Best practices for crack treatments in asphalt pavements

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ABSTRACT

Treating cracks in asphalt pavements is a major part of every maintenance engineer's work. The objective of any crack treatment is to minimize the intrusion of water into underlying layers of the pavement structure. Such water infiltrates the base layers of the pavement and may lead to pavement structural failures.

Crack treatments fall into two broad categories – crack sealing and crack filling. Crack sealing is generally performed on "working" cracks. Crack filling is generally performed on "non-working" cracks.

The objective of this project was to review the state-of-the-art in crack treatments through a literature review, establish the state-of-the-practice regarding construction techniques based on an extensive survey of agencies and contractors, and to develop a Best Practices guideline that will improve the effectiveness of crack sealing and crack filling.

This report addresses only the Best Practices guidelines for crack sealing and crack filling. The work was part of NCHRP Project 20-07, Task 339 which was recently completed by the author.

Keywords: Maintenance, Reflective Cracking, Repair method, Thermal Cracking

1. INTRODUCTION

Reportedly the first asphalt pavement was built in the United States in about 1828 - the National Road between Wheeling, West Virginia and Zanesville, Ohio [1]. Although undocumented, it is likely that within a few years of construction of this first asphalt pavement, engineers began to discuss what to do about cracking in the pavements. Cracks are prevalent throughout the approximately 4.2 million kilometers of paved roads in the United States.

The objective of any crack sealing or crack filling operation is to minimize the intrusion of water into underlying layers of the pavement structure. Such water intrusion weakens the base materials and may lead to pavement structural failures. Much research has been performed in the United States and worldwide on the materials and designs for crack sealing and crack filling for flexible pavements; however, little is known about variability in the current state-of-the-practice regarding construction techniques and the resulting effectiveness of crack sealing and crack filling.

The National Cooperative Highway Research Program has published two previous documents on the subject of crack sealing, NCHRP Report 38 by Cook and Lewis in 1967 [2] and NCHRP Synthesis 98 by Peterson in 1982 [3]. This report presents the Best Practices portion of a recent study published as NCHRP Report 784 by Decker [4]. NCHRP Report 784 summarizes the state-of-the-art and current state-of-the-practice of crack sealing and crack filling and concludes with current best practices. The report was limited to crack sealing and crack filling of asphalt pavements, and did not consider joint filling on concrete pavements, reflective cracking retardation techniques, joint construction techniques, or other related issues.

Crack sealing and crack filling are a widely used maintenance activity for in-service pavements. The techniques are inexpensive, quick and a well-proven approach to extend the life of the pavement, predicated on the use of the right materials at the right time using the right protocols.

In a memo from David Geiger in September 2005 [5], the Federal Highway Administration (FHWA) describes a Pavement Preservation program as consisting of Preventative Maintenance, Pavement Rehabilitation (structural and non-structural) and Routine Maintenance activities. FHWA categorizes crack sealing as Preventative Maintenance and crack filling as Routine Maintenance. Ponniah [7] also describes a crack sealing program as a preventative maintenance treatment, not a corrective maintenance measure.

FHWA published the guidelines presented in Table 1 for the determination of the type of maintenance to be performed [6]. These guidelines establish criteria for when to use crack treatments.

Table 1: Guidelines for Determining the Type of Maintenance to be Performed

Crack Density	Average Level of Edge Deterioration (% of crack length)		
	Low (0-25)	Moderate (26-50)	High (51-100)
Low	Do Nothing	Do Nothing or Crack Treatment	Crack Repair
Moderate	Crack Treatment	Crack Treatment	Crack Repair
High	Surface Treatment	Surface Treatment	Rehabilitation

Chong and Phang [8] describe the consequences of not sealing cracks:

1. Increased maintenance costs because deteriorated cracks are difficult and expensive to repair through corrective maintenance;
2. Increased user costs (vehicle repair and operation);
3. Increased rehabilitation costs, because deteriorated cracks demand special treatment from the designer when pavement rehabilitation is scheduled; and
4. Loss of serviceability and, therefore, service life.

Crack sealing and crack filling are widely used for preventative maintenance of asphalt pavements; however, successful crack sealing and crack filling applications continue to be perceived as an art. When not properly applied, these pavement preservation treatments can result in early failures and costly corrective maintenance for user agencies.

1.1 Scope of Work

The 1967 NCHRP Report on Crack Sealing [2] stated: “Crack sealing is receiving very little engineering attention. Most cracks are simply filled occasionally with a tar or an asphalt.” This statement is still true in some jurisdictions.

A literature review was conducted to determine the state-of-the-art for crack sealing and crack filling. The State-of-the-Practice was developed through the use of a survey sent to maintenance engineers and material suppliers. Approximately 150 responses were received from multiple levels of agency personnel (city, county, state, federal), along with a few private sector people. The State-of-the-Practice provides insight into current techniques for crack sealing and crack filling. Details of these efforts can be found in NCHRP Report 784 [4].

The Best Practices discussed herein present the techniques and protocols necessary to achieve good performance from crack sealing and crack filling operations. Variations between State-of-the-Art and State-of-the-Practice exist as would be expected. The development of the Best Practices emphasizes proper procedures in the hope of improving the state-of-the-practice.

CHAPTER 2 – STATE-OF-THE-ART

2.0 Summary of Literature Review

A literature review was conducted on the state-of-the-art for crack sealing and crack filling. Approximately 115 technical publications, state specifications and test methods were reviewed. A brief overview will be presented herein. Full details can be found in NCHRP 784 [4].

2.1 General Issues/Project Selection

Crack sealing and crack filling have been used as a maintenance procedure for asphalt pavements for many years. The technical literature is in general agreement with the following definitions of the two procedures:

2.1.1 Definitions

Crack sealing: materials are placed into and/or above "working" cracks in order to prevent the intrusion of water and incompressibles into the cracks ("working" cracks refer to cracks that undergo significant amounts of movement"). Crack sealing is commonly used as a transverse crack treatment [9].

