CRUMB RUBBER MODIFIED ASPHALT CONCRETE IN OREGON SUMMARY REPORT

by

Elizabeth Hunt, P.E.
Senior Research Specialist

and

Wendy Peters, E.I.T.
Research Specialist

Oregon Department of Transportation
Engineering Services Section
Research Unit
Salem, Oregon 97310

Prepared for

OREGON DEPARTMENT OF TRANSPORTATION
Salem, OR 97310

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16. Abstract

Over the last nine years, the Oregon Department of Transportation (ODOT) has constructed 13 projects using crumb rubber modifiers (CRM) in asphalt concrete pavements using both the wet and dry process. Three of the projects included more than one type of crumb rubber modifier. All projects included a control section. Research data has been collected on the majority of projects and five construction reports have been written detailing the results. State and federal legislation may require the use of recycled rubber in asphalt concrete, therefore, the Oregon Department of Transportation is interested in determining the most cost-effective crumb rubber modified asphalt concrete.

This report includes a literature review on the use of crumb rubber modifiers in asphalt concrete pavement; a review on non-ODOT CRM paving projects constructed by Oregon counties and cities; and the Washington Department of Transportation. In addition, the report summarizes the data collected on all CRM hot mix asphalt concrete pavement projects constructed by ODOT. The ODOT information includes background, construction, cost, and performance data for each of the test and control sections. Finally, the future activities of the project are reviewed.

The short pavement history precludes selection of a process based on performance. The results of the study indicate that if a CRM process were to be selected today, pavements constructed with PBA-6GR would be the most economical in terms of initial cost/ton. The PBA-6GR is also very easy to use since the rubber modified binder is blended at the refinery and delivered to the job site ready for mixing with the aggregate. This process reduces the number of errors possible during construction since the rubber content and the mixing process are tightly controlled at the refinery. Additional testing of the PBA-6GR is necessary, to insure that a product that meets the ODOT specifications is consistently available.

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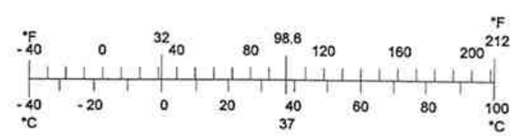
SI* (MODERN METRIC) CONVERSION FACTORS

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	1.8 + 32	Fahrenheit	°F



* SI is the symbol for the International System of Measurement

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CRUMB RUBBER MODIFIED ASPHALT CONCRETE IN OREGON

TABLE OF CONTENTS

CRUMB RUBBER MODIFIED ASPHALT CONCRETE IN OREGON

LIST OF FIGURES

LIST OF TABLES

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1.0 INTRODUCTION

1.1 BACKGROUND

The Oregon Department of Transportation (ODOT) is interested in determining the most appropriate rubber modified hot mix asphalt concrete (HMAC) to meet the intent of Section 1038 of the Intermodal Surface Transportation Efficiency Act (ISTEA) (1). ISTEA, enacted in 1991, requires the use of ground automobile and truck tire rubber in HMAC on federally funded projects. In addition, ODOT is interested in improving asphalt pavement performance. The use of one or more of these processes may help this effort.

ODOT has constructed 17 sections (13 projects) of pavement that have incorporated ground tire rubber into HMAC to determine the advantages and disadvantages of each system. Two of the projects were required under Senate Bill 66 (1991) which stated that ODOT shall conduct two paving projects using the Oregon generic specifications for METRO RUMAC (rubber modified asphalt concrete) (2).

The dry processes used, where the rubber is added to the aggregate prior to mixing with hot asphalt, included Plus Ride® 12 and Metro RUMAC. The wet processes used, where the rubber is first blended with the asphalt cement, included Arm-R-Shield, International Surfacing Incorporated's asphalt-rubber concrete (ISI ARC), powdered rubber asphalt rubber concrete (PRARC), and PBA-6GR (Performance Based Asphalt-6 with ground rubber). A description of the crumb rubber modified (CRM) products used in Oregon is presented in Table 1.1.

The ISTEA mandate was to begin in 1994, but a moratorium has been issued which has delayed implementation until 1996. In 1994, ISTEA was to require that 5% percent of all federally funded HMAC include at least one percent of tire rubber. The percent of federally funded HMAC requiring rubber was to increase to 10% in 1995. If ISTEA is implemented in 1996, the legislation will require that 15% of all federally funded HMAC includes tire rubber at the rate of 20 lbs (9 kg) of rubber per ton of mix. The requirement increases to 20% in 1997.

The decision on the most appropriate rubber modified HMAC to meet the intent of ISTEA, will be based on pavement performance, determined by distress surveys and field test results, and economics.

1.2 PURPOSE OF REPORT

This report summarizes the information collected on rubber modified HMAC projects constructed in Oregon since 1985. Data collected from Oregon cities and counties is also included for information and comparison.

Table 1.1. CRM Products Used in Oregon.

Description	Comments
Arm-R-Shield	
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. (2).
ISI ARC	
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 (3,4).
PRARC	
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 (4).
PBA-6GR	
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 (5).

Table 1.1. CRM Products used in Oregon, continued.

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 (2).
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 (3,6,7).

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2.0 LITERATURE REVIEW

The National Cooperative Highway Research Program (NCHRP) Synthesis 198, *Uses of Recycled Rubber Tires in Highways* summarizes the majority of articles written to date on recycled rubber tire use (8). The synthesis has devoted a chapter to use in asphalt paving materials with a section on HMAC, which includes summaries of design methods, mix properties, construction, recycling, traffic noise, performance, and economic considerations. An appendix notes the performance of crumb rubber modified hot-mix pavements constructed in various states. A list of references pertaining to rubber modified asphalts and asphalt concretes is included.

The subsection on design methods lists the methods available for CRM mixes. The methods are based on Hveem and Marshall procedures with modifications. The synthesis reports that the mixing and compaction temperatures for CRM mixtures are higher than those for conventional mixes. In addition, CRM binder contents are typically 10 to 20 percent higher than conventional mixes. The subsection on mixture properties covers several other areas of interest to ODOT discussed below.

- Hveem and Marshall stabilities will be reduced in CRM mixes for both the wet and dry processes.
- The resilient modulus for modified mixes may be greater or less than conventional mixes depending on a number of factors, such as crumb rubber gradation, type, and amount; mixing temperature and cure time.
- Texas and Nevada determined that CRM mixes have similar resistance to deformation as conventional mixes. A Virginia study found that asphalt-rubber binders have less resistance to permanent deformation.
- For both the wet and dry processes, fatigue life is improved when crumb rubber is added to HMAC.
- The tensile strengths may either increase or decrease when crumb rubber is added to a mixture.
- Water sensitivity may be a problem for CRM mixes.
- Thermal cracking resistance has been reported to improve with the addition of rubber, however, other factors such as base asphalt properties control the low temperature properties.
- California has reported improved resistance to abrasion while other data indicates no improvement.
- The presence of rubber generally lowers friction numbers.

The subsection on construction describes field changes suggested for both the wet and dry processes. For the wet process:

- For asphalt prepared at the construction site, a blending and reacting unit should be added to ensure proper proportioning of the crumb rubber, base asphalt cement, and other modifiers. The blended material should be stored in a reaction vessel where temperature and time can be controlled to produce a binder with the desired properties.
- An interlocking control system should be used to provide accurate binder and rubber quantities.
- The target temperature for mixing, laydown, and compaction should be higher to allow for the binders' greater viscosity at construction temperatures. Typical mixing temperatures are 300 to 350°F (150 to 180°C) and laydown temperatures are at least 250°F (120°C). Compaction must be completed as soon as possible.
- Release agents used for the construction equipment must not be petroleum based. Detergents are recommended.
- Pneumatic tire rollers cannot be used because asphalt rubber will build up on the roller tires.
- Blotter sand may be necessary if traffic will be allowed on a new pavement. Spread rates of 2 to 3 lbs/yd^2 (1.1 to 1.6 kg/m^2) are typically used. Blotter sand should not be applied to open-graded friction courses.
- Joint raking is generally not possible.

For the dry process construction:

- A separate crumb rubber feed system is needed for either batch or drum plants. Manual bag feeding is common at batch plants. Some drum plants have used recycled asphalt concrete hoppers to feed the crumb rubber. The hopper or belt should be tied electronically to the plant proportioning control system.
- Batch plants require a dry mix cycle of 30 to 45 seconds to ensure that the heated aggregate is mixed with the crumb rubber before the asphalt cement application.
- Mixtures should be produced at 300 to 350°F with a laydown temperature of at least 250°F. Compaction must be completed as soon as possible.
- Pneumatic rollers should be avoided.
- Detergent release agents should be used on the compaction equipment.
- The finish roller must continue to compact the mixture until it cools below 140°F (60°C). Otherwise, the continuing reaction of the asphalt and crumb rubber at elevated temperatures will cause the mixture to swell.

The synthesis listed seven field projects that had recycled old CRM pavements. For three of the projects, no problems were noted during construction. One project report indicated that the recycling resulted in a good quality pavement. Four of the projects collected air quality test data, however, only the results of one were reported. The results showed that insignificant amounts of particulates, carbon monoxide and total hydrocarbons were found.

The subsection on traffic noise reported that as much as a 50% reduction may result when using asphalt-rubber open-graded mixes compared to portland cement-bound surfaces. It also states that carefully designed open-graded surfaces without rubber can also provide an improvement in noise levels.

Fourteen states reported the performance of CRM asphalt concrete projects along with an FHWA pooled fund study which analyzed the performance of 61 projects. All results indicate that crumb rubber modified AC pavements, in general, are not superior to conventional pavements. Rubber modified asphalt pavements constructed with the wet process, however, seem to perform better than rubber modified asphalt pavements constructed with the dry process. Dry process open-graded mixes produced the worst results in both the state and national studies. The long term performance of CRM mixtures, however, requires further investigation.

The typical cost of a CRM mix is 1.5 to 2.0 times the cost of a conventional mix. The added cost is associated with the increased asphalt content, cost of the rubber, changes in the construction operation, use of special aggregate, and increased contractor uncertainty.

The issues of environment, health, and safety, are also addressed in the synthesis. The data reviewed, based on laboratory and field leachate studies, indicate that the use of recycled tire rubber may cause environmental problems. The number of emission studies, however, is too small to reach conclusions on environmental, health, and safety. In addition, laboratory leachate tests were done under "worse case" conditions and may not represent field conditions. With the limited amount of data, and the complexity of the issues involved, the questions of adverse effects can not be answered.

In 1994, a questionnaire was sent to the state departments of transportation through the National Cooperative Research Program and the American Association of State Highway and Transportation Officials. The information requested included data on price and performance on recycled crumb rubber projects. The results were compiled in a DRAFT summary report (9).

