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Materials and Procedures for Sealing and Filling Cracks in Asphalt-Surfaced Pavements

Manual of Practice



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FOREWORD

This manual (FHWA-RD-99-147) is an update of the Strategic Highway Research Program (SHRP) manual of practice (SHRP-H-348) on asphalt-surfaced pavement repair. The Federal Highway Administration, Long Term Pavement Performance Program (LTPP) conducted five years of additional research on asphalt-surfaced pavement repair after the conclusion of SHRP. This research validated the repair procedures contained in the original SHRP manual. The manual presents guidelines and recommendations to assist highway maintenance agencies and other related organizations in planning, constructing, and monitoring the performance of asphalt pavement crack treatment (i.e., sealing and filling) projects. Included in the manual are discussions pertaining to when crack treatment operations are appropriate, the types of sealant/filler materials and construction methods that should be used, how each individual step in a crack treatment operation should be performed, and how the performance and cost-effectiveness of crack treatments can be evaluated. This report will be of interest and benefit to various levels of agency maintenance personnel, from crew supervisors to the chief maintenance engineer.

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16. Abstract The Strategic Highway Research Program (SHRP) H-106 maintenance experiment and the Federal Highway Administration (FHWA) <i>Long-Term Monitoring (LTM) of Pavement Maintenance Materials Test Sites</i> project studied the treatment (sealing and filling) of cracks in asphalt-surfaced pavements. Many different treatment materials and methods were investigated between 1991 and 1998 through test sites installed at five locations in the United States and Canada. The findings of these combined studies have been merged with standard highway agency procedures to provide the most useful and up-to-date information on the practice of asphalt crack treatment. This Manual of Practice is an updated version of the 1993 SHRP Crack Sealing and Filling Manual. It contains the latest information pertaining to the performance of treatment materials and methods, the availability and relative costs of sealant/filler materials, and the proper ways of planning, designing, constructing, and monitoring the performance of crack treatment projects. It also provides an updated partial listing of material and equipment manufacturers. This Manual is intended for field and office personnel within highway maintenance agencies and contracted maintenance firms. It contains valuable information for supervisors and foremen in charge of individual crack treatment operations, engineers in charge of planning and overseeing many crack treatment projects, and managers in charge of establishing crack treatment policies and standards.					
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Preface

This manual is intended for use by highway maintenance agencies and contracted maintenance firms in the field and in the office. It is a compendium of good practices for asphalt concrete (AC) crack sealing and filling operations, stemming from the Strategic Highway Research Program (SHRP) pavement maintenance studies and a follow-up study sponsored by the Federal Highway Administration (FHWA).

In SHRP project H-105, *Innovative Materials and Equipment for Pavement Surface Repair*, the researchers conducted a massive literature review and a nationwide survey of highway agencies to identify potentially cost-effective repair and treatment options (Smith et al., 1991). The information and findings from that study were then used in the subsequent field experiments conducted under SHRP project H-106, *Innovative Materials Development and Testing*.

In project H-106, many different test sections were installed and evaluated to determine the cost-effectiveness of maintenance materials and procedures. Test sections were installed at 22 sites throughout the United States and Canada between March 1991 and February 1992, under the supervision of SHRP representatives. The researchers collected installation and productivity information at each site and periodically evaluated the experimental repairs and treatments through the end of 1992. The first version of this manual was prepared in October 1993 and was based on this work effort.

Following the conclusion of SHRP H-106 in 1993, the FHWA sponsored a study to continue monitoring the performance of the experimental repairs and treatments, beginning in October 1993. Under the *Long-Term Monitoring (LTM) of Pavement Maintenance Materials Test Sites* project, the repairs and treatments were evaluated annually through the end of 1997.

Pertinent long-term performance and cost-effectiveness information generated by the continued monitoring of the experimental crack treatments has been included in this revised manual.

For the reader's convenience, potentially unfamiliar terms are italicized at their first occurrence in the manual and are defined in a glossary. Readers who want more information on topics included in this manual should refer to the reference list provided at the back. The final report for the H-106/*LTM* AC crack treatment study may be of particular interest to many readers (Smith and Romine, 1999). It details the installation procedures, laboratory testing of the materials, and long-term field performance and cost-effectiveness of each crack treatment type investigated.

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1.0 Introduction

Cracking in asphalt concrete (AC)-surfaced pavements is a phenomenon that pavement design and maintenance engineers have had to contend with for years. It is one of two principal considerations (fatigue cracking and rutting) in the pavement design process, and it is often the primary mode of deterioration in AC pavements. Cracks are inevitable, and neglect leads to accelerated cracking and potholing, further reducing pavement *serviceability*.*

The problem of cracks is handled in many ways, ranging from pavement maintenance activities, such as surface treatments and crack filling, to full-scale pavement rehabilitation projects, such as resurfacing. Maintenance departments bear most of the burden of dealing with cracks. Departments with sufficient funding are often responsible for adding a few more years of serviceable life to deteriorated pavements through preventive or routine maintenance, or both.

Two of the more common options exercised by maintenance departments are crack sealing and crack filling. These operations have been conducted for many years, generally on a routine basis. However, only in the last two decades has their potential benefits as preventive maintenance tools been realized. With proper and timely application, crack sealing and filling can extend pavement life past the point where the cost-benefit of added pavement life exceeds the cost of conducting the operation.

* Italicized words are defined in the glossary.

