flow may be 5 and 3 for Type I and Type IV, respectively. Bond must be a minimum of 5 for Type I sealants and Bond 200% extension must be a minimum of 3 for Type IV. In accordance with the D 71 WY Modified specification, the relative density of Type I and Type IV must be a maximum of 1.193 and 1.113, respectively. Additionally, the Type IV must pass softening point. The addition of recycled rubber or fillers is permitted to enhance performance, but wire, fabric, or other deleterious materials are not permitted to be in the sealant [72].

Cracks are to be routed to vertical sides and flat bottom, cleaned by air compressor, and dried by compressed air heat lance prior to application. Cracks that are less than 1/8 inch wide shall not be routed or sealed. For Type I sealants, cracks that are 1/8 to 1/2 inch should be routed to 1/2 inch wide by 3/4 inch deep, and cracks between 1/2 and 3/4 inch do not need to be routed. For Type IV sealants, cracks between 1/8 and 3/4 inch should be routed to 3/4 inch wide and 3/4 inch deep. All cracks larger than 3/4 inch do not require routing. Backer rods, in accordance with ASTM D 5249 Type I, shall be installed when Type IV sealant is specified, crack reservoir width is larger than 3/8 inch, and/or if the reservoir exceeds 1 1/2 – inch. Cracks are to be filled flush to the pavement surfaced and squeegeed with a “U” shaped squeegee. The use of aggregate as a blotter material shall be used upon completion of the seal application, but other accepted materials are fly ash, sawdust, paper, Portland cement, or biodegradable, non-toxic, non-hazardous compounds designed for blotting [72].

3. COMPONENTS OF BEST MANAGEMENT PRACTICES OF CRACK MAINTENANCE

Best Management Practices (BMPs) can be seen as effective and practical maintenance methods which can prevent or reduce the deterioration of asphalt pavement as a result of existence of thermal cracking. Typically, for a BMP to be successful in crack maintenance and repair it should address the following four phases [15]:

1. Determining the need for crack treatment
2. Planning and designing the crack treatment project
3. Construction
4. Evaluating and assessing the performance of the crack treatment

3.1. Determining the Need for Crack Treatment

Relatively quick assessments can be utilized to determine whether an asphalt pavement is in need for crack treatment or not. Based on such assessments, the appropriate actions can then be determined. Evaluation of the existing pavement conditions and knowledge of future rehabilitation plans are required to obtain such assessments [15].

3.1.1. Pavement/Crack Evaluation

A review of construction, maintenance, and other records; the following can be determined [15]:

- Pavement age
- Pavement geometric design
- Pavement section boundaries
- Traffic
- Climate
- Type and extent of previous maintenance
- treatments Condition rating

Following the review, the performance of a shoulder survey should then be done on a small representative sample of about 419.1 ft (150 m) of the pavement section. This will determine the amount, type, and condition or severity of cracks, as well as the condition or effectiveness of any previously applied crack treatments [15].

3.1.2. Determining the Type of Maintenance

The density and general condition of the cracks will determine the appropriate type of maintenance for cracked pavements. If the cracks are abundant and not exhibiting a high degree of edge deterioration, then either chip seals, slurry seals, or similar means can be used to treat them. On the other hand, crack repair strategies, such as partial-depth patching or spot patching, can be utilized if cracks are low to moderate in density and have typically progressed to a point of high edge deterioration. Sealing or filling operations can be utilized effectively if cracks are moderate in density and show moderate to no deterioration at the edges [15].

3.1.3. Maintenance Approaches

Although little distinction has been made in the past between crack sealing and crack filling, the purposes and functions of each must be clearly understood so that the most cost-effective and long-lasting treatment is applied [15].

- Crack Filling: The placement of materials into non-working cracks to substantially reduce the infiltration of water and to reinforce the adjacent pavement. Non-working refers to horizontal and/or vertical movements less than 0.1 inch (2.5 mm). Non-working cracks typically include mostly longitudinal, diagonal cracks and some block cracks. Such cracks have do not move much due to the close spacing between the edges. Since there is minimal flexibility expected, the materials used for crack filling are non-rubberized products, e.g. crumb rubber, AC-3, and asphalt emulsion. Crack filling is therefore simply filling the cracks that do not show significant movement [4, 5, 6, 7]. Simple overbands are usually used with filling operations [6, 7]. Crack filling involves placing the filling material and spreading it out over and into the crack(s) with a squeegee. Squeegees are typically U or V shaped to push the material and concentrate it over the crack [6, 7]. Crack filling materials may be hot applied rubber or polymer asphalts, or cold applied emulsion-based products. The emulsion products assist with forming a good adhesive bond with the crack wall and additives such as Styrene Butadiene Rubber (SBR) latex ensure that the material can endure some degree of movement. In some cases, hot applied fiber modified asphalt binders may be used [8, 9]. For short-term crack-fill performance (1 to 3 years) in pavements with nonworking cracks (less than 0.1 inch (2.5 mm) of horizontal crack movement) and low to moderate traffic levels, asphalt cement should be placed in flush-fill configuration [10, 11, 12, 13]. For long-term crack-fill performance (between 5 and 8 years) under the above conditions, an asphalt rubber or rubberized asphalt may be placed in either a flush-fill or overband configuration, or a fiberized asphalt may beplaced in an overband configuration [10, 11, 12, 13].
- Crack Sealing: The placement of specialized materials either above or into working cracks using unique configurations to prevent the intrusion of water and other incompressibles into the pavement cracks. Working cracks refers to horizontal and/or vertical crack movements greater than 0.1 inch (2.5 mm). Transverse cracks are a good example of working cracks; however, some longitudinal cracks may also meet the movement criterion [4]. Crack sealing involves thorough crack preparation followed by the placement of a high-quality material in a specific configuration [5, 6, 7]. Crack sealant materials are rubberized products that have the ability to seal the crack and flex with the pavement’s movement. They are used for active cracks that continue to extend both in size and severity with time and the ravages of the traffic and weather. Crack sealants have excellent adhesive and cohesive properties. In other words they firmly adhere to the walls of the cracks and do not tear or split when the cracks widen [4]. Reservoirs are generally associated with sealing operations [6, 7]. In a sealing operation, sealant is placed either flush with the surface or slightly recessed within a cut reservoir. The purpose of the reservoir is to create room for enough material to be applied, create a desirable sealant shape, and provide a uniform surface for the sealant to adhere to. The sealant also may be recessed to prevent plow and traffic damage [6, 7]. For sealing working cracks, the preferred sealant is usually elastomeric. This means the sealant has a low modulus of elasticity and will stretch easily and to high elongations (usually around 10 times its non-strained dimensions) without fracture. Such sealants also recover over time to close to their original dimensions [8, 9]. For short-term crack-seal performance (between 1 and 3 years) in pavements with ordinary working cracks 0.1- 0.2 inch (2.5-5 mm) of horizontal crack movement) and moderate traffic levels, a standard rubberized

asphalt should be placed in a simple Band-Aid configuration [10, 11, 12, 13]. For medium-term crack-seal performance (between 3 and 5 years) under the above conditions, either a standard rubberized asphalt may be placed in a recessed Band-Aid configuration or a modified rubberized asphalt may be placed in a simple Band-Aid configuration [10, 11, 12, 13]. For long-term crack-seal performance (between 5 and 8 years) under the above conditions, a modified rubberized asphalt sealant should be installed in either a standard or shallow recessed Band-Aid configuration [10, 11, 12, 13].

As these definitions indicate, the objectives of crack sealing are significantly more difficult to accomplish than those of crack filling. Sealing requires considerably more forethought, greater costs, and the use of more specially formulated materials and more sophisticated equipment [15].

Determining whether to seal or fill

Frequently, the first cracks to appear in an asphalt pavement are transverse cracks. However, several different types of cracks may appear at one time. In these cases, one treatment, using a material appropriate for the most demanding crack type, is desirable. Though crack width may be a factor in determining whether to seal or fill, the amount of annual horizontal movement of the targeted crack type should be the principal basis for this decision. Normally, working cracks with limited edge deterioration should be sealed, whereas non-working cracks with moderate to no edge deterioration should be filled. Whether a crack is working or non-working can generally be determined by its type. Working cracks are usually transverse in orientation with an annual horizontal movement that is equal to or more than 0.11 inch (3 mm); however, some longitudinal and diagonal cracks may meet the 0.11 inch (3 mm) movement criteria. Materials placed in working cracks must adhere to the crack sidewalls and flex as the crack opens and closes. Non-working cracks typically include diagonal cracks, most longitudinal cracks, and some block cracks. Because of the relatively close spacing or free edges between non-working cracks, little movement occurs. Minimal movement permits the use of less expensive, less specialized crack-filler materials. Table 3.1 provides recommended criteria for determining which cracks to seal and which to fill [15].

Table 3. 1 Recommended criteria for determining whether to seal or fill [15].

Crack characteristics	**Crack treatment activity**	
	Crack sealing	**Crack filling**
Width, inch (mm)	0.19 to 0.74 (5 to 19)	0.19 to 0.98 (5 to 25)
Edge deterioration (i.e.; spalls, secondary cracks)	Minimal to none(≤ 25% of crack length)	Moderate to none (≤ 50% of crack length)
Annual horizontal movement, inch (mm)	≥ 0.11 (3)	< 0.11 (3)
Types of cracks	Transvers thermal cracks	Longitudinal reflective cracks
	Transverse reflective cracks	Longitudinal cold-joints cracks
	Longitudinal cold joints crack	Distantly spaced blocked cracks
	Longitudinal reflective cracks	Longitudinal edge cracks

When to seal and when to fill

Crack sealing is a preventive maintenance activity. Ideally, it is conducted shortly after working cracks have developed to an adequate extent and when temperatures are moderately cool (7 to 18°C), such as in the spring or fall. When newly developed cracks are sealed, the deteriorated crack segments (i.e., secondary cracks, spalls) that adversely affect seal performance are minimized. Typically, transverse thermal cracks in AC flexible pavements appear 2 to 7 years after construction; whereas transverse reflection cracks in AC overlaid concrete pavements often develop 1 to 3 years after resurfacing [15].

Sealing in moderately cool temperatures is beneficial from two standpoints. First, cracks are partly opened so that a sufficient amount of material can be placed in the crack if cutting is not to be performed. Second, the width of the crack channel, whether cut or uncut, is nearly at the middle of its working range. This is important to the performance of the sealant material because it will not have to undergo excessive extension or contraction. Most crack filling operations can be conducted year-round; however, they often take place during cool or moderately cool weather (2 to 13°C) [15].

Crack filling operations can be preventive or routine in nature, depending on the highway agency's approach to treating the cracks. Like sealing operations, preventive crack filling maintenance should be conducted shortly after non-working cracks have adequately developed. Depending on the type of cracks to be filled, this may occur between 4 and 8 years after construction or resurfacing. Durable filler materials should be used to reduce the number of repeat applications. By filling cracks shortly after they are fully developed, further crack growth is delayed. Historically, most crack filling has been performed on a routine basis with inappropriate materials that provide less than desirable performance. This approach to crack filling is rarely cost-effective because treatment performance is generally poor and maintenance costs are high. In addition, the safety of the workers and traveling public is compromised, since the filling operation must be repeated frequently [15].

3.2. Planning and Design

3.2.1. Primary Considerations

The following factors should be addressed when planning crack sealing or crack filling operations [15]:

- Climatic conditions (general conditions and at the time of installation) Highway classification
- Traffic level and percent trucks
- Crack characteristics and density
- Materials
- Material placement configurations
- Procedures and equipment
- Safety

The choice of an appropriate material, placement configuration, and determination of procedures and equipment to be used, based on existing and future roadway conditions, are mainly the core of the planning process. The choice of given procedures or materials to be used can be influenced by the site-specific climatic conditions during treatment operations. For example, the use of a heat lance may expedite operations in areas where moisture or cold temperatures present scheduling problems. In deciding which materials and procedures are to be used, the overall climatic conditions must also be considered. Materials that will not significantly soften and track at high temperatures is a requirement for hot climates, while very cold climates will generally require materials that retain good flexibility at low temperatures [15].

3.2.2. Selecting a Sealant or Filler Material

There are many crack treatment material products available, each with distinct characteristics. The products essentially comprise three material families and are often grouped by material type, and according to their composition and manufacturing process. The principal material families and types are cold pour sealants, hot pour sealant, and chemically cured processes [15].

Cold pour sealants

Cold pour sealants are those that are applied at ambient temperatures and therefore do not require heating. This type of material is more appropriate for cracks of 3/16 inch or less in width. Cold pour sealant should not be applied if the air temperature is below 50°F and falling. This temperature should be based on a reading taken in the shade and away from any form of artificial heat. Due to the low viscosity of cold pour sealant, the material will penetrate into the crack easily without any need for routing procedures. It is critical that the vertical surface of the crack be clean to insure that the cold pour will adhere to the crack. The sealant should be applied using a barrel pump or pressurizing system to provide an uninterrupted flow of cold pour sealant through the hose to the wand. Depending on the humidity and temperature, curing time can vary from 30 minutes to several hours [28]. Examples for those types of sealants are the cutbacks, emulsified asphalts, and polymer modified liquid asphalts.

<u>Cutback Asphalt</u>

Cutback asphalts are liquid asphalts which are manufactured by adding (cutting back) petroleum solvents (also called cutter stock or diluents) to asphalt cements. They are made to reduce the asphalt viscosity for lower application temperatures. Application to aggregate or pavement causes the solvent to escape by evaporation, thus leaving the asphalt cement residue on the surface. Based on the relative rate of evaporation, cutback asphalts are classified into three types: Rapid Cure (RC), Medium Cure (MC) and Slow Cure (SC). The type of distillate (solvent) used in their production determines the grade of the cutback asphalt. Rapid Cure grades are typically blended with light, highly volatile diluents, such as naphtha, that will evaporate quickly and leave a hard, viscous-base asphalt to function with the aggregate on the road. Medium Cure grades are using a less volatile kerosene-type of solvent which evaporates more slowly, leaving a base asphalt of medium hardness or viscosity. Slow-Curing blends contain a low-volatility fuel-oil type solvent and require the longest curing period [73].

<u>MC-3000</u>

MC-3000 is medium cure cutback asphalt product that is used in bituminous seal coat [73]. Cutback asphalts such as MC-3000 flow more readily than emulsified asphalts and are more likely to penetrate surface cracks. If the distributor does not apply the asphalt uniformly to the roadway surface, the cutback asphalt will flow together better than a high float emulsion will [74].

Asphalt Emulsions

Asphalt emulsions are formed by the milling of raw asphalt into microscopic particles, which are dispersed in water with the aid of a chemical emulsifying agent called a "surfactant" (sometimes referred to as "soap"). In such cases, the dispersed asphalt forms discrete droplets, which are intrinsically insoluble in water. The emulsion is said to be "stabilized" if the asphalt droplets remain well-dispersed such that phase separation does not occur. Stabilization is achieved through the use of surfactants, which consist of polar molecules comprised of a hydrophilic (water loving) "head" and hydrophobic (water avoiding) "tail." The tail of the surfactant molecule is attracted to the asphalt particles, forming a coating around each particle, consisting of the hydrophilic heads of the emulsifying agent. The hydrophilic portions of these surfactants strongly associate with water and aid in keeping the droplets dispersed and in suspension [22]. The primary purpose of emulsions is to coat the edges and partially fill cracks, but they can be used as crack filler. Emulsion are safe and easy to use, but are limited to use in warmer seasons [3].

Polymer modified liquid asphalts

These types of materials are composed of polymer modified asphalts that are emulsified. The physical and chemical characteristics of the polymer and its compatibility with the chemistry of the asphalt determine the physical property enhancements [22].

Hot pour sealants

Hot pour sealants are sealants that must be heated to high temperatures in preparation for application. As the material cools, the hot thermoplastics harden. These types of materials generally consist of asphalt cement with or without the addition of a modifier. The simplest and most common type of modifier added to asphalt cement is rubber. Modifiers give the asphalt desirable properties, such as high elasticity and high melting point. Unlike cold pour sealants, hot pour materials should not be applied when the cracks and pavement surface are damp. The hot pour sealant is heated in a double-jacketed heater using heat transfer oil so that no direct flame comes in contact with the shell of the vessel containing the sealant. To ensure that the sealant is circulated during the heating process to achieve a uniform rise in temperature and to maintain the desired temperature, the heated reservoir should be equipped with an agitator. Temperature should be monitored through accurate temperature gauges to avoid overheating the material. Ideally, the material should be maintained between 350 and 375°F. The placement of hot pour sealant can begin after the application temperature is attained. If bubbling occurs, moisture still exists in the crack and work must be postponed until the cracks are dry. In most cases, the hot pour sealant will cure in about 15 to 30 minutes [28]. Some research has shown that "high-end" hot pours can last more than six years [43]. Most new products are prepackaged. This eliminates mistakes in mixing, assures a uniform product, and ensures a more efficient operation. Not all products are suitable for every climate, as locations with extensive freeze-thaw cycles need sealants with more ductility, whereas warmer areas need sealants with less flow in hot weather [75]. The major categories of hot pour sealant types are the asphalt cement, fiberized asphalt, asphalt rubber, polymer-modified asphalts, and low modulus rubberized asphalt.

Asphalt Cement

Among the thermoplastic bituminous materials, asphalt cements are characterized by little, if any, flexibility and are very temperature-susceptible. Hence, they are limited to use as fillers for non-working cracks. Applicable specifications for asphalt cements are ASTM D3381, AASHTO M20 and, AASHTO M226. Asphalt cements are characterized by their quickness and ease of application, short cure time, and adhesiveness. Asphalt cement materials that are placed flush in un-routed non-working cracks can perform satisfactorily for between 2 and 4 years [15].

Fiberized Asphalt

Fiberized asphalts are most appropriate in crack filling operations since fiber particles provide minimal elasticity to asphalt and do not significantly affect temperature susceptibility. Typical to asphalt cements, fiberized asphalts are characterized by their quick and ease of application, short cure time and adhesiveness. Fiberized asphalt placed in unrouted working cracks with overband configurations can provide a maximum of 2 years of adequate service [15].

Asphalt Rubber

Asphalt rubber crack sealants are characterized by their easiness of application, short cure time, adhesiveness, cohesiveness, flexibility, and elasticity. They also show high resistance to softening, flow, and abrasion in their cured state. One applicable specification for asphalt rubber crack sealant is ASTM D5078 [15].

Low-Modulus Rubberized Asphalt

The use of low-modulus rubberized asphalt crack sealant has shown to be very effective in 3/4 inch by 3/4 inch reservoirs with less overbanding [3]. Low-modulus rubberized asphalt crack sealants are characterized by their easiness of application, short cure time, adhesiveness, and cohesiveness. They also show resistance to aging, weathering, and abrasion, as well as excellent resistance to softening and flow in their cured state. [15]. One example of a low modulus rubberized asphalt product is Elastoflex 52.

Elastoflex 52

Elastoflex 52 is formulated with a high recycled rubber content yielding a high viscosity to resist excess flow during application, and is ideal for highways and county roads. Elastoflex 52 applies and sets best in high to moderate temperatures with a recommended application temperature range of 380°F (193°C) to 400°F (204°C). Elastoflex 52 is quick melting, extremely flexible, and highly durable in cold to hot climates [76].

Polymer-Modified Asphalts

These types of materials are generally used in crack sealing applications, as crack sealing requires high performance materials. Since crack filling requires little crack preparation and leaves rough edges, these sealants do not adhere and perform well in filling applications [3]. The addition of polymer to heated asphalt generally improves field performance because it imparts flexibility to the asphalt. The degree of flexibility basically depends on the type and nature of the asphalt, the percentage of polymer used, and how the polymer is incorporated into the asphalt (i.e., mixed or melted in) [15]. An example of polymer-modified asphalt products is Elastoflex 71.

Elastoflex 71

Elastoflex 71, is a hot applied, polymer modified asphalt crack sealant that is highly durable in very cold to hot climates. Elastoflex 71 is self-leveling, quick-melting, and extremely flexible. Formulated with a low viscosity for maximum crack penetration, it is ideal for highways, county roads, airports, and concrete joints [76].

Chemically cured materials

Chemically cured thermosetting materials are one or two component materials that cure by chemical reaction from a liquid state to a solid state. These types of materials have been used in AC pavements only in recent years [15]. An example of chemically cured materials is self-leveling silicon.

Self-leveling Silicone

Self-leveling silicone is a one-component, cold-applied sealant that requires no tooling. ASTM D5893 can be utilized for the application of such crack sealant material. It is generally used for crack sealing practices other than crack filling. Self-leveling silicon is characterized by its short preparation time, short cure time, and good adhesiveness and cohesiveness. It exhibits excellent flexibility and elasticity, and also poses excellent resistance to softening, flow, aging, and weathering in the cured state [15].

3.2.3. Laboratory Testing

It is highly recommended to make laboratory testing on the selected sealant or filler material to verify that the obtained material exhibits the properties for which it was selected. Material sampling is the first process in laboratory testing. A minimum sample of 2 to 4 kg should be taken from each batch, or lot, of material shipped. An agency-approved testing laboratory can then test these samples to standards or specifications prior to placement [15].

3.2.4. Selecting a Placement Configuration

The placement of sealant and filler materials in cracks can be made through numerous configurations. These placement configurations are grouped into four categories [15]:

- Flush fill: Material is dispensed into the existing, uncut crack and excess material is struck off in the flush fill configuration [15].
- Reservoir: Material is placed only within the confines of a cut crack (crack reservoir) in a reservoir configuration, and the material is placed either flush with or slightly below the pavement surface [15].
- Overband: The material is placed into and over an uncut crack in an overband configuration. The simple Band-Aid configuration is formed if the material over the crack is shaped into a band using a squeegee. The capped configuration is created if the material over the crack is left unshaped. All configurations are based on four controlling variables [15]:
    - Type of application
        - Direct–Material applied directly to crack channel
        - Bond-Breaker–Backer material placed at bottom of crack reservoir prior to material installation in order to prevent three-sided adhesion (i.e., bonding by material to crack reservoir bottom and sidewalls)
    - Type of crack channel

        - Uncut
        - Cut–Router or saw used to create uniform crack reservoir
    - Strike-off or finishing characteristics
        - Recessed
        - Flush
        - Capped
        - Band-Aid
    - Dimensions of crack reservoir and overband
- Combination (reservoir and overband): The overband configuration is applied to a cut or routed crack reservoir.

3.2.5. Selection Procedures and Equipment

Depending on the type of treatment (sealing or filling), treatment policy, and available equipment, crack treatment consists of between two and five steps [15]. These steps are:

- Crack cutting (i.e., routing or sawing) Crack
- cleaning and drying
- Material preparation and application Material
- finishing/shaping
- Blotting

Crack cutting

Routers or saws are used to perform crack cutting. Crack cutting is often the slowest activity in sealing operations because it can inflict additional damage on the pavement if not performed properly [15].

Crack cleaning and drying

This is utilized to provide a clean, dry crack channel that is free of loosened AC fragments and other debris, in which the crack treatment material and any accessory materials can be placed. Because high percentage of treatment failures are adhesion failures that result from dirty or moist crack channels, crack cleaning and drying is perhaps the most important aspect of sealing and filling operations [15].

Material preparation and application

This involves the preparation of the crack sealing/filling materials, as well as the specific application needs that may differ for different materials [15]. Material preparation may include mixing, heating, and specific equipment or attachments required to provide desired material properties during application. Application considerations may include the specified equipment, attachments, and tools needed to properly apply the material, as well as weather restrictions at the time of application.

Material finishing

Material finishing can be accomplished in two ways. First, various sizes of dish-shaped attachments are available that can be connected to the end of the application wand for one-step application and finishing. Second, industrial rubber squeegees can be used behind the material applicator to provide the desired shape [15].

Material blotting

Blotting is the application of material, including sand, dust, toilet paper, or other materials, to a freshly sealed crack to prevent the occurrence of tracking or pulling from traffic loading. Sand will generally require a truck or trailer storage, along with shovels for spreading and other tools for clearing excess sand from the roadway. Toilet paper can often be loaded on the same truck with the prepackaged sealant blocks, and can then be placed on a modified paint roller (equipped with a long handle) for easy application [15].

3.2.6. Estimating Material Requirements

Reliable estimates of material needed for a particular project is very useful in attempting to use the optimal material in each situation [15].

3.3. Construction

Once the most appropriate material and placement procedure are selected, proper field application must be fulfilled [15]. Construction processes will depend on the selected procedures and equipment discussed in section 3.2.5.

3.3.1. Traffic Control

Departmental policies usually stipulate the appropriate traffic control setups. However, identifying any special precautions and additional safety equipment needed during the installation can be established utilizing a quick survey of the roadway to be treated [15]. Sections 1.3.2 to 1.3.7 list construction-related considerations that should supplement topics outlined in section 3.2.5.

3.3.2. Safety

This involves ensuring worker protection from material and equipment hazards [15].

3.3.3. Crack Cutting

This is carried out to create a uniform, rectangular reservoir, centered as closely as possible over a particular crack, while inflicting as little damage as possible on the surrounding pavement [15].

3.3.4. Crack Cleaning and Drying

Operations consist of preparing the crack for treatment materials, and any accessory materials to be placed through cleaning, drying, and removal of loosened AC fragments or other debris [15].

3.3.5. Material Preparation and Application

The aim of this is to install any accessory materials into the crack channel, prepare the crack treatment material for recommended application, and place the proper amount of material into or over the crack channel to be treated. The material installation operation must follow closely behind the crack cleaning and drying operation in order to ensure the cleanest possible crack channel [15].

3.3.6. Material Finishing/Shaping

This operation is carried out to shape or mold the previously applied material to the desired configuration [15].

3.3.7. Material Blotting

Blotting is the application of a sufficient amount of material to protect the uncured crack treatment material from tracking or pulling [15].

3.4. Evaluating Crack Treatment Performance

In order to chart the rate of failure and plan for subsequent maintenance, at least one inspection should be made each year. The treatment effectiveness during a time of near maximum pavement contraction and near maximum crack opening can be evaluated through a mid-winter evaluation. Items signifying treatment failures include the following [15]:

- Full-depth adhesion loss
- Full-depth cohesion loss
- Complete pull-out of material
- Spalls or secondary cracks extending below treatment material to crack Pothole

3.5. Summary of Components of Best Management Practices of Crack Maintenance

The Best Management Practices (BMPs) can be identified as effective and practical maintenance methods which can prevent or reduce the deterioration of asphalt pavement as a result of existence of thermal cracking. The first aspect of BMP is associated with the determination of the need for crack treatment. This is followed by the planning and designing of the crack treatment project as well as the construction associated with the crack treatment project. Finally the evaluation and assessment of the performance of the crack treatment should be addressed.

The determination of the need for crack treatment involves undergoing a pavement/crack evaluation to determine the pavement age, geometric design, and section boundaries. This also involves the evaluation of the traffic and climate. In addition, the type and extent of previous maintenance treatments and current condition rating of the pavement should be considered. The planning and design, on the other hand, involves the choice of an appropriate material, placement configuration, and determination of procedures and equipment to be used, based on existing and future roadway conditions. Cost effectiveness is also a crucial part of the planning and design procedures. In the construction aspect of BMP, once the most appropriate material and placement procedure are selected, proper field application must be fulfilled. This mostly involves traffic as well as safety aspects. Figure 3.1, illustrated below, summarizes the components of a BMP.

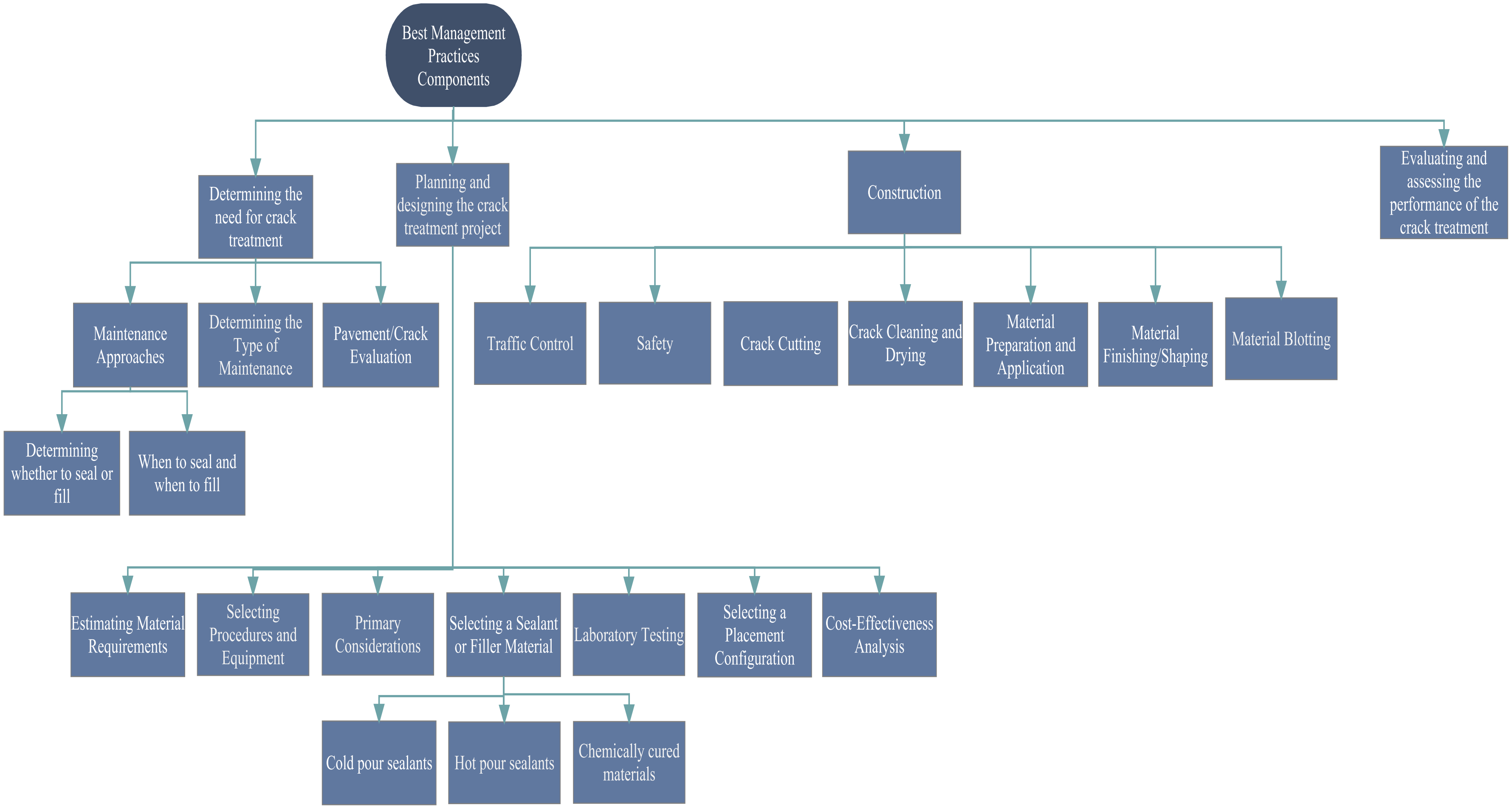

Figure 3. 1 Components of Best Management Practices.

4. SURVEY ANALYSIS

Part of the investigation of thermal cracking maintenance, best management practices, and crack maintenance programs involved a survey of 29 states and provinces in North America. The following section will detail the responses and provide statistics that resulted from the survey. The survey form can be viewed in Appendix A of this report.