The results of the survey indicate that generally, "wet" process" HMAC is more expensive than "dry" process mixes. Wet process open graded HMAC costs ranged from $36.68/ton ($40.35/metric ton) to $62.09/ton ($68.30/metric ton). Wet process dense graded HMAC costs ranged from $23.56/ton ($25.92/metric ton) to $67.02/ton ($73.72/metric ton). Dry process dense graded HMAC costs ranged from $23.69/ton ($26.06/metric ton) to $48.79/ton ($53.67/metric ton).

Performance was reported for 16 wet process open graded HMAC pavements. Of those, 6% (or one project) was reported to be performing better than a conventional pavement and 15% were reported to be performing worse. Of the 57 dense graded HMAC wet process projects reported, better performance was reported for 19% of the projects, and worse for 19%. Performance was also reported for 69 dry process dense graded HMAC pavements. Of those, 16% were performing better and 42% were performing worse than the conventional pavements.

Information on recycling involving CRM asphalt was also collected. The results indicated that recycle projects have been performed in Kansas, Maine, New Jersey, Texas and Wisconsin. Other sources indicate that Michigan, Idaho, District of Columbia, and Ontario also performed recycling operations as well as France and the Netherlands. Several projects were scheduled for the summer of 1994.

A study was prepared for the Florida Department of Transportation on occupational health considerations of the use of rubber in HMAC (10). The study compared measured exposures between conventional and modified mix. The results of air sampling and analysis did not reveal any breathing zone concentrations that exceeded existing Occupational Safety and Health Administration (OSHA) Permissible Exposure Limits (PELs) or other recognized health criteria values. A visible fume was apparent when the rubber asphalt material was handled as compared to the conventional mix. Also, the modified mix had a characteristic "rubber" odor. Direct reading measurements suggested that higher levels of volatile organic compounds (VOCs) and hydrogen sulfide (H_2S) were noted when the modified mix was handled. It is unlikely that hazardous levels of H_2S, however, may accumulate in open air settings. Additional study may be warranted if CRM mixes were ever used in a confining environment where released gases may accumulate.

In general, the known benefits of CRM AC include: improved fatigue life, improved thermal cracking resistance, and a possible reduction in noise levels by 50-90%. On the other hand, CRM AC drawbacks are: increased mixing and compaction temperatures, 10-20% higher binder contents, potential for water susceptibility, lower friction numbers, and a 150-200% increase in cost over conventional asphalt concretes. Finally, the recyclability, long-term performance, environmental, health, and safety impacts of CRM pavements requires additional research (8,9,11,12).

3.0 NON-ODOT PROJECTS

In April 1994, the Research Unit distributed a survey to Oregon cities and counties and to the Washington Department of Transportation (WsDOT) to determine other agency experience with crumb rubber modifiers in asphalt concrete pavements. Responses for 24 projects (two of which were constructed jointly with ODOT) were collected from this survey. Tables 3.1 3.2 summarize project data and performance.

Table 3.1: Non-ODOT Project Summary for CRM Mixes (Wet Process).

Date of Construction Mo/Yr	Project Identification		Mix Type[1]	Process	Price $/ton[3] (Quantity)	Age at Date of Performance Evaluations, Years	Comments
	Agency	Location					
1982	WsDOT	Evergreen Point Bridge - SR-908	E	Wet (ISI)[2]	27.00 (3.80 Lane Miles)	9	Very good performance w/minor rutting and pot holes after 9 yrs. of heavy traffic volumes
1984	WsDOT	S-Curve/Cedar River Bridge & RR Bridge	E	Wet (ISI)[2]	86.85 (0.60 Lane Miles)	7	Successful after 7 years service under high traffic volumes. Has since been rebuilt.
1986	WsDOT	Columbia R - 39th Street	E	Wet (ISI)[2]	55.56 (12.80 Lane Miles)	8	Very good performance after 5 years of service. Ravelling noted in the center lane. Passing and truck lane performing well.
1990	WsDOT	Armstrong Rd.	E	Wet (ISI)[2]	64.10 (7.44 Lane Miles)	5	Very good performance, some reflective cracking.
1992	WsDOT	22nd St.	E	Wet (ISI)[2]	79.50 (4.38 Lane Miles)	3	Excellent, subjected to heavy truck traffic.
1989	Jackson County	Mill Creek Drive	C	Wet (ISI)	56.50 (2,660 tons)	5	Successful. No defects noted.
1991	Jackson County	Butte Falls Road	Gap	Wet (ISI)	51.10 (20,800 tons)	3	4 areas of shoving were repaired. Good performance.
1990	Linn County	Old Salem Road	Gap	Wet (ISI)	56.06 (2,400 tons)	4	Excellent.
1993	Linn County	CR 648 Fish Hatchery Drive	Gap	Wet (ISI)	54.88 (3,800 tons)	1	Good.

1 Mix types: B = Dense graded mix, maximum size 1" (25 mm); C = Dense graded mix, maximum size 3/4", (19 mm) E = Open graded mix, maximum size ¾": Gap = gap graded.

2 The wet process used by WsDOT was the "Arizona Process."

3 To convert from $/ton to $/metric ton multiply by 1.10; from ton to metric ton multiply by 0.907; from mile to km multiply by 1.609.

Table 3.2 Non-ODOT Project Summary for CRM Mixes (Dry Process).

Date of Construction Mo/Yr	Project Identification		Mix Type[1]	Process	Price $/ton[2] (Quantity)	Age at Date of Performance Evaluations, Years	Comments
	Agency	Location					
1982	WsDOT	Main St. - S. 1st	Gap	Plus Ride	41.00 (0.40 Lane Miles)	9	Flushing and rutting.
1982	WsDOT	Br. # 82/205	Gap	Plus Ride	75.00 (0.90 Lane Miles)	8½	Lasted 8½, 7 yrs at different sections, at 50% more cost.
1983	WsDOT	84th Ave S. I/C & Auburn ramps	Gap	Plus Ride	53.60 (0.50 Lane Miles)	8	Several large patches replaced.
1984	WsDOT	S-Curve/Cedar River Bridge & RR Bridge	Gap	Plus Ride	50.00 (0.60 Lane Miles)	7	Large sections ravelled and debonded in wheel paths after 2 yrs.
1985	WsDOT	Fauntleroy Ferry Dock	Gap	Plus Ride	68.50 (0.60 Lane Miles)	6	Total failure due to unstable mix. Replaced.
1985	WsDOT	Skagit Co. Line - Dalgren Rd.	Gap	Plus Ride	55.00 (0.80 Lane Miles)	7	Satisfactory after 7 yrs. Some longitudinal cracking.
1986	WsDOT	35th Ave. NE - SR-5	Gap	Plus Ride	52.50 (1.50 Lane Miles)	6	Satisfactory after 6 years of service.
1987	Benton County	Springhill Drive	Gap	Plus Ride	46.25 (553 tons)	6½	Successful. Some bleeding due to high temperatures.
1988	Benton County	N. 19th Street	Gap	Plus Ride	49.80 (496 tons)	5½	Successful. Some bleeding due to high temperatures.
1988	Benton County	S. 19th Street	Gap	Plus Ride	49.80 (1,046 tons)	5½	Mod. - severe alligator cracking (due to design)
1990	Benton County	Alpine Cut-off	Gap	Plus Ride	47.40 (2,254 tons)	4	Successful. Some bleeding due to high temperatures.
1990	Benton County	Evergreen	Gap	Plus Ride	47.35 (1,650 tons)	4	Successful. Some bleeding due to high temperatures
1986	City of Corval.	NW Garfield Ave: Kings St. - 29th St.	C	Plus Ride	55.00 (not reported)	8	Good to excellent performance.
1991	City of Portland	Marine Drive (Portland)	C	RUMAC	45.00 (3,860 tons)	3	Good shape w/minor pot holes.
1991	Mult. County	Stark Street (Gresham)	B	RUMAC	40.00 (2,000 tons)	3	Ravelling after 3 yrs--some severe. Would not use again.

1 Mix types: B = Dense graded mix, maximum size 1" (25 mm); C = Dense graded mix, maximum size 3/4 (19 mm)".
2 The wet process used by WsDOT was the "Arizona Process."
3 To convert from $/ton to $/metric ton multiply by 1.10; from ton to metric ton multiply by 0.907; from mile to km multiply by 1.609.

Nine wet process projects were reported by WsDOT, Linn County, and Jackson County. All projects monitored received good reviews after as much as nine years of service. The oldest project showed only minor rutting (less than ¼" (6 mm)) and potholing after exposure to heavy traffic volumes.

Thirteen Plus Ride projects were identified, of which only one received a good performance rating. Eight received satisfactory or successful ratings and two failures were identified. Distresses indentified included bleeding, flushing, rutting, ravelling and debonding.

Lastly, two METRO RUMAC sections were constructed (these are also recorded under ODOT projects). One project is in good shape with minor potholing after approximately three years. The other shows severe ravelling after about three years. Multnomah County, the primary sponsor of the second project, noted that they would not use the product again.

The survey indicates that crumb rubber modified asphalt concrete constructed with the wet process yields the most favorable results while METRO RUMAC yields the worst. Plus Ride pavements have recorded mixed results.

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4.0 ODOT PROJECTS

The Oregon Department of Transportation has constructed 14 sections of roadway using crumb rubber modified HMAC. To date, 50,000 tons (45,000 metric tons) of CRM pavement have been placed for a length of more than 45 lane miles (72 km). Figure 4.1 shows the location of each project and Table 4.1 summarizes mix type, CRM process, cost and performance. Appendix A includes the background, construction, and performance details for the ODOT projects. Additional project data is summarized in Appendix B, Table B-1. Table B-1 contains a detailed listing of project data including specific locations, CRM quantities, rubber contents, binder and hot mix costs. Note that the CRM costs in Table 4.1 are for small test quantities and are presented for information only.

