WSDOT Chip Seals — Optimal Timing, Design and Construction Considerations

WA-RD 837.1

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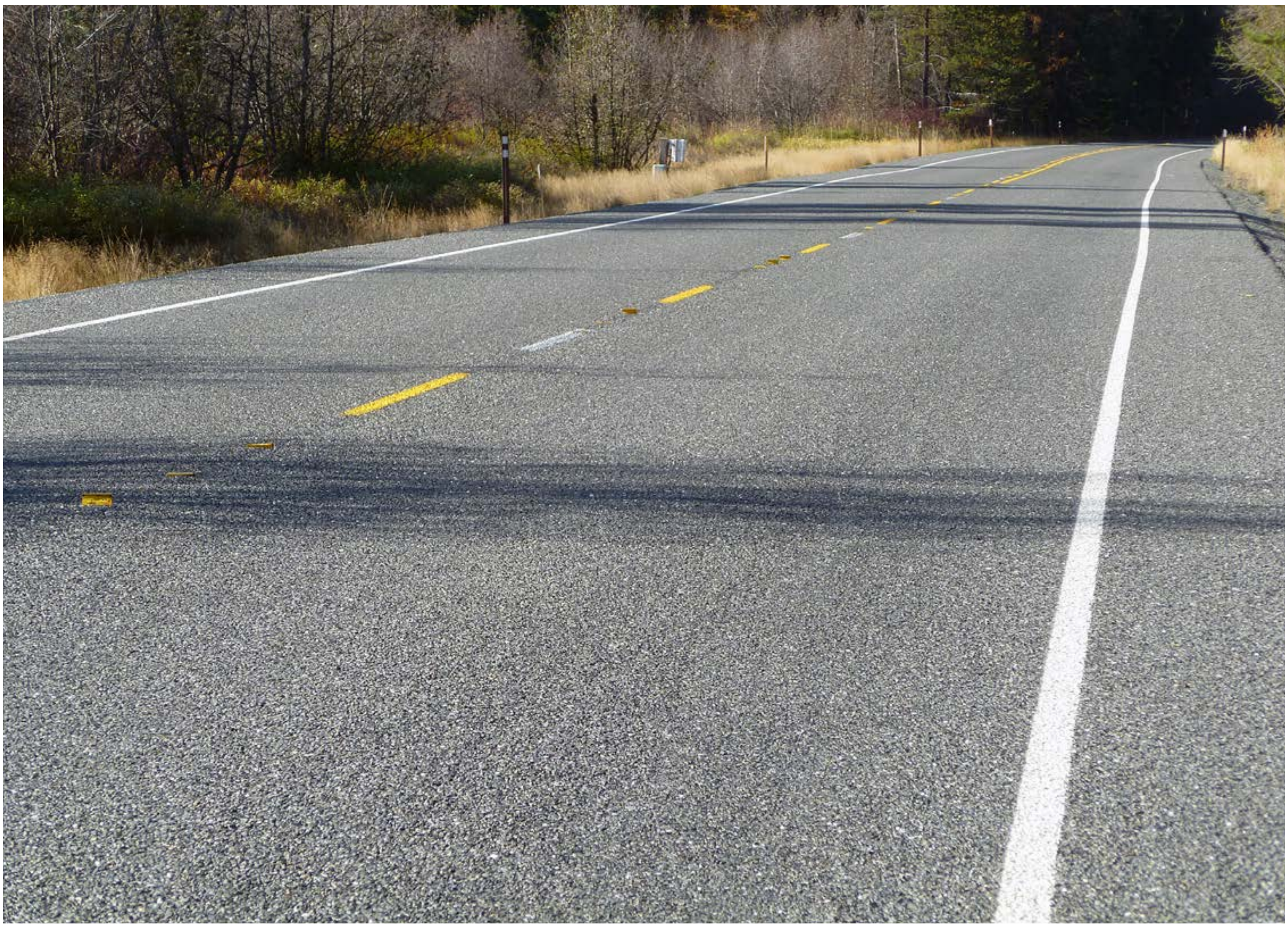

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WSDOT CHIP SEALS—OPTIMAL TIMING, DESIGN, AND CONSTRUCTION CONSIDERATIONS

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16. ABSTRACT:

The Washington State Department of Transportation (WSDOT) does not have sufficient pavement preservation funding to keep up with inflation and pavement needs. This has caused WSDOT to emphasize in its preservation program lower-cost options such as chip seals. The study was conducted on several aspects of WSDOT chip seals including (1) the optimum timing for alternating chip seals (or Bituminous Surface Treatments (BSTs)) with hot mix asphalt (HMA) overlays, (2) design of chip seal application rates, and (3) a range of construction and performance factors. The research incorporated surveys, literature reviews, and five BST meetings that were held between 2006 and 2011. All of these activities are summarized in this report.

WSDOT has continuously changed both policy and specifications as new information became available for improving their chip seal performance. In recent years, a policy change resulted in using chip seals on roadways with up to 10,000 ADT. As such, a secondary factor examined in this study was maximum ADT levels which provide for sensible chip seal construction.

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1.0 INTRODUCTION

1.1 PROBLEM STATEMENT

The Washington State Department of Transportation (WSDOT) does not have sufficient pavement preservation funding to keep up with inflation and pavement needs. This has resulted in WSDOT changing its preservation program to expand the use of lower-cost options. A primary lower-cost option is the use of chip seals. This study will focus on an examination of numerous factors associated with chip seals. This includes an examination of the optimum timing for alternating chip seals (or bituminous surface treatments (BST)) with hot mix asphalt (HMA) overlays, maximum ADT levels appropriate for chip seals, binder and aggregate application rates, and numerous related details associated with the process. Current WSDOT policy (WSDOT, 2011, Section 6.1.3.3 “BST over New Overlays”) encourages the use of an early application of a chip seal over new HMA wearing courses—this study examines that policy statement along with several other chip seal topics as noted earlier.

A prior chip seal oriented study (Li et al, 2007) encouraged a WSDOT policy change as to which routes would receive a chip seal. This revised policy required chip seals on routes with up to an ADT of 5,000 (with some exceptions) (WSDOT, 2011, Section 5.2.2 “Mainline Roadway” and Section 6 “Pavement Rehabilitation”). Additionally, the 2011 Policy <u>allowed</u> chip seals to be applied to roadways with ADTs greater than 5,000. This ADT level was eventually increased to 10,000 largely due to WSDOT budget issues.

Optimum application rates for both binder and aggregate were examined. WSDOT has found that excess/insufficient binder and/or aggregate can cause several challenging post-construction issues. Fortunately, with a sound method for determining binder and aggregation application rates, materials and overall construction costs can be reduced. Another way to potentially reduce costs is to examine the method that WSDOT uses to pay for this type of paving.

Given that the allowable ADT levels on roadways resurfaced with chip seals have increased at least twice within the last seven years, this study examined the issues associated with chip seals and higher traffic volumes. For example, is there a limit that should be exceeded? This included factors that influence chip seal success such as traffic volumes, turning movements, stopping conditions, and design and construction practices.

For this report the terms chip seal and BST are used interchangeably. Most who write about this type of paving in the United States (US) use the term “chip seal” although terms such as “seal coat” or, internationally, “sprayed seals” are used.

1.2 BACKGROUND

WSDOT has seen a decrease in funding for pavement preservation. Along with this decrease, HMA prices have continuously increased over the last 20 years. Figure 1 illustrates these recent trends. Over a 20 year span, HMA prices, on average, have increased by about 200%; although, recent crude oil price drops will likely moderate.

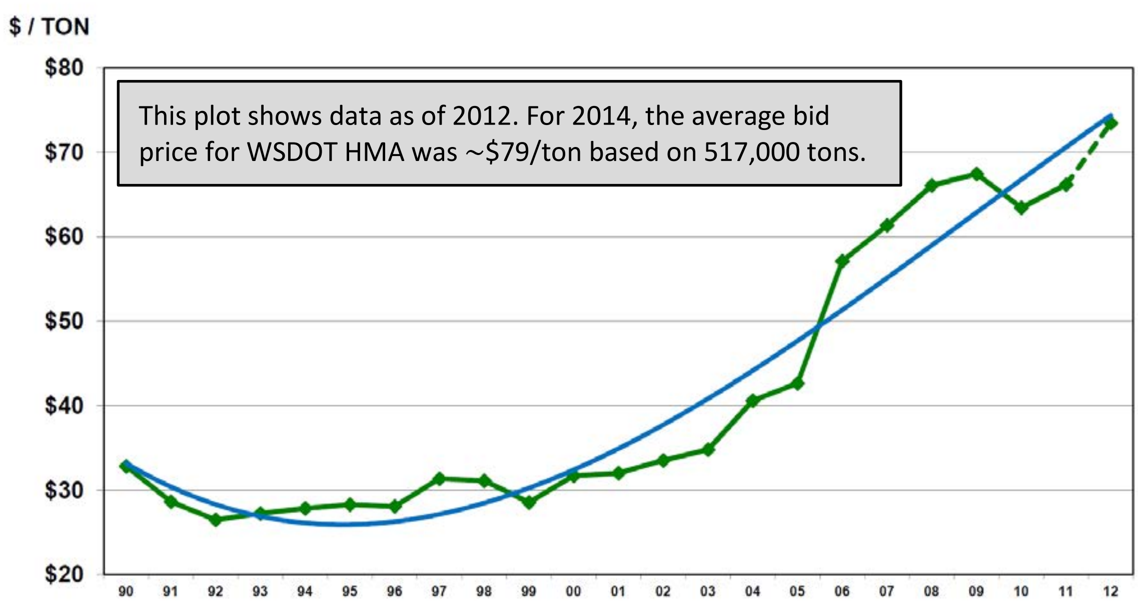

Figure 1 HMA unit bid prices (WSDOT, 2012)

The combination of these two factors, insufficient funding and increasing costs, has required WSDOT to look at less expensive pavement preservation methods. Several other states have experienced this same issue and have taken a similar path (Gransberg and James, 2005). Chip seals are a solid alternative for increasing the time between HMA overlays. At roughly one third of the annual cost of an HMA overlay ($20,000 per lane-mile per year versus $7,000 for a chip seal (WSDOT estimate)).

Over a time period of about five years (2008 to 2013), WSDOT has increased the lane-miles of chip seal surfaces on the state highway system from 23% to 31% (or about 4,200 lane-miles in 2008 to 5,600 lane-miles in 2013 (communication with D. Luhr, WSDOT, 2015)). These percentages, which continue to increase, are based on total system lane miles of 18,000 (includes all surfaces—HMA, chip seal, and PCC). Most of the chip seals are placed on routes with ADTs ≤ 10,000 and, coincidently, that traffic level represents almost 60% of the total WSDOT lane miles.

WSDOT is serious about reducing pavement preservation costs and additional lane miles of chip sealed surfaces are a major component of the cost reduction process. It is estimated that ~ $100 million in costs have been saved by converting HMA surfaces to chip seals (communication with D. Luhr, WSDOT, 2015).

1.3 OBJECTIVES

The four major goals for this study of chip seals were:

1. Examination the current WSDOT Pavement Policy regarding the optimal time for placing chip seals on HMA overlays to extend pavement life.
2. Examine higher ADT levels for application of WSDOT chip seals.
3. Examine and recommend a chip seal design method for use by WSDOT.
4. Examination of a wide range of chip seal factors that influence construction and performance and attempt to develop agreement for moving forward.

1.4 METHOD OF RESEARCH

The study used several methods to achieve the objectives. This included a literature review, a survey of state DOTs, and a series of chip seal oriented meetings held over a span of five years. These meetings included contractors, material suppliers, and agencies (agency invitees were largely from WSDOT but included representatives from other agencies as appropriate for the meeting topics). This report reflects the collective efforts that began in 2006.

2.0 LITERATURE REVIEW

Preventive maintenance programs were being implemented by several agencies (Gransberg and James, 2005). The assumption is that applying preventive maintenance applications to roadways extends the life of the pavement at a lower cost. The primary preservation treatments used by WSDOT are hot mix asphalt (HMA) overlays and chip seals. A WSDOT overlay generally consists of 1.5 to 2 inches of HMA placed over an existing roadway to improve the surface of the roadway as well as its structural capabilities (or, alternatively, milling followed by HMA overlay). A WSDOT chip seal is typically a thin layer of asphalt emulsion sprayed over a clean, existing roadway, with aggregate placed and embedded into the asphalt emulsion. The chip seal covers the small cracks on the surface of a roadway, adds a new wearing course, and extends the life of the roadway. It does not, however, add significant structural stability. Therefore, a chip seal is best placed prior to significant pavement distress (which is a recurring finding throughout this report).

Four areas of research were undertaken:

- the optimal timing of one or more chip seals between HMA overlays
- the maximum average daily traffic appropriate for chip seals
- improved estimates of binder and aggregate application rates for chip seals, and
- related chip seal design, material, and construction factors.

2.1 OPTIMAL TIMING OF SURFACE TREATMENTS

The following summarizes the findings from a selection of literature regarding optimal timing of surface treatments. The reports *NCHRP Synthesis 342: Chip Seal Best Practices* (Gransberg and James 2005), *NCHRP Report 523: Optimal Timing of Pavement Preventive Maintenance Treatment Applications* (Peshkin et al., 2004), *Seal Coat and Treatment Manual* (Webb, 2004), *Evaluation of Timing for Alternating Chip Sealing and Hot Mix Asphalt Overlays* (Keifenheim, 2009), *Life Cycle of Pavement Preservation Seal*

Coats (Romero, 2005), and *Asphalt Pavement Maintenance* (Johnson, 2000) will be summarized.

2.1.1 NCHRP Synthesis 342: Chip Seal Best Practices

The view throughout this report (Gransberg et al, 2005) was that chip seals should be used as a preventive treatment. One indication that multiple chip seals may be constructed between HMA overlays follows:

> "Chip seals are expected to provide at least 5 years of service; therefore, three or four chip seals may be necessary for a pavement to reach its design life. When applied on an existing flexible pavement, a chip seal will provide a surface wearing course, seal the underlying pavement against water intrusion, enhance or restore skid resistance, and enrich the pavement surface to prevent the distresses caused by oxidation."

The report provided results from a survey sent to state agencies. Thirty-three state agencies responded. Relevant information provided included the following:

- Average chip seal rotation: 5.4 years.
- Average chip seal life: 5.8 years.

The report also discussed when a chip seal should be placed. Most agencies have a guideline for how often a roadway should be resurfaced and that is typically based on past experience.

> "The chip seal process begins in the planning stage when the pavement surface is analyzed to determine if a chip seal is an appropriate PM treatment. Surface characterization may consist of assessing the hardness, texture, and other measures of the structural condition of the pavement surface."

Typically in the U.S., agencies stated that a chip seal is usually placed when evidence of distress is seen on the roadway.

The report overviewed best management practices and how chip seals should be used as a preventive maintenance technique. It was recommended that roadways with any structural distress should be considered for a HMA overlay only. This reinforces the view that chip seals should be placed on a roadway that is still in good or fair condition. Of the agencies that responded to the survey about their chip seals, Australia had the largest number of lane miles, followed by the UK. Australia reported “excellent” or “good” results with its chip sealing program and its responses detailed how Australia achieved this level of performance.

Australia reported that, on average, chip seals were placed every 10 years. In addition, Australia also designs its chip seals. The chip seal is used primarily to prevent water infiltration and increase skid resistance. Distress, oxidation, and wearing of the surface were not listed as reasons for chip sealing. The roadway had to be in excellent or good condition for a chip seal to be considered, and the contractor had to have experience with chip sealing to be hired. The report concluded that larger contracts allow contractors to provide better quality equipment for the job. Australia allows chip seals on roadways with a maximum ADT of 20,000.

2.1.2 NCHRP Report 523

The main focus of NCHRP Report 523 (Peshkin et al, 2004) was to provide a method to determine the optimal timing of preventive maintenance to be used by agencies that currently do not have a preventive maintenance program. Several preventive maintenance techniques were evaluated, but most research was on chip seals because of the high success that many state agencies have experienced.

2.1.3 TxDOT Seal Coat and Surface Treatment Manual

TxDOT (Webb, 2010) has a manual for chip seals which is available online. They have a state route system of about 187,000 lane-miles and place, on average, 20,000 lane-miles of chip seals each year (about 85% by contract and 15% with in-house personnel).

A comparison is provided on the cost of preventive maintenance versus delaying more extensive treatments. TxDOT estimates that this delay costs 4X more (this broadly agrees with prior WSDOT findings).

Texas typically places chip seals every 6 to 8 years (although some have performed up to 20 years). Its guidelines for determining when to place a chip seals include:

- condition of existing pavement
- effectiveness of a seal coat in addressing the existing pavement deficiencies
- cost of the seal coat compared to other treatments
- traffic volume
- percentage of truck traffic
- repairs needed prior to the seal coat.

2.1.4 Evaluation of Timing

Keifenheim (2009) examined the practice of alternating HMA overlays with chip seals and the associated timing. State DOTs were surveyed about their pavement preservation programs. Some states reported applying two BSTs between HMA overlays on lower volume roadways, which increased the service life between HMA overlays to about 18 to 20 years. A detailed summary of these survey findings are contained in Section 3.0.

2.1.5 Life Cycle of Pavement Preservation Seal Coats

The Utah Department of Transportation (UDOT, Romero, 2005) reported on their efforts to reduce roadway maintenance costs. UDOT conducted a survey of nearby DOTs and found that the average reported life of a chip seal was 6.5 years, with a range of 3 to 15 years.

2.1.6 Asphalt Pavement Maintenance

The document outlined crack, surface, and pothole treatments and presented roadway maintenance alternatives and cost differences (Johnson, 2000). Table 1 suggests that low severity alligator cracking is appropriate for placing a chip seal—a reoccurring finding. As indicated in this table, a chip seal is not viable when a roadway has medium to high alligator cracking.

Table 1 When chip seal vs HMA should be used? (from Johnson, 2000)

Type of Crack	Type of Treatment		
	Other	Chip Seal	Thin hot-mix overlay
Alligator			
Low Severity		x	
Medium Severity	x		
High Severity	x		
Transverse			
Low Severity		x	
Medium Severity		x	
High Severity		x	
Longitudinal			
Low Severity	x		
Medium Severity	x		
High Severity	x		
Block			
Low Severity		x	
Medium Severity		x	x
High Severity			x
Reflection			
Low Severity	x		
Medium Severity	x		
High Severity	x		x

2.1.7 Top-Down Cracking

Top-down cracking is a common distress that occurs in HMA wearing courses. Maintenance decisions are, of course, influenced by this type of cracking. There are numerous studies worldwide that show this is a common cracking mode for HMA surfaces and is a critical element in examining the need for early application of chip seals on HMA surfaces. The following may be broadly concluded:

- Surface-initiated cracking of HMA is widespread, particularly for asphalt pavement layers with a combined thickness exceeding about 6 in. (although top-down cracking has been reported for thinner HMA, for an example of this refer to Uhlmeyer et al, 2000). Further, this type of cracking occurs for a variety of climate and traffic conditions ranging from cool to tropic climates.
- The age at which top-down surface cracking initiates varies and ranges from 1 to 5 years following surface course construction (Japan: Matsuno and Nishizawa, 1992), 3 to 5 years (France: Dauzats and Rampal, 1987), 5 to 10 years (Florida: Myers et al, 1998), within 10 years (United Kingdom: Nunn, 1998), and 3 to 8 years with an average of 5 years (Washington State: Uhlmeyer et al, 2000).
- Surface cracks are generally attributed to a combination of truck tires, thermal stresses, and age hardening of the binder. Studies based on measured tire-pavement contact pressures and instrumented pavements support the view that truck tires are at least one cause of top-down cracking in HMA wearing courses.
- HMA mix aging has a strong role in top-down cracking. Rolt (2001) reported that top-down cracking is widely observed in tropical environments and appears to be related to the age hardening of the asphalt binder in the upper 2 to 3 mm of surface courses. It was found that the binder is typically 100 to 500 times more viscous in the 2 to 3 mm zone, hence more brittle, than the binder at a depth of about 10 to 25 mm following initial aging (some of the results reported by Rolt noted a field aging period of 24 months). Importantly, Rolt stated that the increase in binder viscosity was strongly related to age, but HMA mix variables such as air voids, binder content, and filler content were positive second order factors. An additional, important finding was that application of a chip seal to the HMA pavement surface soon after construction was observed to reduce binder aging by a factor of about 50.
- Observations made by Rolt (2001) and Uhlmeyer (2000) note that top-down cracking, once initiated, remains at a constant depth for some time before eventually propagating to the full depth of the HMA layer(s).