4.1. Question 1-General-Crack Maintenance Issues

Q-1a. Does your state/province have a crack maintenance program?
Q-1b. If yes, please describe the program (select all that apply).

4.1.1. Question 1a-General- Existence of Crack Maintenance Program

Table 4.1 a Details of question 1a

Q-1a. Does your state/province have a crack maintenance program?		
Objective To determine which states/provinces have an established program for crack maintenance.		
Answer Options	**% (of Received Responses)**	**Response Count**
Yes	86.7%	26
No	13.3%	4
Total Received Responses		**30**
Skipped		**1**

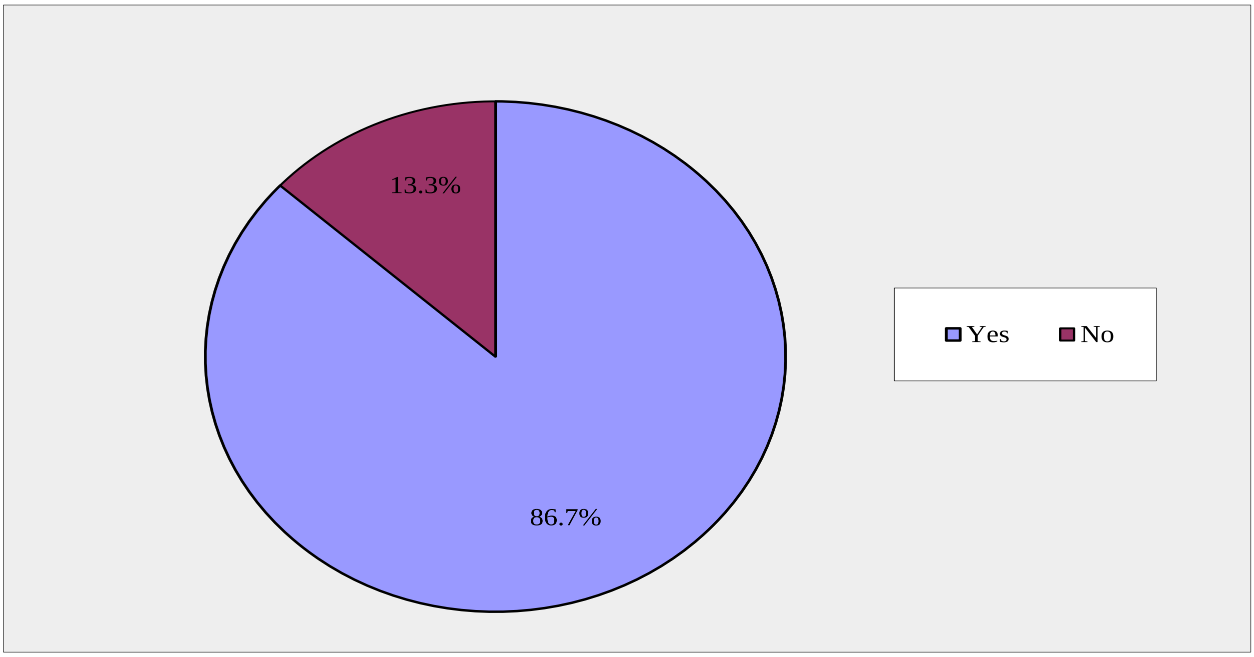

Figure 4. 1a Existence of crack maintenance program in state/province

Survey Details-Q-1a.

State/Province	Individual responses	
Alberta	Yes	
British Columbia	Yes	
Colorado (First response)	Yes	
Colorado (Second response)	Yes	
Idaho	Yes	
Illinois	Yes	
Iowa		No
Kansas	Yes	
Manitoba (First response)	Yes	
Manitoba (Second response)	Yes	
Michigan	Yes	
Minnesota	Yes	
Missouri		No
Montana	Yes	
Nebraska	Yes	
Nevada (First response)	Yes	
Nevada (Second response)	Yes	
Nevada (Third response)	Skipped	
New Hampshire	Yes	
Ohio (First response)	Yes	
Ohio (Second response)	Yes	
Ontario	Yes	
Pennsylvania	Yes	
Saskatchewan	Yes	
South Dakota	Yes	
Utah (First response)	Yes	
Utah (Second response)	Yes	
Utah (Third response)	Yes	
Washington		No
Wisconsin		No
Wyoming	Yes	

Discussions

This question was about the existence of crack maintenance program within the states/provinces surveyed. As can be seen from Figure 4.1a, 86.7% of the surveyed states/provinces answered Yes, indicating existence of crack maintenance programs. On the other hand, 13.3% of the surveyed states/provinces responded No to the question.

4.1.2. Question 1b-General- Description of Crack Maintenance Program

Table 4.1 b Details of question 1b

Q-1b. If yes, please describe the program (select all that apply).		
Objective To determine the primary crack maintenance method used in each state's/province's established crack maintenance program.		
Answer Options	**% (of Received Responses)**	**Response Count**
Seal	75.9%	22
Pour	27.6%	8
Overband	51.7%	15
Rout and seal	69.0%	20
Other	6.9%	2
Please describe if chosen		15
Total Received Responses		**29**
Skipped		**2**

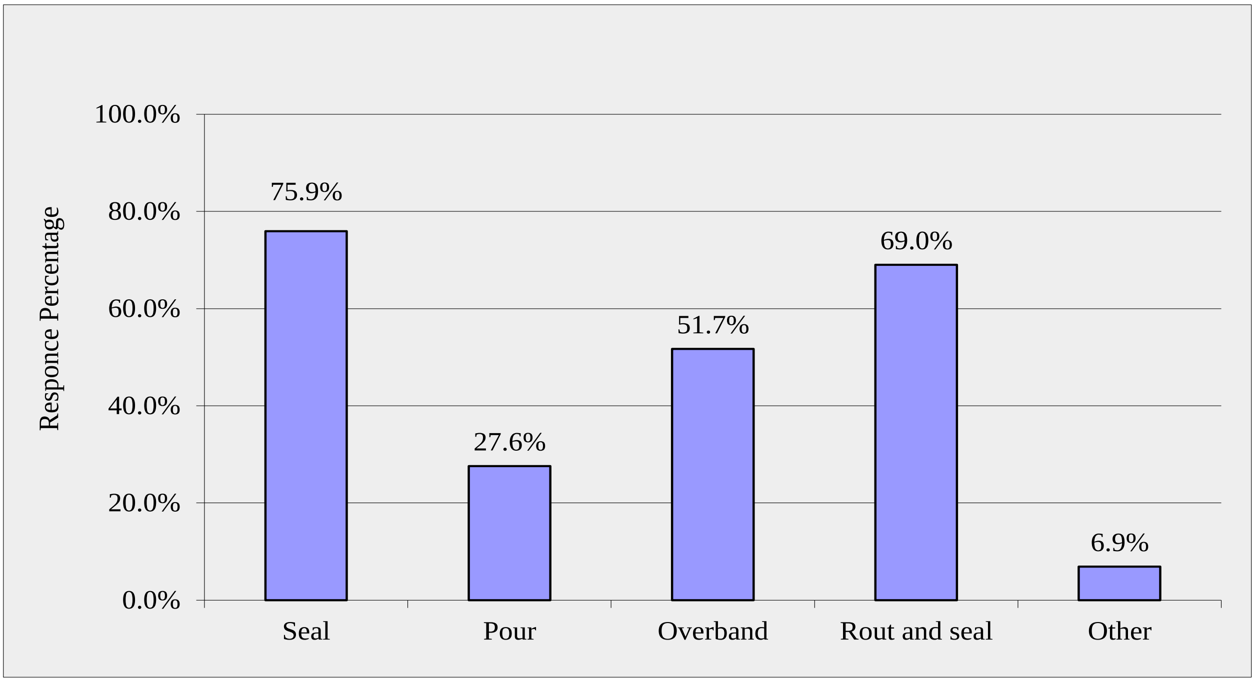

Figure 4. 1b Crack maintenance program applied in state/province

Survey Details-Q-1b.

State/Province	Individual responses				
Alberta		Pour		Rout ad seal	
British Columbia	Seal		Overband		
Colorado (First response)	Seal	Pour			
Colorado (Second response)	Seal	Pour	Overband	Rout and seal	
Idaho	Seal		Overband	Rout and seal	
Illinois	Seal			Rout and seal	
Iowa				Rout and seal	
Kansas	Seal	Pour		Rout and seal	
Manitoba (First response)	Seal			Rout and seal	
Manitoba (Second response)	Seal			Rout and seal	
Michigan	Seal		Overband	Rout and seal	
Minnesota	Seal	Pour	Overband	Rout and seal	
Missouri	Skipped				
Montana				Rout and seal	
Nebraska	Seal	Pour	Overband	Rout and seal	Other
Nevada (First response)	Seal				
Nevada (Second response)	Seal		Overband		
Nevada (Third response)	Skipped				
New Hampshire	Seal		Overband	Rout and seal	
Ohio (First response)			Overband		
Ohio (Second response)			Overband		
Ontario			Overband	Rout and seal	
Pennsylvania	Seal		Overband		
Saskatchewan	Seal	Pour		Rout and seal	
South Dakota	Seal	Pour	Overband	Rout and seal	
Utah (First response)	Seal			Rout and seal	
Utah (Second response)	Seal				
Utah (Third response)	Seal		Overband	Rout and seal	
Washington	Seal				Other
Wisconsin				Rout and seal	
Wyoming	Seal		Overband	Rout and seal	

Survey Details-Q-1b, continued.

State/Province	Please describe if chosen
Alberta	We use a combination of cold-pour emulsion (mostly without crack preparation, but sometime blown out with compressed air) and rout & seal. In terms of quantities, it's about 95% cold-pour and 5% R&S. Not a crack repair, but something we do instead, is spray patch over badly deteriorated cracks. The crack reflects back within a year but the spray patch protects that ACP from breaking up.
British Columbia	BC has several District and privatized Maintenance. Each Maintenance Contractor may have a crack seal program or an annual plan amount but it is not a provincial plan. In addition each of the three Regions do have a modest crack seal program to deal with mid life provincial highway.
Colorado (First response)	Based on actual needs as determined from field inspections
Iowa	We let MP (Maintenance Projects) to route and seal roads that have been recently overlaid with HMA. Typically these projects are conducted 2 to 3 years after an overlay project has been completed. Remaining HMA roadways are sealed as deemed necessary by field maintenance staff.
Kansas	If >1/2" wide, pout if 1/8" to 1/2", rout and seal
Manitoba (First response)	Seal Coat preservation projects determined based on annual modelling of highway network. Rout & Seal is done usually within 3-5 years following paving operations.
Manitoba (Second response)	Seal coats are prioritized based upon extent and severity-manual survey which is done annually for each segment of road. Rout & Seals are done typically on pavements 2-5 years old.
Nebraska	Asphaltic repair mastic for thermal cracks that have resulted in a pavement depression.
Ohio (First response)	We do not have a thermal crack program
Ontario	Routing existing cracks/joints up to 0.59 inch (15 mm) in average width and cleaning and sealing routed and unrouted cracks/joints in hot mix asphalt pavements with hot-poured rubberized asphalt crack sealants. The overband applies to all transverse and skewed cracks but longitudinal routs and cracks are not overband.
Pennsylvania	High Level Bituminous Asphalt Pavements We typically do not crack seal our low level roads that are chip sealed
Utah (First response)	We mainly do flush crack seal operations.
Utah (Second response)	Flush with the pavement to avoid overband
Washington	crack fill
Wyoming	Most jobs are rout and seal with recessed sealant. Still have a few jobs that are sealed flush and squeegeed.

Discussions

This question addressed the methods of crack maintenance approaches utilized in the crack maintenance programs of the states/provinces. The options available for the states/provinces to choose from were seal, pour, overband, rout and seal, and other methods. This question had multiple answers, thus more than one answer could be chosen. As illustrated in Figure 4.1b, 75.9% of the states/provinces choose crack sealing 69% utilized rout and seal, 51.7% choose overband, 27.6% choose pour, and 6.9% choose other methods.

4.2. Question 2-General-Best Management Practices Issues

Q-2. Does your state/province have an established best management practices (BMP) guide?

Table 4. 2 Details of question 2

Q-2. Does your state/province have an established best management practices (BMP) guide?		
Objective To determine which states/provinces have an established Best Management Practice (BMP) guideline and obtain access to the BMP from states/provinces responding, "Yes"		
Answer Options	**% (of Received Responses)**	**Response Count**
Yes	30.0%	9
No	70.0%	21
If yes, please provide the URL for the BMP guide		11
Total Received Responses		**30**
Skipped		**1**

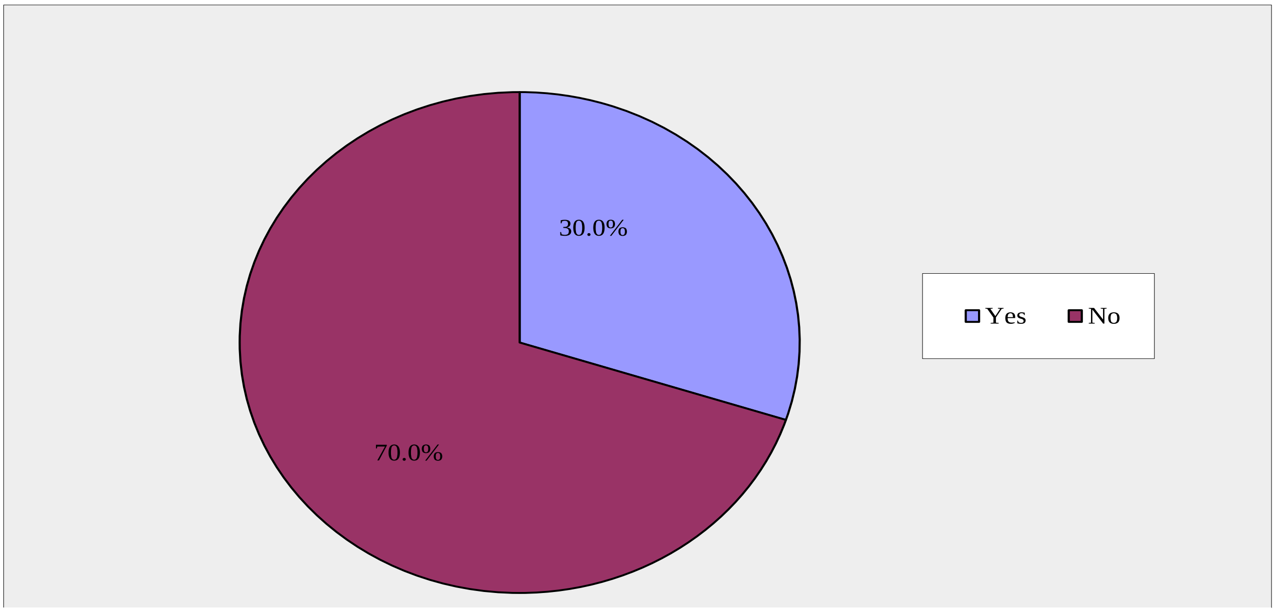

Figure 4. 2 Establishment of BMP within state/province.

Survey Details-Q-2.

State/Province	Individual responses	
Alberta	Yes	
British Columbia		No
Colorado (First response)		No
Colorado (Second response)	Yes	
Idaho		No
Illinois		No
Iowa		No
Kansas	Yes	
Manitoba (First response)		No
Manitoba (Second response)		No
Michigan		No
Minnesota	Yes	
Missouri	Yes	
Montana	Yes	
Nebraska	Yes	
Nevada (First response)		No
Nevada (Second response)		No
Nevada (Third response)	Skipped	
New Hampshire		No
Ohio (First response)		No
Ohio (Second response)		No
Ontario		No
Pennsylvania	Yes	
Saskatchewan		No
South Dakota		No
Utah (First response)		No
Utah (Second response)		No
Utah (Third response)	Yes	
Washington		No
Wisconsin		No
Wyoming		No

Survey Details-Q-2, continued.

State/Province	If yes, please provide the URL for the BMP guide
Alberta	http://www.transportation.alberta.ca/Content/docType253/Production/CrTrtmntGdln.pdf
British Columbia	BC has a Section in the Styandard Spec that deals with crack sealing.
Colorado (Second response)	No URL. I can email our specifications and our manual of maintenance procedures.
Kansas	On Agency Intranet Website
Minnesota	http://www.lrrb.org/media/reports/200854.pdf
Missouri	http://epg.modot.mo.gov/index.php?title=570.2_Joint_and_Crack_Maintenance
Montana	http://www.mdtinfo.mdt.mt.gov/maint/docs/crackseal.pdf#search="crack seal"
Nebraska	http://www.transportation.nebraska.gov/docs/pavement.pdf
Ontario	We have internal agency guidelines.
Pennsylvania	ftp://ftp.dot.state.pa.us/public/pubsforms/Publications/PUB%20113.pdf 711-7128-01 Crack Sealing
Utah (First response)	Udot has an activity standards for a guide. We use SHRP crack sealing practice guidelines

Discussions

Figure 4.2 illustrates the response percentage for the state/province concerning the existence of best management practices within the state/province. As seen from Figure 4.2, only 30% of the respondents indicated the existence of best management practices, whereas 70% indicated that they have no best management practices.

4.3. Question 3-General-Preferred Time for Crack Maintenance

Table 4. 3 Details of question 3

Q-3. What is the time of year cracks are maintained (select all that apply)?		
Objective To determine the approximate time of year when each state/province typically performs crack maintenance.		
Answer Options	**% (of Received Responses)**	**Response Count**
Spring	90.0%	27
Summer	56.7%	17
Fall	80.0%	24
Winter	26.7%	8
Comments		12
Total Received Responses		**30**
Skipped		**1**

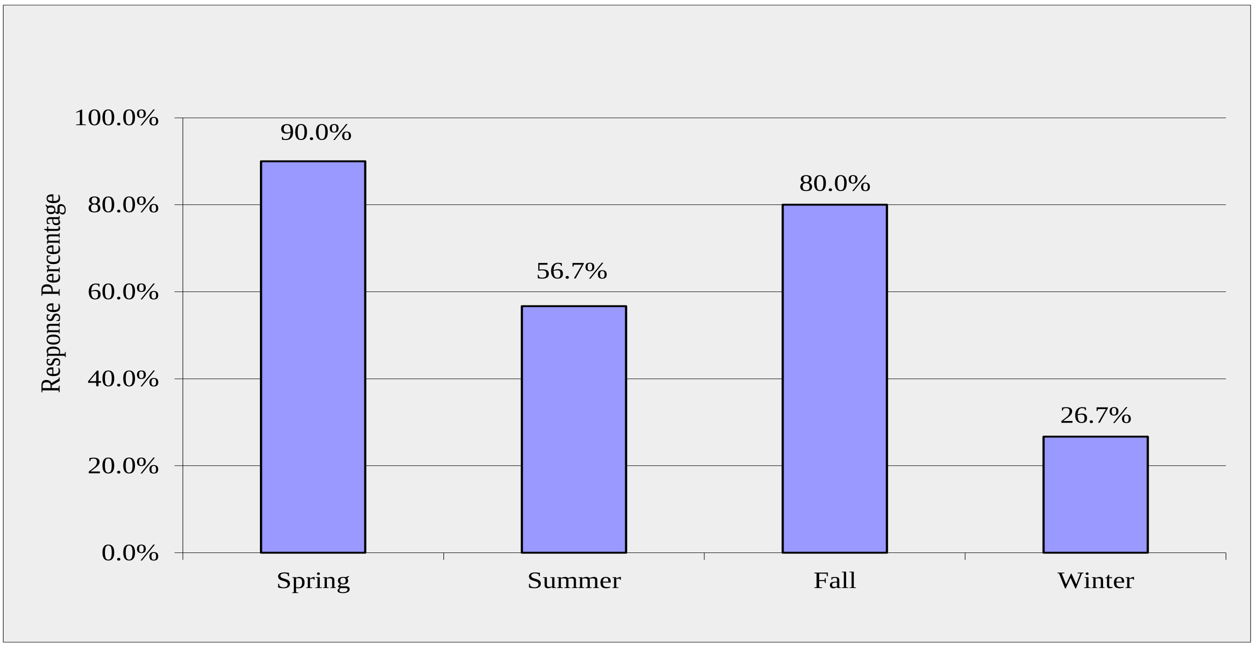

Figure 4. 3 Crack maintenance time of year in state/province.

Survey Details-Q-3.

State/Province	Individual responses			
Alberta	Spring			
British Columbia	Spring			
Colorado (First response)	Spring		Fall	
Colorado (Second response)	Spring	Summer	Fall	Winter
Idaho	Spring		Fall	
Illinois	Spring	Summer		
Iowa		Summer		
Kansas	Spring	Summer	Fall	
Manitoba (First response)	Spring	Summer	Fall	
Manitoba (Second response)	Spring	Summer	Fall	
Michigan		Summer		
Minnesota	Spring	Summer	Fall	Winter
Missouri	Spring		Fall	
Montana	Spring	Summer	Fall	
Nebraska	Spring	Summer	Fall	Winter
Nevada (First response)	Spring		Fall	
Nevada (Second response)	Spring		Fall	
Nevada (Third response)	Skipped			
New Hampshire	Spring	Summer	Fall	
Ohio (First response)	Spring	Summer	Fall	
Ohio (Second response)	Spring	Summer	Fall	Winter
Ontario	Spring	Summer	Fall	
Pennsylvania	Spring	Summer	Fall	
Saskatchewan	Spring	Summer		
South Dakota	Spring	Summer	Fall	Winter
Utah (First response)	Spring		Fall	Winter
Utah (Second response)	Spring		Fall	
Utah (Third response)			Fall	Winter
Washington	Spring		Fall	
Wisconsin	Spring		Fall	
Wyoming	Spring		Fall	Winter

Survey Details-Q-3, continued.

State/Province	Comments
Alberta	In the early 1990s, we did some field studies and found that the most significant time for crack movement in ACP was as the frost set in, or came out, of the underlying soil. So our experience is that the optimum time to seal cracks is early spring, when the crack is wide (not quite as wide as during the depths of winter, but close.)
British Columbia	depending on elevation we try and get the crack in the late spring early summer before the hot weather closes the cracks
Colorado (Second response)	Our preference is late winter or early spring, but we do it when we can.
Iowa	Primarily summertime but on occasion this work could occur during other times of the year.
Manitoba	Time dependent on weather conditions and work schedule of in house staffing.
Montana	Temperature restriction: Pavement temperature 35 F and rising. If the pavement temperature is greater than 120 F then we will discontinue
Nebraska	primarily fall, winter and spring when temperatures have caused the cracks to open up
Ohio (First response)	Question #4 should have a < 10% Ohio would be there
Ohio (Second response)	When time permits
Pennsylvania	Spring and Fall for Crack Seal
Utah (First response)	Most of our crack sealing is done February to March.
Utah (Second response)	Want to crack seal when they are the most open

Discussions

This question investigated the time of year the cracks are maintained. The options available for the states/provinces to choose from were spring, summer, fall, and winter. The question had multiple possible answers, thus more than one answer could be chosen. As illustrated in Figure 4.3, 90% of the states/provinces choose spring, whereas 80% selected fall, 56.7% choose summer and lastly, only 26.7% of the respondents selected winter.

4.4. Question 4-General-Frequency of Crack Maintenance

Table 4. 4 Details of question 4

Q-4. What approximate percentage of asphalt roads in the state/province require thermal cracking maintenance on a regularly basis?		
Objective To determine the amount of roadways subject to thermal cracking and require regularly scheduled maintenance within each state/province.		
Answer Options	**% (of Received Responses)**	**Response Count**
10-20%	35.7%	10
20-40%	39.3%	11
40-60%	10.7%	3
more than 60%	14.3%	4
Total Received Responses		**28**
Skipped		**3**

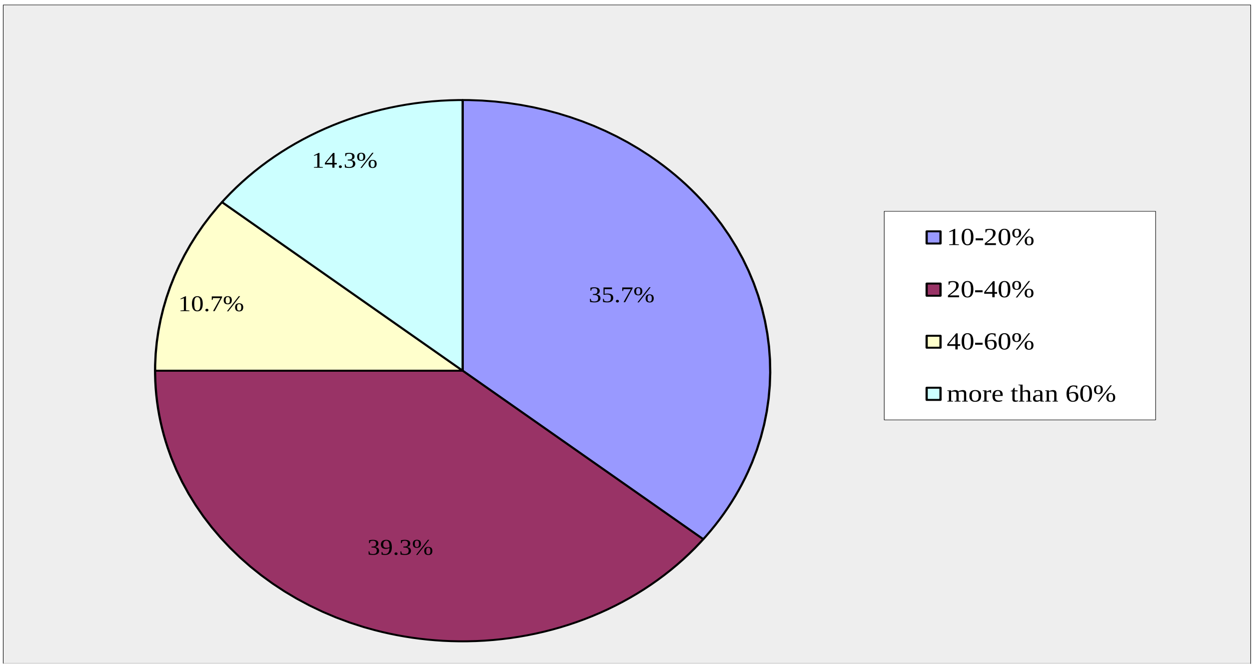

Figure 4. 4 Approximate percentage of asphalt roads in the state/province that require thermal cracking maintenance on a regularly basis

Survey Details-Q-4.

State/Province	Individual responses			
Alberta				more than 60%
British Columbia	10-20%			
Colorado (First response)		20-40%		
Colorado (Second response)				more than 60%
Idaho		20-40%		
Illinois		20-40%		
Iowa		20-40%		
Kansas		20-40%		
Manitoba (First response)		20-40%		
Manitoba (Second response)	10-20%			
Michigan				more than 60%
Minnesota	Skipped			
Missouri	10-20%			
Montana				more than 60%
Nebraska			40-60%	
Nevada (First response)		20-40%		
Nevada (Second response)			40-60%	
Nevada (Third response)	Skipped			
New Hampshire		20-40%		
Ohio (First response)	Skipped			
Ohio (Second response)	10-20%			
Ontario	10-20%			
Pennsylvania			40-60%	
Saskatchewan	10-20%			
South Dakota		20-40%		
Utah (First response)		20-40%		
Utah (Second response)		20-40%		
Utah (Third response)	10-20%			
Washington	10-20%			
Wisconsin	10-20%			
Wyoming	10-20%			

Discussions

Question 4 was investigating the approximate percentage of asphalt roads in the state/province that require thermal cracking maintenance on a regularly basis. The options available for the states/provinces to choose from were 10-20%, 20-40%, 40-60%, and more than 60%. This question was a single answer question. As can be seen from Figure 4.4, 39.3% of the respondents stated that 20-40% of the asphalt roads are maintained on a regularly basis, whereas, 35.7% of the respondents chose the option of 10-20% of the asphalt roads to be maintained on a regularly basis. On the other hand, 14.3% of the respondents indicated that more than 60% of the asphalt roads are maintained on a regularly basis.

4.5. Question 5-General-Expected Life of Crack Maintenance Materials

Table 4. 5 Details of question 5

Q-5. What is the expected life of crack maintenance materials used in the state/province?		
Objective To determine the expected life of maintenance materials used for maintaining cracks by each state/province.		
Answer Options	**% (of Received Responses)**	**Response Count**
1 year	0.0%	0
2-3 years	33.3%	10
3-5 years	46.7%	14
other	20.0%	6
If other, specify		10
Total Received Responses		**30**
Skipped		**1**

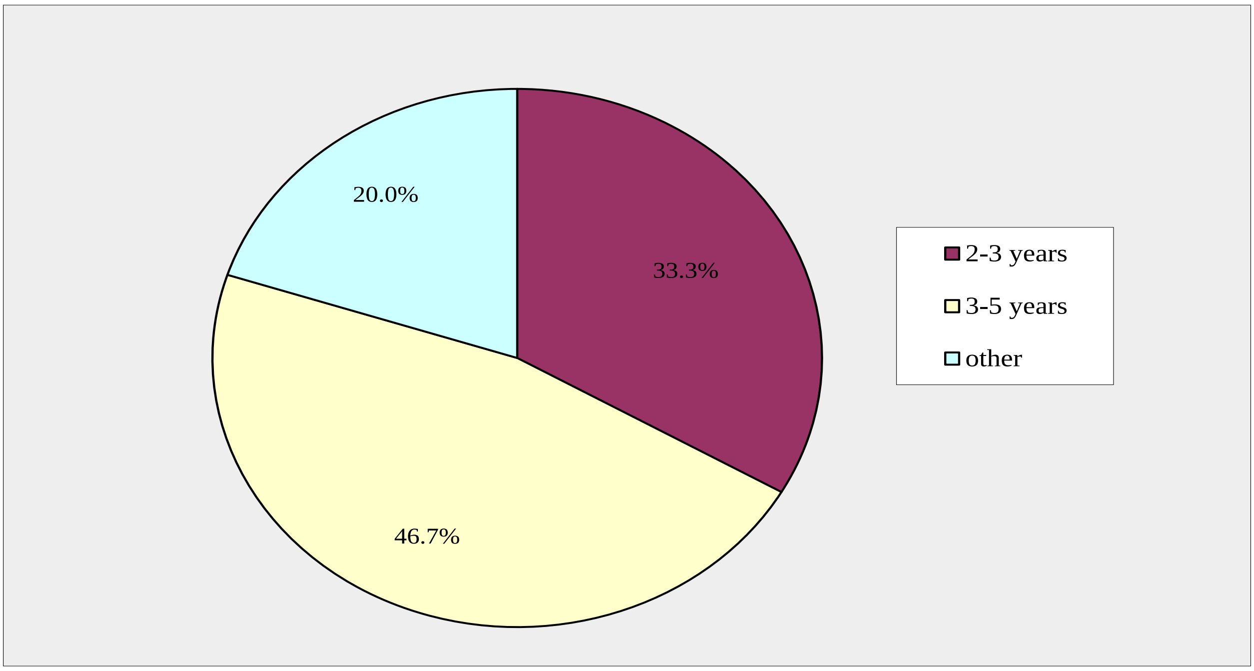

Figure 4. 5 Expected life of crack maintenance materials used in the state/province.

Survey Details-Q-5.