Crack filling: placement of materials into "non-working" cracks to substantially reduce water infiltration and reinforce adjacent cracks. Crack filling is commonly used as a longitudinal crack treatment [9].

Crack routing: routing is used to open up the crack to accommodate enough sealant to provide an effective seal even after the pavement crack opens due to contraction at low temperature during the winter months [8].

Adhesion: The binding force exerted by molecules of unlike substances when brought in contact [10].

Cohesion: That force by which molecules of the same kind or of the same body are held together so that the substance or body resists separation [10].

Working Crack: Identifying whether the crack is "working" (i.e., moving as a result of contraction and expansion) or not is a challenge. In the 1999 LTPP report, FHWA defined the amount of movement for "working" classification as 2.5mm; however, currently the value most commonly referenced is 3mm [8, 9, 12, 13, 14, 15].

Masson, et.al. [16] present Figure 1 to illustrate potential cracking conditions. Cracking illustrated in the top two line sketches are appropriate for crack treatment. The bottom sketch illustrates a branched crack condition that is not appropriate for crack treatment. Figures 1 to 3 illustrate pavements where cracking is excessive and where crack treatments were inappropriately applied.

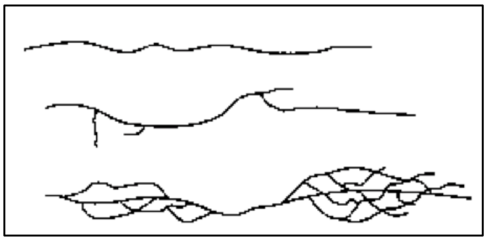

Figure 1. Cracking Graphic from Masson [16]

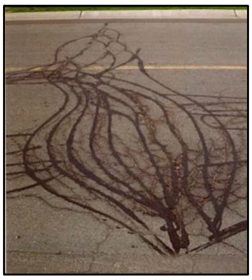

Figure 2. Wrong Application [16]

Figure 3. Excessive Crack Filling (Photograph by Dale Decker)

The California Department of Transportation (CalTrans) has the criteria shown in Table 2 for crack sealing/filling (15).

Table 2: CalTrans Cracking Criteria [15]

	Crack Sealing	Crack Filling
Applicable Width	3-25mm	3-25mm
Edge Deterioration	<25%	<50%
Annual Horizontal Movement	3mm Working	3mm Non-Working
Appropriate Type of Crack	Transverse Thermal Transverse Reflective Longitudinal Reflective Longitudinal Cold Joint	Longitudinal Reflective Longitudinal Cold Joint Longitudinal Edge Block, distantly spaced

2.2 Season for Sealing

Masson, et.al. [16] demonstrate the effect of the time of year on sealing with Figure 4.

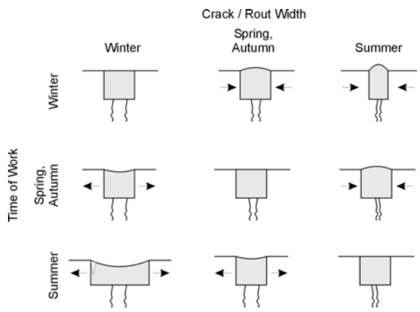

Figure 4. Seasonal Impact on Sealing Operations [16]

Figure 4 can be interpreted as follows:

- When sealing in the winter, the crack width will be at its maximum width as shown in the first row of the graphic. In the other seasons, the crack reduces in size and squeezes the sealer out of the reservoir.

• The center image of the middle row illustrates sealing in the spring/autumn. The crack is at a "middle" size and will have less deformation of the sealant during cold and hot temperatures.

• The bottom images demonstrate that if the crack is filled in the summer when the crack is at its smallest size, during the winter extreme stresses are induced on the sealant potentially leading to cohesive failure.

2.3 Crack Development

Cracks initiate in asphalt pavements for multiple reasons, the discussion of which is beyond the scope of this report. After development of the crack, expansion and contraction of the pavement during hot and cold weather, respectively, causes movement in the crack. In cold weather, the crack widens as the pavement contracts. This widening allows debris to enter the crack. In hot weather, the pavement expands thereby closing the crack. However the debris that was collected while open restricts closure of the crack and deterioration of the cracked pavement results. Cycles such as this cause continued deterioration of the pavement.

Masson and Lacasse provide a discussion of adhesive and cohesive failures. A cohesive failure occurs in the sealant that is still adhered to the crack walls. Adhesive failures occur due to debonding at or near the sealant/asphalt mixture interface. Their discussion includes precautionary comments about the compatibility of sealants and aggregates at a specific location [16].

2.4 Crack Types

While treating any crack may ultimately provide some benefit to the underlying pavement structure through the reduction of moisture intrusion, the most advantageous applications for crack sealing and/or crack filling are block, longitudinal, reflection and transverse. Unless the crack treatment is done in early stage distress development, crack treatments for fatigue cracking do not substantially improve pavement performance; however, the treatment may reduce further deterioration of the pavement. Fatigue cracking is indicative of a structural failure in the pavement system and can only be remedied by removing and replacing the failed materials.

Many references reviewed recommend not performing crack treatments on fatigue cracks (AKA, alligator or chicken wire cracks), edge and slippage cracking. Examples include references 8, 9, 13, 14, 16, 17, 21, 22, 23, 24, 25, and 26.

2.5 Crack Shape Factor

In the late 1950's and early 1960's, Tons and Schutz [27, 28] established that the shape of the crack sealing material was significant. Both concluded that the crack seal material does not change volume, just shape (cross-sectional area) during expansion and contraction. Tons showed that more shallow seals developed lower strains in the sealer. Both demonstrated that the depth-to-width proportion (so called shape factor) had a critical effect on the capacity of the sealer to withstand extension and compression. Subsequent work by Khuri and Tons [29] and Wang and Weisgerber [30] determined that a rectangular shape of the sealer was preferred. Khuri and Tons recommended wide and shallow seals with a width-to-depth ratio > 1.5 to minimize strains in the sealer. Schutz recommended a width-to-depth ratio of 2 based on evaluating the strain on the sealant.

