ASPHALT CEMENT CHIP SEALS IN OREGON

Construction Report

STATE RESEARCH PROJECT #546

Oregon Department of Transportation

ASPHALT CEMENT CHIP SEALS IN OREGON

Construction Report

STATE RESEARCH PROJECT #546

by

Andrew Griffith, P.E

And

Elizabeth Hunt, P.E..

for

Oregon Department of Transportation
Research Group
200 Hawthorne SE, Suite B-240
Salem OR 97301-5192

June 2000

Technical Report Documentation Page

1. Report No. OR-RD-01-01	2. Government Accession No.	3. Recipient's Catalog No.
4. Title and Subtitle Asphalt Cement Chip Seals in Oregon Construction Report		Report Date June 2000 Performing Organization Code
7. Author(s) Andrew Griffith, P.E., and Elizabeth Hunt, P.E.		8. Performing Organization Report No.
9. Performing Organization Name and Address Oregon Department of Transportation Research Group 200 Hawthorne SE, Suite B-240 Salem, Oregon 97301-5192		10. Work Unit No. (TRAIS) . Contract or Grant No. SRS 546
12. Sponsoring Agency Name and Address Oregon Department of Transportation Research Group 200 Hawthorne SE, Suite B-240 Salem, Oregon 97301-5192		13. Type of Report and Period Covered Construction Report July - September 1999 14. Sponsoring Agency Code
15. Supplementary Notes		

16. Abstract

Most chip seals in Oregon have been constructed using an emulsified asphalt binder. However, chip seals using an asphalt cement (hot oil) binder have been tried in limited situations in Oregon. This report includes a literature review and summarizes the construction and short term performance of asphalt cement chip seals constructed during the summer of 1999 in Lane, Clackamas, Lincoln and Deschutes Counties. The hot oil, supplied by Wright Asphalt, was AC-15-5TR which includes 5% tire rubber and 2.5 to 3.0% SBS polymer.

Previous research on asphalt cement chip seals has been done in Texas. Freeman and Rmeili studied six types of maintenance treatments, including asphalt cement chip seals, on 20 test sites. They found that all chip seal treatments including asphalt cement, reduced alligator, transverse and longitudinal cracking. Gransberg and others documented the Texas Department of Transportation chip seal construction program including asphalt cement chip seals. They noted that asphalt cement chip seals are advantageous because "the roadway can be opened for traffic early."

The Oregon Department of Transportation (ODOT) evaluated construction on asphalt cement chip seals constructed on OR Route 126, U.S. Route 101, four Clackamas County roads, and one Deschutes County road. The chip seals were applied using conventional construction techniques. Asphalt cement, pavement, air temperature and humidity measurements were recorded throughout construction operations. Samples of aggregate and asphalt cement were taken for laboratory analysis. Additionally, skid resistance testing was conducted on OR Route 126 and U.S. Route 101.

The chip seals were monitored for chip retention and condition, one month after construction. Localized chip loss was observed on OR Route 126 between MP 29.0 and MP 31.6 in April 2000. Chip loss was attributed to variability in the underlying pavement surface and the low asphalt cement shot rate used during construction. Each chip seal section will be monitored annually for two years, and a final report prepared at the end of the monitoring period.

17.Key Words	18.Distribution Statement
CHIP SEAL, ASPHALT CEMENT, RUBBER, PRECOATED AGGREGATE, OREGON	Available through the Oregon Department of Transportation (Research Group)

19. Security Classif. (of this report).	20. Security Classif. (of this page)	21. No. of Pages	22.Price
Unclassified	Unclassified	40 + Appendices	

Technical Report Form DOT F 1700.7 (8-72) Reproduction of completed page authorized

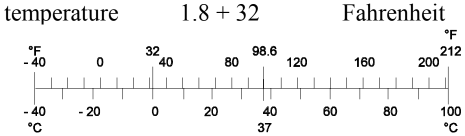
SI* (MODERN METRIC) CONVERSION FACTORS

APPROXIMATE CONVERSIONS TO SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
In	Inches	25.4	Millimeters	Mm
Ft	Feet	0.305	Meters	M
Yd	Yards	0.914	Meters	M
Mi	Miles	1.61	Kilometers	Km
		AREA		
in^2	Square inches	645.2	Millimeters	mm^2
ft^2	Square feet	0.093	Meters squared	M^2
yd^2	Square yards	0.836	Meters squared	M^2
Ac	Acres	0.405	Hectares	Ha
mi^2	Square miles	2.59	Kilometers	Km^2
		VOLUME		
fl oz	Fluid ounces	29.57	Milliliters	ML
Gal	Gallons	3.785	Liters	L
ft^3	Cubic feet	0.028	Meters cubed	m^3
yd^3	Cubic yards	0.765	Meters cubed	m^3
NOTE: Volumes greater than 1000 L shall be shown in m^3.				
		MASS		
Oz	Ounces	28.35	Grams	G
Lb	Pounds	0.454	Kilograms	Kg
T	Short tons (2000 lb)	0.907	Megagrams	Mg
		TEMPERATURE (exact)		
°F	Fahrenheit temperature	5(F-32)/9	Celsius temperature	°C

APPROXIMATE CONVERSIONS FROM SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
Mm	Millimeters	0.039	inches	in
M	Meters	3.28	feet	ft
M	Meters	1.09	yards	yd
Km	Kilometers	0.621	miles	mi
		AREA		
Mm^2	millimeters squared	0.0016	square inches	in^2
m^2	meters squared	10.764	square feet	ft^2
Ha	Hectares	2.47	acres	ac
Km^2	kilometers squared	0.386	square miles	mi^2
		VOLUME		
ML	Milliliters	0.034	fluid ounces	fl oz
L	Liters	0.264	gallons	gal
m^3	meters cubed	35.315	cubic feet	ft^3
m^3	meters cubed	1.308	cubic yards	yd^3
		MASS		
G	Grams	0.035	ounces	oz
kg	Kilograms	2.205	pounds	lb
Mg	Megagrams	1.102	short tons (2000 lb)	T
		TEMPERATURE (exact)		
°C	Celsius temperature	1.8 + 32	Fahrenheit	°F



* SI is the symbol for the International System of Measurement

(4-7-94 jbp)

ACKNOWLEDGEMENTS

The authors would like to thank the following for their assistance in data collection and the report preparation:

Joni Reid, Oregon Department of Transportation Research Group
Eric Brooks, Oregon Department of Transportation Research Group
Deborah Martinez, Oregon Department of Transportation Research Group
Dave Horton, Oregon Department of Transportation Research Group
Oregon Department of Transportation District 4
Oregon Department of Transportation District 5
Doug Putchler, Lane County, Lane County Road Maintenance Section
Darrel Burnum, Clackamas County Department of Transportation and Development
Roger Olson, Deschutes County Road Department
Theodore Stoutt, Wright Asphalt Products Co.

DISCLAIMER

ASPHALT CEMENT CHIP SEALS IN OREGON
CONSTRUCTION REPORT

TABLE OF CONTENTS

APPENDICES

LIST OF TABLES

LIST OF FIGURES

1.0 INTRODUCTION

1.1 PROBLEM STATEMENT

Chip seals are a standard preventive maintenance treatment used to protect the pavement from weathering and the adverse effects of water. A chip seal also improves skid resistance by increasing the surface friction of the pavement. Most chip seals in Oregon have been constructed using an asphalt emulsion as the binder. These emulsified asphalt chip seals have been the treatment of choice, but in some locations, particularly on higher volume/higher speed roadways, they have been less successful. Chip seals using an asphalt cement binder (hot oil) have been tried in limited situations on Oregon state highways, but the construction process and performance of the hot oil seals have not been evaluated. Thus, research is needed to properly assess the effectiveness of asphalt cement (hot oil) chip seals and the appropriate construction processes to employ.

1.2 BACKGROUND

The apparent advantage of using an asphalt cement binder instead of an emulsion is that it can be utilized under heavier traffic volumes and a wider band of temperature conditions. Because less time is required for the aggregate to stick to the asphalt cement, traffic is allowed on the asphalt cement chip seal much sooner than on an emulsified asphalt chip seal. For this reason, asphalt cement chip seals could be an effective pavement maintenance strategy for Oregon highways, particularly in Western Oregon. Alternatively, the use of an asphalt cement binder requires more rigorous quality control measures to ensure adequate bonding of the aggregate to the binder during construction.

As maintenance budgets decrease, longer lasting pavements are needed. Pavement reconstruction and overlays will be accomplished less frequently and effective preventive maintenance will be crucial to prolong pavement life. Therefore, innovative practices to maintain pavements, such as asphalt cement chip seals, should be fully examined.

1.3 RESEARCH OBJECTIVES

The overall goal of this study was to document best construction practices and determine if asphalt cement chip seals can provide a satisfactory chip seal surface. The specific objectives included:

1. Review previous construction experience in Oregon and other states with asphalt cement chip seals, with particular emphasis on construction practices, costs, types of uses (local roads, arterials, freeways), and performance histories.

2. Evaluate the construction of asphalt cement chip seal sections, taking into consideration the following aspects:

   - Existing pavement conditions; site conditions like shade and roadway alignment;
   - Asphalt and aggregate application rates; distance between distributor and spreader;
   - Aggregate gradation; moisture content;
   - Weather conditions (temperature, humidity, wind, prior day conditions, post-construction conditions);
   - Aggregate preparation (precoating, washing, etc.);
   - Material properties (aggregate, liquid asphalt) and process control testing;
   - Preparation of underlying surfaces; pavement temperatures and
   - Provisions for traffic.

3. Evaluate the effectiveness of asphalt cement chip seal applications two years after construction.

2.0 LITERATURE REVIEW

Limited research has been conducted specifically on asphalt cement chip seals. The major focus of previous research has been on emulsified asphalt chip seals.