State/Province	Individual responses		
Alberta			other
British Columbia		3-5 years	
Colorado (First response)	2-3 years		
Colorado (Second response)		3-5 years	
Idaho		3-5 years	
Illinois	2-3 years		
Iowa	2-3 years		
Kansas		3-5 years	
Manitoba (First response)		3-5 years	
Manitoba (Second response)		3-5 years	
Michigan	2-3 years		
Minnesota			other
Missouri	2-3 years		
Montana			other
Nebraska		3-5 years	
Nevada (First response)		3-5 years	
Nevada (Second response)	2-3 years		
Nevada (Third response)	Skipped		
New Hampshire		3-5 years	
Ohio (First response)			other
Ohio (Second response)			other
Ontario		3-5 years	
Pennsylvania		3-5 years	
Saskatchewan		3-5 years	
South Dakota		3-5 years	
Utah (First response)	2-3 years		
Utah (Second response)	2-3 years		
Utah (Third response)		3-5 years	
Washington	2-3 years		
Wisconsin	2-3 years		
Wyoming			other

Survey Details-Q-5, continued.

State/Province	If other, specify
Alberta	Less than 1 year for cold-pour (we expect the crack to remain effective until the following spring) We expect a minimum 3 years for rout & seal, but have seen some where the workmanship was good last more than 7 years.
Minnesota	Depends if the cracked os filled or sealed.
Montana	We try to get 7-10 years
Nebraska	possibly more or less than this depending upon the quality of the installation
Ohio (First response)	We don't have an expected life. ODOT only crack seals on a very limited basis. Our research indicates it is marginally cost effective. We are not dealing with many thermal crack problems. Our thermal cracks seldom get wide enough to create a problem.
Ohio (Second response)	We crack seal on a very limited basis. Our research indicates it is marginally cost effective. We do not really have an expected life. If we do crack seal it is only once in life of a surface course. The crack fill might last 3-5 years. The seal would be much less.
Ontario	We do not obtain information on the type of cracks that are sealed (i.e., thermal or fatigue)
Utah (First response)	Crack sealing is a prep for the pavement one year prior to an overlay or a sealcoat.
Utah (Second response)	Want to prep your surface by crack sealing and pothole patching prior to an overlay. Typically 6 month to a year prior to the overlay or a seal coat application
Wyoming	anticipated life is 5 to 7 years.

Discussions

This question investigated the life duration of the crack maintenance materials used within a state/province. The options available for the states/provinces to choose from were 1 year, 2-3 years, 3-5 years and other. This question was a single answer question. In addition, the respondents were asked to explain their selection, if they selected other. Figure 4.5 illustrates the response percentage for the states/provinces. As can be seen from Figure 4.5, 46.7% of the respondents selected 3-5 years as an expected life for the crack materials used. In addition, 33.3% of the respondents selected the 2-3 years selection of life expectance for crack maintenance. Lastly, 20% of the respondents chose other as their selection.

4.6. Question 6-General-Preparation of Cracks

Table 4. 6 Details of question 6

Q-6. What are the preparation methods for crack maintenance in your state/province (select all that apply)?		
Objective To determine the most common methods used to prepare cracks prior to the application of crack treatments.		
Answer Options	**% (of Received Responses)**	**Response Count**
Sawing	17.2%	5
Routing	65.5%	19
Hot air lance	51.7%	15
Compressed air	96.6%	28
No preparation	3.4%	1
If other, specify		5
Total Received Responses		**29**
Skipped		**2**

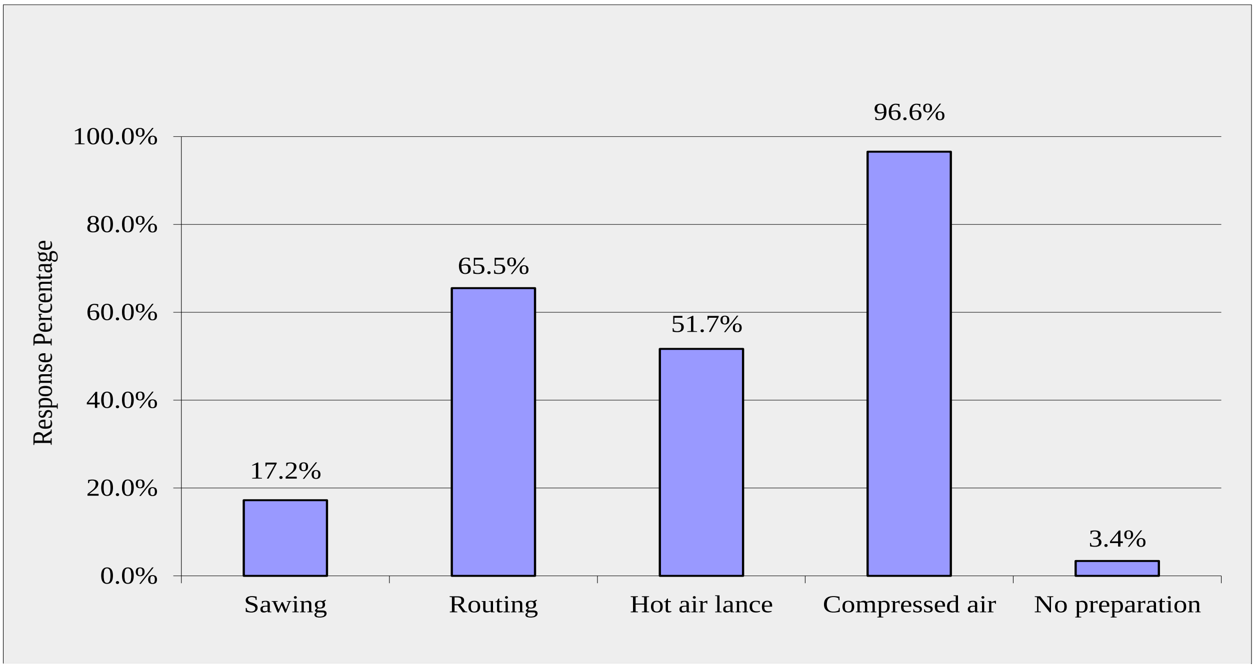

Figure 4. 6 Preparation methods for crack maintenance in state/province.

Survey Details-Q-6.

State/Province	Individual responses					
Alberta	Sawing	Routing	Hot air lance	Compressed air		Other
British Columbia				Compressed air		
Colorado (First response)			Hot air lance	Compressed air		
Colorado (Second response)		Routing	Hot air lance			Other
Idaho		Routing		Compressed air		
Illinois		Routing		Compressed air		
Iowa		Routing		Compressed air		
Kansas		Routing	Hot air lance	Compressed air		Other
Manitoba (First response)		Routing	Hot air lance	Compressed air		
Manitoba (Second response)		Routing		Compressed air		
Michigan	Sawing	Routing		Compressed air		
Minnesota		Routing	Hot air lance	Compressed air		
Missouri		Routing		Compressed air		
Montana		Routing		Compressed air		
Nebraska	Sawing	Routing	Hot air lance	Compressed air		
Nevada (First response)				Compressed air		
Nevada (Second response)			Hot air lance	Compressed air		
Nevada (Third response)	Skipped					
New Hampshire		Routing	Hot air lance	Compressed air		
Ohio (First response)			Hot air lance	Compressed air		Other
Ohio (Second response)			Hot air lance	Compressed air		
Ontario		Routing	Hot air lance	Compressed air		
Pennsylvania				Compressed air		
Saskatchewan	Sawing	Routing	Hot air lance	Compressed air		
South Dakota	Sawing	Routing	Hot air lance	Compressed air		
Utah (First response)				Compressed air		
Utah (Second response)				Compressed air		Other
Utah (Third response)	Skipped					
Washington				Compressed air		
Wisconsin		Routing		Compressed air	No preparation	
Wyoming		Routing	Hot air lance	Compressed air		

Survey Details-Q-6, continued.

State/Province	If other, specify
Alberta	We have very little PCC pavement (less than 1% of the network, mostly around some urban intersections) and do silicone in sawn cracks when we do any repair work. For ACP, cold pour normally doesn't get any preparation. Rout & Seal we allow both hot air lance and compressed air; we haven't seen any difference in initial quality of work or long-term performance.
Colorado (Second response)	Routing on PCCP.
Kansas	if no hot air lance, dry clean compressed air
Ohio (First response)	Our specs provide for the routing option, but is never used
Utah (Second response)	want to clean the surface of any dust and debris and free of moisture.

Discussions

Question 6 investigated the methods for preparation of cracks within states/provinces. The options available for the states/provinces to choose from were sawing, routing, hot air lance, compressed air and no preparation. This question was a multiple answer question. As can be seen from Figure 4.6, 96.6% of the respondents chose compressed air as a preparation method for crack maintenance, 65.5% chose routing as a preparation method for cracks, 51.7% selected hot air lance crack preparation method, 17.2% chose sawing crack preparation method, and 3.4% of the respondents selected no preparation for cracks.

4.7. Question 7-Technology-Experience with crack maintenance Materials

Table 4. 7 Details of question 7

Q-7. What is your experience with using each of the following crack maintenance material products within the state/province (select all that apply)?					
Objective To determine the frequency of experience with each type of crack maintenance material and which materials are most commonly used (or not used) across surveyed states/provinces.					
Answer Options	**Currently Used**	**Preferred Technology**	**Used Before, but no longer**	**Never been used**	**Response Count**
Cutback Asphalt	0	0	13	9	22
MC-3000 (medium-cure cutback)	0	0	8	12	20
Asphalt Emulsion	9	0	4	10	23
Polymer-Modified Liquid Asphalt	7	1	1	13	22
Asphalt Cement Application	3	0	3	15	21
Fiberized Asphalt	5	0	1	14	20
Asphalt Rubber	8	3	2	9	22
Rubberized Asphalt	12	3	0	8	23
Low-Modulus Rubberized Asphalt	9	2	1	8	20
Elastoflex 52 (crumb rubber)	4	0	1	15	20
Polymer-Modified Asphalt	4	1	2	13	20
Elastoflex 71 (polymer sealant)	4	0	0	16	20
Self-Leveling Silicone	1	0	1	17	19
Other	5	1	0	7	13
If other, specify					10
Total Received Responses					**28**
Skipped					**3**

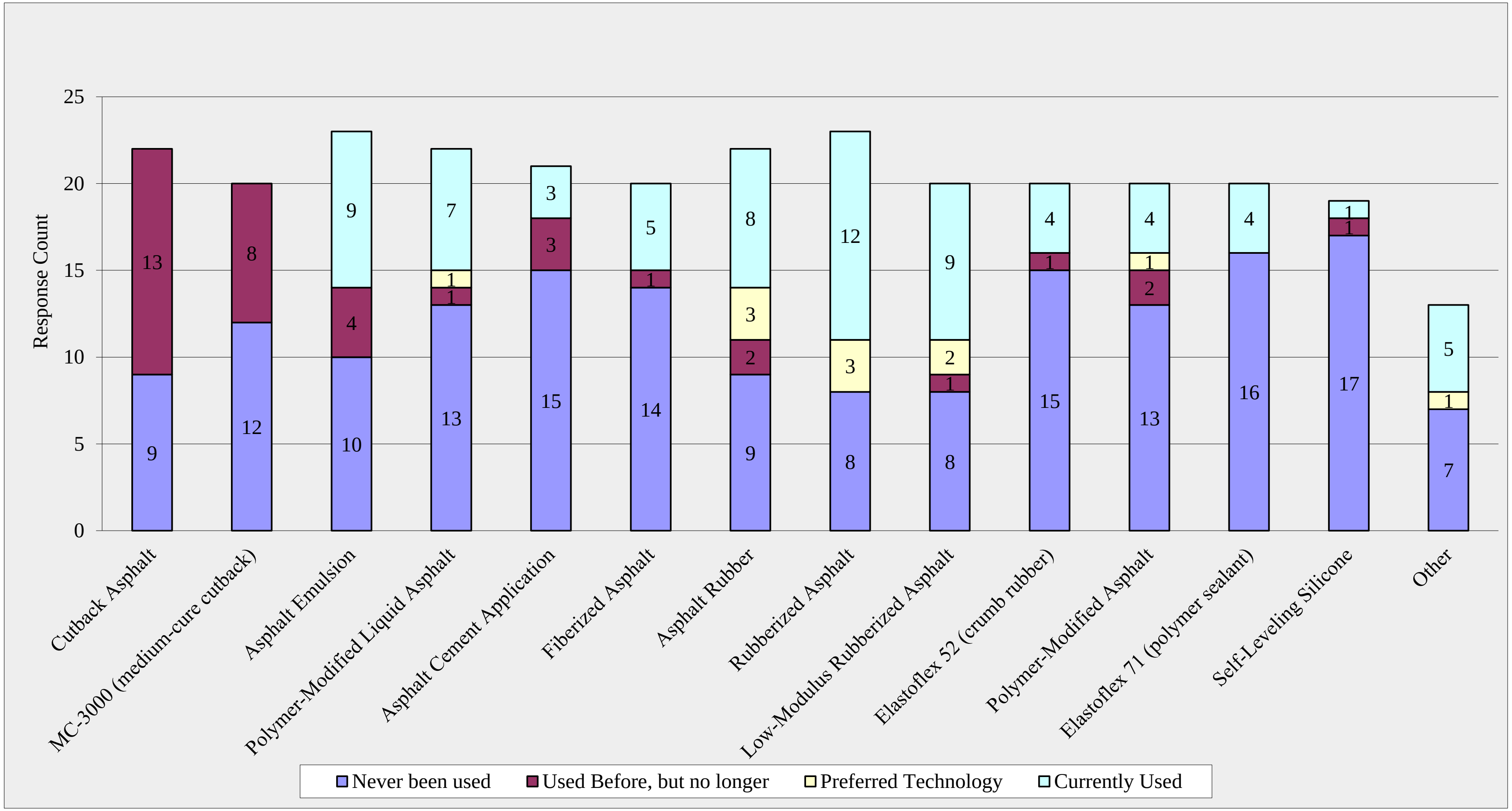

Figure 4. 7 Experience with using crack maintenance material products within the state/province.

Survey Details-Q-7.

State/Province	Cutback Asphalt	MC-3000 (medium-cure cutback)	Asphalt Emulsion	Polymer-Modified Liquid Asphalt	Asphalt Cement Application	Fiberized Asphalt	Asphalt Rubber
Alberta	Never used	Never used	Currently used	Never used	Never used	Never used	No longer
British Columbia	No longer	Never used	Currently used	Currently used	Never used	Never used	Currently used
Colorado First			Currently used				Currently used
Colorado Second				Currently used			
Idaho							
Illinois	No longer	No longer	Currently used	Preferred Technology	Never used	Never used	Never used
Iowa	Never used	Never used	Never used	Currently used	Never used	Never used	Never used
Kansas	No longer	No longer	Never used	Never used	Currently used	Currently used	Never used
Manitoba First	No longer	No longer	Never used	Never used	Currently used	Never used	Never used
Manitoba Second	No longer		Currently used	Currently used			
Michigan	No longer	Never used	Never used	Never used	No longer	No longer	Preferred Technology
Minnesota	No longer	No longer	No longer	Currently used	Never used	Currently used	Currently used
Missouri	No longer	Never used	Currently used	Currently used	No longer	Never used	Currently used
Montana	Never used	Never used	Never used	Never used	Never used	Never used	Never used
Nebraska	No longer	No longer	Currently used	No longer	No longer	Never used	Currently used
Nevada First	No longer		No longer				
Nevada Second	Never used	Never used	No longer	Never used	Never used	Never used	Never used
Nevada Third	Skipped						
New Hampshire	Never used	Never used	Never used	Never used	Never used	Currently used	Currently used
Ohio First					Currently used	Currently used	Currently used
Ohio Second							
Ontario	Never used	Never used	Never used	Never used	Never used	Never used	Never used
Pennsylvania							
Saskatchewan	No longer	No longer	Currently used	Currently used	Never used	Currently used	Preferred Technology
South Dakota	Never used	Never used	Never used	Never used	Never used	Never used	No longer
Utah First	No longer	No longer	Never used	Never used	Never used	Never used	Currently used
Utah Second	No longer	No longer	No longer	Never used	Never used	Never used	Preferred Technology
Utah Third	Skipped						
Washington	Never used	Never used	Currently used	Never used	Never used		Never used
Wisconsin	Skipped						
Wyoming	Never used	Never used	Never used	Never used	Never used	Never used	Never used

Survey Details-Q-7, continued.

State/Province	Rubberized Asphalt	Low-Modulus Rubberized Asphalt	Elastoflex 52 (crumb rubber)	Polymer-Modified Asphalt	Elastoflex 71 (polymer sealant)	Self-Leveling Silicone	Other
Alberta	Currently used	Never used	Never used	Never used	Never used	Never used	Never used
British Columbia	Never used	Never used	Never used	Never used	Never used		
Colorado First							
Colorado Second	Currently used					Currently used	Currently used
Idaho	Currently used						
Illinois	Never used	Never used	Never used	Preferred Technology	Never used	Never used	
Iowa	Never used	Never used	Never used	Currently used	Never used	Never used	Never used
Kansas	Never used	Never used	Never used	Never used	Never used	Never used	Never used
Manitoba First	Never used	Currently used	Never used	Never used	Never used	Never used	Never used
Manitoba Second							
Michigan	Never used	Preferred Technology	Never used	No longer	Never used	Never used	
Minnesota	Currently used	Currently used	Currently used	Currently used	Currently used		Currently used
Missouri	Currently used	Currently used	No longer	No longer	Never used	Never used	
Montana	Currently used	Currently used	Never used	Never used	Never used	Never used	Never used
Nebraska	Currently used	Currently used	Never used	Never used	Never used	No longer	Preferred Technology
Nevada First					Currently used		
Nevada Second	Currently used	Never used	Currently used	Never used		Never used	Never used
Nevada Third	Skipped						
New Hampshire	Currently used	Currently used	Never used	Never used	Never used	Never used	
Ohio First							
Ohio Second							Currently used
Ontario	Currently used	Currently used	Never used	Never used	Never used	Never used	
Pennsylvania	Currently used						Currently used
Saskatchewan	Preferred Technology	Preferred Technology	Never used	Currently used	Currently used	Never used	
South Dakota	Never used	Currently used	Currently used	Currently used	Currently used	Never used	
Utah First	Preferred Technology	No longer	Never used	Never used	Never used	Never used	
Utah Second	Preferred Technology	Currently used	Currently used	Never used	Never used	Never used	
Utah Third	Skipped						
Washington	Currently used	Never used	Never used	Never used	Never used	Never used	Never used
Wisconsin	Skipped						
Wyoming	Never used	Never used	Never used	Never used	Never used	Never used	Currently used

Survey Details-Q-7, continued.

State/Province	If other, specify
British Columbia	a few Maintenance Contractors use a CRF product
Colorado (First response)	Deery 102 (Crafco), Elastoflex 61 (Maxwell), #3405 Regular (Right Point Company) & #3405 Modified (Right Pointe Company)
Colorado (Second response)	Elastoflex 38, Elastoflex 61, Silicone - Non-Sag,
Minnesota	See the MnDOT approved products web page for the list of sealants allowed.
Montana	MDT uses any material that will meet ASTM D5249 Type one.
Nebraska	Repair Mastic: Maxwell NuvoGap, Crafco Level N Go
Ohio (First response)	ASTM D 6690, type 2
Ohio (Second response)	Our specifications can be found on line at http://www.dot.state.oh.us/Divisions/ConstructionMgt/Specification%20Files/2013%20CMS%2011142012%20FINAL.PDF Under Item 423
Pennsylvania	Polyflex Type 2 http://www.crafco.com/PDF%20Files/Product%20Data%20Sheets/34518_polyflex_type2.pdf
Wyoming	sealant must meet the requirements of AASHTO M324 Type I Wyoming Modified or AASHTO M324 Type IV Wyoming Modified as specified in plans. This is per Materials Program and Specifications.

Discussions

Question 7 investigated the states/provinces experience with using different crack maintenance material products. Figure 4.7 illustrates the response count of states/provinces.

As can be seen from the figure, 13 respondents indicated that cutback asphalt was used before, but is no longer being used, whereas 9 respondents indicated that it has never been used before. Investigating a specific type of cutback asphalt (MC-3000), 12 respondents indicated that they have never used it before, while 8 respondents indicated that it was used before, but is no longer being used.

For the asphalt emulsion, 10 indicated never used it before, 9 that it is one of the currently used technologies within the state/province, and 10 that it has never been used before.

For the polymer modified liquid asphalt, 13 respondents indicated that it has never been used before, 7 respondents indicated that it is one of the currently used technologies, 1 respondent indicated that it is the states preferred technology, and 1 respondent indicated that it was used before but no longer.

For the asphalt cement application, 15 respondents answered never been used before, 3 currently used technologies, and 3 used before but is no longer being used.

For the fiberized asphalt, 14 respondents indicated that it has never been used before, 5 currently used, and 1 used before but no longer.

For the asphalt rubber, 9 respondents answered never been used before, 8 currently used, 3 indicated that it is the preferred technology, and 2 respondents indicated that it was used before but is no longer being used.

With regards to the rubberized asphalt, 12 respondents answered that it is currently used, 6 have never used it, and 3 respondents indicated that it is the preferred technology.

For the low modulus rubberized asphalt, 9 respondents indicated that it is currently used within the state/province, 8 that it has never been used before, 2 indicated that it is the preferred technology, while 1 respondent indicated that it was used before but no longer. For the Elastoflex 52, 15 answered that it has never been used before, 4 currently used, and 1 respondent that it was used before but no longer.

Regarding the polymer modified asphalt, 13 indicated that it has never been used, 4 currently used , 2 respondents indicated that it was used before but is no longer being used, while 1 respondent indicated that it is the preferred technology. For Elastoflex 71, 16 respondents answered that it has never been used before and 4 respondents indicated that it is one of the currently used technologies.

For self-leveling silicon, 17 respondents responded never been used, 1 that it is currently used, and 1 respondent indicated that it was used before but is no longer.

For the other technologies, 7 respondents indicated that it has never been used before, 5 respondents indicated that it is one of the currently used technologies, and 1 respondent indicated that it is the states preferred technology.

4.8. Question 8-Technology-Experience with Storage of crack maintenance Materials

Table 4. 8 Details of question 8

Q-8. What is your experience about the storage practices for the following crack maintenance materials (select all that apply)?					
Objective To determine common storage practices with respect to climate exposure.					
Answer Options	**Indoor storage**	**Indoor storage with moderate exposure**	**Outdoor storage**	**NA**	**Response Count**
Cutback Asphalt	0	1	1	12	14
MC-3000 (medium-cure cutback)	0	1	0	13	14
Asphalt Emulsion	2	2	2	12	18
Polymer-Modified Liquid Asphalt	0	2	2	12	16
Asphalt Cement Application	1	2	0	10	13
Fiberized Asphalt	2	1	0	10	13
Asphalt Rubber	4	4	0	9	17
Rubberized Asphalt	4	4	2	8	18
Low-Modulus Rubberized Asphalt	3	3	1	7	14
Elastoflex 52 (crumb rubber)	0	2	0	12	14
Polymer-Modified Asphalt	1	3	0	11	15
Elastoflex 71 (polymer sealant)	1	1	0	13	15
Self-Leveling Silicone	0	0	1	14	15
Other	6	0	1	7	14
If other, specify					9
Total Received Responses					**25**
Skipped					**6**

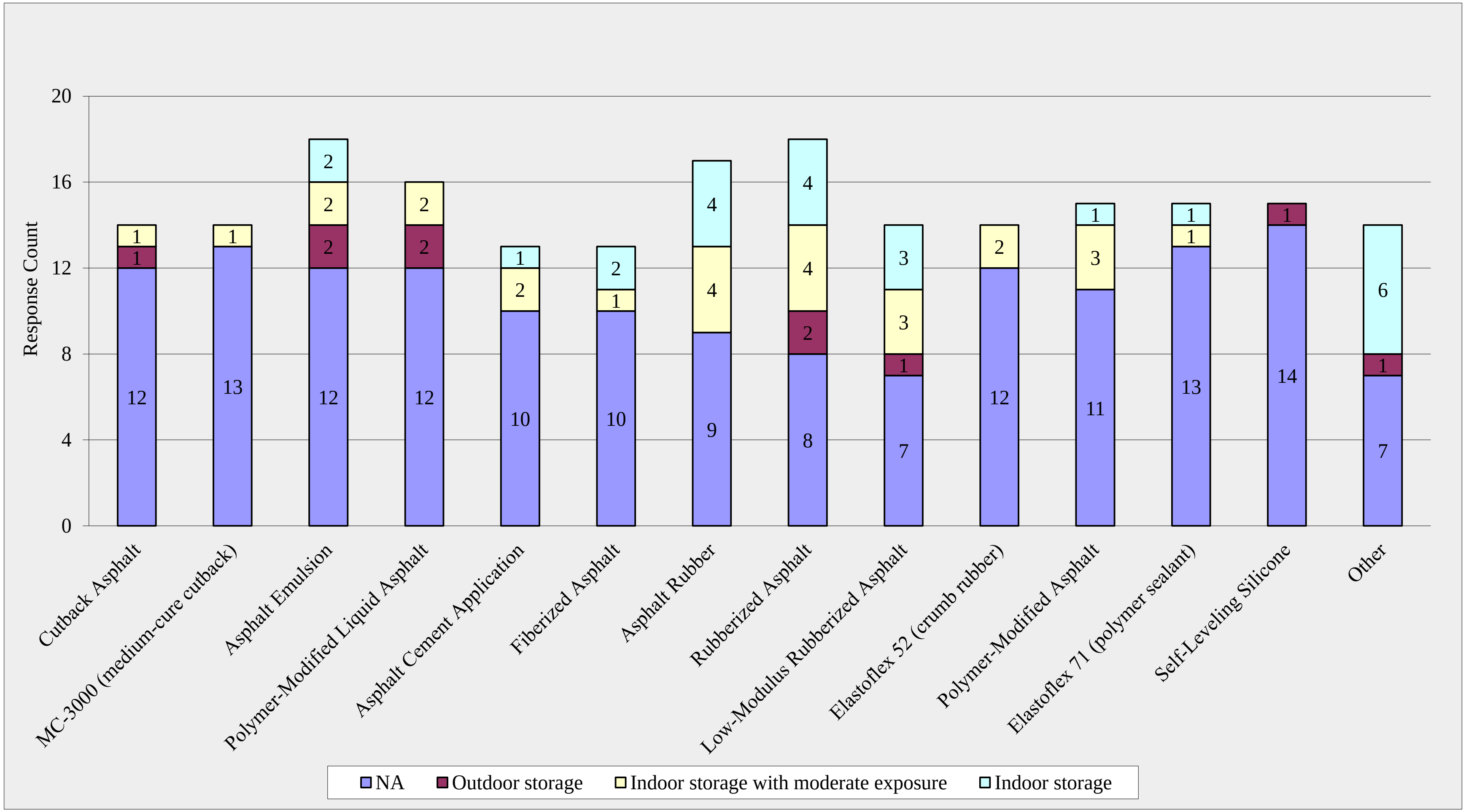

Figure 4. 8 Experience about the storage practices for crack maintenance materials within the state/province.

Survey Details-Q-8.

State/Province	Cutback Asphalt	MC-3000 (medium-cure cutback)	Asphalt Emulsion	Polymer-Modified Liquid Asphalt	Asphalt Cement Application	Fiberized Asphalt
Alberta			Outdoor storage			
British Columbia	NA	NA	NA	NA	NA	NA
Colorado First			Indoor mod. expo.			
Colorado Second				Outdoor storage		
Idaho						
Illinois	NA	NA	Indoor mod. expo.	Indoor mod. expo.	NA	NA
Iowa			NA	Indoor mod. expo.		
Kansas			NA	NA		
Manitoba First	Indoor mod. expo.	Indoor mod. expo.	NA	NA	Indoor mod. expo.	NA
Manitoba Second	Skipped					
Michigan	Skipped					
Minnesota	NA	NA	NA			
Missouri	Outdoor storage	NA	Outdoor storage	Outdoor storage	Indoor mod. expo.	Indoor mod. expo.
Montana						
Nebraska	NA	NA	Indoor storage	NA	NA	NA
Nevada First						
Nevada Second	NA	NA	NA	NA	NA	NA
Nevada Third	Skipped					
New Hampshire	NA	NA	NA	NA	NA	Indoor storage
Ohio First						
Ohio Second						
Ontario	NA	NA	NA	NA	NA	NA
Pennsylvania						
Saskatchewan	NA	NA	Indoor storage	NA	Indoor storage	Indoor storage
South Dakota	NA	NA	NA	NA	NA	NA
Utah First	NA	NA	NA	NA	NA	NA
Utah Second	Skipped					
Utah Third	Skipped					
Washington	NA	NA	NA	NA	NA	NA
Wisconsin	Skipped					
Wyoming	NA	NA	NA	NA	NA	NA

Indoor mod expo. : Indoor storage with moderate exposure.

Survey Details-Q-8, continued.

State/Province	Asphalt Rubber	Rubberized Asphalt	Low-Modulus Rubberized Asphalt	Elastoflex 52 (crumb rubber)	Polymer-Modified Asphalt	Elastoflex 71 (polymer sealant)	Self-Leveling Silicone	Other
Alberta		Outdoor storage						
British Columbia	NA	NA	NA	NA	NA	NA	NA	Indoor storage
Colorado First	Indoor mod. expo.							
Colorado Second		Outdoor storage					Outdoor storage	
Idaho		Indoor storage						
Illinois	NA	NA	NA	NA	Indoor mod. expo.	NA	NA	
Iowa					Indoor mod. expo.			
Kansas	NA	NA	NA	NA	NA	NA	NA	NA
Manitoba First	NA	NA	Indoor mod. expo.	NA	NA	NA	NA	NA
Manitoba Second	Skipped							
Michigan	Skipped							
Minnesota								Indoor storage
Missouri	Indoor mod. expo.	NA	Indoor mod. expo.	Indoor mod. expo.	Indoor mod. expo.	NA	NA	
Montana	Indoor mod. expo.	Indoor mod. expo.						
Nebraska	Indoor storage	Indoor storage	Indoor storage	NA	NA	NA	NA	Indoor storage
Nevada First						Indoor mod. expo.		
Nevada Second	NA	Indoor mod. expo.	NA	Indoor mod. expo.	NA	NA	NA	NA
Nevada Third	Skipped							
New Hampshire	Indoor storage	Indoor storage	Indoor storage	NA	NA	NA	NA	
Ohio First								NA
Ohio Second								Indoor storage
Ontario	NA	Indoor mod. expo.	Indoor mod. expo.	NA	NA	NA	NA	NA
Pennsylvania	Indoor storage							Indoor storage
Saskatchewan	Indoor storage	Indoor storage	Indoor storage	NA	Indoor storage	Indoor storage	NA	Indoor storage
South Dakota	NA	NA	NA	NA	NA	NA	NA	
Utah First	Indoor mod. expo.	Indoor mod. expo.	Outdoor storage	NA	NA	NA	NA	NA
Utah Second	Skipped							
Utah Third	Skipped							
Washington	NA	NA	NA	NA	NA	NA	NA	NA
Wisconsin	Skipped							
Wyoming	NA	NA	NA	NA	NA	NA	NA	Outdoor storage

Survey Details-Q-8, continued.