Subsequent work by Chong and Phang [8] concluded that a 4 to 1 ratio of width to depth performed well, particularly in cold regions, for the following reasons:

1. The strain developed in the sealant was decreased.
2. Cohesive failure in the sealant was decreased.
3. 4:1 ratio provided greater bonding area horizontally in the crack compared to the vertical faces for square configurations.
4. Lower adhesive stress is developed on the sealant.
5. Easier for the router operator to follow meandering cracks.

6. Less stress on the router machine and router bits resulting in higher productivity at lower cost.

Chong [13] further recommends that 12mmx12mm rout configuration provides good performance in warmer climates and particularly for urban expressways.

Schutz noted that a bond breaker was necessary at the bottom of the crack to allow the sealer to expand and contract properly. Wang and Weisgerber further commented that bonding to the bottom of the reservoir does not have significant effect on the adhesion to the vertical walls but may lead to cohesive failure in the sealant. Backer rod as a bond breaker is illustrated in Figure 5.

Figure 5. Backer Rod (*shown as an ellipse*) as a Bond Breaker [31]

2.6 Materials

The Nebraska Department of Roads Pavement Maintenance Manual [26]: *"Value engineering study concluded 66% of total cost of crack sealing operations was for labor, 22% for equipment, and 12% for materials. Because crack sealing takes a lot of time, workers are exposed to traffic and motorists encounter delays. Therefore, it is safer and usually more cost-effective to use a product that will last longer, even if it is more expensive."*

The materials used for crack treatments have varied widely over the years, ranging from neat liquid asphalt to asphalt emulsions to polymer and/or filler modified materials. This report will not address specific products by name but addresses material types and required properties.

The products most commonly used currently can be broadly characterized as modified asphalt products. A wide variety of modification schemes are used to satisfy the specification requirements. Discussion of the specific types of modifiers used is beyond the scope of this report.

ASTM (American Society for Testing and Materials) D6690 [32] has been the reference standard for sealants for many years. Sealant Manufacturers produce a variety of products that will satisfy the ASTM requirements. ASTM D6690-12 identifies four different types of sealants as follows:

- Type I: sealant for moderate climates with low temperature performance tested at -18ºC with 50% extension

- Type II: sealant for most climates with low temperature performance tested at -29ºC with 50% extension

- Type III: sealant for most climates with low temperature performance tested at -29ºC with 50% extension – special tests are also included {ASTM notes that these specification requirements were formerly Federal Specification SS-S-1401C}

- Type IV: Sealant for very cold climates with low temperature performance tested at -29ºC with 200% extension

The reader is referred to ASTM D6690 [32] for details of the specific test requirements and procedures.

While the ASTM procedures have been in use for many years, it is well known that fundamental engineering properties of the materials are not developed from the procedures. In addition, poor correlation between field performance and lab tests exist. As noted in the table above, aging of the material is not usually evaluated. Further complicating the evaluation from a producer's perspective is the fact that many states modify the test values for local conditions [36].

Recent research by Al-Qadi, et.al. [36] in the characterization of sealants has resulted in the development of a new grading system for sealants, loosely based on the same test methods as used for Superpave PG bitumen. The concept is to develop standard methods and procedures based on fundamental material properties. This new approach is called the Performance-Based Grading system for hot-poured crack sealant. The materials are identified by an SG or Sealant Grade designation.

The Sealant Grading is identified as shown in the following example:

SG 70-16

Where

SG = Sealant Grade

70 = the high temperature performance based on tracking resistance, ^{O}C

-16 = the low temperature performance based on stiffness, adhesion and cohesion properties, ^{O}C

As with the Superpave PG grades, the SG grades can be tailored to meet the environmental requirements for the application. The grading system is based on both a high and low temperature requirement. Any combination of high and low temperature grades shown in Table 4 are theoretically possible. However, it is unlikely that there will be availability of all grades in a given region. Sealant manufacturers will undoubtedly produce a few products for a climatic area but it is unlikely that all products will be available everywhere.

At low in-service temperatures, the key issues for the sealant are to achieve proper adhesion for bonding and to have adequate flexibility and extendibility to tolerate the movement of the crack. The tests used to evaluate these low temperature issues are the direct tension test, bending beam Rheometer and adhesion tests.

At high in-service temperatures, the key issues are for the sealant to have sufficient elasticity against intrusion of debris and to resist flow and softening that could result in sealant tracking. The dynamic shear rheometer test is used to evaluate these properties.

At installation temperatures, the rotational viscometer is used to evaluate the sealant properties for easy and proper installation.

In the development of the SG system, some modifications to the PG test protocols were required.

The Sealant Grade system provides a set of evaluation protocols that will assist users in selecting the proper grade of sealant for a specific application. The tests are new to sealant products but are familiar in the asphalt bitumen testing side of the industry, albeit with minor modifications. By evaluating the rheological properties of the sealant materials, this system provides an opportunity for sealant testing to be focused on performance-based criteria.

CHAPTER 3 - BEST PRACTICES

3.0 General Issues/Project Selection

It is well established that crack sealing and crack filling are cost effective pavement maintenance techniques. As with any other activity, it is imperative that the work be done with appropriate equipment and in the best manner possible in order to get good performance. Many organizations have maintenance manuals that include Best Practices for crack sealing and crack filling. Examples can be found in References 14, 15, 17, 18, 19, 21, 22, 23, 26, 34, 35, 36, 37, and 38 . Based on review of the State-of-the-Art and State-of-the-Practice, this chapter synthesizes the Best Practice requirements to achieve a long-lasting crack treatment.