2.2 MAXIMUM AVERAGE ANNUAL DAILY TRAFFIC

Four reports were reviewed: *NCHRP Synthesis 342* (Gransberg and James, 2005)*, Seal Coat and Surface Treatment Manual* (Webb, 2010), *Bituminous Surface Treatment Protocol* (Li et al., 2007), and *Guidelines for the Preservation of High Traffic Volume Roadways* (Peshkin et al, 2010).

2.2.1 NCHRP Synthesis 342: Chip Seal Best Practices

Gransberg et al (2005) reported, in part, on a survey of state DOTs. Of the 13 state agencies that noted good success with chip seals, 11 used them on roadways with an ADT of greater than 5,000. Three of the 11 reported use of chip seals with ADTs of greater than 20,000. A quote from the report follows:

> "One also notices that there is very little difference between those agencies that restrict chip seal usage to lower-volume roads and those that routinely use the system on high-volume roads. The one major difference is that those that apply PM chip seals on high volume roads ensure that the underlying pavement's condition is generally good. Thus, they are not trying to use their chip seal program for short-term repair."

The report also outlined construction practices for high-volume roads. Table 2 outlines the reasoning behind these practices.

Table 2 Best practices for constructing high-volume chip seals (NCHRP Report 342, 2005)

Best Practices for Construction of High Volume Chip Seals	
Practice	**Reason**
Reduce excess aggregate	Sweeping proficiency increased
Reduce aggregate size	Larger aggregate causes more damage
Use of double chip seals	Smaller aggregate in contact with tires
Use of lightweight aggregate	Lower specific gravity causes less damage
Use of choke stone	Locks in larger aggregate
Fog coat	Improved embedment
Precoat aggregate	Improved adhesion
Use of polymer modifiers	Improved adhesion
Allow traffic on chip seal	Vehicles provide additional embedment
Control traffic speed on chip seal	Reduced whip-off

2.2.2 TxDOT Seal Coat and Surface Treatment Manual

In the TxDOT manual (Webb, 2010), roadways with average daily traffic ≥ 10,000 vehicles per day are considered high traffic. A chip seal can be applied to high-traffic volume roadways but are generally limited to low-traffic volume routes. The manual outlined problems that may occur with higher traffic volumes:

- short-term aggregate loss
- vehicular damage from loose aggregate
- potential for flushing
- tire noise
- prolonged traffic control.

2.2.3 WSDOT Bituminous Surface Treatment Protocol

Li et al (2007) examined allowable ADT levels for chip seals. An important factor was that over the life cycle of a roadway, HMA overlays are 4X as expensive as chip seals (although more recent estimates suggest 3X).

Table 3 shows the percentage of roadways by pavement type and ADT in 2014 for Washington State. At that time, a majority of chip seals were on roadways with ADTs less than 2,500. The research showed that ADT levels of 4,000 or higher could be justified and indicated that allowing chip seals cycles in lieu of HMA overlays on roadways with 2,000 to 4,000 ADT could result in a 20 percent cost reduction over the life of the roadway.

Recent communication (January 2015) with David Luhr, WSDOT Pavement Management Engineer, estimates that expanded use of chip seals has saved over $100 million in paving costs since 2010.

Table 3 Types of roadways associated with ADT (provided by Luhr, 2014)

AADT	BST (%)	HMA (%)	PCC (%)
0-2500	74.6	25.4	0.1
2500-5000	32.9	65.6	1.5
5000-7500	16.1	77.2	6.7
7500-10000	2.2	88.3	9.5
10000-12500	7.2	88.8	4.0
12500-15000	0	89.7	10.3
15000-17500	0.3	76.6	23.2
17500-20000	0	78.2	21.8
20000-40000	0	77.6	22.4
…	…	…	…
220000-240000	0	0	100

2.2.4 Guidelines for the Preservation of High Traffic Volume Roadways

This SHRP2 funded study examined pavement preservation for a number of techniques—including chip seals (Peshkin et al, 2010). The authors define "high traffic" as an ADT = 5,000 for rural roads and ADT = 10,000 for urban roadways. These values were largely based on a survey of state DOTs. The authors found that 33 to 66% of the responding state DOTs apply chip seals up to these ADT levels. The authors also noted that > 66% of the state DOTs apply chip seals over existing HMA surface courses to address oxidation or light to moderate surface distress issues associated with HMA. No other causal factor rated as high as these two in the survey.

2.3 BINDER AND AGGREGATE APPLICATION RATES

An examination of methods for designing and calculating the amount of binder and aggregate application rates was made. The report *NCHRP Synthesis 342* (Gransberg and James, 2005) provided insights and the Minnesota Seal Coal Manual (Wood, et al, 2006) was helpful. Numerous reports and papers overview the topic but these two were selected for inclusion in this report.

Though not presented in detail here, TxDOT (Webb, 2010) notes that the agency recognizes two chip seal design methods: Modified Kearby and McLeod methods. The Modified Kearby is the principal method currently used by TxDOT.

2.3.1 NCHRP Synthesis 342: Chip Seal Best Practices

NCHRP Synthesis 342 (Gransberg, 2005) summarized responses from surveyed agencies. Ten of the 25 reporting agencies noted that they used empirical/past experience in designing their chip seal application rates. Two methods, the Kearby/Modified Kearby and McLeod methods were both described. However, only five agencies reported use of those methods at that time.

An additional point raised within the report was that with larger contracts, the contractor gains more local experience, and invests in better equipment that will lower costs.

2.3.2 McLeod Method of Chip Seal Design

To examine the McLeod Method for estimating binder and aggregate application rates, a comparison with current WSDOT standard specifications application rates was made. This comparison along with example calculations is shown in Appendix A. The McLeod Method was chosen since it has widespread use in the US. Further, the modified McLeod Method as described by the Minnesota DOT (Wood et al, 2006) was used. Importantly, the McLeod Method assumes:

- The chip seal is one stone thick.
- The volume around the stone is filled with binder up to 70% of the depth.

2.4 AUSTRALIA, NEW ZEALAND AND SOUTH AFRICAN

NCHRP Synthesis 342 suggested that Australia, New Zealand, and South Africa were industry leaders in chip sealing. While the lifespan of North American chip seals is about 6 to 8 years, these three countries averaged 10 years—a 25 to 70% increase. A review of their chip sealing programs was conducted to examine these differences.

2.4.1 ARRB Research Report 326: The Performance of Sprayed Seals

The Australian Road Research Board (ARRB) has conducted several studies on chip seals and, importantly, has prepared a report similar to NCHRP Synthesis 342 (Oliver, 1999). It surveyed several state agencies to get a general idea of each region's strategy in completing chip seals. The first question addressed was service life (years between reseals). This was separated by aggregate size as shown in Table 4 which summarizes the responses by region. The terms "data" and "estimate" refer to whether the agency got the data from records or simply estimated service life. The Australia State Road Authority (SRA) and New Zealand Road Authority (Transit NZ) are the larger authorities and were categorized into one section with the local governments into another.

Table 4 shows that the larger the aggregate size, the longer the service life, with a peak at roughly the 16 mm aggregate size (approximately 5/8" stone). The last two rows show double seals; for example, 10 mm rock over 7 mm rock. The last line containing "14/7 + 20/7" contains two different chip seal results combined because of low survey results. The report suggested that these seals had a shorter lifespan because they were applied to more highly traveled roadways. Broadly, the service life for local agencies is longer suggesting either lower traffic levels or less funding.

Table 4 Service life (years) of chip seals based on aggregate size (from Oliver, 1999)

Aggregate size (mm)	SRAs and Transit NZ		Aust + NZ Local Gov.	
	data	estimate	data	estimate
7	7.0	5.9	9.6	9.4
10	9.8	9.7	12.1	11.5
14	11.5	11.6	11.9	13.2
≥16	12.8	13.5	13.5	13.8
10/7	9.0	9.5	13.0	12.3
14/7 + 20/7	10.8	11.3	11.8	12.5

Another topic noted in the report was the type of binder used for chip seals. A majority (over 80 percent) of the reporting agencies noted an increase in polymer modified binders.

The third section of the survey sought to rank the factors that affect seal lifespan. Overall, the researchers determined that design of application rates had the most impact on seal lifespan. Traffic was next and quality of bitumen was third. Australia and New Zealand state agencies ranked having a design method as the most important factor contributing to a longer seal life. The remaining factors in order of importance were construction process, timing of work, environment/climate, and quality of aggregate, with maintenance practice being the least important. It is interesting that quality of aggregate was stated to be one of the least important factors.

2.4.2 Sprayed Seal Design

Australia has maintained test sections and improved on its chip seal design since 2000. The updated design guide (Alderson and Balfe, 2004) emphasized properly determining the correct chip seal to place on roadways. The design procedure is based on the same concepts as the McLeod method. The binder rate was determined on the basis of the residual binder being between 50 to 65 percent of the height of the aggregate layer two years after construction. The McLeod method uses a 70 percent aggregate height depth at the time of construction. Size, shape, and orientation of aggregate are also used in determining the binder rate, which is the same for the McLeod method. The aggregate spread rate is determined by the average least dimensions of the aggregate which determines how the aggregate will lay following application of traffic.

3.0 STATE DOT CHIP SEAL PRACTICES

As part of this study, state DOT pavement engineers (or their representatives) were contacted. For the survey, each state DOT was called, in some cases numerous times. In all, 35 states provided information via telephone calls. These state departments of transportation included Alabama, Alaska, Arizona, Arkansas, Colorado, Connecticut, Delaware, Florida, Georgia, Hawaii, Idaho, Illinois, Indiana, Iowa, Kansas, Kentucky, Louisiana, Maine, Michigan, Minnesota, Mississippi, Missouri, Montana, Nebraska, Nevada, New York, North Dakota, Oregon, Rhode Island, South Carolina, South Dakota, Texas, Utah, Virginia, and Wyoming. The remaining states did not respond. The calls initially started as a survey but eventually turned into a discussion on the states' chip seal processes and their experiences or lack thereof in alternating applications of chip seals and HMA overlays. The phone calls had three primary goals:

1. To determine whether the state applies alternating HMA overlays with chip seals.
2. If the state alternated treatments, determine how the alternating cycle compared with typical cycles for only HMA overlays or chip seals, as well as what has and has not worked for that state and whether it had conducted formal studies or prepared reports.
3. Of the remaining states, determine the reasons for not alternating between HMA overlays and chip seals, if possible.

The following summarizes the information provided by the state DOTs. In general, most DOTs do not have a set cycle of applying an HMA overlay and chip seal cycle in alternating sequence. However, some states do conduct this practice without a set cycle. Most DOTs are interested in an alternating application of HMA and chip seals as they attempt to make their pavement preservation dollars stretch further. As in the literature review, a recurring theme was applying the chip seal to pavements that are in good to fair condition.

3.1 STATES PRACTICING AN ALTERNATING CYCLE OF HMA OVERLAY AND CHIP SEAL

3.1.1 Montana

The Montana DOT, reported that it has been alternating HMA overlays and chip seals and with very good success. Montana's methods have been developed over time by trial and error, and its current process is keeping the roadways at an acceptable level. Montana conducts this practice on roadways with a wide range of traffic volumes, including some Interstate highways. It noted that the key to successful chip seals on high volume roadways are the construction and traffic control methods. High speed traffic must be kept off the roadway until the binder is able to gain enough strength that chips will not be dislodged from the surface.

In Montana, a road that is preserved with only a chip seal (lower volume roads) typically lasts 6 to 7 years before it is "due" for treatment and is chip sealed again. A typical HMA pavement in Montana is overlaid about every 11 to 12 years. Roadways that receive only HMA overlays in Montana are high volume roads and roads in urban areas.

On roadways that receive an alternating cycle of HMA overlays and chip seals, a typical cycle includes two or three chip seals between HMA overlays. The process starts with an HMA overlay followed by a chip seal in the same year. This is done to prevent raveling and stripping in the wheel paths. Performance problems have occurred on HMA overlays which do not receive a chip seal. In year 6 to 9, the roadway is crack sealed, followed by a chip seal the next year (year 7 to 10). This treatment then lasts for 5 to 7 years before the roadway is again overlaid with HMA, and the cycle is repeated. These cycle lengths and timings are adjusted on the basis of existing roadway conditions, but the State Pavement Engineer stressed that applying the preservation measure while the pavement is still in fair condition is key to Montana's success. On low to medium volume roadways, Montana may include a third chip seal before the HMA overlay, depending on the condition of the pavement structure.

3.1.2 Colorado

The Colorado DOT reported that the typical cycle length for HMA is 10 to 11 years and for chip seal pavements 6 to 7 years. Colorado has implemented a cycle of HMA resurfacing and chip seals on some roadways. It overlays roadways for cracking and conducts an HMA mill and fill if there is rutting. A typical cycle starts with an HMA overlay or mill and fill. A chip seal follows this in year 6 to 8. Then, depending on the condition of the roadway (based on traffic and environmental conditions), the next cycle is either another chip seal or a HMA overlay, which usually occurs in year 12 or 13. By using a cycle of one chip seal between HMA treatments, Colorado increases the time between overlays from 10 years (the typical lifespan for an HMA overlay before being overlaid again) to 12 to 13 years or longer. Colorado finds that this method is cost effective and keeps the roadway at an acceptable condition level.

It was noted that the timing of the chip seals do vary, depending on the condition of the roadway, but Colorado's goal is to place the treatments while the pavement is still in good condition.

3.1.3 South Dakota

South Dakota also uses alternating HMA overlays and chip seals. The Pavement Management Engineer for the South Dakota Department of Transportation, reported that South Dakota has few roads that are preserved only with HMA applications; rather, most of its roadways are preserved with only chip seals or alternating HMA and chip seal applications.

When the alternating method is used, a typical cycle starts with a HMA overlay. This is followed by a crack seal 2 years later and a chip seal in year 3. A chip seal is placed in year 3 to prevent oxidization and to give the HMA surface good skid resistance. This surface is typically chip sealed again in year 9 to 11, with a crack seal in the preceding year. Then, depending on its condition, the roadway may be chip sealed a third time on yet a shorter cycle of 5 to 7 years. Or, as is the case on most routes, a HMA overlay is applied after two chip seals, somewhere between years 14 and 19. This cycle is typical and adjusted on each road's condition. South Dakota believes this preservation method is cost effective and preserves the roads while maintaining a good ride for the traveler.

3.1.4 Nebraska

The Nebraska DOT noted that the key to applying a chip seal on a HMA pavement is that it be done before the HMA surface has deteriorated. Once a HMA section is due for an HMA overlay, it is probably too late for a chip seal to effectively preserve the pavement. Nebraska's roadways that receive alternating HMA and chip seal applications typically have two chip seals between HMA overlays. A typical cycle starts with an HMA overlay, a crack seal in year 4, a chip seal in year 8, another chip seal in year 13 or 14, and finally an HMA overlay between years 18 and 20. It was reported that typical cycles for HMA only and chip seal only roadways in Nebraska are 13 to 15 years for HMA and 5 to 8 years for chip seals. Nebraska estimates that by applying two chip seals between HMA applications, the pavement life is extended by 4 to 6 years over the use of HMA applications alone.

3.1.5 Minnesota

The Minnesota DOT reported that it uses a cycle of HMA and chip seals on roadways with ADTs up to 18,000. Minnesota's goal is to apply two chip seals between HMA overlays. Typical cycles vary throughout the state and also depend on traffic volumes, but they are finding this process to be very successful, even on the higher volume roadways. It does not have a set cycle time for applications. Rather, it uses past experience and roadway conditions to determine the optimal time.

3.1.6 Texas

Texas does alternate some HMA and chip seals, although it does not have a specific cycle. Texas preserves many of its roadways by chip sealing them every 5 to 10 years, with some going as long as 15. The only time these roads receive an HMA treatment is if they begin to rut, in which case a mill and fill is done and the process starts all over again with chip seals. Texas is preserving some roadways by constructing a chip seal followed by an HMA overlay in the same year. It finds that the chip seal will seal cracks in the pavement, while the HMA overlay provides the necessary structure for the roadway. It was noted that the importance of placing the chip seal on a good to fair surface is crucial in obtaining maximum benefit.

3.2 STATES NOT PRACTICING AN ALTERNATING CYCLE OF HMA OVERLAY AND CHIP SEAL

Most of the states that were contacted do not preserve their roadways with alternating HMA overlays and chip seals. However, most all expressed interest in the idea and are looking for ways to maximize their pavement preservation funding. Some states, such as Oregon, have begun moving toward alternating cycles but have not yet implemented them into practice and therefore had no experience to share at the time of the survey. No states reported having had a poor experience with alternating HMA overlays with chip seals. Some states do not alternate cycles of HMA overlays and chip seals because chip seals are only used on low volume roads. Table 5 summarizes the remaining states that were contacted and the information they provided.

Table 5 Additional state DOTs contacted and selected comments

State	Comments
Alabama	No alternating use of HMA and chip seals. Chip seals used as a maintenance measure to maintain pavements a couple years until they can be overlaid with HMA.
Alaska	No alternating use of HMA and chip seals.
Arizona	No alternating use of HMA and chip seals. Chip seals used primarily for maintenance.
Arkansas	No alternating use of HMA and chip seals but has had good success chip sealing on HMA and chip sealing high volume roads.
Connecticut	No alternating use of HMA and chip seals. Little chip seal use.
Delaware	No alternating use of HMA and chip seals.
Florida	No chip seal use.
Georgia	No alternating use of HMA and chip seals. Chip seals used primarily for maintenance.
Hawaii	No alternating use of HMA and chip seals. Starting to do more chip sealing.
Idaho	Does alternate HMA and chip seals, although not intentional. Typically seals pavement 1 or 3 years after HMA to provide skid resistance and seal surface.
Illinois	No chip seal use.
Indiana	No alternating use of HMA and chip seals.
Iowa	Looking at incorporating a chip seal between HMA applications with about a 7-year cycle of HMA and chip seal.
Kansas	Uses a cycle of chip seals with hot in-place recycle. Typical cycle is HMA overlay, chip seal after 7 years, and hot in-place recycle with chip seal 7 years later.
Kentucky	No alternating use of HMA and chip seals. Getting back into chip sealing.
Louisiana	No alternating use of HMA and chip seals. Chip seals used primarily for maintenance.
Maine	No chip seal use.
Michigan	May do some cycles of HMA and chip seal, but no formal process. Works well on low to medium volume roads. Expect shorter life of seal with each successive seal application.

Mississippi	No alternating use of HMA and chip seals. Chip seals currently used primarily for maintenance.
Missouri	No alternating use of HMA and chip seals - may look at in future.
Nevada	No alternating use of HMA and chip seals.
New York	No alternating use of HMA and chip seals.
North Carolina	No alternating use of HMA and chip seals. Note that a chip seal must be applied on an HMA route prior to the roadway being due for another HMA.
North Dakota	Does alternate HMA and chip seals, although does not have a set cycle. Typically chip seals roadway 3 years after HMA to seal surface and provide skid resistance. Second chip seal occurs 7 to 8 years later, followed by an HMA at an unknown time. This process is working well for North Dakota.
Oregon	Does not currently alternate HMA and chip seals but would like to start incorporating a chip seal between HMA overlays. Roadways would be rural with low to medium traffic in fair to good condition.
Rhode Island	No alternating use of HMA and chip seals.
South Carolina	No alternating use of HMA and chip seals.
Utah	No alternating use of HMA and chip seals.
Virginia	No alternating use of HMA and chip seals - may look at in future.
Wyoming	No alternating use of HMA and chip seals. Chip sealing is set up by districts, so it varies greatly.