State/Province	If other, specify
Alberta	Both liquid emulsion and solid rubberized asphalt can be stored outside during warm (above freezing) weather, but have to be moved inside if stored out of season. Very rare to have quantities of crack sealant on hand outside of spring and early summer, but sometimes the delivery comes when we're still getting below-freezing temps overnight and storage has to be indoors until it warms up.
British Columbia	We do it by contract so we store nothing
Minnesota	I do not know how sealants are stored.
Montana	Mostly we store the crack seal material indoors, occasionally we will store outdoors but there has been no known problems with this practice.
Ohio (First response)	Not qualified to answer this question. Contact Thomas Lyden thomas.lyden@dot.state.oh.us Phone: 614-644-7105
Ohio (Second response)	Contractors store according to the manufacuturers specifications
Pennsylvania	Polyflex Type 2 http://www.crafco.com/PDF%20Files/Product%20Data%20Sheets/34518_polyflex_type2.pdf
Washington	unknown
Wyoming	Material typs are AASHTO M324 Type I and IV WY Modified.

Discussions

Question 8 investigated the storage practices of states/provinces for the different crack maintenance materials. Figure 4.8 illustrates the response count of the states/provinces for the storage practices for the various crack maintenance materials.

As seen from the figure, for the cutback asphalt 12 respondents indicated that it not applicable for them (NA), 1 respondent indicated that it is stored outdoors, and another 1 respondent indicated that it is stored indoors with moderate exposure. Investigating a specific type of cutback asphalt (MC-3000), 13 respondents said NA, while 1 responded that it is stored indoors with moderate exposure.

For the asphalt emulsion, 12 respondents indicated (NA), 2 stored outdoors, 2 stored indoors with moderate exposure, and 2 stored indoors.

For the polymer modified liquid asphalt, 12 respondents responded that it not applicable (NA), 2 stored outdoors, and 2 stored indoors with moderate exposure.

For the asphalt cement application, 10 respondents indicated not applicable (NA), 2 stored indoors with moderate exposure, and 1 stored indoors.

For the fiberized asphalt, 10 respondents responded that it not applicable (NA), 2 stored indoors, and 1 stored indoors with moderate exposure.

For the asphalt rubber, 9 respondents indicated that it not applicable (NA), 4 stored indoors, and 4 stored indoors with moderate exposure.

With regards to the rubberized asphalt, 8 respondents indicated that it not applicable for them (NA), 4 respondents indicated that it is stored indoors, 4 respondents indicated that it is stored indoors with moderate exposure, and 2 respondents indicated that it is stored outdoors.

For the low modulus rubberized asphalt, 7 respondents answered NA, 3 stored indoors, 3 stored indoors with moderate exposure, and 1 respondent stored outdoors. For the Elastoflex 52, 12 respondents indicated that it not applicable for them (NA), and 2 respondents indicated that it is stored indoors with moderate exposure.

Regarding the polymer modified asphalt, 11 respondents responded that it not applicable (NA), 3 respondents stored indoors with moderate exposure, and 1 respondent stored indoors. For Elastoflex 71, 13 answered that it not applicable for them, 1 stored indoors with moderate exposure, and 1 stored indoors.

For self-leveling silicon, 14 respondents indicated that it not applicable for them (NA), and 1 respondent indicated that it is stored outdoors.

For the other technologies, 7 respondents indicated that it not applicable for them (NA), 6 respondent indicated that it is stored indoors, and 1 respondent indicated that it is stored outdoors.

4.9. Question 9-Organization-Scheduling of crack maintenance

Table 4. 9 Details of question 9

Q-9. How do you schedule the thermal cracking maintenance within the state/province?		
Objective To determine the primary and popular methods used to schedule thermal crack maintenance within each state/province, and across all surveyed states/provinces.		
Answer Options	**% (of Received Responses)**	**Response Count**
Question 9-Organization-Scheduling of crack maintenance On annual basis	31.0%	9
Condition of current sealant	3.4%	1
Cracking occurrence	34.5%	10
Manufacturer recommendation	0.0%	0
Other	17.2%	5
No schedule	13.8%	4
If other, specify		10
Total Received Responses		**29**
Skipped		**2**

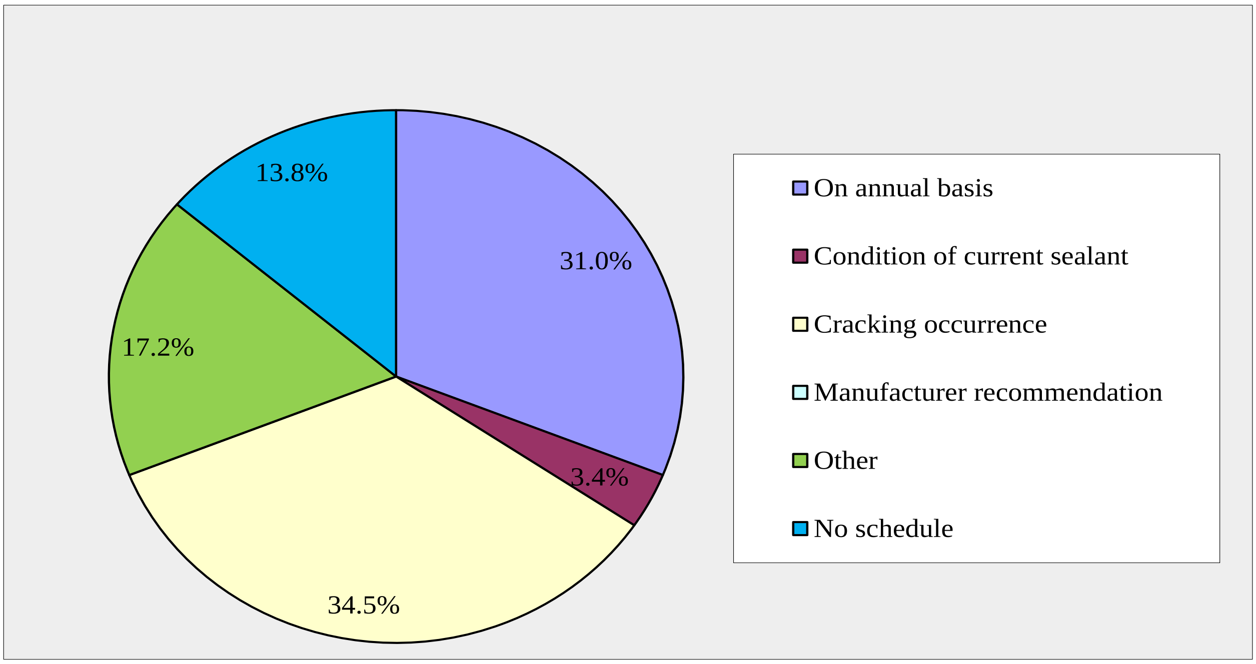

Figure 4. 9 Schedule of thermal cracking maintenance within the state/province.

Survey Details-Q-9.

State/Province	**Individual responses**				
Alberta				Other	
British Columbia			Cracking occurrence		
Colorado (First response)			Cracking occurrence		
Colorado (Second response)				Other	
Idaho	On annual basis				
Illinois			Cracking occurrence		
Iowa			Cracking occurrence		
Kansas			Cracking occurrence		
Manitoba (First response)	On annual basis				
Manitoba (Second response)					No schedule
Michigan			Cracking occurrence		
Minnesota				Other	
Missouri	On annual basis				
Montana			Cracking occurrence		
Nebraska				Other	
Nevada (First response)	On annual basis				
Nevada (Second response)			Cracking occurrence		
Nevada (Third response)	Skipped				
New Hampshire	On annual basis				
Ohio (First response)					No schedule
Ohio (Second response)					No schedule
Ontario	On annual basis				
Pennsylvania				Other	
Saskatchewan			Cracking occurrence		
South Dakota			Cracking occurrence		
Utah (First response)	On annual basis				
Utah (Second response)	On annual basis				
Utah (Third response)	Skipped				
Washington		Condition of current sealant			
Wisconsin					No schedule
Wyoming	On annual basis				

Survey Details-Q-9, continued

State/Province	If other, specify
Alberta	Cold pour done on a budget-limited basis - we'd love to schedule annual treatment but can't afford it, so we put our priority for each year's work on newer pavements or higher volume highways. Rout & Seal scheduled according to crack occurrence and condition, on newer pavements (normally less than 7 years old) on a funding-available basis - again, we've got more cracks than we have money to treat.
Colorado (Second response)	Each maintenance section schedules their crack sealing program annually.
Minnesota	Locals maintenance areas all do their own scheduling.
Montana	We do schedule on an annual basis and by condition as well but our primary method would be cranking occurrence
Nebraska	Periodic by time and condition
Ohio (Second response)	The survey uses thermal on only a few questions. Those questions that do not state "Thermal" were not answered w/r/t thermal
Pennsylvania	We use cycle maintenance on our high level bituminous pavements that are on a 5 year crack sealing cycle.
Utah (First response)	We evaluate the roads annually and determine the needs
Utah (Second response)	semiannual basis
Wyoming	Road sections are reviewed annually in each of our 5 districts and district wide projects are awarded each year to seal the roadways that have the greatest need.

Discussions

This question investigated the approach with which the states/provinces schedule the thermal crack maintenance. The options available for the states/provinces to choose from were on annual basis, condition of current sealant, cracking occurrence, manufacturer recommendation, other, and no schedule. This question was a single answer question and only one answer could be chosen. Figure 4.9 illustrates the response percentage for the states/provinces. As seen in Figure 4.9, 34.5% of the respondents stated that the thermal cracking maintenance scheduling is based on cracking occurrence, 31% stated that scheduling of thermal cracking maintenance is carried out annually, 17% other options for scheduling of thermal crack maintenance, 13.8% stated that there is no scheduling approach adopted, and 3.4% attributed the scheduling of thermal crack maintenance to the condition of current sealant.

4.10. Question 10-Specification-Methods of Development

Q-10a. How did the state/province develop the agency specification or approval procedure (select all that apply)?
Q-10.b. Please list the source (URL or document) of current agency specification if it is based on.

4.10.1. Question 10a-Specification- Sources of development of specification

Table 4. 10a Details of question 10a

Q-10a. How did the state/province develop the agency specification or approval procedure (select all that apply)?		
Objective To determine how states/provinces have developed current crack maintenance specifications or approval procedures.		
Answer Options	**% (of Received Responses)**	**Response Count**
Based on national studies/guidelines such as NCHRP	24.1%	7
Developed by your own state/province	82.8%	24
Based on other states/DOT experience	24.1%	7
Other	13.8%	4
Please provide a link for your agency's current specification or approval procedure in the box		14
Total Received Responses		**29**
Skipped		**2**

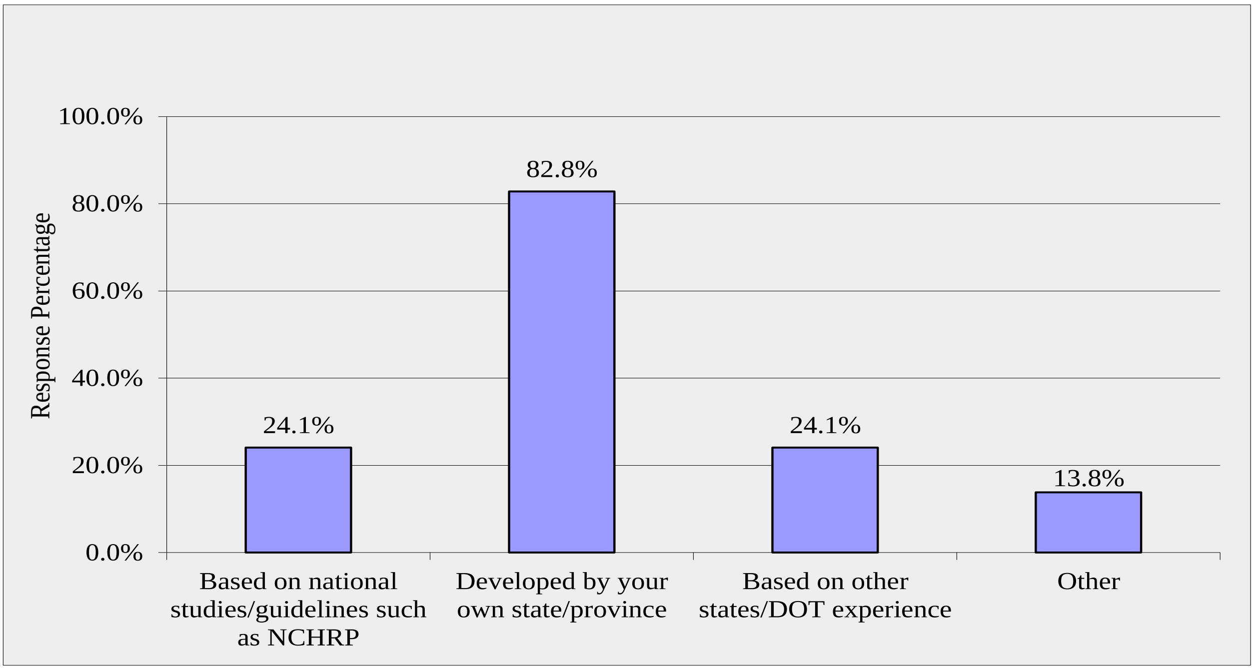

Figure 4. 10a Approach followed by the state/province to develop the agency specification or approval procedure.

Survey Details-Q-10a.

State/Province	Individual responses			
Alberta		Developed by your own state/province		
British Columbia		Developed by your own state/province		
Colorado (First response)		Developed by your own state/province		
Colorado (Second response)		Developed by your own state/province		
Idaho		Developed by your own state/province		
Illinois		Developed by your own state/province	Based on other states/DOT experience	
Iowa		Developed by your own state/province		
Kansas	Based on national studies/guidelines such as NCHRP	Developed by your own state/province	Based on other states/DOT experience	
Manitoba (First response)			Based on other states/DOT experience	
Manitoba (Second response)		Developed by your own state/province		Other
Michigan	Based on national studies/guidelines such as NCHRP	Developed by your own state/province		
Minnesota	Based on national studies/guidelines such as NCHRP	Developed by your own state/province	Based on other states/DOT experience	
Missouri		Developed by your own state/province		
Montana				Other
Nebraska	Based on national studies/guidelines such as NCHRP	Developed by your own state/province		
Nevada (First response)		Developed by your own state/province		
Nevada (Second response)		Developed by your own state/province		
Nevada (Third response)	Skipped			
New Hampshire		Developed by your own state/province		
Ohio (First response)		Developed by your own state/province		
Ohio (Second response)				Other

Survey Details-Q-10a, continued.

State/Province	Individual responses			
Ontario		Developed by your own state/province		
Pennsylvania		Developed by your own state/province		
Saskatchewan		Developed by your own state/province		
South Dakota	Based on national studies/guidelines such as NCHRP	Developed by your own state/province	Based on other states/DOT experience	
Utah (First response)	Based on national studies/guidelines such as NCHRP	Developed by your own state/province	Based on other states/DOT experience	
Utah (Second response)	Based on national studies/guidelines such as NCHRP		Based on other states/DOT experience	
Utah (Third response)	Skipped			
Washington		Developed by your own state/province		
Wisconsin				Other
Wyoming		Developed by your own state/province		

Survey Details-Q-10a, continued.

State/Province	Please provide a link for your agency's current specification or approval procedure in the box
Alberta	Specification 5.7 for supply of asphalt, including emulsions, in http://www.transportation.alberta.ca/Content/docType245/Production/2010_Highway_Construction.pdf For rout & seal, construction testing and material requirements found in http://www.transportation.alberta.ca/Content/docType245/Production/2010_Highway_Construction.pdf Approved products list for both cold pour and rout and seal materials found at: http://www.transportation.alberta.ca/Content/docType253/Production/ASPHALTMATERIALS.pdf
Colorado (First response)	http://www.coloradodot.info/business/apl
Colorado (Second response)	I will email
Manitoba (Second response)	ASTM and MIT testing.
Minnesota	http://www.dot.state.mn.us/products/index.html
Montana	Mostly AASHTO and ASTM standards and specifications
New Hampshire	http://www.nh.gov/dot/org/projectdevelopment/materials/research/products.htm http://www.nh.gov/dot/org/projectdevelopment/highwaydesign/specifications/documents/2010_Division_400.pdf Section 413 pertains to crack sealing
Ohio (First response)	http://www.dot.state.oh.us/Divisions/ConstructionMgt/OnlineDocs/Pages/ProposalNotesSupplementalSpecificationsandSupplements.aspx
Ohio (Second response)	Approval procedure for what? Are you asking about our acceptance criteria for a sealed crack? Our specs are older than me, and I have been here 28 years.
Ontario	attached with the e-mail.
Pennsylvania	http://www.dot.state.pa.us/Internet/Bureaus/pdDesign.nsf/ConstructionSpecs408and7?readForm
South Dakota	Each Region within the State chooses which roads within their Region need crack sealing.
Utah (First response)	Using past experience and performance we have evolved into the specification for UDOT
Wyoming	http://www.dot.state.wy.us/files/live/sites/wydot/files/shared/Construction/2010%20Standard%20Specifications/2010%20Standard%20Specifications.pdf Section 403 of Specifications covers crack sealing and also references the materials specification sections.

Discussions

Question 10a investigated the sources for development of crack maintenance specifications within states/provinces. The options available for the states/provinces to choose from were; based on national studies/guidelines such as NCHRP, developed by your own state/province, based on other states/DOT experience, and other. Figure 4.10a illustrates the response percentage for the states/provinces. As illustrated in Figure 4.10a, , 82.8% of respondents answered that their specifications were developed by their own state/province, 24.1% was chose based on either national studies/guidelines such as NCHRP or based on other states/DOT experiences, and 13.8% selected other sources.

4.10.2. Question 10b-Specification- Sources of current agency specification

Table 4. 10b Details of question 10b

Q-10b. Please list the source (URL or document) of current agency specification if it is based on:		
Objective To collect sources states/provinces have used to develop current specifications if the specifications are based on previously completed studies or experience.		
Answer Options	**% (of Received Responses)**	**Response Count**
National studies/guidelines	50.0%	2
Other states/DOT experience	75.0%	3
Total Received Responses		**4**
Skipped		**27**

Survey Details-Q-10b.

State/Province	**Individual responses**	
Manitoba (Second response)	ASTM	
Ohio (Second response)		http://www.dot.state.oh.us/Divisions/ConstructionMgt/OnlineDocs/Pages/ProposalNotesSupplementalSpecificationsand Supplements.aspx
Ontario	http://www.library.mto.gov.on.ca/webopac/zoomrecord.asp?recordkey=474acaed-8f38-4185-9fcf-c70fffd49ea7&TemplateGUID=26c8336a-34a4-4079-8514-5cf60c65e6eb&passport=ed8329ab-3dce-4ede-a893-7dbc05424c45&data_dictionary=8f50e9f0-c70a-43f7-91db-4a46daaf56a8&CommandQuery=+%28Title+%25+%27field+evaluation+of+rout+and+seal+crack+treatment+in+flexible+pavement%27+%29&SearchButton=Command&SearchTemplate=&page=1&RootTemplateGUID=f1273652-1c89-4feb-b4ed-aa5525c2792b&rpt_session_guid=&hpp=25&searchmode=basic&ParentTemplateGUID=&CurSortCol=&CurSort=0&LinkGUID=&mode=&hide=1 http://www.fcm.ca/Documents/reports/Infraguide/Guidelines_for_Sealing_and_Filing_Cracks_in_Asphalt_Concrete_Pavements_EN.pdf; mplate=&page=3&RootTemplateGUID=f1273652-1c89-4feb-b4ed-aa5525c2792b&rpt_session_guid=&hpp=10&searchmode=basic&ParentTemplateGUID=&CurSortCol=&CurSort=0&LinkGUID=&mode=	http://archive.nrc-cnrc.gc.ca/obj/irc/doc/pubs/nrcc41098/nrcc41098.pdf
Utah (First response)		Western states such as Colorado, Wyoming, Nevada

4.11. Question 11-Practices-Type of Crack Maintenance Work assignment

Table 4. 11 Details of question 11

Q-11. Does the state/province use in-house or contracted work for maintenance of thermal cracking (select all that apply)?		
Objective To determine if the most common way for performing crack maintenance work is contracted, done by state/province personnel, or both.		
Answer Options	**% (of Received Responses)**	**Response Count**
In house only	14.8%	4
Contractor only	18.5%	5
In house and contractor	66.7%	18
Comments		10
Total Received Responses		**27**
Skipped		**4**

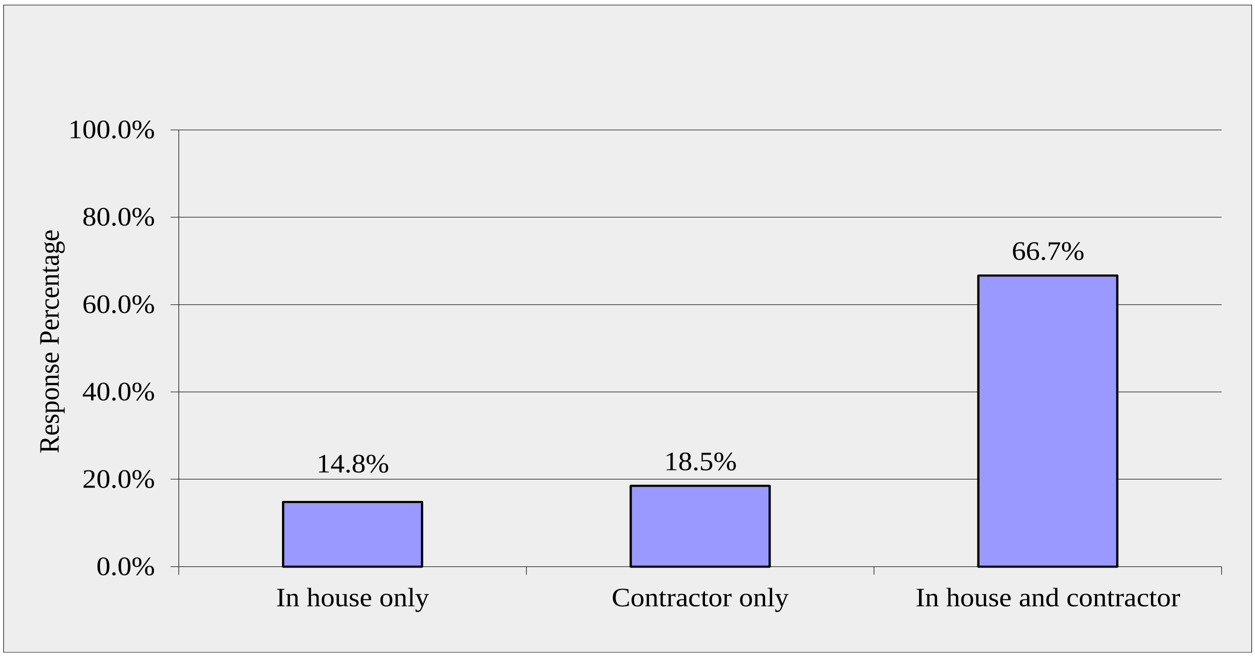

Figure 4. 11 Utilization of in-house or contracted work for maintenance of thermal cracking in state/province.

Survey Details-Q-11.

State/Province	Individual responses	
Alberta		Contractor
British Columbia		Contractor
Colorado (First response)	In house	Contractor
Colorado (Second response)	In house	Contractor
Idaho	In house	
Illinois	Skipped	
Iowa	In house	Contractor
Kansas	In house	Contractor
Manitoba (First response)	In house	
Manitoba (Second response)	Skipped	
Michigan	In house	Contractor
Minnesota	In house	Contractor
Missouri	In house	Contractor
Montana	In house	Contractor
Nebraska	In house	Contractor
Nevada (First response)	In house	
Nevada (Second response)	In house	
Nevada (Third response)	Skipped	
New Hampshire	In house	Contractor
Ohio (First response)		Contractor
Ohio (Second response)	In house	Contractor
Ontario		Contractor
Pennsylvania	In house	Contractor
Saskatchewan	In house	Contractor
South Dakota	In house	Contractor
Utah (First response)	In house	Contractor
Utah (Second response)	In house	Contractor
Utah (Third response)	Skipped	
Washington	In house	Contractor
Wisconsin		Contractor
Wyoming	In house	Contractor

Survey Details-Q-11, continued.

State/Province	Comments
Alberta	All highway maintenance work in Alberta done under contract.
Minnesota	Both.
Nebraska	Mostly in house
Ohio (First response)	For problematic thermal cracks we would suggest a 6 ft wide mill (crack centered), 4" deep, with a leveling course at the bottom, a geogrid/fabric of some sort, and new asphalt up to the surface. We have used this once and it worked well.
Pennsylvania	PennDOT uses both in house and contracted work
South Dakota	The State uses both, but utilizes as much State Maintenance as possible depending on their workload.
Utah (First response)	Mostly in-house.
Utah (Second response)	mix of both in house and contract
Washington	Both
Wyoming	Most work is done by district wide annual contracts awarded to private contractors. Our district Maintenance personnel still do some sealing in house.

Discussions

This question investigated the states/provinces' utilization of in-house and/or contractor for the work of thermal cracking maintenance. As can be seen from Figure 4.11, 66.7% of the respondents selected both in-house and contractor for the thermal cracking maintenance work, 18.3% selected contractor only, whereas 14.8% selected in-house only.

4.12. Question 12-Practices-Assessing of Crack Frequency

Table 4. 12 Details of question 12

Q-12. What methods are used to assess the severity/frequency of thermal cracking (select all that apply)?		
Objective To determine the most common methods of assessing crack occurrence (severity/frequency) across surveyed states/provinces.		
Answer Options	**% (of Received Responses)**	**Response Count**
Field assessment	96.0%	24
Scheduled maintenance	24.0%	6
Testing in the fields	8.0%	2
Other	16.0%	4
If other, specify		9
Total Received Responses		**25**
Skipped		**6**

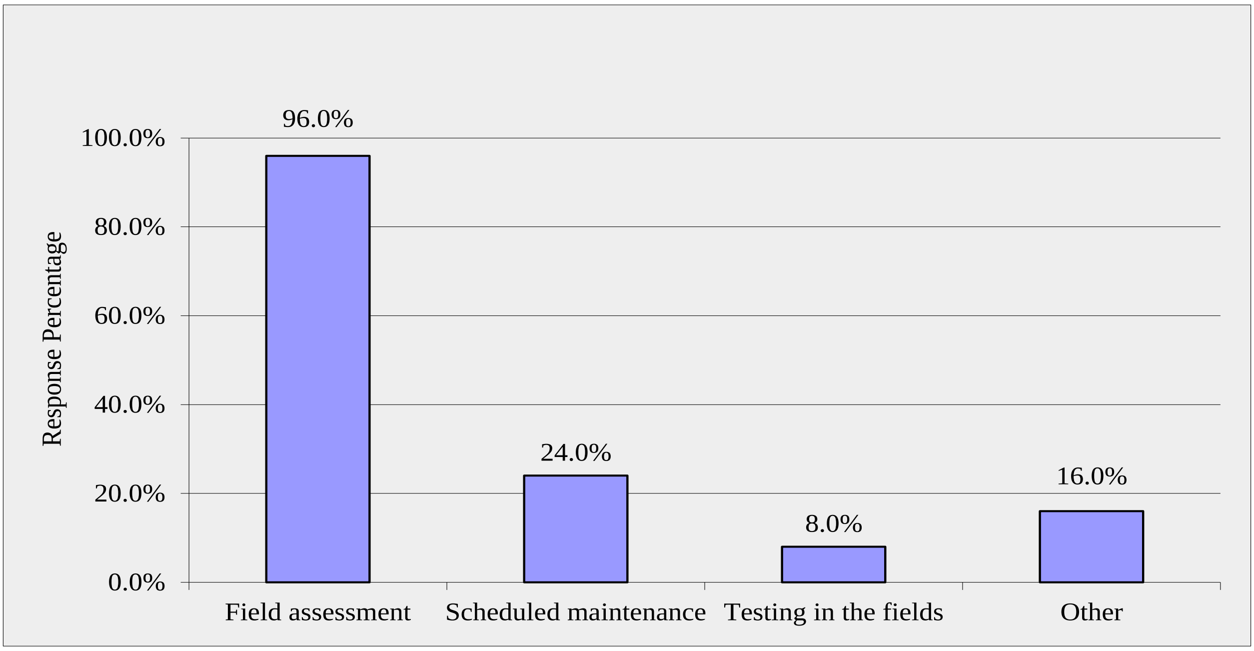

Figure 4. 12 Methods used to assess the severity/frequency of thermal cracking within state/province.

Survey Details-Q-12.

State/Province	Individual responses			
Alberta	Field assessment			
British Columbia	Field assessment			
Colorado (First response)	Field assessment	Scheduled maintenance		
Colorado (Second response)	Field assessment			
Idaho	Field assessment			
Illinois	Skipped			
Iowa	Field assessment			
Kansas	Field assessment			
Manitoba (First response)	Field assessment			
Manitoba (Second response)	Skipped			
Michigan	Field assessment			
Minnesota	Skipped			
Missouri	Field assessment			
Montana	Field assessment			
Nebraska	Field assessment	Scheduled maintenance		
Nevada (First response)	Field assessment			
Nevada (Second response)	Field assessment	Scheduled maintenance		
Nevada (Third response)	Skipped			
New Hampshire	Field assessment			Other
Ohio (First response)				Other
Ohio (Second response)	Skipped			
Ontario	Field assessment	Scheduled maintenance		
Pennsylvania	Field assessment	Scheduled maintenance		
Saskatchewan	Field assessment	Scheduled maintenance	Testing in the fields	
South Dakota	Field assessment			
Utah (First response)	Field assessment			Other
Utah (Second response)	Field assessment			
Utah (Third response)	Skipped			
Washington	Field assessment			
Wisconsin	Field assessment		Testing in the fields	
Wyoming	Field assessment			Other

Survey Details-Q-12, continued.

State/Province	If other, specify
Alberta	Cracking of ACP measured & recorded using our in-house Surface Condition Rating system, which is available on-line at http://www.transportation.alberta.ca/documents/Appendix_2.pdf
Minnesota	I do not understand the question.
New Hampshire	Annual pavement condition survey performed by van
Ohio (First response)	None
Pennsylvania	PennDOT utilizes scheduled maintenance but always conducts a field assessment prior to scheduling work.
Utah (First response)	Annual automated pavement condition survey
Utah (Second response)	semi annual inspection
Washington	Condition surveys
Wyoming	Roadway are run every two years with pathview van and roadway cracking conditions are recorded and analyzed by Materials Program. Districts use this information along with visual field assessments.

Discussions

This question focuses on of the methods utilized by states/provinces to assess the severity/frequency of thermal cracking. The options available for the states/provinces to choose from were; field assessment, scheduled maintenance, testing in the fields, and other methods. This question was a multiple-answer question, and more than one answer could be selected. As can be seen from Figure 4.12 field assessment was selected by 96% of the states/provinces respondents, scheduled maintenance by 24%, Other methods of assessing by 16%, and testing in the fields by 8% of the respondents.