FHWA describes the steps in a crack treatment program as follows:

1. Obtain and review construction and maintenance records. This includes determination of the pavement age, design, repairs done to date, etc.
2. Perform a pavement crack survey. Record the distress types present, the amount of distress and the severity of distress.
3. Determine appropriate type of maintenance for the cracked pavement based on density and condition of cracks.
   a. A pavement surface treatment is appropriate for a pavement with high density of cracks having moderate to no crack edge deterioration.
   b. A crack treatment is proper for a pavement with moderate density of cracks having moderate to no crack edge deterioration.
   c. A crack repair is necessary for pavements with moderate density of cracks with a high level of crack edge deterioration.
4. For crack treatment, determine whether cracks should be sealed or filled.
   a. Cracks with significant annual horizontal movement ("working" cracks) should have a crack seal treatment.
   b. Cracks with little annual horizontal movement ("non-working cracks) should have a crack filling treatment.
5. Select materials and procedures for crack treatment operation based on environmental, equipment, personnel and cost effectiveness considerations.
6. Acquire materials and equipment to perform work.
7. Conduct and inspect crack treatment operation.
8. Periodically evaluate treatment performance. (6)

The first three steps are contained within a typical pavement management system. The remaining steps will be discussed in the following sections.

The definitions for crack sealing and crack filling presented previously are considered as the Best Practice for evaluation of pavement cracking. It is widely accepted that crack sealing is for "working" cracks with an opening greater than 3mm in the summer and with minimal crack edge deterioration. The opening will be much greater in the winter in cold weather climates. The cracks will often be uniformly spaced along the pavement and have limited edge deterioration. Often these cracks are routed prior to sealant installation. Crack filling is applicable for "non-working" cracks that show little movement over time and with low to moderate crack edge deterioration. "Non-working" cracks are not typically routed. These definitions generally lead to transverse cracking having a crack seal treatment and a longitudinal crack receiving a crack filling treatment. It is possible for both crack sealing and crack filling to be performed at the same time in different areas of a given project.

Michigan DOT recommends the evaluation of crack density as shown in Table 3 (36).

Table 3: Evaluation of Crack Density

Linear Crack Length per 100m pavement section	Density Definition
< 10 m	Low
10m to 135m	Moderate
>135m	High

These recommendations roughly translate into two or three full width transverse cracks in the 100 m evaluation section for crack treatment to be justified (36). These guidelines of course require good engineering judgment to ensure appropriate work is performed.

In order to make the determination between a "working" and "non-working" crack, an owner must evaluate the pavement over a period of time to determine the extent of the crack movement. Proper evaluation of pavement cracking condition is often not performed prior to crack treatment operations.

As a generality, crack sealing is typically performed in cold weather climates and crack filling is performed in warm weather climates. It was noted in the state-of-the-practice survey that many agencies do not differentiate between crack sealing and crack filling. This likely precipitates some of the performance issues experienced by some agencies.

3.1 Contracting Procedures

The manner in which an owner specifies and pays for crack treatment services is not the primary determinant for the performance of the treatment. The work may be done in-house or by contract personnel. Whether low bid, lump sum, cost plus, indefinite delivery/indefinite quantity or warranty contracting approach was used is not the key crack treatment performance predictor. Any of these approaches have the possibility of producing a crack treatment with good performance.

Consideration must be given to what works best for a specific owner, what works best for the project and what fits within the economic and political environment of the project. The deciding factors are using the right materials at the right time for the right conditions, coupled with the right people with the right training to perform the work.

3.2 Materials

The materials used for crack treatments vary in different regions of the country. States with extensive freeze/thaw activity need sealants with more ductility while warmer areas require sealants with less flow in hot weather (11).

The materials used for crack sealing are generally polymer modified asphalt based materials and are applied at high temperature (hot poured sealants). The materials used for crack filling can be either hot poured or cold-applied materials and are often asphalt emulsions. It has been shown that cold-applied materials, while easily penetrating into the crack, do not perform nearly as well as hot poured sealants. However, the emulsion products are typically significantly less expensive.

The materials used for any crack treatment project must be decided by the project engineer. This report makes no attempt to recommend or evaluate specific commercially available products. There are many products available with each having advantages and disadvantages. The purchaser of the sealant must make the product determination based on local experience and knowledge.

Sealants are selected in a given region based on manufacturer's test results for the product. The American Society for Testing and Materials (ASTM) D977 (Standard Specification for Emulsified Asphalt (39) and D2397 (Standard Specification for Cationic Emulsified Asphalt (40)) are used to evaluate cold-applied emulsion products. The emulsion specifications are focused on the emulsion product and not on the crack fill application.

ASTM D6690 (32) is used to evaluate hot poured materials. These ASTM sealant specifications have been in use for many years. A new Sealant Grade (SG) system has been developed to better address environmental variables that impact the performance of hot poured materials as was discussed previously. It is expected that sealant purchasers and manufacturers will adopt the SG system at some time in the future.

3.3 Construction

This section of the Best Practices will discuss the following issues:

- climatic conditions;
- crack configurations;
- crack preparation;
- crack cleaning;
- material preparation;
- sealant installation; and
- safety.

3.3.1 Climatic Conditions

The environmental conditions at the time of sealant placement have a significant impact on the performance of the sealant. Typically the temperature should be between 4.4 and 21.1 ^{O}C for both crack sealing and crack filling.

Montana DOT (19) has requirements for the following weather considerations:

- Temperature of the roadway surface should be 1.7^{O}C and rising.
- Humidity should be 50 percent or lower. High humidity may reduce adhesion of the sealant to the crack edges. Excess moisture can be observed as small bubbles forming in the sealant.
- Wind may be a friend or a foe. A gentle wind can help to cool the sealant more quickly, minimizing sealant tracking issues. Wind can cause problems with cleaning the cracks with potential for flying debris. Cold winds will increase melter heating time.
- Rain is cause for immediate shutdown of the crack treatment operation. If an unexpected shower occurs, any crack that has been clean and dried must be reevaluated for proper conditions.