3.3 SURVEY SUMMARY

The survey identified six states that placed at least one BST between HMA overlay as described in Section 3.1. All six states reported that on some, if not all, roadways, they placed at least two chip seals between each HMA overlay. Table 6 is used to summarize the results from four states with the most complete information. The treatments shown start with an HMA overlay at year = 0. Typically this is followed two to nine years later with crack sealing then shortly thereafter with a chip seal. At the end of the cycle a new HMA overlay is placed 16 to 20 years after the initial HMA overlay. To better define the effectiveness of this process, Table 7 shows typical HMA overlay and chip seal lives for those four states without the chip seal process. Typically their HMA overlays last 10 to

13 years. On average the crack sealing/chip seal process adds about eight years to the HMA to HMA overlay cycle based on this information or about a 60% increase between HMA cycles.

Table 6 Cycle times for four state DOTs using both HMA overlays and chip seals (Data from Keifenheim, 2009)

State	Treatment and Timing (years)					
	1	2	3	4	5	6
Montana	HMA Overlay @ 0 year	Crack Seal @ 6-9 years	Chip Seal @ 7-10 years	HMA Overlay @ 16-20 years	--	--
Colorado	HMA Overlay @ 0 year	Chip Seal @ 6-8 years	HMA Overlay @ 13-14 years	--	--	--
South Dakota	HMA Overlay @ 0 year	Crack Seal @ 2 years	Chip Seal @ 3 years	Crack Seal @ 8-10 years	Chip Seal @ 13-14 years	HMA Overlay @ 18-20 years
Nebraska	HMA Overlay @ 0 year	Crack Seal @ 4 years	Chip Seal @ 8 years	Crack Seal @ 13-14 years	HMA Overlay @ 18-20 years	--

Table 7 Traditional cycle times for four state DOTs (Data from Keifenheim, 2009)

State	Treatment and Timing (years)	
	Typical Cycle Time HMA only	Typical Cycle Time Chip Seal Only
Montana	11-12 years	6-7 years
Colorado	10-11 years	6-7 years
South Dakota	10-12 years	6-8 years
Nebraska	12-13 years	5-8 years

Keifenheim also evaluated the cost savings realized by placing one chip seal between HMA overlays and found that 18 percent savings could be realized over the 60 year life cycle of a roadway as a result of alternating treatments instead of placing only HMA overlays. He used present values of $240,000 for one lane-mile of HMA overlay and $21,000 for one lane-mile of chip seal.

4.0 BST FACT FINDING MEETINGS

A total of five meetings were held which included attendees from WSDOT, paving contractors, material suppliers, and other agencies. The attendance and topics varied for each of the meetings with the first one held in 2006 and the last one in 2011. To ensure that a variety of attendees (and opinions) were obtained, the meetings were by invitation only which also served to keep the size manageable. The format was structured in that a set of topics selected for each meeting were discussed by all participants. Each meeting was limited to one day. Summaries of these five meetings are contained in Appendices B through E.

Tables 8 through 12 follow and contain summaries of factors for which there was general agreement by the attendees—sort of a listing of do's and don'ts and acceptable practices. Importantly, a consensus on all chip seal factors that were discussed was not attempted but at least broad agreement was often achieved. The tables are organized by chip seal design factors (Tables 8 and 9), material factors (Table 10), construction factors (Table 11), and performance factors (Table 12). Table 13 is included for the reader's convenience which contains a summary of current chip seal gradation band options and application rates from the 2014 WSDOT Standard Specifications.

A selection of the content in the tables will be included in the conclusions in Section 5.0.

Table 8 Chip seal design factors—1

Factor	Finding(s)	Supplementary Comments
Upper limit for ADT	• No specific upper limit identified. • WSDOT and other State DOTs experience suggest ADTs ≥ 20,000 are possible.	• Traffic control is critical for applying chip seals at high ADT locations. • Binder: at a minimum use CRS-2P • Consider application of hot seals. • Consider changes to binder specifications and tests (for example use of elastic recovery).
Maximum grade and superelevations	• Chip seals can be applied to grades of 12 to 15%.	• Traffic control is critical—need longer duration and low speeds. • Overall, steep grades should have very low ADT. • Use choke stone. • Use clean (low fines) aggregate.
Intersections, stop-go locations, acceleration/deceleration lanes	• Do not apply a chip seal. • Consider use of a thin lift of 3/8" HMA	• Experience about this factor does vary through the state. • Chip seals that are applied to intersections appear to perform better in Western Washington with its generally lower summer temperatures.
Rutted pavement—how deep a rut is excessive for applying a chip seal?	• Ruts ≤ 3/8", probably OK to apply a chip seal. • Ruts > 3/8", apply prelevel before chip sealing	• Ruts over 3/8" (10 mm) are excessive. • If you can feel the ruts while driving, then they are too deep for applying a chip seal. • When chip sealing ruts deeper than desirable, consider use of a max aggregate size stone greater than 3/8".
Cracked pavements—how large can the cracks be?	• Cracks less than 0.25," do not crack seal. • Portion of road structure around very large cracks should be removed and replaced prior to a chip seal. • Double chip seals can better deal with cracked pavement. • Two types o Crack seal—use rubber filler. o Crack fill—use sand slurry	• Crack seal, prelevel, etc, need to be in the contract as bid items. • Attendees generally recommended that crack sealing should be paid by the lineal foot. • One estimate was that large cracks are 0.5" or greater in width and best to seal with sand slurry. Less than 0.5" then do crack seal. Opinions varied on threshold crack widths.
Crack filling/sealing—when should this material be applied?	• Crack sealing should be done 1 year in advance of placing the chip seal.	• ER only seals cracks greater than 0.25".
Prelevel	• Typical depths of prelevel 0.10'. • Prelevel should be fog sealed prior to the chip seal.	• Policy has typically limited prelevel to 70 tons/lane-mile. • Good practice is to prelevel one year prior to placing the chip seal although opinions did vary a bit.
Can you chip seal rumble strips?	• Yes, you can chip seal rumble strips if original surface is HMA. • Can chip seal rumble strips 2 to 3X.	

Table 9 Chip seal design factors—2

Factor	Finding(s)	Supplementary Comments
McLeod Method	• If used, best to apply the Minnesota DOT modified McLeod Method.	• Inputs into the McLeod method were discussed. • Must have aggregate available prior to construction to allow McLeod process to be done.
Use of hot chip seal applications [updated WSDOT information as of 2014]	• WSDOT has typically not done hot seals but placed their first in 2014. • Evidence suggests that cost is the same as conventional chip seal when sweeping and striping occur on the same day as placement. • Further applications will be conducted in 2015.	• Laydown takes about 15 minutes. • Asphalt binder shot at 350°F. • Chips typically 3/8" – N0.6, clean and precoated. • Minimum surface temperature for hot seals is 70°F and rising. • Oregon DOT does hot seals and Idaho DOT has started. WSDOT has observed the Oregon DOT process.

Table 10 Chip seal material considerations

Factor	Finding(s)	Supplementary Comments
Binder type	• CRS-2P generally works well. • High float emulsions have had some success in Western Washington.	• Attendee views about the use of high float emulsions ranged from positive to very negative. • High float emulsion—must use clean aggregate. • Attendees discussed whether performance specifications are needed for asphalt emulsions.
"Best" maximum aggregate size for chip seals	• 3/8" best for ride/roughness and more acceptable to motorists. • ½" better for variable binder application rates. • WSDOT dominant aggregate gradations currently: o ½" – No. 4 o 3/8" – No. 4 plus… o Choke stone (No. 4 – 0)	• 5/8" should only be considered for very low volume routes. Requires higher binder application rates. • Some agreement that larger max aggregate size results in longer chip seal life—particularly for higher volume routes. • Broad agreement that the goal is to achieve an aggregate gradation that approximates a single sized chip.
Choke stone gradation	• ¼" – 0 works well. • WSDOT concrete sand can be considered for use as a choke stone—as noted in WSDOT SS 2014.	• Consider use of aggregate that is readily available without special processing (hence less costs). • Class 2 concrete sand has been used as choke. • ER view is that use of choke stone reduces snow plow damage. Additional cost about $500 per lane-mile.
Maximum percent passing No. 200 sieve	• Use clean aggregate. • Max of 1% passing No. 200 although it appears that WSDOT statistical based 1.5% might be equivalent (information at the meeting showed average of 0.9% passing No. 200 with the 1.5% specification).	• Numerous failed chip seals attributed to "dirty rock." • Basalt rock requires extra attention.
Note: Gradation types and application rates for BSTs (new construction) and chip seals are shown below for convenience.		

Table 11 Chip seal construction factors

Factor	Finding(s)	Supplementary Comments
Start of chip seal shots	• Use paper at beginning of chip seal binder shots.	• If paper not used, binder typically tracks down the roadway.
Allowable time between binder and aggregate applications (assumes use of asphalt emulsion binder)	• 1 minute specification item works well and is the current requirement in WSDOT Standard Specifications (2014)	• The 1 minute specification value can be difficult for a contractor to achieve. • Experience with this specification requirement based on the use of CRS-2P.
Aggregate embedment	• Minimum of 50% up to 70%.	• Embedment depths of 25 to 33% will not hold the aggregate. • Attendees generally agreed that a 50% embedment depth is a common outcome for chip seals. • It was noted by some states, such as Texas, use an embedment depth of 30%--largely due to high temperatures embedment increases with time.
Contract administration	• Best to pay on a SY basis for chip seals.	• SY measure used in Idaho. • Easier to measure with SY as opposed to CY. • Not uniform agreement on this factor.
Temperatures for applying chip seals	• Only use pavement temperatures, not air temperatures. • Minimum surface temperature shall be at least 60°F and rising. • Maximum pavement surface temperature is 130°F.	• Have choke stone available for use in case pavement temperatures become excessive.
Start and end dates for chip seals	• May 1 to August 15. Some variation exists between WSDOT Regions.	
Fog seal—when to place and diluted or undiluted	• ER requires 3 to 14 days between chip seal and fog.	• Opinions vary on this question. • Kittitas County places sand over their fog seals. • Noted that undiluted fog breaks faster than diluted fog.
Chip seal warranties	• Idaho DOT uses warranties and early experience reported as good.	• Mixed views of attendees about the use of chip seal warranties. o Contractors are concerned about their risk associated with warranties. o Idaho DOT notes reduced personnel and in-house costs on warranty projects.

Table 12 Chip seal performance considerations

Factor	Finding(s)	Supplementary Comments
Minimize rock loss	• Traffic control: speeds less than ≤ 25 mph. • Apply fog seal over the chip seal. • Embed 70% of chip depth into the binder.	• Avoid excessive aggregate application rates. • Traffic speeds through the construction zone of about 35 mph or higher likely to pick up rock. • Broom before applying fog seal. • Wet aggregate can contribute to rock loss.
Expected chip seal lives	• General view was to expect a 6 to 7 year life. Counties 6 to 8 years. • Larger max aggregate size may increase chip seal life. • General view that a fixed cycle time between chip seals produces improved system performance.	• ER has a typical chip seal life of 6 years with a range of 4 to 8 years. • P1 programming for 2010 assumed paving every o 14.7 year lives for HMA surfaces. o 7.0 years for chip seal surfaces.
Flushing chip seal—what to do?	• ER has used a two lift chip seal over a severely flushed pavement. o First shot 3/8”–No.4 with a light binder shot... o Second shot also 3/8” – No.4 with a heavier shot (achieved 50 to 70% aggregate embedment). o Choke stone applied to second shot.	• Flatter (less cubical) rock contributes to flushing issue.
Maximize HMA performance	• Best to place a chip seal on new HMA within 1 to 2 years to minimize aging of the HMA binder.	• ER has tried this combination of HMA followed by chip seal. • Broad agreement by attendees that placing a chip seal on new HMA within 3 to 4 years should enhance performance. • UK TRL research has shown that the HMA binder is 100 to 500 times more viscous in the upper 2-3 mm of the wearing course. A chip seal applied soon after construction to a HMA layer reduces the binder aging by a factor of 50.

Table 13 BST and Chip Seal Gradation Bands and Application Rates (2014 WSDOT Standard Specifications)

Application Rate			
	Undiluted Emulsified Asphalt (gal. per sq. yd.) Applied	Aggregate Size	Aggregate Application Rate (lbs. per sq. yd.)
New Construction			
First Application	0.35-0.65	½ inch - No. 4 or ¾ inch - ½ inch	25-45
Second Application	0.35-0.60	½ inch - No. 4	25-40
Choke Stone	N/A	No. 4 - 0	4-6
Seal Coats			
⅝ inch – No. 4 Choke Stone	0.40-0.65	⅝ inch - No. 4 No. 4 - 0	25-45 4-6
½ inch – No. 4 Choke Stone	0.35-0.55	½ inch - No. 4 No. 4 - 0	20-35 4-6
⅜ inch – No. 4	0.35-0.55	⅜ inch - No. 4	20-30
Choke Stone	N/A	No. 4 - 0	4-6

4.0 CONCLUSIONS

The conclusions from this study are organized by the following: optimal chip seal timing, design and materials, construction considerations, and chip seal performance. Given the extensive meeting discussions, surveys conducted, and literature, only the major conclusions will be presented in this section.

5.1 Optimal Chip Seal Timing

The limited information about the need and timing for placing chip seals between HMA overlays supports the view that state DOTs do so for at least two major reasons. One, South Dakota does so to reduce mix oxidation, or, two, states such as Colorado, Montana, and Minnesota to address other pavement performance issues (such as minor cracking, raveling, etc). The survey of State DOTs shows that several states place at least one chip seal between HMA overlays—some try to use two chip seal cycles. Four states start with a HMA overlay followed 2 to 9 years later with crack sealing then shortly thereafter with a chip seal. At the end of the cycle a new HMA overlay is placed 16 to 20 years after the initial HMA overlay. Typically their traditional HMA overlays last 10 to 13 years (those without a chip seal cycle). On average the crack sealing/chip seal process adds about 8 years to the HMA to HMA overlay cycle or about a 60% increase in HMA cycle time (the time between placing HMA overlays).

UK TRL (Rolt, 2001) research has shown that the HMA binder is 100 to 500 times more viscous in the upper 2-3 mm of the wearing course following a two year exposure to the sun. Further, a chip seal applied soon after construction to a HMA layer reduces the binder aging by a factor of 50. Placing a chip seal on new HMA within 1 to 2 years should minimize aging of the HMA binder and the potential for top-down cracking (which appears to be largely an issue of binder aging). The UK TRL work strongly supports the South Dakota view concerning the need for and timing of chip seal/HMA overlay cycles.

Literature and discussions between agency, paving contractor, and material suppliers supports the view that there is no true limit concerning ADT and the placing of chip seals. What is critical is careful attention to all chip sealing details and particularly traffic control. Although, a commonly reported “upper limit” by state DOTs for placing chip seals is typically an ADT of 20,000, the current WSDOT policy encourages placing chip seals on roadways up to an ADT ≤ 10,000 although occasionally exceeded.

5.2 Chip Seal Design and Materials

Currently, WSDOT Standard Specification 5-02.3(3) Application of Emulsified Asphalt and Aggregate states “The Project Engineer will determine the application rates.” Attendees at the BST meetings (summarized in Appendices B through E and Tables 8 to 12 in the main body of the report) agreed that binder and aggregate application rates can be an issue during chip seal construction and should be improved. Several chip seal design methods are available to estimate pre-construction binder and aggregate application rates to assist the contractor with the initial job set-up. One of these were selected for examination—the McLeod Method as modified by the Minnesota DOT. Typical calculations are included in this report and suggest that calculated binder and aggregate application rates can fall close to or within WSDOT application ranges—which is important since specification application bands are based on extensive field experience. If a design method is used, it is reasonable that it would be done by the paving contractor, since the binder and aggregate to be used on a project must be available for testing. Standard specification changes would be needed to accommodate this change.

Another option for verification/modification of binder and aggregate application rates includes one currently in WSDOT Standard Specifications—a test section at the beginning of construction. The requirement from 5-02.3(3) is: “To ensure uniform distribution of emulsified asphalt and that the distributor is correctly calibrated, the Contractor shall provide a minimum 1,000-foot test strip when beginning a BST section.”

In this specification requirement, no statement about aggregate application rates is made.

Based on the experience of those within WSDOT who apply choke stone followed by a fog seal over a chip seal, anecdotal evidence suggests that a chip seal better survives the early days/weeks/months following construction. There is less loss of chip seal aggregate and the surface is smoother. An unresolved question is how soon after placing the choke stone can the fog seal be applied. The current requirement in WSDOT Standard Specification 5-02.3(3) is "Fog sealing shall be applied no sooner than 3 days, but no later than 14 days after new construction or seal coat."

As to a rutting limit for chip seals, apply a single chip seal only to pavement with ruts ≤ 3/8" or, alternatively, apply sufficient prelevel to fill the ruts prior to chip seal construction. Adhering to these "rules" will enhance chip seal performance and reduce follow-up maintenance.

Broadly, the currently used WSDOT chip seal specifications relevant to the binder (CRS-2P) and aggregate bands (largely 3/8" – No. 4 and ½" – No. 4) work well. However, the road environment continues to be a challenge with limited funding and ever increasing traffic. Hence consideration of new approaches such as hot seals in lieu of asphalt emulsion show promise. As of 2014, one recent hot seal was constructed in the NCR and more are planned for 2015. The performance of these seals will be of significant value as to whether hot seals become a standard practice for WSDOT.

5.3 Chip Seal Construction

The BST meetings allowed a number of construction related issues to be addressed. Because of these discussions, selected WSDOT standard specification changes have been made between 2006 and 2014. Several construction factors either currently in WSDOT Standard Specifications or commonly used practices were reconfirmed. These include: (1) the one minute rule between binder application and aggregate placement (5-02.3(3)), (2) the use of paper to start binder shots (5-02.3(3)), (3) checking chip embedment depth with a general goal of 50 to 70%, and (4) weather limitations (5-02.3(10)). Other construction related options discussed were payment for chip seals on a SY basis and the use of warranties (such as done by Idaho). Given the discussions in the BST meetings, it is evident that contractors would rather not see the widespread use of warranties applied to chip seal construction—and their concerns should be considered if warranties are further considered by WSDOT. No recommendation about warranties is offered at this time.

The use of diluted or undiluted emulsion for applying fog seals was discussed at the BST meetings. A majority of attendees felt that use of undiluted emulsion was best; however, there was not uniform agreement on the issue.

The issue of paving intersections, city streets, stop-and-go locations were summarized for the six WSDOT Regional offices and meeting attendees. A best practice is to place HMA mix at these locations since the horizontal shear caused by both trucks and light duty vehicles is excessive during the early life phase of a chip seal. Typically the HMA placed is 3/8” NMAS applied in a relatively thin layer.

5.4 Chip Seal Performance

Single shot chip seals are thin—about 0.25” to 0.50” in thickness. It should not be expected that such a thin layer would have a long performance life—and it does not. Typically for WSDOT and many other states, it is reasonable to expect a chip seal will last 6 to 8 years if placed on a road surface with no or very limited distress. Given the use of studded tires and limited construction weather in portions of the state, performance does and will vary.

