# CRUMB RUBBER MODIFIED ASPHALT CONCRETE IN OREGON

## Final Report

### SPR 355

# CRUMB RUBBER MODIFIED
# ASPHALT CONCRETE IN OREGON

**Final Report**

**SPR 355**

by

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Prepared for

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16. Abstract

Since 1993, the Oregon Department of Transportation (ODOT) has been monitoring performance of seventeen rubber modified asphalt and asphalt concrete sections constructed on Oregon highways. The study originated in response to the Intermodal Surface Transportation Efficiency Act (ISTEA, 1991) which mandated the use of tire rubber in pavements. The ISTEA requirement was eventually repealed, however, the study continued to document pavement performance in an effort to determine if rubber modified asphalt concrete pavements are feasible in terms of construction and life cycle cost.

The rubber modified sections that performed the worst included those constructed using the dry process (rubber modified asphalt concrete—RUMAC). The sections performing the best included open graded mixes constructed using the binder PBA-6GR (a rubber modified asphalt). After five years, the PBA-6GR pavements were performing as well or better than the control sections. The cost of the mixes constructed in 1993 and 1994 with PBA-6GR was about 12% more than the control sections. Over the life of the pavement, the terminal blend asphalt rubber (PBA-6GR) may be cost effective.

This report documents the performance of the rubber modified and control sections including distress information, skid and ride data and laboratory testing results. In addition, non-ODOT projects were reviewed and discussed.


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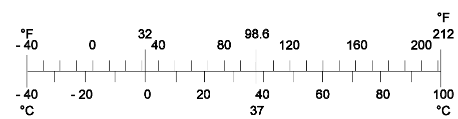
# SI* (MODERN METRIC) CONVERSION FACTORS

## 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 squared | $mm^2$ |
| $ft^2$ | 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 squared | $km^2$ |
| | | **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 | 1.8C + 32 | Fahrenheit | °F |




* SI is the symbol for the International System of Measurement

(4-7-94 jbp)

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## CRUMB RUBBER MODIFIED ASPHALT CONCRETE IN OREGON

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# 1.0 INTRODUCTION

## 1.1 BACKGROUND

Mountains of discarded tires present health and safety hazards and disposal difficulties. The Intermodal Surface Transportation Efficiency Act of 1991 mandated states to incorporate waste tires into asphalt mixes (*ISTEA 1991*). In response, the Oregon Department of Transportation (ODOT) initiated a 1993 study to determine the most effective rubber-modified hot mix asphalt concrete (HMAC) to meet the intent of ISTEA. The mandate has since been repealed; there is still interest, however, in determining if there are any cost effective rubber-modified systems that may improve pavement performance.

ODOT has constructed 17 sections (13 projects) of pavements that have incorporated ground tire rubber into HMAC. The projects were constructed between 1985 and 1994. The project locations are shown in Figure 1.1.

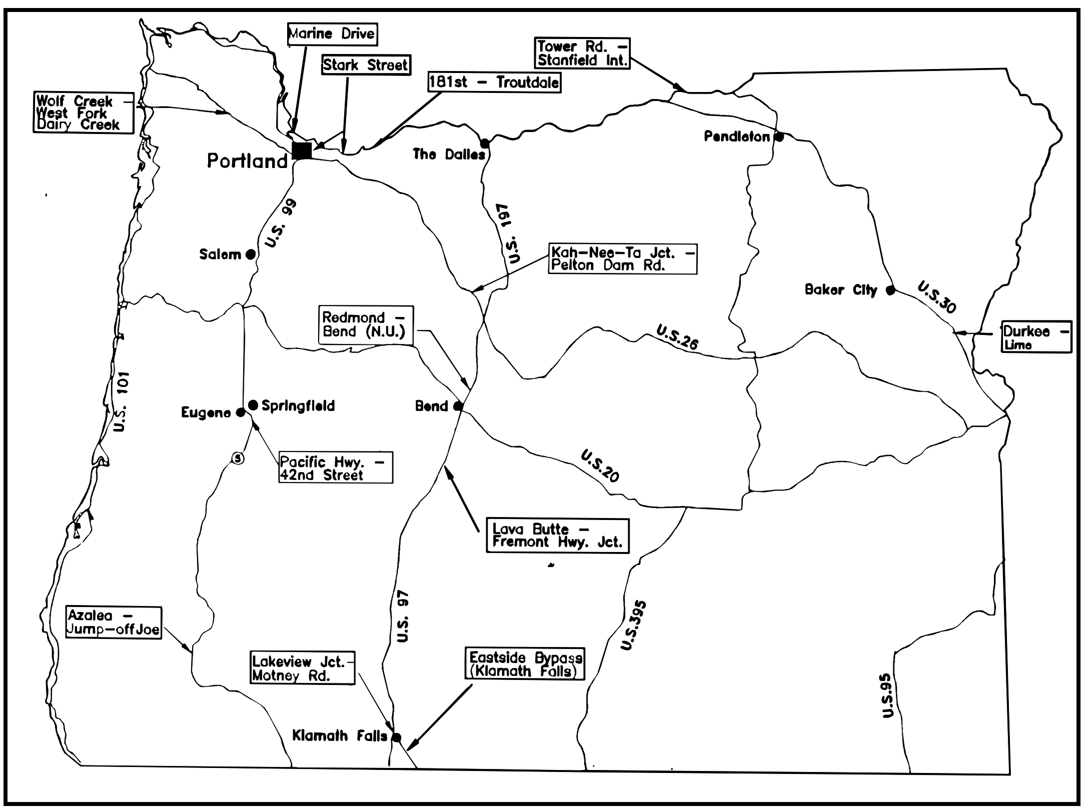


Figure 1.1: Location of crumb rubber modified asphalt concrete projects

## 1.2 RESEARCH OBJECTIVE

The objective of this research was to evaluate the performance of various crumb rubber modified (CRM) mixes in both Oregon and other locations in the U.S. and Canada. The projects discussed in this report used rubber in either a wet process (in which the rubber is blended with the asphalt cement) or a dry process (in which the rubber is added to the aggregate). Open graded mixes were evaluated with asphalt rubber (wet process) and dense graded mixes were evaluated with asphalt rubber (wet process) and rubber added to the aggregate (dry process). All projects were built with controls of similar mixes without rubber.

Table 1.1 describes the materials used by ODOT. For the ODOT, projects data collection included the following:

- Condition survey data;
- Rut and friction data; and
- Field core laboratory data, including void content and stripping data.

For projects in other states and Canada, field performance information was obtained about the CRM mix performance.