3.3.2 Crack Configurations

From the survey, there was no single crack treatment configuration that was overwhelmingly favored. Rather, different applications call for different treatment configurations. Reservoir configurations are commonly used when crack sealing will occur. The reservoir provides a mechanism for expansion and contraction during which adhesion of the sealant to the crack edges remains intact. Reservoirs are not typically used for crack filling operations. Each of the configurations has advantages and disadvantages. A discussion of each configuration follows.

3.3.2.1 Recessed Crack Treatment Configuration

The recessed crack treatment configuration (Figure 6) is often used when an overlay is to be placed. This application is usually considered more aesthetically acceptable, having better adhesion of the sealer to the vertical faces of the crack, and reduced tensile strains in the sealant. The only disadvantage is the additional cost.

The recess minimizes the potential for a bump to form in the overlay that can occur when the hot overlay comes in contact with the sealant. A recess depth of approximately 9mm is commonly used. The sealant should be placed six to twelve months prior to the overlay to minimize potential for bumps. Survey results indicated that the recessed crack treatment configuration is not commonly used (35% usage).

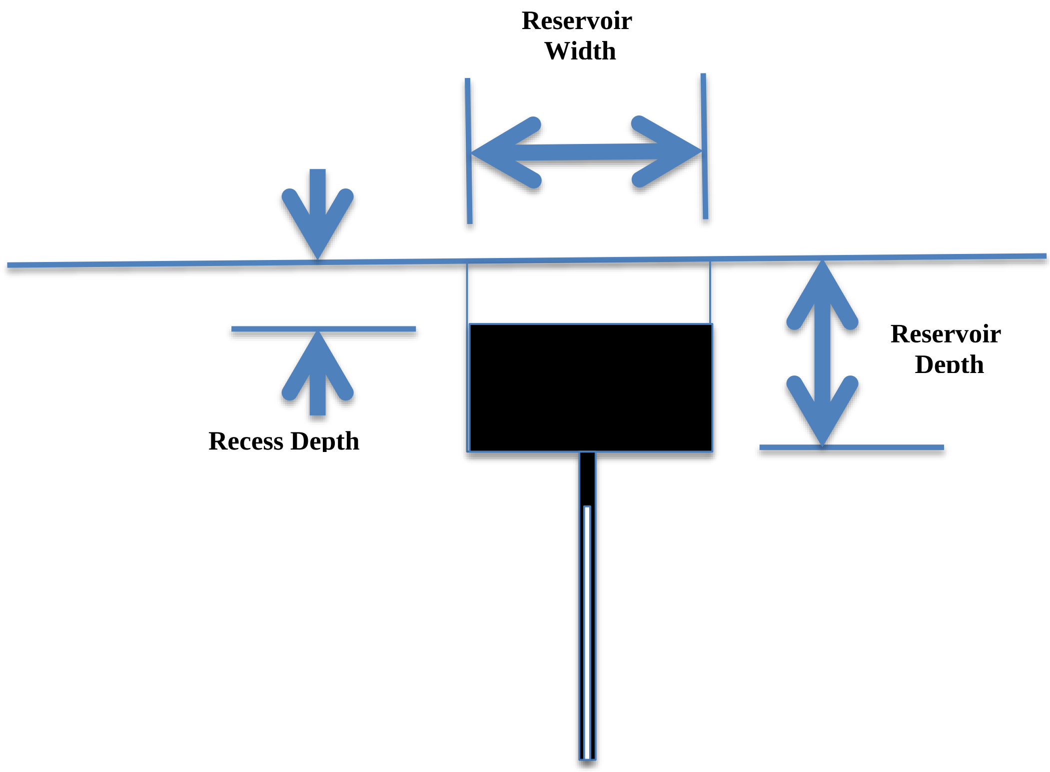

Figure 6: Recessed Crack Treatment Configuration

3.3.2.2 Flush Fill Crack Treatment Configurations

Approximately 50 percent of the survey respondents use flush fill configurations all the time. The configuration can be used with either a routed (Figure 7(A)) or non-routed approach (Figure 7(B)). The flush fill is commonly used when a chip seal or microsurfacing is to be applied on the pavement. Because of the lower temperature of the surface treatment, there should be no concern about bump formation. The non-routed flush fill is commonly utilized with crack filling using an emulsion. The emulsion will readily flow into the crack.

Figure 8(A) and (B) illustrate squeegee operations to smooth the surface of the treated crack. The type of squeegee is determined by the sealant used. A hot sealant uses the all-metal squeegee shown on the left while cold poured materials have a rubber-faced squeegee as shown on the right.

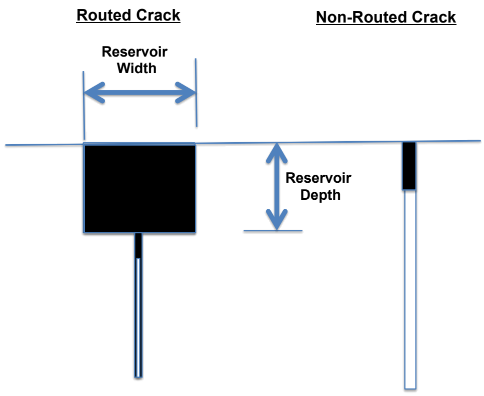

Figure 7: Flush Fill Configurations

Figure 8 : Squeegee for Sealant
((A)Hot Poured Sealant on left, (B)Cold Poured Sealant on Right) (31)

3.3.2.3 Overband Crack Treatment Configurations

Overband crack treatment configurations (Figure 9(A) and (B)) are used when traffic will be on the treatment soon after placement. Low traffic roadways are good candidates for this type of treatment. Care must be taken to avoid excess sealant on the surface from a traffic safety perspective and from a sealant integrity perspective. If the sealant sticks to vehicle tires, it can be pulled out of the crack, resulting in a failure of the crack sealant. This application should not be used if an overlay is planned, as the potential for a bump in the overlay is high. The non-routed application is often used for crack filling. The surface may be squeegeed to smooth the overband.