6.0 RECOMMENDATIONS

The major recommendations are:

- **Hot seals**: Program a limited number of hot seals and assess cost, construction issues, and performance. WSDOT has constructed at least one recent hot seal during 2014 and more are planned for 2015. These provide an excellent opportunity for follow-up assessment. The assessment will aid the decision as to whether hot seals will become a standard practice for WSDOT.
- **McLeod Method for chip seal design**: WSDOT should partner with at least one and possibly two chip seal contractors and/or material suppliers to further assess the efficacy of the McLeod Method for widespread use in Washington State. This could include sharing equipment expenses and gaining expertise on the required tests and outcomes associated with estimates for binder and aggregate application rates. Following this assessment, a decision can be made whether to more broadly implement this design process.
- **Alternating chip seal and HMA overlay cycles**: WSDOT should consider an expansion of this process by the Regions. The WSDOT PMS will allow for a reasonable assessment of this preservation cycle over a span of about five years. A reasonable limit for roadway ADT for which this process would be considered should fall within a range of 10,000 to 20,000. An ADT level of 10,000 represents a bit less than 30% of the lane miles paved with HMA and 20,000 about 40% (as of 2014).
- **Use of Choke Stone and Fog Seals**: Better quantify the performance gained by use of this process. Determine the earliest time to apply the fog seal portion of the application.
- **BST meetings**: The BST meeting format should be restarted during 2015. Numerous chip seal related topics are possible but could include discussions on a wider variety of thin surfaces such as microsurfacing, cape seals, slurry seals, etc.

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APPENDIX A—MCLEOD DESIGN METHOD: WSDOT EXAMPLE

To determine how the McLeod Method matches with current WSDOT standard specifications application rates for chip seals, example calculations are shown in this appendix. Values and properties of aggregate were estimated from various sources.

For all calculations it was assumed:

- The traffic on the roadway is greater than 2,000 vehicles per day.
- The pavement surface is a slightly pocked, porous, and oxidized surface.
- The binder will be a CRS-2 emulsion with 65% residual asphalt.

A common aggregate blend used for WSDOT chip seals is the 3/8" – No. 4 gradation which is used to illustrate the calculations.

The calculations are done via eight steps.

Step 1: Determine the aggregate gradation, bulk specific gravity and percent absorption

The following table below shows the results of percent passing for the case study.

Table B-1: Percentage passing for WSDOT design example

Sieve Name	Maximum Percentage Passing	Minimum Percentage Passing
1"	100	100
3/4"	100	100
5/8"	100	100
1/2"	100	100
3/8"	90	70
No. 4	5	0
No. 10	2.95	0
No. 200	1.5	0

* Aggregate absorption assumed = 0%

Step 2: Determine the Median Particle Size

To determine median particle size, Table A-1 is plotted on a gradation chart. The Median Particle Size is determined by extending a horizontal line at 50 percent passing mark until it intersects the gradation curve. This vertical line is then projected and the median size is determined. From this graph, an average aggregate size will be used which is 7.7 mm or 0.303".

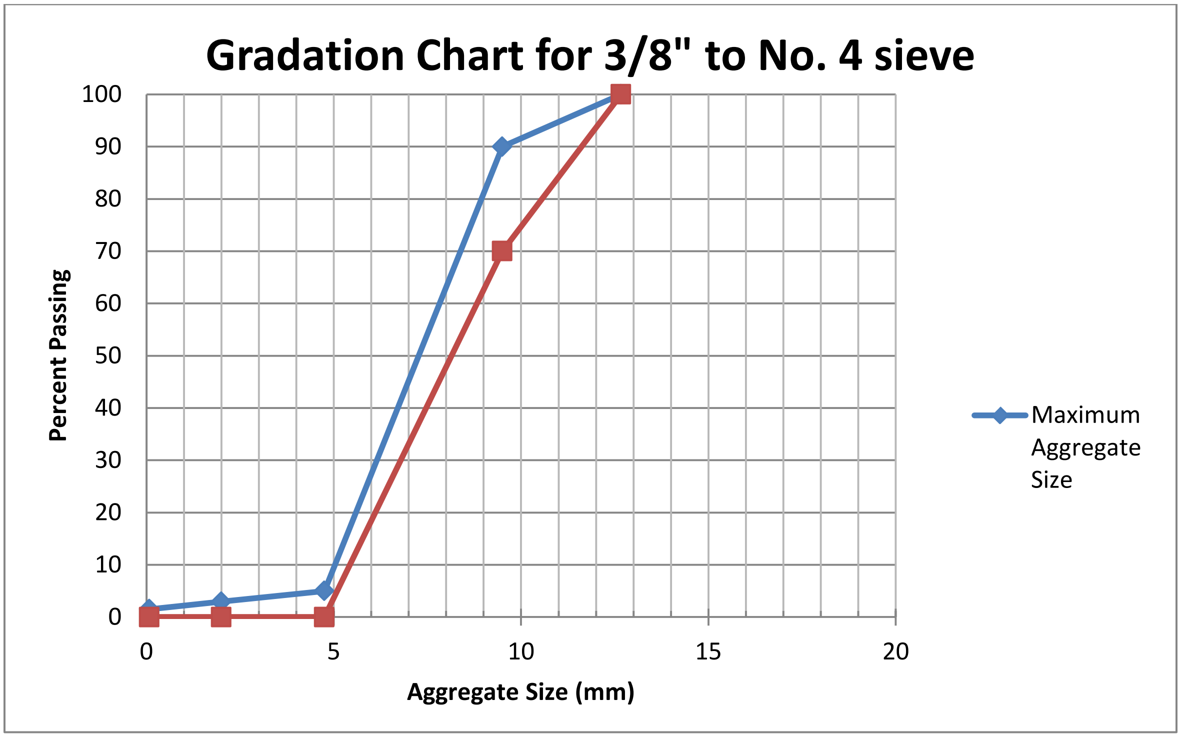

Figure A-1: Gradation chart for design example

Step 3. Determine Flakiness Index (FI)

The aggregate used to determine the gradation is then broken down into the five following groups.

1. Passing the 1 in. sieve but retained on the ¾" sieve.
2. Passing the ¾" sieve, but retained on the ½" sieve.
3. Passing the ½" sieve, but retained on the 3/8" sieve.
4. Passing the 3/8" sieve, but retained on the ¼" sieve.
5. Passing the ¼" sieve, but retained on the No. 4 sieve.

Flakiness Index (FI) can be calculated by the following equation:

$$FI = \frac{(Weight\ of\ Flat\ Chips)}{(Weight\ of\ Sample)}$$

At the time these calculations were done, no Flakiness Index was available for WSDOT aggregate. Therefore, FI values were assumed. From a case study in Minnesota, the

Flakiness Index was determined to be 28 percent. The aggregate used was a natural aggregate. WSDOT typically uses crushed rock, which provides more cubical aggregate, thus we would expect a FI lower than 28 percent. From the BST review meetings (summarized in Appendices B through E), it was noted that rock quality does vary throughout Washington State, as expected, however it is generally of good quality. To represent a range of realistic FI values, test data from Idaho were used (Zoghi et al, 2010). For their six districts, samples tested resulted in FI values which ranged from 5 to 21%. Those will be used here. The value for Median Size Aggregate (M) is 0.303" as noted earlier.

Step 4. Determine the Average Least Dimension (H)

Least average dimensions is calculated from the results of step 2 and step 3.

U.S. Customary Units

$$H = \frac{M}{1.139285 + (O.011506) * (FI)}$$

Lower H

$$H = \frac{0.303\ in}{1.1139285 + (0.011506) * (21)} = \mathbf{0.224\ inches}$$

Upper H

$$H = \frac{0.303\ in}{1.1139285 + (0.011506) * (5)} = \mathbf{0.259\ inches}$$

Step 5. Determine the Loose Weight of the Aggregate (W)

Loose weight is determined by filling a metal cylinder with a volume of 0.50 ft^3 and then determining the weight of the material. From the Minnesota design example, a range of 80-100 lbs/ft^3 was noted. For the Idaho test data, the range of W for their six districts was 87 to 96 lbs/ft^3. The data from Idaho will be used as a range.

The Loose Unit Weight (W) was calculated by the straightforward relationship:

$$W = \frac{Weight\ of\ Aggregate}{Volume\ of\ Cylinder}$$

Step 6. Determine the Voids in the Loose Aggregate (V)

Once W is determined, voids are calculated as below. A specific gravity of 2.67 was assumed (same as for Idaho calculations):

U.S. Customary Units

$$V = 1 - \frac{W}{62.4\,G}$$

Lower W

$$V = 1 - \frac{87\ lbs/ft^3}{(62.4) * (2.67)} = \mathbf{0.48}$$

Upper W

$$V = 1 - \frac{96\ lbs/ft^3}{(62.4) * (2.67)} = \mathbf{0.42}$$

Step 7: Application Rate

Now that the variables are all calculated, the application rate and binder design equation can be calculated including wastage (E) of 1.05 (whip-off) with G = 2.67:

Aggregate Application Rate in U.S. Customary Units

$$C = 46.8 * \left(1 - (0.4)(V)\right) * (H)(G)(E)\big)$$

Lower C

$$C = 46.8 * \left(1 - (0.4)(0.48)\right) * (0.224in)(2.67)(1.05) = \mathbf{24\ lbs/yd^2}$$

Upper C

$$C = 46.8 * \left(1 - (0.4)(0.42)\right) * (0.259in)(2.67)(1.05) = \mathbf{28\ lbs/yd^2}$$

Step 8: Binder Design Equation

The binder application rate is determined from the equation below and the variables calculated in the earlier example.

$$B = \frac{(2.244)(H)(T)(V) + S + A}{R}$$

*Variables T, S, and A, are calculated from the traffic condition, surface condition, and Aggregate Absorption. Below are the tables where these factors can be found

Table A-2: Traffic Factor (T)

Traffic factor				
Traffic Vehicles per day				
Under 100	100 to 500	500 to 1000	1000 to 2000	Over 2000
0.85	0.75	0.7	0.65	0.6

Table A-3: Surface Condition (S)

Existing Pavement Texture	**Correction, S**
Black, flushed asphalt surface	-0.01 to -0.06
Smooth, nonporous surface	0
Slightly porous, oxidized surface	0.03
Slightly pocked, porous, oxidized surface	0.06
Badly pocked, porous, oxidized surface	0.09

For this example: T = 0.60, S = 0.06, and R = 0.65 (WSDOT SS 9-02). Aggregate absorption was considered to be 0.0 in this example.

<u>Binder application rate in U.S. Customary Units</u>

$$B = \frac{(2.244)(H)(T)(V) + S + A}{R}$$

<u>Lower B</u>

$$B = \frac{(2.244)(0.224)(0.60)(0.48) + 0.06 + 0.00}{0.65} = \mathbf{0.32\ gal/yd^2}$$

<u>Upper B</u>

$$B = \frac{(2.244)(0.259)(0.60)(0.42) + 0.06 + 0.00}{0.65} = \mathbf{0.32\ gal/yd^2}$$

Below in Table A-4 are the Median Particle Sizes for all three primary WSDOT chip seal bands. Using the same assumptions as for 3/8" – No. 4, the results for all three bands are shown in Table A-5.

Table A-4: Minimum and maximum median particle sizes for WSDOT aggregate sizes

	Median Particle Size		
	Minimum	Maximum	Average
5/8" - No. 4	0.378	0.417	0.398
1/2" - No. 4	0.299	0.346	0.322
3/8" - No. 4	0.283	0.323	0.303

Results

Below in Table A-5 are the results for typical WSDOT chip seal gradation bands using the McLeod Method. The Minnesota DOT recommends an average of (1) calculating the binder application rate by use of the Average Least Dimension and (2) the same calculation but done with the Median Particle Size. This provides a "starting" point for selecting an acceptable binder application rate. These overall averages would then be about **0.46 gal/yd^2 for 5/8"- No.4, 0.37 gal/yd^2 for ½" – No.4 and 0.35 gal/yd^2 for 3/8" – No.4** all of which fall within the current WSDOT Standard Specifications range. The caveat is the various assumptions made—other assumptions would certainly produce different results which would not necessarily fit within the current specification ranges.

Table A-5: Results of McLeod method applied to WSDOT aggregate

	McLeod Method			WSDOT SS 2014	
	(1) Emulsified Asphalt (gal/yd^2)	(2) Emulsified Asphalt Averaged (gal/yd^2)	Aggregate (lbs/yd^2)	Emulsified Asphalt (gal/yd^2)	Aggregate (lbs/yd^2)
5/8" - No. 4	0.42	0.47-0.51	32-37	0.40-0.65	25-45
1/2" - No. 4	0.34	0.38-0.41	26-30	0.35-0.55	20-35
3/8" - No. 4	0.32	0.36-0.39	24-28	0.35-0.55	20-30

APPENDIX B—BST MEETINGS 1 AND 2

BST Fact Finding Meetings 1 and 2—Summary of Discussions

Conference Room, Washington Apple Commission Building
2900 Euclid Ave, Wenatchee, WA
September 6, 2006
and
2830 Euclid Ave
WSDOT Maintenance Area 1 Conference Room
Wenatchee, WA
February 26, 2007

Introduction

A bituminous surface treatment (BST) or chip seal is a frequently used preventive maintenance treatment for flexible pavements. Typically, a BST is a single or double course of aggregate placed onto asphalt binder that has been applied to the surface of a flexible pavement. Due to WSDOT budget issues for pavement preservation funding (often referred to as P1 funds), the use of BSTs may increase. As such, WSDOT is examining several issues associated with this type of resurfacing. A portion of this examination is being done through the Department of Civil and Environmental Engineering at the University of Washington with support from WSDOT.

This BST Fact Finding Workshop was used to obtain facts and opinions from a variety of persons that design, build, and/or maintain BST surfaces. The topics discussed and a summary of the responses from the attendees follow. Initials identify individual responses—a list of the attendees is included.

A total of 17 persons attended the BST Fact Finding Workshop on September 6, 2006, and 12 on February 26, 2007.

Summary of Topic Discussions

1. **Discussion: Selection of WSDOT BST types and limitations**

   1.1. What is a reasonable upper limit for average daily traffic (ADT)?

   - NJ – The ADT = 2,000 was originally intended to be a lower limit – below 2,000 you should chip seal. We were chip sealing up to 30,000 ADT.
   - ES – Can chip seal just about anywhere but need traffic control.
   - ST – Standing traffic can cause problems. City of Seattle – cleanliness and moisture content of rock is the key.
   - BH – I-90 Moses Lake has been done – the key is making sure traffic is kept off the roadway until the next day (after brooming). That chip seal was a preseal before an HMA overlay.
   - ST – Faster breaking, harder material available because we know that traffic control is not as ideal as wanted. The CRS-2P can be used so that the aggregate holds quicker, broom quicker and harder, and open to traffic quicker. Fog sealing vs. pre-coated rock and opening to traffic as quickly as possible.

- ST – Pushing for elastic recovery on residue for emulsions with user-producer group (PACCAS). If approved, this would go into the WSDOT Standard Specifications. PACCAS vote is supposed to take place in October 2006.
- TD – Noted differences in products from different suppliers (i.e. CRS-2P very different from different suppliers)
- ST – CRS-2P does have a shelf life – even over the two weeks that WSDOT is allowed to test within (especially within a quart container vs. a tanker)
- ST – Rubberized crack sealant will reflect up through US Oil's emulsion, but not other, non-rubber, crack sealers (the oil in the tire rubber in the crack seal reacts with emulsion). Polymers in CRS-2P can react differently with polymers or glue to hold tab or lane markers.
- ST – CRS-2P is a standard product now (CRS-2 would be a special order product if specified for a project). When it comes to emulsions, counties have substantial influence in the control of specification or material changes.

1.2. What is a reasonable upper limit on grade—beyond which it will be difficult to construct a BST or the BST is likely to perform poorly?

The responses were:

- BH – Can do a 12-15% grade (SR 142, ADT=50, hair pin turns), but the key is low traffic or the ability to close the road.
- TD – Cannot do these very steep grades if you have to deal with the traffic.
- TD – Cushman Road (6-8%) – would have been fine if we didn't have traffic or would have had choke stone there.
- NJ – That is the reason why we kept choke stone in the WSDOT Standard Specifications.
- TM – 24 hour traffic control next year.
- BH – Discussed limits on traffic control (i.e. 1.5-2 mile limit) – need to release those limits because they can place 8-10 miles of chip seals a day.
- JU/JR – Pine Canyon – had steep grade, heavy trucks, and dirty aggregate
- ES – BST materials have gotten much better i.e. he has seen material placed before noon and swept around 4 pm without much more chip loss
- NJ – CRS-2 would have to wait until the next morning; CRS-2P can easily be swept later that day.
- BH – Constructability issues/traffic control can make it difficult to sweep right away.
- WS – Surface temperatures, humidity, traffic can play into when you can sweep, what type of roadway you can place a chip seal on, etc.
- TD – Different emulsions/materials can play into time limits as well.
- WS/TM – Surface distress on pavement before chip seal will reflect through the new chip seal.
- WS – Tried to extend cure time by waiting for brooming and keeping traffic off the roadway, but once traffic was released (because of high surface temperatures (125°F)), pickup started almost immediately.

1.3. What is a reasonable geometric curve restriction for a BST—or does such a restriction make any sense?

- TM – High superelevations can make it difficult to pave.
- TD – One type of material vs. another can make a difference.
- TD – Choke stone always helps in difficult situations.

1.4. Intersections

1.4.1.Should intersections receive BST applications?

1.4.2.If YES, what restrictions should be applied?

1.4.3.Are Cape seals the solution for intersections?

The responses below address all 3 questions:

- WS – Current pavement condition plays a big role in how the chip seal will perform.
- BH – Skip intersections completely (high traffic) because they are not going to survive (high truck traffic, the way trucks tend to turn, will scrub the aggregate lose).
- JS – The existing conditions will play a big role in the chip seal performance within an intersection.
- WS – Keep the BST away from the radius, stop/go, and acceleration/deceleration areas.
- ST – West side intersections work well mainly because we don't have the high temperatures such as those in Eastern Washington.
- TD – Choke stone helps to hold the bigger rock down in intersections.
- BH – How long before applying choke stone? TD/ST – A week to 2 weeks before the choke stone is placed. If damage at I/S? Lighter application rate (because flushing already) with smaller chip.
- BH – Choke for 3/8" chip seal? NJ – Choke wasn't meant for 3/8" chip seal
- ST – Bumping PG for intersections, smaller tonnage, is it worth doing? May need to leave intersections for the end of the job (or beginning) if you are using high temperature PG binders.
- BH – Smaller projects with higher PG binders are very difficult to deal with (binder storage issues).
- ST – Training is key for making successful chip seals!
- JM – What kind of training needs to be done? ST – Statewide training over a number of years – includes cities, counties – training in all different forms (flyers, training sessions).
- ST – Chip seals need to be placed on a roadway when there is not much distress. If they are placed on roadways with lots of surface distress, they are not going to perform well
- BH – PG bumping from small cities and counties primarily originate with consulting engineers.

2. Discussion: BST materials

2.1. What is the maximum percent passing the No. 200 sieve that should be allowed for:

2.1.1.½" BST?

2.1.2.3/8" BST?

The responses were:

- TD – 1 percent was fine, not sure why it was changed to 1.5%. Need to stay away from coating the rocks. Costs go up with cleaner aggregate, but so does the success rate.
- ST – 1% clay vs. 1% dust – big difference in the way it performs. Sand Equivalent requirement has been removed from WSDOT Standard Specifications for chip seals.
- ST – Cleaner rock, less rolling, better performance.
- JS – Number of work days also play into being able to get the cleaner chips. Poe Construction uses basalts mainly, best to take it after washed. 1% is a better specification level to get the cleaner rock.

- ES – Most of the jobs that fail are due to dirty rock. Best to wash the rock before using, but in EW difficult to have the water available. Basalt rock looks clean, but has a coating.
- BH – The change (to 1.5%) came about when the DOT went to statistical acceptance. Crushers will target 1% or less. TM – The average % passing the No. 200 sieve this year was 0.5%.
- JS – The statistical acceptance for aggregates came about a couple years ago, so the change from 1 to 1.5% did not happen at the same time.
- RR – Dust is not the biggest issue; it is the coating of aggregate that causes problems. WSDOT Standard Specifications state that coating is not allowed, but who makes the call? Moving down to 1% will keep the rocks from being coated. Is there a test that can be run?
- BH – CRS-2P less susceptible to coating of aggregate? ST – Yes, clay is more likely the culprit with coating of aggregates (and can also cause problems with the adhesion with CRS-2P).
- ST – Better equipment (distributors) have improved the stability of the emulsions (less contamination from cleaning distributors).