4.13. Question 13-Quality Assurance-Verification

Table 4. 13 Details of question 13

Q-13. For quality assurance verifications, which of the following does the state/province apply (select all that apply)?		
Objective To determine the primary methods used by each state/province for quality assurance assessments of crack maintenance materials.		
Answer Options	**% (of Received Responses)**	**Response Count**
Visual field testing	96.0%	24
Laboratory Assessment	44.0%	11
Comments		5
Total Received Responses		**25**
Skipped		**6**

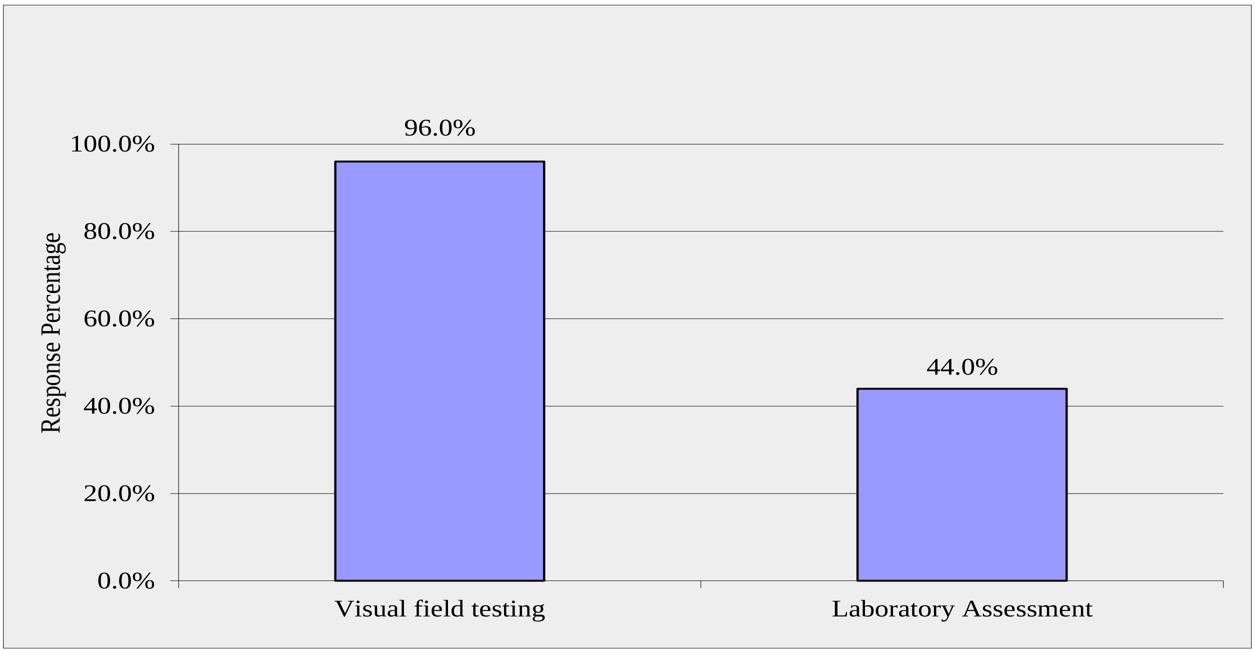

Figure 4. 13 Quality assurance verifications methods utilized within state/province.

Survey Details-Q-13.

State/Province	Individual responses	
Alberta	Visual field testing	
British Columbia	Visual field testing	
Colorado (First response)	Visual field testing	Laboratory Assessment
Colorado (Second response)	Visual field testing	Laboratory Assessment
Idaho	Visual field testing	
Illinois	Skipped	
Iowa	Visual field testing	
Kansas	Visual field testing	Laboratory Assessment
Manitoba (First response)	Visual field testing	
Manitoba (Second response)	Skipped	
Michigan	Visual field testing	
Minnesota	Visual field testing	Laboratory Assessment
Missouri	Visual field testing	
Montana	Visual field testing	Laboratory Assessment
Nebraska	Visual field testing	Laboratory Assessment
Nevada (First response)	Visual field testing	
Nevada (Second response)	Visual field testing	
Nevada (Third response)	Skipped	
New Hampshire	Visual field testing	Laboratory Assessment
Ohio (First response)	Skipped	
Ohio (Second response)	Skipped	
Ontario	Visual field testing	Laboratory Assessment
Pennsylvania	Visual field testing	Laboratory Assessment
Saskatchewan	Visual field testing	Laboratory Assessment
South Dakota	Visual field testing	
Utah (First response)	Visual field testing	
Utah (Second response)	Visual field testing	
Utah (Third response)	Skipped	
Washington	Visual field testing	
Wisconsin	Visual field testing	
Wyoming		Laboratory Assessment

Survey Details-Q-13, continued.

State/Province	Comments
British Columbia	BC has a Recognized Products List for the actual material. We visual the workmanship.
Minnesota	Contracts follow construction procedures. Maintenance follows their system.
Ontario	Lab assessment not done on every contract. QA lab testing is very limited and only done on selected jobs.
Pennsylvania	Laboratory testing is conducted on the materials. Visual QA assessments are conducted on the work performed.
Washington	Typically accepted based on manufacturers cert.

Discussions

This question investigates the quality assurance verifications that are utilized within the states/provinces. The options available for the states/provinces to choose from were either; visual field testing or laboratory assessments. This question was a multiple-answer question. Figure 4.13 illustrates the response percentage of the state/province respondents. As seen from Figure 4.13, 96% of the respondents from the states/provinces chose visual field testing, while only 44% of the respondents selected laboratory assessment.

4.14. Question 14-Performance-Field Data

Table 4. 14 Details of question 14

Q-14. Please list the source of available field performance data (URL or document) for the following crack maintenance materials. Please email or attach any available documents.		
Objective To collect examples of data collected of crack maintenance material performance in the field, if applicable.		
Answer Options	**% (of Received Responses)**	**Response Count**
Cutback Asphalt	33.3%	2
MC-3000 (medium-cure cutback)	33.3%	2
Asphalt Emulsion	33.3%	2
Polymer-Modified Liquid Asphalt	33.3%	2
Asphalt Cement Application	33.3%	2
Fiberized Asphalt	33.3%	2
Asphalt Rubber	33.3%	2
Rubberized Asphalt	50.0%	3
Low-Modulus Rubberized Asphalt	50.0%	3
Elastoflex 52 (crumb rubber)	33.3%	2
Polymer-Modified Asphalt	33.3%	2
Elastoflex 71 (polymer sealant)	33.3%	2
Self-Leveling Silicone	33.3%	2
Other	50.0%	3
Total Received Responses		**6**
Skipped		**25**

Survey Details-Q-14.

State/Province	Asphalt Rubber	Rubberized Asphalt	Low-Modulus Rubberized Asphalt	Other
Kansas				none available
Montana				all crack sealant must meet ASTM D5249 Type one
Ontario		http://www.library.mto.gov.on.ca/webopac/zoomrecord.asp?recordkey=474acaed-8f38-4185-9fcf-c70fffd49ea7&TemplateGUID=26c8336a-34a4-4079-8514-5cf60c65e6eb&passport=ed8329ab-3dce-4ede-a893-7dbc05424c45&data_dictionary=8f50e9f0-c70a-43f7-91db-4a46daaf56a8&CommandQuery=+%28Title+%25+%27field+evaluation+of+rout+and+seal+crack+treatment+in+flexible+pavement%27+%29&SearchButton=Command&SearchTemplate=&page=1&RootTemplateGUID=f1273652-1c89-4feb-b4ed-aa5525c2792b&rpt_session_guid=&hpp=25&searchmode=basic&ParentTemplateGUID=&CurSortCol=&CurSort=0&LinkGUID=&mode=&hide=1	http://www.library.mto.gov.on.ca/webopac/zoomrecord.asp?recordkey=474acaed-8f38-4185-9fcf-c70fffd49ea7&TemplateGUID=26c8336a-34a4-4079-8514-5cf60c65e6eb&passport=ed8329ab-3dce-4ede-a893-7dbc05424c45&data_dictionary=8f50e9f0-c70a-43f7-91db-4a46daaf56a8&CommandQuery=+%28Title+%25+%27field+evaluation+of+rout+and+seal+crack+treatment+in+flexible+pavement%27+%29&SearchButton=Command&SearchTemplate=&page=1&RootTemplateGUID=f1273652-1c89-4feb-b4ed-aa5525c2792b&rpt_session_guid=&hpp=25&searchmode=basic&ParentTemplateGUID=&CurSortCol=&CurSort=0&LinkGUID=&mode=&hide=1	
South Dakota	none	none	none	
Utah (Second response)	1 to 3 yrs	1 to 3 yrs	1 to 3 yrs	
Wyoming				http://www.dot.state.wy.us/files/live/sites/wydot/files/shared/Construction/2010%20Standard%20Specifications/2010%20Standard%20Specifications.pdf

Discussions

Only 6 states/provinces provided some sources that are illustrated in the table.

4.15. Question 15-Performance-Non Permittance criteria

Table 4. 15 Details of question 15

Q-15. Please select reasons of why the following crack maintenance materials were not permitted as applicable (select all that apply).						
Objective To determine reasons why states/provinces have disallowed use of crack maintenance material types or specific materials.						
Answer Options	**Literature review**	**Other DOT experience**	**Previous experience**	**Never been used**	**Other**	**Response Count**
Cutback Asphalt	2	1	5	9	2	16
MC-3000 (medium-cure cutback)	1	1	5	9	2	16
Asphalt Emulsion	0	0	0	10	1	11
Polymer-Modified Liquid Asphalt	0	0	0	12	0	12
Asphalt Cement Application	0	0	3	11	0	14
Fiberized Asphalt	1	1	2	10	0	12
Asphalt Rubber	1	1	3	6	0	9
Rubberized Asphalt	0	0	0	5	0	5
Low-Modulus Rubberized Asphalt	0	0	1	7	0	8
Elastoflex 52 (crumb rubber)	0	0	1	12	1	13
Polymer-Modified Asphalt	0	0	1	9	0	10
Elastoflex 71 (polymer sealant)	0	0	0	12	1	12
Self-Leveling Silicone	1	1	1	13	0	14
Other	1	0	0	4	0	5
If other, specify						6
Total Received Responses						**16**
Skipped						**15**

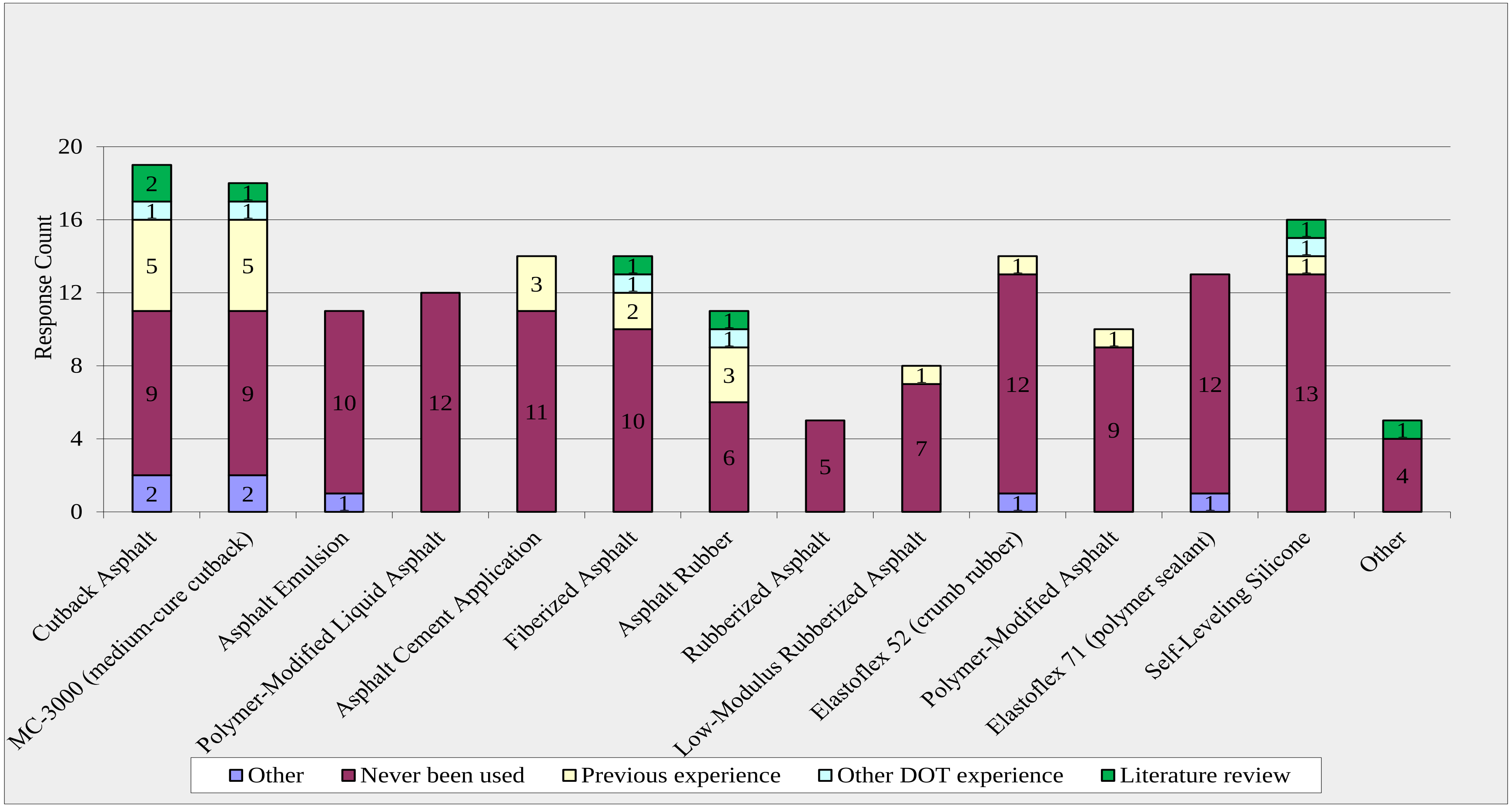

Figure 4. 15 Reasons of why certain crack maintenance materials were not permitted as applicable**.**

Survey Details-Q-15.

State/Province	Cutback Asphalt	MC-3000 (medium-cure cutback)	Asphalt Emulsion	Polymer-Modified Liquid Asphalt	Asphalt Cement Application	Fiberized Asphalt
Alberta	Never used	Never used		Never used	Never used	Never used
British Columbia	Other	Other				
Colorado First	Skipped					
Colorado Second	Skipped					
Idaho	Skipped					
Illinois	Skipped					
Iowa	Never used	Never used	Never used		Never used	Never used
Kansas	Previous experience	Previous experience	Never used	Never used		Literature review-Other DOT experience-Previous experience
Manitoba First	Literature review-Previous experience	Previous experience	Never used	Never used	Previous experience	Never used
Manitoba Second	Skipped					
Michigan	Never used	Never used	Never used	Never used	Previous experience	Previous experience
Minnesota	Other	Other	Other		Never used	
Missouri	Skipped					
Montana	Skipped					
Nebraska	Previous experience	Previous experience		Never used	Previous experience	Never used
Nevada First	Skipped					
Nevada Second	Skipped					
Nevada Third	Skipped					
New Hampshire	Never used	Never used	Never used	Never used	Never used	
Ohio First	Skipped					
Ohio Second	Skipped					
Ontario	Literature review-Other DOT experience-Never used	Literature review-Other DOT experience-Never used	Never used	Never used	Never used	Never used
Pennsylvania	Never used	Never used	Never used	Never used	Never used	Never used
Saskatchewan	Previous experience	Previous experience			Never used	
South Dakota	Never used	Never used	Never used	Never used	Never used	Never used
Utah First	Previous experience	Previous experience	Never used	Never used	Never used	Never used
Utah Second	Skipped					
Utah Third	Skipped					
Washington	Never used	Never used		Never used	Never used	Never used
Wisconsin	Skipped					
Wyoming	Never used	Never used	Never used	Never used	Never used	Never used

Survey Details-Q-15, continued.

State/Province	Asphalt Rubber	Rubberized Asphalt	Low-Modulus Rubberized Asphalt	Elastoflex 52 (crumb rubber)	Polymer-Modified Asphalt	Elastoflex 71 (polymer sealant)	Self-Leveling Silicone	Other
Alberta	Previous experience		Never used	Previous experience	Never used	Never been used	Never been used	
British Columbia								Literature review
Colorado First	Skipped							
Colorado Second	Skipped							
Idaho	Skipped							
Illinois	Skipped							
Iowa	Never used	Never used	Never used	Never used		Never been used	Never been used	Never been used
Kansas	Literature review-Other DOT experience-Previous experience	Never used	Never used	Never used	Never used	Never been used	Never been used	Never been used
Manitoba First	Never used	Never used	Previous experience	Never used	Never used	Never been used	Never been used	Never been used
Manitoba Second	Skipped							
Michigan				Never used	Previous experience	Never been used	Never been used	
Minnesota								
Missouri	Skipped							
Montana	Skipped							
Nebraska				Never used-Other		Never been used-Other	Previous experience	
Nevada First	Skipped							
Nevada Second	Skipped							
Nevada Third	Skipped							
New Hampshire				Never used	Never used	Never been used	Never been used	
Ohio First	Skipped							
Ohio Second	Skipped							
Ontario	Never used			Never used	Never used	Never been used	Literature review-Other DOT experience-Never been used	
Pennsylvania	Never used		Never used	Never used	Never used	Never been used	Never been used	
Saskatchewan				Never used			Never been used	
South Dakota	Previous experience	Never used					Never been used	
Utah First			Never used	Never used	Never used	Never been used	Never been used	
Utah Second	Skipped							
Utah Third	Skipped							
Washington	Never used		Never used	Never used	Never used	Never been used	Never been used	Never been used
Wisconsin	Skipped							
Wyoming	Never used	Never used	Never used	Never used	Never used	Never been used	Never been used	

Survey Details-Q-15, continued.

State/Province	If other, specify
British Columbia	Any new product is literature searched and if approved will undergo a performance trial before making it on to the Recognized Product List. Because of the sixe of the province, elevation changes and the different climate zones we tend to use certain products in different areas.
Colorado (First response)	Those used are on our Approved Products List, and meet ASTM 6690 & AASHTO M 324
Colorado (Second response)	I do not know.
Nebraska	Not familiar with product
Saskatchewan	Comment: Cutback Asphalt is not used because of the high VOC emissions.
Wyoming	Please contact Bruce Morgenstern from our Materials Program if you have specific questions on materials specifications. Bruce can be contacted by e-mail at bruce.morgenstern@wyo.gov .

Discussions

This question investigated the reasons behind the not permitting certain crack sealing products within a state/province. Figure 4.15 illustrates the response count of the states/provinces for reasons why various crack maintenance materials are non-permitted.

As can be seen from Figure 4.15, for the cutback asphalt; 9 respondents indicated that it has never been used before, 5 indicated that they had previous experience with it, 2 indicated that this was based on literature review, 2 attributed non-permittance to other reasons, and 1 respondent attributed the non permittance to experience of other DOTs. Investigating a specific type of cutback asphalt (MC-3000), 9 respondents indicated that it has never been used before, 5 had previous experience with it, 2 to other reasons, 1 based on literature review, and 1 based on other DOT experience.

For the asphalt emulsion, 10 respondents indicated that it has never been used before, and 1 attributed the non permittance to other reasons.

For the polymer modified liquid asphalt, 12 respondents answered that it has never been used before.

For the asphalt cement application, 11 respondents indicated that it has never been used before, and 3 respondent previous experience.

For the fiberized asphalt, 10 respondents indicated that it has never been used before, 2 indicated previous experience, 1 based on literature review, and 1 based on other DOT experience.

For the asphalt rubber, 6 respondents answered that it has never been used before, 3 had previous experience, 1 based on literature review, and 1 respondent attributed non permittance to other DOT experience.

With regards to rubberized asphalt, 5 respondents indicated that it has never been used before.

For the low modulus rubberized asphalt, 7 respondents answered that it has never been used before, whereas 1 respondent indicated previous experience with it. For the

Elastoflex 52, 12 respondents indicated that it has never been used before, 1 respondent had previous experience, and 1 attributed non permittance to other reasons.

Regarding the polymer modified asphalt, 9 respondents answered that it has never been used before and 1 indicated previous experience with it. For Elastoflex 71, 12 respondents indicated that it has never been used before, whereas 1 respondent indicated other reasons.

For self-leveling silicon, 13 respondents indicated that it has never been used before, 1 had previous experience, 1 indicated that this was based on literature review, and 1 was based to other DOT experience.

For the other technologies, 4 respondents indicated that it has never been used before and 1 respondent attributed the non permittance to literature review.

The terminology for crack sealing and crack filling is not uniformly agreed in terms of the literature and across states/provinces surveyed. The literature definition of these terms is featured in section 1.1 of this report, with the primary difference being the maintenance approach of working and non-working cracks (further defined in Chapter 2). The in- field practice was established through an overview of the specifications, follow-up questions, and a second round of follow-up questions for select states. The terminology is often not distinguished, or used interchangeably as shown in 6 of the 8 responses of the second set of follow-ups. Generally, states/provinces that have separate criteria for sealing and filling use the crack size as the differentiating factor. Larger cracks are filled with the treatments material after cleaning the existing crack. Smaller cracks are subjected to routing/sawing and cleaning before being sealed to a finishing configuration. This was supported by the 2 remaining selected surveyed states, as well as the terminology used in the state/province specifications. The responses of second round follow-up questions for the selected states are provided in Table 4.18.

4.16. Survey Details Follow-Up Questions

Table 4.16 illustrates the responses of states/provinces follow-up general questions. This included three questions; the first question was dealing with the definitions of seal and fill of cracks. Another question inquired about the actual percentage of asphalt pavements that are regularly maintained within the states/provinces. The last question was about the procedures for quality assurance within the states/provinces.

Table 4. 16 Survey details-follow-up general questions

State/Province/Organization	1. Do you agree with the definition of the following activities that describe the thermal cracking maintenance program in your state/province?				2. Of the actual asphalt pavement sections with thermal cracking in your state/province, what percentage is regularly maintained?	3. For quality assurance purposes, which of the following does your state/province apply (select all that apply)?
	a. Seal of individual cracks: Placement of specialized treatment materials above or into routed/sawed and cleaned working crack.	b. Fill of individual cracks: Placement of ordinary treatment materials into cleaned non-working cracks.	c. Overband: Placement of material into and over a crack channel.	d. Seal coat: Treatment of large areas of cracks with material asphaltic slurry.		
Alberta	Agree	Do not agree	Agree	Do not agree	Less than 40% (of total sections with thermal cracks)	Visual field inspection on treated cracks after application
British Columbia	Do not agree, please describe activity	Agree	Agree	Agree	40-80% (of total sections with thermal cracks)	Visual field inspection on treated cracks after application
Colorado	**NA**					
Illinois	Agree	Agree		Agree		
Iowa	Agree	Agree	Agree	Do not agree	40-80% (of total sections with thermal cracks)	Visual field inspection on treated cracks after application
Kansas	Agree	Agree	Agree	Agree	40-80% (of total sections with thermal cracks)	Lab assessment on materials prior to application, Visual field inspection on treated cracks after application
Manitoba	**NA**					
Michigan	Agree	Agree	Agree	Agree	More than 80% (of total sections with thermal cracks)	Visual field inspection on treated cracks after application
Minnesota	Agree	Agree	Agree	Do not agree	Skipped	Lab assessment on materials prior to application, Visual field inspection on treated cracks after application
Missouri	**NA**					

Survey details-follow-up questions, continued

State/Province/Organization	1. Do you agree with the definition of the following activities that describe the thermal cracking maintenance program in your state/province?				2. Of the actual asphalt pavement sections with thermal cracking in your state/province, what percentage is regularly maintained?	3. For quality assurance purposes, which of the following does your state/province apply (select all that apply)?
	a. Seal of individual cracks: Placement of specialized treatment materials above or into routed/sawed and cleaned working crack.	b. Fill of individual cracks: Placement of ordinary treatment materials into cleaned non-working cracks.	c. Overband: Placement of material into and over a crack channel.	d. Seal coat: Treatment of large areas of cracks with material asphaltic slurry.		
Montana	Agree	Do not agree	Agree	Agree	40-80% (of total sections with thermal cracks)	Lab assessment on materials prior to application, Visual field inspection on treated cracks after application
Nebraska	**NA**					
Nevada	Agree	Agree	Agree	Do not agree	Less than 40% (of total sections with thermal cracks)	Visual field inspection on treated cracks after application, No lab testing or verification assessments is performed
New Hampshire	Agree	Agree	Agree	Do not agree	Less than 40% (of total sections with thermal cracks)	Lab assessment on materials prior to application, Visual field inspection on treated cracks after application
New York	**NA**					
Ohio	Do not agree	Agree	Agree	Agree	Less than 40% (of total sections with thermal cracks)	Lab assessment on materials prior to application
Ontario	Do not agree	Do not agree	Do not agree	Agree		Visual field inspection on treated cracks after application
Oregon	**NA**					
Pennsylvania	Agree	Agree	Agree	Do not agree	More than 80% (of total sections with thermal cracks)	Lab assessment on materials prior to application, Visual field inspection on treated cracks after application, Field testing on treated cracks after application

Survey details-follow-up questions, continued

State/Province/Organization	1. Do you agree with the definition of the following activities that describe the thermal cracking maintenance program in your state/province?				2. Of the actual asphalt pavement sections with thermal cracking in your state/province, what percentage is regularly maintained?	3. For quality assurance purposes, which of the following does your state/province apply (select all that apply)?
	a. Seal of individual cracks: Placement of specialized treatment materials above or into routed/sawed and cleaned working crack.	b. Fill of individual cracks: Placement of ordinary treatment materials into cleaned non-working cracks.	c. Overband: Placement of material into and over a crack channel.	d. Seal coat: Treatment of large areas of cracks with material asphaltic slurry.		
Saskatchewan	Agree	Agree	Agree	Agree	40-80% (of total sections with thermal cracks)	Lab assessment on materials prior to application, Visual field inspection on treated cracks after application, Field testing on treated cracks after application
South Dakota	Agree	Agree	Agree	Agree	Less than 40% (of total sections with thermal cracks)	Visual field inspection on treated cracks after application
Utah	Agree	Agree	Agree	Do not agree	More than 80% (of total sections with thermal cracks)	Lab assessment on materials prior to application, Visual field inspection on treated cracks after application
Vermont	**NA**					
Washington	Agree	Agree	Agree	Agree	Less than 40% (of total sections with thermal cracks)	Visual field inspection on treated cracks after application
Wisconsin	Agree	Agree	Agree	Agree	Less than 40% (of total sections with thermal cracks)	Lab assessment on materials prior to application, Visual field inspection on treated cracks after application, No lab testing or verification assessments is performed
Wyoming	Agree	Do not agree	Agree	Agree	40-80% (of total sections with thermal cracks)	Lab assessment on materials prior to application, Visual field inspection on treated cracks after application

4.17. Survey Details-Follow-Up-Specific States/Provinces Questions

Table 4.17 illustrates the responses of selected states/provinces follow-up general questions. This was oriented towards the follow-up of the selected states/provinces responses on the main survey, in order to further investigate the states/provinces crack maintenance procedures.

Table 4. 17 Survey details-follow-up-specific states/provinces questions

State/Province/Organization	Questions	Responses
Alberta	In Question 5 of our survey, "What is the expected life of crack maintenance materials used in the state/province?" you responded "3-5 years and "other," with added the following comments, "We do not obtain information on the type of cracks that are sealed (i.e., thermal or fatigue)." Since cracks are not individually categorized, is the 3-5 years an estimate based on Alberta's experience, manufacturer claims, or another agency's practice?	No, it is our experience with the service life of rubberized asphalt sealant used in routed cracks (both thermal and fatigue, although we don't use rout & seal treatment on areas of block cracking), But we're getting the same service life from the treatment, since the thermal expansion of cracks is essentially the same whether the crack was originally caused by thermal stresses or pavement fatigue.
	In Question 6 of our survey, "What are the preparation methods for crack maintenance in your state/province (select all that apply)?" you responded "other," and added the following comments, "For ACP, cold pour normally doesn't get any preparation. Rout & Seal we allow both hot air lance and compressed air; we haven't seen any difference in initial quality of work or long-term performance." Can you elaborate on your statement? Does Alberta have the option for routing, sawing, hot-air lance, and compressed air; but none of them are required?	For rout & seal treatment, the contractor doing the work is allowed to choose whether to use no treatment, a hot lance or compressed air - the warranty period is the same, so we don't care how the contractor does the work as long as it performs the same. We require routing of all treated cracks with our rout & seal treatments in ACP pavements. We have very little PCC pavement, so sawing isn't really an option.
British Columbia	How are materials on the "recognized Products List" for BC determined/permitted (experience, literature review, guidelines of other states/provinces, national/international studies, etc…)?	Rubberized and elasticized crack sealants - twenty seven (27) and Asphalt Crack Filler Sealent two (2) (HF 150P and CRF)
Colorado	NA	
Illinois	Why is polymer-modified asphalt and polymer modified liquid asphalt the preferred technology over asphalt emulsions?	**Skipped**
Iowa	NA	
Kansas	In Question 6 of our survey, "What are the preparation methods for crack maintenance in your state/province (select all that apply)?" you responded "other," and added the following comments, "if no hot air lance, dry clean compressed air." Can you elaborate on acceptance of projects using compressed air compared to hot air lance?	When we seal, hot air lances are required. If, for some reason the hot air lance were not functioning or not lit (it has been known to happen, they better have a drier on the air line.
	What previous experience/other DOT experience made you decide not to use fiberized asphalt and asphalt rubber for crack sealing?	We had an issue with the polypropylene fibers having a lower melting point than the temperature we were heating the sealant to. We may try other fiber types, but are not currently.
Manitoba	**NA**	
Michigan	You responded that over 60% of your asphalt roads experience thermal cracking and require maintenance. What is the reason for continual maintenance (poor materials, heavy traffic, poor application, roads maintained section by section, etc…)?	5.Why is Fiberized Asphalt no longer used in Michigan?
	Roads maintained section by section	This is toO stiff of a product for our climate.
Minnesota	In Question 5 of our survey, "What is the expected life of crack maintenance materials used in the state/province?" you responded "other," and added the following comments, "Depends if the cracked or filled or sealed." To Mn/Dot what materials and practices are considered "fills" and what are considered "seals?" What are the expected lives of each of the processes?	I do not know the answer to question 2. If a crack is routed, I think it can be sealed. I the carck is cleaned and filled, I do not think it is sealed. Also, Each MnDOT District probably does things slightly different.
	Can you describe the differences in your crack maintenance practices that allow for both summer and winter applications (such as material differences, preparation, is practice based on need/emergency, etc…)?	MOst summer work is probably through let contracts. MnDOT maintenance forces do some crack maintenance in the winter, when the pavement is clean and dry.
Missouri	**NA**	

Survey details-follow-up-specific states/provinces questions, continued

State/Province/Organization	Questions	Responses
Montana	In Question 5 of our survey, "What is the expected life of crack maintenance materials used in the state/province?" you responded "other," and added the following comments, "We try to get 7-10 years" What type of material, operations, and/or factors allow you to extend the crack sealing life up to 5 to 7 years?	We chip seal over the top of the crack seal which greatly extends the life of the crack
	In Question 14 of our survey, "Please list the source of available field performance data (URL or document) for the following crack maintenance materials. Please email or attach any available documents." you responded "other," and added the following comments, "all crack sealant must meet ASTM D5249 Type one." Is there any field data available? Has there been any need for studies since adopting the ASTM D5249 Type One criteria for sealants?	None
Nebraska	**NA**	
Nevada	What preparation is needed prior to the use of the hot air lance?	Work will not be performed unless the pavement is dry; no frost, snow, ice or standing water may be present. The crack may be cut or routed to form a reservoir.
New Hampshire	In Question 12 of our survey, "What methods are used to assess the severity/frequency of thermal cracking (select all that apply)?" you responded "other," and added the following comments, "Annual pavement condition survey performed by van." What equipment or procedures are used to collect and analyze cracks from the van survey?	Our data collection vehicle (van) collects pavement images that are then rated by the van vendor and Quality controlled "QC'd" by our staff. Transverse cracks are rated from the images as either sealed or not sealed. This information is aggregated and reported on 0.1-mile intervals and is used to calculate a transverse cracking index (0-5 scale). The 0-5 scale represents a frequency of thermal cracks (crack count) which provides a sense of the severity and extents of the cracking and which treatments should be considered.
	The survey response indicated New Hampshire uses fiberized asphalt, asphalt rubber, rubberized asphalt, and low-modulus rubberized asphalt; which of these materials is preferred or most used and why?	We prefer rubberized asphalt for thermal cracks based on past experience where the sealant will not be paved over or surfaced over with a chip seal, micro surfacing, etc within the same year. We prefer fiberized sealant when the roadway will be surfaced cover with a chip seal, micro surfacing, etc. the same year and a low modulus rubberized sealant when it will be paved over the same year. A not on asphalt rubber. We have applied asphalt rubber chip seals over roads with closely spaced transverse cracks. The cracks reflect thru the chip seal but remain tight and then reseal themselves in the hotter summer months in the wheel paths.
New York	**NA**	

Survey details-follow-up-specific states/provinces questions, continued

State/Province/Organization	Questions	Responses
Ohio	In Question 5 of our survey, “What is the expected life of crack maintenance materials used in the state/province?” you responded “other,” and added the following comments, “We don't have an expected life. ODOT only crack seals on a very limited basis. Our research indicates it is marginally cost effective. We are not dealing with many thermal crack problems. Our thermal cracks seldom get wide enough to create a problem.” When crack seals are used, what is the primary need to initiate the sealing process (such as formation of large cracks or high severity)? Can you supply the research you refer to, either by internet URL or PDF?	Crack sealing is recommended when pavement condition reaches a certain threshold (66<PCR<80) and the pavement is not expected to be rehabilitated in the next few years. http://www.dot.state.oh.us/Divisions/Planning/SPR/Research/reportsandplans/Pages/PavementReports.aspx State project #134364
	In Question 6 of our survey, “What are the preparation methods for crack maintenance in your state/province (select all that apply)?” you responded “other,” and added the following comments, “Our specs provide for the routing option, but is never used.” Can you explain why routing is never used in preparation? Is preparation needed prior to the use of the hot air lance?	I am not sure why we never route. Likely the cost and the number of cracks in the pavement when crack sealing is done make it impractical.
Ontario	What is the reason for not making overband for longitudinal cracks?	For longitudinal cracks, the sealant material should be at or slightly above the adjacent asphalt pavement surface and the reason for this is that if there are multiple longitudinal cracks in the wheel path that are sealed with overband , then there might be a risk of surface becoming slippery.
Oregon	**NA**	
Pennsylvania	In Question 9 of our survey, “How do you schedule the thermal cracking maintenance within the state/province?” you responded “other,” and added the following comments, “We use cycle maintenance on our high level bituminous pavements that are on a 5 year crack sealing cycle.” Are any other factors considered for scheduling, or is the 5-year cycle the exclusive schedule?	we are on a five year cycle but if while field viewing roads that it is found as a need to crack seal it is scheduled
Saskatchewan	What field tests are used for assessing the severity/frequency for thermal cracking?	Here are some Specifications for Rubber Asphalt Crack Sealing: The Contractor shall not rubber asphalt crack seal the following unless directed by the Engineer: (a) severely fatigue-blocked areas. (b) centerline cracks except on curves. (c) cracks less than 0.078 inch (2 mm) in width. (d) cracks in excess of 0.98 inch (25 mm) in width.
South Dakota	Can describe the differences in your crack maintenance practices that allow for both summer and winter applications (such as material differences, preparation, is practice based on need/emergency, etc…)?	Generally, new asphalt roads are crack sealed within 2 years. Depending on the amount of sealing needing to be done it is done with either maintenance forces or contractor. Normally, the maintenance forces will seal or fill cracks in the Winter or early Spring as weather conditions allow. The contractor will usually seal throughout the Spring into the Summer and Fall. Obviously this is all dependent upon need and money available. There is some crumb rubber used in the Winter time, but a majority of the material is a low to extra low modulus material.