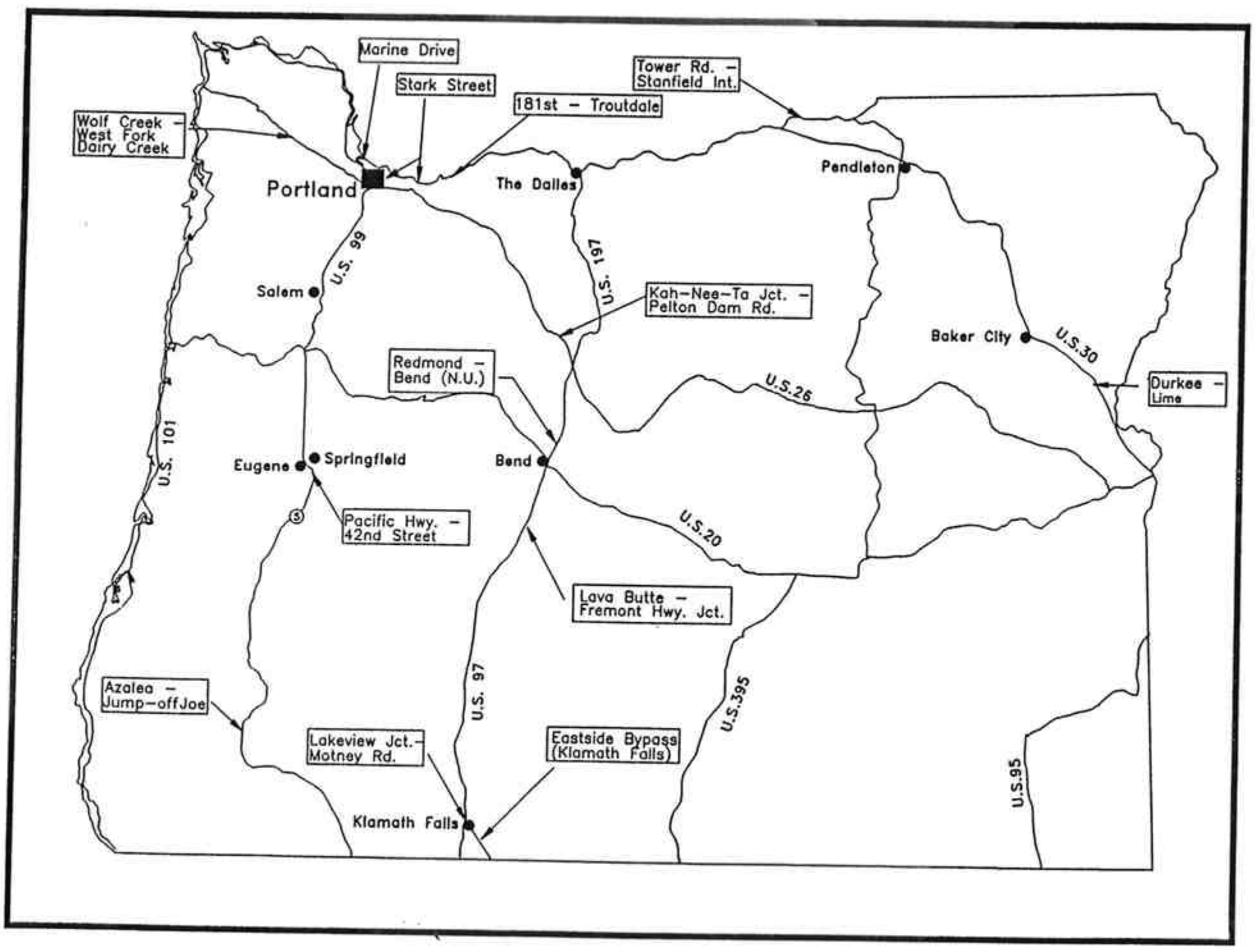

Figure 4.1: Location of Crumb Rubber Modified Asphalt Concrete Projects in Oregon.

Table 4.1: Price and Performance Information by Project.

Construction Year/ Constr. Report available(Y/N)	Project Identification		Mix Type[1]	Process	Price $/ton[2] (Control)	Age at Date of Performance Evaluations, Years	Comments
	Agency	Location					
DENSE OR GAP GRADED MIXES							
1985/Y	ODOT	Lava Butte - Fremont Hwy	Gap	PlusRide	45.72 (22.13)	9	Alligator & block cracked - worse than control.
1985/Y	ODOT	Lava Butte - Fremont Hwy	C	Arm-R-Shield	80.00 (21.65)	9	Performed slightly better than control.
1991/Y	ODOT	181st - Troutdale	B	RUMAC	46.10 (30.35)	3	Equal to control, both ravelling.
1991/Y	ODOT	Stark Street	B	RUMAC	44.77 (28.01)	3	Ravelling. Worse than control.
1991/Y	ODOT	Marine Drive	C	RUMAC	40.29 (28.04)	3	Equal to control. (Minor pot holes outside of control)
1992/N	ODOT	Pacific Hwy. - 42nd Street	B	RUMAC	42.00 (20.15)	2	Base. Comparable to control.
1992/N	ODOT	Eastside Bypass	B	ISI ARC	58.59 (34.39)	2	Slight flushing similar to control.
1992/N	ODOT	Lakeview Jct. - Matney Rd.	B	RUMAC	35.37 (27.79)	2	Moderate ravelling, worse than control.
1993/N	ODOT	Wolf Cr. - W. Fork Dairy Cr.	B	RUMAC	29.39 (22.88)	1	Base. Similar results to control
1993/N	ODOT	Durkee - Lime	A	RUMAC	33.61 (23.63)	1	Base. Equal to control.
OPEN GRADED MIXES							
1991/Y	ODOT	181st - Troutdale	F	ISI	67.43 (30.54)	3	Ravelling - worse than control.
1992/N	ODOT	Redmond - Bend (N.U.)	F	PBA-6GR	45.59 (30.80)	2	No control established. Performance as expected, no problems
1992/N	ODOT	Eastside Bypass	F	PRARC	63.12 (34.85)	2	Equal to control.
1992/N	ODOT	Eastside Bypass	F	ISI	58.45 (34.85)	2	Equal to control.
1993/N	ODOT	Kah-Nee-Ta - Pelton Dam Rd	F	PBA-6GR	32.78 (26.16)	1	Same as control.
1994/N	ODOT	Tower Rd. - Stanfield	F	PBA-6GR	27.47 (24.01)	0	New pavement.
1994/N	ODOT	Azalea - Jump-off Joe	F	PBA-6GR	32.76 (30.53)	0	New pavement.

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 3/4" (19 mm); F = Open graded mix, maximum size 1".

2 Conversion from $/ton to $/metric ton requires multiplying by a factor of 1.10.

4.1 ODOT PROJECT COSTS

Cost data was collected for all CRM projects constructed by ODOT. Figures 4.2 and 4.3 include a comparison of the costs of CRM dense and open-graded mixes to the control mixes. The costs presented may be suitable for general comparison but other factors should be considered. The majority of CRM mixes were bid as a small quantity. That is, the mixes were constructed as "modified" hot mixes over short sections of pavement. The unknown construction characteristics of the new mixes could have caused the contractors to increase the bid prices. In some cases, too, the cost of the rubber, not always available locally, could have caused higher prices.

The actual cost to produce CRM asphalt concrete should also be considered. When analyzing the full impact of using rubber in pavements, consideration should be given to the accelerated use of the associated non-renewable resources such as diesel fuel and asphalt cement. As noted in the literature review, the modified mixes typically require higher mixing and compaction temperatures and higher binder contents than conventional mixes. Figures 4.4 and 4.5 present the range of temperatures at discharge for dense and open-graded mixes recorded during construction in Oregon. Figures 4.6 and 4.7 present the binder contents for both mix types.

RUMAC mixes comprised the majority of the dense-graded CRM mixes. The average cost for the RUMAC was $38.79/ton ($42.67/metric ton). The cost compares with $25.79/ton ($28.37/metric ton) for the conventional dense-graded mixes. Modifying the dense-graded mixes with rubber increased the costs by 50%.

All of the CRM open-graded mixes were constructed using the wet process. The average cost of the three projects constructed by ISI was $63.00/ton ($69.30/metric ton). The high unit cost could be attributed to the expense of mobilizing the equipment to blend the asphalt rubber concrete at the jobsite and/or the cost of a patented system. The ISI ARC compares to a cost of $34.65/ton ($38.12/metric ton) for the PBA-6GR mixes and $29.31/ton ($32.24/metric ton) for the conventional open-graded mixes. The ISI cost is more than 115% of the conventional mix costs. The PBA-6GR cost is about 18% more than the conventional open-graded mix costs. Of all the CRM mixes, the PBA-6GR appears to be the most economical based on a straight cost comparison.

A more thorough comparison of PBA-6GR to PBA-6 open-graded mixes was done in the *Evaluation of PBA-6GR Binder for Open-Graded Asphalt Concrete, 1993 and 1994 Projects* report (5). Since the first PBA-6GR project was not included in the original contract, the bid cost was disproportionately higher than the 1993 and 1994 costs. The average total cost of "F" mix in place with PBA-6GR including only the 1993 and 1994 projects is $30.99/ton ($34.09/metric ton). This compares to a 1994 bid price of $27.64/ton ($30.47/metric ton) for PBA-6 "F" mix. The resulting difference is that the PBA-6GR mixes cost 12% more than the PBA-6 mixes.

An alternative method to consider the cost of using rubber modified mixes, is to determine the additional cost to produce a ton of mix per ton of rubber. Table 4.2 presents the cost of using one ton of rubber for each of the mix types. Included in the table, are the additional rubber costs when using PBA-6GR as compared to PBA-5. The open-graded mixes constructed west of the Cascade mountains are usually specified with PBA-5 binder. To meet the requirements of the ISTEA legislation, some of the PBA-5 open-graded mixes would have to be specified with PBA-6GR to dispose of the tire rubber. As shown in the table, that additional cost would be about $970/ton ($1,070/metric ton). There would be value in using the PBA-6GR versus PBA-5 since the PBA-6GR would be less temperature susceptible. Whether that value is worth $970/ton of rubber would be questionable.

Because of the high cost of the ISI and RUMAC mixes, the PBA-6GR substituted for PBA-6 would be the most efficient means of utilizing tire rubber in pavements. If the cost of the RUMAC dropped to about $36.00/ton ($39.60/metric ton), the cost of using rubber would be comparable the current PBA-6GR prices. If the cost of the RUMAC was less than $36.00/ton, the process would be a more efficient means of using rubber because of the relatively high rubber content of the mix (2%). Issues of constructability and performance, however, must also be considered. At least with the PBA-6GR, mix properties may stay the same and may even be enhanced compared to RUMAC type (dry process) mixes which have more reported performance problems.

Table 4.2: Additional Cost to Use a Ton of Rubber by Mix Type.

Mix Type	Modified Mix Costs ($/ton)[2]	Rubber Content [1]	Tons of mix required to dispose of 1 ton of rubber	Conventional Mix Costs ($/ton)[2]	Add'l. Cost/ton Rubber ($/ton)[2,3]
ISI-Dense compared to control costs	$58.59	1.08%	93	$25.79	$845.91
RUMAC compared to control costs	$38.79	2.00%	50	$25.79	$650.00
ISI-Open compared to control costs	$62.94	1.08%	93	$29.31	$3,127.59
PBA-6GR compared to control costs	$34.65	0.66%	152	$29.31	$811.68
1993, 1994 PBA-6GR costs compared to 1994 PBA-6 mix costs	$30.99	0.66%	152	$27.64	$509.20
1993, 1994 PBA-6GR costs compared to 1995 PBA-5 mix costs	$30.99	0.66%	152	$24.62	$968.24

1Percent by weight of mix based on an asphalt content of 6%.
2Conversion from $/ton to $/metric ton requires multiplying by a factor of 1.10.
3For example: ($58.59/ton ISI -$25.79/ton conventional mix) X 93 tons = $845.91/ton of rubber added.