1.1 Scope of Manual

This manual has been prepared to guide pavement maintenance personnel (i.e., engineers, supervisors, and crewpersons) in the selection, installation, and evaluation of materials and procedures used to treat (seal or fill) cracks in AC-surfaced pavements. The information contained herein is based on the most recent research, obtained through literature reviews and current practices, and on the results of a large-scale, long-term crack treatment field study sponsored by the Strategic Highway Research Program (SHRP) and the Federal Highway Administration (FHWA) (Smith et al., 1991; Evans et al., 1993; Smith and Romine, 1999).

This manual provides both general and specific information for carrying out each of four primary phases associated with a *crack treatment* program. These phases are as follows:

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

Crack treatment is far from being the long, involved process typical of a pavement construction or rehabilitation project. However, like these projects, it must be carefully planned and conducted to be successful. Table 1 illustrates the steps involved in the crack treatment process, as well as the factors that must be considered.

Table 1. Steps in a crack treatment program.

Step	Description
1	Obtain and review construction and maintenance records. - Pavement age, design, repairs, and so on.
2	Perform pavement/crack survey. - Record distress types, amounts, and severities.
3	Determine appropriate type of maintenance for cracked pavement based on density and condition of cracks. - High density of cracks having moderate to no edge deterioration Y pavement surface treatment. - Moderate density of cracks having moderate to no edge deterioration Y crack treatment. - Moderate density of cracks having high level of edge deterioration Y crack repair.
4	For crack treatment, determine whether cracks should be sealed or filled. ^a - Cracks typically showing significant annual horizontal movement Y crack sealing. - Cracks typically showing very little annual horizontal movement Y crack filling.
5	Select materials and procedures for crack treatment operation based on the following considerations: - Climate (dry-freeze, dry-nonfreeze, wet-freeze, wet-nonfreeze). - Traffic (high, medium, low). - Crack characteristics (width, deterioration). - Available equipment. - Available manpower. - Cost-effectiveness (anticipated treatment cost and performance).
6	Acquire materials and equipment.
7	Conduct and inspect crack treatment operation.
8	Periodically evaluate treatment performance.

^a See sections 2.3 and 2.4.

2.0 Need for Crack Treatment

If a particular cracked pavement appears to be in need of some sort of maintenance, a relatively quick assessment can be made to ascertain the need and, more importantly, to help in determining the appropriate action. Such an assessment requires an evaluation of existing pavement conditions and a knowledge of future rehabilitation plans, both of which may be found in a pavement management system (PMS).

2.1 Pavement/Crack Evaluation

Although maintenance engineers or supervisors are normally quite familiar with the roads they maintain, a quick review of construction, maintenance, and other records will provide important general information regarding the following:

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

After these records are reviewed, a shoulder survey should then be performed on a small representative sample of the pavement section, about 150 m, to determine the amount, type, and condition or severity of cracks, as well as the condition or *effectiveness* of any previously applied crack treatments (see section 5.0). A sample survey form for recording pavement and crack information is provided in figure 1.

Asphalt Pavement/Crack Survey Form

Location and Geometrics

Highway/Road:	Milepost/Station of Section:
Number of Lanes:	Length of Section:
Lane Widths:	Shoulder Type and Width:

Design, Construction, and Rehabilitation

Pavement Type (full-depth AC, conventional AC, composite AC/PCC):
Year of Original Construction:
Type and Year of Most Recent Rehabilitation:
Future Rehabilitation Planned:

Climate, Traffic, and Highway Classification

Average Annual Precipitation (mm):	Pavement Cross-Section
No. Days Below 0°C:	Material 1 (top) = Thickness =
No. Days Above 38°C:	Material 2 = Thickness =
Functional Classification:	Material 3 = Thickness =
Most Recent 2-Way ADT:	Material 4 (bottom) = Thickness =

Pavement Condition

Cracking Distress

Primary Crack Type/Orientation:
Density (lin m/150-m section): Average Width (mm):
Edge Deterioration (%):
Cupping? Lipping? Faulting? Average Depth/Height (mm):
Previous Treatment? Y N
Material Type?
Effectiveness (% crack length not failed):

Other Crack Type/Orientation:
Density (lin m/150-m section): Average Width (mm):
Edge Deterioration (%):
Cupping? Lipping? Faulting? Average Depth/Height (mm):
Previous Treatment? Y N
Material Type?
Effectiveness (% crack length not failed):

Other Significant Distresses

Type:	Density:
Type:	Density:
Type:	Density:

Figure 1. Asphalt pavement/crack survey form.

2.2 Determining the Type of Maintenance

The appropriate type of maintenance for cracked pavements often depends on the density and general condition of the cracks. If cracks are abundant and do not exhibit a high degree of *edge deterioration*, they may best be treated through chip seals, slurry seals, or the like. If cracks are low to moderate in density and have typically progressed to a point of high edge deterioration, then *crack repair* strategies, such as partial-depth patching or spot patching, may be warranted. If cracks are moderate in density and show moderate to no deterioration at the edges, then they may be treated effectively through sealing or filling operations. Table 2 summarizes these guidelines.

As table 2 indicates, crack density levels are described in general terms. This is because experienced personnel can make reasonable assessments of density. Figures 2 through 5 illustrate typical crack situations and potential remedies.

Table 2. Guidelines for determining the type of maintenance to be performed.

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



Figure 2. Pavement candidate for surface treatment:
high-density cracking.



Figure 3. Pavement candidate for
crack repair.