2.2. Best maximum aggregate size for BST resurfacings?

The responses were:

- BH –Likes ½" – more forgiveness in application rate. The 3/8" chips are difficult to control with respect to the application rate (emulsion and aggregate). The 5/8" chips work for low volume roads, but have to place a lot of emulsion to hold the chips down.
- BH – Some counties are using ¾" chips.
- WS – Public doesn't like putting chips on a nice pavement. With the fog seal on top, the public seems to accept that more.
- NJ – The ¾" top size in the WSDOT Standard Specifications was originally intended for a three shot system
- BH – Superior has had success with ¾" chips, but you must use a substantial amount of binder to keep the chips down. As such, need traffic control for high emulsion application rate to cure.
- TD – 1/2" chip better, but 3/8" is more accepted with the public. The fog seal makes it looks like HMA and is definitely more acceptable to the public.
- RR – ¾" okay, but needs to be choked (our specification is not very good).
- JM – How did we get to the modified gradation used by the Eastern Region? Steve Noland starting looking at single size aggregate that was recommended and fell upon ½"- No. 4 spec (found a suitable specification from Utah—which might have originated in Australia).
- TD – The width of the specification bands makes it difficult to get the single size aggregate. He suggested that the specification band should be tightened, but the resulting aggregate will cost more. Also depends on time of year that it is bid.
- RR/TM – Sometimes programming can cause late bid dates, or complexity of projects (add-ins of prelevel, etc.).
- ST – A training issue—cities and counties need to know that bids need to go early so that crushing can take place in a reasonable manner.
- ST – Cost escalation/de-escalation clause should be in the contracts for chip seals.

- JS – Plan on hauling aggregates – crushers don't like to bring in equipment because there's a lot of waste in making BST rock.

2.3. Choke stone gradation—what will work? Current specification? Concrete sand? RAP?
The responses were:

- BH – Whatever you have will work (1/4" minus, concrete sand, etc.).
- JR – Going back to choke stone, looking at products that are available and don't need to be produced.
- CJ – Fine aggregate for concrete will work.
- CJ – Total of 20 centerline miles in NW Region for 2007. What can we use as off-the-shelf products?
- TD – Most likely the aggregates will come from Tacoma.
- ST – Some counties stockpile their aggregates for a year or two and have the contractors work from those sources.
- JS – Concrete sand is a little on the finer side and it may be difficult to spread if wet (hangs up in the spreader).
- WS – Use the ½" modified (Eastern Region gradation) and stay away from the choke stone. The choke can be dusty and more equipment is needed to do the job. Able to keep traffic control tight to operations, the ½" is forgiving for application rates.
- BH – The Eastern Region modified gradation doesn't require the choke – best to have it available if needed, but don't use if you don't have to.

2.4. Binder costs—current prices and trends?

- ST – The price is a function of the crude oil prices. We (US Oil) are still only guaranteeing prices for 30 days.

2.5. High float emulsions—better than CRS-2P? If so, why?
The responses were:

- ST – High float emulsion less sensitive to moisture.
- TD – High float has worked in some places, but not in others. It is difficult for controlling quality.
- ST – High float is a designed system. The aggregate being used has to be compatible. Has an anionic charge.
- ST – High floats are not needed to extend the BST paving season. With the extension, the weather is typically wet and you cannot place it anyhow. High floats have a 50 percent success rate. Placing high floats later does not allow the chip seal to cure as it would if you placed a CRS-2P earlier.
- ST – Counties that have used high floats include Grays Harbor, Clark, Clackamas, and Lewis.
- ST – As a supplier there does not appear to be a benefit.

3. Discussion: BST construction

3.1. Binder distributors

3.1.1.What is the allowable time between binder application and aggregate application? [WSDOT Standard Specifications (2006) require a maximum of 1 minute.]

The responses were:

- ES – CRS-2P is more forgiving (more so than CRS-2). The one minute time limit is difficult to meet, especially in intersections. Rolling has been able to offset the time limit. The 1 minute limit needs to be flexible – training is necessary and particularly so for inspectors.
- General consensus—Training is necessary to address some of these special issues.

3.2. Rock loss

3.2.1.How can this be minimized?

The responses were:

- BH – Need to determine the amount of oil needed for the chips to stick. If you have enough oil for the chips to stick, then you won't have a lot of rocks to lose.
- ST – Some counties over-rock because they are concerned about flushing.
- BH – Too much rock is detrimental to the chip seal – abrades surface.
- NJ – Determine yield first to get application rate for chips. Check yield for emulsion rate by going back about half a mile (embedment).
- WS – Likes to see the emulsion through the aggregate especially on low-volume roads, but on higher volume roads, insurance is more chips to protect the emulsion.
- TD – Keep speeds down (25 mph is best, 35 mph starts kicking the rock up). Variable message signs seem to catch the driver's eyes and are much better than traditional signage.
- TD – Fog seals make a big difference in keeping the rock loss to a minimum. Broom before you fog, anywhere between 3-14 days following placing of the chips.
- NJ – Make sure that the chips are not over-embedded (85-90%) before a fog seal (very light fog seal if high embedment rate).
- KL – Flat and elongated? TD – not an issue with their sources
- ST – Rock loss can happen up to a year or two later – after a freeze/thaw or snowplow operations.
- MD – Any complaints after fog seal? WS – not unless we don't pre-sweep before fog seal.
- JS – Wet rocks will cause rock loss.

3.3. What is the best way to determine the binder application rate?

- ES – Used to be the rule of thumb where a 3/8 inch aggregate gets 0.38 gal/SY and a ½ inch aggregate gets 0.50 gal/SY.
- ST – A test section at least 1,000 feet long is needed.
- TD – Actually the whole project is a test section, we are constantly calibrating.
- WS – Experience works best but you also have to consider air temperature and humidity.
- TD – Shade and humidity are concerns.
- ST – Start with what you know and do, then adjust accordingly.
- ES – Education is the key.

3.4. What is the best way to determine the aggregate application rate?

Responses for Questions 3.3 and 3.4 are combined and follow:

- WS – Experience is key! Need a knowledgeable inspector, will call oil manufacturers if needed in special situations.

- BH – Like HMA test section – need to try the application (binder and aggregate) rates, roll it, and check embedment rates.
- NJ – Need to fog seal prelevel prior to chip seal.
- ES – Patches (whoever is doing it) need to be fog sealed. There is no compaction requirement, so the BST emulsion penetrates into those sections and changes the target application rate.
- Patch the year before, do you still need to fog seal?
    - WS – Yes, makes it less volatile, better chance for the chips to stick.
    - TD – No.
- BH – Patches perform better as 3/8" vs. ½" HMA – less voids.
- JR – Will have 140 centerline miles of chip seals in NC for 2007, 20 miles in NW for 2007.
- WS – Application rates are checked throughout the project. The application rate does not stay the same – can be changed because of surface type, temperature, grade, etc. Training is key to make sure that everyone is on board – adjustments are necessary.
- WS – If you see bubbles forming on the surface following application of the CRS-2P, the application rate needs to increase but do so in small increments (~0.03 gal/SY). The air bubbles indicate that the emulsion is penetrating into underlying pavement voids (not unusual for shooting over prelevel) thus reducing the amount of binder available for chip embedment.

3.5. What are the best methods to fix a flushing BST?
The responses were: Assumption: You have built a BST and it is flushing (thus, construction related).

- ES – Find out what is causing it – is it ruts? Big believer of prelevel, need to fix rutting before chip seal.
- NJ – If rutted, shoot to embed in ruts and fog seal the high sides afterward (check embedment in the wheelpaths).

3.6. Pre-BST repairs
3.6.1. Rutted pavements: How much rutting can be allowed to preclude pooling of binder?
The responses were:

- ES – If you can feel the ruts while driving, then they are too deep for the proper application of a BST.
- BH – Use threshold for HMA rutting as starting point ~3/8" (~10 mm).
- RR – Would prefer to do 0.20' overlay and require pneumatic rollers rather than prelevel plus 0.15' HMA– no control over prelevel.
- CJ – Need to use pneumatic roller – with a 0.15' overlay, you will get about 0.12' on high side and 0.15' in wheelpath.
- JR – Programming issues sometime prevent prelevel but still need to do some kind of preventive maintenance or you are stuck with chip sealing with larger than desirable rut depths. Probably best to stay away from 3/8" chip seal in these situations.
- RR – Jerry makes a good point, sometimes they will take the funds they have and put it all towards one route within the Eastern Region seal program rather than spreading the funds around on more routes.
    - General Consensus — with 3/8" or less ruts, probably okay for placing a BST without prelevel. More than 3/8" ruts, need prelevel.

3.6.2. Cracked pavements: (1) How large of cracks can be allowed before they must be presealed? (2) How long in advance of BST construction is needed for "curing" of crack filling materials? (3) How long in advance of BST construction is needed to complete HMA prelevel?

The responses were:

- NJ – Worked with regions to do double chip seal with cracked pavements some years ago.
- ST – Need to address cracking or else you will find that some seals will not last.
- RR – Uses rubberized crack sealant under chip seals. Use slurry seal under HMA to keep away from bump.
- NJ – Slurry seal meant to be under HMA as filler, not used under BST.
- BH – It is best for an agency to pay for crack sealing by the lineal foot; it is a better deal than force account work.
- ST – Portion of road around very large cracks needs to be removed and replaced prior to BST.
- RR – Smaller amounts could be left to maintenance, above $60,000 needs to be contracted out
- BH – Items that relate to chip seal, crack seal, prelevel etc., need to be in contract as a bid item.

3.6.3. Prelevel: (1) Is enough prelevel typically allowed by WSDOT? (2) Should prelevel by fog sealed prior to BST application? If so, why?

- ES – Typically there is not enough prelevel, you do the best with what you have been given.
- SN – The Eastern Region selects a section and places most if not all the prelevel on it rather than mobilizing over several locations (projects). We put the prelevel and resources in one area knowing some areas will not get done. But, eventually, on future seals, we will get the areas that need substantial repairs. The typical depth of prelevel placed on the area selected is 0.10 to 0.15'. WSDOT Maintenance provides a lot of input into needs.
- JR – The NC Region scatters prelevel around. Some areas get crack sealing. The NC Region tries to program crack sealing a year ahead of time.
- RR – Crack sealing is set up on Eastern Region projects.
- SN – The Eastern Region does crack sealing on some projects. Crack sealing is helping the seals last longer with less cracks occurring on future seals.
- TD – There would be a big advantage to do preseal repairs a year ahead of the seal.
- ES – Prelevel should be fog sealed.
- RR – Eastern Region prelevel is fog sealed.

3.6.4. Who should do the preseal repairs—the contractor or WSDOT maintenance?

- ES – In the Eastern Region, the contractors are doing the big jobs.
- RR – Unlike 10 years ago, maintenance is not allowed much prelevel. Their funds are being tied up with other concerns.
- RR – 12 to 15,000 tons for a chip seal is typical. Prelevel is done the same year as the chip seal. Since the prelevel is put in one or two areas, maintenance understands they will be doing pothole repairs on other areas. Maintenance likes the concentrated prelevel approach.

- TD – Does not do HMA paving, chip seals only, does not have to worry about prelevel and this frees him up to concentrate on the chip sealing.
- BH – South Central Region does the similar approach as the Eastern Region.

3.7. Aggregate embedment—what is a reasonable range?

The responses were:

- BH – 70% embedment is different than 70% contact area – maybe we should be looking at contact area.
- TM – Remove rock and measure embedment – if they are not laying on the flat side, is it because there are too many rocks?
- ES – The first rollers are the trucks and if we could get the cars to break their track, we could get better seating of the rocks.
- WS – If the existing road is a chip seal surface, then I would shoot for 40% embedment because I know that it may embed into the underlying seal. This needs to be considered and monitored throughout a project.
- NJ – 25 to 33% embedment will not hold the aggregate.
- TD – At least 50% embedment or more is needed on the West side of the state for proper embedment.
- WS – 0.48-0.50 and there are times that it needs more. The bigger issues are surface temperatures and traffic. In the spring, 0.40 may work better with the 3/8" chips.
- JM - Recap of the September meeting shows many of the participants feel 50% embedment is typical.
- BH - Sometimes there are problems with contract administration where you are told to shoot the upper range and then when it bleeds it is your problem.
- ST- Shot rate is job determined.
- TD – Inspectors need training to know what is acceptable.
- BH – Embedment depth is probably something that does not need to be placed in the specification, it needs to be determined by knowledgeable people.
- ST – Inspectors need pictures to describe the good and the ugly.
- JR – Not enough oil is a concern, it seems to be best for the contractor to work with the region.
- SN – Texas feels a 30 percent embedment rate is acceptable at the time of placement and then over time a greater percentage is obtained.
- ST – The reason why Texas holds off is due to their high temperatures. Even at 30 percent they often experience over embedment problems.

3.8. Contract administration

3.8.1. Improved payment approaches?

- JS – Would like see a SY rather than CY measurement. Let the contractor determine what application rate they are comfortable with for bidding. Also, easier to calculate at the end of the job for pay. The SY measure is used in Idaho and it works well.

3.8.2. Pay on basis of per unit area (for example $/SY)? See above.

3.8.3. Should BST warranties be used?

3.8.4. Communication with WSDOT offices?

3.9. Training

3.9.1. What training is working well?

3.9.2. What training needs to be done that is currently not available?

3.9.3. Who needs the training?

The combined responses for these questions were:

What training is working well?

- ES – Using the same inspectors in the Eastern Region two years in a row. Better product this year. Training on the job.
- BH – Every year it's a new training session in North Central Region for the last 15 years. Eastern Region same office, new people rotate through. Experience is key.
- RR – Experience is important in chip seals.
- TD – Olympic Region had class and got us all talking. New players coming together. Training was not as important as getting all the principal players together.
- ST – 1st year – here's a chip seal, here's what you need to look for, inspect, etc. 2nd year – inspectors have some experience, the questions reflect that (i.e. more detailed questions).
- WS – Has seen very little training. All our training comes from experience. Pre-construction meetings – address issues and open up a dialog. Training is most important thing we can do. Should have the most experienced people on the job.
- TM – Need to bring in designers so that the issues are addressed in the design stage as well.
- JS – Need just-in-time training (we have 6 projects a year, one in each region).
- CJ – Prior to pre-con or with pre-con, get together the inspectors, contractors, industry, etc. to go through Tim Moomaw's class and ask the questions relevant to the specific project.
- ES – Chip seals administered out of one office gives good success. By the second or third year you have a good knowledge base and good program. Projects where inspectors are new each year lead to have problems.
- BH – Inspectors often get passed around, every time you do that you have concerns. It is important to have consistency. Cross training is different as experienced people are still on the project. Eastern Region jobs are proof of the benefit, everyone knows what to expect.
- ES – Recently, on SR 26 we were able to fix some bad ruts by increasing the oil shot. Improvements were made as WSDOT's crew knew what to expect.
- BH – Need people who can make judgment calls. It is difficult to write specifications for variations for such factors as shady and sunny areas.
- BH – In the North Central Region a 3/8 inch to No. 10 has 30 to 56 percent passing the No. 4. There will be more variation in the shot rate as compared to the Eastern Region 3/8 inch to No. 10 where the aggregated gradation is tighter. The shot rate is very consistent.
- TD – A range of 30 to 56 passing the No. 4 is too wide. More judgment on the part of inspectors will be required to get the proper shot rate.
- WS – Any training is a good deal. It is good to see those involved asking questions. Joint training would be beneficial.
- JM – How big of a group should be involved?
- ST – Cities and Counties may jump on board making it difficult if training was provided.

- WS – Training for East/West or both sides is a consideration.
- JS – Just in time training - taking training to those who need exposure or training works for other areas of WSDOT.
- RR – There is a whole lot of interest in BST training but there is only a select group that needs it.
- TD – Just in time training after a preconstruction meeting would be a possibility.
- JM – Will web applications help with training?
  - TD – Absolutely, a place to post information.
  - JS – What do we have on BSTs? JM—the Pavement Guide has basic information on BSTs.
  - WS – Any type of filling the knowledge gap is good.
  - JS – The Pavement Guide is a great reference tool.
  - WS – Nice to have somewhere to reference people/questions to.

3.10. Temperatures

3.10.1. Construction season: What in your experience makes for a reasonable construction season (start month and end month)? [WSDOT Standard Specifications (2006) limit the construction season for BSTs between May 15 and August 15.]

3.10.2. Pavement and air temperatures for constructing BST surfaces: (1) what is a reasonable minimum pavement temperature? (2) What, if any, is a reasonable maximum pavement temperature?

The responses were:

- ST – Surface temperatures were in the WSDOT Standard Specifications because there wasn't a dateline. Now there are dates in the SS.
- Standard Specification now state May 15 to August 15.
- May 15 could be pushed sooner.
- BH – Would rather see temperatures, not dates, wouldn't go past Sept 1 because of curing issue.
- JS – Bigger projects, more open time frames are needed.
- ST – Would like to see Sept 15.
- Earlier than May 15 would be better for start. Would rather see earlier in spring than later (past Sept) because of cure.
- BH – When surface temperatures are the same as the emulsion temperature, you are going to have problems.
- ES – On the same route, surface temperatures can vary dramatically, how hot is too hot? Need to have choke available on the job and have been able to "calm" the areas down that were too hot.
- CJ – What is too cold? ST: At 50°F and rising, but moisture will kill a chip seal faster than anything. Also, need to regulate the traffic.
- JS – Air temperature vs. surface temperature? ST/NJ – air temperature is a carryover from the old days of specifying cutback binders. Surface temperature is what we care about day.
- ES – Surface temperature is 50°F, going to be 80°F, can we pave? ST – yes. NJ – The 60°F temperature criterion is a carryover from the use of cutbacks, and, as such, needs to be changed.

- General: The clause in the WSDOT Standard Specifications that is being referred to is from 5-02.3(10), a portion of which reads "The roadway surface temperature shall be at least 60°F and the air temperature at least 60°F and rising, or…."

4. Discussion: BST performance

4.1. How long do you think a BST resurfacing should last (in years):

- SN – Eastern Region, BST is done on a 6 year cycle.
- RR – Six years seems to work well; however, we should expect more than six years in some cases. Maybe 10 years where the underlying pavement is in good condition.
- JR – NC Region does seals on a 7 year cycle.
- TD – Chip size may allow some seals to go longer than others.
- RR – In some areas, freeze and thaw cycles drive the need.
- BH – Depends on the type of volume of traffic. Six to 8 years is typical for counties around Yakima. Some counties go out and look at the roadways and if they can get more like they extend the cycle until the next BST.
- SN – The Eastern Region tries to program sections to do less mobilization.
- WS – Those counties that "cycle" seem to have better roads. Those who pick and choose sites based on the worst condition often come to a point where the roadway needs to be paved with HMA rather than a BST.
- BH – Yakima County uses a fixed cycle, but, if the roadway looks good then they may skip the roadway and catch it later – fixed cycles with judgment.
- TD – Chip sealing will not hurt the roadway if you do it earlier.

4.2. Should BST resurfacings be done on a regular or fixed cycle for a specific road or street (say every 8 years regardless of pavement surface condition)?

- Several comments were made previously in Paragraph 4.1.
- RR – We could probably take a look at roads in the southern part of the Eastern Region and perhaps extend the cycles.

4.3. Discussion of projects that performed well and poorly. Factors that contribute to success or not.

4.3.1. Factors for success?

4.3.2. Factors for failure?

- SN - Aggregate cleanliness; appropriate aggregate size for the roadway and conditions; aggregate size selection; aggregates in specification; emulsion in specification.
- JS - Construction operations; application of oil/aggregate for the conditions.
- WS - Training and knowledge of those individuals involved; experienced people; open conversation.
- BH - Materials in specification – oil and aggregate; communication of those involved with construction.
- ST - Project Engineers need to understand that with chip seals other options come into play; application rates of aggregate and emulsion.
- TD - Rock cleanliness and application rate. Recognizing changing conditions such as shady spots requiring an increased application rate. One person cannot run the whole chip seal show.