In Oregon, Beecroft and others *(1982)* evaluated rubber asphalt chip seals in three locations in Klamath and Lake Counties. The chip seals were on Warner Highway (Oregon Route 140), The Dalles - California Highway (U. S. Route 97), and on three bridge decks on The Dalles - California Highway (U. S. Route 97). The rubber-asphalt binder consisted, by weight, of three parts AR 1000 asphalt cement blended with one part finely ground tire rubber. Additionally, to reduce the viscosity for spraying, 6% kerosene was added to the binder. The aggregate was a 9.5 mm (3/8″) chip precoated with a 0.7% asphalt cement. The rubber-asphalt chip seals performed significantly better than the control sections over the course of a three-year evaluation period. However, the researchers noted the cost of the rubber-asphalt chip seal was about three times as expensive as a conventional chip seal.

Freeman and Rmeili *(1994)* studied six types of maintenance treatments on 20 test sites located on Texas Department of Transportation highways. The treatments included asphalt cement chip seals using AC-5, AC-10, AC-5 with 2% latex and AC-10 with 20% rubber. There was also a chip seal using a polymer modified asphalt emulsion binder. Two other treatments, a fog seal and a microsurfacing section, were applied and studied. The test section for each type of binder was 213.4 m (700 ft) long. A control section of the same length where no treatment was applied was included at each site. The asphalt cement application rates on the 20 sections for the AC-5, AC-10, AC-5 with 2% latex binders ranged from 1.09 to 1.68 l/m^2 (0.24 to 0.37 gal/yd^2). The application rate for the AC-10 with 20% rubber binder ranged from 2.22 to 3.17 l/m^2 (0.49 to 0.70 gal/yd^2). The researchers re-inspected the sites approximately six years after construction (*Freeman 1999*) and compared the distress noted on the test sections to the control section. All treatments except for microsurfacing resulted in increased bleeding relative to the control section.

The Federal Highway Administration *(CATR 1996)* published general information on preventive maintenance treatments including chip seal applications. In discussing chip seals, the publication notes "an asphalt emulsion is preferred over asphalt cement since it can be used with damp aggregates." Also from the literature, displayed in Table 2.1, are typical quantities of aggregate and binder for various aggregate sizes used in chip seal applications.

Table 2.1: Typical Quantities of Aggregate and Binder for Chip Seal Applications Using an Asphalt Cement Binder

Nominal Size of Aggregate (Nominal)	Quantity of Aggregate kg/m^2	Quantity of Asphalt liters/m^2
19 to 9.5 mm	22 to 27	1.6 to 2.0
12.5 to 4.75 mm	14 to 16	0.9 to 1.4
9.5 to 2.36 mm	11 to 14	0.7 to 1.1

The U. S. Army Corps of Engineers discuss asphalt cement binders briefly in their User Guide for Double Surface Bituminous Treatments *(Burke 1994).* The User Guide describes the benefits of asphalt cements. They harden quickly and do not require a curing time. Asphalt cements provide an impervious seal and have less tendency to bleed than other binder types. Alternatively, the User Guide lists the disadvantages with using an asphalt cement. Asphalt cements require heating to high temperatures. Additionally, when the underlying pavement surface is cold, they may chill before the aggregate can bond and be fully embedded. Asphalt cements do not penetrate well into old pavements.

Wyckoff, for the Washington State Department of Transportation (WsDOT), in "Asphalt Seal Coats" *(1987)* discusses the use of asphalt cement binders. He lists the following as advantages of using asphalt cement binders:

- The binder is made of pure asphalt.
- The asphalt cement requires little or no curing period. As soon as it has cooled, the binder has obtained its full strength (holding power).

Alternatively, Wyckoff provides some disadvantages associated with asphalt cement binders:

- The cover aggregate must be spread rapidly after the binder is distributed to ensure proper embedment.
- The asphalt cement must be heated to high temperatures to make it fluid enough for it to work well.

Gransberg and others *(1998)* documented the Texas Department of Transportation (TxDOT) chip seal construction program including asphalt cement chip seals. Their research reviewed best construction practices currently in use and TxDOT design plans and specifications for chip seal construction. The researchers noted, "Asphalt cements are advantageous because after seal coat application, the roadway can be opened for traffic early." However, disadvantages included high application temperature, sensitivity to moisture in aggregate, and additional rolling requirements. They stated that asphalt cements should be used when ambient temperatures are greater than or equal to 21°C (70°F) and emulsions should be used when temperatures are greater than or equal to 16°C (60°F). Additionally, asphalt cements should be avoided during cool weather when temperatures are low and the aggregate is wet.

Gransberg and the other researchers also interviewed TxDOT maintenance staffs in order to reveal the best practices of their chip seal programs. Based on the interviews, most of the TxDOT Districts are using asphalt cement binders. The most widely used binder is AC-15-5TR, though AC-15P and AC-5 are also used. The maintenance personnel reported that asphalt cements provide satisfactory seals with good adhesion to the aggregate. They typically use a precoated aggregate on an asphalt cement chip seal to eliminate a dust problem with dirty aggregate and for better adhesion. The maintenance staffs also like precoating because of aesthetics. It results in a darker pavement surface and provides better contrast for striping than an uncoated chip.

Kandhal and Motter *(1991)* who did a study on precoating aggregates for sealcoats, indicate "precoating with a bituminous material almost guarantees good adhesion." Additionally, excessive dust in the aggregate can lead to chip seal failures. Dust prevents good adhesion between the binder and the aggregate. Two ways to eliminate the dust problem are:

- Washing and drying the aggregate prior to its application; and
- Precoating the aggregate with a bituminous material.

3.0 TEST SECTIONS

The ODOT Research Group coordinated with Lane, Clackamas, Deschutes, and Lincoln County Road Departments to gather construction information on asphalt cement chip seal projects. Projects monitored included two state highways in Lane and Lincoln counties and several county roads in Clackamas and Deschutes counties. Table 3.1 lists the section locations by mileposts (MP) and their average daily traffic estimates.

Table 3.1: Chip Seal Project Sections Evaluated

Highway	County	Project Limits		Average Daily Traffic
		From	To	
OR Route 126	Lane	MP 13.0	MP 16.4	4,400
OR Route 126	Lane	MP 26.0	MP 31.6	4,400
U.S. Route 101	Lincoln	MP 129.0	MP 132.2	18,500
Sunnyside Road	Clackamas	172nd Avenue	OR Route 212	37,200
Foster Road	Clackamas	Multnomah County Line	OR Route 212	5,350
232nd Avenue	Clackamas	OR Route 212	OR Route 224	5,050
Wilsonville Road	Clackamas	Yamhill County Line	Wilsonville West City Limits	2,700
Canal Blvd.	Deschutes	Young Avenue	Yew Avenue	2,600 – 3,200

For each section listed in Table 3.1, hourly ambient and pavement temperature, and humidity measurements were recorded during the operation. Air and humidity measurements were taken using a digital humidity/temperature meter. Pavement temperatures were measured by a hand-held Raytek Raynger ST2™ non-contact thermometer. Also, for each continuous pass on all sections, pavement surface temperatures were recorded following the application of the asphalt cement, and immediately after the chips had been spread. Additionally, intervals between the equipment used in the chip seal construction (distributor, chip spreader, and rollers) were timed.

The temperature, humidity, and interval data is presented in Appendix A of this report. On the first section, OR Route 126, MP 13.0 to MP 16.4, temperature and interval data were not collected on the section constructed the first day between MP 13.0 and MP 15.0. Since this was the first day to monitor chip seal construction, emphasis was placed on observing techniques and sequence of operation.

The following sections provide a detailed discussion about the construction of each chip seal project section.

3.1 OR ROUTE 126; MP 13.0 – MP 16.4

The asphalt cement chip seal construction on OR Route 126 (MP 13 - MP 16.4) took place over two days, July 14 - July 15, 1999. Most of the existing pavement surface was visibly high in asphalt content between MP 13.0 and MP 16.0. In the previous year, this 4.8 km (3.0 mi) section had been sealed with an asphalt cement chip seal. However, because of dirty aggregate, most of the chips were stripped in the wheel paths soon after placement, leaving a heavy buildup of asphalt binder on the surface (Figures 3.1 and 3.2). As a result, skid resistance on the existing pavement had become a problem, and ODOT decided to apply another chip seal to increase skid resistance to acceptable levels.

Figure 3.1: Close-up of Pavement Surface on OR Route 126

Figure 3.2: OR Route 126 with Asphalt Cement Buildup in the Wheel Paths

In accordance with an established intergovernmental agreement, Lane County's Road Maintenance Section provided most of the labor and equipment used on the chip seal. Their resources included eight trucks, two pneumatic tire rollers, four bridge and driveway cleanup workers, three sweepers with operators, and three operators on the chip spreader. ODOT purchased the aggregate and the asphalt cement, and provided the traffic control and flagging. The project was flagged on each end with traffic being directed by a pilot car. The asphalt cement, distributor and operator were supplied by Wright Asphalt Products Co.

The aggregate had been precoated with 0.75% PBA-5 by weight of aggregate in a batch plant. However, in testing done on samples taken from stockpiles, the actual asphalt content ranged from 1.1 to 1.8%. The asphalt cement (AC-15-5TR) includes 5% tire rubber and 2.5 to 3.0% SBS polymer. The asphalt cement was delivered in the tank at about 163°C (325°F).

The asphalt cement was originally applied at 1.59 liters/m^2 (0.35 gal/yd^2) and later reduced to 1.50 liters/m^2 (0.33 gal/yd^2), shown in Figure 3.3. The chips were 9.5 mm to 6.3 mm (3/8″ to ¼″) in size. The chip application rate was 9.2 kg/m^2 (17 lbs/yd^2). Lane County's chip spreader was self-propelled and equipped with computerized controls that adjusted the opening and closing of gates based on the speed of the spreader (Figure 3.4).

Figure 3.3: Asphalt Distributor Applying Asphalt Cement on OR Route 126

The operations started at approximately 8:00 a.m. The ambient air temperature was 16°C (62°F) and the pavement temperature in the sun was about 24°C (75°F). The first 2.4 km (1.5 mi) pass from MP 13 to MP 14.5 in the eastbound lane was completed in about 45 minutes. The chip-sealed pavement appeared very rich with areas of asphalt cement showing between the chips. The rollers were intended to reorient the aggregate filling in the spaces. Five passes were made by two pneumatic tired rollers and the pavement was swept starting at 9:00 a.m. A self-contained sweeper and two towed sweepers were used. A water truck then sprayed only the outer edge of the pavement to remove any remaining loose rock.