**Table 1.1: CRM products used in Oregon**

| Arm-R-Shield | |
|---|---|
| **Description** | **Comments** |
| A modified asphalt cement containing ground and dissolved tire rubber (wet process). | The binder consisted of 80% Chevron AR-4000W asphalt, 19% ground rubber, and 1% extender oil, by weight of asphalt cement. The binder was blended in a special truck on the jobsite by Arizona Refining, Inc. (Miller 1990). |
| **ISI ARC** | |
| **Description** | **Comments** |
| International Surfacing Inc. Asphalt Rubber Cement (ISI ARC): A modified asphalt containing ground and dissolved tire rubber (wet process). | The base asphalts used for the ISI ARC (Type II) included AC-5 and PBA-2. The ARC included 77 to 81% asphalt; 17 to 19% rubber; and 0 to 6% extender oil (Miller 1992, Hunt 1999, Hunt 1995). |
| **PRARC** | |
| **Description** | **Comments** |
| Powdered Rubber Asphalt Rubber Cement (PRARC): A modified asphalt containing powdered rubber (wet process). | The base asphalt used to produce the PRARC was PBA-2. The PRARC included 79% asphalt, 15% rubber, and 6% extender oil. Natural rubber was supplied for the project as opposed to tire rubber. The binder was blended at the jobsite in a special truck provided by ISI. This material was tested as a "generic" comparison to ISI ARC (Hunt 1999). |
| **PBA-6GR** | |
| **Description** | **Comments** |
| Performance Based Asphalt with Ground Rubber (PBA-6GR): A powdered rubber modified asphalt (wet process) which meets the specifications for PBA-6 with two modifications: the Kinematic Viscosity on Original Binder specification may be deleted if the Contractor assumes responsibility for pumpability; and the ductility on the RTFO aged residue is deleted. | PBA-6GR is currently being produced by U.S. Oil and Refining Company in Tacoma, Washington. The material includes approximately 10-12% rubber as the only modifier. The powdered rubber (80-minus) and binder is blended at the refinery then delivered to the jobsite in the same manner as conventional asphalt (Hunt 1995). |

**Table 1.1 (continued): CRM products used in Oregon**

| Plus Ride® 12 | |
|---|---|
| **Description** | **Comments** |
| A dry process, which includes gap graded mineral aggregate, and granulated tire rubber produced by the shearing technique. The system is a patented design. | The material includes AC-20 asphalt with 3% rubber by weight of the mix. The rubber was added to the aggregate in the batch plant prior to mixing (Miller 1990). |
| **METRO RUMAC** | |
| **Description** | **Comments** |
| METRO Rubber Modified Asphalt Concrete (METRO RUMAC): A dry process developed for the Oregon Department of Environmental Quality and The Metropolitan Services District of the Portland metropolitan area. The system incorporates crumb rubber from recycled tires into dense-graded asphalt concrete. | RUMAC mix included 1.5% to 2% rubber by weight of total mix with PBA-2, 3 or 5 asphalt. The METRO RUMAC design specifies a rubber content of 2%, however, on two projects the rubber content had to be reduced to 1.5% to obtain a satisfactory mix. The rubber was added to the aggregate at the plant prior to mixing (Miller 1992, Miller 1995). |

# 2.0 NON-ODOT PROJECTS

## 2.1 OREGON AND WASHINGTON PROJECTS

The performance of non-ODOT and Washington State DOT (WSDOT) pavements that included rubber were initially documented in the CRM summary report (*Hunt 1995*). The projects were evaluated again in 1999, and the findings are presented in Tables 2.1 and 2.2. Comments for the WSDOT projects were provided by WSDOT staff.

The wet process projects included pavements constructed using the ISI process and PBA-6GR binder. Review of the projects revealed inconsistencies in the performance of Washington's ISI projects. Two of the five WSDOT ISI projects experienced rutting with six years of contruction. The Oregon county ISI projects appeared to be performing adequately, which could be a function of lower average daily traffic (ADT) compared to WSDOT projects. The WSDOT PBA-6GR projects appeared to be performing as well as the control sections. Since the oldest section was less than eight years old at the time of the evaluation, additional time is required to determine if there is a difference between the two binders and if the addition of rubber is cost effective.

Dry process projects reviewed included the PlusRide process. Low ADTs may also have affected the favorable performance of the PlusRide projects constructed by Benton County and the City of Corvallis. PlusRide experience at ODOT and other DOTs has not been as favorable.

**Table 2.1: Oregon and Washington DOT project summary for CRM mixes (Wet Process)**

| Date of Construction Year | Project Identification | | Mix Type[1] | Process | Comments |
|---|---|---|---|---|---|
| | Agency | Location | | | |
| 1982 | WSDOT | Evergreen Point Bridge - SR-908 | E | Wet (ISI)[2] | Lasted 15 years under severe traffic conditions. Good to Fair Structural Rating. Rutting and raveling were major problems in the latter years. Exceptional performance for an open-graded pavement under severe traffic conditions. |
| 1984 | WSDOT | S-Curve/Cedar River Bridge & RR Bridge | E | Wet (ISI)[2] | Service life was estimated to be about 8-9 years as determined by PMS. Section was realigned and replaced with PCCP in 1995. |
| 1986 | WSDOT | Columbia R - 39th Street | E | Wet (ISI)[2] | Lasted 11 years. Poor performance with rutting a major problem after only 6 years of service. |

[1] Mix types: B = Dense graded mix, maximum size 1" (25 mm); C = Dense graded mix, maximum size ¾" (19 mm); E = Open graded mix, maximum size ¾" (19 mm): Gap = gap graded.
[2] The wet process used by WSDOT was the "Arizona Process."

**Table 2.1 (continued): Oregon and Washington DOT project summary for CRM mixes (Wet Process)**

| Date of Construction Year | Project Identification | | Mix Type[1] | Process | Comments |
|---|---|---|---|---|---|
| | Agency | Location | | | |
| 1990 | WSDOT | Armstrong Rd. | E | Wet (ISI)[2] | Ten-year service life to date. Moderate rutting a problem after only 4 years of service. |
| 1992 | WSDOT | 22nd St. | E | Wet (ISI)[2] | Nine-year service life to date. Rutting still not a problem. Better than average performance. Low traffic volumes and no studded tires. |
| 1992 | WSDOT | Lewis County Line to SR 12 | Open | PBA-6 | Good performance, 9 mm (0.35 in) of rutting. |
| 1992 | WSDOT | Lewis County Line to SR 12 | Open | PBA-6GR | Very good performance, 4 mm (0.16 in) of rutting. WSDOT's first PBA-6GR. Too much binder was used, but it is still performing well. |
| 1993 NB/ 1994 SB | WSDOT | Nisqually River to Gravelly Lake | Dense | PBA-6 | Very good performance, 2-3 mm (0.08-0.12 in) of rutting. |
| 1993 NB/ 1994 SB | WSDOT | Nisqually River to Gravelly Lake | Dense | PBA-6GR | Very good performance, 4 mm (0.16 in) of rutting. |
| 1993 NB/ 1994 SB | WSDOT | Nisqually River to Gravelly Lake | Dense | AR4000W | Very good performance, 2-4 mm (0.08-0.16 in) rutting. |
| 1993 EB & WB | WSDOT | West Ellensburg I/C to Ryegrass Rest Area | Open | PBA-6 | Good performance, 3 mm (0.12 in) of rutting. |
| 1993 EB & WB | WSDOT | West Ellensburg I/C to Ryegrass Rest Area | Open | PBA-6GR | Good performance, 4 mm (0.16 in) of rutting. |
| 1989 | Jackson County | Mill Creek Drive | C | Wet (ISI) | No surface defects noted. |
| 1991 | Jackson County | Butte Falls Road | Gap | Wet (ISI) | No surface defects or major maintenance required. Pavement placed at ½ of design thickness 12.5 mm (1.5 in) which may have contributed to pavement separating. |
| 1990 | Linn County | Old Salem Road | Gap | Wet (ISI) | Performing adequately. Planned for overlay due to widening. |
| 1993 | Linn County | CR 648 Fish Hatchery Drive | Gap | Wet (ISI) | No problems. |

[1] Mix types: B = Dense graded mix, maximum size 1" (25 mm); C = Dense graded mix, maximum size ¾", (19 mm); E = Open graded mix, maximum size ¾": Gap = gap graded.
[2] The wet process used by WSDOT was the "Arizona Process."