Figure 4. Pavement candidate for transverse crack sealing.



Figure 5. Pavement candidate for longitudinal crack filling.

In general, a large number of cracks or severely deteriorated cracks indicate a pavement in an advanced state of decay. Crack sealing or filling in these circumstances is both uneconomical and technically unsound, as it does little to delay the need for more extensive corrective actions.

Most highway agencies have established policies that specify the type of maintenance to be performed on cracked pavements and when to perform it. The policies are often based on an assessment of the overall pavement condition (extent of cracking) or specific crack characteristics (type and width).

2.2.1 Other Considerations

On occasion, cracks may have other types of deficiencies. In particular, crack edges may exhibit vertical distresses, such as *cupping*, *lipping*, or *faulting*, or may undergo significant vertical deflections or movements under traffic loading. Such deficiencies can add significantly to overall pavement roughness and can deteriorate rapidly.

Normally, repair alternatives such as patching or milling are appropriate for correcting these deficiencies. However, if the amount of vertical deflection and the severity of the distress are not too high, a temporary fix with crack treatment may be adequate.

2.3 Objectives of Sealing and Filling

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

Crack Sealing—The placement of specialized treatment materials above or into *working* cracks using unique configurations to prevent the intrusion of water and *incompressibles* into the crack.

Crack Filling—The placement of ordinary treatment materials into *non-working* cracks to substantially reduce infiltration of water and to reinforce the adjacent pavement.

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

It is assumed in this manual that where cracks are exhibiting significant vertical deflections, the appropriate repair strategy will be sought. Hence, for cracks with limited vertical movement, horizontal movement becomes the critical factor in determining the need for, and planning of, a crack treatment operation.

2.4 Determining Whether to Seal or Fill

Frequently, the first cracks to appear in a pavement are *transverse* cracks. However, several different types of cracks may appear at one time. In these cases, one treatment, using a material appropriate for the most demanding crack type, is desirable.

Though crack width may be a factor in determining whether to seal or fill, the amount of annual horizontal movement of the targeted crack type should be the principal basis for this decision. Normally, working cracks with limited edge deterioration should be sealed, whereas non-working cracks with moderate to no edge deterioration should be filled.

Whether a crack is working or non-working can generally be determined by its type. Working cracks are usually transverse in orientation; however, some *longitudinal* and diagonal cracks may meet the 3-mm movement criteria. Materials placed in working cracks must adhere to the crack sidewalls and flex as the crack opens and closes. Rubber-modified materials designed for low-stress elongation, especially at low temperatures, are preferred for treating these cracks.

Non-working cracks typically include diagonal cracks, most longitudinal cracks, and some block cracks. Because of the relatively close spacing or free edges between non-working cracks, little movement occurs. Minimal movement permits the use of less expensive, less specialized crack-filler materials. Experienced personnel can usually determine if the targeted crack type is working or non-working, and table 3 provides recommended criteria for determining which cracks to seal and which to fill.

2.4.1 When to Seal and When to Fill

Crack sealing is a preventive maintenance activity. Ideally, it is conducted shortly after working cracks have developed to an adequate extent and at a time of year when temperatures are moderately cool (7 to 18°C), such as in the spring or fall. When newly developed cracks are sealed, deteriorated crack segments (i.e., *secondary cracks, spalls*), which adversely affect seal performance, are minimized. Typically, transverse

Table 3. Recommended criteria for determining whether to seal or fill.

Crack Characteristics	Crack Treatment Activity	
	Crack Sealing	Crack Filling
Width, mm	5 to 19	5 to 25
Edge Deterioration (i.e., spalls, secondary cracks)	Minimal to None (≤ 25 percent of crack length)	Moderate to None (≤ 50 percent of crack length)
Annual Horizontal Movement, mm	≥ 3	< 3
Type of Crack	Transverse Thermal Cracks Transverse Reflective Cracks Longitudinal Reflective Cracks Longitudinal Cold-Joint Cracks	Longitudinal Reflective Cracks Longitudinal Cold-Joint Cracks Longitudinal Edge Cracks Distantly Spaced Block Cracks

thermal cracks in AC flexible pavements appear 2 to 7 years after construction, whereas transverse reflection cracks in AC-overlaid concrete pavements often materialize 1 to 3 years after resurfacing.

Sealing in moderately cool temperatures is beneficial from two standpoints. First, cracks are partly opened so that a sufficient amount of material can be placed in the crack if cutting is not to be performed. Second, the width of the *crack channel*, whether cut or uncut, is nearly at the middle of its working range. This is important to the performance of the sealant material because it will not have to undergo excessive extension or contraction.

Most crack filling operations can be conducted year-round; however, they often take place during cool or moderately cool weather (2 to 13°C). At these temperatures, cracks are mostly or completely open, and more material can be applied.

Crack filling operations can be preventive or routine in nature, depending on the highway agency's approach to treating the cracks. Like sealing operations, preventive crack filling maintenance should be conducted shortly after non-working cracks have developed adequately. Depending on the type of cracks to be filled, this may occur as early as between 4 and 8 years after construction or resurfacing. Durable filler materials should be used to reduce the number of repeat applications. By filling cracks shortly after they are fully developed, further growth is delayed.

Historically, most crack filling has been performed on a routine basis with inappropriate materials that provide less than desirable performance. This approach to crack filling is rarely cost-effective because treatment performance is generally poor and maintenance costs are high. In addition, the safety of the workers and traveling public is compromised, since the filling operation must be repeated frequently.