Survey details-follow-up-specific states/provinces questions, continued

State/Province/Organization	Questions	Responses
Utah	In Question 12 of our survey, "What methods are used to assess the severity/frequency of thermal cracking (select all that apply)?" you responded "other," and added the following comments, "Annual automated pavement condition survey." Can you elaborate on your response? What is meant by automated? How is the condition survey conducted?	In the past we used to assess condition annually by driving the roads and visually inspect the roads. Now we are implementing new. We use statewide gps photolog with computer-assisted crack identification and extent mapping. Survey is done biennially. Automated lidar technology to asses condition.
	Why is Low-Modulus rubberized asphalt no longer used in Utah?	We have better products with less failure. Utah has multiple freeze thaw cycles and require more flexibility. We found other product that worked better.
Vermont	**NA**	
Washington	In the survey, you indicated that Washington does not have a crack maintenance program, however you listed sealing. In Question 1b of our survey, "Does your state/province have a crack maintenance program? If yes, please describe the program (select all that apply)" you responded "other," and added the following comments, "crack fill." You also selected "seal" for this question. Can you elaborate on the Washington State DOT's selection process for "seal" or "fill"?	NA
Wisconsin	In Question 10a of our survey, "How did the state/province develop the agency specification or approval procedure (select all that apply)?" you responded "other," and did not add comments. Can you explain how Wisconsin DOT developed the specification or the approval procedure?	The answer depends on if the specification for a contractor working as part of an improvement project or a county highway department working as part of a maintenance activity.
Wyoming	In Question 5 of our survey, "What is the expected life of crack maintenance materials used in the state/province?" you responded "other," and added the following comments, "anticipated life is 5 to 7 years." What type of material, procedures, and/or other factors allow you to extend the crack sealing life up to 5 to 7 years?	We try to crack seal a section of roadway one year and then follow up with a chip or surface seal the second year. This anticipated schedule to come back in and do a follow up treatment is 5 to 7 years after the chip seal or longer depending on roadway volume.
	In Question 12 of our survey, "What methods are used to assess the severity/frequency of thermal cracking (select all that apply)?" you responded "other," and added the following comments, "Roadway are run every two years with pathview van and roadway cracking conditions are recorded and analyzed by Materials Program. Districts use this information along with visual field assessments." Can you provide details or a specification for the Pathview Van and Materials Program	Additional details on the pathview specification, tracking and analysis can obtained from our Materials Program. Contact is Bruce Morgenstern 307-777-4271.

4.18. Survey Details-Follow-Up-Specific States/Provinces Questions (second round)

Table 4.18 illustrates the responses of second round of selected states/responses follow-up questions. This included four questions dealing with the definitions of seal and fill of cracks. Another question inquired about the actual percentage of asphalt pavements that are regularly maintained within the states/provinces.

Table 4. 18 Survey details-follow-up-specific states/provinces questions (second round)

State/Province	1. Does your state have separate criteria for "Crack Sealing" and "Crack Filling" practices?	2. Does one practice require more specialized treatment materials?	3. What materials are used strictly for the following practices? Crack Sealing	3. What materials are used strictly for the following practices? Crack Filling	3. What materials are used strictly for the following practices? Both Practices	4. What are the operation processes used for each practice?
Idaho	No.	No, we consider the terms as equal.	SKIPPED	SKIPPED	SKIPPED	SKIPPED
Kansas	yes, based on size of the crack. Smaller cracks are sealed, while larger cracks are filled	SKIPPED	SKIPPED	SKIPPED	SKIPPED	SKIPPED
Minnesota	Yes, but may not be well documented.	YES. Route and seal to "seal" a crack. Use 3725 or 3723 spec. Clean and seal to fill a crack. Use 3719 or 3723 spec. material.	3725, 3723	3719, 3723	SKIPPED	see spec.
Montana	No	No	DEERY 101 is a low modulus, hot applied, single component, elastically modified composition of asphalt cement, virgin synthetic polymer, premium rubber, and other modifiers. The sealant contains no solvent, is pre-reacted and conforms to the requirements of **ASTM D6690 Type IV, ASTM D3405 Low Modulus, AASHTO M324 Type IV and AASHTO M301 Low Modulus**. Material is tested for low temperature performance at -20°F (-29°C) using 200% extension. VOC=0 g/l. previously labeled as CMC #101 . **Beram 3060 LM** is a high performance, hot applied, single component extra low modulus joint and crack-sealant. Beram 3060 LM is a very soft sealant that offers excellent low temperature bonding properties, while still maintaining a high degree of resiliency to reject incompressibles. Beram 3060 LM permits high elongation at cold temperatures with low stress development. Beram 3060 LM will not flow from the joint or be picked up by vehicle tires at high service temperatures.			

Pennsylvania	No	No	Asphalt Rubber	SKIPPED	SKIPPED	N/A
South Dakota	no	no	The sealant shall conform to the requirements of ASTM D 3405 with some modifications.	The sealant shall conform to the requirements of ASTM D 3405 with some modifications.	SKIPPED	Even though South Dakota does not distinguish between crack sealing and crack filling the following criteria is used. Crack sealing involves routing working and non-working cracks up to ¾" in width. If a crack is encountered that is wider than ¾", the crack is blown out and then filled. This is what South Dakota considers "crack filling", but is not called crack filling?
Washington	No per WSDOT Standard Specifications. If crack sealing is desired a special provision will be used, this is not common in Washington.	Rubberized or sand slurry can be used for crack filling depending on the application. Rubberized sealant will be used on chip seal roadways prior to the chip seal. Sand slurry will be used on asphalt roadways prior to an overlay. Unpaved shoulders will receive rubberized sealant. Crack filling is also used for routine maintenance applications to fill cracks. Rubberized crack filling shall meet the requirements of ASHTO M 325 Type II.	SKIPPED	Crack filling must meet the requirements of AAHTO M 325 Type II (used prior to a chip seal, unpaved shoulders or maintenance applications). Sand Slurry required 20 percent CSS-1 asphalt emulsion, 2 percent cement, water if required and 4-0 clean paving sand (prior to an overlay)	SKIPPED	Crack filling – the surface is cleaned with a stiff bristled broom and compressed air before sealant application.
Wyoming	No.	N/A	807.2 Hot-Poured Elastic Sealant: Provide and use sealant in accordance with AASHTO M 324 Type I WY Modified or AASHTO M 324 Type IV WY Modified as specified. Use AASHTO M 324 WY Modified if the sealant type is not specified. To enhance performance, materials including recycled rubber and fillers (such as calcium carbonate to prevent rubber particles from sticking together) may be blended into the sealant mixture; do not allow the incorporation of wire, fabric, or other deleterious matter. As applicable, ensure that sealant is in accordance with Table 807.2-1, Hot-Poured Elastic Sealant Specification Limits.	SKIPPED	SKIPPED	Please refer to following web site link: http://www.dot.state.wy.us/files/live/sites/wydot/files/shared/Construction/2010%20Standard%20Specifications/2010%20Standard%20Specifications.pdf Section 403 starting on page 307 covers our crack sealing specs in detail. Section 807.2 starting on page 767 covers the material specifications.

5. SUMMARY AND RECOMMENDATIONS

The primary objective of this study was to investigate the maintenance practices for thermal cracking in asphalt pavements of states and provinces with similar climates to North Dakota for the ultimate goal of assembling a best management practices policy for the NDDOT. Thermal cracking is an inherent distress of asphalt pavements in cold-weather due to the yearly expansion and contraction of the pavement in changing weather. To combat the severity of thermal cracking, preventative and corrective maintenance strategies are used to stop the development of cracks and prevent distresses that develop as cracking worsens.

A literature review was conducted regarding the current state of practice of thermal cracking development, maintenance, and evaluation. The best management practices for thermal crack maintenance were identified as determining the need for treatment, selecting the maintenance material, selecting an application approach, and performing preparation of the cracks, quality control testing, and proper construction. Literature identified the mechanisms and influencing factors of thermal crack development. In addition, the evaluation of cracks, maintenance method determinations, maintenance scheduling, crack modeling, and quality assurance testing were reviewed and presented from published research works.

State/province specifications and available best management practices guidelines were reviewed for states and provinces exhibiting similar climatic conditions to North Dakota. The goal of this section of the literature review was to identify the materials and practices used in each state and province before the survey. Crack sealing and crack filling specifications for states and provinces are summarized by the materials used, crack identification and designation for maintenance, equipment used, crack preparations, filling and/or sealing configurations, quality assurance requirements, and finishing techniques. 10 states/provinces indicated the use of a BMP or equivalent guideline for crack maintenance during the survey. A summary of each of these BMPs is included in the Appendices.

A survey of 29 states and provinces with similar climates to North Dakota was conducted. 31 responses covering 24 states/provinces were returned at the time of this report. The purpose of the survey was to identify the best and preferred practices that are not detailed in specifications, BMPs, or field manuals of the surveyed states and provinces. Survey questions focused on the details, if any, of BMPs for each agency. This included questions of the time of year for maintenance, field assessments and scheduling, the amount of AC roads requiring maintenance, expected life of maintenance materials, crack preparation methods, an overview of the used and preferred materials, approval processes, and quality assurance practices. The results and analysis of the survey responses are presented.

5.1. Summary of Literature

A thorough literature discussing the thermal cracking in cold regions is illustrated in the literature review in Chapter 2. Research of thermal cracking mechanisms, best management practices, pavement management, crack maintenance operations, field and lab assessments, and quality assurance testing, and best management practices testing shows the current state of industry practices for thermal cracking maintenance.

Research of thermal cracking mechanisms, best management practices, pavement management, crack maintenance operations, field and lab assessments, and quality assurance testing shows the current state of industry practices for thermal cracking maintenance.

Best management programs incorporate a number of different factors culminating in a method or process that can optimize cost, performance, and planning. For thermal cracking maintenance, the BMP guidelines consider the need for crack treatment, planning and designing the crack treatment, construction, and evaluation of treatment performance as the major components for the BMP. The need for crack treatments is dependent on factors unique to each specific roadway. The type of maintenance and maintenance procedures will also depend greatly on the pavement cracking present in the existing pavement. A typical BMP guide will outline the crack size and characteristics that determine if sealing or filling procedures will be selected. Sealing procedures are used for working cracks that have 0.11 inch (3 mm) or less of annual horizontal movement, while filling procedures are used for non-working cracks that have more than 0.11 (3 mm) of horizontal movement annually. Planning and design for maintenance practices will also be unique for each road, but the primary considerations involve selection of the optimal material for maintenance. There are several types of crack maintenance materials available for use, and they are grouped into one of three general categories; cold-pour, hot-pour, and chemically cured materials. BMPs may include a list of approved manufacturers and/or a list of testing standards that acceptable materials must pass before they are permitted for use. Upon evaluation of the crack and selection of the appropriate material, the overall configuration of the completed crack should be considered. Generally, there are 4 major configurations used in sealing or filling operations; flush fill, reservoir, overband, and reservoir and overband combination. Cracks are prepared for treatment using a variety of methods that should be outlined in the BMP which may include cutting, cleaning, and drying. The material should be prepared properly, applied, and the finished crack should match the specified manner. Planning should also consider the cost effectiveness of the treatments in terms of performance and overall cost. All construction procedures should be clearly outlined in the BMP as well, with considerations to specific processes and materials. A BMP will also include information on assessing the finished cracks, with considerations to what the agencies considers as acceptable or failing.

Research of thermal cracking identifies two major mechanisms leading to the occurrence of cracks; volumetric contraction and overall contraction of the pavement and/or subgrade. For both mechanisms, the driving force for contraction is the temperature drop that occurs during the winter season, however the pavement design; including the asphalt material, mix proportions, subgrade properties, and pavement geometry; will also influence the occurrence of thermal cracking. Cracks begin to form at the surface and continue to propagate through to the full depth of the pavement. As cracks develop and continue to grow wider, the pavement becomes increasingly more susceptible to water infiltration and loss of structural support.

To combat the potential damage that follows the occurrence of cracks, three categories of maintenance operations are considered; preventative, corrective, and emergency. Preventative maintenance is used before the appearance of or at the onset of distresses. These measures are utilized to improve the quality of the pavement and extend the life of the pavement. Corrective maintenance is used when the pavement is in need of repair after minor distresses have worsened, and serves as a means to retard the severity of distresses. Emergency maintenance is used when repair is needed immediately, such as cases were the public’s safety is of concern. Crack maintenance is generally considered preventative, but there may be cases where the severity of cracks may require more extensive repair work.

The selection of construction processes for maintenance work will consist of the initial evaluation of cracks and field assessments, maintenance method selection, scheduling, and modeling. Crack assessments and evaluations are typically conducted annually or under a regularly scheduled timeframe. Current practices incorporate digital camera technology and sensory equipment on a collection vehicle which automatically enters collected data readings into a database system. This is used to generate a pavement condition rating or detect the severity of cracking. In certain cases, nondestructive testing is used to assess specific sections of road for increased planning capability. Scheduling of maintenance practices varies by state, province, or agency, but work is often planned with the use of a pavement management system. These systems are typically based on network-level analysis where maintenance decisions are made with considerations to funding and pavement condition ratings. Maintenance may be performed on a cyclic basis, and modeling may be utilized to predict future need. There is currently no standardized model for thermal cracking prediction due to the large amount of influencing factors, but research shows the applicability of asphalt pavement mix design characteristics and performance testing as a means to predict cracking behavior.

Quality assessments of the materials and finished project are major considerations to crack maintenance operations as well. Materials must meet a minimum requirement or testing standard prior to application and acceptance. Material manufacturers typically list ASTM or AASHTO testing specifications that each material passes, and states or provinces perform quality assurance testing to verify the quality of batches or lots of materials they receive. Upon completion of work, field assessments and/or visual inspections of the in-place materials are performed with adhesion loss, cohesion loss, tensile failure, and pullouts serving as the typical criteria for failure. Evaluations of completed work are often performed multiple times following application to track performance of the work. Research works have indicated that performance-based specifications, not solely laboratory standardized testing, for materials and evaluations will improve the quality of pavements.

A summary of the findings from the states/provinces specifications are summarized in Table 5.1. This table is formulated from the collected literature and not based on the responses of surveyed of states.

Table 5. 1 Summary of states/provinces specifications

State/Province/Organization	Crack maintenance program	Best management practices	Crack preparation methods	Crack treatment	material	Specifications utilized	Temperature of application
Alberta	Yes	Yes	NA	NA	Cold pour rubber filled bituminous emulsified pavement crack sealant and hot pour bituminous pavement crack sealant.	EC-101, HC-200, ASTM D562, ASTM D244, ASTM D5, ASTM D2170, ASTM D36	Atmospheric temperature is above 0°C.
British Columbia	Yes	Yes	Rout reservoirs should be cleaned with a hot air lance	Cracks measuring 0.62 inch (16mm) or less shall be routed to 0.62 inch (16mm) wide and form a vertical-walled reservoir 0.74-0.98 inch (19-25mm) deep	Rubberized asphaltic and/or elasticized asphalt sealants	ASTM D 6690, ASTM C 117	At least 10°C.
Colorado	Yes	Yes	Loose and foreign matter shall be cleared from the crack to a depth of approximately twice the width of the crack.	NA	NA	ASTM D 6690 Type I or Type II	40°F and rising.
Illinois	Yes	No	The routed crack should be cleaned of debris and dust immediately ahead of sealer placement with the use of a power brush/blower or compressed air at a minimum of 90 psi.	Cracks are to be routed as neatly as possible to approximately 3/4-in wide by 3/4-in deep to provide a 1:1 depth to width ratio.	Hot-poured joint sealer.	ASTM 6690, Type II	40°F or higher in the shade.
Iowa	No	No	Cracks cleaned by air compressor.	Cracks are sawed or routed to be 1/2 to 3/4-inch wide.	NA	NA	NA
Kansas	Yes	Yes	Cracks are to be cleaned and dried with heat lance without burning the existing pavement.	cracks between 1/8 and 1/2-inch wide should be routed to follow the existing crack, cracks between/8 to 3/8-inches should be routed with a 5/8-inch head, cracks between 3/8 and ½ inch should be routed with a 3/4-inch router head, and cracks larger than 1/2-inch do not require routing.	Hot type joint compound and fiber-reinforced asphalt.	ASTM D 5329 sections 9, 8, 12, and 6	NA
Manitoba	Yes	No	Routed cracks should be cleaned and dried by hot air lance	Cracks are to be routed to a width to depth ratio of 3:1	Hot-applied and cold-applied crack sealants.	ASTM D6690 and ASTM D5329	NA
Michigan	Yes	No	All cracks should be cleaned and dried with compressed air to remove debris.	Saw or rout and seal practices should occur with cracks no larger than 1 1/4-inches wide on working cracks.	Hot poured joint sealant, asphalt binder, polyester fibers, and asphalt rubber	ASTM D 6690, Type II , ASTM D 3937, ASTM D 2256,	Between 45 and 85°F.

					products.	ASTM D 1577	
Minnesota	Yes	Yes	NA	NA	Hot-poured, crumb rubber type crack sealer; hot-poured, elastic type joint and crack sealer; and hot-poured extra low modulus, elastic type joint and crack sealer.	Modified ASTM D 6690, Type I , ASTM D 5329, modified ASTM D 6690, Type II	NA
Missouri	No	Yes	All cracks should be dried and heated by hot compressed-air lance no more than 10 minutes prior to sealant application.	Cracks of width 1/4 to 1 1/4-inch shall be routed to remove at least 1/8-inch from each sidewall of the crack, and with a minimum and maximum width of 1/2-inch and 1 1/2-inch, respectively	Hot pour elastomeric sealant.	Modified ASTM D 6690 Type II	Above 40°F.
Montana	Yes	Yes	NA	All existing cracks between 1/8 inch and 1 inch, all longitudinal cracks shall be routed to ¾ inch walls and ¾ inch wide flat bottom reservoir, and transverse cracks shall be routed to 1/2-inch walls and 1 1/2-inch wide bottom reservoir.	NA	ASTM D 5167 , ASTM D 5329 modified	Between 35 and 120°F.
Nebraska	Yes	Yes	Cracks must be cleaned prior to sealing, and hot-air lance should be used if the presence of moisture is suspected.	Cracks of widths 3/8-inch or less shall be routed to 1/2-inch wide by 3/4 to 1-inch deep to form a reservoir	Rubberized asphalts and low-modulus rubberized asphalts.	ASTM D5078-90, ASTM D 5078, ASTM D-5329, ASTM D-36, ASTM D-113, ASTM D-4	
New Hampshire	Yes	No	Cracks must be cleaned with air compressors that are portable and capable of 100cfm flow and no less than 90psi at the nozzle.	Crack routing to 3/4-inch (plus/minus 1/8-inch) and 5/8-inch deep in a rectangular shape shall be implemented for cracks between 1/8-inch and 3/4-inch, unless otherwise directed.	Type II hot-poured crack sealants and low modulus Type IV hot-poured crack sealant.	ASTM D 6690	NA
New York	Yes	No	Cracks between 1/4-inch and 1-inch should be cleaned of all dirt and loose material by compressed air stream of at least 80psi.	Routing and sealing should only occur in well-defined cracks.	Asphalt filler and asphalt shim	AASHTO T 49, AASHTO T 48, AASHTO T 47, AASHTO T 53, AASHTO T 51, NYSDOT Specification Table 401-1, ASTM D 3405	Air temperature must be greater than 5°C above the dew point.
Ohio	Yes	No	All dust, dirt, moisture, vegetation, and other foreign matter should be removed from the prepared crack.	For cracks where sawing is specified, all cracks shall be sawed to between 3/4-inch and 7/8-inch wide, and between 7/8-inch and 1-inch deep. For cracks where routing is specified, all cracks less than 3/4-inch wide shall be routed to 3/4-inch wide and	Type I, II, III, and IV crack sealant materials	ASTM D 6690, ASTM D 1577, ASTM D 3937, ASTM D 2256	Below 45°F.

				1-inch deep.			
Ontario	Yes	Yes	Cracks and routed cracks shall be cleaned and dried using a hot air lance	Cracks of width up to 0.78 inch (20mm) shall be routed.	Hot poured rubberized asphalt joint sealing compound.	ASTM D 6690-01, ASTM D 5329, and ASTM D 5	NA
Oregon	Yes	No	NA	NA	Any materials that are intended for sealing cracks in asphalt pavements that conform to the requirements of the specification.	ASTM D 6690	At least 45°F.
Pennsylvania	Yes	Yes	Compressed air of at least 100psi or a hot air lance may be used for air blasting.	NA	Polymer modified asphalt. Asphalt rubber sealing compound and rubberized joint sealing material.	NA	Air temperature is between 40 and 90°F.
Saskatchewan	Yes	No	The routed cracks should be cleaned of loose material and dried by hot compressed air	Cracks should be routed to a width of 1.18 inch (30mm) and a depth of 0.59 inch (15mm).	Hot poured rubber asphalt sealant.	ASTM D 3405 and ASTM D 3407	NA
South Dakota	Yes	No	All cracks shall be cleaned, dried, and free of loose material and debris by compressed air.	Cracks under the width of 3/4-inch shall be routed to a width of 3/4-inch and cracks larger than 3/4-inch are not routed.	NA	Modified ASTM D 3405	NA
Utah	Yes	No	Cracks are to be dried and free of loose material by the use of hot compressed air.	NA	NA	ASTM D 5329, AASHTO T 51, AASHTO T 300 , ASTM D 3405, ASTM D 4402, ASTM D 5329	NA
Vermont	Yes	No	Use of a hot air lance capable of blowing clean air and drying cracks.	Cracks measuring between 1/8-inch and 3/4-inch in width shall be routed to a 3/4-inch by 3/4-inch square reservoir.	Hot poured joint sealer.	AASHTO M 324	The ambient air temperature of 40-104°F and pavement temperature 50-140°F,
Washington	No	No	NA	NA	NA	AASHTO M 324 Type IV, AASHTO T 48, ASTM D 5167, ASTM D 5329	NA
Wyoming	Yes	No	Cracks cleaned by air compressor.	Cracks are to be routed to vertical sides and flat bottom.	Hot-poured elastic sealant.	AASHTO M 324 Type I, AASHTO M 324 Type IV	NA

5.2. Summary of Crack Maintenance Specifications and Best Management Practices

26 state and province specifications and 10 BMPs were reviewed with focus on crack maintenance materials, preparation methods, application methods, and acceptance policies. For states and provinces that have crack maintenance programs in place, the specifications have a division or section dedicated to general crack maintenance which covers the previously mentions topics. These specifications are overviewed fully in section 2.14 of this report.

Hot pour sealants are preferred by most states and provinces in this literature. The most common specifications used for material acceptance are ASTM D 6690 or AASHTO M 324 (Types, I, II, III, and IV) and ASTM D 5329. Materials must meet the requirements of one or both of these testing criteria in 15 of the 26 states/provinces reviewed. It should be noted, ASTM D 6690 and AASHTO M 324 have 4 types and states/provinces may not utilize all types of materials. Hot pour crack or joint sealer is the preferred category of crack maintenance materials among all states and provinces. Fiberized and rubberized sealants are commonly used.

Generally, sealant applications are only permitted when the air temperature is 40°F or higher, with Alberta allowing sealing to 0°C (32°F) and Montana allowing temperatures as low as 35°F. Routing of existing cracks is the most common practice for crack preparation; however states do not have uniform criteria for when to rout or not rout. Generally, cracks should not be routed to a width larger than 3/4 inch and cracks larger than 3/4 inch are commonly filled without routing. Cracks smaller than 1/2 inch are typically routed to either 1/2 inch or 5/8 inch. For routing practices, the vertical-walled reservoir is nearly exclusive. The use of a star-shaped router bit is allowed on a very limited basis. Rout reservoir widths should be equal to or larger than depths, with width to depth ratios between 1:1 and 3:1. All states and provinces require the routed or unrouted cracks to be cleaned and dried prior to application of maintenance materials with compressed air or hot-air lance. The hot air lance is preferred for enhanced cleaning and warming of the crack channel for increased bonding. The use of hot-pour sealants, which is preferred by all states and provinces, is applied using an applicator wand attached to a double-boiler melting kettle. This is the exclusive practice among reviewed specification, with deviations allowed only under the approval of the engineer. Materials are evaluated for quality assurance testing by the agency’s materials division or materials engineer prior to approval of the material lot.

Configurations of the final sealed/filled crack vary greatly between states and provinces. However, most sealing applications utilize a squeegee or other similar tools to level excess materials from the cracks. Most states and provinces have specific details for banding over the existing pavement surface, with maximum and minimum widths and heights. Generally, the banding should be 1 to 3 inches from either side of the crack channel and no higher than 1/16 inch. Acceptance of work is usually based on an inspection by the engineer. Pull-outs and loss of bond are the most common criteria determining failure.

A summary of the findings from the states/provinces specifications are summarized in the previously illustrated Table 5.1. This table is formulated from the collected literature and not based on the responses of survey of states.

5.3. Summary of Survey

The majority of surveyed states and provinces have a crack maintenance program in place. On the other hand, this was not the case for the existence of best management practices programs, as most states don’t adopt a crack maintenance best management practice.

The treatment procedures of cracks are oriented towards crack sealing in addition to rout and seal. Overband of cracks also is a choice following sealing and rout & seal. The least used operation chosen was crack pour.

The preferred time for crack maintenance operations is spring as well as fall, followed by summer and lastly winter. The majority of respondents stated that 10-40% of the roads are maintained on a regularly basis. A few states indicated that more than 60% of the asphalt roads are maintained on a regularly basis. Based on the states/provinces responses, the expected life of crack maintenance materials is about 2-5 years.

For crack preparation approaches, the most used method is compressed air which is followed by hot air lance. Routing of crack is also common among states/provinces and sawing of cracks was chosen by a limited number of states/provinces. Very few states/provinces have no crack preparation methods.

Based on the responses of the states/provinces with regards to their experience with crack sealing products, it can be implied that most states/provinces are not utilizing cutback asphalt products. The most utilized crack sealing materials are rubberized asphalts, followed by asphalt emulsions and low modulus rubberized asphalts. The preferred technologies for states (arranged based on respondents choices) are the rubberized asphalts, asphalt rubber low modulus rubberized asphalt, and polymer modified asphalts.

The storage practices of states/provinces are inclined towards indoor as well as indoor with moderate exposure policy. Some states, however, utilize outdoor storage for some crack maintenance products.

According to the states/provinces responses, the thermal cracking maintenance scheduling is mainly based on cracking occurrence as well as annual maintenance. Some states/province, however, adopt no scheduling approach. Finally, very few states/provinces attributed the scheduling of thermal crack maintenance to the condition of current sealant

For specification development, the majority of states/provinces have stated that they developed the specification by their own policies, practices, and experience. Other states/provinces indicated that the development of the specifications was based on either national studies/guidelines, such as NCHRP, or based on other states/DOT experiences.

Most of the states/provinces selected both in-house and contractor for the thermal cracking maintenance work. A few selected either contractor only or in-house only for thermal cracking maintenance work within state/province.

The approach utilized by states/provinces for assessing the severity of cracks is mainly field assessments, which is followed by the scheduled maintenance. Few states/provinces chose testing in the fields as a way for assessing severity of cracks. For the quality assurance verification methods most states/provinces adopt visual field testing as a first choice followed by laboratory assessment.

Certain crack maintenance materials, such as cutback asphalt, are not permitted for crack maintenance is mainly because of previous experience, as well as literature review and other states/provinces experience. Other materials such as asphalt cement, fiberized asphalt, and asphalt rubber are not permitted mainly because of previous experience and sometimes other states/provinces experience as well as literature review. A summary of the survey responses is provided in Table 5.2.

