GUIDELINES FOR SEALING AND FILLING CRACKS IN ASPHALT CONCRETE PAVEMENT

A BEST PRACTICE BY THE NATIONAL GUIDE TO SUSTAINABLE MUNICIPAL INFRASTRUCTURE

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Guidelines for Sealing and Filling Cracks in Asphalt Concrete Pavement
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FOREWORD

In spite of recent increases in public infrastructure investments, municipal infrastructure is decaying faster than it is being renewed. Factors such as low funding, population growth, tighter health and environmental requirements, poor quality control leading to inferior installation, inadequate inspection and maintenance, and lack of consistency and uniformity in design, construction and operation practices have impacted on municipal infrastructure. At the same time, an increased burden on infrastructure due to significant growth in some sectors tends to quicken the ageing process while increasing the social and monetary cost of service disruptions due to maintenance, repairs or replacement.

With the intention of facing these challenges and opportunities, the Federation of Canadian Municipalities (FCM) and the National Research Council (NRC) have joined forces to deliver the *National Guide to Sustainable Municipal Infrastructure: Innovations and Best Practices*. The Guide project, funded by the Infrastructure Canada program, NRC, and through in-kind contributions from public and private municipal infrastructure stakeholders, aims to provide a decision-making and investment planning tool as well as a compendium of technical best practices. It provides a road map to the best available knowledge and solutions for addressing infrastructure issues. It is also a focal point for the Canadian network of practitioners, researchers and municipal governments focused on infrastructure operations and maintenance.

The *National Guide to Sustainable Municipal Infrastructure* offers the opportunity to consolidate the vast body of existing knowledge and shape it into best practices that can be used by decision makers and technical personnel in the public and private sectors. It provides instruments to help municipalities identify needs, evaluate solutions, and plan long-term, sustainable strategies for improved infrastructure performance at the best available cost with the least environmental impact. The five initial target areas of the Guide are: potable water systems (production and distribution), storm and wastewater systems (collection, treatment, disposal), municipal roads and sidewalks, environmental protocols and decision making and investment planning.

Part A of the *National Guide to Sustainable Municipal Infrastructure* focuses on decision-making and investment planning issues related to municipal infrastructure. Part B is a compendium of technical best practices and is qualitatively distinct from Part A. Among the most significant of its distinctions is the group of practitioners for which it is intended. Part A, or the decision making and investment planning component of the Guide, is intended to support the practices and efforts of elected officials and senior administrative and management staff in municipalities throughout Canada.

It is expected that the Guide will expand and evolve over time. To focus on the most urgent knowledge needs of infrastructure planners and practitioners, the committees solicited and received recommendations, comments and suggestions from various stakeholder groups, which shaped the enclosed document. Although the best practices are adapted, wherever possible, to reflect varying municipal needs, they remain guidelines based on the collective judgements of peer experts. Discretion must be exercised in applying these guidelines to account for specific local conditions (e.g., geographic location, municipality size, climatic condition).

For additional information or to provide comments and feedback, please visit the Guide at <www.infraguide.gc.ca> or contact the Guide team at infraguide@nrc.ca.

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This best practice was developed by stakeholders from Canadian municipalities and specialists from across Canada, based on information from a scan of municipal practices and an extensive literature review. It was written by Jean-François Masson, Ph.D., Sylvain Boudreau, ing., M.Eng. and Claire Girard, Ph.D. The following members of the National Guide's Municipal Roads and Sidewalks Technical Committee provided valued assistance in the development of this best practice.

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EXECUTIVE SUMMARY

This best practice provides municipal engineers with updated guidelines for crack treatment in asphalt concrete (AC) based on the Canadian experience. Crack treatments, pavement and sealant selection, sealant installation, work procedures and cost effectiveness are reviewed, along with the needs. A quality control checklist for material installation is provided.

If performed in an effective and timely manner, crack treatment can extend the life of AC pavements by two to five years. Pavements with failed sealant are unlikely to show much longer service life than pavements without sealants. Hence, there is a need for effective crack treatments and durable sealants.

In a well-established maintenance program, crack treatments are repeated more than once. Crack sealing, for example, is first done on pavements that are three to five years old. A second crack sealing can be performed after eight to ten years on a pavement in fair condition, provided the crack treatment is effective for five years. When sealant effectiveness is shorter than five years, the number of crack treatments must increase. Considering that a pavement is rehabilitated 12 to 15 years after construction, and the goal is to circumvent difficult sealant replacements, sealant durability should extend to 12 years. Current durability is typically two to seven years.

Crack treatments can only be effective and sealant durability extended after careful pavement and sealant selection, and sealant installation. Most often, pavement and sealant selection is the responsibility of a city's public works department, whereas sealant installation is that of a contractor. Pavement selection requires that pavements in good condition be identified for treatment. The pavement condition rating should be greater than about 75 for a first crack treatment, and greater than 50 for a second treatment. Crack treatments on pavements in poor condition are not effective.

Crack treatments include crack sealing (rout and seal) and crack filling (no routing). Crack sealing is used to treat active cracks, which open in winter and close in summer, whereas crack filling can only be used to treat cracks that show little, if any, movement over time. Despite higher installation costs, crack sealing is more cost effective than crack filling.

Sealant selection can be based on one- or two-year field trials, from which a list of approved materials is drawn, or based on a material specification (e.g., ASTM D 6690). Neither method allows for a consistent selection of sealants with extended service life in Canadian urban conditions. Field trials do not predict long-term performance because performance is not linear in time, whereas sealant specifications only allow for the selection of materials with limited durability. When crack filling is performed, it is often done with bituminous

emulsions. Specifications for these emulsions are only effective for the selection of fillers that last one winter, two at the most.

Sealant installation is the third major element of crack treatments, after pavement and sealant selection. Installation is affected by a number of factors, including, air and AC temperature and humidity, rout size, rout cleaning method, sealant temperature and heating time, and sealant finishing and protection. These elements are all covered in this guide. The "best time" to do crack sealing or crack filling depends on the local climate and conditions, and is always a compromise between what the ideal crack size should be during installation and whether it is best in spring or fall, and the other application conditions, which are best in summer.

Crack sealing has improved much in the last decade, and it will keep improving. Two elements would help extend the durability of sealants and the effectiveness of the treatments: the use of performance-based specifications for sealant selection, and the implementation of worker certification, together with performance contracts.

1. GENERAL

Preventive maintenance is the first and most important way to delay road deterioration, extend service life, and maximize shrinking public funds. While surface treatment by crack sealing or filling is one of the most common methods of preventive maintenance, sealant durability is often low. Ideally, a sealant would last six to twelve years without debonding to avoid the need to replace failed sealants during the lifetime of the wearing course (i.e., until the road receives a new overlay). In Canadian cities, sealant durability is much shorter (Masson et al., 1999; Marino, 1995; Corbett and Lauter, 2000), as can be the case elsewhere (Lynch and Janssen, 1997), mainly because of inappropriate installation and the inability to select durable sealants for local conditions.