**Table 2.2: Oregon and Washington DOT project summary for CRM mixes (Dry Process)**

| Date of Construction Year | Project Identification | | Mix Type[1] | Process | Comments |
|---|---|---|---|---|---|
| | Agency | Location | | | |
| 1987 | Benton County | Springhill Drive | Gap | Plus Ride | Performing better than conventional AC. |
| 1988 | Benton County | N. 19th Street | Gap | Plus Ride | Underdesigned—alligator cracking. Rebuilt in 1995. |
| 1988 | Benton County | S. 19th Street | Gap | Plus Ride | Performing better than conventional AC. |
| 1990 | Benton County | Alpine Cut-off | Gap | Plus Ride | Performing well. Placed on shaded hillside and is effective for preventing snow and ice buildup. |
| 1990 | Benton County | Evergreen | Gap | Plus Ride | No problems. |
| 1986 | City of Corval. | NW Garfield Ave: Kings St. - 29th St. | C | Plus Ride | Pavement doing well. One pothole noted. |

[1]Mix types: B = Dense graded mix, maximum size 1" (25 mm); C = Dense graded mix, maximum size ¾" (19 mm): Gap = gap graded.

## 2.2 OTHER DOT EXPERIENCES

A literature review was done to identify CRM projects constructed by other DOTs, including Virginia, Ontario, Alaska, and Colorado. Performance and cost effectiveness were considered in the review.

CRM projects constructed by Virginia included dense and gap graded mixes using the wet process. Over the short term the pavements were evaluated, the CRM pavements performed as well as the conventional mixes. The use of the rubber increased the costs by 50 to 100% for the test sections (*Maupin 1996*).

Ontario evaluated 11 rubber modified asphalt demonstration projects between 1990 and 1993. Eight of the projects were rubber modified asphalt concrete (RUMAC) and one was rubber modified asphalt cement (ARC). The short-term performance indicated generally poor performance for the RUMAC sections and enhanced performance with the ARC section. Raveling, considerable pop-outs and poor longitudinal and transverse joints were noted in the RUMAC (*Emery 1995*).

Life cycle cost analyses done by Ontario under several scenarios indicated that the cost of RUMAC was always higher than conventional mixes. The comparative life cycle costs of ARC pavements were also evaluated. The ARC life cycle costs were 5% less than the conventional mix over 15 years when the maintenance costs were assumed to be half of the conventional mix maintenance costs. The ARC life cycle costs were 18% lower when the replacement frequency was estimated to be 20 years compared to a conventional mix with a replacement frequency of 15 years (*Emery 1995*).

In 1997 Alaska evaluated several CRM pavements, including PlusRide projects constructed in 1979 and 1985; an ARC section constructed in 1988; and a rubberized ARC section (asphalt rubber binder and granulated rubber) placed in 1988. The study focused on fatigue, thermal cracking, and permanent deformation resistance.

Alaska laboratory tests indicated the crumb rubber should increase the fatigue life of the asphalt concrete pavements; however, no differences between control and test sections were noted in the field. Differences in thermal cracking resistance were also measured in the laboratory. The wet process mixes had the best thermal cracking resistance. Laboratory results were mirrored in the field, with the ARC mixes being less temperature susceptible than conventional mixes (*Saboundjian 1997*).

Colorado investigated two dry processes – the PlusRide process and a process which involved just adding rubber to the mix. Three PlusRide projects showed early distress in the form of raveling; one PlusRide project performed well. The process which involved the addition of small amounts of crumb rubber to asphalt concrete pavement tested the effects of adding 1 lb/ton (0.5 kg/Mg), 3 lbs/ton (1.5 kg/Mg), and 1%, i.e., 20 lbs/ton(10 kg/Mg). After five years, the control and test sections performed equally. The mix cost per ton with 1% crumb rubber added was increased by 21% (*Harmelink 1999*).

The limited review presented here supports the common belief that wet process rubber mixes perform better than dry process mixes. Wet process mixes may be more forgiving, while dry process mixes require care in material selection, mix design and material production. Inconsistencies in the dry process mixes appear to be the primary factor leading to early failures. Ontario's life cycle cost analysis for the wet process pavements indicates a potential for savings over the long-term pavement life; additional monitoring is needed, however, to determine the actual life of ARC pavements.

# 3.0 FIELD PERFORMANCE REVIEWS

## 3.1 CONDITION SURVEYS

All of the ODOT CRM projects were evaluated visually to identify distresses used to determine a condition rating. The distress rating system was developed under the Strategic Highway Research Program (*SHRP 1993*) and modified by ODOT. Performance ratings were generated by entering the condition data into ODOT's pavement management system (PMS) software, developed by the Texas Research and Development Foundation (*TRDF 1996*). A condition rating of 100 indicated perfect condition. Deductions from 100 were then made for identified distresses.

During the course of the project, two changes were made that impacted the calculated condition ratings. In 1996, the distress survey methodology was changed. Prior to 1996, only generalized distress information was collected. In order to make the pre-1996 data compatible with future data, assumptions were made to generate useable numbers for the PMS software. Second, all survey data collected from 1997 on were collected in the spring. Prior to 1997 all information had been collected in the fall when less distress typically would be apparent.

In addition to distress data information, friction testing and ride testing were done periodically. Friction testing was done with a K.J. Law 1270® friction trailer. The ride information was obtained by using a South Dakota type profilometer.

Table 3.1 presents a summary of the pavement conditions in relation to the control sections. In February and March 2002, an additional site visit was made to select projects. The goal of the additional visit was to determine if the sections had changed considerable from the 1999 inspection. Results of the site visit are noted in parenthesis in the *Test Section Comments* column in Table 3.1. Friction and ride discussions follow in subsequent sections.