Table 5. 2 Summary of states/provinces survey responses

State/Province/ Organization	Crack maintenance program	Best management practices	Time for crack maintenance	Crack Treatment methods	Roads requiring maintenance	Life of materials	Crack preparation methods	Scheduling of maintenance	Specifications Source	Maintenance type	Assessment method	Quality assurance
Alberta	Yes	Yes	Spring	Pour, Rout and seal	more than 60%	other	Sawing, Routing, Hot air lance, Compressed air	Other	Developed by your own state/province	Contractor	Field assessment	Visual field testing
British Columbia	Yes	No	Spring	Seal, Overband	10-20%	3-5 years	Compressed air	Cracking occurrence	Developed by your own state/province	Contractor	Field assessment	Visual field testing
Colorado	Yes	Yes	Spring, Summer, Fall, Winter	Seal, Pour, Overband, Rout and seal	more than 60%	3-5 years	Routing, Hot air lance, Compressed air	Cracking occurrence	Developed by your own state/province	In house, Contractor	Field assessment, Scheduled maintenance	Visual field testing, Laboratory Assessment
Idaho	Yes	No	Spring, Fall	Seal, Overband, Rout and seal	20-40%	3-5 years	Routing, Compressed air	On annual basis	Developed by your own state/province	In house	Field assessment	Visual field testing
Illinois	Yes	No	Spring, Summer	Seal, Rout and seal	20-40%	2-3 years	Routing, Compressed air	Cracking occurrence	Developed by your own state/province, Based on other states/DOT experience			
Iowa	No	No	Summer	Rout and seal	20-40%	2-3 years	Routing, Compressed air	Cracking occurrence	Developed by your own state/province	In house, Contractor	Field assessment	Visual field testing
Kansas	Yes	Yes	Spring, Summer, Fall	Seal, Pour, Rout and seal	20-40%	3-5 years	Routing, Hot air lance, Compressed air	Cracking occurrence	Based on national studies/guidelines such as NCHRP, Developed by your own state/province, Based on other states/DOT experience	In house, Contractor	Field assessment	Visual field testing, Laboratory Assessment
Manitoba	Yes	No	Spring, Summer, Fall	Seal, Rout and seal	20-40%	3-5 years	Routing, Hot air lance, Compressed air	On annual basis	Developed by your own state/province, Based on other states/DOT experience	In house	Field assessment	Visual field testing

State/Province/ Organization	Crack maintenance program	Best management practices	Time for crack maintenance	Crack Treatment methods	Roads requiring maintenance	Life of materials	Crack preparation methods	Scheduling of maintenance	Specifications Source	Maintenance type	Assessment method	Quality assurance
Michigan	Yes	No	Summer	Seal, Overband, Rout and seal	more than 60%	2-3 years	Sawing, Routing, Compressed air	Cracking occurrence	Based on national studies/guidelines such as NCHRP, Developed by your own state/province	In house, Contractor	Field assessment	Visual field testing
Minnesota	Yes	Yes	Spring, Summer, Fall, Winter	Seal, Pour, Overband, Rout and seal	Skipped	other	Routing, Hot air lance, Compressed air	Other	Based on national studies/guidelines such as NCHRP, Developed by your own state/province	In house, Contractor	Field assessment	Visual field testing, Laboratory Assessment
Missouri	No	Yes	Spring, Fall	NA	10-20%	2-3 years	Routing, Compressed air	On annual basis	Developed by your own state/province	In house, Contractor	Field assessment	Visual field testing
Montana	Yes	Yes	Spring, Summer, Fall	Rout and seal	more than 60%	other	Routing, Compressed air	Cracking occurrence	Other	In house, Contractor	Field assessment	Visual field testing, Laboratory Assessment
Nebraska	Yes	Yes	Spring, Summer, Fall, Winter	Seal, Pour, Overband, Rout and seal, Other	40-60%	3-5 years	Sawing, Routing, Hot air lance, Compressed air	Other	Based on national studies/guidelines such as NCHRP, Developed by your own state/province	In house, Contractor	Field assessment, Scheduled maintenance	Visual field testing, Laboratory Assessment
Nevada	Yes	No	Spring, Fall	Seal, Overband	20-40%	3-5 years	Hot air lance, Compressed air	On annual basis, Cracking occurrence	Developed by your own state/province	In house	Field assessment, Scheduled maintenance	Visual field testing
New Hampshire	Yes	No	Spring, Summer, Fall	Seal, Overband, Rout and seal	20-40%	3-5 years	Routing, Hot air lance, Compressed air	On annual basis	Developed by your own state/province	In house, Contractor	Field assessment, Other	Visual field testing, Laboratory Assessment
Ohio	Yes	No	Spring, Summer, Fall, Winter	Overband	10-20%	other	Hot air lance, Compressed air	No schedule	Developed by own state/province, Other	In house, Contractor	Other	

State/Province/ Organization	Crack maintenance program	Best management practices	Time for crack maintenance	Crack Treatment methods	Roads requiring maintenance	Life of materials	Crack preparation methods	Scheduling of maintenance	Specifications Source	Maintenance type	Assessment method	Quality assurance
Ontario	Yes	No	Spring, Summer, Fall	Overband, Rout and seal	10-20%	3-5 years	Routing, Hot air lance, Compressed air	On annual basis	Developed by your own state/province	Contractor	Field assessment, Scheduled maintenance	Visual field testing, Laboratory Assessment
Pennsylvania	Yes	Yes	Spring, Summer, Fall	Seal, Overband	40-60%	3-5 years	Compressed air	Other	Developed by your own state/province	In house, Contractor	Field assessment, Scheduled maintenance	Visual field testing, Laboratory Assessment
Saskatchewan	Yes	No	Spring, Summer	Seal, Pour, Rout and seal	10-20%	3-5 years	Sawing, Routing, Hot air lance, Compressed air	Cracking occurrence	Developed by your own state/province	In house, Contractor	Field assessment, Scheduled maintenance, Testing in the fields	Visual field testing, Laboratory Assessment
South Dakota	Yes	No	Spring, Summer, Fall, Winter	Seal, Pour, Overband, Rout and seal	20-40%	3-5 years	Sawing, Routing, Hot air lance, Compressed air	Cracking occurrence	Based on national studies/guidelines such as NCHRP, Developed by your own state/province, Based on other states/DOT experience	In house, Contractor	Field assessment	Visual field testing
Utah	Yes	No	Spring, Fall, Winter	Seal, Overband, Rout and seal	20-40%	2-3 years	Compressed air	On annual basis	Based on national studies/guidelines such as NCHRP, Developed by your own state/province, Based on other states/DOT experience	In house, Contractor	Field assessment, Other	Visual field testing
Washington	No	No	Spring, Fall	Seal, Other	10-20%	2-3 years	Compressed air	Condition of current sealant	Developed by your own state/province	In house, Contractor	Field assessment	Visual field testing
Wisconsin	No	No	Spring, Fall	Rout and seal	10-20%	2-3 years	Routing, Compressed air, No preparation	No schedule	Other	Contractor	Field assessment, Testing in the fields	Visual field testing
Wyoming	Yes	No	Spring, Fall, Winter	Seal, Overband, Rout and seal	10-20%	other	Routing, Hot air lance, Compressed air	On annual basis	Developed by your own state/province	In house, Contractor	Field assessment, Other	Laboratory Assessment

5.4. Recommendations

Through the review of literature, specifications, BMPs, and the results of the survey, the research team has included recommendations for the NDDOT for their crack maintenance practices. The recommendations will be presented with respect to the material selection, application processes, and future research.

5.4.1. Materials

There are many options for materials for crack sealing. However, the most commonly used and preferred materials, according to specifications and survey results, are:

- Rubberized asphalts
- Low modulus rubberized asphalt
- Asphalt emulsion
- Asphalt rubber
- Polymer modified liquid asphalts.

Based on the survey results, 52% of the respondents currently use rubberized asphalt, 45% currently use low modulus rubberized asphalt, 39% currently use asphalt emulsion, 36% currently use asphalt rubber, and 32% currently use polymer modified liquid asphalt; as illustrated in section 4.7 of the survey analysis. It is recommended that these material types be considered in the order presented, and according to product availability.

For the specific products used by the NDDOT; 59% of the state/province respondents have used cutback asphalt but are no longer using it, whereas the rest of the states (41%) have never used it before. For the specific type MC-3000 cutback asphalt, 40% of the states/provinces respondents have used this product before but are no longer using it, while the rest of states/provinces respondents (60%) have never used it before. 20% of the respondents are currently using Elastoflex 52 (crumb rubber modified asphalt), and 20% of the respondents are currently using Elastoflex 71 (polymer modified asphalt sealant). Thus, Elastoflex 52 or Elastoflex 71 may be used, while it is recommended not to use MC-3000.

For the chosen materials to be utilized as crack sealants, it is recommended that they should fulfill the ASTM D 6690 standard, as it is commonly used across states and provinces. In addition, ASTM D 5329 should be used for quality assurance testing and acceptance of received materials.

5.4.2. Application Processes

The most commonly preferred constructions processes for crack maintenance from the literature, specifications, and survey results are the seal, (rout and seal) practice, and overband. Based on the survey results, 76% of the respondents chose seal as their crack program, 69% of the state respondents chose rout and seal as their crack program, whereas, 52% chose overband; as seen in section 4.1.2 of the survey analysis. It is recommended that sealing techniques are used, with a specific preparation using routing methods and finishing with overbanding techniques.

It is also recommended that the NDDOT perform routing on working cracks less than 3/4 inch wide. Cracks smaller than 1/2 inch should be routed to 1/2 inch wide, and cracks between 1/2 and 3/4 inch should be routed to 3/4 inch. Cracks that are larger than 3/4 inch should be filled (without routing) after other cleaning and drying. Routing should be performed using equipment capable of making a vertical-sidewall crack channel, following the center of the crack. Materials should be prepared in accordance with the manufacturer's recommendations as most state/province specifications indicate.

Routed and unrouted cracks should be cleaned using compressed air systems or hot air lance. Based on the survey results, 97% of the respondents utilize compressed air for crack cleaning, whereas, 52% of the respondents utilize hot air lance, as shown in section 4.6 of the survey analysis. Compressed air systems should be hot air discharge. Those methods are preferred over manual cleaning or air blowers because the heat removes moisture and warms the crack channel, in addition to removing debris in the crack. Sealant applications should occur immediately after cracks are cleaned.

The final configuration of the seal crack should include overbanding techniques, as indicated by the literature and survey results. The sealed crack should be squeegeed using a "V" or "U" shaped squeegee. This commonly stated in state and province specifications to leave a depression along the finished sealed crack. The squeegeed sealant should leave a Band-Aid seal between 1 and 3 inches on both sides of the crack. Blotting material, such as toilet paper, Portland cement, or fine sand should be applied to the finished sealed crack to prevent immediate tracking and pull-outs.

5.4.3. Recommended Future Research

The recommended materials and applications processes are based on the experiences and practices of the states and provinces listed in this report. However, the most successful pavement management systems and BMPs incorporate cost-effectiveness analysis as a part of the practice, as indicated by the literature of research works. It is recommended that the NDDOT perform a cost-effectiveness analysis to the recommended practices and materials.

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APPENDIX A: ASPHALT PAVEMENT THERMAL CRACKING MAINTENANCE SURVEY FOR NORTH DAKOTA

ASPHALT PAVEMENT THERMAL CRACKING MAINTENANCE

Please return by August 9th, 2013

Introduction

The purpose of this questionnaire is to accumulate information from Departments of Transportation (DOTs) regarding experience with materials and procedures for thermal cracking maintenance of asphalt pavements. The results of the questionnaire will help the research group to formulate a best management practices guideline for thermal cracking maintenance in the state of North Dakota.

Contact Details

NDSU research group would be more than happy to receive your emails or calls if you have any questions or would like to submit any documents or information related to the survey.

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Legal Disclaimer

By participating in this survey, you are giving permission to the research group to use your questionnaire results in their analysis and publish the results. The information obtained from this survey is considered as NDDOT property and can be published or reproduced in any format and in any media.

Contact Information (Not mandatory)

Name	
State/Province/Organization	
Position/Title	
Phone number	
E-mail address	

ASPHALT PAVEMENT THERMAL CRACKING MAINTENANCE

Thermal Cracking Maintenance Practices and Processes Summary

1.a. Does your state/province have a crack maintenance program?

◯ Yes

◯ No

1.b. If yes, please describe the program (select all that apply).

☐ Seal

☐ Pour

☐ Overband

☐ Rout and seal

☐ Other

Please describe if chosen

2. Does your state/province have an established best management practices (BMP) guide?

◯ Yes

◯ No

If yes, please provide the URL for the BMP guide

ASPHALT PAVEMENT THERMAL CRACKING MAINTENANCE

3. What is the time of year cracks are maintained (select all that apply)?

- ☐ Spring
- ☐ Summer
- ☐ Fall
- ☐ Winter

Comments

4. What approximate percentage of asphalt roads in the state/province require thermal cracking maintenance on a regularly basis?

- ○ 10-20%
- ○ 20-40%
- ○ 40-60%
- ○ more than 60%

5. What is the expected life of crack maintenance materials used in the state/province?

- ○ 1 year
- ○ 2-3 years
- ○ 3-5 years
- ○ other

If other, specify

ASPHALT PAVEMENT THERMAL CRACKING MAINTENANCE

Technologies

6. What are the preparation methods for crack maintenance in your state/province (select all that apply)?

- ☐ Sawing
- ☐ Routing
- ☐ Hot air lance
- ☐ Compressed air
- ☐ No preparation

If other, specify

ASPHALT PAVEMENT THERMAL CRACKING MAINTENANCE

7. What is your experience with using each of the following crack maintenance material products within the state/province (select all that apply)?

	Currently Used	Preferred Technology	Used Before, but no longer	Never been used
Cutback Asphalt	○	○	○	○
MC-3000 (medium-cure cutback)	○	○	○	○
Asphalt Emulsion	○	○	○	○
Polymer-Modified Liquid Asphalt	○	○	○	○
Asphalt Cement Application	○	○	○	○
Fiberized Asphalt	○	○	○	○
Asphalt Rubber	○	○	○	○
Rubberized Asphalt	○	○	○	○
Low-Modulus Rubberized Asphalt	○	○	○	○
Elastoflex 52 (crumb rubber)	○	○	○	○
Polymer-Modified Asphalt	○	○	○	○
Elastoflex 71 (polymer sealant)	○	○	○	○
Self-Leveling Silicone	○	○	○	○
Other	○	○	○	○

If other, specify

ASPHALT PAVEMENT THERMAL CRACKING MAINTENANCE

8. What is your experience about the storage practices for the following crack maintenance materials (select all that apply)?

	Indoor storage	Indoor storage with moderate exposure	Outdoor storage	NA
Cutback Asphalt	◯	◯	◯	◯
MC-3000 (medium-cure cutback)	◯	◯	◯	◯
Asphalt Emulsion	◯	◯	◯	◯
Polymer-Modified Liquid Asphalt	◯	◯	◯	◯
Asphalt Cement Application	◯	◯	◯	◯
Fiberized Asphalt	◯	◯	◯	◯
Asphalt Rubber	◯	◯	◯	◯
Rubberized Asphalt	◯	◯	◯	◯
Low-Modulus Rubberized Asphalt	◯	◯	◯	◯
Elastoflex 52 (crumb rubber)	◯	◯	◯	◯
Polymer-Modified Asphalt	◯	◯	◯	◯
Elastoflex 71 (polymer sealant)	◯	◯	◯	◯
Self-Leveling Silicone	◯	◯	◯	◯
Other	◯	◯	◯	◯

If other, specify

ASPHALT PAVEMENT THERMAL CRACKING MAINTENANCE

Thermal Cracking Construction Processes

9. How do you schedule the thermal cracking maintenance within the state/province?

- ◯ On annual basis
- ◯ Condition of current sealant
- ◯ Cracking occurrence
- ◯ Manufacturer recommendation
- ◯ Other
- ◯ No schedule

If other, specify

ASPHALT PAVEMENT THERMAL CRACKING MAINTENANCE

Thermal Cracking Maintenance Specification

10.a. How did the state/province develop the agency specification or approval procedure (select all that apply)?

- ☐ Based on national studies/guidelines such as NCHRP
- ☐ Developed by your own state/province
- ☐ Based on other states/DOT experience
- ☐ Other

Please provide a link for your agency's current specification or approval procedure in the box

10.b. Please list the source (URL or document) of current agency specification if it is based on:

National studies/guidelines

Other states/DOT experience

Please email or attach any available documents.

ASPHALT PAVEMENT THERMAL CRACKING MAINTENANCE

Thermal Cracking Maintenance Assessments and Quality Assurance

11. Does the state/province use in-house or contracted work for maintenance of thermal cracking (select all that apply)?

☐ In house

☐ Contractor

Comments

12. What methods are used to assess the severity/frequency of thermal cracking (select all that apply)?

☐ Field assessment

☐ Scheduled maintenance

☐ Testing in the fields

☐ Other

If other, specify

13. For quality assurance verifications, which of the following does the state/province apply (select all that apply)?

☐ Visual field testing

☐ Laboratory Assessment

Comments

ASPHALT PAVEMENT THERMAL CRACKING MAINTENANCE

14. Please list the source of available field performance data (URL or document) for the following crack maintenance materials. Please email or attach any available documents.

Cutback Asphalt	
MC-3000 (medium-cure cutback)	
Asphalt Emulsion	
Polymer-Modified Liquid Asphalt	
Asphalt Cement Application	
Fiberized Asphalt	
Asphalt Rubber	
Rubberized Asphalt	
Low-Modulus Rubberized Asphalt	
Elastoflex 52 (crumb rubber)	
Polymer-Modified Asphalt	
Elastoflex 71 (polymer sealant)	
Self-Leveling Silicone	
Other	

ASPHALT PAVEMENT THERMAL CRACKING MAINTENANCE

15. Please select reasons of why the following crack maintenance materials were not permitted as applicable (select all that apply).

	Literature review	Other DOT experience	Previous experience	Never been used	Other
Cutback Asphalt	☐	☐	☐	☐	☐
MC-3000 (medium-cure cutback)	☐	☐	☐	☐	☐
Asphalt Emulsion	☐	☐	☐	☐	☐
Polymer-Modified Liquid Asphalt	☐	☐	☐	☐	☐
Asphalt Cement Application	☐	☐	☐	☐	☐
Fiberized Asphalt	☐	☐	☐	☐	☐
Asphalt Rubber	☐	☐	☐	☐	☐
Rubberized Asphalt	☐	☐	☐	☐	☐
Low-Modulus Rubberized Asphalt	☐	☐	☐	☐	☐
Elastoflex 52 (crumb rubber)	☐	☐	☐	☐	☐
Polymer-Modified Asphalt	☐	☐	☐	☐	☐
Elastoflex 71 (polymer sealant)	☐	☐	☐	☐	☐
Self-Leveling Silicone	☐	☐	☐	☐	☐
Other	☐	☐	☐	☐	☐

If other, specify

FOLLOWUP QUESTIONS-ASPHALT PAVEMENT THERMAL CRACKING

GENERAL QUESTIONS

Dear Respondent,
Thank you for your time and effort on our survey of thermal cracking maintenance practices. Based on the responses provided by you and other survey respondents, we have a few follow-up questions that will provide helpful information and greatly improve the quality of our survey results. We greatly appreciate a few more minutes of your time in completing these additional questions.
Thank you.

1. Do you agree with the definition of the following activities that describe the thermal cracking maintenance program in your state/province?

a. Seal of individual cracks: Placement of specialized treatment materials above or into routed/sawed and cleaned working crack.

◯ Agree ◯ Do not agree, please describe activity

Activity description

b. Fill of individual cracks: Placement of ordinary treatment materials into cleaned non-working cracks.

◯ Agree ◯ Do not agree, please describe activity

Activity description

c. Overband: Placement of material into and over a crack channel.

◯ Agree ◯ Do not agree, please describe activity

Activity description

d. Seal coat: Treatment of large areas of cracks with material asphaltic slurry.

◯ Agree ◯ Do not agree, please describe activity

Activity description

FOLLOWUP QUESTIONS-ASPHALT PAVEMENT THERMAL CRACKING

GENERAL QUESTIONS

2. Of the actual asphalt pavement sections with thermal cracking in your state/province, what percentage is regularly maintained?

- ◯ More than 80% (of total sections with thermal cracks)
- ◯ 40-80% (of total sections with thermal cracks)
- ◯ Less than 40% (of total sections with thermal cracks)

3. For quality assurance purposes, which of the following does your state/province apply (select all that apply)?

- ☐ Lab assessment on materials prior to application
- ☐ Visual field inspection on treated cracks after application
- ☐ Field testing on treated cracks after application
- ☐ No lab testing or verification assessments is performed

Specific States/Provinces Follow-Up Questions

- **Alberta**
    - In Question 5 of our survey, “What is the expected life of crack maintenance materials used in the state/province?” you responded “3-5 years and “other,” with added the following comments, “We do not obtain information on the type of cracks that are sealed (i.e., thermal or fatigue).” Since cracks are not individually categorized, is the 3-5 years an estimate based on Alberta’s experience, manufacturer claims, or another agency’s practice?

    - In Question 6 of our survey, “What are the preparation methods for crack maintenance in your state/province (select all that apply)?” you responded “other,” and added the following comments, “For ACP, cold pour normally doesn't get any preparation. Rout & Seal we allow both hot air lance and compressed air; we haven't seen any difference in initial quality of work or long-term performance.” Can you elaborate on your statement? Does Alberta have the option for routing, sawing, hot-air lance, and compressed air; but none of them are required?

- **British Colombia**
    - How are materials on the “recognized Products List” for BC determined/permitted (experience, literature review, guidelines of other states/provinces, national/international studies, etc…)?

- **Colorado**
    - What preparation is needed prior to the use of the hot air lance?
    - Can you describe the differences in your crack maintenance practices that allow for both summer and winter applications (such as material differences, preparation, is practice based on need/emergency, etc…)?

- **Idaho**
    - Can you please provide your agency specification and what were the bases for its development?

- **Illinois**
    - Why is Polymer-modified asphalt and polymer modified liquid asphalt the preferred technology over asphalt emulsions?

- **Kansas**
    - In Question 6 of our survey, “What are the preparation methods for crack maintenance in your state/province (select all that apply)?” you responded “other,” and added the following comments, “if no hot air lance, dry clean compressed air.” Can you elaborate on acceptance of projects using compressed air compared to hot air lance?
    - What previous experience/other DOT experience made you decide not to use fiberized asphalt and asphalt rubber for crack sealing?

- **Manitoba**
    - In Question 10a of our survey, “How did the state/province develop the agency specification or approval procedure (select all that apply)?” you responded “other,” and added the following comments, “ASTM and MIT testing.” Can you provide the MIT testing specifications used? Does Manitoba

conduct the MIT and ASTM testing, or are materials approved based on manufacturer's claims?

  - What modeling approach do you perform for your network to decide crack maintenance needs?

- **Michigan**
  - You responded that over 60% of your asphalt roads experience thermal cracking and require maintenance. What is the reason for continual maintenance (poor materials, heavy traffic, poor application, roads maintained section by section, etc…)?

  - Why is Fiberized Asphalt no longer used in Michigan?

- **Minnesota**
  - In Question 5 of our survey, "What is the expected life of crack maintenance materials used in the state/province?" you responded "other," and added the following comments, "Depends if the cracked or filled or sealed." To Mn/Dot what materials and practices are considered "fills" and what are considered "seals?" What are the expected lives of each of the processes?

  - Can describe the differences in your crack maintenance practices that allow for both summer and winter applications (such as material differences, preparation, is practice based on need/emergency, etc…)?

- **Missouri**
  - In the survey, you indicated that Missouri does not have a crack maintenance program. How does Missouri handle cracking in roads?

  - Why is Elastoflex 52 (crumb Rubber) no longer used in Missouri?

- **Montana**
  - In Question 5 of our survey, "What is the expected life of crack maintenance materials used in the state/province?" you responded "other," and added the following comments, "We try to get 7-10 years" What type of material, operations, and/or factors allow you to extend the crack sealing life up to 5 to 7 years?

  - In Question 14 of our survey, "Please list the source of available field performance data (URL or document) for the following crack maintenance materials. Please email or attach any available documents." you responded "other," and added the following comments, "all crack sealant must meet ASTM D5249 Type one." Is there any field data available? Has there been any need for studies since adopting the ASTM D5249 Type One criteria for sealants?

- **Nebraska**
  - In Question 1b of our survey, "Does your state/province have a crack maintenance program?, If yes, please describe the program (select all that apply)" you responded with all possible responses and "other," and added the

following comments, “Asphaltic repair mastic for thermal cracks that have resulted in a pavement depression.” Can you clarify this statement? Is repair mastic problematic to short/long term-performance?

- In Question 7 of our survey, “What is your experience with using each of the following crack maintenance material products within the state/province (select all that apply)?” you responded “other for preferred technology,” and added the following comments, “Repair Mastic: Maxwell NuvoGap, Crafco Level N Go.” Are both of these materials preferred and useable for any crack repair? Is one favored and why?

- **Nevada**
  - What preparation is needed prior to the use of the hot air lance?

- **New Hampshire**
  - In Question 12 of our survey, “What methods are used to assess the severity/frequency of thermal cracking (select all that apply)?” you responded “other,” and added the following comments, “Annual pavement condition survey performed by van.” What equipment or procedures are used to collect and analyze cracks from the van survey?

  - The survey response indicated New Hampshire uses fiberized asphalt, asphalt rubber, rubberized asphalt, and low-modulus rubberized asphalt; which of these materials is preferred or most used and why?

- **Ohio**
  - In Question 5 of our survey, “What is the expected life of crack maintenance materials used in the state/province?” you responded “other,” and added the following comments, “We don't have an expected life. ODOT only crack seals on a very limited basis. Our research indicates it is marginally cost effective. We are not dealing with many thermal crack problems. Our thermal cracks seldom get wide enough to create a problem.” When crack seals are used, what is the primary need to initiate the sealing process (such as formation of large cracks or high severity)? Can you supply the research you refer to, either by internet URL or PDF?

  - In Question 6 of our survey, “What are the preparation methods for crack maintenance in your state/province (select all that apply)?” you responded “other,” and added the following comments, “Our specs provide for the routing option, but is never used.” Can you explain why routing is never used in preparation? Is preparation needed prior to the use of the hot air lance?

- **Ontario**
  - What is the reason for not making overband for longitudinal cracks?

- **Pennsylvania**
  - In Question 9 of our survey, “How do you schedule the thermal cracking maintenance within the state/province?” you responded “other,” and added the following comments, “We use cycle maintenance on our high level bituminous pavements that are on a 5 year crack sealing cycle.” Are any other

factors considered for scheduling, or is the 5-year cycle the exclusive schedule?

- **Saskatchewan**
  - What field tests are used for assessing the severity/frequency for thermal cracking?

- **South Dakota**
  - Can you describe the differences in your crack maintenance practices that allow for both summer and winter applications (such as material differences, preparation, is practice based on need/emergency, etc…)?

- **Utah**
  - In Question 12 of our survey, "What methods are used to assess the severity/frequency of thermal cracking (select all that apply)?" you responded "other," and added the following comments, "Annual automated pavement condition survey." Can you elaborate on your response? What is meant by automated? How is the condition survey conducted?

  - Why is Low-Modulus rubberized asphalt no longer used in Utah?

- **Washington**
  - In the survey, you indicated that Washington does not have a crack maintenance program, however you listed sealing. In Question 1b of our survey, "Does your state/province have a crack maintenance program? If yes, please describe the program (select all that apply)" you responded "other," and added the following comments, "crack fill." You also selected "seal" for this question. Can you elaborate on the Washington State DOT's selection process for "seal" or "fill"?

- **Wisconsin**
  - In Question 10a of our survey, "How did the state/province develop the agency specification or approval procedure (select all that apply)?" you responded "other," and did not add comments. Can you explain how Wisconsin DOT developed the specification or the approval procedure?

- **Wyoming**
  - In Question 5 of our survey, "What is the expected life of crack maintenance materials used in the state/province?" you responded "other," and added the following comments, "anticipated life is 5 to 7 years." What type of material, procedures, and/or other factors allow you to extend the crack sealing life up to 5 to 7 years?

  - In Question 12 of our survey, "What methods are used to assess the severity/frequency of thermal cracking (select all that apply)?" you responded "other," and added the following comments, "Roadway are run every two years with pathview van and roadway cracking conditions are recorded and analyzed by Materials Program. Districts use this information along with visual field assessments." Can you provide details or a specification for the Pathview Van and Materials Program.

APPENDIX B: BEST MANAGEMENT PRACTICES AND CRACK PROGRAM URLS

B1 Alberta

The Alberta Ministry of Transportation defines criteria for the crack density and crack edge deterioration as follows [1].

Crack Density

Crack density is a measure of how closely-spaced the transverse cracks are on a given length of roadway. The Alberta Ministry of Transportation adopts a table (Table B.1) for crack density that was originally developed by the Michigan Department of Transportation to determine crack density.

Table B. 1 Crack density criteria.

Linear crack length per 100 m pavement section	**Density**
Smaller than 32.8 ft (10 m)	Low
From 32.8 ft (10 m) to 442.9 ft (135 m)	Moderate
Greater than 442.9 ft (135 m)	High

Crack Edge Deterioration

Edge deterioration is a measure of how much the crack edge has deteriorated. Table B.2, from the Surface Condition Rating Manual for Alberta Transportation, can be used to determine severity of Edge Deterioration.

Table B. 2 Criteria for severity of edge deterioration.

Edge deterioration	**Severity**
Crack width smaller than 0.11 inch (3 mm)	Slight
Crack width from 0.11 inch (3 mm) to 0.39 inch (10 mm) or secondary crack	Moderate
Crack width larger than 0.39 inch (10 mm) or block cracking	Extreme

Determining the appropriate crack maintenance application

Crack Sealing is carried out to seal ordinary working cracks (greater than 0.98 inch (2.5 mm) of horizontal crack movement) for cost-effectiveness. For short-term crack treatment performance (between 1 and 3 years) in pavements with ordinary working cracks and moderate traffic levels, a crack sealant applied as a filler (i.e. an overband or flush-fill configuration) is considered most appropriate. For cost-effective medium-term crack treatment performance (between 3 and 5 years) under the above conditions, a modified rubberized sealant placed in a shallow 1.57 X 0.39 inch (40 X 10 mm) or standard 0.74 X 0.74 inch (19 X 19 mm) reservoir with overband configuration (Rout & Seal) is considered most appropriate. For long-term crack treatment performance (between 5 and 8 years) under the above conditions, a modified low modulus rubberized asphalt sealant installed in a standard or shallow reservoir with overband configuration should be used. These materials provide a high level of flexibility and adhesiveness, so that annual crack movements can be accommodated. Moreover, the combination of a reservoir and an overband helps to maximize sealant performance [1].

Crack Sealing (Rout and Seal) is recommended if the crack opening is between 0.11-0.47 inch (3-12 mm) and pavement is less than five year old. Pavements with crack opening between 0.47-0.78 inch (12-20 mm) should be evaluated to determine whether or not routing is appropriate. Pavements with crack openings greater than 0.74 inch (19 mm) should be cleaned and filled without routing [1].