There are excellent guides and reports that detail crack treatment procedures in the United States (Smith and Romine, 1993a; Eaton and Ashcraft, 1992), but they predate Canadian work on sealant degradation during installation (Masson et al., 1998). There are also reports on the use of the hot-air lance on routs and its effect on the sealant/asphalt concrete (AC) bond (Masson and Lacasse, 1999, 2000), the effect of rout size in an urban setting (Masson et al., 1999), and the effect of dew and fog (Marino, 1995; Marino, 1996). This best practice provides municipal engineers with updated guidelines for crack treatment in asphalt concrete based on the Canadian experience. The following topics are reviewed: crack treatments, pavement selection, sealant selection, sealant installation and seasonal factors, cost effectiveness, work procedures and the current needs. This is followed by a quality control checklist for material installation.

2. CRACK TREATMENTS AND RATIONALE

Cracks in asphalt concrete can be sealed or filled. Crack sealing is the routing and sealing of cracks, whereas crack filling is sealing without routing. Both treatments reduce the ingress of water, brine, and incompressibles into the cracks and pavement sub-structure and, as a result, crack treatment delays pavement degradation and helps extend service life (Ponniah and Kennepohl, 1996). The treatments are most effective when applied to pavements in good condition (FHWA, 1998), with low-to-moderate crack density, and where cracks show little or no branching (Figure 2–1). Cracks illustrated on top and in the middle are suitable for sealing, but the bottom crack shows excessive branching.

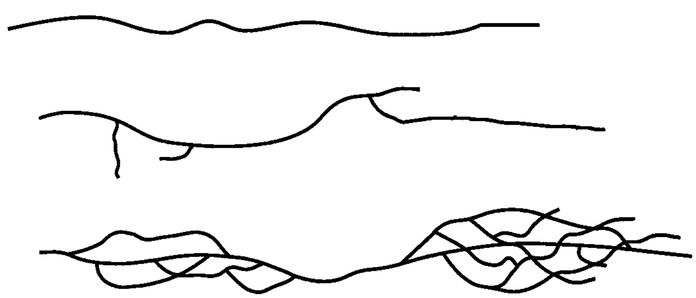


Figure 2–1: Various crack densities

Pavements with moderate-to-high crack density must be treated using other techniques, such as patching or resurfacing. Cracks with severe vertical distress (i.e., cupping, lipping, or faulting) that may show significant movement on traffic loading are also unsuitable for crack sealing or filling. For example, the photograph on the right in Figure 2–2 shows that cracking progressed despite crack sealing. Section 2.4 provides details on pavement selection.

Figure 2–2: Pavement sections unsuitable for crack sealing

2.1 CRACK SEALING

Crack sealing is used to treat active cracks, which open in winter and close in summer. An active crack is typically greater than 3 mm in width in the summer and 15 to 100 percent larger in the winter. Active cracks are routed to a predefined geometry, cleaned, and then sealed. Routs with a width-to-depth ratio of one or greater than one ($W/D \geq 1$) provide a profile that enhances sealant performance (Wang and Weisgerber, 1993; Ketcham, 1996; Khuri and Tons, 1992; Chong and Phang, 1988). The technique is also referred to as rout-and-seal.

2.2 CRACK FILLING

Cracks that show little, if any, movement over time can be filled. These cracks are typically less than 3 mm wide, less than one year old, and found in regions where winter is mildest (e.g., Southern Ontario and British Columbia). Cracks are not routed, but cleaned with compressed air and covered with an overband of hot-applied sealant, or flush-filled with a cold-applied bitumen emulsion. The overband is subject to wear in high traffic areas (Marino, 1995). Consequently, crack filling is most suitable for the warmer Canadian regions with low traffic density (e.g., residential areas). Marino (1996) reported a sealant durability of seven to nine years in sections of Vancouver where crack filling was used.

2.3 COMBINED SEALING AND FILLING

Crack sealing and filling are sometimes combined in one treatment: longitudinal cracks are filled, transverse cracks are sealed. This method has been used successfully to delay degradation of relatively short segments of highways where crack treatment is repeated every one or two years (Saulnier and Lemieux, 2000). In the city, this approach must be used with caution, as it suffers from the same limitations as crack filling alone. In slow moving and high traffic areas, the overband gets worn out, or is moved in the direction opposite of traffic, leaving an open crack (Marino, 1995). The crack filling of all longitudinal cracks also assumes that these cracks are fairly inactive, which may not be true. In Montréal, for example, longitudinal cracks show 70 to 90 percent as much movement as transverse cracks (Masson et al., 1999).

2.4 PAVEMENT SELECTION

For a most successful treatment careful considerations must be given to pavement selection, sealant selection and sealant application.

Crack sealing is a preventive maintenance method that applies only to pavements that have a) sufficient structural strength to meet current needs and those in the foreseeable future, and b) show low pavement distress. Pavement distress is assessed from the pavement condition rating (PCR), which is calculated from the severity and density of pavement distress (Anderson 1987; Chong et al. 1989; Tessier 1990). Table 2–1 provides a typical PCR scale with some pavement characteristics.

Table 2–1: Typical pavement condition ratings (MTO 1990).

PCR	Description
100-90	Pavement is in excellent condition with few cracks. Rideability is excellent with few areas of slight distortion.
90-75	Pavement is in good condition with frequent very slight or slight cracking. Rideability is good with intermittent rough and uneven sections.
75-65	Pavement is in fairly good condition with slight or very slight dishing and a few areas of slight alligatoring. Rideability is fairly good with intermittent rough and uneven sections.
65-50	Pavement is in fair condition with intermittent moderate and frequent slight cracking and with intermittent slight or moderate alligatoring and dishing. Rideability is fair and surface is slightly rough and uneven.

Crack sealing applies to AC pavements in good condition and with a smooth ride (e.g., PCR >75, bearing in mind that a rating of 75 may not have the same significance for different evaluators). Consequently, crack sealing is first done on pavements that are three to five years old. Typically more than 90 percent of the cracks are transverse and longitudinal, crack width is slight to moderate, and crack density is intermittent to frequent (Table 2–2). Pavements with cracks larger than 20 mm, rated as severe in Table 2–2, are unsuited for crack sealing, no matter the density. These cracks are really elongated potholes, and they are better suited for a rehabilitation treatment.

Table 2–2: Classes of crack widths and densities. Adapted from Chong et al., 1989.