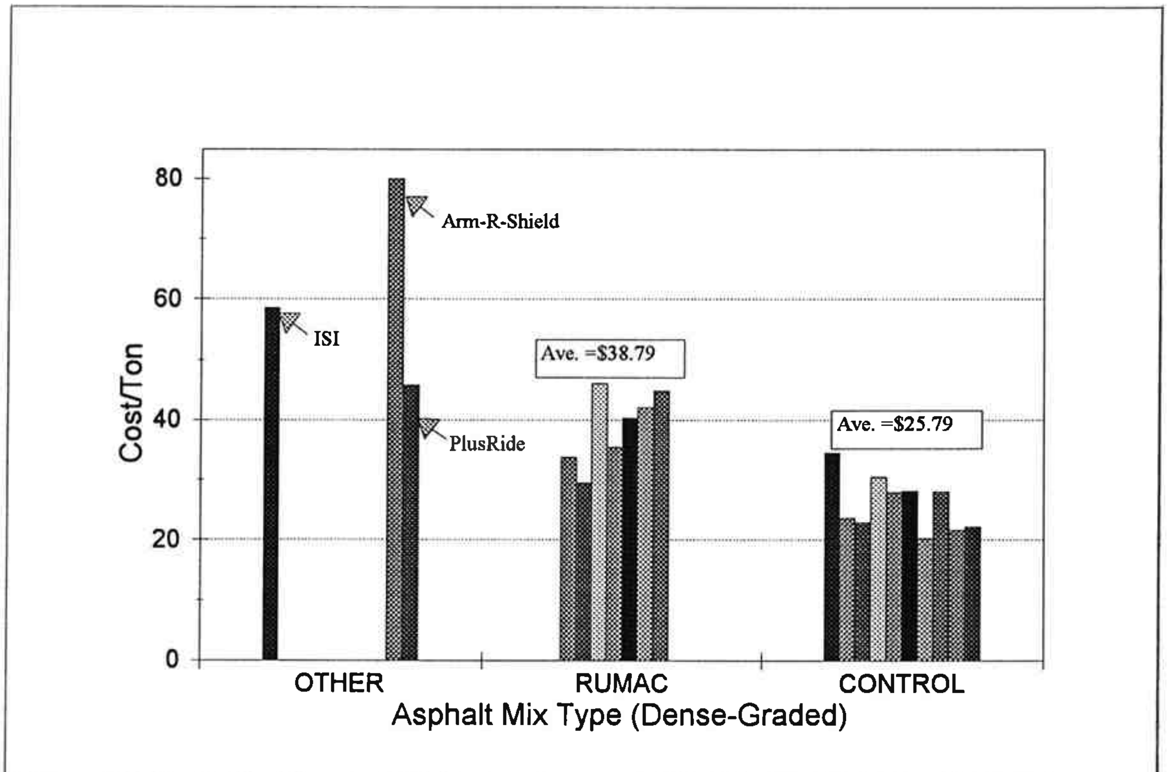

Figure 4.2. CRM Mix Price Comparison for Dense-Graded Mixes.

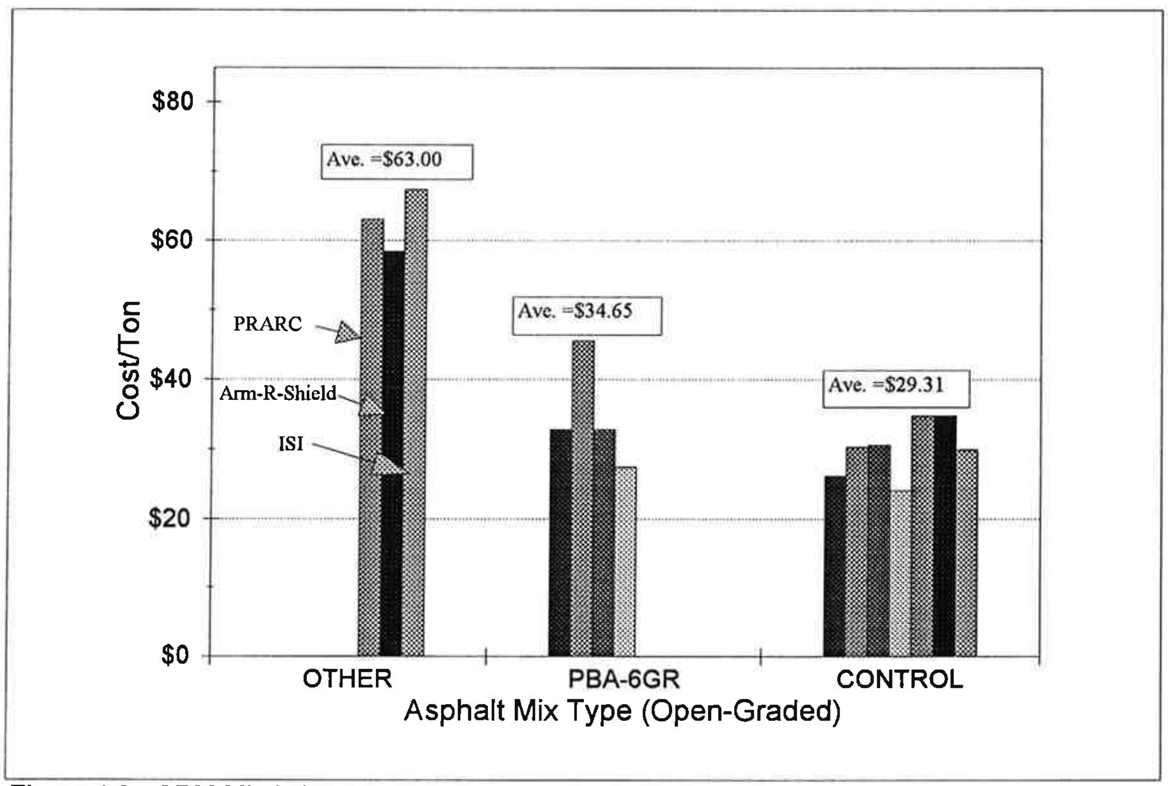

Figure 4.3. CRM Mix Price Comparison for Open-Graded Mixes.

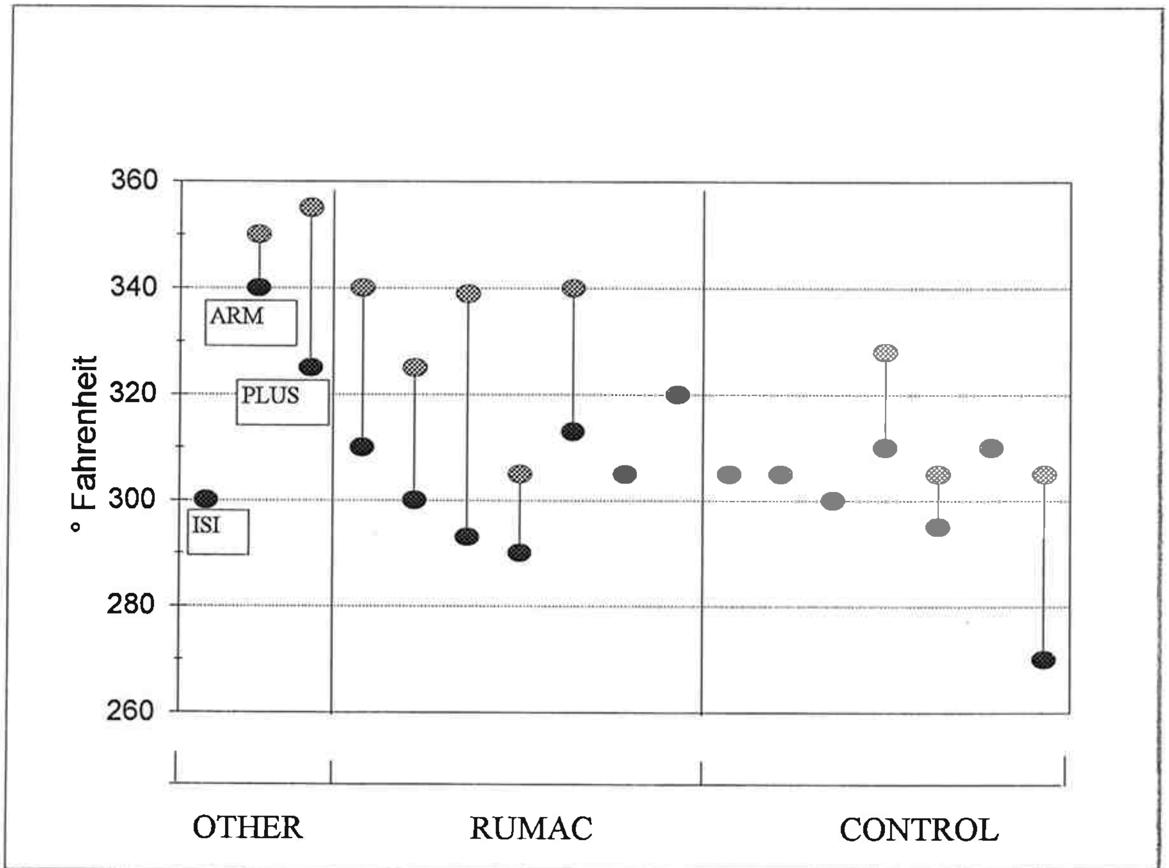

Figure 4.4. Discharge Temperatures for Dense-Graded Mixes (highs and lows by project).