- ES - Everything that has been said. Attitude of those on the project. Need to correct Contractor and State attitudes up front.
- JR - Relationship built during first day of the project. Traffic control
- JU - Experienced people. Aggregates and oil in specification.

5. Wrap-up comments

The following comments were made as both the meetings were finishing:

- Bill H – Specification changes coming? Will we get to see them?
- Jeff U – Yes and yes. We are working on them and this meeting will help to refine any changes.
- Tim M – Great forum, need more of it.
- Mike D – ditto.
- Jerry R – ditto, timing of things. Programming issues play more into it that we would like.
- Kevin L – Noted the study done 15 years ago by Newt and Joe on WSDOT chip seals – not much different than then.
- Jim S – Great for me.
- Bill H – Thanks, great to hear comments, Shauna has been great to have attend.
- Willy S – Great to have the people in this room out on projects, Tim's interactions on projects is much appreciated.
- Ed S – Delighted to see this and follow-up would be great.
- Josh S – Great curriculum, all the right people.
- Chris J – Great to learn more about BSTs. Now feels a bit more comfortable with the upcoming BST work in 2007 in the Northwest Region.
- Tom D – BST needs more of a partnership, what works, what doesn't, need to work together.
- Newt J – Strongly recommend that you come back to this forum and revisit with projects as a learning experience.
- Shauna T – Would like to see another one, step two – guideline to look at what works, what doesn't. The condition of the roadway and where in the state is different to how things work differently…
- Jeff U – Specification changes will be coming to the attendees for review but no specific date is set for completion of the draft changes.
- Ralph R – Great representation, special thanks to industry.
- Willy S - Being able to stop something if a project is doomed for failure. There needs to be a stop button.
- Ralph R – There have been times that people would have pushed this button and asked questions rather than progressing with work.
- Bill H – In retrospect, there are times we need to reconsider what we are doing.
- Ralph R – Encourage people to talk to the Project Engineer in some instances. Field people to well but sometimes concerns need to be taken to a higher level
- Willy S – Temporary stripe for prelevel operations should also consider paint. If temporary markers are put down too early, they are gone before the chip seal is placed.

Meeting attendees for Sept 6, 2006 followed by the meeting for Feb 26, 2007

		Attendee	Organization	Email/Telephone
1.	JM	Joe Mahoney	University of Washington	jmahoney@u.washington.edu 206-685-1760
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12	Ralph Robertson	WSDOT—Eastern Region	robertr@wsdot.wa.gov 509-324-6021

APPENDIX C—BST MEETING 3

BST Fact Finding Meeting 3 – Summary of Discussions
Conference Room, NCR Area 1 Maintenance Facility
2900 Euclid Ave., Wenatchee, WA
April 28, 2009

Introduction

This third BST Fact Finding Workshop was used to obtain facts and opinions from a variety of persons that design, build, and/or maintain BST surfaces. The topics discussed and a summary of the responses from the attendees follow. For a list of the attendees see the last page of this document.

A total of 17 persons attended the BST Fact Finding Workshop on September 6, 2006, 12 on February 26, 2007, and 16 on April 28, 2009. The third meeting focused mostly on BST specifications and WSDOT's 2008 Standard Specifications. A number of changes to BST specifications were made between 2006 and 2008 and the primary purpose of this meeting was to discuss how those changes are performing and discuss improvements.

Summary of Topic Discussions

1. Initial topics

- Joe began the meeting with a PowerPoint presentation summarizing the previous two meetings.
- Package BST contracts together into a larger contract? East side – yes; SW and Olympic Regions still doing separate contracts.
- Maximum surface temperature of 140°F: Both E and NC Regions dropped to 130°F.
- Apply aggregate as quickly as possible: In the spec book, it states this must be done within 1 minute. Shauna would like to see this wording changed. Joe thinks it is fine as is.
- Percent passing the No.200 should be no more than 1%. Jeff said the historical average is about 0.9% % (the specification value is 1.5% because of statistical acceptance). Bottom line: The specification requirement for No.200 is adequate.
- Start and end dates – was May 15 to Aug 15: changed to May 1 (and August 1 by E and NC Regions). Eastern Region requires BST to be completed by Aug 15.
- North Central Region is placing 3/8" HMA in intersections, if they do a chip seal, they don't have ADA issue to deal with, so will sometimes skip HMA in the cities.

2. Materials

2.1 Binder

- Shauna: 5-02.1(1) needs an update to the language – get away from using prime and tack coat (instead single and double shot).
- Shauna: Wants to add other types of chip seals, i.e. microsurfacings, slurry seal, cape seal (which Pierce County is using), hot applied chip seals – especially for cities and counties using WSDOT Standard Specifications.

- Shauna: 5-04 language needs to be cleaned up.
  - Demulsibility: Specification states 30 days, but WSDOT does within 14 days.
  - Coating test: Take out (don't have job aggregate to run test).
  - Solubility, trichlor – eliminate trichlor
  - CRS-2P: Add elastic recovery to distillation residue (has been approved by Pacific Coast User's Group). One of three tests needs to be run to determine polymer.
- Joe: Can you tell us the cost difference between a cape seal vs. a single chip seal and a fog?
- Shauna: A cape seal is more expensive, but you need 2 flaggers on a fog seal and not on a slurry, so you'd have to work through the numbers.
- Shauna: Slurry seals could be used for parking lots.
- Kim: We can look at putting some of this into the LAG (Local Agency Guidelines) Manual.
- Jim: Maybe we could do GSP's too.
- Shauna: Good, but some need to be put into specifications. What does WSDOT maintenance do, what do they follow? Good question…no one had an answer.
- Shauna: If we don't test it, then why are we specifying it?
- Shauna: In SS 9-02.1 the distillation paragraph needs to be updated (AASHTO M320 takes care of it).
- Tom: Revision to CSS-1…<u>shall</u> be diluted at a rate of one to one… this needs to be changed to <u>may</u> be diluted up to 50%.
- Shauna: The more water, the longer it will take to break. Maybe eventually, WSDOT can change to undiluted for everything.

2.2 Aggregate gradations (including choke stone)

- Joe: 3 gradations for seals, 1 for new – do we need all these gradations?
- Dave: 3/8"-#10 spec just doesn't work, need to reduce the flat and elongated particles and get more one size aggregate.
- Dave: 3/8"-#4 gets the one size aggregate, but need to get rid of the #8 sieve and change the #4 to 0-4%.
- Tom: He uses 3/8"-#10 but has 0-15 on the #4 (Pierce County) – but need new name if we keep it.
- Jerry: He noted that using 3/8"-#10 – has performed well in some places, not so well on others.
- Dave: We use way less than the 35% max spec for #4 – but this keeps the production low and the cost high.
- Tom: There's a problem with the ½" mix – doesn't say how much on the 3/8", so don't have any large aggregate.
- Tim: The Olympic Region likes the old ½"-#4 spec.
- Dave: Recommends the following ½ "-#4 specification

Sieve	Percent Passing
½"	80-95
3/8"	20-50
1/4	No spec requirement
No.4	0-3
No.10	No spec requirement
No.200	0-1.5

- Dave: Recommends the following 3/8”-#10 specification

Sieve	Percent Passing
3/8”	90-100
1/4”	No spec requirement
No.4	0-20
No.8	0-10 or 0-5
No.10	No spec requirement
No.200	0-1.5

- Scott: Recommends the following 3/8”-#4 specification

Sieve	Percent Passing
½”	100
3/8”	70-90
1/4	No spec requirement
No.4	0-4
No.8	No spec requirement
No.200	0-1.5

- Tom: 3/8”-#10 needs a change to 90-100 on 3/8” sieve (same as Dave’s recommendation), 0-17 on #4 sieve (need for city work).
- Dave: pg 9-16 9-03.4(2) point of acceptance should be at one point, in stockpile (original) or off belt – Tom agreed.
- Jim: The Construction Manual should have instructions for sampling – should be fixed at one point, will check.
- Tom: Choke stone in the 2008 spec book is hard to make (needs to be washed, but then it won’t come out of the chip spreader).
- Dave: Has no problem making the choke.
- Tom: The ability to use concrete sand would be great (WSDOT Class 2 concrete sand).
- Jeff: When previously considering changes to the SS on choke gradation, found that the Class 2 concrete sand was more restrictive – could we keep choke spec same but allow use of Class 2 concrete sand?
- Tom: Tom replied to Jeff’s question with a yes.
- Kevin: The ER is using Class 2 concrete sand already.
- Jeff: Should chip with choke be the standard?
- Kevin/Scott: Wouldn’t use choke on 3/8”-#4 unless at intersections, curves, etc.
- Jerry: Use choke stone with the ½” rock.
- Jeff: Need to make chip w/ choke standard (back from the Dec 08 revision) because some regions need to have the guidance.

2.3 Quality Control

- Dave: Where an aggregate sample is taken (see above discussion) is an issue.
- Shauna: May take sample correctly, but transport needs to be specified – in small sizes, emulsions are more sensitive. SEM Group (Steve V.) has a presentation with suggestions.

- Shauna: Make sure to get a representative sample (w/ the new distributors and self-flushing bars, we need to make sure that the material isn't contaminated).
- Kevin to Shauna: Can we get a cheat sheet for inspectors on sampling and transport?

3. Construction Processes

3.1 Fog Seal

- Scott: Eastern Region requires 3 to 14 days as per the standard specs for fog sealing after BST.
- Tim: Olympic Region fog seals after BST.
- Tim: North Central Region does not fog seal after BST, SC does the same as the Eastern Region.

3.2 Choke Stone Practices

- Tim: Just do it, NC Region chokes ½"-#4, does not choke 3/8"-#10 (does not fog either).
- Kevin: Eastern Region chokes ½"-#4, does not choke 3/8"- #4 except for lighter traffic intersections or grades, and fogs both. Eastern Region found that they aren't losing chips, they were just rolling and being covered with asphalt.
- Terry: Olympic Region chokes and fogs ½"-#4.
- Tim: SW Region chokes and sometimes fogs ½"-#4; SW Region only uses ½"-#4.
- Dave: City used 3/8"-#4 with no choke but fogged, the county used 3/8"-#10 adjacent to the 3/8"-#4 and performance with 3/8"-#10 has been poor.

3.3 Pay Items

- Tom: Discourage pay by SY – contractor will always seek the minimum, by the ton, need scales and don't have them in remote locations.
- Tom/Terry: Like by the cu yd (Dave too).
- Tim: Pay by SY for rock, by the ton for asphalt (delivered).
- Jerry: Pay by SY to control quality. If you have a constant width, then the SY for the rock is okay.
- Rumble strips: BST over them if existing in HMA.
- Jeff: Can probably do this 2 times, maybe 3.
- Recessed pavement markers: have to remove first, grinding after the BST clogs up the grinder – what do we do?
- Kirk: there's a new rumble strip – shallow depth.

3.4 Prelevel

- Jeff: Pavement policy says 70 tons/ln-mile, if you need more, put it in rehab report to get buy-off early.
- Kevin: Will look at it in the scoping phase.
- Terry: Prelevel quantities of 70 tons/ln-mile should be ok.
- Jerry: 70 is low for them, but are trying to get roads up to standards over 3-4 cycles.
- Eastern Region: Using about ½ of the 70 tons/ln-mile for shape issues, not rutting.
- Kirk: 70 fits what they've been doing with the HMA intersections and over the average of the entire seal (all routes).
- Jerry: Used to do 7 year BST cycles, now performance based (anywhere from 3-8 years).
- Eastern Region: Uses a 6 year cycle.
- Olympic Region: Uses a 5-6 year cycle.

- Terry: Olympic Region requires 2 days minimum before presealing prelevel for BST, no fog sealing after BST.
- Scott: Eastern Region requires presealing prelevel but no specific time limit.
- Tim: NCR preseals after 3 days.

3.5 Crack Sealing

- Tim: Have seen a benefit to doing crack sealing prior to chip seal
  - Crack Seal – use rubber filler
  - Crack fill – use sand slurry
- Tim: Paying by lineal foot rather than force account is a better approach. Crack sealing on contract okay (don't have to do it the year before like HMA).

3.6 Quality Control

- Tim: Training for inspectors going well – delivering just-in-time training.
- Kirk: State inspector and contractor need to be on the same page prior to start.

3.7 Regional Special Provisions

- Change top binder temperature to 130°F.
- NC Region using flat and elongated particle requirement.
- Prelevel and seal before BST, but don't seal right away
- What are the correct times to seal?
- Need to wait "awhile" – 2-7 days or more? What is the right amount of time?
- Jeff: Will take a look at the other regions.

4. Performance

4.1 HMA at intersections

- Jerry/Kirk: The NC Region is happy with using 3/8" HMA, mainly at truck turning movement locations:
  - There are issues with using thin lifts of 3/8" HMA and can see why they don't use thinner lifts for mainline paving projects.
  - Using commercial mix for prelevel and at intersections (which is the wearing course).
  - The commercial mix comes from different plants because of the region wide chip seal program.
- Kevin: Higher volume (e.g. where SR 20 & 31 meet), using HMA. At an intersection at a county road, just choke the seal.
- Terry: Pavement repair and prelevel, haven't gone through cities yet.

4.2 Optimal timing for a BST

- Joe: HMA then BST to prevent distress or prolong life?
- Tim: BST after 3-4 years to prevent distress.
- Kevin: Same year as placement of HMA up to 2 years afterward to prevent raveling.
- Jerry: Can we use the PMS for distress prediction to determine when to BST on HMA? Another good question.

4.3 Corridor approaches

- Jeff: Look at putting corridors together.

- Jeff: In the future, there will probably be increasing funds in the P1 program for BSTs.

4.4 Regional views on performance

- Regions typically on place BSTs on set cycles.
- Jerry: SR 20 used to do every 7 years, but maintenance is putting a lot of $ into it, so now down to about 5 years based on visual inspection by maintenance and mats lab personnel.
- Jerry: PMS is valuable, but data lags behind especially for BST with a life of 3-8 years.

5. Chip Seal Design

- Tim: It would be good to go from an empirical to a 'design' method for BSTs.
  - Kirby method
  - McCloud method
  - 3/8"-#10 meeting our spec, but knew it wasn't going to work on the road (dirty and F&E issues).
  - F&E spec: NC and Eastern Regions both put into spec (but a little different), but found that these early F&E specs need modification or elimination. Additional work is needed on this issue.
- Kirk: Headed down this road and thought they were okay, but need to take a step back because they got some of the 3/8"-#10 that they didn't like – don't know if it was an isolated case or not.
- Kevin: Wanted to prevent flushing, have pits that tend to produce F&E, found that the spec was a bit too restrictive.

6. Recommended Changes for the 2010 Standard Specifications

- Kurt: Get minutes, make changes to binder testing.
- Jim: Point of acceptance for aggregates needs review.
- Jerry: Aggregate gradations, need to re-review.
- Terry: Ditto.

Final Notes:

1. Do we want to meet again? Consensus was yes, no more than 2 years from now, but many said meet again in one year after another construction season.
2. Joe had asked if anyone was using ¾" HMA – there wasn't much of a response, but Jerry did say that they will be placing a chip seal over a ¾" HMA on I-90 because of worries about permeability. They are hoping to get an additional 3-5 years from that HMA.
3. Kevin said that they placed a two lift chip seal over a severely flushed roadway (SR 20). It looks like it may have helped, but after this summer, we should know more. The first shot was a 3/8"-#4 with a light binder shot, the second was a 3/8"-#4 with a heavier shot rate (had about 50-70% embedment), then they choked it. This type of application appears to be an inexpensive fix for flushing. Also, it seemed that there was no problem with the 2 layers of the same size rock.

Attendees on April 28, 2009

	Invited	Organization	Email/Telephone
1	Joe Mahoney	University of Washington	jmahoney@u.washington.edu 206-685-1760
2	Kim Willoughby	WSDOT—Research Office	willouk@wsdot.wa.gov 360-705-7978
3	Jerry Roseburg	WSDOT—North Central Region	rosebuj@wsdot.wa.gov 509-667-3035
4	Jeff Uhlmeyer	WSDOT—Mat Lab Tumwater	uhlmeyj@wsdot.wa.gov 360-709-5485
5	Jim Spaid	WSDOT—Construction HQ	spaidj@wsdot.wa.gov 360-705-7824
6	Tim Moomaw	WSDOT—North Central Region	moomawd@wsdot.wa.gov 509-667-3032
7	Shauna Teclemariam	US Oil (Tacoma)	smt@usor.com 253-680-2495
8	Tom Doolittle	Doolittle Construction	doocons@aol.com 425-455-1150
9	Dave Schofield	Central Washington Asphalt	daves@cwainc.us 509-750-6134
10	Joe Devol	WSDOT—Mat Lab Tumwater	devolj@wsdot.wa.gov 360-709-5421
11	Kevin Littleton	WSDOT—Eastern Region	littlek@wsdot.wa.gov 509-324-6170
12	Terry Macualey	WSDOT—Olympic Region	macualt@wsdot.wa.gov 360-704-3279
13	Kirk Berg	WSDOT—North Central Region	bergk@wsdot.wa.gov 509-577-3030
14	Kurt Williams	WSDOT—Mat Lab Tumwater	willikr@wsdot.wa.gov 360-709-5410
15	Scott Dunham	WSDOT—Eastern Region	WSDOT—Mat Lab Tumwater 509-324-6176
16	Indridi Einarsson	University of Washington	Indridi@u.washington.edu

APPENDIX D—BST MEETING 4

BST Fact Finding Meeting 4 – Summary of Discussions
The Renewable Energy Center at Wild Horse
25901 Vantage Highway, Ellensburg, WA
July 13, 2010

Introduction

This is the fourth meeting to discuss BST usage criteria, specifications, and related issues. The major goal is to review recent past specification changes and what has worked and what has not.

The topics discussed and a summary of the responses from the attendees follow. A list of the attendees is attached and follows the discussion summary.

Summary of Topic Discussions

Initial topics

1. **Introduction**
   - Joe began the meeting with a PowerPoint presentation which summarized the previous three meetings and Standard Specifications (SS) changes that have been influenced by these discussions.
   - Attached is a comparison of FHWA and WSDOT SS for seal coats.

2. **Matrix of practices**
   - Four of six Regions responded. The summary was distributed at the meeting and is included as an attachment to these minutes.

3. **Chip seal design**
   - Summary of the McLeod method estimates for binder and aggregate application rates were prepared and distributed for WSDOT SS gradations.

4. **Eastern Region BST cycle times (Kevin Littleton)**
   - Kevin provided a handout to the attendees on a process ER has developed to estimate seal coat life.
   - In effect, ER chip seals last 4 to 8 years with 6 years being the normal cycle. Higher ADT is risky so subtract a year or two. Rain Factor north and south of SR 2 is a factor. SR 2 has a 4 year cycle and is the only road with such short cycle.
   - Kevin: Typical seal coat lives are 8 years south of SR 2 with low traffic. A side concern in using the formula results in year to year lane miles needs—which presents a challenge from a programming view.
   - Steve: Does Kevin think that the northern portion of the ER is alright with embedment?
   - Kevin: Embedment not an issue in that portion of the ER.