Crack	Class	Description
Width	Slight	2 to 12 mm single crack.
	Moderate	13-20 mm single or multiple cracks. Crack below 20 mm that show cupping or lipping.
	Severe	Single or multiple cracks with cupping and lipping or cracks larger than 20 mm. Crack below 20 mm that show spalling.
Density	Intermittent	No set pattern. Less than 20% of pavement surface is affected. Transverse cracks are 30-40 m apart.
	Frequent	20-50% of surface is affected. Longitudinal cracking can be localized or distributed evenly over pavement section. Transverse cracks are 20-30 m apart.
	Severe	Cracking is distributed evenly over more than 50% of pavement surface. Transverse cracks are 10-20 m apart.

In a well-established maintenance program, crack sealing is repeated more than once. A second crack sealing can be performed after 8-10 years on a pavement in fair condition, provided the crack treatment is effective 5 years. The second treatment applies to pavements with a PCR greater than 50, which are about 5 years from rehabilitation (Chong et al., 1989). When sealant effectiveness is shorter than 5 years, the number of crack treatments must increase. Considering that a pavement is rehabilitated 12-15 years after construction, and the need to circumvent difficult sealant replacements, sealant durability should extend to 12 years. Current durability is typically 2-7 years.

2.5 SEALANT SELECTION

2.5.1 CRACK SEALING

Products used in crack sealing are thermoplastic bitumen-based materials that can be poured at 175°C to 200°C, hence their designation as hot-pour sealants. Cold-pour bituminous emulsions are not used for crack sealing. Hot-pour sealants can be selected based on one- or two-year field tests, from which a list of approved materials is drawn. However, the method should be used with caution to assess medium- or long-term sealant performance. Performance does not show a linear time dependence (Masson et al., 1999).

Sealants can be selected based on a standard specification, such as ASTM D6690, which calls for measurements of penetration, resilience, flow, and cyclic extension in temperatures from –18°C to –29°C (Table 2–3). ASTM D6690 classifies sealants as Type I to Type IV, and replaces ASTM D1190 (Type I) and ASTM D3405 (Type II). Before ASTM D6690, the Type IV sealant was known in Canada as the low modulus type. Table 2–4 provides a glimpse of sealant performance in Vancouver, Montréal, and Ottawa for products that met the appropriate ASTM specification at the time of the study. Sealant performance varies, and long-term durability (six to twelve years of service life with less than 50 percent failure) is not ascertained, even with Type IV sealants. To help select sealants with greater durability, the specification would need to account for sealant ageing (Masson and Lacasse, 1998; Masson, 2000).

Table 2–3: Summary of ASTM D6690 Used for Sealant Selection in Canada

	Type I	Type II	Type IV
Cone Penetration at 25°C	<90 dmm[a]	<90 dmm	90 dmm to 150 dmm
Flow at 60°C	≤5 mm	≤3 mm	≤3 mm
Resilience	--	<60%	<60%
Cyclic extension	50% ext. at –18°C (5 cycles)	50% ext. at –29°C (3 cycles)	200% ext. at –29°C (3 cycles)

[a] 1dmm = 0.1 mm

Table 2–4: Performance of Hot-Pour Sealants

	Vancouver	Montréal	Ottawa
Temp. range (°C)[a]	–22 to 52	–28 to 58	–34 to 58
Original sealant type	I	II	IV
1-year failure[b] level	0% to 5%	6% to 11%	7% to 55%
4-year failure level	20% to 23%	16% to 28%	not determined

[a] Pavement surface temperatures according to Superpave.

[b] Sum of debonding, splitting, and pull-out lengths.

Sources: Vancouver (Marino, 1995); Montréal (Masson et al., 1999); Ottawa (Corbett and Lauter, 2000).

2.5.2 CRACK FILLING

Hot-poured sealants or cold-applied bituminous emulsions can be used for crack filling. The selection of the former is the same as with crack sealing, and the selection of the latter is based on ASTM D977 or D2397, which specify emulsion composition, stability, and consistency. There is, at best, a weak correlation between the results for consistency (penetration and resilience at 25°C) and field performance, as there are no tests to measure elasticity or relaxation in cold weather, nor flow in hot weather, as is the case with ASTM D6690. Consequently, emulsions used in crack filling typically fail after one or two winters (Evers, 1981; Neiss, 2001).

2.6 SEASONAL FACTORS

Crack treatment performance depends on three factors: initial pavement condition, product selection, and product installation. Installation is affected by air temperature and humidity, AC surface temperature and humidity, and sealant application. This last point includes the routing of cracks, the heating of the sealant, and its pouring, finishing, and protection. Traditionally, emphasis has been placed on the effect of air temperature on crack size and movement, and the associated effect on sealant stress and strain (Figure 2–3). In most of Canada, large seasonal variations in air temperature cause AC pavement cracks to be active, longitudinal cracks being less active than transverse cracks (Masson et al., 1999). Maximum crack opening occurs in a six-to-eight month period with a peak in February (Masson and Légaré, 1991). Sealants are thus strained most in winter, when temperatures are low and extension is high, with movements of 5 mm to 25 mm in an annual cycle. On this basis alone, crack treatment should be performed in spring or fall, when temperatures are moderate and cracks are mid-course in their annual cycle. However, crack sealing during summer provides for the best conditions in terms of sealant installation, as AC surface humidity is low and morning temperatures are the highest. Hence, the selection of a crack treatment time is a compromise between the effect of crack movement on sealant performance and sealant installation.