Installation of an overband application is shown in Figure 10. The overband material may be squeegeed flat or may be left as a "cap". The overband should be no more than 75mm wide. Figure 11 illustrates the condition of a pavement with excessive sealant overband application.

Chong (13) recommends overfilling the crack to just cover both edges of the crack and to allow for shrinkage during cooling. This approach minimizes snowplow damage for routed cracks.

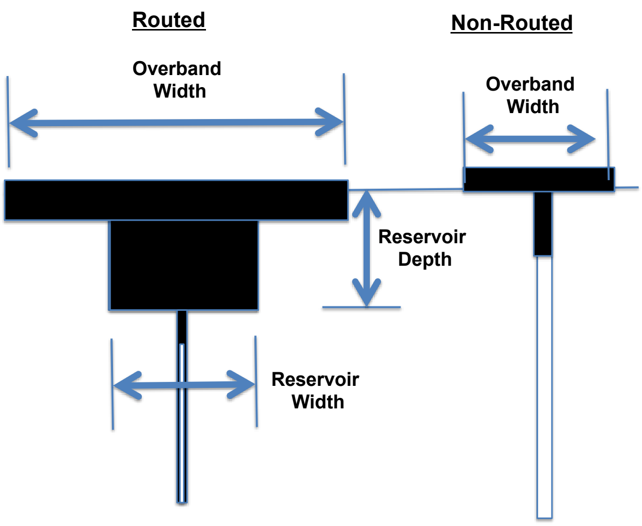

Figure 9: Overband Crack Treatment Configuration

Figure 10 **Overbanding (A) (15)**

Figure 11 **Excessive Overbanding (B)(15)**

3.3.2.4 Crack Preparation

A controversial subject is whether to cut the crack prior to the treatment. Crack cutting can be performed either by a diamond saw or a rotary impact router, shown in Figures 12 and 13, respectively. Both approaches have advantages and disadvantages. As a result of the productivity advantage and the ability to follow the crack more closely, the router is the more common cutting procedure used. However, less than half of respondents in the survey routinely rout cracks (recessed routed 35%, flush routed 48% and overband routed 43%). Routing is a process that should be evaluated by agencies in more detail – it's a good tool for the toolbox.

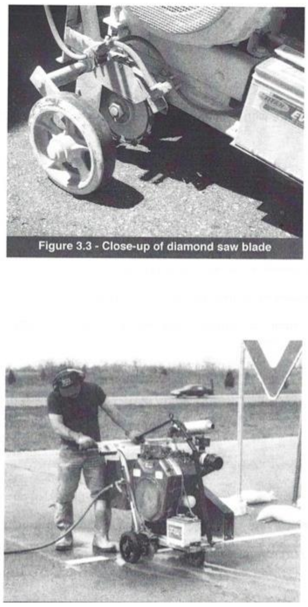

Figure 12: Diamond Saw Crack Cutting (35)

Figure 13: Router Head and Machine
(Router Head on left and Router Device on Right)
(Courtesy of Crafco and Marathon Mfg.)

Felice provides recommendations for routing selection (24):

Do Rout:

- crack opening 3mm to 12mm
- cracks 12 to 20mm shall be evaluated to determine appropriateness
- cracks > 19mm shall be cleaned and filled;
- types of cracks for consideration
  - longitudinal cracks
  - transverse cracks
  - edge cracks

Do not Rout:

- crack opening less than 3mm
- fatigue cracks
- pavements with high density cracking
- pavements being considered for rehabilitation

The router or saw width must touch both sides of the crack for proper cutting. It is recommended that the router remove 3mm from each side of the crack and cut back to sound pavement. A minimum and maximum width of cut are recommended as 12.5mm and 37.5mm, respectively with a recommended cut depth of 19mm. The pavement should not spall during the routing in order to obtain the best adhesion of the sealant to the crack edges (25).

When treating large cracks, backer rod may be used to eliminate drainage of the sealant to the bottom of the crack as previously shown in Figure 5. This allows better expansion and contraction of the sealant during cooling and heating and reduces the amount of sealant required. If the sealant is placed too deep in the crack, the potential for cohesive failure in the sealant is high. Almost 50% of the participants in the survey indicated that cohesive failure was frequently observed.

3.3.2.5 Crack Cleaning

The crack must be clean and dry prior to the placement of any sealant material. If this is not completed correctly, the sealant will not adhere to the sides of the crack and performance will be poor (adhesive failure). Lack of bond was the most common source of failure identified in the state-of-the-practice survey.

Best Practice suggests that the pavement should be swept to remove dirt and debris prior to starting crack treatment operations. A power sweeper or vacuum cleaner should be used as shown in Figure 14.

Figure 14: Pavement Sweeping
(Photograph by Dale Decker)

High pressure air blasting should be used to remove dust, debris and loose pavement fragments for both crack sealing and crack filling operations as shown in Figure 15. The compressor to accomplish this should develop a minimum of 690 kPa and have a minimum blast flow of 4250 l/min (16, 21, 22). The compressed air must be free of oil and moisture to ensure that the sealant will adhere to the crack edges. A backpack blower (leaf blower) should not be used for crack cleaning. Almost 90% of the survey participants indicated that compressed air was used for crack cleaning. The compressed air cleaning should be directed away from passing traffic and should not blow debris into an already cleaned crack.

Figure 15: Compressed Air Cleaning of Crack (Courtesy Crafco)

Crack vacuuming can also be performed if necessary to clean the crack. Figure 16 shows a vacuum system cleaning the crack.