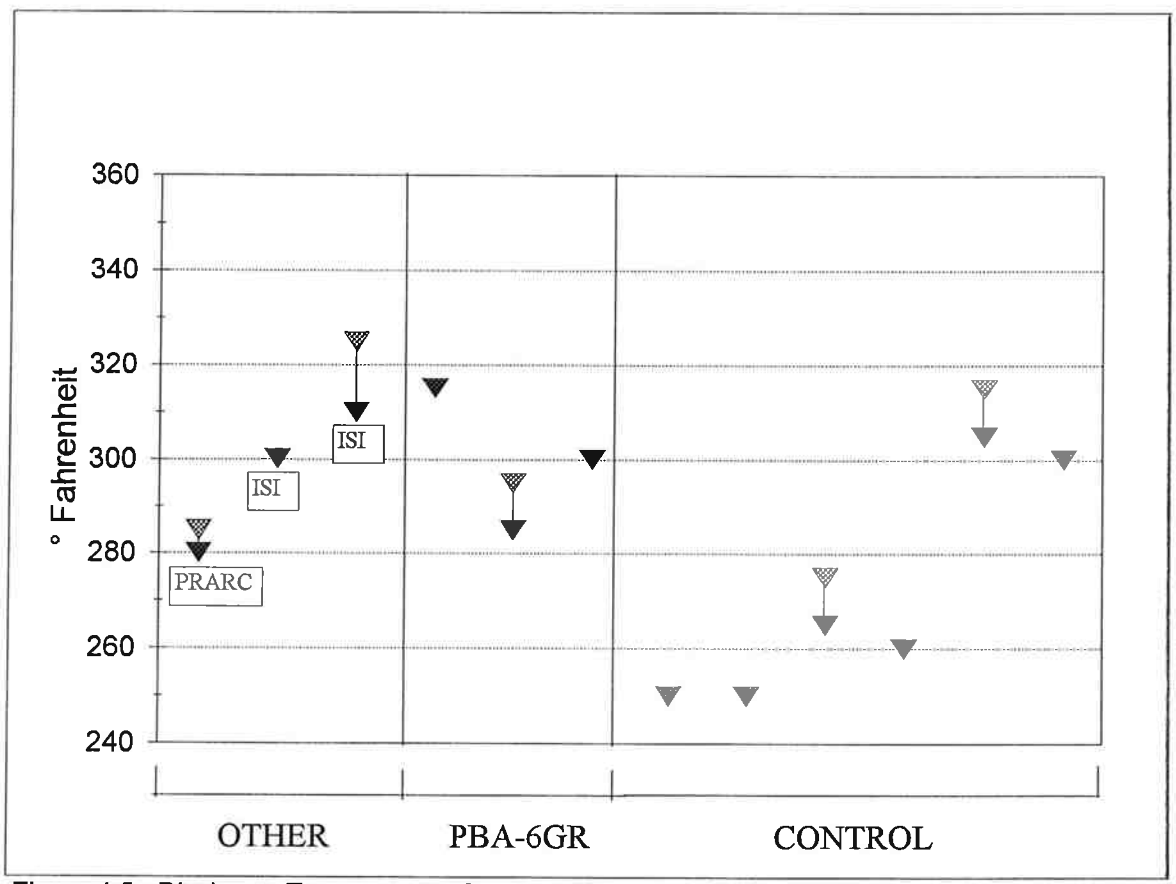

Figure 4.5. Discharge Temperatures for Open-Graded Mixes (highs and lows by project).

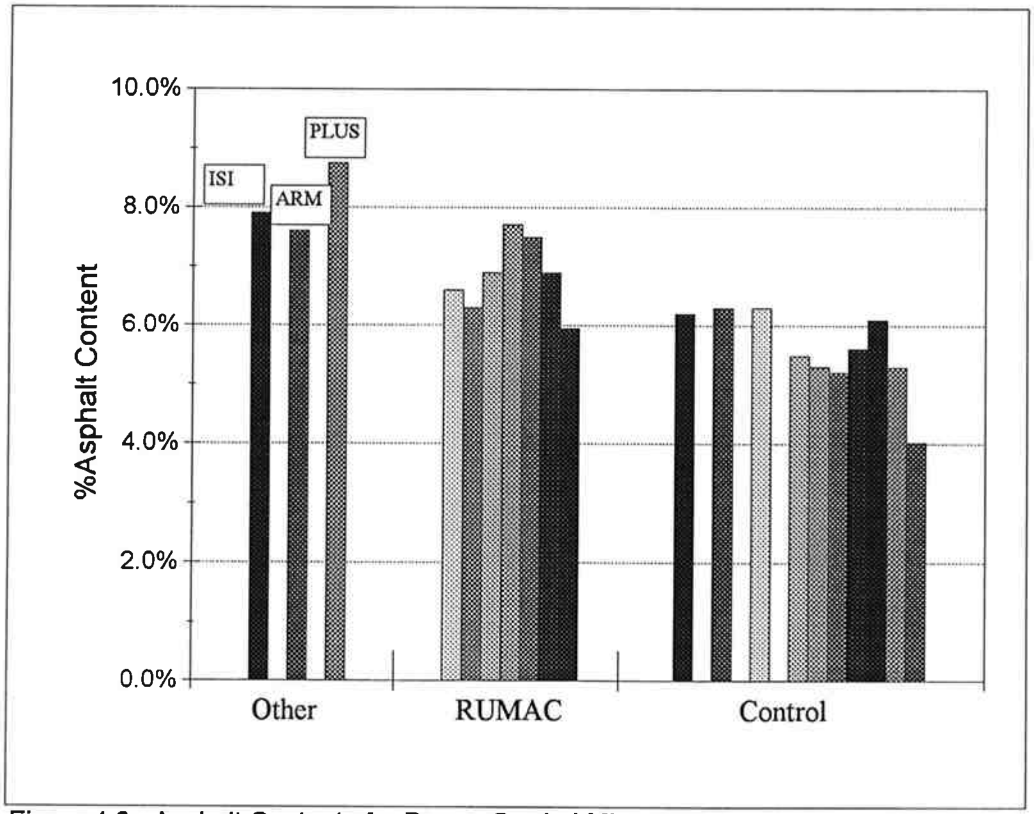

Figure 4.6. Asphalt Contents for Dense-Graded Mixes.

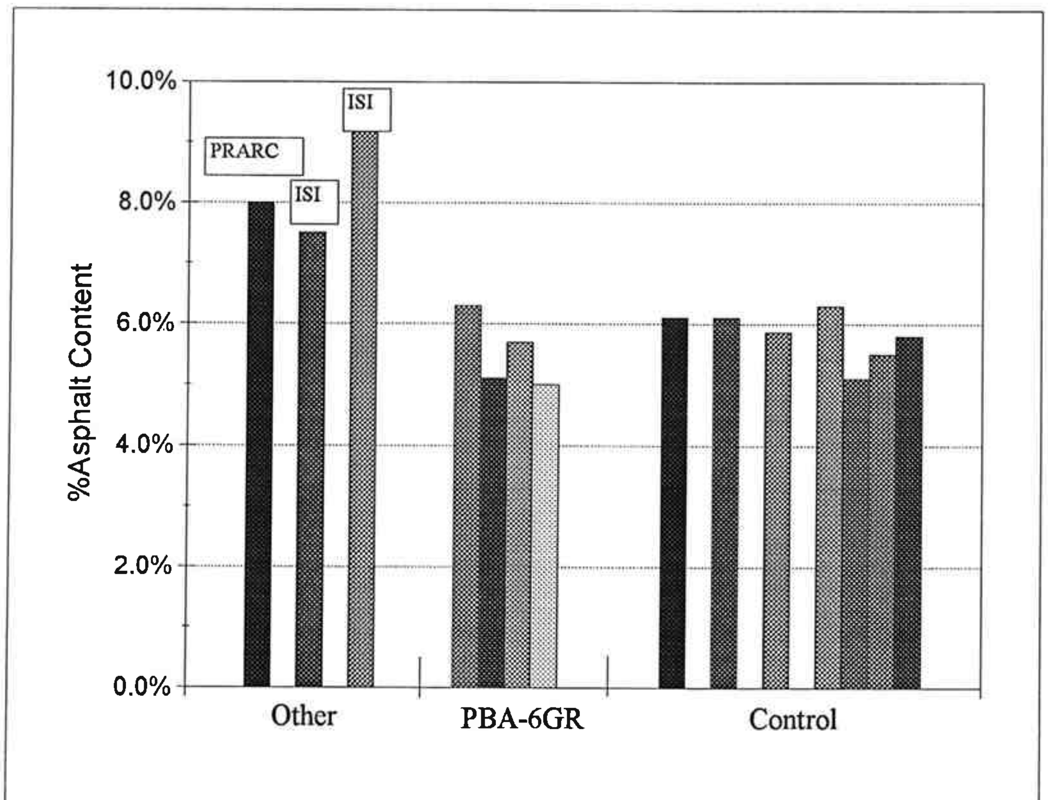

Figure 4.7. Asphalt Contents for Open-Graded Mixes.

4.2 ODOT PROJECT PERFORMANCE

The CRM projects have been and will continue to be surveyed for yearly distresses. Following is a brief discussion of the CRM pavement performance in general terms. Figures 4.8 and 4.9 present the relative performance for dense and open-graded mixes, organized by CRM type. The graphs indicate the performance compared to the control. The performance was rated as worse than, equal to, or better than the control determined during distress surveys. More detailed pavement performance discussions are contained in the Appendix.

The Plus Ride section constructed in 1985, was reported to be block cracked as well as alligator cracked over greater than 50 percent of the surface. Slight ravelling was also reported. In comparison, the control section had a longitudinal crack a foot or so from the centerline that was evident nearly the entire length of the section. Transverse cracks were also noted that connected the longitudinal cracks at one foot (0.3 m) to 10 feet (3 m) apart, and block cracking was noted between the wheel tracks. In general, it appeared that the Plus Ride test section was performing worse than the control since signs of load related distress were evident.

The seven RUMAC sections have received mix reviews. Three of the RUMAC mixes were used as base material where it has performed comparably to the control section. In the four sections where RUMAC was used as the wearing course, two sections are ravelling and two are performing comparably to the control. It should be noted that during construction, a section of the best pavement is selected and marked for the long-term evaluation. On three of the RUMAC projects, severe potholing was noted outside of the evaluation sections. The potholing was attributed to too much rubber in the mix and in some cases not enough asphalt cement.

The wet process, dense-graded mixes include the Arm-R-Shield and ISI ARC processes. The Arm-R-Shield section is performing slightly better than the comparable control section. The ISI ARC "B" section is showing slight flushing similar to the control.

Seven wet process, open-graded mixes were constructed by ODOT in the last three years. Six of the projects were reported to be equal to the control with average performance. The 181st - Troutdale project is ravelling worse than the control. The Kah-Nee-Ta Junction - Pelton Dam project constructed with PBA-6GR, is reported to be resisting wear more effectively than the control. The other PBA-6GR sections have been in place less than a year and are performing satisfactorily.