3.0 Planning and Design

3.1 Primary Considerations

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

1. Climatic conditions.
 - a. At time of installation.
 - b. In general.
2. Highway classification.
3. Traffic level and percent trucks.
4. Crack characteristics and density.
5. Materials.
6. Material placement configurations.
7. Procedures and equipment.
8. Safety.

The planning process centers on selecting an appropriate material and placement configuration, and determining the procedures and equipment to be used based on existing and future roadway conditions.

The site-specific climatic conditions during treatment operations can occasionally influence which procedures or materials should be used. For instance, in areas where moisture or cold temperatures present scheduling problems, the use of a heat lance may expedite operations.

Overall climatic conditions must also be considered in deciding which materials and procedures are to be used. Hot climates necessitate the use of materials that will not significantly soften and track at high temperatures. Very cold climates, on the other hand, will generally require materials that retain good flexibility at low temperatures.

Highway classification and traffic characteristics are important from two standpoints. First, highway geometrics and traffic levels may be such that overall safety during installation is greatly compromised. Applying longer lasting treatments reduces the number of subsequent applications. Fewer applications means less time on the roadway and increases safety.

Second, if a material is to be placed in an *overband* configuration, consideration must be given to the amount of traffic expected over the material and whether or not snowplows, particularly direct-contact plows, are used. The most durable, yet flexible, material would be desirable on roads where traffic levels are medium or high (average daily traffic [ADT] > 5,000 vehicles/day) or snowplows are operated.

Crack characteristics, such as width, movement, and edge deterioration, will also influence which materials and procedures should be used. Some of these characteristics, along with crack density, are needed for estimating the amount of material required for the project.

3.2 Selecting a Sealant or Filler Material

There are many crack treatment material products on the market today, each with distinct characteristics. The products essentially comprise three material families and are often grouped by material type, according to their composition and manufacturing process. The principal material families and types are as follows:

- ! Cold-applied *thermoplastic* bituminous materials.
- ŷ Liquid asphalt (emulsion).
- ŷ Polymer-modified liquid asphalt.

- ! Hot-applied thermoplastic bituminous materials.
 - ŷ Asphalt cement.
 - ŷ Fiberized asphalt.
 - ŷ Asphalt rubber.
 - ŷ Rubberized asphalt.
 - ŷ Low-modulus rubberized asphalt.
- ! Chemically cured *thermosetting* materials.
 - ŷ Self-leveling silicone.

Three materials excluded from the list above are asphalt cutbacks, mineral-filled (stone, lime, flyash dust) asphalts, and sand–asphalt mixes. Cutbacks are rarely used today because of environmental hazards, whereas mineral-filled asphalts have generally been found not cost-effective. Sand–asphalt mixes are considered to be crack repair materials.

Among the thermoplastic bituminous materials, asphalt cement and liquid asphalt possess little, if any, flexibility and are very temperature-susceptible. Hence, they are limited to use as fillers for non-working cracks. Similarly, since fiber particles provide minimal elasticity to asphalt and do not significantly affect temperature susceptibility, fiberized asphalts are most appropriate in crack filling operations.

The addition of rubber polymer to liquid or heated asphalt generally improves field performance because it imparts flexibility to the asphalt. The degree of flexibility basically depends on the type and nature of the asphalt, the percentage of vulcanized rubber used, and how the rubber is incorporated into the asphalt (i.e., mixed or melted in). Other polymers are often incorporated into asphalt, either exclusively or along with rubber, to increase resilience. The following is the generally increasing trend in performance characteristics of polymer-modified asphalts:

Polymer-Modified Liquid Asphalt 6 Asphalt Rubber 6
Rubberized Asphalt 6 Low-Modulus Rubberized Asphalt

Chemically cured thermosetting materials are one- or two-component materials that cure by chemical reaction from a liquid state to a solid state. This type of material has been used in AC pavements only in recent years. Self-leveling silicone is a one-component, cold-applied sealant that requires no tooling.

Table 4 provides general information about each material type, including applicable specifications, recommended applications, and typical cost ranges. Generally speaking, the complexity and quality of the materials increase as one scans down the table. Consequently, the costs also increase and the recommended application changes from crack filling to crack sealing.

The first step in selecting a material is to identify the key properties that a material must possess to be efficiently placed and to perform successfully under the conditions provided for the time desired. Several of the more desirable properties include the following:

- ! Short preparation time.
- ! Quick and easy to place (good workability).
- ! Short cure time.
- ! *Adhesiveness*.
- ! *Cohesiveness*.
- ! Resistance to softening and flow.
- ! *Flexibility*.
- ! *Elasticity*.
- ! Resistance to aging and weathering.
- ! *Abrasion* resistance.

Table 5 illustrates the material types that possess most of the above properties. As can be seen, the rubberlike properties associated with some materials make them good choices for

Table 4. Summary of AC crack treatment materials.