Figure 3.4: Lane County Chip Spreader Operating on OR Route 126

Traffic was back on the first section by 9:30 a.m. following a pilot car. Minimal flying rock was noted. The westbound lane from MP 13 to MP 15.0 was started at 9:35 a.m. Overall, there were five sections on this segment of OR Route 126 that were chip sealed on July 14. Table 3.2 provides a summary of the construction sequence.

Table 3.2: Sequence of Chip Seal Operations for July 14

Panel Section	Lane ID	Start Time	Time When Brooming was Completed
MP 13.0 – MP 14.5	WB	8:00 a.m.	9:30 a.m.
MP 13.0 – MP 14.5	EB	9:30 a.m.	10:30 a.m.
MP 14.5 – MP 15.0	WB	10:30 a.m.	11:00 a.m.
MP 14.5 – MP 15.0	EB	11:00 a.m.	11:30 a.m.
Partridge Lane-MP 15.0	Middle Turn Lane	11:30 a.m.	12:00 noon

During construction, the chips were usually placed within one minute after the asphalt cement was shot. The rollers were operating behind the trucks hauling the chips, so it took from one to several minutes for the rollers to reach the chip sealed section (Figure 3.5). Haul trucks traveled behind the chip truck and provided the initial compaction. The trucks were also staggered across the panel in order to compact as much of the chip seal as possible (Figure 3.6). After the panel was rolled, it was watered to cool it and then swept with the rotary sweepers.

Figure 3.5: Pneumatic Roller Operating Behind Dump Trucks

At about 12:00 noon, after the middle turn lane section had been completed to MP 15.0, flushing was observed in the pavement in areas near MP 13. At this time, a decision was made to sand the chip seal from MP 13.0 to MP 15.0 and discontinue chip seal construction for the day. Sanding was initially done with 9.5 mm to 6.3 mm (3/8″ to ¼″) rock, however, it was too large. By 1:50 p.m., 6.3 mm to 2.1 mm (¼″ to #10) rock was delivered and applied full width on the chip seal. The rollers followed after the sanding truck and made only one pass. Water was applied full width at 3:00 p.m. The pilot cars remained in operation until 7:00 p.m.

Figure 3.6: Staggered Dump Trucks Providing Initial Chip Seal Compaction

During construction, two representatives from Wright Asphalt Products Co., Theodore Stoutt and Goode Rogers, were on site. In addition to monitoring construction, they also discussed the use of asphalt cement binders and precoated aggregate. Mr. Rogers indicated that coated aggregates and asphalt cement are used extensively in Texas. He estimated the cost for an asphalt cement chip seal with coated chips at about \$0.96/m^2 to \$1.26/m^2 (\$0.80/yd^2 to \$1.05/yd^2) depending on the trucking costs. They said the advantage of an asphalt cement is that it allows traffic on the road within an hour, which is critical on higher volume roads. The material works well on 5,000 to 10,000 average daily traffic (ADT) and has been used on roads in Texas with as much as 25,000 ADT.

Aggregate and asphalt cement samples were taken by an ODOT Quality Assurance representative during construction for testing at the Department's Materials Laboratory. Aggregate tests included a sieve analysis, asphalt content and percent of fractured particles. Results of the aggregate testing are included in Appendix B.

On July 15, 1999, chip seal construction was continued from MP 15.0 to MP 16.4. The operation included the same equipment, materials and number of personnel used the day before on MP 13.0 to MP 15.0. This day, operations again started at approximately 8:00 a.m. The air temperature at the start was 17°C (62°F). The relative humidity at 8:00 a.m. was measured at 49%.

Due to the previous day's flushing problem, the asphalt cement application rate was reduced to 1.00 liters/m^2 (0.22 gal/yd^2) between MP 15.0 and MP 16.4. In shaded areas, the asphalt cement application rate was increased to 1.09 liters/m^2 (0.24 gal/yd^2) because of lower pavement surface temperatures.

The first section, the westbound travel lane between MP 15.0 and MP 15.3, was completed (chipped and rolled) in about 10 minutes. The underlying pavement appeared very rich with asphalt as did most of the pavement in the two travel lanes between MP 15.0 and MP 16.4.

The construction operations were carried out in the same sequence and manner as the previous day. The chip spreader usually operated within thirty seconds to one minute behind the asphalt distributor. The two pneumatic rollers that followed the chip spreader were operating, at times, right behind the chip spreader (less than 30 seconds). Generally though, the aggregate haul trucks, staggering their wheel paths, provided the initial compaction. Within an hour after rolling, the pavement was swept by a self-contained rotary sweeper and two towed, rotary sweepers.

Chip seal operations for the 2.3 km (1.4 mi) section were completed by 11:30 a.m. The air temperature at this time was 21°C (70°F), and the relative humidity had decreased to 36%.

3.2 OR ROUTE 126; MP 26.0 - MP 31.6

Lane County Road Maintenance Section constructed this section four days after the previous OR Route 126 section between MP 15.0 and MP 16.4. This section had also been chip sealed the previous summer and had failed because of dirty uncoated aggregate.

The asphalt cement, AC-15-5TR was supplied by Wright Asphalt Products Co. The asphalt cement temperature in the distributor truck was maintained at about 163°C (325°F) throughout the construction.

The asphalt cement was applied at 1.00 liters/m^2 (0.22 gal/yd^2). In shaded areas, the asphalt cement application rate was increased to 1.09 liters/m^2 (0.24 gal/yd^2) because of the lower pavement temperatures. Within the 8 km (5 mi) plus project site, there were several areas where the pavement was completely shaded from the sun by overhanging trees on both sides of the roadway.

The chips were 9.5 mm to 6.3 mm (3/8″ to ¼″) in size. The chip application rate was 9 to 10 kg/m^2 (17-18 lbs/yd^2). The aggregate had been precoated with 0.75% PBA-5 by weight of aggregate in a batch plant.

At 8:00 a.m. the ambient air temperature was 17°C (63°F) and pavement surface temperature was 17°C (63°F). The recorded ambient temperatures ranged from 17°C (63°F) at 8:00 a.m., to 33°C (91°F) at the completion of operations in late afternoon. The humidity ranged from 50% recorded in the morning, to 31% measured at 2:45 p.m.

The crew started at 7:00 a.m. and had completed chip sealing of both travel lanes from MP 26.1 to MP 27.0 by 8:00 a.m. It took approximately eight hours to finish construction operations. The last section was completed at approximately 3:00 p.m.

The entire process was very efficient with downtime occurring only when the asphalt distributor was refilling. During construction, the chip spreader usually operated within thirty seconds to one minute behind the asphalt distributor. However, there were instances when the haul trucks were changing at the spreader, where there were slight delays in spreading the aggregate on the binder.

During the day, as the ambient air temperature increased, some sections of the chip seal were watered to cool the mat. Additionally, a choke aggregate, 6.3 mm to 2.1 mm (¼″ to #10) was placed in some areas where the asphalt cement had started bleeding. By 3:00 p.m., the portion of the highway from MP 26.0 to MP 28.5 was completely open to traffic. Pilot cars remained in operation from MP 28.5 to 31.6 until approximately 6:00 p.m.

3.3 U.S. ROUTE 101; MP 129.0 – MP 130.2

U.S. Route 101, from MP 129.0 to MP 130.2 was chip sealed on September 16, 1999. The ADT of this section is 18,500. The existing wearing surface was an open graded asphalt pavement, constructed in 1993. The aggregate had become very polished, and in some areas, there was moss growing in the voids (Figure 3.7). This section of U.S. Route 101 had a history of low skid resistance and several accidents. Throughout the project area, there were shady and sunny areas (Figure 3.8). Within this section is a hill with a horizontal curve at the crest.

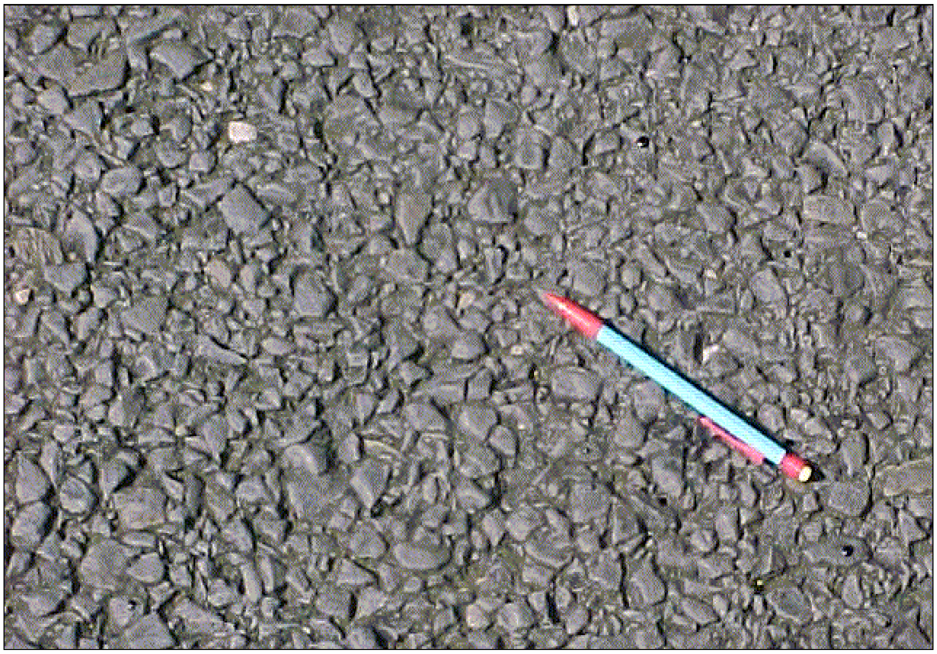


Figure 3.7: Close-up Image of Open Graded Pavement on U.S. Route 101; MP 130.0

Figure 3.8: U.S. Route 101 at MP 130.0 with the Pacific Ocean in the Background

The work was done with support from Benton, Lincoln, Polk and Lane Counties. Benton County supplied the chip spreader and roller with operators. Lincoln County provided the trucks, rollers and operators. Polk County provided a roller and operator. Lane County provided technical assistance and ODOT provided additional laborers and the traffic control. ODOT purchased the asphalt cement and chips and Wright Asphalt Products Co. paid for precoating the chips.