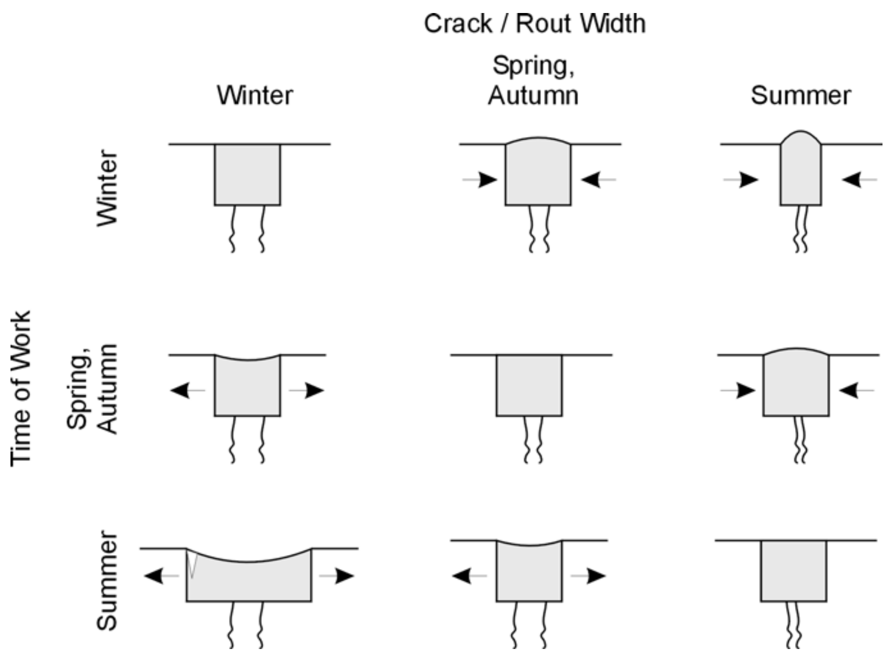


Figure 2–3: Effect of crack opening and time of work on sealant strain

2.6.1 CRACK SEALING

When cracks are active, and crack movement may affect sealant performance more than installation conditions, a good time to rout and seal is late summer to mid fall. In spring, frost is coming out of the ground, and pavement moisture is normally at its maximum. However, if pavement moisture does not appear to be a problem, crack sealing can be done in late spring. The treatment of cracks in spring can be advantageous when the ground is dry, because it leaves the sealant with an extended period of hot weather during which it can fully penetrate and wet the surface of the crack (Masson and Lacasse, 2000). Notwithstanding, local climates and conditions should govern the final choice. As detailed above, crack sealing in summer can be acceptable, especially in northern Canada where summer is short and spring and fall are rainy.

Air temperature during sealant installation is especially critical in the early morning. Cool morning air reduces the temperature of the AC surface, which may cause a hot-pour sealant to gel more rapidly than when the surface is warm or hot. Rapid gelation can reduce sealant penetration and leave interfacial defects that lead to lower than expected adhesion and performance (Masson and Lacasse, 2000). The use of a hot-air lance may be most advantageous for crack treatment when the air temperature is 5°C to 10°C, as it may provide for a slightly warmer AC surface over which sealant can be poured. However, the beneficial use of a hot-air lance in the early morning can be counterbalanced by dew (Marino, 1995). The problem is especially acute in September and October when the pavement temperature in early morning can be 3°C less than the air temperature. To prevent sealant debonding related to dew, the City of Vancouver specifies that crack sealing operations should begin after 9:00 a.m. when crack treatment is delayed beyond August. Local air temperatures and percent relative humidity, which govern dew point temperature, dictate when crack sealing operations should begin — about two hours after air expelled by the lungs (100% relative humidity) has stopped condensing. Crack treatment during summer minimizes the effect of air temperature on sealant installation.

2.6.2 CRACK FILLING

Crack filling with cold-pour bituminous emulsions should be done in late spring when the cracks that formed during winter are the youngest and least active. This leaves several months for the emulsion to shed its residual water before it is exposed to winter. Notwithstanding, cold-pour emulsions should be applied in air temperatures above 15°C, although they can be applied down to 10°C. At 15°C, the surface of the emulsion becomes dry in 15 to 45 minutes, but a complete cure takes eight to twelve hours. Low temperatures and a high relative humidity extend curing time. Freezing temperatures or rain will also adversely affect curing within 24 hours of application. Given these conditions and the possible formation of dew in the morning, cold-pour bituminous emulsions are best applied in late morning or afternoon. Inactive cracks can be treated in summer. For crack filling with a hot-pour product, it can be done as detailed for crack sealing.

2.7 COST EFFECTIVENESS

Crack treatment is only cost effective when it delays pavement deterioration and extends pavement service life. Performed effectively, in a timely manner, it can extend the life of AC highways by two to five years (Evart and Bennett, 1998; Chong, 1990). Similar estimates for streets and urban settings have not been made, but crack treatment is generally considered as effective in the city as on highways.

The effectiveness of crack treatment depends on pavement characteristics and locations. Hand et al. (2000) produced an excellent synthesis.

- The treatment is effective on AC pavements in good condition, but not effective on AC pavements in poor condition (Hand et al., 2000; Morian et al., 1998). Figure 2–2 provides a good example of poor effectiveness in an urban setting.

- Crack treatment is not effective in a dry climate, but is effective in wet-freeze climates (Morian et al., 1998). In Canada, it can be quite effective.

- Not treating cracks leads to increased maintenance costs, because deteriorated cracks are difficult to repair, and can lead to increased user costs related to vehicle repair and operation, and increased rehabilitation costs, because deteriorated cracks demand special treatment from the designer when pavement rehabilitation is scheduled. This affects serviceability and service life.

Crack treatment can be effective in delaying AC pavement deterioration and in extending service life, if the sealant is effective. A sealant is considered to have failed when it shows less than 50 percent effectiveness (Masson et al., 1999; Belangie and Anderson, 1985; Smith and Romine, 1993a). With sealants that show less than 10 percent debonding after three winters and less than 50 percent debonding after eight years, service life is said to be extended by at least two years (FHWA, 1998; Hand et al., 2000). Pavements with failed sealants are unlikely to show much longer service life than pavements without sealants. There is thus a great incentive to select durable sealants, as the extension in pavement service life is related to sealant durability.

Sealant durability, or service life, is assessed by periodic monitoring of the effectiveness in waterproofing the AC surface. The crack opening in a yearly cycle dictates when sealant effectiveness should be monitored. Sealants really show their effectiveness, or lack thereof, in February when cracks are at their maximum opening. An effective sealant shows adhesive and cohesive integrity in these demanding conditions. At other times, especially in summer, sealants can heal and appear effective.

Once sealant effectiveness, or failure rates, have been measured, it is possible to compare the cost effectiveness of various crack treatments. Table 2–5 shows the estimated cost of installation and cost effectiveness for sealants with a hypothetical 1- to 10-year service life. For the comparison, it was assumed that crack filling is done with a cold-pour emulsion and crack sealing with a hot-pour material; that the former is cheaper than the latter, given the reduced crew and simpler equipment (line J); and that 30 percent more cracks can be treated per unit of time by crack filling than by crack sealing (line K). More durable products were also taken as more expensive (line A). Hence, a 10-year service life was given to a yet-to-be-designed performance grade. Hot-pour sealant, which is three times as expensive as a rubberized product, was given a four-year service life. The standard cold-pour was given a one-year service life.

For the stated conditions, the cost of crack treatment is proportional to material price (lines A and L). When a user delay cost is considered (normally distributed and with a mean of $100/hour), the increase in crack treatment cost increases by about five percent (line N). Crack filling is about half the cost of crack sealing, in accordance with the report by Marino (1995). This ratio may explain the preferential use of crack filling in some municipalities with low annual pavement maintenance budgets. Crack treatments are best compared based on cost effectiveness rather than installation cost, however. The annualized cost per installation is useful in this regard (lines R and S), as it shows that cost effectiveness increases with durability as would be expected, and that a higher initial material cost is offset by the benefits of longer service life. It also shows that crack filling would be more cost effective than crack sealing, if crack fillers were to show comparable durability.