Material Type	Applicable Specifications	Recommended Application	Cost Range, \$/kg ^a
Asphalt Emulsion	ASTM ^b D 977, AASHTO ^c M 140, ASTM D 2397, AASHTO M 208	Filling	0.15 to 0.30
Asphalt Cement	ASTM D 3381, AASHTO M 20, AASHTO M 226	Filling	0.15 to 0.30
Fiberized Asphalt	Manufacturer's recommended specs	Filling	0.35 to 0.60
Polymer-Modified Emulsion	ASTM D 977, AASHTO M 140, ASTM D 2397, AASHTO M 208	Filling (possibly sealing)	0.80 to 1.20
Asphalt Rubber	State specs, ASTM D 5078	Sealing (possibly filling)	0.45 to 0.65
Rubberized Asphalt	ASTM D 1190, AASHTO M 173, Fed SS-S-164	Sealing	0.55 to 0.85
	ASTM D 3405, AASHTO M 301, Fed SS-S-1401	Sealing	0.65 to 1.10
Low-Modulus Rubberized Asphalt	State-modified ASTM D 3405 specs	Sealing	0.75 to 1.40
Self-Leveling Silicone	ASTM D 5893	Sealing	5.75 to 6.75

^a Based on 1998 costs.

^b ASTM = American Society for Testing and Materials.

^c AASHTO = American Association of State Highway and Transportation Officials.

Table 5. Properties associated with various material types.

Property	Material Type							
	Emulsion	Asphalt Cement	Fiberized Asphalt	Polymer- Modified Emulsion	Asphalt Rubber	Rubberized Asphalt	Low-Modulus Rubberized Asphalt	Self-Leveling Silicone
Short Preparation	T			T				TT
Quick & Easy to Place	T	TT	TT	T	TT	TT	TT	
Short Cure Time		TT	TT		TT	TT	TT	T
Adhesiveness	TT	TT	T	T	T	T	T	T
Cohesiveness					T	T	TT	T
Resistance to Softening & Flow (cured state)				T	T	T	TT	TT
Flexibility				T	T	T	TT	TT
Elasticity				T	T	T	T	TT
Resistance to Aging & Weathering						T	T	TT
Resistance to Abrasion					T	TT	T	

T Applicable
 TT Very Applicable

sealing working cracks, whereas the preparation and installation attributes of emulsion and asphalt cement make them desirable for crack filling.

Table 5 shows which material types will best meet the demands of the project. For instance, if the material to be used must be moderately flexible, resistant to tracking and abrasion, and rapidly installable, then a rubberized asphalt should be considered. If the project requires a material that is adhesive, resistant to abrasion, rapidly installable, and quick to cure, then asphalt rubber or rubberized asphalt should be considered.

Actual field performance should always be considered when determining which material to use. Maintenance planners should not only keep abreast of the results of national and State crack treatment studies, they should also stay informed of local experiences with material performance. Results from the recently concluded SHRP H-106 crack treatment study indicate the following material performance capabilities, given proper installation (Smith and Romine, 1999):

- ! Emulsion and asphalt cement filler materials placed flush in unrouted, non-working cracks can perform satisfactorily for between 2 and 4 years, whereas rubber- and fiber-modified asphalt fillers placed flush or overbanded in the same cracks can serve effectively for 6 to 8 years.

- ! Rubberized asphalt sealants placed flush or overbanded in routed, working cracks can provide between 5 and 9 years of service, whereas placed overbanded in non-routed working cracks, they can provide 2.5 to 5 years of service.

- ! Self-leveling silicone placed recessed in routed/sawn working cracks can perform satisfactorily for at least 4 to 6 years.
- ! Fiberized asphalt placed overbanded in unrouted, working cracks can provide a maximum of 2 years of adequate service.

To obtain the maximum benefit from each maintenance dollar spent, all costs associated with installing a material must be added and compared with the service life of the material. This is referred to as a cost-effectiveness analysis.

The process of cost-effectiveness analysis is discussed in detail in section 3.6. Results from the SHRP H-106 crack treatment study indicate that the most cost-effective crack fillers are rubber-modified asphalts placed flush or overbanded and fiber-modified asphalts placed overbanded (Smith and Romine, 1999). Results also showed that the most cost-effective, long-term (5 to 8 years) crack sealants are modified rubberized asphalts placed overbanded in routed cracks (Smith and Romine, 1999).

3.2.1 Laboratory Testing

Laboratory testing of the selected sealant or filler material is highly recommended. Testing ensures that the material obtained exhibits the properties for which it was selected.

The testing process begins with material sampling. As a general rule, a minimum sample of 2 to 4 kg should be taken from each batch, or lot, of material shipped. These samples should then be submitted for testing at an agency-approved testing laboratory prior to placement.

Laboratory testing should be conducted in full accordance with the test methods specified for the material. Variations in testing parameters, such as rates, temperatures, and specimen sizes, can significantly affect test results.

If the material does not meet all applicable specifications, it should be rejected. On the other hand, good performance does not guarantee material compliance with specifications. **Proper installation is a must, no matter how good the material!**

For commonly used test criteria for the major sealant material types, refer to appendix A.

3.3 Selecting a Placement Configuration

Sealant and filler materials can be placed in cracks in numerous configurations; the most common are shown in figure 6. These placement configurations are grouped into four categories (Cook et al., 1991):

- ! Flush fill.
- ! Reservoir.
- ! Overband.
- ! Combination (reservoir and overband).

In the flush fill configuration, material is simply dispensed into the existing, uncut crack and excess material is struck off. Configuration A in figure 6 illustrates the flush fill configuration.

In a reservoir configuration, material is placed only within the confines of a cut crack (i.e., *crack reservoir*). The material is placed either flush with or slightly below the pavement surface. Configurations D, F, H, J, and K in figure 6 are reservoir-type configurations.