The operation included a pneumatic roller, a single drum rigid frame roller, a double drum rigid frame roller, a distributor truck with an operator (contracted), two sweepers, and a Spread King chip spreader. The project was flagged on each end with traffic being directed by a pilot car.

The 9.5 mm to 6.3 mm (3/8″ to ¼″) chips had been precoated with a target of 0.6% PBA-5 asphalt cement three days earlier and trucked to a stockpile a few miles south of the project on U.S. Route 101. Approximately 236 Mg (260 tons) of chips were used. The asphalt cement used was AC-15-5TR.

Due to traffic and temperature considerations, the chip seal construction did not start until after 9:30 a.m. The first section completed was in the turning lane of U.S. Route 101 at about MP 130.2. The pavement surface appeared very tight with loose chips throughout. Construction required multiple passes of the spreader to get the chips out, as they were sticking together and not evenly distributed. An inspection of the stockpile revealed that the chips were still warm >35°C (95°F). The chip stockpile was moved around in an attempt to cool off the chips (Figure 3.9). The chips also appeared to stick together because of a heavy coat of asphalt. Samples were collected for testing. The actual asphalt precoat amount, determined by incineration at the ODOT Materials Laboratory, was 1.70%, almost three times the target. Gradation and tests for fracture however, conformed to specification requirements. The results of incineration testing, and other lab testing for the precoated aggregate are contained in Appendix B.

Figure 3.9: Stockpile of Precoated Chips Being Leveled and Turned Over to Cool

After about an hour of moving the chips, the decision was made to proceed, and the sections were built with one truckload of chips at a time. By controlling the chip delivery rate, workers were able to cover light spots with aggregate by raking or spreading with a shovel (Figure 3.10). In other areas, the chip application was much higher than the target of 10 kg/m^2 (18 lbs/yd^2).

Controlling the chip application rate in spite of the clumping may have been possible with a newer chip spreader. The chip spreader used was reported to be somewhat outdated. Newer spreaders allow a computerized application rate to be set and more flexibility in opening and closing selected gates.

Figure 3.10: Workers Spreading Chips Across the Mat to Ensure a Uniform Application

The asphalt cement application rate at the start for the first pass was 1.73 l/m^2 (0.38 gal/yd^2) and was increased to 1.82 l/m^2 (0.40 gal/yd^2) on subsequent sections. The temperature of the asphalt cement out of the spray bar averaged 155°C (311°F). Pavement temperatures ranged from 14 to 33°C (57 to 91°F), depending on whether the readings were taken in the sun or shade. Air temperatures ranged from 16 to 19°C (60 to 66°F). The humidity ranged from 56 to 63%.

The chip spreader stayed very close to the distributor with chips applied within an average of 12 seconds after the asphalt cement was applied to the pavement. Rollers were further out and hit the new sections anywhere from 39 seconds to 4 minutes after chip application (Figure 3.11). Each roller made a minimum of three passes. The first pass was done with the rollers close together. The steel wheel rollers were on the outside with the pneumatic roller in the middle. Sweeping was done within about an hour after rolling. Multiple sweeper passes were required to remove the excess rock. Work was completed about 3:00 p.m.

3.4 CLACKAMAS COUNTY SECTIONS

In Clackamas County, four asphalt cement chip seals placed on county roads were evaluated. The work was done by Clackamas County's Department of Transportation and Development Road Maintenance Crew. The chip seals were constructed during the first week in August and on August 17th. Data was collected for the chip seals constructed on Foster Road, Sunnyside Road, 232nd Avenue, and Wilsonville Road.

Figure 3.11: Pneumatic Roller Operating Behind Chip Spreader

The operation typically included pneumatic rollers (and on some projects a double drum rigid frame roller), a distributor truck with an operator (contracted), a sweeper, eight trucks, and a Spread King chip spreader (Figure 3.12). Two rakers followed the project, which was flagged on each end with traffic being directed by a pilot car.

The 12.5 mm to 6.3 mm (½″ to ¼″) chips used on the project had been precoated with 1.8% CSS-1 emulsion, diluted 1:1 with water. The target residual asphalt was 0.6%. As on the ODOT chip seals, AC-15-5TR asphalt cement, supplied by Wright Asphalt Products Co. was used.

Figure 3.12: Spread King Chip Spreader in Clackamas County

3.4.1 Foster Road

On August 2, 1999 a chip seal was placed on Foster Road from the intersection of OR Route 212 to the Multnomah County Line. The ADT for Foster Road is 5,350. The section had been chip sealed three years earlier. The road was hilly and shady in some areas. No cracking was noted, however, chips were missing in several areas of the wheel path (Figures 3.13 and 3.14).

Figure 3.13: Foster Road Prior to Chip Sealing

Figure 3.14: Close-up of Wheel Path on Foster Road Prior to Chip Sealing

The asphalt cement application rate varied from 2.05 to 2.14 l/m^2 (0.45 to 0.47 gal/yd^2). The temperature of the asphalt cement out of the spray bar averaged 151°C (303°F). The higher shot rate was applied on the steep hills. The rock application rate varied from 11 to 12 kg/m^2 (20 to 23 lbs/yd^2).

Pavement temperatures ranged from 80 to 125°F depending on whether the readings were taken in the sun or shade. Air temperatures ranged from 21 to 33°C (70 to 92°F). The humidity ranged from 49% in the morning to 30% in the late afternoon.

The trucks and rollers staggered their passes to optimize chip embedment (Figure 3.15). The sections were covered with two to three roller passes. The steel drum roller was not on the job until 3:30 p.m. Delays were caused when the haul trucks could not keep up with the spreader. Additional delays were caused when the distributor truck had to be refilled.

Figure 3.15: Staggered Pneumatic Rollers Operating to Ensure Maximum Coverage

3.4.2 Sunnyside Road

On August 3, 1999 a chip seal was placed on Sunnyside Road from the intersection of to OR Route 212 to 172nd Avenue. The ADT for Sunnyside Road is 37,200. The section was chip sealed three years earlier. The road was hilly and shady in some areas. No cracking was noted, however, chips were missing in the wheel path and in some areas the wheel path looked flushed (Figure 3.16).

The asphalt cement application rate was set at 2.05 l/m^2 (0.45 gal/yd^2). Through a hilly section with full canopy shade, the application rate was bumped up to 2.18 l/m^2 (0.48 gal/yd^2). The aggregate application rate was set at 11 kg/m^2 (21 lbs/yd^2).

Figure 3.16: Sunnyside Road Prior to Chip Sealing

The temperature of the asphalt cement out of the spray bar averaged 146°C (294°F). Pavement temperatures ranged from 27 to 46°C (80 to 114°F), depending on whether the readings were taken in the sun or shade. Air temperatures ranged from 26 to 27°C (79 to 81°F). The humidity ranged from 37 to 42% between 10:40 a.m. and 1:00 p.m.

The trucks and rollers staggered their passes to optimize chip embedment. The first three passes were made by the two pneumatic rollers on the job followed by an additional pass by the steel wheel roller. The sections were broomed about 40 minutes after construction.

3.4.3 232nd Avenue

On August 4, 1999 a chip seal was placed on 232nd Avenue from the intersection of OR Route 224 to the intersection of OR Route 212. The ADT for 232nd Avenue is 5,050. The chip seal was being applied as a preservation treatment. The existing overlay was placed in 1992. The road was hilly and shady in some areas (Figure 3.17). No distresses were noted.

The asphalt cement application rate ranged from 2.18 to 2.28 l/m^2 (0.48 to 0.50 gal/yd^2). The aggregate application rate was set at 12 kg/m^2 (22 lbs/yd^2). The temperature of the asphalt cement out of the spray bar averaged 148°C (298°F). Pavement temperatures ranged from 34 to 48°C (94 to 119°F), depending on whether the readings were taken in the sun or shade. Air temperatures ranged from 23 to 28°C (73 to 83°F). The humidity varied between 53 and 40% between 10:00 a.m. and 12:00 p.m.

The trucks and rollers staggered their passes to optimize chip embedment. The first three passes were made by the two pneumatic rollers on the job followed by an additional pass by the steel wheel roller. Uncoated chips were used starting at about MP 0.7. A fog seal was placed later that day over the uncoated section. The shot rate was 0.55 l/m^2 (0.12 gal/yd^2) of CSS-1 emulsion diluted 1:1 with water.

Figure 3.17: 232nd Avenue Prior to Chip Sealing

3.4.4 Wilsonville Road

On August 17, 1999 a chip seal was placed on Wilsonville Road from the Yamhill County Line to the Wilsonville West City Limits (MP 4.52). The section was constructed with uncoated chips and then later fog sealed. The ADT for Wilsonville Road is 2,700. The chip seal was being applied as a preservation treatment. The existing overlay was placed in 1991. The road was hilly and shady in some areas (Figure 3.18). No distresses were noted.

Figure 3.18: Wilsonville Road Prior to Chip Sealing

The asphalt cement application rate was set at 2.28 l/m^2 (0.5 gal/yd^2). The aggregate application rate was set at 10 kg/m^2 (18 lbs/yd^2). The asphalt cement temperature at the spray bar averaged 141°C (286°F). Pavement temperatures ranged from 27 to 46°C (80 to 114°F), depending on whether the readings were taken in the sun or shade. Air temperatures ranged from 23 to 51°C (73 to 124°F). The humidity ranged from 50 to 35% between 11:30 a.m. and 3:00 p.m.

The trucks and rollers staggered their passes to optimize chip embedment. Three passes were made by the two pneumatic rollers. A portion of the project had been chip sealed on August 6th before it began to rain. Some of the chips in that area were lost, so the section was re-shot on the 17th. The sweeper lagged behind the operation by a couple of hours; however, traffic was allowed on the new sections after they were rolled.