- Steve: Is rock in the northern portion of the ER of adequate quality? Is that the issue? Length of life of that seal depends on traffic. Softer rock may be why ER has not had much success in that area.
- Dave: Flatter rock causes flushing.
- Kevin: Plans to choke the seals in the northern portion of the ER.
- Dave: Reason for end of life the same because of surface loss, cracking, flushing. Are there certain criteria that you are noticing more than other
- Dave: Nicer weather, less traffic in South?
- Steve: How many tires run over that road? Are they studded? Wore through in 2 years with high stud count in Yakima, 3/8 aggregate. It's the traffic that counts with 50% studded tires through the winter. What can you do to compensate for traffic? Double seal?
- Dave: Have you considered larger rock?
- Kevin: Really like 3/8 one sized rock, get a better price, and don't believe we will see better quality with ½."
- Steve: Might think about more double seals.
- Joe M: When applying double seals, how much on first shot?
- Kevin: 0.2 gal/SY on test section and 20 lbs/SY aggregate. Both shots used 3/8 – No.4 aggregate.
- Joe M: Second shot rates were?
- Kevin: 0.35-0.40 gal/SY and 40-45 lbs for second shot. First shot may go down to 0.15 gal/SY and 18 lbs.
- Steve: Sandwich seal prevents flushing. European locations use sandwich.
- Steve: Watching for two years now, which combinations gave best success rate?
- Kevin: Will e-mail report of SR 20 test sections [Kevin sent the report to the meeting attendees the following day.]
- Tom: Just shot the wheelpath with 0.35 gal/SY with ½" rock. Cooler and larger rock higher shot rate. Next day full width 0.45 gal/SY shot. Good results using this process for Thurston County. Should get report from County engineer.
- Kevin: Since the double seal is an experimental feature it be documented and reported. Job to be complete next week. Application is when flushing exists.

5. Jeff Uhlmeyer presentation on BST costs

- Jeff: Provided handouts which overviewed the costs of WSDOT BSTs. These attachments were scanned into these minutes.
- The summary shows seal coat costs for 2006 through 2010 by Region. Over time, seal coat costs are creeping up. WSDOT plans to increase the seal coat lane-miles substantially; however, over the last 5 years the annual lane-mile totals for WSDOT are.

2006	2007	2008	2009	2010
924 ln-mi	648 ln-mi	665 ln-mi	888 ln-mi	665 ln-mi

- All costs calculated for the handout include engineering, contingency and taxes but not safety items. On the second sheet, we can see range of CRS-2P binder costs on a per ton basis.
- Costs were calculated by adding shoulder and converting to equivalent lane miles. Used bid item total and divided by lane-miles.

- Pat: HMA is $250,000/rural lane mile and $350,000/lane mile for urban.
- Jeff: Seal coats provide a significant cost savings based on life cycle costing.

6. Planning and Budgeting Process (discussion led by Pat Morin)

- Bottom line is all we have is fed funds by 2017. Revenue dropping $50-60 million every year of gas tax. What will it look like?
- Cost side. In 2005, we hit 60% inflation over five years. Expected was only 20%. Cost was much higher to build roads. How do we preserve the assets we own and improve safety. Goal: Drop 10% a year for safety of roadways. There were 335 deaths 1995, estimating 205 this year. Trying to improve safety and control congestion.
- Top program is Preservation program which includes.
    - Roadway
    - Structures
    - Other facilities
    - Program support
- We keep bridges until it is cost effective to the rebuild. Goal is to keep I-90, I-5 operational during a 9.0 earthquake
- In safety program, WSDOT loaded every traffic collision on GIS platform and used spatial analysis to find problem areas. Also look at trends.
- Trends: Cable barriers are 95% effective at preventing head on collisions.
- Intersections
- Two major projects that need to look at.
- Roadway Preservation: Plan 7 years for a chip seal. Paving every 14.7 years for HMA.
    - Need $500 million
    - Have $240 million
- Huge challenges just to maintain and operate this system. Making sure we are cost effective at what we do. Most life for least cost.
- Bob Glenn: Write a letter to our Legislatures.
- Pat: Concrete: As PCC approaches 30 years, we get panel faulting. Eventually will crack quickly. Replacing PCC runs $2.5 million a lane mile. But we can get 20 years more out of them for $700,000 dollars per lane mile.
- Pat: Rumble strips are low cost for the safety gained.
- Bryan: Do you see us within the next year bumping up ADT to maybe 10,000 for application of BSTs? Right now it is 5,000.
- Pat: He leaves that up to this group. If we can get adequate performance for less money, better for all of us.
- Dave: 50% lane miles increase by just increasing to 5000 ADT.
- Bob: What about quiet pavements?
- Joe M: Don't like them since they deteriorate rapidly due to studded tires and buses with chains.
- Jeff: WSDOT performance data for quiet pavements shows poor performance in Washington.
- Joe M: WSDOT pulled out all stops on quiet pavements and studs and chains are the culprits. As long as we don't get rid of those, quiet pavements don't work on the WSDOT route system's higher traffic areas.
- Jeff: He has received phone calls from people saying how they enjoy quiet pavements, and haven't been paved yet.

7. Other early comments

- P200 passing WSDOT seal coat aggregate about 0.9% on average. WSDOT SS set at 1.5% maximum. Most agencies suggest 1.0% max but 1.5% works for WSDOT. Thus, not an issue at this time.
- Binder: Update "Languages" Do not use Prime and Tack coat.
- We currently do not have SS sections on slurry seals, cape seals, or microsurfacing. Should we do something about it?
- Tom: Didn't like opening up on 90-100 "3/8 to No. 10."
- NCR used Class 2 concrete sand, SWR asked about it.
- Tim: Concrete Class 2 has less fugitive dust which is a good feature.
- Bill: Prefers it because of less fugitive dust
- Class 1 concrete sand—maybe that should be examined as choke stone.
- Scott: cleaner but coarser
- Kevin: Best to choke the seal coat and fog because of snow plows. He believes it helps to reduce plow damage.
- Steve: Increased cost?
- Kevin: Roughly $500/lane-mile. An inexpensive treatment which helps save the chip seals.

<u>Materials</u>

1. Binders

- Shauna: Product specification in 9.02 table. Is there a test required and different limits. As a supplier they say they will meet all tests. I want to know how many people run that test. Never have job aggregate for testing. Also the 1950's wording which is asphalt can't ever reach flash point, but in reality it does. Section 5: don't like 14 days to get sample in. That's fine, but does it say you can't freeze it or go over a certain temperature? These things need to be addressed. For CRS-2P don't need same cure time. Temperature and weather should be considered, not "3 to 14 days" Set a meeting to discuss these.
- Joe D: Have set up an emulsion task group. Working on regional level (CA, OR, WA, HI,) on new tests and we want performance, rather than keep the test because it's been in existence for so long. Question is if we have failing rate of 1% do we test it all the time?
- Shauna: Want uniform tests that you can get product from anywhere and know it will perform.
- Shauna: Dealing with FHWA, WA, OR, CA, NV, HI, AK. Take PG grading and flop into emulsion SS. As a group, studied and found it doesn't make sense. Nobody is tying it to performance though. Should we use a faster more accurate test (DSR) on binder? Where do you spec it? What temperature do you use? Would like to see a smaller task group to look at just Washington.
- Joe D: Short term would like to set up meeting to kick start this sort of discussion. Ready to sit down and discuss, just a matter of getting together outside of this group.
- Joe M: To broader group, it is good to know these types of discussions are taking place. Steve, input?
- Steve: He does think WSDOT is doing good job on making changes, but would like to see them standardized and documented.
- Shauna: Should it be in the WSDOT SS or as guidelines?

- Joe D: Fog seal task group emphasis was that last year we saw products fail. Why do we have failures? Fail in viscosity, taking steps to change requirements. Sample a couple tack coat projects to see what product looks like and discuss what needs to be done to test fog coat. Hard to get sampling due to lots of variable. End product should be sampled before hits the road.
- Bill: When doing all submittals and requirements, contractor may not have enough time to complete project. Cure periods are too long, how necessary is it? As far as constructability-are they all really necessary?
- Shauna: Other ways to evaluate to say "it's ready to go." CRS-1 takes longer to cure, CRS-2P faster cure, no one says temperature and weather any more.
- Joe M: Sounds like we need to look at chemistry. If you change from fixed range of days to chemistry like weather, it may be out of range.
- Jim S: BSTs are the least of their worries.
- Tim: Prelevel one season, chip seal following season works well.
- Joe M: Don't we do that sometimes or are we so compressed?
- Tim: State program used to do it one year before.
- Pat: WSDOT Maintenance cannot spend more than $60,000 per activity.
- Steve: Cure before we chip. Is it really curing? Or is it filling the voids? Worked with smaller agencies we just fill voids and it works. Are we curing or just filling voids? If you can find an artificial void filler then don't need to cure.
- Joe M: In my opinion it is just filling voids.
- Steve: Every void is filled and we get no absorption of the seal coat emulsion.
- Tom: I agree the delay on fogging. If we fog right after we patch, it sucks it in. They want to do that because traffic control is already set up.
- Steve: We are talking 14 day cure, but we just want to fill voids.
- Steve: Kittitas County uses sand over fog seal.
- Kevin: One job we didn't fog seal the prelevel before applying the seal coat. Right after prelevel (SR 20), the oil soaked into the mat, didn't fill voids. Lost a lot of aggregate.
- Steve: You're not waiting to age the pavement; you're waiting to seal it.
- Joe M: Sand seems to get the job done to fill the voids.
- Joe M: Food for thought. Any other comments?
- Bill: Pay by diluted ton, not just undiluted binder for fog seal.
- Joe: What is the benefit?
- Bill: Less confusion, last year paid by diluted ton. Confusion by WSDOT on how to pay. Someone audited a month later and had to correct it. Saves a lot of confusion.
- Jerry: Do you need to dilute it?
- Shauna: Undiluted fog breaks much quicker, takes 2 hours to break with water, normally 20 minutes with undiluted. Less success with diluted than undiluted. Takes knowledge with handling diluted.
- Steve: Talking fog, there are new products that are rapid breaking fog materials. He is under the impression that at that low of shot rate will have a film thickness issue. If it works I'm sure that's a possibility. Generally, hotter faster break. Colder water will then increase time.
- Steve: State of Oregon requires inspection at supplier of oil. If contractor wants consistency, require pre-diluted at supplier facility. Probably depends on distance.
- Tim: Jerry and I completed field review. With diluted see less problems with shooting. Traffic doesn't like it but traffic doesn't throw it. The "h" isn't tacky.

- Tom: If fog shot is undiluted, the material won't get into pores.
- Bill: His rule-of-thumb on binder application rates are (1) 3/8" then start with 0.38 gal/SY, and (2) ½" then start with 0.5 gal/SY.

2. Aggregate gradations (including choke stone)

- Joe M: Lot of people happy with 3/8"– No. 4.
- Tim: Mountainous terrain yields soft rock. How do we prevent degradation?
- Dave S: Stipulate where you want to crush rock from. Prevent elongation. 3/8" to No. 10 everyone likes that. More cubical. Can't do same thing up North like can in Moses Lake. Unless go to larger product, can't go to cubical. Still in specs, but softer. Wants to break flatter and elongated with softer rock. It will sink into the binder. Not cost effective to haul better rock from further.
- Steve: Did WSDOT, in the past, use larger rock?
- Joe M: Over long span of time, rock has gotten smaller.
- Steve: What is the reasoning?
- Tim: The apparent reasoning is that larger stone requires more oil and hence is more expensive.
- Joe M: I don't think we see a difference in life based on rock size. The major issue is about getting through construction, and then you should have good seal performance.
  - Steve: I would be interested to know if we have studied this issue. From what I see, smaller rock wears through easier due to studded tires.
  - Brian: Larger rock results in a better structure and a longer time before digouts reflect through. I think the seal will last longer with larger rock.
  - Steve: Want a singular size, aesthetically looks nicer. Maybe try out larger chip sizes.
  - Joe M: Agree with Steve, best performance if obtained from shooting a single size rock. South Africans use 3/8" and larger sizes as well. Have seen South African seals which last 25 years (but aggregate was larger than 3/8).
  - Steve: We used to worry about larger rock, but techniques improved so could upsize chips and try it out and see if you get more life. Some high traffic wearing through fast still with larger rock. Attribute it partly to studs.
- Joe M: From Eastern Region perspective, how do you feel about max aggregate size?
  - Kevin: With big rocks, you get big gaps between them.
  - Brad: We have used that big stuff as a base and double shot did great.
  - Jerry: On low volume roads, wearing through chips isn't big concern. Issue becomes how much does it cost to crush rock. What's the cost savings?
  - Steve: Vast majority don't need it, but higher traffic roads need larger rocks.
  - Jerry: Don't see a lot of places where seals are wearing out.
  - Shauna: Possibly specific gravity or something related that would be a better idea to address what type of rock to use.
- Joe M: Do we like what we have with gradations?
  - Dave: For the 3/8 - No. 10 performance from contractors looking good.
  - Tim: Good quality east of Moses Lake on I-90. 3/8 – No. 10 looks good.
  - Bill: Traffic control, shut down 1 lane each direction on either side until it's completely broomed off the following night, then opened the next morning.
  - Jeff: Do other contractors wash aggregate?
  - Tom: Do what they want. I have to wash, know what I need.

- Joe M: Sounds like specs as written you are reasonably happy with current aggregate gradations.

3. Quality Control

- Dave: Thanks to WSDOT for sampling in a timely manner and working with contractors.
- Tim: Quality control of CRS-2P. Not all CRS-2P created equal. Would like tests that would accurately depict how it will act once hits the road. Possibly with polymers.
- Shauna: That is like saying oil is all created equal. Need to look at these things and say what's performance based? How can we get a performance based specification?
- Shauna: Use a little less aggregate and wouldn't have to sweep as much and that should be looked at.
- Kevin: Eastside experimented with paying by S.Y. and happy with results. One issue that may come up is too much oil.
- Bill: It would be helpful in the bidding stage at what rate to apply aggregate with smaller range. How to resolve if we put down 25 lbs/SY and you want 30 lbs/SY then how do we do that?
- Brad: If pay on a SY basis is good, then how do we resolve issues on application rates?
- Dave: Likes pay by the SY.
- Tom: Likes pay by the SY as well; we need to resolve payment and how much WSDOT wants to put down.
- Kevin: So far pay by the SY is working well.
- Joe M: McLeod method allows estimation of oil and aggregate application rates. Today we will focus on aggregate application rates.
- Tim: Has seen application rates of 32 to 21 lb/SY. Most application rates are falling within this range.
- Steve: Basic McLeod works for dryer climates. Oil Shot rates much higher for wetter climates.
- Pat: Development of performance tracking is ongoing.
- Joe M: There has been a lot of advice, knowledge, experience shared along with some national best practices. Colle Wycoff wrote a chip sealing guide for WSDOT a while back. Additionally there are various reports done in the 1980's on what was and wasn't going well. We will try and coalesce what's been said and what's relevant.
- Pat: We know where we are, can we each get better each construction season to demonstrate we are learning.
- Joe M: It appears that we can document improvements.
- Dave: Monitor overall performance that we need to improve. What metric do we use to monitor chip seal performance? Mean profile depth would be the best method. Over time, measure how that changes and that could be a good measurement. Right now we have roughness, hard to see cracks, measure rutting, but texture is really what we want to look at.
- Jeff: WSDOT does have a van to measure texture.
- Dave: How do we quantify what's "good" and what's not. Different ways to do it, but it's expensive. WE don't have history though, starting with a brand new number.
- Joe D: Once you get that number you can measure what those numbers mean against visually how it looks.
- Dave: We can use that number and compare to visually what we see for a basis.
- Steve: Most counties don't chip because the rock wore out and cracks come through. .

- Tim: Expand on cracks. 5-04.3(5)C addresses crack seal vs. crack filling (2010 SS). Should pay by lineal foot instead of force account. In spec book doesn't define well. For cracks larger than 0.25," fill with sand slurry, below 0.25" fill with tack.
- Bryan: The OR does not have thermal cracking like Tim in the NCR. Most cracks are about 0.25". That is working fine for us.
- Bryan: East vs West almost two states.
- Joe M: Do we need a better solution?
- Steve: Is a believer in large cracks filled with sand. If can't fill with sand, seal it. Probably 0.5" would be better to fill with sand; seal cracks less than 0.5" wide.
- Tim: Break it up by 0.25" so contractor knows what they're up against.
- Scott: 0.25" and below don't seal. If 0.25"-1", use rubberized crack fill.
- Tim: Not doing it. Bid it by sight unseen by lineal foot.
- Joe M: Below 0.25" chip seal take care of it. From >25" to 0.75", use rubberized crack sealing and above that (>0.75) fill with sand slurry.
- Tim: Do rubber crack filling most everywhere.
- Andrew: Always use force account, not by the lineal foot.
- Tim: Best not to use force account. We have had high expenses due to force account work.

<u>Construction Processes</u>

1. Weather Considerations

- Joe M: WSDOT changed surface temperature. Lowered it a bit and expanded the allowable paving start and end dates; in effect, WADOT added a month to paving season. Any comments?
- Steve: Likes early work thus allowing for the whole summer for traffic to beat in rock. Good weather after seal is what is best. May 1-Definitely. Do it in April if weather is good. By good "not raining every day." Critical to have good weather following BST application.
- Bill: May 1st good but weather is unpredictable, so contractor may not go for that date.
- Kasey: Window has to be big enough
- Joe M: So where we are is good and there is a consensus about weather limitations and the language in the SS.

2. Construction manual enhancements

- Jim: If we elect to change payment methods should go back and add that to construction manual.
- Bill: Should we take chip seals by the ton out?
- Joe: Current SS has one clause on tons and one on cubic yard basis.
- Bryan: Started out using CY basis but preferred by ton so allows both options.
- Joe: Would you be inclined to change Standard Specifications to SY?
- Jim: A few folks are concerned about going to SY; particularly since we are talking about saving an inspector. If we are talking about eliminating an inspector, that's not a good thing for us. Losing an inspector results in losing oversight on quality.
- Bill: How do you compute yield on chip calculation?
- Kevin: Not sure it boils down to what the rate is as long as you get coverage.
- Bryan: Are we considering aggregate by SY or aggregate and binder by the SY?
- Bill: Concern of how wide road is, what is measured?

- Jim: Nervous about cutting back on people and losing track of quality and our ability to report back to legislature on what we are getting from contractors.
- Bob: Contractors want quality as well. We are all doing same project.

Performance

1. **General**
   - Bill: Chip sealing on I-90 in Moses Lake area. Maybe should have looked at thin lift overlay since the difference in cost was about $800,000. Saved quite a bit with chip seal and it seems to be working for the 20 lane-mile job. Project was about $2.5 million.
   - Bill Preston: BST or pave it? 14 miles and the difference was a little over a $1 million. Chipped shoulder, prelevel main lanes, then chipped all.
   - Jeff: How are thin HMA lifts performing?
   - Dave: Performance depends on underlying structure.
   - Chris: Thin lifts will rip right up if underlying roadway in poor condition. Thin lifts need a good sound base.

2. Snow Plow Damage

- Kevin: Snow plow damage has been extensive. He is concerned that it something specific to ER BSTs? He asked maintenance about the use of new plows/blades? Nothing new, but maybe the issue is snow plow speed related. Adding choke to chip seals everywhere seems to be helping to reduce the damage. Test section appears to be working well. Same rock is being use 3/8" – No.4 which is then choked and fogged. This combination seems to be performing well. Can't remove any rock out without the use of pliers. SR 21 was not choked and it was ripped up in one year.
- Dave: Maybe graders are being used?
- Kevin: I would like to look at what the plows are doing.
- Jerry: Sometimes plows start at paint stripe at center and oil doesn't stick well to paint?

3. Rumble Strips

- Jeff: In what order should rumble strips be done? Do the rumble strip first? Then BST? Is that typical practice? How many BST cycles can you get through without having to do rumble strips again? How do you manage rumble strips with HMA overlays? Any difficulties? Starting to see increase in popularity since rumble strips have a proven safety record (comments provided by Pat on safety).
- Kevin: Ask about recessed pavement markers. How did you do I-90 pavement markers?
- Tim: We cut right through chip seal
- Jeff: Typically problems with rumble strips occur at overlapping joints. Centerline rumble strips deteriorate. East side jobs: 10:1 jobs that have problems and jobs that don't.
- Scott: Rumble strips at centerline causing problems for new HMA overlays. Next time around need to chip seal in between. Rumble strips then seal is the best way to go.
- Jeff: Cost benefit on rumble strips. $17,000 a lane mile.
- Pat: Noted that rumble strips are 45% effective at preventing head on collisions. Return still huge improvement on spending more to get higher safety.