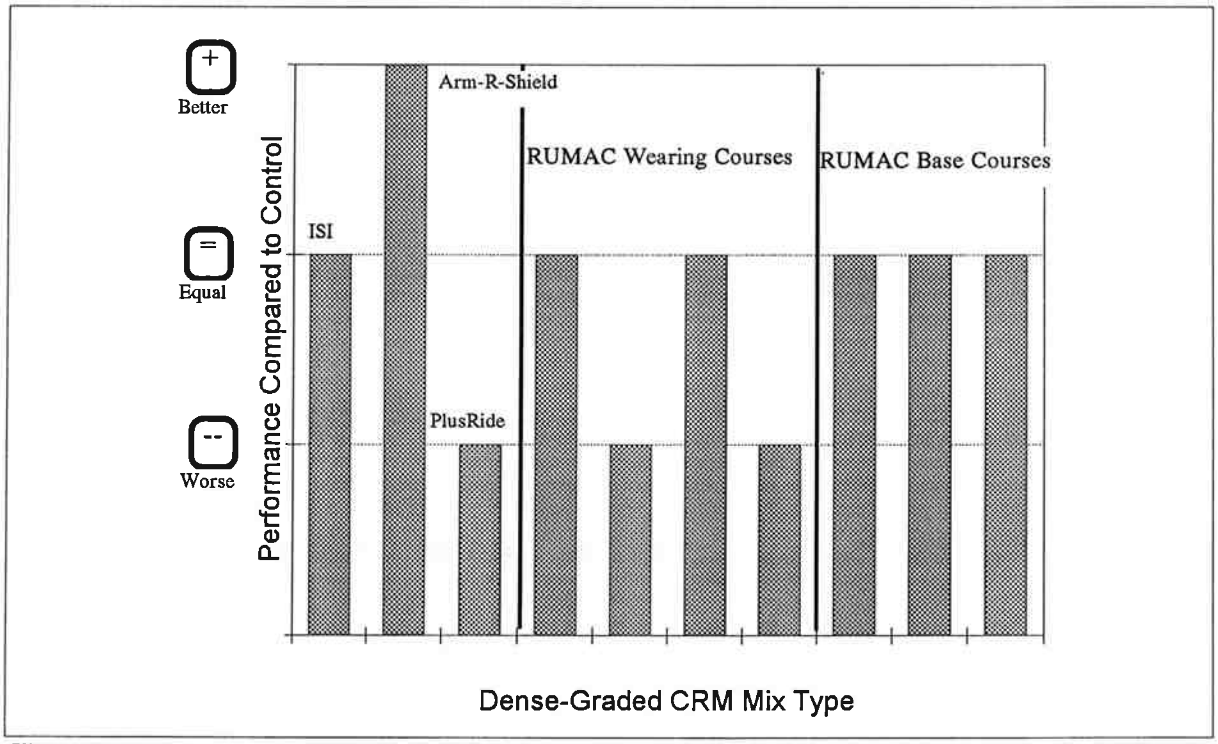

Figure 4.8. Relative Dense-Graded CRM Pavement Performance.

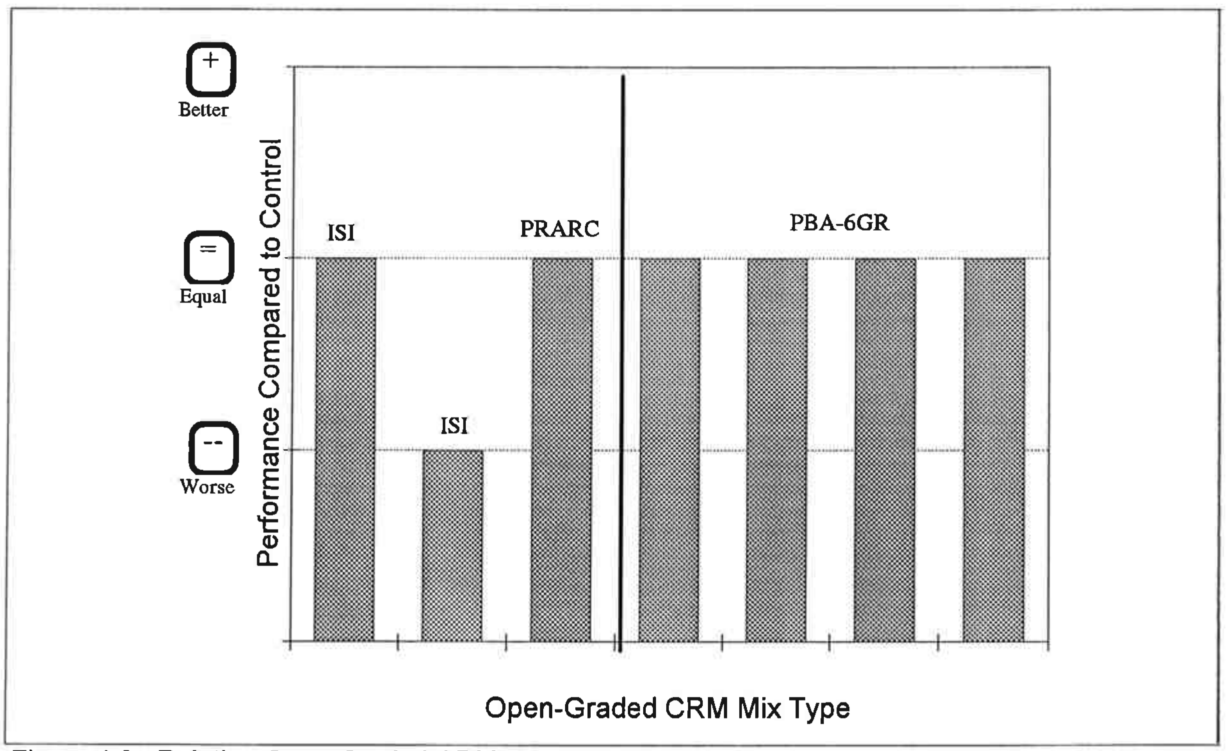

Figure 4.9. Relative Open-Graded CRM Pavement Performance.

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5.0 CONCLUSIONS, RECOMMENDATIONS AND FUTURE ACTIVITIES

5.1 CONCLUSIONS

ODOT is monitoring 17 pavements constructed with crumb rubber to determine the most appropriate CRM process to meet the requirements of ISTEA. The longest any of the pavements has been in place is nine years. The majority of the pavements, however, have been in place less than three years. The short pavement history precludes selection of a process based on performance.

If a CRM process were to be selected today, pavements constructed with PBA-6GR would be the most economical in terms of initial cost/ton. The PBA-6GR is also very easy to use since the rubber modified binder is blended at the refinery and delivered to the jobsite ready for mixing with the aggregate. This process reduces the number of errors possible during construction since the rubber content and the mixing process are tightly controlled at the refinery. Additional testing of the PBA-6GR is necessary, to insure that a product that meets the ODOT specifications is consistently available.

5.2 RECOMMENDATIONS

ODOT Should specify the use of PBA-6GR to meet the requirements of the ISTEA mandate, if/when enacted.

5.3 FUTURE ACTIVITIES

The *Crumb Rubber Modifiers in Asphalt Concrete Pavements* State Planning and Research Project will continue through FY'99 (June 30, 1999). The project will include monitoring the performance of all the test and control pavements for comparison. Sampling and testing will be done on constructed pavements at one and five years to determine the in-place properties of the mix. If the sections begin to fail, additional sampling and testing will be done on an as-needed basis.

An interim report will be prepared in FY'97 detailing performance of the pavements to date along with information regarding any new CRM pavements constructed. A final report will be prepared in FY'99. The final report will include recommendations for the use of crumb rubber modifiers on Oregon roads.

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4. Bo Miller, Elizabeth Hunt, and Glenn Boyle, *Asphalt-Rubber Concrete (ARC) Evaluation Eastside By-Pass (Klamath Falls) Section*, DRAFT Construction Report (Salem, Oregon: Oregon Department of Transportation, December 1993).

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6. Bo Miller, *Rubber Modified Asphalt Concrete (METRO RUMAC) Evaluation, N. Marine Drive in Portland, Oregon; S.E. Stark Street in Gresham, Oregon*, Construction Report (Salem, Oregon: Oregon Department of Transportation, November 1992).

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APPENDIX A

ODOT CRM PROJECT BACKGROUND, CONSTRUCTION, AND PERFORMANCE DETAILS

ODOT PROJECT BACKGROUND, CONSTRUCTION, AND PERFORMANCE DETAILS

The projects listed below are grouped by the reports in which they are or will be discussed.

A.1.0 LAVA BUTTE TO FREMONT HIGHWAY JUNCTION (2)

A.1.1 BACKGROUND

This study covers construction and performance of ten test sections using dense-graded hot mix asphalt concrete with additives. The project was constructed south of Bend, in central Oregon, in 1985. The sections that include rubber are: Plus Ride mix containing granulated tire rubber, and Arm-R-Shield modified asphalt containing ground and dissolved tire rubber. The control section used conventional AC-20 asphalt. The rubber modified mixes were used as wearing courses.

A.1.2 CONSTRUCTION

The Plus Ride mix was blended in a batch plant where the shredded tire rubber was added via the top hopper. The Arm-R-Shield mix was also blended in a batch plant. Recycled rubber was melted with the AC-20 asphalt by Arizona Refining. Once blended, the asphalt-rubber mixture was transferred to a distributor truck for storage. The production of the mix was extremely slow. This may have been due to the material being very viscous and hard to pump. Under normal production, with larger tanks and hoses, this may not be a problem.

The Plus Ride mix construction proceeded rapidly without any major problems. The Arm-R-Shield mix was difficult to compact. The pavement was also stickier than the Plus Ride and remained sticky until traffic had been on it for some time

A.1.3 PERFORMANCE

A survey of the pavements containing rubber was performed in September, 1994. The Class "C" mix control section had a longitudinal crack a foot or so from the centerline that was evident nearly the entire length of the section. Transverse cracks were also noted that connected the longitudinal cracks at 1 foot to 10 feet apart. Block cracking was noted between the wheel tracks. Rutting varied from 1/8 to 3/8".

Two lanes have been added through the Plus Ride section to allow for passing. The original section appears to be intact. The Plus Ride section looked block cracked as well as alligator cracked over greater than 50 percent of the surface. Slight ravelling was noted. Portions of the Plus Ride section had been milled out and patched in the inside lane, outside wheel track. Rutting varied from 1/8 to 1/4".

The Arm-R-Shield section appeared to have minimal distress with few transverse cracks and wheel ruts of 1/8 to 5/8". Very slight ravelling was also noted.

Based on the results of the inspection, it appears that the Arm-R-Shield pavement is performing slightly better than the control pavement and the Plus Ride section is performing worse than the control.

A.2.0 N.E. 181ST AVENUE - TROUTDALE SECTION (3)

A.2.1 BACKGROUND

This study covers the September 1991 construction of two test pavements using asphalt concrete modified with tire rubber. The materials were used as an overlay for a heavily traveled freeway in the Portland metropolitan area.

One test pavement used an open-graded asphalt rubber binder (ISI ARC). The binder was made by blending asphalt with shredded tire rubber. This test pavement is compared to a control pavement of an open-graded ODOT mix. The other test pavement included METRO RUMAC.

A.2.2 CONSTRUCTION

Other than the blending of the asphalt-rubber the construction of the ISI ARC and the control section were similar, and few problems were encountered.