A fog seal was placed on the 18th and 23rd with a shot rate of 0.55 l/m^2 (0.12 gal/yd^2) (CSS-1 emulsion diluted 1:1 with water). The fog seal was used to provide better resistance to skidding since the roadway includes shaded areas with sharp corners.

3.5 DESCHUTES COUNTY

In Deschutes County, an asphalt cement chip seal was constructed on Canal Boulevard in Redmond on August 11th. The work was done by Deschutes County's Road Department on a section of Canal Boulevard from the intersection of Yew Avenue to the intersection of Young Avenue, a distance of approximately three miles. The construction was observed from 9:30 a.m. to 2:00 p.m.

Canal Boulevard has an ADT between 2,600 and 3,200. The pavement had been chip sealed previously and was due for another chip seal. There was some minor rutting and random transverse cracking on the pavement (Figure 3.19). In one section, there was alligator cracking in the left wheel path and full width transverse cracks.

Figure 3.19: Canal Boulevard Prior to Chip Sealing

Because of the added costs, Deschutes County typically uses asphalt cement chip seals only on roads scheduled for double chip seals (double bituminous surface treatments) or on roadways with more distress and higher volumes. The overall operation included six trucks, two pneumatic tire rollers, a distributor truck with an operator (contracted), a sweeper, and a chip spreader. The project was flagged on each end with traffic being directed by a pilot car.

The 12.5 mm to 6.3 mm (½″ to ¼″) aggregate had been precoated with reportedly 0.75% PBA-5 by weight of aggregate in a drum mix plant. The cost was $8.62/Mg ($9.50/ton) for the chips and an additional $5.44/Mg ($6.00/ton)for the precoating. The chips were from the Lone Pine Pit. The asphalt cement (AC-15-5TR) was provided by Wright Asphalt Products Co.

The asphalt cement for the coated chips was shot at 2.05 l/m^2 (0.45 gal/yd^2). The coated chip application rate was 5 kg/m^2 (10 lbs/yd^2). The asphalt cement for the uncoated chips was increased to 2.28 l/m^2 (0.50 gal/yd^2) with a chip application rate of 6 kg/m^2 (11 lbs/yd^2). The temperature of the asphalt cement out of the spray bar averaged 154°C (310°F).

Throughout the operation, pavement temperatures ranged from 23 to 50°C (73 to 122°F). Air temperatures ranged from 21 to 28°C (69 to 82°F). The humidity ranged from 40 to 61% between 9:50 a.m. and 2:00 p.m.

The two pneumatic tire rollers used by Deschutes County Road Department made six passes when rolling. After rolling, the pavement was swept about a half hour later. The trucks did not drive ahead of the rollers as was observed in Lane and Clackamas Counties.

Near the intersection of McVey Avenue, in the northbound lane, uncoated chips were placed since the Road Department was out of coated chips. The aggregate appeared damp but dried out quickly when placed on the asphalt cement.

4.0 BEST CONSTRUCTION PRACTICES

Asphalt cement chip seals require care in construction. Best construction practices as identified in the literature and in 1999 project monitoring are discussed below.

4.1 MATERIAL CONSIDERATIONS

4.1.1 Aggregate

Aggregate should be clean and clear of excess fine material (less than 1% passing the 75 µm (#200) sieve). An effective way to ensure its cleanliness and to eliminate dust, is to precoat the aggregate with either an emulsified asphalt or an asphalt cement. Precoating involves running the aggregate through an asphalt plant and lightly coating the chips with asphalt. The target concentration of asphalt should be no greater than 1% by weight. Precoating also helps achieve a better bond between the asphalt cement sprayed on the roadway and the chips when they are applied to the roadway surface. Additionally, a chip seal with precoated aggregate provides a darker pavement surface and contrasts better with striping.

When precoating aggregate, there should be adequate time for cooling after the aggregate is coated. As mentioned earlier, the precoated aggregate used on U. S. Route 101 had not cooled to ambient temperatures. In this case, because of adequate available space, the stockpiles could be flattened and the chips could be spread and turned over several times before their use. Due to space constraints, accelerating the cooling process this way might not be possible. Therefore, adequate time is needed for the precoated chips to properly cool.

4.1.2 Asphalt Cement

The asphalt cement documented in this report was classified as AC-15-5TR. In Texas, the most common types of asphalt cement binders used by the Texas DOT include AC15-5TR, AC15P and AC5 *(Gransberg, et al. 1998)*. Since asphalt cements undergo no "chemical break," embedment of the aggregate and subsequent bonding to the asphalt cement is temperature-dependent (air and asphalt). For the asphalt cement chip sections constructed in Oregon, the temperature of the asphalt cement at the distributor bar ranged from 143 to 154°C (290 to 310°F). The air temperatures ranged from 14 to 34°C (58 to 93°F). The asphalt cement shot at these temperatures was suitable for good chip embedment and adequate bonding. Cool air or pavement temperatures (under 13°C (55°F)) can affect the binding characteristics of the asphalt by making it less tacky (sticky) and/or increasing its viscosity *(Wyckoff 1987)*. In hotter temperatures, even when the pavement surface temperature exceeds 60°C (140°F), asphalt cements have worked effectively.

4.2 EQUIPMENT CONSIDERATIONS

4.2.1 Asphalt Distributor

In Oregon, asphalt cement delivery and placement is generally contracted out rather than done in-house, because of the time and energy required to clean the distributor when the project is completed. In the sections evaluated for this report, the asphalt cement supplier, Wright Asphalt Products Co., used the same individual for each project to operate the asphalt distributor. Using the same operator for each chip seal section proved very instrumental in ensuring the asphalt cement was applied consistently at the correct rate, width and location.

Alternatively, on some of the sections, particularly the longer projects (greater than 4.8 km (3.0 mi)), using only one distributor resulted in some inefficiency. There was usually a 45-minute wait each time the distributor had to be refilled. If two distributors were available, chip seal operations could have continued while one distributor was being refilled by the asphalt tanker.

4.2.2 Chip Spreader

The chip spreader must be able to apply a uniform, even layer of aggregate across the width of the panel. On the U.S. Route 101 (MP 129.0 – MP 130.2) section, the chip spreader had problems when the aggregate bridged across some gate openings rather than falling freely. This bridging kept the aggregate from being spread evenly across the pavement width. As a result, the chip spreader was required at times, to make multiple passes over the same area, and the amount of handwork to spread chips evenly using shovels, lutes, and brooms increased significantly.

The chip spreader used by Lane County on OR Route 126 (MP 13.0 – MP 16.4 and MP 26.0 – MP 31.6) was equipped with computerized controls that adjusted the opening and closing of the gates based on the speed of the spreader. Lane County's chip spreader operated very effectively throughout the operation. Its application rate was uniform and there was no equipment downtime. Chip spreaders like Lane County's are very practical, especially when chip sealing on high volume/high speed roadways.

4.2.3 Rollers

Pneumatic rollers provided most of the rolling effort on each section. Clackamas County augmented two pneumatic rollers with a steel drum roller. On U. S. Route 101, rolling requirements were accomplished using one pneumatic roller, a single drum rigid frame roller, and a double drum rigid frame roller. It appears that no one combination worked more effectively than another. However with regard to rolling, there are several consistent themes, which if applied, can lead to successful rolling operations.

Rolling operations should be accomplished promptly. The rollers should operate closely behind the chip spreader. On OR Route 126, Lane County used its dump trucks to provide the initial compaction. At times, there were five trucks queued behind the chip spreader. The trucks staggered their wheel paths to ensure maximum coverage across the panel. Operating closely behind the trucks were two pneumatic rollers.

Well-timed rolling is even more critical in cooler temperatures and shaded areas. In shade, it is very important to quickly roll the panel to embed the chips into the binder and to orient them on their flat side before the asphalt cement cools too much. Also, during cooler weather it is essential that the rolling occur without delay.

4.2.4 Power Brooms

Before the asphalt cement is applied, the roadway should be swept to provide a clean surface. Sweeping with a power broom can be done using rotary sweepers or a pick-up sweeper. After an asphalt cement chip seal is in place and rolling completed, it is important to sweep the excess aggregate which has not embedded into the binder off the panel. In the sections evaluated for this report, rotary power brooms were used. The brooms were employed within one hour after the rolling was completed. Their timely operation resulted in traffic being allowed back on the roadway at normal speeds within a few hours of completion of the chip seal.

4.3 CONSTRUCTION CONSIDERATIONS

4.3.1 Asphalt Cement Application Rate

Application rates vary depending on a number of factors including:

- The size of the aggregate;
- Aggregate gradation, cleanliness and amount (if any) of precoating;
- The surface texture of the existing pavement; and
- Ambient air and pavement temperatures.

In the chip seals evaluated for this report, the application rates varied among the sites. They ranged from 0.82 to 2.28 l/m^2 (0.18 to 0.50 gal/yd^2). The application rates were determined in the field based on the judgement and experience of the crew supervisors. In areas where the underlying pavement was rich in asphalt content, a lower application rate was used. If the existing pavement's asphalt content was low, a higher application rate was used. Aggregate precoating was also a factor. Higher binder application rates were used with uncoated aggregate. Also, larger aggregate gradations required higher binder application rates because of the increased air voids and larger rock size. In shaded areas, the asphalt cement application rates were also raised to compensate for the lower temperatures.

4.3.2 Aggregate Spread Rates

The aggregate spread rates for the sections evaluated in this report were determined based on past experience. Generally, the spread rates ranged from 10 to 12 kg/m^2 (18 to 22 lbs/yd^2). In Deschutes County, the spread rates were much lower, 5 to 6 kg/m^2 (10 to 11 lbs/yd^2), because of the larger aggregate size (12.5 mm to 6.3 mm (½″ to ¼″)).

Although there are design methods and guidelines for spread rates, typically they are established by the crew supervisors, based on their previous experience and judgement. The spread rate should be set to provides enough aggregate on the roadway surface to prevent pick-up under traffic. On OR Route 126 (MP 13.0 – MP 16.4), pick-up did occur, primarily because of the bleeding of asphalt from the underlying pavement. To prevent pick-up, a choke aggregate, 6.3 mm to 2.1 mm (¼″ to #10), was applied to the surface.