4. Optimal Timing of BSTs

- Joe M: To maximize HMA overlay life, when should you put that BST down over HMA?

- Pat: Instead when talking about optimal timing, talk of lowest life cycle cost. There is an additional cost to give you maximum life but may not necessarily result in a lower cost.
- Kevin: Stated that you should wait no more than 2 years. There was broad agreement that application of the BST earlier than 3-4 years is best.

5. High Float Emulsion vs. CRS-2P

- Steve: Agree with Shauna; need clean rock in using high float emulsions.
- Shauna: More handling with high float. Request sample of aggregate if customer asks for high float emulsion binder. I would want to do a mix design when the customer is using high float.

6. More Comments on McLeod Design Method

- Steve: Firmly believes in using the McLeod method. A lot of roadways have flushed and often have excessive rock application rates. Uses McLeod method with Minnesota design of 70% embedment. Make adjustments for traffic count.
- Tom: Easier to determine 70% embedment with 3/8 - No. 4. Hard to determine with ½" to No. 4.
- Steve: Need good rock. Hard rock required for success.

WSDOT Regional Practices (4 of 6 regions responding)

Item or Data	North Central Region	Eastern Region	South Central Region	Olympic Region
Preferred BST gradations	3/8" – #4	3/8" – #4	3/8" – #4	½ - #4
Fog or choke practices	Fog on 3/8" - #4 starting in 2010 Choke ½" - #4	- Fog unless it is rich - Choke medium volume county I/S & high snow plow area	Fog on 3/8" - #4 starting in 2006 No choke	Choke #4 -0 Fog yes
Intersection paving—decisions for use of HMA	HMA @ high volume and truck routes	HMA @ high volume county I/S and SR I/S	HMA @ intersections with significant turning movements	HMA in cities with high turning movements anticipated
Prelevel (How much?)	~35 to 40 tons/lane-mi	Pave 0.10'	As needed for greater than 0.5" ruts.	Less than 50 tons /lane-mi typical
Fogging of prelevel? When?	Yes, open surface texture	Min. rut 3/8" as funding allows	--	Always fog new prelevel and digouts
No. of lane-miles per year of BSTs	180 to 250	130 to 160	120 to 230	145 for 2011-13 biennium
Max BST ADT level(s)	7,000 2-way 5,000 – 6,000 directional	-BST routes generally less than 2,000. -HMA conversions up to 7,000	One section @ 6,200. Most under 4,000	Less than 5,000 ADT
Packaged vs individual contracts	Package	Package	Package	Both
When to place BST over HMA?	~ 2 years before due year – Present practice in NCR	As soon as funding allows	When HMA shows early signs of distress. 8 years is typical.	Based on field review of condition thus no regular cycle.
Typical BST cycle time (time between BSTs)	7 years or sooner if needed	In transition. Past practices were 6 yr cycle. Looking to extend some up to 8.	Average 10 year cycle.	Varies but typically at least 6 years
Binder types used for BSTs	CRS-2P	CRS-2P	CRS-2P	CRS-2P & RSLTP
Traffic control practices	Mobile variable speed zones and pilot car	Pilot car	Pilot cars (2 cars on high volume roads).	Varies
Use of double seals to control bleeding	None to date	Yes	No	None

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APPENDIX E—BST MEETING 5

BST Fact Finding Meeting 5 – Summary of Discussions
The Renewable Energy Center at Wild Horse
25901 Vantage Highway, Ellensburg, WA
September 26, 2011

Introduction

This was the fifth meeting which was used to discuss chip seals. The meeting started with presentations/comments by Joe Mahoney, Jeff Uhlmeyer, Matt Neeley, Dave Luhr, and Tim Moomaw. Those presentations will be summarized first.

Joe Mahoney

- WSDOT specification changes have taken place since these meetings have occurred.
- Preservation funding will be discussed.
- Idaho DOT representatives will talk about their chip seal practices.
- Binder issues will be included.
- Regional personnel will note their chip seal practices.
- WSDOT lane-miles by ADT: the number of lane-miles of chip seals is increasing, up to 4710 lane-miles in 2010.
- How to make a HMA last longer including discussion of top-down cracking.
  - UK TRL research has shown that the HMA binder is 100 to 500 times more viscous in the upper 2-3 mm of the wearing course.
  - A chip seal applied soon after construction to a HMA layer reduces the binder aging by a factor of 50.
- WSDOT dominant chip seal rock is ½"-No. 4 and 3/8"-No. 4, will also use choke stone (No.4-0)

Jeff Uhlmeyer – Overview

- Recent chip seal specification revisions started in 2006.
- Met again in April 2009 to find out how the specs were working.
- In July 2010, talked about the details of constructing chip seals.
- September 2011, regional representation to find out what everyone is doing and how it's working
- Most WSDOT roadways are structurally sound, but require preservation the wearing surface.
  - When is a roadway too far gone that BST won't help anymore?
  - When should a BST be placed?
  - Application of early seals to preserve roadways.
  - Continued conversion of HMA to BST lane-miles.
  - Better understanding of the BST life – what is the proper frequency?
- Potential use of hot chip seal applications. Recent observations include:
  - Some cities and counties in Washington use hot chip seals. Appear to performance well.
  - Laydown takes about 15 minutes from the time of binder shot to finish brooming.

- Asphalt binder shot at 350°F.
- Chips are 3/8”- No. 6, precoated, and clean (low P200).
- Do not want complete coverage on the chips or they will stick together.
- Shot rate was 0.40 to 0.42 gal/SY.
- Rolling of the chips into the binder is required (similar to shots with asphalt emulsions).
- Minimum surface temperature required for hot chip seals is 70°F and rising
- No presealing of pavement prior to chip seal.
- Less than 1 minute from chips to rolling. Target surface temperature for rolling is 160°F.
- Project on US 58 in Oregon was 16 lane miles with no complaints on rock loss (ADT = 5,000). Very minimal rock loss.

Matt Neeley – WSDOT Preservation Funding

- BST funding in P1 program: 11-13 has about $183 million for just BST.
- Cost per lane mile for WSDOT personnel constructed chip seals: about $25,000 per lane mile (12 feet wide).

Dave Luhr – Preservation Funding

- HMA lasts about 13.5 years (statewide average), BSTs last about half as long.
    - About $20,000 per lane mile per year for HMA (includes roads with higher ADT, may require more traffic control, etc.).
    - About $8,000 per lane mile per year for BST.
    - These costs are all-inclusive.
- Savings from converting HMA to BST: at 5,000 ADT, saving about $27M; at 10,000 ADT, saving about $52M; at 15,000 ADT, saving $62M.
- Assumes 70% of the lane miles under ADT of 5,000 can be converted from HMA.
- In 2009, we paved about 600 miles each of BST and HMA, after that, we are paving considerably more BST miles than HMA.
- We expect to convert more lane miles from HMA to BST: in 2011, about 400 lane miles, in 2015, over 1500 lane miles and out to year 2025, we will be converting about 2300 lane miles to BST if this funding scenario continues.

Kevin Littleton – Eastern Region Chip Seal Program and comments by attendees

- Three chip seal programs: BSTs on BSTs, HMA conversions; etc. Total of about 300 miles.
- Use 3/8”- No. 4, with choke and fog seal – this is a relatively new process for the ER.
    - Better performance with the snow plows.
- New process: pay by the square yard. Works well as long as they are accurate.
- Choke stone: $500 per lane mile to fill in the gaps, choke the shoulders too.
- Problems/issues/suggestions
    - Crack seal prior to BST (pre-seal) – only sealing cracks greater than ¼”, rely on chip seal to fill smaller cracks.
    - Preseal on some roadways are become excessively tacky and cars are tracking the material.
    - Should we preseal or crack seal first? Columbia says clean cracks, preseal then crack seal.
    - Why are we presealing? Newt: if not open texture, not worth presealing.

- Brett: like to preseal on roadways that are applying pavement repairs.
- Having a bond issue associated with crack sealing – cracks weren't being properly prepped.
- Seal agent (Andy – ODOT) over crack sealing? No.
- Overbanding for crack sealing prior to BST is not a good thing to do – chips are "buried" into the crack seal material.
- Need to use paper at beginning of chip seal binder shots – if not, the binder typically tracks down the roadway, looks very ugly, and won't go away until the next time they chip seal.
- BST conversions (from HMA) are where they had all the construction issues this past year.
- Rolled a lot of rock (turned over the rock due to traffic) – placed a chip seal right at harvest time with heavy trucks. For heavy haul routes, chip seal timing needs to be considered…or avoided.
- Seeing a lot of flushing on the heavy haul routes.
- Shauna: There are a lot of states that are chip sealing up to 20,000 ADT and don't have these issues; can share the best practices and design.
  - Suggest high float for this type of application (Albina).
- Slow moving trucks and harvest time are wreaking havoc on HMA conversions.
- Kevin thinks that for the flushing issue, just keeping traffic off as long as possible will help to allow curing.
- Tom D: Using pilot cars for 5 miles may control traffic better.
- Andy: Keeping construction trucks off and let the seal set up helps.
- Tried to put a chip seal in an intersection to save money: saw nothing but flushing (Springdale).
- SR 20 Tiger junction – bleeding in both directions uphill and downhill
  - All curves failed.
  - Found out that the torsional recovery (presence of polymer) failed (only got half of the minimum spec).
- Shauna: Closer to the CRS-2 than the CRS-2P (will see the rocks moving a lot more).
- Mike: Is there any way to find out if the binder is going to fail prior to placing or a better way to accept it?
  - Albina – ring and ball softening point.
  - Shauna – other states require a certification of compliance, the bill of lading that we have in WSDOT just has a signature, but WSDOT can ask for the data prior to placement.
  - Shauna – US Oil does not do torsional recovery but does toughness and tenacity. Pushing for elastic recovery and feels like it is more indicative of a failure. If we made US Oil do torsional recovery, they would walk away.
  - Chad (Idaho) – test for torsional recovery at HQ
- At corners and hills, increase binder application rate and hold traffic off.
- Newt: fan of checking embedment rate, time is an issue (give it some time to cure).
- Dave E. hot seals? Andy – hot seal decrease oil shot rate on hills but will still see it shine up
- Jeff: on grades – HQ is listening to the regions and if you can make your case, they will listen.
- Shauna: did a 30% grade – will talk about this later. Having the correct design and construction controls and it can work.

Tim Moomaw – NC Region

- Hills, curves and intersections are rough on a chip seal…we are building our own rumble strips into our chip seals (washboarding) by letting traffic on it too soon and other construction related issues
- McLeod method: chip seal design and a bit more
  - Inputs: aggregate gradation, flakiness index, bulk specific gravity and absorption, voids in loose aggregate, residual asphalt, traffic volumes, and pavement condition
  - Minnesota DOT using a modified McLeod method – we will probably need to follow suit.
  - Need to have the aggregate prior to design to do the McLeod method
  - We have the pavement condition and the traffic, but need to look at the change in pavement condition since we are designing a few years out.
  - McLeod method uses the ALD (average least dimension) – this is better now that we are using 3/8”- No. 4 gradation
  - Flakiness in the McLeod method
  - WSDOT needs to get more rolling after chips are spread
  - Aggregate loss – Tim took pictures in August, got calls in February about significant rock loss
  - Oil still sticky even in February.
  - Adequate embedment necessary.
  - All CRS-2P are not created equal.
  - WSDOT doesn’t tell suppliers what type of polymer to use, just a spec to meet.
  - Are we specifying correctly?
  - We may have too much aggregate…
  - Moses Lake – 25% embedment after the failure (City of Moses Lake spec’d binder and aggregate by the square yard)
- Lessons learned
  - Use less cover stone.
  - Get 80% embedment.
  - Roll, roll, and roll some more (Newt: Spec 75% embedment, came from paper in 1936).
  - Use choke stone to fill voids.
  - Fog seal when needed.
  - Albina: fog before or after choke? Fog after choke.
  - For the choke: needs to be clean aggregate (our spec allows up to 10% - may be too dirty).
  - Fog shot rates are 0.12-0.14 gal/SY.
  - Albina: Heavier fog seal to get embedment. Tim: can cause problems with traffic.
  - Fog seal – Diluted or not? Albina – when diluted, easier to control shot rate and the water breaks the tension on the rock to allow the CSS-1 to flow down and help with embedment.
  - Shauna: Key is to know how much binder you have.
  - Tom: Add hot water to the emulsion to dilute.
  - Newt: Never shoot a fog unless it is diluted.
  - Steve D: Not testing fog seal, but are testing tack coat.
  - Bill H: Fog seal should always be diluted AND should be diluted at the supplier. If DOT not willing to pay for the freight of the water, then the contractor doesn’t want to either.

- Albina: Caltrans likes 60-40 dilution, someone else likes 70-30. Tag it differently and ship it out that way.
- Shauna: diluted 50/50 versus 60/40 depending on the product.
- Most complaints are that it didn't cure.
- Krista: recommend 1 or 1H? Shauna, 1H because it will cure quicker.
- Shauna: Bill of lading – viscosity still tested. Krista – DOT should keep viscosity but include on the certified bill of lading. Once an emulsion is diluted more than 30%, the viscosity is going to be 10 because it's going to test out as water. Viscosity needs to be tested prior to dilution.

<u>Bryan Dias – Chip Seals on High Volume Routes</u>

- Will use RSLTP on shadow areas, etc. Use CRS-2P other places .
- SR 8 MP 115, 1996 chip seal, ADT 11,000, had a choke and fog seal.
- SR 8 MP 19.2, 2000 chip seal, ADT 11,000, choke and fog seal.
- SR 161 MP 3.35, 2006 chip seal, ADT 5100, no choke or fog seal.
  - A little bleeding, rock being pushed into surface.
- SR 119 MP 0.4, 2006 chip seal, ADT 1400, no choke or fog.
  - Looks fabulous.
- SR 116 MP 3.25 2009, ADT 1300 has choke.
- If the shoulder is 4' or smaller, they chip the entire shoulder. If it's wider, they go about a foot or so beyond the fog stripe.
- CRS-2P/RSLTP test section
  - Observations: environmental factors, shading, road geometry, pavement condition have a greater effect on life
  - When constructed within WSDOT specs, RSLTP and CRS-2P are comparable
  - If constructed outside of spec, would lean toward RSLTP
- Joe M. what did you say about the hot seals and whether they would save us on higher volume routes?
  - Dave: only have one season under our belt. Has 8000 ADT with 40% trucks (ODOT) – performing really well…but cautiously optimistic.
  - ODOT – held up really well in intersections.
  - Albina – like to get aggregate samples in their lab prior to job. Boil test for compatibility.

<u>Chad Clawson – Idaho DOT</u>

- Six districts in Idaho – he is in District 2, Materials Engineer.
- Most districts have their own way of doing things and have their own special provisions.
- CSR-2P most commonly used.
- Both choke stone and fog been cut out for the last 5 years and have not seen any difference in performance.
- Moving to McLeod – by contractor for each section of roadway and any changes in truck traffic or environmental conditions.
- Use WSDOT specs too.
- Have two gradations, one for urban and one for rural.
- Referred to Performance Evaluation of Chip Seals in Idaho, August 2010 report.
- District 2 mostly mountainous terrain. When in canyons, have a lot of shade and need to make sure that it is constructed during the correct times of year.

- Project timing when associated with paving (maintenance patches and new paving are issues).
  - No bond with chips because the emulsion sucked into new pavement.
  - Pre-fog prior to sealing on new pavement or pre-leveling.
- Pre-wetting 24 hours before chip sealing. Sometimes done too late and the chips are too wet.
- Meaningful QC/QA
  - Doesn't happen in a timely manner and the chips are already on the road and cannot do anything about the results.
  - US12: placed late in season, met specs, the following weekend rocks started to pick through October. In January, complaints of asphalt on cars. With snow on the ground, still picking up chunks of asphalt.
- Warranty specifications: Idaho is now using warranties for chip seals. Warranty for following year.
  - Failure due to state (snow plows), okay. Something wrong with shade or too dirty or something wrong with construction, then the contractor pays.
  - One lump item (contains traffic control).
  - How to show failure and who it belongs to – Montana guidelines.
  - Shows what is and isn't a failure.
  - Shows what is and isn't a contractor's responsibility.
  - $1.80-$1.90/SY pre warranty, about $2.20/SY with warranty.
  - Spec'ing CRS-2P. Follows WSDOT specs. Idaho DOT does no testing at all.
  - Two gradations, use McLeod method.
  - Chad included the warranty spec and points to the items that need to be completed by contractor.
  - Everything else left up to contractor
- First year warranty lessons:
  - Higher asphalt with McLeod, some tracking
  - Lower chip spread rate
  - No fog seal
  - Traffic staggering with pilot car
  - Pacing traffic speed
  - Better traffic control for chip seal, but worse for traffic flow
- Every road in district is on a rotation basis.
- Chip seals occur every 8 years.
- Some roadways are open-graded and don't get chipped.
- HMA roadway will be rotated into BST cycle after 1-3 years after HMA placed and continue on the BST cycle until something else needs to be done.
- Seems that they last longer if they get an early chip seal.
- Bill D.: the warranty looks like it is hard to figure out why it failed – how do they make the determination of what caused the failure? Chad: only put the chip seal on good roads.
- McLeod method – Joe: use Minnesota method? Don't think so, but will be looking into the different methods.
- Happy with it, seems like they are getting good embedment, etc.
- Microsurfacing for rut filling, Type 3.

- Krista – does contractor have any say on the pavement included? Would have to be before the contract is let.
- Any failures yet? No, not yet. Max penalty is 15% right now.
- Brad (Poe): don't like warranty. There's a lot of risk and speculation on failure.
- Paying 85%, holding 15% until they see how it does.
- Chad: have reduced number of people on the job – reduced in-house costs. This could go to maintenance contracts (yearly basis) – the contractor would have responsibility for a small time period.
- Traffic controls (Brett) – the contractor has born the responsibility for this during construction (mainly because they know it is important).

<u>Shauna Teclemariam - Emulsions</u>

- Suppliers and WSDOT meeting and changes to specs
  - 9-02 table upgrades (STE-1 taken out)
  - CSS-1 and 1H changes: no viscosity, sieve, mixing test
- Particle charge still tested and others, more realistic to what's in the field.
- Elastic recovery, torsional recovery, and toughness and tenacity all can tell if polymers are present.
  - PCCAS agreed on ER.
  - Spec book allows TR and T&T. WSDOT testing but not reporting ER.
- Adhesion and cohesion are important for chip seals. How do we test?
- Adhesion test is truly what they are seeking. If we can hold the rock to binder we are in good shape. Problem: no one knows how to get there…
- High volume roads
  - Many states do chip seals on over 20000 ADT.
  - Key is the condition of the road prior to the chip seal.
  - Use of strong aggregate (is the aggregate breaking down and just doesn't exist on the roadway?)
  - Double shot.
  - Fog seal and some use choke.
- A lot of the existing specs are from CRS-2 and they may not apply to CRS-2P. WSDOT needs to look at these specs and do research to create performance specifications.
- Albina: CRS-2P breaks sooner (Shauna), Dave doesn't agree. It should be based on the amount of binder. Shauna – I agree, but that's where we need a performance specification!
- Emulsions are not the same as they were 10 years ago. We need [performance] specifications that match the new products.
- Dave: polymer prices have increased 6X over the past few years. Worldwide shortage.

<u>Joe Mahoney – Remaining issues to discuss?</u>

- Bill – Escalators. Some regions don't have any, some have for certain products, why is this? Like to see a little more uniformity.
- Dave: if it's not a big job or if it's only one year, we typically don't worry about it. Can we talk about it at the mid-year meeting?
- Bill D. – rubber tire modifiers? Dave (Albina) – costs for tires different and there are major differences in quality. Stick with a more uniform product.
- Newt – tire rubber been tested, but typically 3X the cost and no life differences.

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