Table 2–5: Cost Effectiveness of Various Treatments and Materials

Material	Units	Crack Sealing				Crack Filling	
		Rubberized bitumen	Rubberized bitumen #2	Low modulus bitumen	Performance grade	Cold-pour	Performance grade cold-pour
A. Material cost on a weight basis	$/kg	0.7	0.825	1.125	2.25	0.5	1.5
B. Material density	kg/m^3	1300	1300	1200	1200	1100	1100
C. Sealant configuration	mm^2	30x15	30x15	30x15	30x15	5x10	5x10
D. Volume of a linear metre, C/10E6 x 1 m	m^3/m	0.00045	0.00045	0.00045	0.00045	0.00005	0.00005
E. Material use including waste (BxDx1.4 or 1.15)	kg/m	0.67	0.67	0.62	0.62	0.08	0.08
F. Material cost on a volume basis (AxE)	$/linear m	0.47	0.56	0.70	1.40	0.04	0.12
Labour and equipment							
G. number of workers at $100/day		10	10	10	10	8	8
H. supervisor at $200/day		1	1	1	1	1	1
I. equipment cost	$/day	500	500	500	500	200	200
J. Labour and equipment cost (G+H+I)	$/day	1700	1700	1700	1700	1200	1200
Installation							
K. Installation rate	Linear m/day	3000	3000	3000	3000	6000	6000
L. Material installation cost (F+J/K)	$/linear m	1.04	1.12	1.27	1.96	0.24	0.32
M. User delay cost	$/day	2000	2000	2000	2000	2000	2000
N. Total installation cost (L+M/K)	$/linear m	1.70	1.79	1.93	2.63	0.57	0.65
Cost effectiveness							
O. Interest rate		0.05	0.05	0.05	0.05	0.05	0.05
P. Service-life (time to failure)	Year	1	4	6	10	1	10
Q. Annual material cost [a]	$/linear m	1.09	0.32	0.25	0.25	0.25	0.04
R. Annual total cost [b]	$/linear m	1.79	0.50	0.38	0.34	0.60	0.08
S. Normalized annual cost		5.25	1.48	1.12	1.00		

Note:

[a] : Annual material cost :$L[O(1 + O)^P] / [(1+ O)^P - 1]$; [b] : Annual total cost : $N[O(1 + O)^P] / [(1+ O)^P - 1]$

3. WORK DESCRIPTION

Crack treatment consists of a number of steps associated with management and technical issues (Figure 3–1).

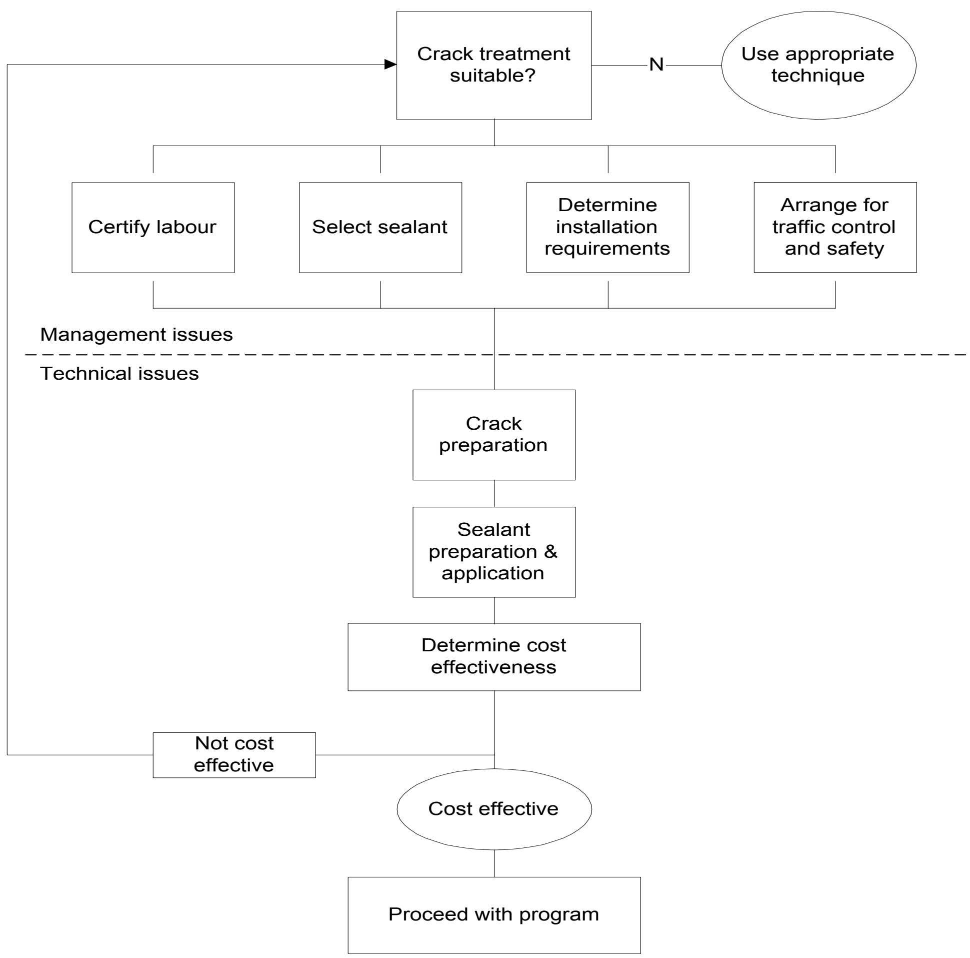


Figure 3–1: Managerial and technical issues

3.1 MANAGEMENT ISSUES

3.1.1 TRAINING

Sealants can only perform adequately if installed correctly, which requires good workmanship. Yet, work crews are often characterized by high turnover on a year-to-year basis. As a result, it is common to find workers unfamiliar with many aspects of crack treatment operations, and with the importance of crack treatment as a pavement preventive maintenance tool. As a result, workmanship can be uneven. Supervisors and inspectors should also have a thorough knowledge of each crack treatment step. Consequently, contractors and municipalities are both responsible for proper training in crack treatment procedures. Annual certification of personnel involved in crack treatment is being discussed, but it has yet to be implemented in Canada.

3.1.2 TRAFFIC CONTROL AND WORKER SAFETY

Safety issues affect sealant performance. An uncomfortable worker, or one who feels unsafe, is unlikely to produce the best workmanship. Hence, traffic control must provide a safe working environment, while maintaining good traffic flow. Requirements for traffic control are usually stipulated by local transport authorities, and often include the use of delineators, flashers, barricades, and traffic signs. Particular attention should be paid to intersections, high-volume streets, operations that encroach onto adjacent lanes, and unusual road segments. They may require additional safety equipment and a flag person.