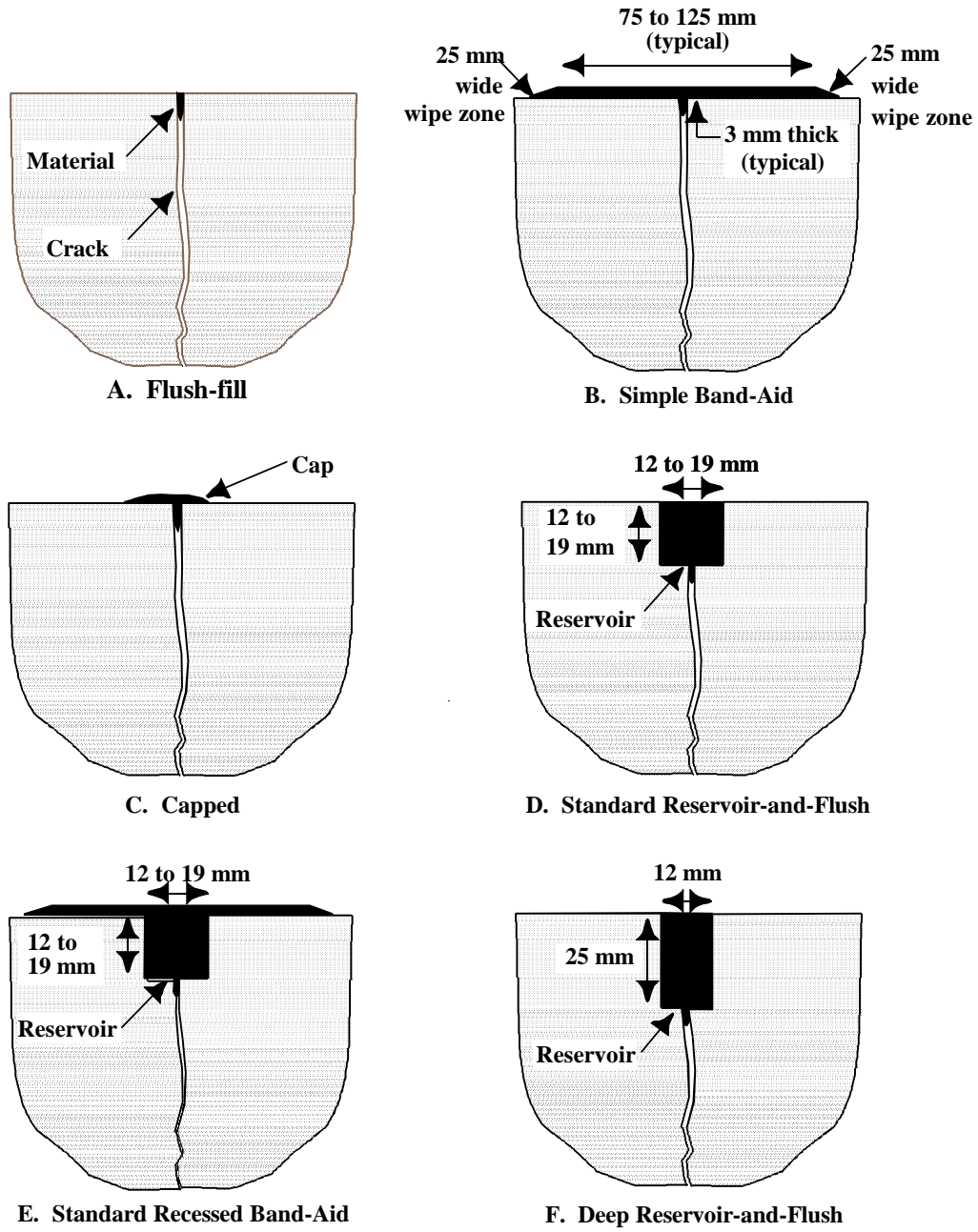
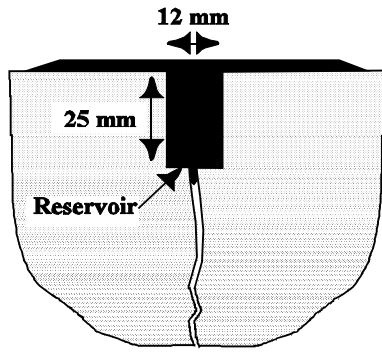
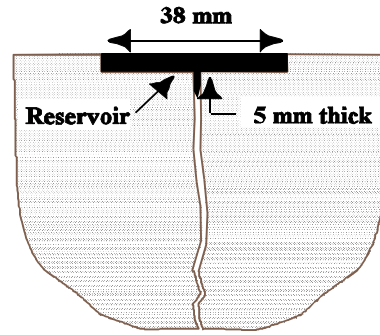


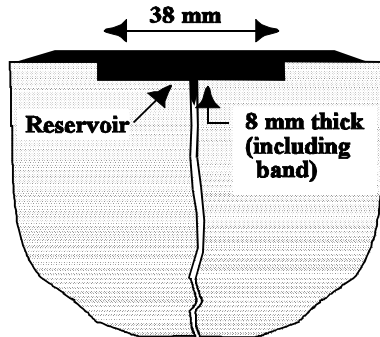
Figure 6. Material placement configurations