Types of cracks considered for routing and sealing are [1]:

- Transverse cracks
- Edge cracks
- Longitudinal cracks on low volume roads

Crack Sealing (Rout and Seal) is not recommended if [1]:

- Crack opening is less than 0.11 inch (3 mm)
- Cracks are alligator (or map) type
- Crack is severe in density (it is assumed that rout and seal would be ineffective in delaying further deterioration)
- Pavement is more than 10 years old, or is being considered for rehabilitation
- Longitudinal cracks with moderate to high traffic unless treatment is followed up with a chip seal that same year (centerline, mid-lane, wheel track single crack, and meandering cracks)

Crack Filling is carried out to fill non-working cracks (less than 0.098 inch (2.5 mm) of horizontal movement) for cost-effectiveness in pavements with low to moderate traffic levels [1].

- Short-term crack filler (1 to 3 years) utilizes asphalt cement, cold pour or hot pour sealant placed in a flush-fill or overband configuration is considered most appropriate.
- Long-term crack filler (between 5 and 8 years) utilizes an asphalt rubber or rubberized asphalt placed in either a flush-fill or overband configuration is considered most appropriate. The higher quality of these materials and the added life provided by the overband make for the most cost effective options in this scenario.

The following Table provides recommended Crack Treatment Criteria for determining which cracks to seal and which to fill, given various crack characteristics. In comparison to crack filling, crack sealing involves much more planning and uses specially formulated materials and more sophisticated equipment [1].

Table B. 3 Criteria for sealing or filling of cracks.

Crack characteristics	Crack treatment activity	
	Crack sealing	Crack filling
Width, inch (mm)	0.19 to 0.98 (5 to 25)	0.19 to 0.98 (5 to 25)
Edge deterioration (i.e.; spalls, secondary cracks)	Minimal to none(≤ 25% of crack length)	Moderate to none (≤ 50% of crack length)
Annual horizontal movement, inch (mm)	≥ 0.098 (2.5)	> 0.098 (2.5)
Types of cracks	Transvers thermal cracks	Longitudinal reflective cracks
	Transverse reflective cracks	Longitudinal cold-joints cracks
	Diagonal cracks	Distantly spaced blocked cracks

Crack Performance

Central and Northern Alberta can experience horizontal crack movements in excess of 0.78 inch (20 mm). This extreme amount of crack movement requires a high level of workmanship to ensure that the crack is located in the center of the rout and the use of high quality modified rubberized asphalt materials. Performance of the crack treatment is dependent on three factors; initial pavement condition, product selection, and production installation.

It is very important that the crack/rout be as clean and dry as possible. Sealant should be applied soon after the crack has been routed and cleaned with the hot-air lance. Air temperature, AC surface temperature and humidity all need to be considered during the product installation. Route and seal should not be applied following a rain event. The pavement must be as dry as possible. In addition to that, the selection of what time of the season the crack sealant should be applied is often a compromise between the effect of crack movement on sealant performance and sealant installation.

Cool air temperatures can reduce the temperature of the pavement surface thus causing a hot-pour sealant to gel more quickly. As a result of this, sealant penetration is reduced which can then lead to lower than expected adhesion and performance. Crack sealant should not be applied when the pavement temperature is below 10^{o}C. Crack sealing in the summer months reduces the effect of air temperature. Crack filling with cold-pour bituminous emulsions should be applied in late spring when the air temperature is 10^{o}C or higher. This will permit sufficient time for the emulsion to shed its residual water. Low temperatures and high relative humidity will extend curing time. In addition, a filler that experiences freezing temperatures or rain within 24 hours of application will be adversely effective. Crack filling can be done on non-working cracks during the summer months.

Crack Repair Options

Crack repair is carried out on cracks with extreme edge deterioration (cupping or lipping). Spray Patching and Mill & Fill are two treatments that can be considered for cost-effective crack repair with low to moderate traffic levels. For medium-term crack repair performance (3 to 4 years), spray patch and sand/sulfur slurry patch (thermo patch) are considered most appropriate. Spray patching should only be considered if cracks are depressed more than 0.39 inch (10 mm). It can be used as a pre-overlay treatment. For long-term crack repair performance (5 to 8 years), Mill & Fill is considered most appropriate. Mill & Fill should be used at locations were tented, or failed transverse cracks exist.

This treatment will improve the ride and restore structural integrity at the repaired locations. Mill & Fill can be used as a pre-overlay repair. It should not be considered if the base of the structure is weak, and a more extensive repair is required.

B2 British Columbia

The government of British Columbia ministry of transportation provides a guideline for the materials to be used in crack sealing and also the equipment and construction considerations as follows [2].

Materials requirements

- Asphaltic: The rubberized asphaltic and/or elasticized asphalt sealant products shall meet the requirements of ASTM D 6690. It shall be noted that ASTM D 6690 requirements are not mandatory in the Lower Mainland, Vancouver Island or the Sunshine Coast.

- Sand: On pavements that require the use of High Float Emulsified Asphalt, the Contractor shall supply "blinding sand." The sand, when tested according to ASTM C 117, shall meet the gradation requirements shown in Table B.4.
- Dust Cover: Pavements that are sealed with rubberized or elasticized sealant shall receive a dust coating with a material such as Portland Cement, talc, lime.

Table B. 4 Gradation requirements for blinding sand

Sieve inch (mm)	% Passing
0.24 (6.3)	100
0.18 (4.75)	95-100
0.092 (2.36)	50-100
0.02 (0.6)	20-70
0.01 (0.3)	5-25
0.003 (0.075)	0-3

Equipment requirements

- Router: The Contractor shall provide a vertical router capable of routing asphaltic pavements to a depth of 0.98 inch (25 mm) and a width of 0.62 inch (16 mm). It shall be capable of a minimum production of 656.1 ft (200 m) per hour, even when following meandering cracks without unnecessary pavement cutting.
- Cleaner: The cleaner unit shall be a hot compressed air fed propane fired device capable of cleaning, heating and drying routed cracks with not less than 1.7 m^3/min. of compressed air at 690 kPa. It shall have valve/hose and fittings for the mixture of liquid propane gas and compressed air. The hot air exhaust shall not exceed 315^{o}C.
- Melter: The melting kettle shall be of the double boiler type supplying indirect heating to slowly heat the asphaltic material with heat transfer oil. It shall have built in calibrated thermometers for both transfer oil and the sealing compound. The heating of the sealant shall be efficient and thermostatically controlled so as not to exceed the manufacturer's maximum safe heating temperature and shall be such as to maintain a constant temperature once the sealant is heated. The melter shall be capable of constantly agitating the asphaltic material as it is being heated and shall have a pump circulating the sealant from the bottom to the top of the kettle.
- Filler Tools: Crack filler devices and strike off tools must be such that successful forming of the bead of sealant over the prepared crack is achieved.

Construction requirements

Crack sealing shall only be performed when the pavement surfaces are dry, and the crack and road base are dry or nearly dry (no visible moisture), and the temperature shall be 10^{o}C. Cracks up to 0.62 inch (16 mm) in width shall be widened by using a router to form a sealant reservoir 0.62 inch (16 mm) in width and from keeping the crack centerline within ± 0.31 inch (8 mm) of the center of the rout and shall be cleaned with a hot compressed air lance.

The routing speed shall be such that the pavement is carefully cut, not broken or torn out, and the sides of the rout are smooth and uniform. The surface of the pavement and routed crack shall be cleaned of all dust and routing debris.

Routing should not be carried out on pavements that are of such an age that pavement fractures or spalls occur along the edge of the freshly routed crack. Normally pavement fractures or spalls should not occur unless pavements are in excess of 10 years old.

The crack shall be filled with sealant from the bottom to the surface level in such a manner that the sealant does not bridge entrapped air pockets. Material shall be placed to overfill the crack. It will then be struck off to leave a uniform amount of sealant directly over the crack, with the edges of the spread evenly feathered to overlap on the pavement surface from a minimum of 0.98 inch (25 mm) to a maximum of 1.57 inch (40 mm) on each side of the crack. The sealant overband shall not be so thick that it can be removed during snow plowing or produce a noticeable bump when traversed by traffic.

Selection of materials

- Rubberized and Elasticized Asphalt Sealants: These shall be used on pavements that are less than 10 years old and where the majority of cracks are less than 0.98 inch (25 mm) in width. The sealant shall be applied to cracks that have been routed to a uniform depth and width. Cracks having a width greater than 0.62 inch (16 mm) need not be routed but shall be cleaned to a minimum depth of 0.98 inch (25 mm). Within two minutes of the completion of the cleaning operation, the crack shall be filled with sealant from a melter using a connecting wand or manual applicator (pouring cone) which ensures minimum pour application temperatures for the product are maintained. Upon completion of the pouring, the sealant shall be dusted to prevent the asphalt from tracking. Excess dusting material shall be removed.
- High Float Emulsified Asphalt: High Float Emulsified Asphalt shall be used on pavement where there are depressions or lipping at the cracks, or where the majority of cracks are over 0.98 inch (25 mm) in width. The cracks shall be cleaned, as close to the actual depth as possible and the removed material shall be disposed of in an environmentally compliant and sound manner. Immediately after cleaning, they shall be filled with sealant from a distributor truck or melter. The distributor truck or melter shall have an efficient means of heating the sealant to any temperature up to 100^{o}C and maintaining it constantly at the manufacturer's prescribed temperature without overheating. Upon completion of the sealing of the crack, the sealant shall be sanded to prevent the asphalt from tracking. Excess sand shall be removed and disposed of.

B3 Colorado

The Colorado DOT has an outline to elaborate on the construction requirements and material requirements used for crack maintenance that can be summarized as follows [3].

Construction requirements

Immediately before applying hot poured crack sealant, the cracks shall be cleaned of loose and foreign matter to a depth approximately twice the crack width. Cleaning shall be performed using a hot compressed air lance. This lance shall be used to dry and warm the adjacent asphalt immediately prior to sealing. Direct flame dryers shall not be used. Cracks shall be filled with hot poured joint and crack sealant flush with the pavement surface. Immediately following the filling of the crack, excess sealant shall be leveled off at the wearing surface by squeegee, a shoe attached to the applicator wand, or other suitable means. The squeegeed material shall be centered on the cracks and shall not exceed 3 inches in width or 1/16 inch in depth. The sealant material shall be heated and applied according to the manufacturer’s recommendations. The equipment for heating the material shall be an indirect heating type double boiler using oil or other heat transfer medium and shall be capable of constant agitation. The heating equipment shall be capable of controlling the sealant material

temperature within the manufacturer's recommended temperature range and shall be equipped with a calibrated thermometer capable of ±5 °F accuracy from 200 to 600 °F.
The face of the crack shall be surface dry and the air and pavement temperatures shall both be at least 40 °F and rising at the time of sealant application [3].

Materials requirements

Hot poured material for filling cracks shall conform to the requirements of ASTM D 6690, Type I or II. Sealant material shall be supplied pre-blended, pre-reacted, and prepackaged. During the crack sealing operation, the following guidelines should be considered [3]:

- Crack Width: Crack sealing is done for cracks between 0.125 and one inch in width.
- Crack Preparation: Prior to sealing, cracks should be properly cleaned of loose and foreign material to the specified depth. This operation is generally performed with hot compressed air. Immediately prior to sealing, the vertical faces of the joint or crack should be clean, dry, and warm. This promotes a positive bond of the sealant material to the vertical faces.
- Sealant Temperature: The sealant temperature should be periodically verified for conformance. Overheating degrades the material and should not be permitted.
- Sealing Operation: The sealant should be poured in the crack reservoir to a height flush with the pavement surface. Excess sealant material must not remain on the surface but should be squeegeed to the specified width on either side of the crack or joint.

B4 Kansas

Kansas DOT provides the following guidelines for crack sealing [4]:

- Crack should be sealed in asphalt pavement when they are equal to or greater than 1/8 inch wide.
- Cracks less than 1/8- inch wide should not be sealed.
- Cracks wider than 2 inches should not be sealed also.
- Cracks that are 1/8 to 1/2 inch wide should be routed following the existing crack.
- Cracks should be routed as follows: 1/8 to 3/8 inch with a 5/8 inch router head, 3/8 to 1/2 inch with a 3/4 inch router head and to a depth equal to or greater than the router head width.
- Cracks wider than 1/2 inch do not require routing.
- The full depth of the cracks should be cleaned. All foreign material that will prevent bonding of the sealant should be removed. Loose material on the surface immediately adjacent to the cracks should be removed immediately.
- The cracks should be cleaned and dried with a heat lance. The pavement should not be burnt (indicated by smoke) with the heat lance.
- The routed cracks (1/8 to 1/2 inch) should be filled with hot type joint sealing compound. The un-routed cracks wider than 1/2 inch should be filled with hot fiber-reinforced asphalt.
- All cracks should be filled to a level slightly recessed from the pavement surface.
- Cracks greater than 1/8 inch, but less than 3/8 inch, and greater than 3/8 inch but less than or equal to1/2 inch wide shall be routed to a depth and width of 5/8 inch and 3/4 inch respectively, then cleaned and filled with hot type joint sealing compound asphalt.
- Cracks greater than 1/2 inch wide should not be routed.

B5 Minnesota

Minnesota DOT provides a guideline for typical crack maintenance operations as well as suggested materials to be utilized as follows [5].

Crack repair treatments

- Clean and seal: Prepare cracks by blowing out debris and heating the crack face. Use hot air lances and compressed air before filling with sealant.
- Crack filling: This treatment differs from crack sealing mainly in the preparation given to the crack prior to treatment and the type of material used. Various fillers may not exhibit the same type of adhesive or elastic properties that is expected of sealant. Crack filling is most often reserved for more worn pavements with more random cracking that is usually wider than 3/4 inch.
- Rout and seal: This treatment is used on transverse cracks. A pavement saw or router creates a reservoir centered over existing cracks. The routed crack is then filled with sealant.
- Saw and seal: Pavement saws create transverse joints at regular intervals along a newly placed pavement, and are then filled with sealant [5].

Rout and Seal Treatment

- Timing: Recommend spring or autumn time frame during dry conditions.
- Preparation options: Transverse cracks less than or equal to 19 mm [0.75 inches] wide shall be routed, cleaned and sealed.
- Material choices:
  - Transverse cracks – Sealant meets requirements of Mn/DOT specification 3725, low modulus type sealant.
  - Longitudinal cracks – Clean and seal, do not rout. Use Mn/DOT specification 3723 sealant, or 3719 sealant on more severe longitudinal cracks.
- Methods: Mn/DOT standard rout configuration is 3/4 inch x 3/4 inch. A rout Width/Depth ratio =1 may improve sealant performance, but excessive widths are prone to failure [5].

B6 Missouri

The following guidelines illustrate the crack maintenance procedures in Missouri DOT [6]:

- Cracks should be opened sufficiently (1/8" or more) to allow pouring. Cracks should be filled or sealed to exclude foreign matter and prevent spalling, preserve the original filler and provide a smooth riding surface.
- Pouring or sealing of cracks should be done in the latter part of the year when cracks have opened and temperatures are below 40 °F. It should be completed preferably before January 1, to exclude moisture for heavy winter snows. Work should not be done during extremely low temperatures, cutbacks should not be used when the pavement is wet and emulsions should not be used when the temperature is below freezing.
- RC-800 or RC-3000 cutback asphalt or CRS-2 emulsified asphalt is used for the filler.
- Pouring is usually done with cone shaped pouring pots or with wands connected to a distributor.

- The asphalt filler must be maintained to required temperatures. Care must be exercised in pouring to limit pouring and minimize tracking of asphalt on to the centerline stripe.
- Blotting material, usually sawdust or sand, should be applied immediately to help prevent tracking.
- Cracks which have become excessively spalled or open should be filled with a sand-asphalt mix, such as "Black Annie" or other fine graded mix. This should be done in conjunction with crack pouring if of a minor nature.
- Filler Material that is emerging from cracks to such an extent that it forms objectionable ridges and bumps and, in some cases, is being tracked, should be removed. This can be accomplished by cutting off the excess material with a motor-grader or by heating with a burner and scraping [6].

B7 Montana

Cracks can be classified as either working or non-working. Working cracks change crack width more dramatically with temperature changes in the mat. This requires the crack sealant be more elastic than sealants for non-working [7].

- Transverse or diagonal cracks are usually found to be working cracks because of the sizable spacing between adjacent cracks.
- Longitudinal and block cracks, on the other hand, are normally found to be non-working cracks due to the short crack spacing or close proximity to the free edge of the pavement.

The following guidelines can be attributed to the selection of materials for crack maintenance [7]:

- Asphalt cement and liquid asphalt have little flexibility and are very temperature susceptible. Thus, they are limited to use as crack filler, not as a crack sealer. Additives such as mineral fillers and fibers provide minimal elasticity to asphalt and do not significantly affect temperature susceptibility. Mineral-filled and fiberized asphalt are most appropriate in crack filling operation.
- The addition of rubber polymer to liquid or heated asphalt generally improves field performance because it gives flexibility to the asphalt. The degree of flexibility basically depends on the type and nature of the asphalt, the percentage of vulcanized rubber used, and how rubber is incorporated into the asphalt (i.e. mixed or melted in). Other polymers are often incorporated into asphalt either exclusively or along with rubber to increase resilience.

The following capability and testing specification requirements shall be satisfied for a material to be utilized in crack maintenance [7].

- Cone penetration, 77°F dmm (ASTM D5329) →3.9-5.9inch (100-150 mm)
- Cone penetration, 0°F dmm (ASTM D5329 MOD) →25 Min.
- Flow, 140°F, 5h (ASTM D5329) →0.39 inch (10 mm) max.
- Resilience. (ASTM D5329) →30-60%
- Bond, -20°F, 200% ext. (ASTM D5329) →Pass 3 Cycles
- Recommended pour temperature →380°F
- Safe heating temperature →410°F
- Asphalt compatibility (ASTM D5329) →Pass
- Product shall be free of fabric, metal, water, volatile solvents or any other contaminating debris.

- Product shall, during the production process, be heated to a sufficient temperature to guarantee activation of all product components.

Material application consideration

Begin the hot-pour application once the material has reached the recommended application temperature and the first few cracks have been prepared. From this point, the focus is on three items [7]:

- Ensure material remains at or near die recommended application temperature without overheating.
- Maintain a sufficient supply of heated material in the kettle.
- Properly dispense die right amount of material into the crack reservoir.

Guidelines for maintaining hot-applied material in a sufficient quantity and at the proper temperature during application are:

- Check the temperature of the material at the nozzle and in the melting vat. It is recommended that the temperatures be checked using a hand-held infrared temperature gun.
- Adjust the heating controls to reach the recommended application temperature (or as near to as possible without exceeding the safe heating temperature.)
- Check the sealant temperatures regularly and adjust as necessary.
- Watch for carbon buildup on the sidewalk of the heating chamber and visually inspect material for changes in consistency.
- Check the level of material in the melting vat periodically. Add material on a regular basis to avoid heat loss from a large quantity of cold material

General guidelines for material application include:

- Apply the material with the nozzle in the crack channel so that the channel is filled from the bottom up and air is not trapped beneath the material.
- Apply the material in a continuous motion, making sure to fill the channel to the proper level (flush with the pavement surface).
- Re-circulate material through the wand into the melting vat during idle periods.
- Reapply material to crack segments where material has sunk into the crack or an insufficient amount was furnished in the previous pass.

Weather considerations

Weather plays an extremely important role in crack seal operation. A sudden change of weather may adversely affect the project. The ideal conditions for applying a crack seal are warm temperatures with relatively low humidity', and little or no wind. There are, however, periods when weather patterns are more likely to follow these requirements than at other times. Early spring or late fall brings low temperatures and high wind problems.

Humidity

It is best if the humidity is 50 percent or lower when the sealant is applied. With any asphalt the lower the humidity the better. High humidity will cause an invisible film of moisture to collect m the cracks, which detract from the sealant sucking properly to the surface. You will often see small bubbles forming and breaking as the air and moisture works its way to the sealant surface.

Rain

Sealant should never be applied during rain. If rains is in the vicinity and predicted for the area, operations should be suspended until it clears. In case of sudden raining shut off the crack sealing pot immediately and wait until the shower is gone and the cracks dry. After a rain always suspend operations until the cracks have ample time to dry. Recheck pavement temperatures and be aware of the increased humidity.

Table B.5 illustrates the troubleshooting matrix for causes of problems during crack sealing operations developed by Montana DOT.

Table B. 5 Matrix for troubleshooting causes for problems during crack sealing operations.

Problem encountered	Possible causes	Possible solutions
Bubbles in Sealant.	Damaged backer rod. Wrong backer rod.	Change rod installation method or rod diameter.
	Moisture in joint.	
	Grass or weeds in joint.	
	Bubbles in melter. Moisture present.	Add sealant material.
		Reduce agitator speed.
		Slowly heat until water evaporates.
	Air trapped by sealant.	Fill reservoir from bottom.
Sealant is deeply sunken in reservoir.	Rod is slipping into crack. No rod present.	Use proper rod diameter.
Sealant surface is not consistent.	Operator control is poor. Operator movement is uneven. Reservoir width/depth	Use a nozzle with a depth control plate. Use a wand with a shutoff at the nozzle. Use an experienced operator.
	Inconsistent material temperature	
Sealant is not sticking to routed reservoir walls.	Reservoir walls are not clean.	Remove all old sealant, oil, dust, dirt, and other contaminant.
	There is moisture on the walls from rain, dew, or condensation.	Wait for pavement to dry. Use a heat lance if slightly damp. Use an air compressor with a moisture trap.
	Sealant temperature is too low.	Maintain recommended sealant temperature.
	Pavement temperature is too low.	Wait until warm.
Sealant remains tack) after installation.	Kettle is contaminated with heat transfer oil, solvent or other sealant.	Remove sealant.
		Replace with uncontaminated sealant.
	Sealant has been overheated or heated too long.	Remove and replace with fresh sealant. Check melter temperatures.

B8 Nebraska

Nebraska Department of Roads uses a pavement maintenance manual for guidelines in crack maintenance practices, as outlined below [8]:

Preparation of crack surface

Surface preparation can be accomplished with compressed air and a simple blowpipe. This technique works well when the dirt is dry and not packed hard. If the cracks are filled with wet dirt, the dirt needs to be removed and the crack must be completely dried. An air compressor or a hot air lance generating temperatures of approximately 2,500°F is the best tool.

Cutting a reservoir above the crack allows adequate sealant expansion and contraction. The reservoir also ensures that the proper amount of sealant penetrates the crack. An operator passes the pavement cutter or router over the crack and cuts a reservoir into the crack. Once the routing is complete, use compressed air (hot or cold) to remove the dust created by the router. Engine-powered steel wire brushes also can be used to clean routed and non-routed cracks [8].

Application of materials

Hot pour sealants are effectively applied through a delivery hose and wand. These materials are commonly applied at 375°F. To prevent sealant cooling, set up, and clog, the hose is placed under constant pressure and the sealant constantly circulates back into the main tank [8].

Environmental conditions for application of materials

It is important to remember that, although crack filling and sealing is not totally dependent on the size of the opening and that the operation can be performed at any time of the year, moisture in the crack is the critical factor in preventing a quality seal. The fall of the year usually provides the best conditions because of the moderate temperatures, minimal rainfall, and the cracks are reaching their midpoint in width. This time-frame also prevents the intrusion of water and chemicals during the winter months. During the summer, crack openings would be too small to seal. During the spring, although temperatures are often moderate, crack filling crews may have to contend with the moisture in the pavement.

The optimum environment for performing the crack filling and sealing operations are; temperature above freezing, minimal moisture present in the pavement, and cracks open to approximately the midpoint

To minimize the problem of moisture in cracks, a commercial heating unit (heat lance) should be used. Heat lances have produced good results, when capable of producing approximately 2,500°F air and operating velocities of approximately 3000 FPS at the nozzle orifice, [8].

Materials utilized

To obtain a good seal, it is important to use a quality product. For cracks 1 inch wide or less, an ASTM D5078-90 sealant should be used. Application should be made under pressure, using a 1⁄8 inch diameter nozzle. Asphalt with crumb rubber has been shown to work satisfactorily on cracks over 1 inch wide and up to 1 1⁄2 inch, but caution must be used. With rubber asphalt products, it is very important to follow the manufacturer’s recommended specifications for handling and placing the sealant [8].

Table B.6 illustrates the Nebraska DOR decision matrix table dealing with the different cracks.

Table B. 6 Decision matrix for crack maintenance in Nebraska DOR.

Flexible pavements distresses	Low		Moderate		High	
	Occasional	Frequent	Occasional	Frequent	Occasional	Frequent
Alligator cracking	3, 1	3, 6	3, 4, 6, 11	5, 6	6, 11, 13	13, 15
Edge cracking	1, 2	1, 2	2, 13	2, 13	13	13,
Longitudinal cracking	1, 2	1, 2, 6	2, 6	2, 6	2, 6, 13	2, 6, 13
Random/block cracking	1, 2	2, 3	2, 6	2, 6	6, 11, 12	6, 12, 14
Raveling/weathering	1, 3, 6	3, 5, 6	4, 6	6, 7	5, 6, 11	6, 11, 12
Distortion	1, 8, 13	1, 8, 13	2, 8, 13	2, 6, 8, 13	6, 8, 11, 13	8, 13, 14
Rutting	1	1	6+8	6+8	6+8, 12	8, 12, 14
Excess asphalt	1	1, 6	1, 6, 8	6, 8	6+8	6+8, or 12
Transverse cracking	1, 2	2	2, 6	2, 6	2, 6	2, 6, 13

Pavement treatments key

1 = Do nothing	9 = Cold in-place recycle
2 = Crack seal or fill	10 = Hot in-place recycle
3 = fog seal	11 = Thin cold mix overlay
4 = Scrub seal (Broom seal)	12 = Thin hot mix overlay
5= Slurry seal	13 = Patching
6 = Chip seal/ Armor coat	14 = Thick overlay
7 = Micro surfacing	15 = Total reconstruction
8 = Mill	

B9 Ontario

Ontario sets criteria for definitions as well as operations related to crack maintenance as follows [9]:

- Crack sealant: Crack sealant shall be hot poured rubberized asphalt sealant conforming to OPSS 1212.
- Router: The router shall be a mechanical router capable of following meandering cracks, keeping the rout centerline within 0.31 inch (8 mm) of the center of the crack, and providing a rout width of 1.57 inch (40 mm) to 1.96 inch (50 mm) and a depth of 0.23 inch (6 mm) to 0.31 inch (8 mm).
- Heating Kettle: The heating kettle for sealant compound shall be a double boiler oil heat transfer type, with built in agitator and equipped with thermometers to measure the temperature of both heat transfer oil and the sealing compound. The heating kettle shall have automatic thermometric controls which will prevent overheating of the sealant.
- Compressed air lance: The hot compressed air lance shall have a discharge air temperature greater than 1000°C and an air velocity greater than 3280.8 ft (1000 m) per second.

- Construction: The work of routing and sealing cracks in hot mix asphalt pavement shall include preparation of the crack sealant, routing and cleaning the cracks, and the placing of the crack sealant compound.
- Crack routing: Cracks up to 0.78 inch (20 mm) in width shall be routed.
- Sealant preparation: The sealant compound shall be melted slowly with constant agitation until it is in a lump-free, free-flowing state, within the temperature range recommended by the manufacturer for application. Heating above the manufacturer's recommended range for application is not permitted.
- Crack cleaning: Immediately prior to pouring the sealant compound, the routed cracks shall be cleaned and dried using a hot compressed air lance. The routed grooves shall be treated with hot compressed air until the pavement in the groove is darkened.
- Placing sealant: The sealant compound shall be placed within two minutes of the hot lance treatment by a manual pouring cone, or hose and wand fitted with proper size tip from a low pressure pump connected to the heating kettle. The tip of the cone or wand shall be placed to the bottom of the crack to ensure uniform application. The routed cracks are to be filled with sealant compound so that upon cooling, the sealant compound is flush with the adjacent pavement surface.
- If after the initial placement, the material subsides below the pavement surface, then additional material shall be applied prior to sealant dusting. On surfaces to be overlaid with hot mix, cracks shall be filled such that the top of the sealant is 0.15 inch (4 mm) to 0.23 inch (6 mm) below existing asphalt pavement surface.
- Sealant Dusting: When traffic is to be maintained during crack sealing, the surface shall be dusted with Portland cement, to eliminate the adhesiveness prior to allowing traffic on the treated areas [9].

B10 Pennsylvania

Only well-defined cracks, 1/4 inch to 1 inch in width shall be sealed. Areas that have multiple cracks or cracks less than 1/4 inch wide should be skin patched. Cracks that vary in width within the prescribed parameters shall be sealed along their entire length. Care must be taken not to overlap, run together, or cause a dense amount of sealant to accumulate on the pavement [10]. The following procedure should be carried out for crack maintenance:

- Routing: Routing is required for transverse cracks and single random cracks when the pavement is less than 5 years old and is not scheduled for resurfacing for at least 2 years. Areas that contain a significant amount of old sealant material should not be routed. A reservoir should be created for sealant material with the router that has the approximate dimensions of 1/2 inch wide by 1/2 inch depth.
- Cleaning: Cracks shall be thoroughly cleaned of all dirt, dust or foreign materials with compressed air at 100 psi.
- Drying: It is very important that all cracks be dry. A Hot Compressed Air Lance (HCAL) shall be used to dry all damp cracks. Care must be taken so as to not burn, scorch, or damage the pavement.
- Sealing Equipment: A “double boiler” style kettle with calibrated temperature gauges and full sweep agitator must be used for prepackaged sealing material.
- Materials: The preferred material for roads with multiple cracking situations (with cracks that require routing and cracks that don’t require routing) is Type IV – AASHTO 173. It is also important to heat and apply the sealant being used to the manufacturers specifications both for quality performance and safety concerns. The

temperature limits as listed on the outside of the shipping package shall be adhered to at all times.

- Sealing: All cracks should be uniformly filled and sealed. Cracks shall be sealed by placing the applicator wand in or directly over the crack and carefully placing the sealant to just fill the crack. The sealant shall be wiped off flush with the pavement surface using a squeegee. Only a narrow, thin film of material shall be permitted on the pavement surface. The film shall not be greater than 3” wide and 1/32” thick. Sealant placed in excess of these dimensions shall be removed [10].

B11 URLs of Best Management Practices

1. http://www.transportation.alberta.ca/Content/docType253/Production/CrTrtmntGdln.pdf (9/4/2013)
2. http://www.th.gov.bc.ca/publications/const_maint/contract_serv/standard_specs/Volume_1_SS2012.pdf (9/4/2013)
3. http://www.coloradodot.info/business/designsupport/bulletins_manuals/cdot-construction-manual/2002-construction-manual-2004-revisions/Section%20400-Rev%2004%20vers%202.pdf/view (9/4/2013)
4. http://www.igga.net/specs/pdfs/KS-RESmr.pdf (9/4/2013)
5. http://www.lrrb.org/media/reports/200854.pdf (9/4/2013)
6. http://epg.modot.mo.gov/index.php?title=570.2_Joint_and_Crack_Maintenance (9/4/2013)
7. http://www.mdtinfo.mdt.mt.gov/maint/docs/crackseal.pdf
8. http://www.transportation.nebraska.gov/docs/pavement.pdf
9. http://applications.roadauthority.com/Standards/Home/FileDownload?standardFileId=7f29fb98-1ad1-4b1d-81d4-d63c7c923814 (9/4/2013)
10. ftp://ftp.dot.state.pa.us/public/pubsforms/Publications/PUB%20113.pdf (9/4/2013)