**Table 3.1: Performance information by project through 1999 (2002 update included under comments)**

| Construction Year | Project Identification | Mix Type[1] | Process | Age at Date of Evaluation, Years | Condition of Control[2] | Condition of Test Section[2] | Test Section Comments |
|---|---|---|---|---|---|---|---|
| **DENSE OR GAP GRADED MIXES** | | | | | | | |
| 1985 | Lava Butte - Fremont Hwy | Gap | PlusRide | 14 | Poor | Very Poor | Alligator & block cracked; 75% medium severity raveling. No major distress was reported in the first five years. Because the PlusRide section was widened to four lanes, the test section is now in the left lane and carries only about 25% of the total traffic. (2002—control has been overlayed; longitudinal cracks are more pronounced in the test section) |
| 1985 | Lava Butte - Fremont Hwy | C | Arm-R-Shield | 14 | Poor | Poor | A few transverse cracks. (2002—little change) |
| 1991 | 181st - Troutdale | B | RUMAC | 6 | Good | Poor | Some medium and high severity raveling. Out of service, replaced with concrete. |
| 1991 | Stark Street | B | RUMAC | 8 | Fair | Fair | Some low severity raveling, patching. |
| 1991 | Marine Drive | C | RUMAC | 8 | Poor | Poor | Low severity alligator cracking; low severity longitudinal cracking. In 1996, 200 feet of the westbound lanes were ground out and replaced due to raveling and potholes. The control section has shown alligator and longitudinal cracking. Comparison to the original condition survey indicated that these are reflective cracking from the very poor pavement in the control area. Truck traffic for both sections has increased because of industrial expansion, which could explain the relatively short life of the control overlay. |
| 1992 | Pacific Hwy. - 42nd Street | B | RUMAC | 7 | Fair | Fair | Base. |
| 1992 | Eastside Bypass | B | ISI ARC | 7 | Good | Poor | Low to medium severity raveling, low severity rutting. (2002—Little change in both sections since 1999) |
| 1992 | Lakeview Jct. - Matney Rd. | B | RUMAC | 7 | Fair | Fair | Low severity raveling, low to medium severity transverse cracking. (2002—transverse cracking has increased in both test and control sections) |
| 1993 | Wolf Cr. - W. Fork Dairy Cr. | B | RUMAC | 6 | Good | Good | Base. |
| 1993 | Durkee - Lime | A | RUMAC | 6 | NA | NA | Base. Problems were associated with an excessive amount of rubber were noted shortly after construction. The majority of the section has since been milled out and replaced. |

[1] Mix Types: A = Dense graded mix, maximum size 1½" (38 mm); B = Dense graded mix, maximum size 1" (25 mm); C = Dense graded mix, maximum size ¾" (19 mm); F = Open graded mix, maximum size 1" (25 mm).
[2] Condition rating based on distress data entered and analyzed using ODOT 's pavement management software.

**Table 3.1 (continued): Performance information by project through 1999 (2002 update included under comments)**

| Construction Year | Project Identification | Mix Type[1] | Process | Age at Date of Evaluation, Years | Condition of Control[2] | Condition of Test Section[2] | Test Section Comments |
|---|---|---|---|---|---|---|---|
| **OPEN GRADED MIXES** | | | | | | | |
| 1991 | 181st - Troutdale | F | ISI | 6 | Very Good | Poor | Medium severity raveling, some patching and alligator cracking. Out of service, replaced with concrete. |
| 1992 | Eastside Bypass | F | PRARC | 7 | Fair | Poor | Low and medium severity raveling. High severity rutting. (2002—raveling has increased in both test and control sections; rutting has increased in the inside wheel tracks in the PRARC section) |
| 1992 | Eastside Bypass | F | ISI | 7 | Fair | Poor | Medium severity raveling. High severity rutting. (2002—rutting has increased in the test section; about the same in the control) |
| 1993 | Kah-Nee-Ta - Pelton Dam Rd | F | PBA-6GR | 6 | Fair | Very Good | Control showing low and medium severity raveling; low severity rutting. (2002—little change from 1999 survey) |
| 1994 | Tower Rd. - Stanfield | F | PBA-6GR | 5 | Good | Very Good | Control showing low severity raveling. (2002—control section includes two additional transverse cracks; test section about the same except for slight large aggregate loss outside the wheel track (18 to 24 rocks per station)) |
| 1994 | Azalea - Jump-off Joe | F | PBA-6GR | 5 | Very Good | Very Good | No distresses observed. (2002—Both sections look uniform with no notable distresses) |

[1] Mix Types: A = Dense graded mix, maximum size 1½" (38 mm); B = Dense graded mix, maximum size 1" (25 mm); C = Dense graded mix, maximum size ¾" (19 mm); F = Open graded mix, maximum size 1" (25 mm).

[2] Condition rating based on distress data entered and analyzed using ODOT 's pavement management software.

### 3.1.1 Pavement Performance Indices

Pavement performance indices were calculated by the pavement management software program, TRDF PMS. The 1999 performance indices for dense-graded mixes are shown in the bar chart in Figure 3.1 (except for the 181st - Troutdale project, which was out of service in 1997). The chart for open-graded mixes is shown in Figure 3.2. Figure 3.1 (dense-graded mixes) indicates that for all sections the control sections were in better condition than the CRM sections.