Workers must be protected from flying debris, as well as material and equipment hazards. Hard hats, reflective vests, long-sleeved shirts, long pants, gloves, steel-toed boots, safety glasses, and hearing protection should be mandatory for all site personnel, including supervisors. Material safety data sheets for hot- and cold-applied materials should also be consulted as they provide information about health hazards and safety procedures.

3.2 TECHNICAL ISSUES

3.2.1 CRACK SEALING

Routing and Rout Geometry

Routs with a width/depth greater than or equal to one (W/D ≥1) enhance sealant performance, but excessive widths provide greater sealant exposure to slow-moving traffic and raise failure rates (Marino, 1995; Masson et al., 1999). Hence, rout width should not exceed 30 mm. Good performance is obtained with routs of 30 by 15, 25 by 12 and 12 by 12 [W (mm) x D (mm)], with the smallest width being most difficult to centre over a crack. Routs must be square or rectangular, because rounded bottoms and V-shaped routs create debonding conditions (Wang and Weisgerber, 1993). The use of a metal die with template cylinders is highly recommended to check the width and depth of routs (Figure 3–2). The cylinders on the die correspond to the prescribed rout geometry. The diameter of the cylinder equals the prescribed rout width, and the height corresponds to the depth of the rout. Four cylinders of various dimensions can be screwed onto the die.

The die can be run along any length of crack, but 1 m is typical.

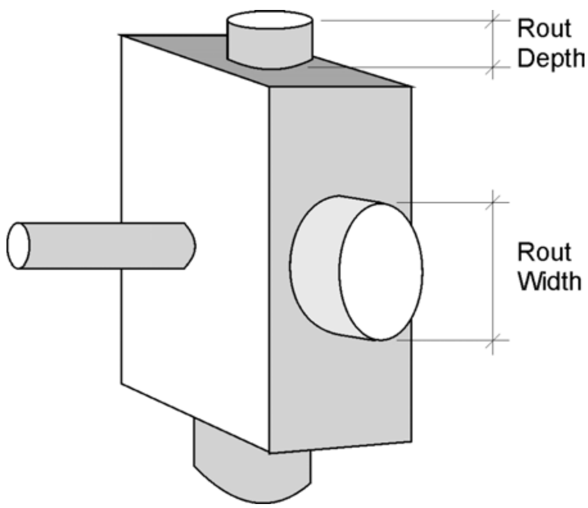


Figure 3–2: Metal die for the quality control of routing depth and width

The router must be designed to follow wandering cracks without tearing, chipping, or spalling the crack edge. It must produce a selected geometry in a single pass, and it must be capable of centering the crack evenly over the rout (Photograph 3–1). Routing can also introduce some micro-cracks at the rout surface, which may lead to premature sealant failure (Masson and Lacasse, 1999). The routing of old and oxidized pavements should be avoided if possible. For thin cracks in young pavements, crack filling should be considered, bearing in mind the limitations.

Photograph 3–1: A typical impact router (top) and its carbide-tipped cutters (bottom)

Cleaning

Routs must be cleaned before being sealed. Crack preparation is most important. A high percentage of material failure can be attributed to adhesion failure that results from dirty or moist cracks (Masson and Lacasse, 1999). Duct tape can be used to check crack cleanliness. After proper cleaning, there should be very little residue, if any, on the surface of 1 m of tape that has been pressed into the rout surface.

Cleaning is a two- or three-step operation in crack sealing.

1. Dust and debris from the routing operation must be cleaned out. As much debris as possible must be removed from the pavement surface so dust is not blown back into the rout just before it is sealed. Environmental conscientiousness would commend the use of a mechanical sweeper in order to reduce dust and its impact on the nearby environment. For this first cleaning step, a large mechanical sweeper or a large vacuum system should be used (Photograph 3–2).

Debris and loose AC fragments in the rout must be removed before sealing. This is best done with dry high-pressure air, free of oil. A compressor equipped with oil and moisture filters and providing at least 700 kPa must be used. To check for oil or moisture, the compressor hose can be aimed at the side of a tire. Clean, dry air leaves no residue. Dry high-pressure air removes some moisture from the rout.

2. A hot-air lance (HAL) may be used as a final step before sealing the rout (Photograph 3–3). It allows for some warming of the rout surface (Masson and Lacasse, 2000) and for the removal of some humidity (Smith and Romine, 1993b). The use of the HAL does not replace Step 2; it supplements it. The HAL is not a cleaning tool and should only be used at temperatures below 500°C and when the tip is 5 cm to 10 cm from the crack or rout. The colour of the hot end of the HAL is a good indication of its temperature. If it is bright orange to bright red, the temperature is 600°C to 1100°C; if it is dark red, 500°C to 600°C; if it is black, 400°C to 500°C. Overheating of the rout, most common at higher HAL temperatures, leads to lower sealant adhesion (Masson and Lacasse, 2000). The HAL may be most beneficial when crack sealing operations are done at air temperatures that are relatively low (5°C to 10°C), keeping in mind the possible effect of dew at such temperatures.

Photograph 3–2: A mechanical sweeper cleans away routing dust

Photograph 3–3: A hot-air lance

Preparation and Application of Hot-Applied Sealants

Before being poured, a sealant is melted in a double-jacketed reservoir. Hot oil circulates in the jacket, preventing the direct heating of the sealant. This reduces the sealant degradation. The melter is also equipped with a central agitator that must allow for efficient heat transfer throughout the sealant and for preventing hot spots. Gauges measure oil and sealant temperatures. The gauges must be calibrated every spring. It is highly recommended that supervisors and inspectors carry a hand-held thermometer to verify that the sealant gauge is indeed calibrated. An infrared thermoscope can also be used to monitor temperature, but it becomes unreliable when the sealant emits fumes.

Sealant degrades on heating (Figure 3–3). Degradation is kept to a minimum by short heating times below 180°C. Hence, sealants should be heated to the lowest temperature recommended by the supplier (e.g., 175°C if the recommended application temperature is 175°C to 195°C). High temperatures can increase the rate of sealant degradation, and long heating times lead to sealant degradation, even at recommended installation temperatures (Masson and Lacasse, 1999). Reheating sealant must be avoided; a workday should begin with an empty melter. The overnight heating of sealant at 75°C to 125°C, to allow for a rapid start-up in the morning, must also be avoided.