Figure 16: Crack Vacuum (Courtesy Crafco)

For crack filling, use of the compressed air and/or vacuuming may be adequate, particularly if a cold-poured asphalt emulsion is to be used as the sealant. However, if crack sealing is to be done or if a hot-poured product is to be used for crack filling, the crack must be dried prior to sealant placement.

Hot air lances as shown in Figure 17 are used to dry the crack. Not only does the hot air lance dry the pavement but it also warms the surface of the crack to enhance bonding of the sealant. A significant challenge for the hot air lance operator is to avoid overheating the asphalt mixture. Overheating can damage the asphalt binder and potentially weaken the crack edge.

There is not agreement in the technical literature regarding the temperature and velocity of the hot air lance as is shown in Table 4. Temperatures range from about 500 to 1,400 ^{O}C and velocities range from approximately 600 to 914mps.

Table 4: Hot Air Lance Temperature and Velocity

Agency	Hot Air Lance Temperature, ºC	Hot Air Lance Air Velocity, mps
Michigan DOT (16)	1,370	600
Minnesota DOT (43)	980	914
Canadian Research Council (24)	500	(not specified)

While there is disagreement about the specific operational characteristics, there is no disagreement that the hot air lance is a valuable tool for crack sealing and should be used cautiously to avoid damage to the existing pavement. Appropriate safety gear should always be used.

Figure 17: Hot Air Lances

(Courtesy Crafco, Inc.) (Courtesy LAB Mfg.)

Sandblasting has also been used to clean cracks. However, clean-up and environmental issues can be problematic. While effective, the cost is usually high so the process is seldom used.

3.3.2.6 Material Preparation

The manufacturer of every sealant provides handling and heating recommendations for the specific product. The recommendations must be followed. Issues such as melting recommendations, minimum placement temperature, heating temperatures, and guidelines for length of time for heating to avoid overheating will typically be included in the recommendations. Improperly handling the material, particularly overheating, may result in significantly different material properties for some sealants, affecting both application and performance of the material. The user must know and follow the recommendations from the manufacturer. In addition, the manufacturer is required to provide Material Safety Data Sheets (MSDS) for each product. All personnel should be familiar with the MSDS requirements for safe handling.

For crack sealing installation to proceed, the sealant must be brought to application temperature. For hot poured sealant, the material must be heated to proper application temperature. For cold poured sealant, the sealant will have minimal if any heat applied to the material.

It is recommended that the melter for hot poured applications be a self-contained double boiler device with the transmittal of heat through a heat transfer oil to the sealant vessel. Direct-fired melters are used in some areas but with the sealants commonly used today, there is a considerable concern for damage to the sealant. Direct-fired melters are not considered Best Practice for modified crack sealants.

The melter equipment from three manufacturers is illustrated in Figures 18-20. The melter must be equipped with an on-board automatic heat-controlling device to achieve and maintain the proper sealant temperature for the proper installation of material. The melter must be capable of safely heating product to 204 ^{O}C. The temperature control should not allow the heat transfer oil to exceed 274 ^{O}C. There should be temperature readings of the sealant within the melting vessel and within the discharge plumbing to provide monitoring of the sealant throughout the operation (40).

The unit shall also have a means to vigorously and continuously agitate the sealant that meet requirements of ASTM D6690. Extreme caution must be used when charging the sealant into the melter to avoid injury to the operator. The sealant should be applied to the pavement under pressure supplied by a gear pump with a direct connecting applicator tip (40).

The melters are manufactured with different size melting chambers for use on jobs of different sizes. Some models of melter allow two operators to be working at the same time, thereby greatly increasing productivity.

Figure 18: SealMaster Melter (Courtesy SealMaster)

Figure 19: Marathon Melter (Courtesy Marathon Mfg.)

Figure 20: Loading Crafco Melter (Courtesy Crafco)

3.3.2.7 Sealant Installation

For cold poured crack filling applications, if the sealant is an emulsion, it can be placed in the crack through a gravity feed system or using something as simple as a cone as shown in Figure 21. These gravity feed systems are used in some areas but are not considered Best Practice. It is difficult to get the sealant into the crack and a significant amount of sealant is wasted on the surface (24).

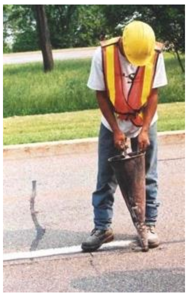

Figure 21: Application of Emulsion Crack Treatment (24)

After installation of the crack treatment, it may be necessary to apply a blotter material to minimize tracking by traffic. Sand, toilet paper and commercial products have all been used as blotting material. Figure 22 A illustrates a sand blotter being applied, (B) illustrates use of toilet paper, and (C) illustrates a spray-on application of anti-tracking solution (sprayer on right side of photo). While the sand and paper will serve as a blotter, there is debris created because of the residue generated. There is also a potential for the toilet paper to be mistaken for lane markings on longitudinal cracks.

Figure 22: Blotter Applications
((A) Sand Blotter and (B) Toilet Paper from (36)), ((C) Anti-Tracking Solution by Dale Decker)

For hot pour applications, the conditions at the time of installation are critical to the success of the treatment. Figure 22 illustrates the wrong times for crack sealing (42). If sealant is applied in the winter when the crack is wide, the sealant will be squeezed out of the crack in the summer when the crack is more narrow as shown in row one of the graphic. The middle row of the graphic demonstrates that if the crack is sealed in the summer, there is a risk for cohesive failure in the sealant during the winter when the crack width is at its highest value. The final row of the graphic illustrates that spring or fall are optimum times for crack sealing in order to get best performance of the sealant.

It is noted that the survey respondents indicated that the average crack sealing season is May to August, which for many areas in North America, may not be considered optimum timing for crack treatment installation. Since a significant percentage of crack treatment is done with agency personnel, the decision on timing likely revolves around availability of personnel rather than on performance of the crack treatment.