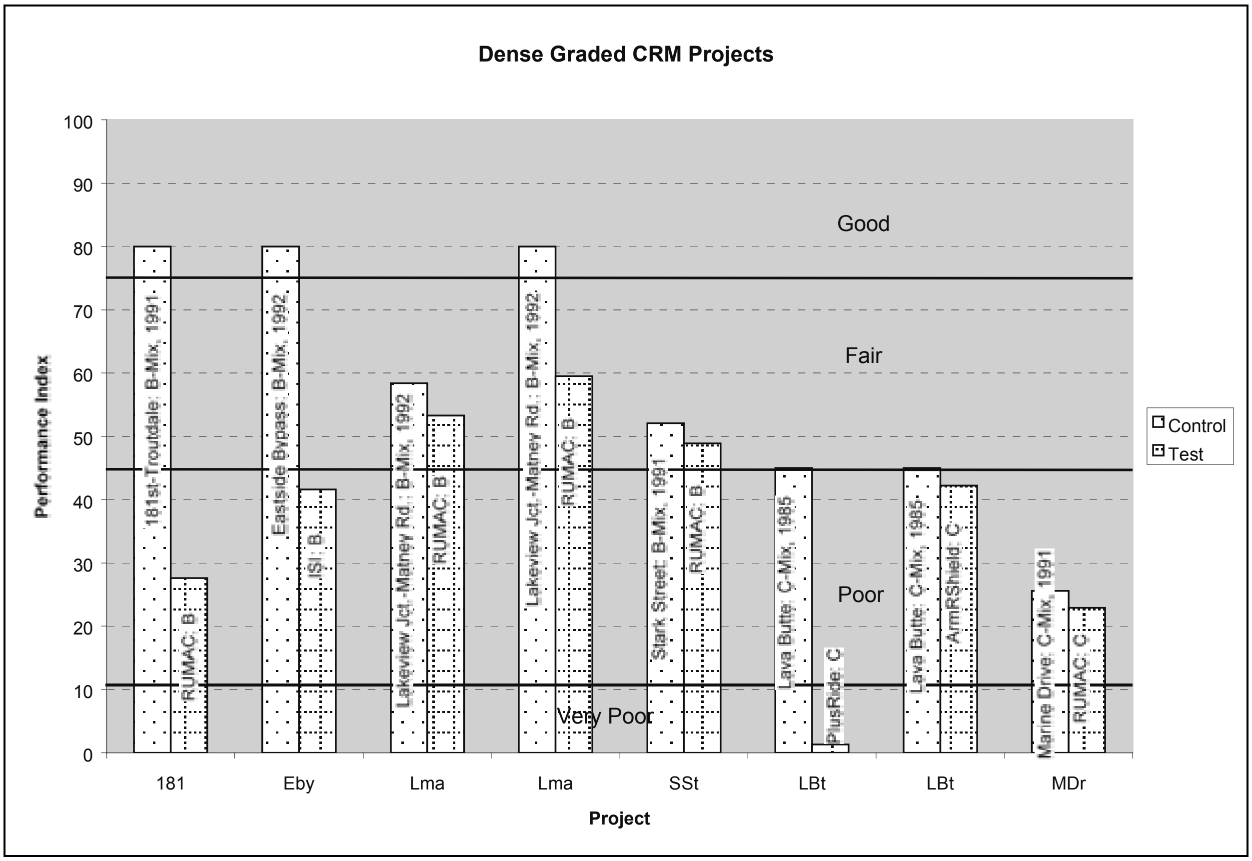


Figure 3.1: 1999 Condition rating for dense-graded CRM projects

Figure 3.2 (open-graded mixes) indicates that sections constructed with PBA-6GR binder were in the same condition or better than the control sections. Open-graded pavements constructed using the ISI and PRARC method were in poorer condition than the controls. Differences between the terminal blended PBA-6GR and the on-site blended ISI binder could be attributed to particle size and/or product consistency. The PBA-6GR was produced using 10-12% powdered rubber (#80-minus) The ISI binder was produced using #16-minus rubber at 15-20%.

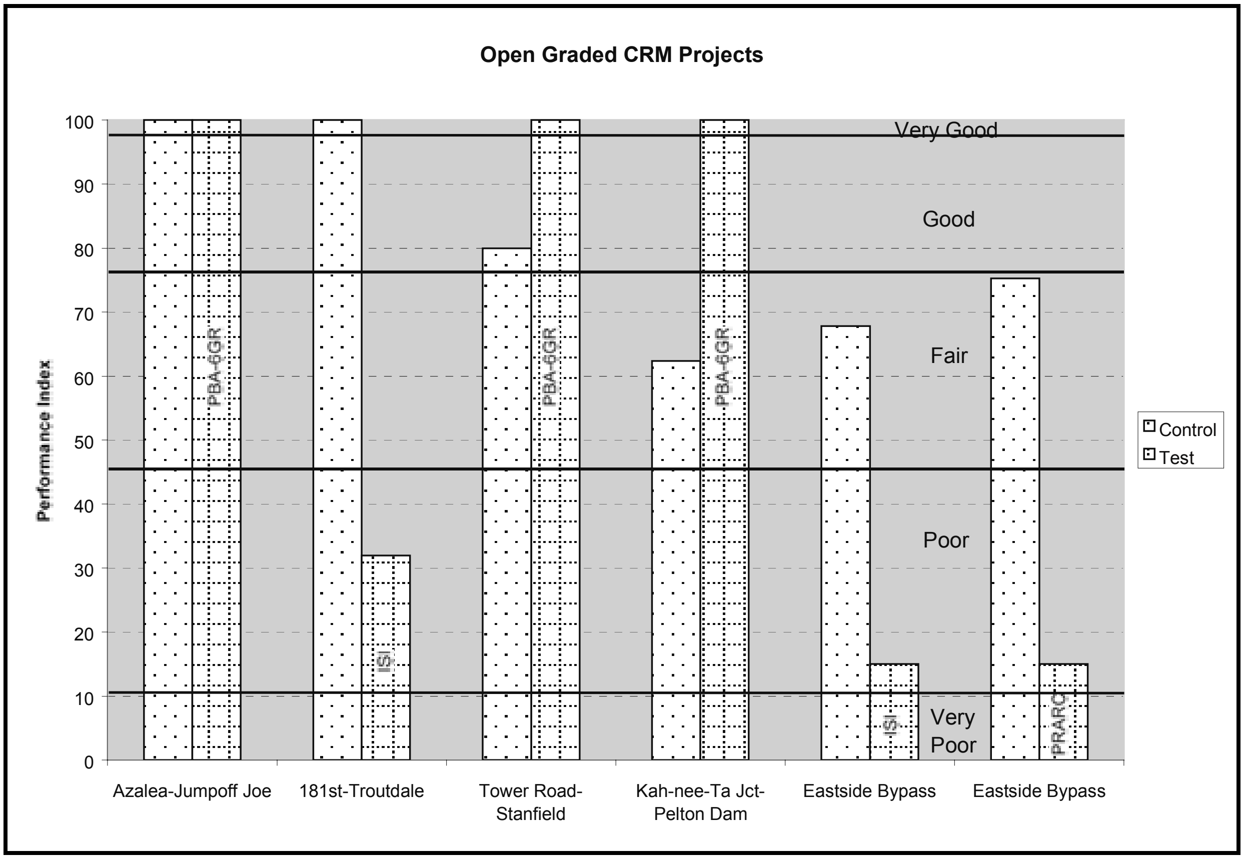


Figure 3.2: 1999 Condition rating for open-graded CRM projects

### 3.1.2 Estimated Wear Rates

Since the projects were constructed in different years, a wear rate was estimated for comparison. The wear rate was calculated based on the overall performance index calculated by TRDF PMS. The equation assumes a straight-line rate of deterioration, which is not necessarily the case; however, it does provide a means for general comparison. Wear rate comparisons also do not account for different traffic or environmental factors that could affect performance. The equation used was:

$$\text{Wear Rate} = \frac{100 - \text{latest available performance index}}{\text{age at the time the performance index was determined (years)}} \qquad \textbf{(3-1)}$$

Calculated values for dense-graded mixes are shown in Table 3.2 in order of best to worst.

**Table 3.2: Dense-graded mix performance wear rates**

| Year Const. | Project Name | Hwy | Beg. MP | End MP | DOT | Mix Type | Product | Age | Wear Rate |
|---|---|---|---|---|---|---|---|---|---|
| 1992 | Eastside Bypass | 50 | -5.18 | -5.04 | EB | B | Control | 7 | 2.9 |
| 1992 | Lakeview Jct.-Matney Road | 50 | 0.55 | 0.91 | NB | B | Control | 7 | 2.9 |
| 1991 | 181st -Troutdale | 2 | 15.42 | 15.92 | EB | B | Control | 6 | 3.3 |
| 1985 | Lava Butte-Fremont Jct. | 4 | 160.2 | 160.8 | SB | C | Control | 14 | 3.9 |
| 1985 | Lava Butte-Fremont Jct. | 4 | 158.4 | 159.2 | SB | C | Arm-R-Shield® | 10 | 4.1 |
| 1992 | Lakeview Jct.-Matney Road | 50 | 0.96 | 1.64 | NB | B | RUMAC | 7 | 5.8 |
| 1992 | Lakeview Jct.-Matney Road | 50 | 0.55 | 0.91 | SB | B | Control | 7 | 5.9 |
| 1991 | Stark Street | ST | 197 | 199 | EB | B | Control | 6 | 6.0 |
| 1991 | Stark Street | ST | 199 | 202 | EB | B | RUMAC | 6 | 6.4 |
| 1992 | Lakeview Jct.-Matney Road | 50 | 0.96 | 1.64 | SB | B | RUMAC | 7 | 6.7 |
| 1985 | Lava Butte-Fremont Jct. | 4 | 157.9 | 158.4 | SB | GAP | PlusRide 12® | 10 | 7.1 |
| 1992 | Eastside Bypass | 50 | -5.02 | -4.49 | E | B | ISI ARC | 5 | 8.3 |
| 1991 | Marine Drive | MD | ST41 | ST46 | E/W | C | Contol | 6 | 9.3 |
| 1991 | Marine Drive | MD | ST66 | ST72 | E/W | C | RUMAC | 6 | 9.6 |
| 1991 | 181st -Troutdale | 2 | 16 | 16.84 | EB | B | RUMAC | 6 | 12.1 |

Values for open-graded mixes are shown in Table 3.3, also in order of best to worst.