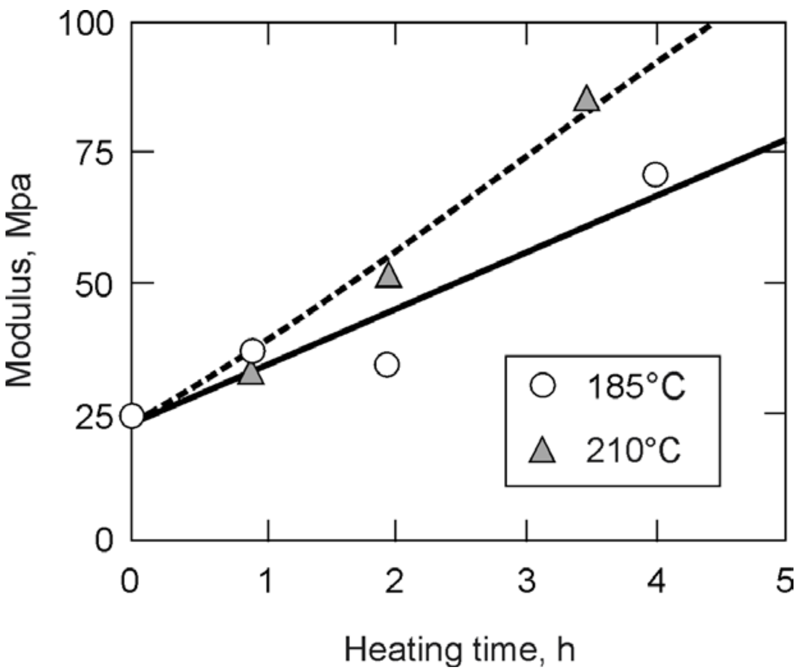
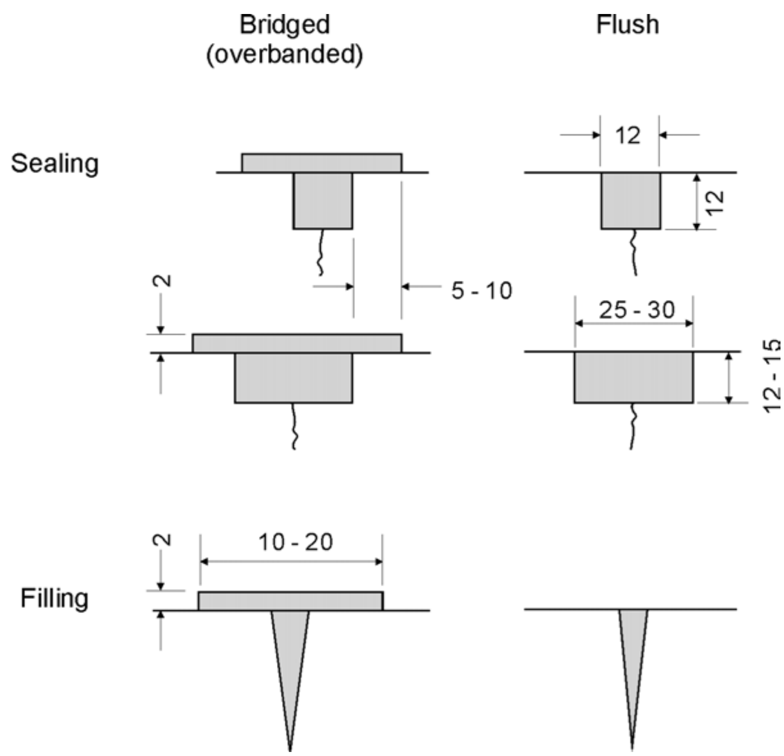


Figure 3–3: Effect on heat on sealant modulus

Shaping the Sealant and its Protection

Routs should be flush-sealed or preferably bridged (Figure 3–4). The bridge prevents water pooling on the sealant, which is often in recess after cooling. A 5 to 10 mm overlap with AC on either side of the rout is considered optimal. Large bridges may lead to excessive contact with slow-moving traffic and, subsequently, to failure (Marino, 1995). The bridge should be about 2 mm thick after sealant application. Thicker bridges lead to snowplow damage in winter. On cooling, the bridge thickness will be reduced to about 1.5 mm. The flush-sealed configuration is preferred when there is concern plowing will pull out the sealant.



Note:
Dimensions are in millimetres.

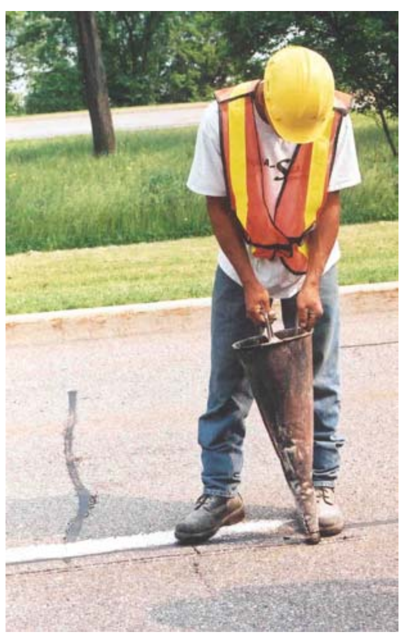
Figure 3–4: Sealant and filler geometries

Once the sealant is poured, it should be protected from traffic until it sets completely, and it should be covered with fine wood shavings (Photograph 3–4). Such material is inexpensive, and environmentally and user friendly. The use of cement dust to protect sealant should be avoided as it affects the sealant properties, pollutes, and burns the skin on repeated exposure. The use of hygienic paper is unsafe for motorists and should also be avoided. The paper can be confused with white pavement markings.

Photograph 3–4: Fine wood shavings to protect hot sealant from tires

3.2.2 CRACK FILLING

Crack filling is the sealing of cracks without routing. Hence, the method is not as labour intensive as crack sealing, and allows for a greater daily rate of crack treatment. Both cold- and hot-pour sealants can be used for crack filling. The hot-pour sealants require a kettle for heating and a cone, a wand, or a pour pot for application, but the cold-pour only requires a pour pot or a cone (Photograph 3–5).



Photograph 3–5: Emulsion application with a cone

Cleaning
When filling relatively deep and unrouted cracks, they must be cleaned. To do this, dry high-pressure air is used. The air compressor requirements are the same as for crack sealing. If a hot-pour sealant is used, the use of a HAL is also advantageous (Smith and Romine, 1993b). Since it is difficult to dry small cracks effectively without damaging the AC surface, particular attention must be paid to the HAL temperature as detailed for crack sealing. The HAL is unnecessary when a cold-applied emulsion is used as it contains water.

Preparation and Application of Hot-Applied Fillers
The preparation and application of hot-applied fillers are as described for crack sealing. Particular attention should be paid to sealant temperature and viscosity. With Type II sealants (Table 2–3), there can be a tendency to heat a sealant close to 200°C to minimize sealant viscosity and maximize its flow into thin cracks, but this may lead to rapid sealant ageing (Masson et al., 1998). For greater flow, a Type IV sealant, which has a high penetration index at 25°C and low viscosity at 185°C, is preferred (Masson et al, 1998; Masson et al., 1999).