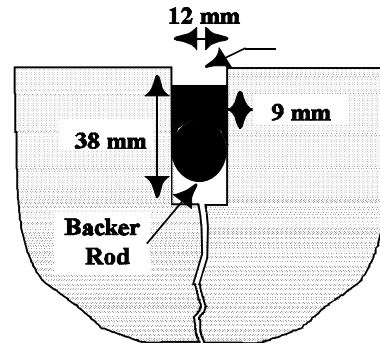
G. Deep Recessed Band-Aid



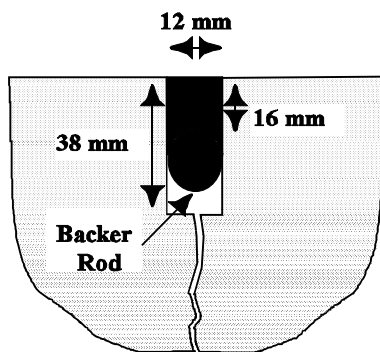
H. Shallow Reservoir-and-Flush



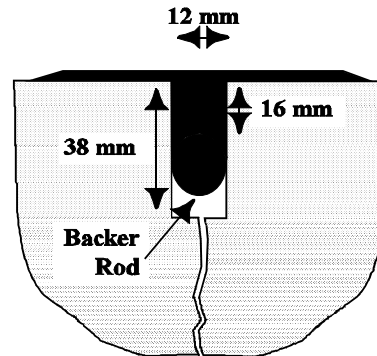
I. Shallow Recessed Band-Aid



J. Deep Reservoir-and-Recess (backer rod)



K. Deep Reservoir-and-Flush (backer rod)



L. Deep Recessed Band-Aid (backer rod)

Figure 6. Material placement configuration (continued).

In an overband configuration, the material is placed into and over an uncut crack. If the material over the crack is shaped into a band using a squeegee, then the simple *band-aid* configuration is formed (configuration B). If the material over the crack is left unshaped, then the *capped* configuration is created (configuration C).

A combination configuration consists of a material placed into and over a cut crack. A squeegee is used to shape the material into a band that is centered over the crack reservoir. Configurations E, G, I, and L in figure 6 are combination-type configurations.

Individual configurations are based on four controlling variables.

1. Type of application.
 - a. Direct—Material applied directly to crack channel.
 - b. Bond-Breaker—Backer material placed at bottom of crack reservoir prior to material installation in order to prevent three-sided adhesion (i.e., bonding by material to crack reservoir bottom and sidewalls).
2. Type of crack channel.
 - a. Uncut.
 - b. Cut—Router or saw used to create uniform crack reservoir.
3. Strike-off or finishing characteristics.
 - a. Recessed.
 - b. Flush.
 - c. Capped.
 - d. Band-aid.
4. Dimensions of crack reservoir and overband.

Nearly all sealing and filling operations have the material applied directly to the crack channel (configurations A through I). Occasionally, however, a bond-breaker material, such as

polyethylene foam backer rod, is placed at the reservoir bottom of a working crack prior to sealant application (configurations J, K, and L). The backer rod prevents sealant material from running down into the crack during application and also from forming a three-sided bond with the reservoir perimeter. As a result, the sealant's potential performance is enhanced.

Sealant shape, particularly for reservoir configurations, also influences performance. It is the primary design consideration and is often dealt with in terms of shape factor. The shape factor is defined as the ratio between the width and depth of the sealant (Peterson, 1982). In direct applications, shape factor is controlled solely by the crack-cutting operation (i.e., cutting width and depth). In backer rod applications, shape factor is controlled by both the cutting operation and the depth to which the backer rod is placed.

Current recommendations for both direct and bond-breaker applications are to give rubber-modified asphalt sealants a shape factor of 1 and silicone sealants a shape factor of 2. Generally, seals with smaller shape factors risk adhesion loss, while those with larger shape factors have increased resistance to adhesion loss.

Bond-breaker application should only be considered when the following two factors apply:

- ! The costs of installing backer rod are anticipated to be lower than the cost benefits of improved performance.
- ! Working cracks are relatively straight (as with joint reflection cracks) and are accompanied by very little edge deterioration.

Most hot-applied rubber-modified sealants are recommended for direct application; the increased costs of using backer rod with these materials is not justified. Silicone is perhaps the only material recommended for placement with backer rod.

A meandering crack is often difficult to follow accurately with cutting equipment. Portions of the crack may occasionally be missed, resulting in two adjacent channels. This presents the dilemma of whether to seal both the cut and uncut crack segments or to cut the missed crack segment and seal both reservoirs. A similar dilemma arises with secondary cracks along the primary crack.

Routers and saws are usually equipped with controls for varying the depth of cut, and the width setting can normally be adjusted manually. Backer rod can be placed in deep reservoirs (25 to 38 mm) to a depth that allows for the desired shape factor. This depth normally varies between 12 and 19 mm. The backer rod should be about 25 percent wider than the width of the crack reservoir for it to maintain its vertical position and provide proper shape for the material.

The decision of whether to overband a sealant or filler material depends primarily on the material being used. Some materials, such as silicone and emulsion, simply must not come in contact with traffic. Also, some materials wear away more easily under traffic than others.

If overbanding of hot-applied, rubber-modified asphalt is desired, it also must be decided if the material will be shaped into a band-aid or left as a capped configuration. The latter process generally means one less laborer, but possibly at the sacrifice of treatment effectiveness. This is because shaping with a squeegee or dish attachment helps in establishing a "hot bond" for the entire band. In capped configurations, the material may continue to flow and level out after being applied.

Bonds occurring as a result of this self-leveling are likely to be weaker because the material will have decreased in temperature.