**Table 3.3: Open-graded mix performance summary**

| Year Const. | Project Name | Hwy | Beg. MP | End MP | DOT | Mix Type | Product | Age | Wear Rate |
|---|---|---|---|---|---|---|---|---|---|
| 1993 | Ka-Nee-Ta - Pelton Dam | 53 | 104.9 | 105.4 | SB | F | PBA6-GR | 6 | 0 |
| 1994 | Tower Road - Stanfield Jct. | 2 | 167.2 | 167.4 | EB | F | PBA6-GR | 5 | 0 |
| 1994 | Azalea-Jumpoff Joe-Fremont Jct. | 1 | 83.5 | 83.69.2 | NB | F | PBA-6 | 5 | 0 |
| 1994 | Azalea-Jumpoff Joe-Fremont Jct. | 1 | 78.38 | 80.75.2 | NB | F | PBA6-GR | 5 | 0 |
| 1991 | 181st -Troutdale | 2 | 15.42 | 15.92 | WB | F | Control | 6 | 0 |
| 1994 | Tower Road - Stanfield Jct. | 2 | 163.5 | 167.1 | EB | F | PBA-6 | 5 | 4.0 |
| 1993 | Eastside Bypass | 50 | -3.97 | -3.83 | EB | F | Control | 7 | 4.1 |
| 1993 | Eastside Bypass | 50 | -3.97 | -3.83 | WB | F | Control | 7 | 4.6 |
| 1993 | Ka-Nee-Ta - Pelton Dam | 53 | 105.4 | 105.6 | SB | F | PBA-6 | 6 | 6.3 |
| 1993 | Eastside Bypass | 50 | -4.28 | -4.13 | WB | F | ISI ARC | 7 | 12.1 |
| 1993 | Eastside Bypass | 50 | -4.28 | -4.13 | EB | F | PRARC | 7 | 12.1 |
| 1991 | 181st-Troutdale | 2 | 16 | 16.84 | WB | F | ISI ARC | 6 | 11.3 |

Assuming that pavements with a condition index of 45 are in poor condition and that the expected life of a pavement is 15 years, an acceptable straight line wear rate would be 3.7 ((100-45)/15 years). Under this standard, all of the dense-graded CRM projects had unacceptable performance. For the open-graded mixes, all of the PBA-6GR projects had acceptable wear rates, but the ISI and PRARC projects were unacceptable. Assuming a straight line wear rate is liberal as pavements typically show little distress in the first years followed by more extensive distress towards the end of service life.

## 3.2 FRICTION MEASUREMENTS

Friction tests were generally performed soon after construction and also in following years. The results are summarized in Tables 3.4 and 3.5. A complete list of test results is included in Appendix A.

For the dense-graded projects, friction values remained at an acceptable level. The values for the rubber modified sections were not notably different than the control sections.

**Table 3.4: Friction values for dense-graded projects**

| Project Name | Construction Year | Product | Friction after Construction | Friction 1999 |
|---|---|---|---|---|
| Lava Butte-Fremont Jct. | 1985 | PlusRide 12® | 60 | 51 |
| Lava Butte-Fremont Jct. | 1985 | Control | 60 | 61 |
| Lava Butte-Fremont Jct. | 1985 | Arm-R-Shield® | 55 | 57 |
| Lava Butte-Fremont Jct. | 1985 | Control | 58 | 61 |
| 181st -Troutdale | 1991 | RUMAC | 52 | 53 (1997) |
| 181st -Troutdale | 1991 | Control | 51 | 51 (1997) |
| Stark Street | 1991 | RUMAC | 53 | 45 |
| Stark Street | 1991 | Control | 56 | 38 |
| Marine Drive | 1991 | RUMAC | 50 | 40 |
| Marine Drive | 1991 | Control | 49 | 44 |
| Lakeview Jct.- Matney Road NB | 1992 | RUMAC | 55 | 37* |
| Lakeview Jct.- Matney Road NB | 1992 | Control | 59 | 31* |
| Eastside Bypass | 1992 | ISI ARC | 41 | 47 |
| Eastside Bypass | 1992 | Control | 45 | 48 |

*Skid truck driver reported something slick on the pavement that was expected to be a temporary effect.

Open-graded pavement values remained within acceptable limits over time, as shown in Table 3.5. In two cases, the rubber modified sections had lower skid values after construction. Over time, however, the skid values for the control and modified sections were comparable.

**Table 3.5: Friction values for open-graded projects**

| Project Name | Construction Year | Product | Friction after Constrction | Friction 1999 |
|---|---|---|---|---|
| Ka-Nee-Ta - Pelton Dam | 1993 | PBA-6 | 59 | 47 |
| Ka-Nee-Ta - Pelton Dam | 1993 | PBA6-GR | 49 | 45 |
| Tower Road - Stanfield Jct. | 1994 | PBA-6 | 41 | 40 |
| Tower Road - Stanfield Jct. | 1994 | PBA6-GR | 43 | 39 |
| Azalea - Jumpoff Joe - Fremont Jct. | 1994 | PBA-6 | 34 | 43 |
| Azalea - Jumpoff Joe - Fremont Jct. | 1994 | PBA6-GR | 38* | 43 |
| Eastside Bypass | 1992 | ISI ARC | 51 | 47 |
| Eastside Bypass | 1992 | PRARC | 39 | 50 |
| Eastside Bypass | 1992 | CONTROL | 46 | 53 |
| 181st-Troutdale | 1991 | CONTROL | 45 | 46 (1997) |
| 181st-Troutdale | 1991 | ISI ARC | 45 | 46 (1997) |
| Redmond-Bend | 1992 | PBA6-GR | 43 | 49 (1997) |

*This value dropped to 32 after the second year. Much of the section was ground out and inlaid with B-mix. The problem was not attributed to the PBA-6GR binder.

## 3.3 RIDE TRENDS

Ride tests were performed soon after construction and also in the following years. A "South Dakota" type profilometer was used that measured the International Roughness Index (IRI). Because of a computer circuit board malfunction, however, IRI readings recorded before early 1994 were inaccurate and are not included. The results available are summarized in Tables 3.6 and 3.7.

The roughest pavements for the dense-graded projects are the RUMAC sections at Stark Street and Marine Drive and the control at Marine Drive. In all cases, the rubber modified dense-graded sections were rougher than the control sections. The roughest pavements for the open-graded projects were the PBA-6GR section on the Ka-Nee-Ta project; the PBA-6GR section at Redmond-Bend; and the Eastside Bypass sections.