When the METRO RUMAC was mixed, the system used to add the rubber to the drum was hard to control and monitor. As a result, the rubber content of the mix varied considerably from the desired proportion. This mix was hard to compact to the desired density. The compaction problem may be linked to variations in the mix's rubber content and/or placement temperature.

After construction, both the ISI ARC and METRO RUMAC test sections had appearances, ride values, deflection reductions, and surface friction values typical of conventional asphalt concrete pavements.

These rubberized mixes need specialized sampling and testing methods to assure that the rubber quality and proportioning were correct.

A.2.3 PERFORMANCE

Based on the results of an inspection made in 1994, the following conditions were noted:

Class "B" AC control: Station 694+40: an accident caused damage to the pavement in the form of a gouge across the right lane. Stations 692 - 705: the mixture was denser between the wheel tracks (possible truck drippings). Stations 701 - 705: more raveling than last report. Stations 705 - 706: heavy raveling. Stations 707 - 708, 710 - 712: more raveling with tire skid mark: outside wheel track - rubber on the surface. Stations 711 - 715: raveling at the flair and at the longitudinal construction joint.

Class "B" RUMAC: Moderate to heavy raveling on more than 25% of test section. Stations 749+62 to 757: wheel tracks are pitted, there is some large aggregate loss, and the RUMAC has been ground out and replaced with a "boney" looking class "B" AC. The raveling problems could be attributed to construction problems like incorrect metering of the rubber, low delivery mix temperature, and/or the presence of moisture on the existing pavement.

Class "F" AC Open-graded Mixture: Slight rutting and low level of raveling. In general, the inside lane looks worse, from extreme openness at the center of the panel where it is starting to ravel from center break of the paver screed. Station 712: "boney" at the center of the left lane. Station 710: fat strip 9' x 12" inside lane in the outside wheel track. Station 709+80: fat spots in outside lane. Station 707+10: fat area in the outside lane between wheel tracks. Station 706: fat area in the outside lane. Station 705+50: fat area in the outside lane between wheel tracks. Stations 703+50, 695+10, 694+20, and 691+80: fat pavement.

ISI ARC Open-graded Mixture: Slight rutting with medium to heavy raveling over 25% to 40% of test area. Left lane generally looks the same or worse than right lane. Stations 742+75 and 741+25 look very dense in outside lane while the inside lane looks open and it is starting to ravel at center of the panel (center of screed). Station 734+75: fat spots in the inside wheel track (softball and football size).

The METRO RUMAC appears to be performing comparably to the control Class "B" mix. The ISI ARC "F" mix appears to be performing worse than the control with more apparent raveling.

A.2.4 CURRENT STATUS

Much of this project is being reconstructed at this time. Final condition surveys will be performed

A.3.0 S.E. STARK STREET AND NORTH MARINE DRIVE (6)

A.3.1 BACKGROUND

This study covers the 1991 construction of two test pavements using asphalt concrete modified with crumb rubber from scrap tires. The pavements are on arterial roadways in the Portland, Oregon metropolitan area. Both test pavements were METRO RUMAC, dense-graded mix (ODOT Class "B" or "C" mix). Adjacent to the test pavements, control pavements were paved with conventional asphalt concrete.

A.3.2 CONSTRUCTION

The METRO RUMAC was successfully blended in both a batch and a drum mixing plant. In both cases, the plant's exhaust gas opacity was at an acceptable level. The rubberized mixes were placed and compacted by conventional equipment.

Experience on these projects showed that caution is needed in determining the mix properties by solvent extraction and in measuring pavement density by a nuclear gauge. Testing showed that two solvents commonly used in vacuum extractions dissolve finer particles of the crumb rubber. Using mathematical modeling, it was found that solvent dissolving rubber during the extraction had these effects on test results: it did not significantly affect the test results for the overall gradation of the mix, it had a significant effect on the asphalt content test results, and it invalidated rubber gradation and rubber content test results. To get accurate nuclear density test results, special care was needed when the gauge was seated on the surface of the METRO RUMAC.

After construction, both the METRO RUMAC test sections had appearances, ride values, deflection reductions, and surface friction values similar to their respective control pavements and typical ODOT dense-graded overlays.

A.3.3 PERFORMANCE

A survey of the METRO RUMAC pavements was conducted in July, 1994. The inspection results are presented below:

S. E. Stark Street (Multnomah County)

Class "B" AC control: Minor rutting with medium level raveling was noted. The curb lane and outside half of the travel lane appeared to be a fine, very dense "C" mix that may contain ground tire rubber. The left lane and left turn lane showed a loss of fine aggregate.

Class "B" METRO RUMAC: In the inside lane and inside half of the left turn lane, minor rutting with a medium to high level of raveling was noted. A patch was noted in the outside wheel track between Stations 783+50 to 784. All of the test section had scattered large aggregate missing. Outside of the test area at Stations 281 - 282, the outside wheel track was raveled and golf ball size to softball size pot holes were noticed.

North Marine Drive (City of Portland)

Class "C" AC control: Minor rutting and a low level of raveling was noted. Although this section was not supposed to have crumb rubber in it, all of the eastbound lane had a minor amount of crumb rubber in the mixture. The westbound lane appeared to have less crumb rubber than the eastbound lane. Because of the minor amount of rubber in the "control", direct comparisons with the RUMAC should be carefully considered.

Class "C" METRO RUMAC: Minor rutting and a low level of raveling was noted. Fat spots were noted between Stations 70 to 71: 12 spots baseball to softball size, 1@12" x 12" and 1@18" x 12". Stations 68+60 (inside wheel track), 69+40 (outside wheel track), and Stations 68 to 71 showed a loss of fine aggregate in the left lane.

Based on these inspections, the Stark Street RUMAC section is performing worse than the control; the North Marine Drive section is performing equal to the control.

A.4.0 LAKEVIEW JUNCTION TO MATNEY ROAD, PACIFIC HIGHWAY TO 42ND STREET (7)

A.4.1 BACKGROUND

This study includes the 1992 construction of test sections on two projects using METRO RUMAC. One project's test sections are part of a single lift overlay on a lightly travelled two-lane road south of Klamath Falls, Oregon. The other project's test sections are part of the base course of a three-lift overlay on a heavily travelled four-lane divided highway between Eugene and Springfield. Control sections were paved with conventional asphalt concrete adjacent to the test sections.

A.4.2 CONSTRUCTION

The METRO RUMAC was successfully blended for both projects by adding unopened bags of the rubber to the pugmill of the mix supplier's batch plants. The rubberized mixes could be placed and compacted by conventional equipment. One project's test sections could not be rolled to the desired density where an improper mix gradation may have prevented compaction. The other project's test sections could be compacted to the desired density. Immediately after compaction, construction traffic travelled on one project's hot METRO RUMAC pavement, and the vehicle's tires adhered to and damaged the surface.

Experience on these projects indicate that the specification limits for crumb rubber need to be revised, and in some cases, the percentage of rubber required in the METRO RUMAC needs to be lowered to obtain satisfactory mix properties. In addition, solvent extractions were successfully used on one project to determine the overall gradation of the METRO RUMAC.

After construction, both project's METRO RUMAC and conventional pavement sections had similar appearances and surface friction values. On one project, the test and control section's ride quality and ability to reduce surface deflections were compared, and the METRO RUMAC and conventional mixes had similar characteristics.

A.4.3 PERFORMANCE

Following is a discussion of pavement performance based on 1994 surveys.

Lakeview Jct - Matney Road

Class "B" Control: This section is showing slight ravelling over 10 - 25 percent of the lane with two transverse cracks in the northbound lane between Stations 2+00 and 3+00. The cracks are within five feet of a telephone utility box and are from the shoulder to the center of the outside wheel track from one and just across the fog strip.

METRO RUMAC: The test section is showing moderate surface ravelling over more than 25 percent of the lanes. Transverse cracks are noticeable in the southbound lane near Station 1+00 and 15+00. The northbound lane has transverse cracks at Stations 17, 15, 14, 11, 7 and 1. These cracks are from the shoulder to about the center of the outside wheel track.

Pacific Highway - 42nd Street

The control and the METRO RUMAC sections were overlaid with an open-graded mix one year after construction.

The METRO RUMAC wearing surface is performing worse than the control. The METRO RUMAC base course is performing equal to the control.

A.5.0 EASTSIDE BYPASS (4)

A.5.1 BACKGROUND

This study covers the 1992 construction of three test pavements using asphalt rubber concrete (ARC), where the rubber is blended with the binder before mixing with the aggregate. The pavements are located on a 4-lane section of highway located in Klamath Falls, Oregon.

The three types of asphalt rubber concrete used included International Surfacing Incorporated (ISI) ARC Modified Class "B" (gap-graded), ISI ARC Class "F" (open-graded), and powdered rubber ARC (PRARC) Class "F" mix. The asphalt rubber used for the gap and open-graded mixes was made with tire rubber. The PRARC binder was inadvertently made by blending asphalt with natural rubber.

A.5.2 CONSTRUCTION

Construction using the ISI ARC rubberized mixes went fairly smoothly. In addition, using this system placed little burden on the contractor, as ISI obtained the rubber and base asphalt, mixed the rubber with the asphalt to make the binder, and pumped the binder into the mix plant. ISI did, however, have a problem meeting their own specifications for binder properties. In addition, the ISI mixes had problems passing ODOT moisture susceptibility tests. It is unknown whether these mixes will strip.

The frictional values and deflection reductions of the ISI ARC were similar to those of typical ODOT open-graded pavements.

Construction using the PRARC was not much different than ISI ARC Class "F" mix except that a field adjustment was made to increase the binder content. The higher binder content and use of natural rubber (NR80) made it necessary to use a sand blotter over the entire test section to keep the mix from picking up on car tires after compaction.

A.5.3 PERFORMANCE

Following is a discussion of pavement performance based on 1994 surveys.

Class "B" Control: This section looked good. The right lane looked a little dark in the wheel path. Two cracks were observed at Station 78+50, eight feet out from the curb and at 78+75, nine feet out from the curb. Both cracks, located on the canal structure, were observed the previous year.

Modified "B" Gap Graded ARC: No structural distress was observed, however, the outside lane showed signs of densification. The surface is indicating slight to medium flushing in the outside wheel track from Station 82+00 to 95+00 and through the intersection at 86+00 to 88+00.

Modified "F" Powdered Rubber PRARC - This test area showed no distress.

Class "F" Control Southbound - This section showed signs of ravelling over more than 25% of the lane with bleeding also at Station 143+00 to 144+00 in the outside wheel track.

Class "F" Control Northbound - This test area showed moderate ravelling over more than 25% of the lane with two small gobs at the end of windrow dumps. Fat streaks were noticed at Station 141+00 in both wheel tracks. The excess asphalt that was noted on the 1993 survey may have been worn off by studded tire use during the winter.