Alternatively, when spreading chips, if too much is applied it may produce a surplus of aggregate on the shoulders after brooming. Too much aggregate will reduce embedment, and result in increased chip loss and greater potential for windshield damage. On U.S. Route 101, because of problems with the spreader, extra chips were used to ensure adequate coverage across the panel. As a result, a lot of excess aggregate was eventually swept off the roadway by the power brooms.

5.0 POST CONSTRUCTION MONITORING

5.1 ONE MONTH AFTER CONSTRUCTION

Each asphalt cement chip seal test section was inspected approximately one month after construction. The purpose of the inspections was to visually examine the chip seal and establish a baseline for chip retention, chip embedment and the overall condition of the roadway. On each section, digital images were taken of the pavement surface. A 305 mm x 305 mm (1 ft x 1 ft) template was used to mark an outline on the pavement surface. The images were taken at approximately 0.4 km (¼ mi) intervals in the wheel path of each travel lane. Figure 5.1 and 5.2 are two of the close-up pavement images taken on OR Route 16 and U.S. Route 101 one month after the chip seal construction.

Figure 5.1: Image of the Pavement Surface on OR Route 126

The position of each image was measured from a known point along the roadway and the information recorded in a database. Where each image was taken, a PK nail was driven into the pavement along the edge line to mark the site and the position was recorded in the database.

At each recorded position where an image was taken, the pavement surface will be reexamined at 12- and 24-months after construction. The inspection will include a visual examination to measure chip retention, exposed surface asphalt in the wheel track, and aggregate embedment in the wheel track. Skid resistance testing will also be done at the same intervals. The observations for each location and the results of the skid testing will be recorded in the database.

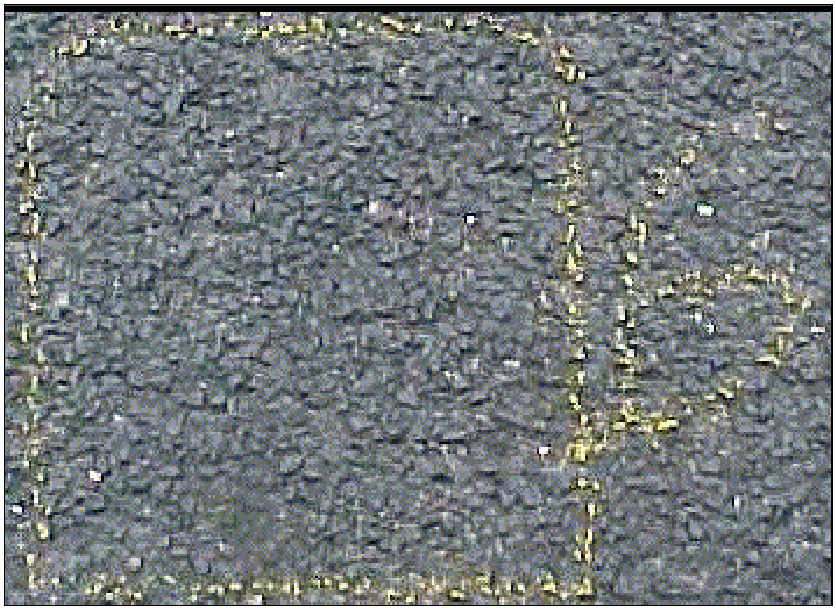


Figure 5.2: Image of the Pavement Surface on U.S. Route 101

Overall, after being open for traffic for about one month, each section looked very good. Chip retention was over 90 percent on all sections. In addition, there did not appear any noticeable areas where pick-up had occurred.

On OR Route 126 and U.S. Route 101 sections, skid resistance was measured after chip seal construction using the ODOT skid trailer test (ASTM E 274-90, "Standard Test Method for Skid Resistance of Paved Surfaces Using a Full-Scale Tire"). Results are presented in Appendix C. Within the chip sealed sections, all measurements were above 37. In Oregon, a skid number less than 37 at 64.4 km/hr (40 mph) indicates the pavement should be evaluated for potential skid resistance issues *(Sposito 98).*

The sections evaluated in 1999 will be inspected again in 2000 and 2001. A final report will be written after the inspection in 2001, documenting the performance of each section.

5.2 OR ROUTE 126 INSPECTION –APRIL 2000

In April 2000, ODOT District 5 maintenance personnel notified the Research Group about problems with the chip seal on OR Route 126 between MP 29.0 and MP 31.6. A meeting and on-site inspection was conducted on April 18, 2000. Between , MP 29.0 and MP 31.0, there were several locations where there was a significant chip loss in the wheel path. The condition was particularly conspicuous along curve sections (Figure 5.3).

In the area between MP 31.0 and MP 31.6, there was also a localized loss of chips (Figure 5.4). The chip loss was attributed to snow plow damage. The snow plow blades had peeled sections of the chip seal away in both lanes for much of the section.

Figure 5.3: Loss in Chips in the Wheel Path near MP 30.0

Figure 5.4: Loss of Chips Due to Snow Plow Damage at MP 31.6

There were several reasons suggested to account for the accelerated chip loss between MP 30.0 and MP 31.6. As discussed earlier in Section 3.1, the asphalt cement application rate between MP 26.0 and MP 31.6 was very low, 1.00 to 1.09 liters/m^2 (0. 22 to 0.24 gal/yd^2). With the low shot rate, there was not enough binder to provide adequate chip retention. From MP 29.0 to MP

31.6, the situation was exacerbated because more canopy shade covers the highway and there are more curves in this portion of the project.

It was also theorized that the loss in chips could be attributed to the variability in the underlying pavement surface. The previous year's chip seal failure resulted in some random variability in the amount of asphalt on the surface. Some segments were very rich and other areas were much leaner in residual asphalt.

Coupled together, the inconsistency in the asphalt content at the surface and the low shot rate of asphalt cement are viewed as contributing factors in the accelerated chip loss in random locations in this part of the project. Some sections between MP 29.0 and 31.6 show expected chip retention of 90% or more.

6.0 SUMMARY AND CONCLUSIONS

Monitoring the asphalt cement chip seal project construction process provided information on a wide range of conditions. Table 6.1 provides a summary of the average conditions encountered at each location.

Table 6.1: Summary Data

	OR Route 126	U. S. Route 101	Clackamas County	Deschutes County
ADT Range	4,400	18,500	4,800 to 37,200	2,600 to 3,200
Aggregate Size	9.5 mm to 6.3 mm (3/8″ to 1/4″)	9.5 mm to 6.3 mm (3/8″ to 1/4″)	12.5 mm to 6.3 mm (1/2″ to 1/4″)	12.5 mm to 6.3 mm (1/2″ to 1/4″)
Precoat Target (Actual)	0.75% - PBA-5 (1.21%)	0.60% - PBA-5 (1.70%)	1.80% - CSS-1 (1.12%)	0.75% - PBA-5 (0.51%)
Chip Application Rate	9 to 10 kg/m^2 (17 to 18 lbs/yd^2)	10 kg/m^2 *-Target* (18 lbs/yd^2)	10 to 12 kg/m^2 (18 to 23 lbs/yd^2)	5 to 6 kg/m^2 (10 to 11 lbs/yd^2)
Asphalt Application Rate	1.59 to 1.00 liters/m^2 (0.35 to 0.22 gal/ yd^2)	1.73 to 1.82 liters/m^2 (0.38 to 0.40 gal/yd^2)	2.05 to 2.28 liters/m^2 (0.45 to 0.50 gal/yd^2)	2.05 to 2.28 liters/m^2 (0.45 gal/yd^2)
Ambient Air	21 to 33°C (69 to 92°F)	16 to 19°C (60 to 66°F)	21 to 33°C (70 to 92°F)	21 to 28°C (69 to 82°F)
Pavement Temperature	17 to 54°C (63 to 130°F)	14 to 32°C (57 to 89°F)	15 to 53°C (59 to 128°F)	23 to 50°C (73 to 122°F)
Humidity	30 to 50%	56 to 63%	30 to 53%	40 to 61%
Average Asphalt Cement Delivery Temperature	146°C (295°F)	155°C (311°F)	147°C (297°F)	154°C (310°F)
Average Time Between Distance and Spreader	55 sec	12 sec	40 sec	51 sec
Average Time Between Spreader and 1st Roller*	95 sec	119 sec	59 sec	85 sec
Average Cost	Not Available	\$3.10/m^2 (\$2.59/yd^2)	\$1.14/m^2 (\$0.95/yd^2)	\$0.85/m^2 (\$0.71/yd^2)

* Initial rolling was often done by haul trucks.

The information gathered from the monitored projects was reinforced in the literature and should be considered for future asphalt cement chip seals. Most importantly:

- Asphalt cement chip seals are suitable as a preventive maintenance treatment for roads where traffic impacts need to be minimized. Because the chips embed quickly, traffic may be allowed on the sealed pavement sooner than an emulsified asphalt chip seal.

- An aggregate precoat is recommended to ensure a good bond. The precoating also provides a better contrast between the pavement and striping. If possible, the precoating amount should be monitored so adjustments may be made to reach the intended target.

- Initially, it was speculated that asphalt cement chip seals could be applied over a wider range of temperatures than emulsified asphalt seals. However, cool temperatures and pavement temperatures (under 13°C (55°F)) may impact embedment and bonding.

- Construction equipment requirements should be matched to the size of the project to insure continuous operation to minimize traffic impacts. The chip spreader used on U.S. Route 101 slowed construction since the equipment was not fully automated. Also, two of the monitored projects were stopped during construction to refill the distributor truck. Finally, the lead workers on several of the projects stated they could have used an additional roller to better keep up with the chip spreader.

Asphalt cement chip seal construction is an art. Initial application rates are based on experience and visual acceptance that may require adjustments based on field conditions. Expect each project to be unique as was experienced with the projects monitored in 1999.

Initial inspections of the completed projects looked very good with over 90% chip retention after one month. One project that included an asphalt cement chip seal over a previously failed asphalt cement chip seal had scattered areas with chip loss. This project is considered unique, however, and not indicative of expected performance of the other projects. Longer-term field performance will continue to be monitored over the next two years. The results will be documented in a final report in 2001.