**Table 3.7: Ride values for dense-graded projects**

| Project Name | Construction Year | Product | Ride 1998 |
|---|---|---|---|
| Lava Butte-Fremont Jct. | 1985 | PlusRide 12® | 81 |
| Lava Butte-Fremont Jct. | 1985 | Control | 79 |
| Lava Butte-Fremont Jct. | 1985 | Arm-R-Shield® | 95 |
| 181st -Troutdale | 1991 | RUMAC | NA |
| 181st -Troutdale | 1991 | Control | NA |
| Stark Street | 1991 | RUMAC | 150 |
| Stark Street | 1991 | Control | 104 |
| Marine Drive | 1991 | RUMAC | 149 |
| Marine Drive | 1991 | Control | 141 |
| Lakeview Jct.- Matney Road NB | 1992 | RUMAC | 106 |
| Lakeview Jct.- Matney Road NB | 1992 | Control | 98 |
| Eastside Bypass | 1992 | ISI ARC | 116 |
| Eastside Bypass | 1992 | Control | 91 |

**Table 3.7: Ride values for open-graded projects**

| Project Name | Construction Year | Product | Ride 1998 |
|---|---|---|---|
| Ka-Nee-Ta - Pelton Dam | 1993 | PBA-6 | 98 |
| Ka-Nee-Ta - Pelton Dam | 1993 | PBA6-GR | 119 |
| Tower Road - Stanfield Jct. | 1994 | PBA-6 | 101 |
| Tower Road - Stanfield Jct. | 1994 | PBA6-GR | 91 |
| Azalea - Jumpoff Joe - Fremont Jct. | 1994 | PBA-6 | 79* |
| Azalea - Jumpoff Joe - Fremont Jct. | 1994 | PBA6-GR | 89* |
| Eastside Bypass | 1992 | ISI ARC | 116 |
| Eastside Bypass | 1992 | PRARC | NA |
| Eastside Bypass | 1992 | CONTROL | 113 |
| 181st-Troutdale | 1991 | CONTROL | NA |
| 181st-Troutdale | 1991 | ISI ARC | NA |
| Redmond-Bend | 1992 | PBA6-GR | 115 |

*1994 measurements

# 4.0 LABORATORY TESTING

In addition to the standard testing required for all ODOT paving projects, the CRM mixes were tested for voids and stripping. Tests were performed by the ODOT Materials Laboratory on cores cut at the interval noted.

## 4.1 DENSE-GRADED CRM PAVEMENTS

Both the dense-graded test sections and control sections were tested for density and stripping soon after construction, again at one year after construction, and at five years after construction. The results of the tests are summarized in Table 4.1.

**Table 4.1: Void contents of dense-graded mixes**

| Project Name | Product | Voids Post Construction | Voids 1 Year | Voids 5 Years | Stripping Percent |
|---|---|---|---|---|---|
| Lava Butte-Fremont Jct. | PlusRide 12® | 3.7 | 4.4 | 4 | N/A |
| Lava Butte-Fremont Jct. | Control | 7.1 | 6.9 | 8.7 | N/A |
| Lava Butte-Fremont Jct. | Arm-R-Shield® | 6.9 | 5.8 | 7.7 | N/A |
| Lava Butte-Fremont Jct. | Control | 6.9 | 6.6 | 7 | N/A |
| 181st - Troutdale | RUMAC | 10.3 | 5.6 | 4.3 | 0 |
| 181st - Troutdale | Control | 6.9 | 5 | 8 | 0 |
| Stark Street | RUMAC | 11.3 | 3.9 | 5.6 | 10 |
| Stark Street | Control | 9.2 | 9.2 | 6.6 | 10 |
| Marine Drive | RUMAC | 8.5 | 5.8 | 8.7 | 10 |
| Marine Drive | Control | 6.2 | 5.5 | 4.3 | 7.5 |
| Lakeview Jct. - Matney Rd. | RUMAC | 4.4 | 4.7 | 3.4 | 0 |
| Lakeview Jct. - Matney Rd. | Control | 5.6 | 4.7 | 3.4 | 0 |
| Eastside Bypass | ISI ARC | 3.4 | N/A | 3.8 | 0 |
| Eastside Bypass | Control | 3.5 | N/A | N/A | N/A |

All of the RUMAC sections except Lakeview Jct. - Matney Road had voids greater than the design void of 3% - 5% in the post-construction tests. The east end of the RUMAC section on the 181st project failed before the end of the first year. The Stark Street and Marine Drive RUMAC sections developed problems two and three years after construction, respectively. The primary failure modes were raveling and potholing. The remaining mixes tested closer to the design voids and had less distress. For all of the mixes, stripping did not appear to be a problem.

## 4.2 OPEN-GRADED CRM PAVEMENTS

The open-graded mixes were tested for density and examined for stripping. The design void content of these mixes was in the range of 7% to 16%. Some variations of density measurement occurred due to a change in the method of measuring specific gravity. On earlier projects specific gravity was determined by water displacement. This procedure was changed to caliper measurement for open-graded mixes, due to the water absorption of these mixes. The caliper method showed higher void contents.

**Table 4.2: Open-graded friction and ride values**

| Project Name | Product | Voids Post Construction | Voids 1 Year | Voids 5 Years | Stripping Percent |
|---|---|---|---|---|---|
| Ka-Nee-Ta - Pelton Dam | PBA6 | N/A | 11 | 7.7 | 0 |
| Ka-Nee-Ta - Pelton Dam | PBA6-GR | N/A | 10.9 | 7.5 | 0 |
| Tower Road - Stanfield Jct. | PBA6 | 15.5 | 17.6 | N/A | 0 |
| Tower Road - Stanfield Jct. | PBA6-GR | 11.1 | 14.4 | N/A | 0 |
| Azalea - Jumpoff Joe-Fremont Jct. | PBA6 | 9.1 | 14.3 | N/A | 0 |
| Azalea - Jumpoff Joe-Fremont Jct. | PBA6-GR | 10 | 16.3 | N/A | 0 |
| Eastside Bypass | ISI ARC | 5.9 | N/A | 8.9 | 5 |
| Eastside Bypass | Control | 9.2 | N/A | 9.4 | 0 |
| 181st - Troutdale | Control | 15.7 | 12.8 | N/A | 0 |
| 181st - Troutdale | ISI ARC | 12.4 | 8.5 | N/A | 0 |
| Redmond - Bend | PBA6-GR | N/A | N/A | N/A | N/A |

All sections met the design voids on post-construction testing. Both the control and test sections of the Ka-Nee-Ta job had a decrease in void content after the first year. This was also noted in visual observations of densification in the wheelpaths of the asphalt mix.

# 5.0 CONCLUSIONS

From 1993 to 1999, ODOT monitored performance of 17 rubber modified asphalt and rubber modified asphalt concrete projects to identify cost effective systems.

All of ODOT's RUMAC and PlusRide (dry process) sections performed worse than the corresponding control section with a tendency towards raveling. Although, other dry process systems like PlusRide constructed in Oregon counties have performed adequately, experience by other DOT's does not support good performance. Other states have found that dry processes require additional care in material selection, mix design and material production. Inconsistencies in the dry process mixes lead to construction problems and early failures. Also, cost analyses done for dry process systems indicate increased costs from 50 to 100% over conventional mixes.