The dimensions of the band-aid are typically 75 to 125 mm wide and 3 to 6 mm thick. The simple band-aid configuration (configuration B) evolved out of a desire to make application quick and easy by eliminating crack-cutting operations. The recessed band-aid configuration was devised to improve the performance of reservoir-type configurations through the addition of the band as a wearing surface.

Selecting a placement configuration is an involved process. Table 6 offers a few basic considerations to aid the planner.

3.4 Selecting Procedures and Equipment

Crack treatment consists of at least two and up to five steps, depending on the type of treatment (sealing or filling), treatment policy, and available equipment. These steps are:

1. Crack cutting (i.e., routing or sawing).
2. Crack cleaning and drying.
3. Material preparation and application.
4. Material finishing/shaping.
5. Blotting.

Steps 1, 4, and 5 are considered optional. Crack cutting is rarely done in filling operations, but is frequently done in sealing operations. In regions with significant annual temperature variations, typical of many northern States, crack cutting is often performed to achieve material shape factors that can provide added flexibility for withstanding high crack movements.

Table 6. Placement configuration considerations.

Consideration	Applicability
Type and Extent of Operation	Most filling operations, and some sealing operations, omit crack cutting operation. Many northern States find crack cutting necessary or desirable.
Traffic	Overband configurations experience wear and, subsequently, high tensile stresses directly above the crack edges, leading to internal rupture.
Crack Characteristics	Overband configurations are more appropriate for cracks having a considerable amount of edge deterioration (> 10 percent of crack length), because the overband simultaneously fills and covers the deteriorated segments in the same pass.
Material Type	Materials such as emulsion, asphalt cement, and silicone must be placed unexposed to traffic due to serious tracking or abrasion problems.
Desired Performance	For long-term sealant performance, flush, reservoir, and recessed band-aid configurations should be considered.
Aesthetics	Overband and combination configurations detract from the general appearance of the pavement.
Cost	Omission of crack cutting operation reduces equipment and labor costs. Combination configurations require significantly more material than reservoir configurations, resulting in higher costs.

Most crack treatment programs use squeegees to finish or shape the material at the surface; capped and recess configurations require no finishing.

Finally, blotting, in which a temporary covering such as toilet paper, sand, or limestone dust is placed directly on top of the treatment material, may be necessary to prevent tracking. Asphalt emulsions and hot-applied materials placed in overband configurations and prematurely subjected to traffic are prime candidates for blotting.

Many types and brands of equipment are available for crack treatment operations. Table 7 lists the types of equipment commonly used, examples of equipment manufacturers, and general recommendations concerning each piece of equipment. Table 8 provides additional information about the manpower requirements and typical production rates associated with each procedure.

3.4.1 Crack Cutting

Crack cutting is done with routers or saws, as illustrated in figures 7 and 8. However, because crack cutting can inflict additional damage on the pavement and is often the slowest activity in sealing operations, it is desirable to use a high-production machine that follows cracks well and produces minimal spalls or fractures.

The vertical-spindle router is perhaps the least damaging and most maneuverable cutting machine; however, its production rate is quite low. Rotary-impact routers are much more productive than vertical-spindle routers; however, depending on the type of cutting bit used, they can cause considerably more damage. Carbide router bits are highly recommended over steel router bits.

Table 7. Crack treatment equipment characteristics and recommendations.

Operation	Type of Equipment	Recommendations
Crack Cutting	Vertical-Spindle Router	Use only with sharp carbide-tipped or diamond router bits.
	Rotary-Impact Router	Use only with sharp carbide-tipped router bits.
	Random Crack Saw	Use only on fairly straight cracks. Diamond-blade saw, 200-mm maximum diameter.
Crack Cleaning/ Drying	Blowers (Backpack & Power-Driven)	Not recommended —Insufficient blast velocity (60 to 100 m/s).
	Air Compressor	Equipped with oil and moisture filters. Pressure—690 kPa minimum. Flow—0.07 m ³ /s minimum. Velocity—990 m/s minimum.
	Hot-Air Lance	Velocity—610 m/s minimum. Temperature—1370°C minimum. No direct flame on pavement. <u>Highly Recommended</u> Velocity—915 m/s minimum. Temperature—1650°C minimum.
	Sandblaster	Acceptable air compressor (minimum 690 kPa pressure and 0.07 m ³ /s flow). Minimum 25-mm-inside-diameter lines and 6-mm-diameter nozzle.
	Wirebrush	Do not use with worn brushes. Not recommended for cleaning previously treated cracks, as there is a tendency to smear material.

Table 7. Crack treatment equipment characteristics and recommendations (continued).

Operation	Type of Equipment	Recommendations
Material Installation	Pour Pots	Not recommended for production operations.
	Asphalt Distributor	Not suitable for fiber- or rubber-modified asphalt materials.
	Melter-Applicator	Direct-heat kettles not suitable for fiber- or rubber-modified asphalt materials. Indirect-heat kettles should be equipped with: * Double-boiler, mechanical agitator with separate automatic temperature controls for oil and melting chamber. * Sealant heating range to 230°C. * Full-sweep agitator. * Accurately calibrated material and heating oil temperature gauges.
	Backer Rod Installation Tools	Maintains proper recess. Does not damage backer rod.
	Silicone Pump & Applicator	Flow Rate—0.025 L/s minimum. Hose lined with Teflon; all seals and packing made from Teflon.
Material Finishing	Squeegee	Heavy-duty, industrial U- or V-shaped.