7.0 REFERENCES

Beecroft, Gordon, Thomas Hardy, and Richard J. Steyskal. *Evaluation of Rubber-Asphalt Chip Seals in Oregon*. Final Report for Federal Highway Administration Demonstration Projects Division, Contract DOT-FH-15-201, Oregon Department of Transportation, Salem, OR., 1982.

Burke, William E. *User's Guide: Double Bituminous Surface Treatment*. Miscellaneous Paper GL-94-29, Agency Report No. FEAP-UG-94/01, U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS., 1994.

Center for Advanced Transportation Research. *Pavement Maintenance Effectiveness – Preventive Maintenance Treatments*l. Publication No. FHWA-SA-96-027, U.S. Department of Transportation, Federal Highway Administration, Washington, D.C., 1996.

Freeman, Thomas J. and Elias H. Rmeili. *Development and Construction of the Texas Supplemental Maintenance Effectiveness Research Program (SMERP)*. Research Report 1981-1F, Texas Transportation Institute, College Station, TX., 1994.

Freeman, Thomas J. *Results of the Seventy Two Month Evaluation of the Texas Supplemental Maintenance Effectiveness Research Program (SMERP) Sites*. Research Report 0645-3F, Texas Transportation Institute, College Station, TX., 1999.

Gransberg, Douglas, Sanjaya Senadheera, and Ilker Karaca. *Analysis of Statewide Seal Coat Constructability Review*. Interim Report, Departments of Engineering Technology and Civil Engineering, Texas Tech University, Lubbock, TX.,1998.

Jackson, Dennis, Newton Jackson, and Joe P. Mahoney. *Washington State Chip Seal Study*. Transportation Research Record 1259, TRB, National Research Council, Washington, D.C., 1990, pp. 1-10.

Janisch, David W. and Frank S. Gaillard. *Minnesota Seal Coat Handbook*. Report No. MN/RC –1999-07, Minnesota Department of Transportation, St. Paul, MN., 1999.

Kandhal, Prithvi and John B. Motter. *Criteria for Accepting Precoated Aggregates for Seal Coats and Surface Treatments*. Transportation Research Record 1300, TRB, National Research Council, Washington, D.C., 1991, pp. 80-89.

Karaca, Ilker, Douglas Gransberg, Douglas, and William R. Burkett. *Seal Coat Evaluation Using Information Theory*. Draft Paper for the Texas Department of Transportation, 1999.

Sposito, Brett. *Comparison of Skid Resistance Testing to Stopping Distance Testing*. Report No. OR-RD-98-13, Oregon Department of Transportation, Salem, OR., 1998.

Wyckoff, Coleman P. Asphalt Seal Coats – *Factors Affecting and Techniques for Obtaining Consistently Good Seal Coats*. Report No. WA-RD 136.1, Washington Department of Transportation, Olympia, WA., 1987.

APPENDIX A

SUMMARY OF CHIP SEAL OPERATIONS

Summary of Chip Seal Air Temperature and Humidity Readings at OR Route 126; MP 13.0 – MP 15.0

Time	Air Temperature (°C)	Air Temperature (°F)	Relative Humidity %	Surface Temperature of Existing Pavement (°C)	Surface Temperature of Existing Pavement (°F)
8:00 a.m.	16	62	42	24	75
9:00 a.m.	20	68	38	28	82
10:00 a.m.	21	70	37	33	91
11:00 a.m.	21	70	36	39 21 (shade)	102 70 (shade)
12:00 noon	21	70	35	43	109
1:00 p.m.	24	75	32		
2:00 p.m.	26	79	30		

Summary of Chip Seal Operations on OR Route 126; MP 15.0 – MP 16.4

Location of the Start of the Pass	Lane ID	Start Time	Temperature of Existing Pavement		Temperature of the Oil at Distributor Spreader Bar		Temperature of Oil on Pavement Before Chip Spreader		Time Measured Between Distributor and Chip Spreader	Temperature of Mat Before Roller		Time Measured Between Chip Spreader and Roller	Oil Application Rate (10^{-2})	
			(°F)	(°C)	(°F)	(°C)	(°F)	(°C)		(°F)	(°C)		gal/ yd^2	L/m^2
MP 15.0	WB	8:40 a.m.	76	24	286	141	111	44	32 sec	81	27	90 sec	22	100
MP 15.0 (shade areas)	EB	8:50 a.m.	77	25	288	142	101	38	38 sec	92	33	20 sec	24	109
MP 15.0	Center Turn Lane at School	9:00 a.m.	83	28	290	143	130	54	40 sec	100	38	50 sec	30	137
40726 Hwy 126	WB	9:20 a.m.	87	31	300	149	142	61	40 sec	106	41	88 sec	22	100
40726 Hwy 126	EB	10:00 a.m.	91	338	290	143	120	49	40 sec	104	40	120 sec	22	100
MP 16.0	WB	10:20 a.m.	95	35	304	151	120	499	155 sec	102	39	90 sec	28	127
MP 16.0	EB	10:40 a.m.	94	34	305	152	122	50	40 sec	102	39	140 sec	22	100
Lane Creek	EB	11:00 a.m.	106	41	280	138	120	49	160 sec	100	38	20 sec	22	100

Summary of Chip Seal Operations on OR Route 126; MP 26.0 – MP 31.6

Location of the Start of the Pass	Lane ID	Start Time	Temperature of Existing Pavement		Temperature of the Oil at Distributor Spreader Bar		Temperature of Oil on Pavement Before Chip Spreader		Time Measured Between Distributor and Chip Spreader	Temperature of Mat Before Roller		Time Measured Between Chip Spreader and Roller	Oil Application Rate (10^{-2})	
			(° F)	(° C)	(° F)	(° C)	(° F)	(° C)		(° F)	(° C)		gal/yd²	L/m²
MP 27.1 (shade areas)	WB	8:25 a.m.	62 (shade)	17 (shade)	297	147	114	46	35 sec	86	30	105 sec	22	100
MP 27.1	EB	8:50 a.m.	79 (sun)	26 (sun)	300	149	103	39	78 sec	84	29	20 sec	22	100
MP 27.1	Passing Lane	9:05 a.m.	80	27	301	149	104	40	74 sec	88	31	50 sec	28	127
46151 Hwy 126; MP 27.8	WB	9:50 a.m.	73 (sun) 65 (shade)	23 (sun) 18 (shade)	295	146	115	46	38 sec	83	28	190 sec	24	109
46151 Hwy 126; MP 27.8	EB	10:10 a.m.	70 (sun) 66 (shade)	21 (sun) 19 (shade)	296	147	190	88	15 sec	Not recorded	Not recorded	Not recorded	24	109
46421 Hwy 126	WB	10:20 a.m.	100	38	296	147	170	77	30 sec	110	43	240 sec		
46421 Hwy 126	EB	11:30 a.m.	116 (sun) 74 (shade)	47 (sun) 23 (shade)	294	146	151	66	30 sec	113	45	150 sec		
MP 29.3	WB	11:50 a.m.	114 (sun) 89 (shade) 73 (canopy shade)	46 (sun) 32 (shade) 23 (canopy shade)	291	144	143	62	42 sec	120	49	55 sec	24	109
MP 29.3	EB	12:35 p.m.	133	45	296	147	154 (sun) 137 (shade)	68 (sun) 58 (shade)	40 sec	118	48	240 sec	22	100
MP 30.0	WB	1:00 p.m.	130	54	297	147	142	61	58 sec	111	44	99 sec		
MP 30.0	EB	1:55 p.m.	112 79 (shade)	44 26 (shade)	295	146	119	48	80 sec	120 (sun) 95(shade)	49 (sun) 35 (shade)	75 sec		
48039 Hwy 126; MP 31.3	WB	2:35 p.m.	115 (sun) 104 (shade)	46 (sun) 40 (shade)	305	152	155	68	35	114 (sun) 111 (shade)	46 (sun) 44 (shade)	45 sec		
48039 Hwy 126; MP 31.3	EB	2:45 p.m.	110 95 (shade)	43 (sun) 35 (shade)	290	143	142	61	45	106	14	20 sec		

Summary of Chip Seal Operations on U. S. Route 101; MP 129.0 – MP 130.2

Location of the Start of the Pass	Lane ID	Start Time	Temperature of Existing Pavement		Temperature of the Oil at Distributor Spreader Bar		Temperature of Oil on Pavement Before Chip Spreader		Time Measured Between Distributor and Chip Spreader	Temperature of Mat Before Roller		Time Measured Between Chip Spreader and Roller	Oil Application Rate (10^{-2})	
			(° F)	(° C)	(° F)	(° C)	(° F)	(° C)		(° F)	(° C)		gal/yd^2	L/m^2
Otter Crest Loop	NB	11:20 a.m.	57 (shade) 72 (sun)	14 (shade) 22 (sun)	290	143	127	53	28 sec	94	34	70 sec	38	173
30 m south of the “Slippery When Wet” traffic sign	NB	11:30 a.m.	Not recorded	Not recorded	298	148	240	116	9 sec	95	35	83 sec	40	182
30 m south of intersection with wayside access drive	NB	11:45 a.m.	57	14	320	160	230	110.0	8 sec	88	31	120 sec	40	182
At “Do Not Pass Sign”	NB	12:00 noon.	61	16	315	157	220	104	9 sec	110	43	65 sec	40	182
At Divided Highway sign (located adjacent to SB shoulder)	NB	12:20 p.m.	57	14	305	152	195	91	15 sec	88	31	97 sec	40	182
MP 129.2	NB	12:35 p.m.	85	29	315	157	279	137	6 sec	85	29	240 sec	40	182
MP 129.1	NB	12:50 p.m.	85	29	295	146	225	107	8 sec	95	35	80 sec	40	182
MP 129.0	SB	1:50 a.m.	78	26	311	155	238	114	10 sec	100	38	68 sec	40	182
MP 129.4	SB	2:25 p.m.	79	26	320	160	250	121	9 sec	101	38	160 sec	40	182
At wayside park entrance	SB	2:45 p.m.	89	32	337	169	191	88	18 sec	105	41	202 sec	40	182