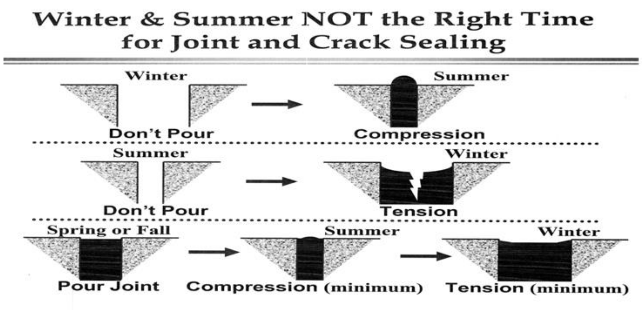

Figure 22: Not the Right Time for Crack Treatment (42)

It is not recommended to apply hot pour sealants over cold patches (15). The sealant may cause failure of the cold patch.

3.3.2.8 Safety

It is important for all sealant crewmembers to understand safety requirements for handling the sealants and for the equipment being used. Sealant and equipment manufacturers provide recommended safe operating procedures for their products. The following Personal Protective Equipment (PPE) are recommended for application of sealants:

- Long pants;

- Long sleeved shirt buttoned at the wrist;
- Heat resistant gloves;
- Eye protection (safety glasses or face shield);
- Hard soled work shoes; and
- Traffic safety vests and hard hats (when exposed to traffic).

Figure 23 illustrates proper protection for workers involved in crack treatment applications. Basically, all skin should be covered to prevent a potential burn from skin contact with the hot sealant. If skin contact does occur, cool the affected area with cool water – do not attempt to remove the material from skin by either mechanical or chemical means. Once cool, the sealant will fall off the affected skin in a few days. In addition, good safety practices include availability of a fire extinguisher, a first aid kit and burn packs.

Figure 23: Crack Treatment Operations (31)

3.3.2.9 Quality Control

For most construction operations, inspection of the work performed is an integral part of the construction process. The survey responses indicated that inspection is generally not performed during crack sealing operations even though participants indicated better performance of the crack treatment if an inspector is present. Inspection of the crack treatment installation is important regardless of the personnel performing the work. In order to optimize performance of the sealant, verification of the quality of the work is critical.

Some agencies have used warranty contracts to relieve the owner of inspection responsibility. Since 60% of the respondents indicated that crack treatments are performed with in-house personnel, a warranty contract model cannot be used effectively for a substantial portion of the crack treatments that are installed under current practices.

Masson (14) discussed an inspection method for evaluating the efficiency of the routing procedure. A metal die was developed (Figure 24) that enables the inspector to measure the rout depth and width.

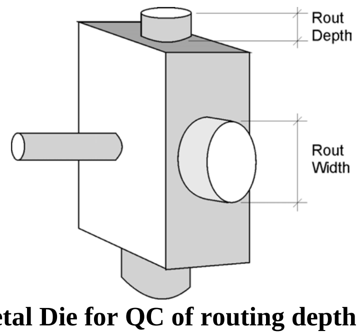

Figure 24: Metal Die for QC of routing depth and width (14)

Included in the inspector's duties are verification of:

- Proper sealant for the project;
- Proper equipment for the project;
- Inspection of the equipment to be used;
- Proper equipment operation;
- Equipment calibration;
- Temperature of the melter;
- Sample sealant for specification testing;
- Proper crack cleaning and routing (if used);
- Proper sealant installation;

- Usage of proper PPE; and
- Safe workzone.

In addition, the inspector should maintain a professional diary of project activities.

Montana DOT published the Troubleshooting guide found in Table 5 (19). This guide provides good insight into issues that may be encountered.

Table 5: Troubleshooting Crack Treatment Issues (19)

Problem Encountered	Possible Causes	Possible Solutions
Bubbles in Sealant	Damaged backer rod Wrong backer rod	Change backer rod installation method or rod diameter Use proper backer rod for hot-poured sealants
	Moisture in joint Grass or weeds in joint	Dry reservoir
	Bubbles in melter Moisture present	Add Sealant Reduce agitator speed Slowly heat to evaporate water
	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 is variable Inconsistent material temperature	Use nozzle with depth control plate Use wand with shutoff at nozzle Use an experienced operator
Sealant not sticking to routed reservoir walls	Reservoir walls are not clean	Remove all contaminants
	Moisture on walls from rain, dew, or condensation	Wait for pavement to dry Use hot air lance Use compressor with moisture trap
	Sealant temperature too low	Maintain recommended sealant temperature
	Pavement temperature too low	Wait until it warms up
Sealant remains tacky after installation	Melter is contaminated with heat transfer oil, solvent or other sealant	Empty and clean melter
	Sealant has been overheated or heated too long	Empty melter and replace with fresh sealant Check melter temperature regularly

3.4 CLOSURE

The primary focus of crack treatments is to achieve a pavement maintenance application that will perform well under a variety of environmental and traffic conditions. The devil is in the details as the saying goes. As with most pavement construction activities, the work is not that difficult but there are many, many details that must be given attention. Crack treatments are no exception to that statement.

The state-of-the-art review highlighted areas in which the state-of-the-practice has not kept up with the technology. This is all too easy to happen. People applying crack treatments have learned how to do their job mainly by experience. As a result, it is often challenging to implement new technology.

Based on the effort of this project, areas in which improvements in the state-of-the-practice should be considered include:

- Evaluation of pavement condition prior to sealant application – i.e. what type of crack is present, how severe is the cracking, and what is the density of the cracking;
- Acceptance of the new Sealant Grade evaluation system;
- Proper preparation of the crack prior to sealant application – make sure that the crack is clean, dry and properly configured for the application;

- Training for sealant application personnel – this is an ongoing need;
- Quality Control testing for sealant product – establishment of uniform sampling and testing protocols;
- Inspection of the crack treatment operations – many agencies do very little if any inspection of the treatment work; and
- Evaluation of sealant performance – understanding how the sealant performs enables the owner to make knowledgeable decisions about materials and procedures.

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