Preparation and Application of Cold-Applied Fillers
Cold-applied fillers are bitumen emulsions (i.e., suspensions of bitumen droplets in water). The emulsion can also contain suspended polymer droplets (latex), fibres, and fines. They are ready to use, but they have a finite shelf life. Emulsions that have settled have likely exceeded their shelf life and should not be used. On application, emulsions break, which means suspended droplets and particles settle and water evaporates to leave a solid film. Volume shrinkage occurs. The settling of emulsions depends on temperature and humidity. They become dry to the touch in 15 to 45 minutes. Complete hardening takes eight to twelve hours. Hence, emulsions should only be exposed to traffic several hours after application.

Shaping of the Filler and its Protection
Cracks should be bridged or flush-filled with sealant (Figure 3–4). The flush-filled configuration may be preferred when a cold-pour material is used so its exposure to traffic during settling is minimized or when damage to sealants by plows is a major concern.

Once the filler is poured, it should be protected from traffic until it has cured (longer for emulsions). Hot-applied fillers can be covered with fine wood shavings to prevent tracking, but cold-applied emulsions should be left uncovered until fully cured.

3.3 NEEDS

There are still installation parameters for which our understanding is limited. In this respect, the relative performance of sealant installed in summer and fall/spring remains undetermined. In other words, the effect of the compromise between the best installation conditions (summer) and the best crack size to treat (fall/spring) is uncertain. Of particular importance is the lowest pavement temperature at which a sealant can be poured and still provide good adhesion.

It is also noteworthy that much research in crack treatments has focused on sealant application and very little on sealant selection. Current specifications for material selection are not performance-based and do not allow for the selection of sealant with extended durability in a demanding Canadian climate. The development of such specifications would benefit industry and users, and would increase cost effectiveness. A blueprint for a performance-based specification for hot-pour bituminous sealants already exists (Masson, 2000; Masson and Lacasse, 1998).

The certification of personnel affected to crack sealing work would also benefit the industry in general, including field surveillants and supervisors. This certification could be a 1 or 2 day course provided by a recognized association, (i.e., the Ontario Good Roads Association). However, little incentive exist for this type of certification, which may only be reinforced by the general application of performance contracts.

APPENDIX A: QUALITY CONTROL CHECKLIST

To increase the likelihood of extended service life, proper sealant installation is essential. Crack treatment has evolved over several decades, and best practices are most often the result of field experience, which is not always well documented. The following checklist, based on the current Canadian experience, is an update of an earlier one (Smith and Romine, 1993a). The greater the number of check marks (✓), the greater the possibility of a successful crack treatment.

1. Climatic Conditions

- ❑ 1.1 Ambient temperature is at least 5°C to 7°C and rising.
- ❑ 1.2 Fog/dew is absent.
- ❑ 1.3 Early morning operations are in direct sunlight.

2. Routing

- ❑ 2.1 Cutting tips are sufficiently sharp to minimize spalling and cracking.
- ❑ 2.2 Router operators wear appropriate safety attire: hard hat, reflective vest, long-sleeved shirt, long pants, steel-toed boots, safety glasses, and hearing protection.
- ❑ 2.3 Guards and safety mechanisms on equipment work properly.
- ❑ 2.4 The router follows cracks without difficulty.
- ❑ 2.5 Asphalt concrete pavement gives routs free of spalling.
- ❑ 2.6 Rout dimensions are checked with a die every 30 minutes.

3. Material Preparation

- ❑ 3.1 Melter operator wears appropriate safety attire: hard hat, reflective vest, long-sleeved shirt, long pants, gloves, steel-toed boots, and safety glasses.
- ❑ 3.2 Before the workday began, the melter was empty and no material was reheated.
- ❑ 3.3 The heating oil in the melter jacket is not fuming and its level is adequate.
- ❑ 3.4 The melter's temperature gauge was calibrated in the last 6 months.
- ❑ 3.5 If the temperature gauge was not calibrated, then
    - a) the sealant temperature is measured with a hand-held thermometre every 30 minutes;
    - b) the reading of the melter temperature gauge is the same as that for a hand-held thermometer.
- ❑ 3.6 Throughout the day, the sealant was never heated above the manufacturer's recommended pouring temperature.
- ❑ 3.7 The material safety data sheet (MSDS) for the product to be applied is available on-site.

4. Cleaning of AC and Routs

- ❑ 4.1 Operators of cleaning equipment wear appropriate safety attire: hard hats, reflective vests, long-sleeved shirts, long pants, gloves, steel-toed boots, safety glasses, and hearing protection.
- ❑ 4.2 Dirt and debris are removed from the pavement surface with a power sweeper or vacuum cleaner.
- ❑ 4.3 The compressor for high-pressure air provides at least 700 kPa of pressure.
- ❑ 4.4 The oil and moisture filters on the compressor work properly. (Check by directing the airflow at the side of a tire.)
- ❑ 4.5 If in use, the temperature of the hot-air lance (HAL) is below 500°C (tip is not coloured), and the tip is 5 cm to 10 cm from the crack or rout. Confirm that the rout and pavement surface are not discoloured from overheating with the HAL and that its use immediately precedes the sealing operation (i.e., within 2 metres).
- ❑ 4.6 Crack/rout cleanliness is checked every 30 minutes. (Use 1 m of duct tape to check for dirt, dust, or grit.)
- ❑ 4.7 The rout/crack is dry. There is no moisture or condensation visible along the crack sidewalls or edges, both before and after the cleaning/heating treatment.

5. Sealant Application

- ❑ 5.1 The hot-pour sealant is poured at the manufacturer's recommended pouring temperature and, preferably, at the lowest recommended temperature.
- ❑ 5.2 The sealant recirculates in the hose when the installation train is idle.
- ❑ 5.3 The crack or rout is bridged rather than flush-filled.
- ❑ 5.4 There is sufficient sealant to allow for a 5 to 10 mm band or bridge on either side of the sealant, when applicable.
- ❑ 5.5 Bubbles due to moisture are absent from the sealant after application.

6. Overbanding of Sealant (if not applicable go to section 7)

- ❑ 6.1 The overband is about 5 to 10 mm on either side of the crack or rout.
- ❑ 6.2 The overband is formed during sealant application, or immediately after.
- ❑ 6.3 Excess sealant is removed before it hardens.

7. Sealant Protection

- ❑ 7.1 At intersections, the hot-poured sealant surface is covered with wood shavings. Emulsions are not covered.
- ❑ 7.2 Traffic is rerouted until sealant has set. Always applies to emulsions.

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