Summary of Chip Seal Operations on Foster Rd. (Clackamas County)

Location of the Start of the Pass	Lane ID	Start Time	Temperature of Existing Pavement		Temperature of the Oil at Distributor Spreader Bar		Temperature of Oil on Pavement Before Chip Spreader		Time Measured Between Distributor and Chip Spreader	Temperature of Mat Before Roller		Time Measured Between Chip Spreader and Roller	Oil Application Rate (10^{-2})	
			(° F)	(° C)	(° F)	(° C)	(° F)	(° C)		(° F)	(° C)		gal/yd^2	L/m^2
90 m N of the intersection of SE Hemrick Rd.	NB	9:25 a.m.	59 (shade) 61 (sun)	15 (shade) 16 (sun)	295	146	190	88	10 sec	95	35	32 sec	45	205
18160 Foster Rd (1/4 mile from county line)	NB	10:15 a.m.	Not recorded	Not recorded	306	152	210	99	10 sec	90	32	45 sec	45	205
County Line	SB	10:30 a.m.	69 (shade) 94 (sun)	21 (shade) 34 (sun)	310	154	215	102	21 sec	96	36	27 sec	45	205
18440 Foster Rd.	SB	11:00 a.m.	101	38	306	152	248	120	11 sec	100	38	53 sec	45	205
180 m N of the intersection of Troge Rd.	NB	1:00 p.m.	125	52	290	143	215	102	31 sec	115	46	120 sec	47	209
60 m S of 19501 Foster Rd.	NB	1:45 p.m.	123	51	307	153	203	95	30 sec	108	42	42 sec	45	182
At intersection of Troge Rd.	SB	2:12 p.m.	121	49	297	147	154	68	92 sec	Not recorded	Not recorded	20 sec	45	205
40 m N of 20160 Foster Rd.	SB	2:50 p.m.	78	26	302	150	131	55	85 sec	91	33	35 sec	45	205
Halfway between Troge and Vogel	NB	3:00 p.m.	128	53	306	152	204	96	23 sec	107	42	107 sec	45	205
15 m south of 20125 Foster Rd.	NB	4:00 p.m.	121	49	297	147	192	89	35 sec	112	44	75 sec	45	205

Summary of Chip Seal Operations on Sunnyside Rd. (Clackamas County)

Location of the Start of the Pass	Lane ID	Start Time	Temperature of Existing Pavement		Temperature of the Oil at Distributor Spreader Bar		Temperature of Oil on Pavement Before Chip Spreader		Time Measured Between Distributor and Chip Spreader	Temperature of Mat Before Roller		Time Measured Between Chip Spreader and Roller	Oil Application Rate (10^{-2})	
			(° F)	(° C)	(° F)	(° C)	(° F)	(° C)		(° F)	(° C)		gal/yd^2	L/m^2
At the intersection of Youngs Lane	WB	10:40 a.m.	104	40	299	148	196	91	35 sec	101	38	105 sec	45	205
17505 Sunnyside	WB	11:00 a.m.	101	38	291	144	128	53	60 sec	83	28	30 sec to 180 sec	48	218
At the intersection of 172^{nd}	EB	12:00 noon	114	46	298	148	182	83	35 sec	94	34	79 sec	45	205
At the intersection of Youngs Lane	EB	12:55 p.m.	80	27	289	143	146	63	36 sec	92	33	54 sec	45 to 47 (on hill)	205 to 214 (on hill)

Summary of Chip Seal Operations on 232Nd Ave. (Clackamas County)

Location of the Start of the Pass	Lane ID	Start Time	Temperature of Existing Pavement		Temperature of the Oil at Distributor Spreader Bar		Temperature of Oil on Pavement Before Chip Spreader		Time Measured Between Distributor and Chip Spreader	Temperature of Mat Before Roller		Time Measured Between Chip Spreader and Roller	Oil Application Rate (10^{-2})	
			(° F)	(° C)	(° F)	(° C)	(° F)	(° C)		(° F)	(° C)		gal/yd^2	L/m^2
Approx. MP 1	SB	10:07 a.m.	69 (shade) 94 (sun)	21 (shade) 34 (sun)	311	155	146	63	56 sec	84	29	34 sec	48	218
16969 232nd Ave.	SB	10:54 a.m.	103	39	279	137	150	66	33 sec	94	34	30 sec	48	218
60 m south of Ondo Dr.	NB	11:52 a.m.	114	46	302	150	205	96	45 sec	92	33	40 sec	50	228
15 m south of the intersection of Blue Ridge Dr.	NB	12:08 p.m.	119	48	298	148	179	82	39 sec	103	39	38 sec	50	228

Summary of Chip Seal Operations on Wilsonville Rd. (Clackamas County)

Location of the Start of the Pass	Lane ID	Start Time	Temperature of Existing Pavement		Temperature of the Oil at Distributor Spreader Bar		Temperature of Oil on Pavement Before Chip Spreader		Time Measured Between Distributor and Chip Spreader	Temperature of Mat Before Roller		Time Measured Between Chip Spreader and Roller	Oil Application Rate (10^{-2})	
			(° F)	(° C)	(° F)	(° C)	(° F)	(° C)		(° F)	(° C)		gal/yd^2	L/m^2
Approx. MP 2.0	EB	Not recorded	73	23	280	138	220	104	27 sec	88	31	30 sec	50	228
14900 Wilsonville Rd.	WB	12:20 p.m.	105	41	280	138	202	94	30 sec	102	39	26 sec	50	228
14900 Wilsonville Rd.	EB	1:10 p.m.	120	49	286	141	179	82	50 sec	106	41	48 sec	50	228
Approx. MP 3.0	EB	3:00 p.m..	124	51	299	148	123	51	83 sec	90	32	30 sec	50	228

Summary of Chip Seal Operations on Canal Boulevard (Deschutes County)

Location of the Start of the Pass	Lane ID	Start Time	Temperature of Existing Pavement		Temperature of the Oil at Distributor Spreader Bar		Temperature of Oil on Pavement Before Chip Spreader		Time Measured Between Distributor and Chip Spreader	Temperature of Mat Before Roller		Time Measured Between Chip Spreader and Roller	Oil Application Rate (10^{-2})	
			(° F)	(° C)	(° F)	(° C)	(° F)	(° C)		(° F)	(° C)		gal/yd^2	L/m^2
80 m N of the intersection of SW 39th Street	NB	9:50 a.m.	73	23	317	158	162`	72	34 sec	76	24	44 sec	45	205
80 m N of the intersection of SW 39th Street	SB	10:15	76	24	312	156	152	67	32 sec	86	30	105 sec	45	205
40 m S of the intersection of 43rd Avenue	NB	11:24	80	27	304	151	152	67	38 sec	90	32	106 sec	45	205
300 m N of the intersection of Helmholtz Way	NB	12:50 p.m.	116	47	319	159	174	79	62 sec	91	33	31 sec	45	205
300 m N of the intersection of Helmholtz Way	SB	1:05 p.m.	115	46	309	154	186	86	53 sec	100	38	108 sec	45	205
30 m S of the intersection of McVey Ave.	NB	1:51 p.m.	120	49	305	152	163	73	90 sec	104	40	85 sec	50	228
30 m S of the intersection of McVey Ave.	SB	2:05 p.m.	122	50	304	151	192	89	48 sec	111	44	116 sec	50	228

APPENDIX B

LAB TESTING RESULTS

Highway	Sieve Analysis (ODOT TM 204/205)	Percent Asphalt Content of Aggregate (AASHTO TP 53)	Percent of Fractured Particles (ODOT TM 213)
OR Route 126 (MP 13.0 – MP 15.0)	Within Limits	1.29	99.0
OR Route 126 (MP 15.0 – MP 16.4)	Within Limits	1.21	98.6
OR Route 126 (MP 26.0 – MP 31.6)	Within Limits	1.12	98.6
U.S. Route 101	Within Limits	1.70	100.0
Sunnyside Road	Not Tested	Not Tested	Not Tested
Foster Road	Within Limits	1.20 (sample 1) 1.04 (sample 2)	99.1 (sample 1) 99.9 (sample 2)
232nd Avenue	Not Tested	Not Tested	Not Tested
Wilsonville Road	Within Limits	Uncoated Chips	99.9
Canal Boulevard	Not Tested	0.51	Not Tested

APPENDIX C
SKID TEST RESULTS FOR OR ROUTE 126 AND U. S. ROUTE 101

Skid Tests on OR Route 126 - 11/02/99		
Milepoint	**Test Direction**	**Adjusted Skid Number**
13.25	EB	48.30
13.74	EB	47.10
14.26	EB	39.40
14.76	EB	49.60
15.27	EB	46.60
15.75	EB	49.40
17.05	EB	48.10
26.52	EB	49.90
26.98	EB	49.00
27.49	EB	54.00
28.00	EB	51.20
28.50	EB	54.30
29.00	EB	54.20
29.43	EB	55.20
29.86	EB	51.70
30.31	EB	52.80
30.76	EB	51.20
32.08	EB	53.60
31.96	WB	49.50
31.27	WB	50.70
30.77	WB	54.10
30.25	WB	49.10
29.75	WB	51.30
29.23	WB	55.50
28.74	WB	52.00
28.24	WB	54.50
27.75	WB	54.10
27.25	WB	53.20
26.73	WB	52.40
26.35	WB	59.10
17.00	WB	42.00
15.75	WB	48.00
15.25	WB	49.70
14.76	WB	50.10
14.25	WB	48.60
13.75	WB	45.10
13.25	WB	43.40

Skid Tests on U.S. Route 101 - 9/23/99		
Milepoint	**Test Direction**	**Adjusted Skid Number**
128.99	SB	51.4
129.05	SB	53.2
129.13	SB	52.5
129.22	SB	52.0
129.35	SB	53.1
129.47	SB	52.8
129.61	SB	51.5
129.77	SB	55.2
130.17	NB	51.9
129.99	NB	50.8
129.84	NB	54.6
129.65	NB	52.9
129.53	NB	53.4
129.40	NB	51.5
129.24	NB	53.1
129.07	NB	52.5
128.93	NB	37.6