The open-graded mixes constructed with the wet process had varying results. The ISI ARC products both in Oregon and the WSDOT showed early distress, whereas the sections constructed with PBA-6GR appeared to be performing as well or better than the controls. Other states' experience supports the success of the wet process. Life cycle cost analyses done in Ontario indicate a potential for cost savings assuming a longer life expectancy and reduced maintenance with the addition of rubber to the binder.

Pavements constructed with the PBA-6GR binder appear to have the best performance of all the rubber modified test sections constructed in Oregon. In order to determine a reliable performance model for using asphalt rubber cement in Oregon, the PBA-6GR projects should continue to be monitored. Currently, the use of PBA-6GR and other terminal blend asphalt rubber cements should be encouraged where it is cost effective.

# 6.0 REFERENCES

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# APPENDIX

**Table A.1: Friction Values for Dense-Graded Projects**

| Project Name | Product | 1987 | 1992 | 1993 | 1994 | 1995 | 1996 | 1997 | 1998 | 1999 | Constr. Year |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Lava Butte-Fremont Jct. | PlusRide 12® | 65 | 58 | 57 | | 57 | 63 | 69 | 58 | 51 | 1985 |
| Lava Butte-Fremont Jct. | Arm-R-Shield® | 55 | 59 | 63 | | 62 | 62 | 66 | 55 | 57 | 1985 |
| Lava Butte-Fremont Jct. | Control | 58 | 64 | 62 | | 67 | 62 | 66 | 57 | 61 | 1985 |
| 181st -Troutdale | RUMAC | | 52 | 54 | 53 | | | 53 | | | 1991 |
| 181st -Troutdale | Control | | 51 | 55 | 56 | | | 51 | | | 1991 |
| Stark Street | RUMAC | | 58 | | 50 | 48 | 44 | 54 | 44 | 45 | 1991 |
| Stark Street | Control | | 56 | | 51 | 46 | 45 | 51 | 46 | 38 | 1991 |
| Marine Drive | RUMAC | | 51 | | 44 | 45 | 45 | 46 | 43 | 40 | 1991 |
| Marine Drive | Control | | 52 | | 49 | 47 | 46 | 47 | 42 | 44 | 1991 |
| Lakeview Jct.- Matney Road NB | RUMAC | | 55 | 60 | 60 | 60 | 58 | 61 | 60 | 37* | 1992 |
| Lakeview Jct.- Matney Road NB | Control | | 59 | 56 | 61 | 60 | 58 | 60 | 55 | 31* | 1992 |
| Eastside Bypass | ISI ARC | | 40 | | 50 | 57 | 57 | 57 | 56 | 47 | 1992 |
| Eastside Bypass | Control | | 44 | | 53 | 54 | 56 | 59 | 54 | 48 | 1992 |

* Skid truck driver reported something slick on the pavement that was expected to be a temporary effect.

**Table A.2: Friction Values for Open-Graded Projects**

| Project Name | Product | 1992 | 1993 | 1994 | 1995 | 1996 | 1997 | 1998 | 1999 | Constr. Year |
|---|---|---|---|---|---|---|---|---|---|---|
| Ka-Nee-Ta - Pelton Dam | PBA6-GR | | | 48 | 44 | 45 | 51 | 44 | 45 | 1993 |
| Ka-Nee-Ta - Pelton Dam | PBA-6 | | | 50 | 49 | 46 | 52 | 45 | 47 | 1993 |
| Tower Road - Stanfield Jct. | PBA6-GR | | | 43 | 49 | 43 | 47 | 38 | 39 | 1994 |
| Tower Road - Stanfield Jct. | PBA-6 | | | 41 | 51 | 46 | 49 | 40 | 40 | 1994 |
| Azalea - Jumpoff Joe - Fremont Jct. | PBA6-GR | | | 39 | 33 | 41 | 41 | | 43 | 1994 |
| Azalea - Jumpoff Joe - Fremont Jct. | PBA-6 | | | 34 | 45 | 48 | 44 | | 43 | 1994 |
| Eastside Bypass | ISI ARC | 51 | | 50 | 59 | 53 | 57 | 49 | 47 | 1992 |
| Eastside Bypass | PRARC | 39 | | 57 | 56 | 54 | | 53 | 50 | |
| Eastside Bypass | CONTROL | 51 | | 54 | 56 | 56 | 56 | 54 | 53 | 1992 |
| 181st-Troutdale | ISI ARC | 45 | 48 | 50 | | | 46 | | | 1991 |
| 181st-Troutdale | CONTROL | 45 | 46 | 48 | | | 46 | | | 1991 |
| Redmond-Bend | PBA6-GR | | | 54 | 50 | | 49 | | | |

All ride data available is reported in the following tables. However, prior to early 1994, a computer circuit board malfunction created faulty high IRI readings.

**Table A.3: IRI Values for Dense-Graded Projects**

| Project Name | Product | 1991 | 1992 | 1993 | 1995 | 1998 | Constr. Year |
|---|---|---|---|---|---|---|---|
| Lava Butte-Fremont Jct. | PlusRide 12® | | | | 70 | 81 | 1985 |
| Lava Butte-Fremont Jct. | Arm-R-Shield® | | 67 | | 80 | 79 | 1985 |
| Lava Butte-Fremont Jct. | Control | | 59 | | 80 | 95 | 1985 |
| 181st -Troutdale | RUMAC | 81 | 117 | 111 | | | 1991 |
| 181st -Troutdale | Control | 83 | 83 | 76 | | | 1991 |
| Stark Street | RUMAC | 94 | | | | 150 | 1991 |
| Stark Street | Control | 82 | | | | 104 | 1991 |
| Marine Drive | RUMAC | 117 | | | | 149 | 1991 |
| Marine Drive | Control | 123 | | | | 141 | 1991 |
| Lakeview Jct.- Matney Road NB | RUMAC | | 75 | | | 106 | 1992 |
| Lakeview Jct.- Matney Road NB | Control | | 75 | | | 98 | 1992 |
| Eastside Bypass | ISI ARC | | 80 | 67 | | 116 | 1992 |
| Eastside Bypass | Control | | | | | 91 | 1992 |

**Table A.4: IRI Values for OpenGraded Projects**

| Project Name | Product | 1992 | 1994 | 1998 | Constr. Year |
|---|---|---|---|---|---|
| Ka-Nee-Ta - Pelton Dam | PBA6 | 136 | | 98 | 1993 |
| Ka-Nee-Ta - Pelton Dam | PBA6-GR | 136 | | 119 | 1993 |
| Tower Road - Stanfield Jct. | PBA6 | | | 101 | 1994 |
| Tower Road - Stanfield Jct. | PBA6-GR | | | 91 | 1994 |
| Azalea - Jumpoff Joe - Fremont Jct. | PBA6 | | 79 | | 1994 |
| Azalea - Jumpoff Joe - Fremont Jct. | PBA6-GR | | 89 | | 1994 |
| Eastside Bypass | ISI ARC | 80 | | 116 | 1992 |
| Eastside Bypass | CONTROL | | | 113 | 1992 |
| 181st-Troutdale | CONTROL | | | | 1991 |
| 181st-Troutdale | ISI ARC | 97 | | | 1991 |
| Redmond-Bend | PBA6-GR | 85 | | 115 | 1992 |