Modified "F" ISI ARC - Moderate ravelling was noted over more than 25% of lane. Slight bleeding was noticed between Stations 126 - 127 in the outside wheel track.

The modified "B" mix appears to be performing similar to the control. The PRARC and ISI ARC "F" mixes also appear to be performing equal to the control.

A.6.0 WOLF CREEK - WEST FORK DAIRY CREEK SECTION, DURKEE INTERCHANGE - LIME SECTION

A.6.1 BACKGROUND

Two projects using METRO RUMAC were constructed in the summer, 1993. Control and test sections were constructed on each project. The sections provided a base course for an open-graded wearing course. One project was constructed on a two-lane road west of Portland. The other project was constructed in eastern Oregon, east of Baker City.

Mix designs for the RUMAC were contracted out since the ODOT does not have the Marshall mix design equipment required for the design. Two consultants prepared mix designs for each project so that ODOT would have mix design options to compare. Difficulties were encountered in obtaining the materials for the mix designs since the crumb rubber had not been produced when the consultants were ready to start. The crumb rubber the supplier had on hand was provided instead. Using the rubber supplied was not a problem for the projects, however, it could be a problem in the future if the mix design rubber gradations differed significantly from the rubber used in construction. The mix designs from the two consultants varied significantly, even though the RUMAC mix design process was designed to be repeatable. In one case, the consultant dropped the rubber content by 0.5% to 1.5% to obtain a workable design. Contracting the mix designs for RUMAC added to the cost and complexity of the project. Using RUMAC may also compromise the timeframe for paving since all materials may not be available (i.e., crumb rubber) when the mix design is requested.

A.6.2 CONSTRUCTION

Both projects were constructed with a drum mixing plant where the rubber was fed into the drum on the RAP feed. Control of the rubber content was difficult to monitor on the belt. Conventional paving equipment was used to place and compact the mixes. No construction problems were noted.

A.6.3 PERFORMANCE

The control and the METRO RUMAC sections were overlaid with an open-graded mix shortly after construction. The control and test sections are performing the same. Problems associated with an excessive amount of rubber were encountered in a section of RUMAC pavement outside the test section on the Durkee-Lime project. The section potholed and raveled to the point where it was milled out and replaced. Cores were sampled to identify the source of the distress. It appeared that the problem may have been related to too much rubber compounded by too little asphalt resulting in reduced rock to rock bonding

A.7.0 REDMOND - BEND (N.U.), KAH-NEE-TA JUNCTION - PELTON DAM ROAD, TOWER ROAD - STANFIELD INTERCHANGE, AZALEA - JUMP-OFF JOE SECTION (5)

A.7.1 BACKGROUND

This study covers construction of open-graded asphalt concrete with an asphalt-rubber binder, PBA-6GR. The PBA-6GR is manufactured at a refinery and delivered to the jobsite similar to conventional asphalt cement. Test and control sections were constructed in 1992, 1993 and 1994. The projects are located in central, eastern, and southern Oregon

The PBA-6GR binder specifications are the same as the PBA-6 conventional asphalt specifications with the following exceptions: the kinematic viscosity on the original binder specification and the ductility test on the rolling thin film oven aged residue specification were deleted, following a written request by the contractor, as allowed in the Special Provisions.

Analysis is underway to determine the most appropriate mix design approach since all the PBA-6GR mixes were significantly different.

A.7.2 CONSTRUCTION

Construction of the asphalt-rubber mixes progressed smoothly. The mixes appeared to be easier to handle than similar conventional mixes: the binder was not sticky and stringy; it did not collect on the truck dump gates; it did not allow the paver to settle into the mat during delays; it did not shove laterally during compaction; and it did not separate at higher temperatures. The mix was also easier to handle than other types of asphalt-rubber mixes since the contractor did not need to bring in extra mixing and handling equipment.

Data compilation, analysis, and evaluation is currently underway for the Construction Report.

A.7.3 PERFORMANCE

Redmond - Bend (N.U.)

No test and control sections were established for this project.

Kah-Nee-Ta Junction - Pelton Dam Road

The control and test sections for this project were inspected in April, 1994. The general appearance of the PBA-6GR test section was very good with a slight amount of consolidation in the wheel tracks. The surface of the mat still contains asphalt adhering to the larger aggregate, indicating it has a little better bonding tendency than the PBA-6.

A darker area was noted from the center of the panel, outside toward the GM guardrail. The darker area was caused when the shoulder was paved: the paver was wider than the shoulder area. Therefore, some mix was dragged along on top of the test section panel. A fat area noted near Station 1629+/- is due to the patch over the utility trench.

The general appearance of the PBA-6 control section was good with some light ravelling or picking out at the meet lines and where the center of the screed had passed. Due to the layout of the paved lanes, such as left turn lanes, tapers, and intersections, the slightly ravelled areas are carried from the outside edge of the left turn lane to the inside wheel track. The slight ravelling may also be caused by the affect of the screed augers operation which may cause segregation at the gap between the augers. The outside 25 percent of the panel is more tight due to the shoulder paving when the screed was dragged over the travel panel.

The PBA-6 panel appears to be more open on the surface than the PBA-6GR and has less binder actually remaining on the surface aggregate. This will be quantified with the lab testing.

Azalea - Jump-Off Joe Section, Tower Road - Stanfield Interchange

These projects were constructed during the 1994 construction season.

For the PBA-6GR sections being monitored, the test sections are performing comparably to the control sections for the short time they have been in service.

APPENDIX B

DETAILED PROJECT INFORMATION TABLES

Table B.1. Detailed Project Information for Dense-Graded Mixes

Date of Construction Mo/Yr	Project Identification				Mix Type (1)	Process	Quantity Containing CRM		Concentration of CRM in		Price	
	Project	Highway/ Direction (Lane)[2]	MP	to MP			Binder, Tons	Hot Mix Asphalt, Ton	Binder, % by wt. of Asphalt Cement	Hot Mix Asphalt, % by total wt. of Mix	Binder, $Per Ton	Hot Mix Asphalt $Per Ton
8/85	Lava Butte-Fremont Hwy.	US97/S (SB)	157.94	158.44	Gap	PlusRide	0	636	—	3.1%	197	46
8/85	Lava Butte-Fremont Hwy.	US97/S (SB)	160.18	160.77	C	Control	0	0	0	0	197	22
8/85	Lava Butte-Fremont Hwy.	US97/S (SB)	158.44	159.24	C	Arm-R-Shield	80	0	20%	—	750	80
8/85	Lava Butte-Fremont Hwy.	US97/S (SB)	160.77	161.3	C	Control	0	0	0	0	189	22
9/91	181st-Troutdale	I-84/E (S,I,O)	16.00	16.84	B	RUMAC	0	1652	—	2%	150	46
9/91	181st-Troutdale	I-84/E (S,I,O)	15.42	15.92	B	Control	0	0	0	0	150	30
8/91	Stark Street	Stark Street/E (S,I,O)	SE Burnside	SE 202nd	B	RUMAC	0	1786	—	1.8%	170	45

(1) A: 1½"-minus, dense graded
B: 1"-minus, dense graded
C: ¾"-minus, dense graded
F: 1"-minus, open graded

(2) SB: Southbound
S: Shoulder
I: Inner
O: Outer
M: Median
NB: Northbound
WB: Westbound

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Date of Construction Mo/Yr	Project Identification				Mix Type (1)	Process	Quantity Containing CRM		Concentration of CRM in		Price	
	Project	Highway/ Direction (Lane)[2]	MP to	MP			Binder, Tons	Hot Mix Asphalt, Ton	Binder, % by wt. of Asphalt Cement	Hot Mix Asphalt, % by total wt. of Mix	Binder, $Per Ton	Hot Mix Asphalt $Per Ton
8/91	Stark Street	Stark Street/E (S,I,O)	Sta. 274	Sta. 279	B	Control	0	0	0	0	170	28
8/91	Marine Drive	Marine Drive (S,O,M)	Terminal 6 Access Rd	N. Bybee Lake Rd	C	RUMAC	0	3859	—	2%	—	40
8/91	Marine Drive	Marine Drive (S,O,M)	Sta. 41+00	Sta. 46+00	C	Control	0	0	0	0	—	28
9/92	Pacific Hwy. -42nd Street	OR126/E (S,I,O) OR126/W (S,I,O)	4.73 X5.42	5.39 X5.97	B	RUMAC	0	3269	—	2.0%	100	42
9/92	Pacific Hwy. -42nd Street	OR126/E (S,I,O) OR126/W (S,I,O)	5.60 X5.09	5.79 X5.28	B	Control	0	0	0	0	100	20
9/92	Eastside Bypass	OR39/E (S,I,O,M) OR39/W (S,I,O,M)	X4.49 4.49	X5.21 5.02	B	ISI	516	0	17%	—	440	59
9/92	Eastside Bypass	OR39/E (S,I,O,M)	X5.04	X5.18	B	Control	0	0	0	0	187	34

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	Project	Highway/ Direction (Lane)[2]	MP to	MP			Binder, Tons	Hot Mix Asphalt, Ton	Binder, % by wt. of Asphalt Cement	Hot Mix Asphalt, % by total wt. of Mix	Binder, $Per Ton	Hot Mix Asphalt $Per Ton
5/92	Lakeview Jct.- Matney Rd.	OR39/N (S,NB) OR39/S (S,SB)	X0.96 0.95	X1.64 1.63	B	RUMAC	0	1329	—	1.5%	175	35
5/92	Lakeview Jct.- Matney Rd.	OR39/N (S,NB)	0.55	0.91	B	Control	0	0	0	0	175	28
6/93	Wolf Cr. - W. Fork Dairy Cr.	US-26/W (I,O)	X41.05	X41.70	B	RUMAC	0	1202	—	1.5%	100	29
6/93	Wolf Cr. - W. Fork Dairy Cr.	US-26/W (I,O)	X41.72	X42.00	B	Control	0	0	0	0	1	23
10/93	Durkee - Lime	I-84/W (I)	X327.45	X328.45	A	RUMAC	0	1274	0	2.0%	—	34
10/93	Durkee - Lime	I-84/W (I)	X328.89	X329.18	A	Control	0	0	0	0	174	24

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Table B.2. Detailed Project Information for Open-Graded Mixes

Date of Construction Mo/Yr	Project Identification				Mix Type (1)	Process	Quantity Containing CRM		Concentration of CRM in		Price	
	Project	Highway/ Direction (Lane)^2	MP	to MP			Binder, Tons	Hot Mix Asphalt, Ton	Binder, % by wt. of Asphalt Cement	Hot Mix Asphalt, % by total wt. of Mix	Binder, $Per Ton	Hot Mix Asphalt $Per Ton
9/91	181st - Troutdale	I-84/W (S,I,O)	X16.00	X16.84	F	ISI	151	0	19%	—	480	67
9/91	181st- Troutdale	I-84/W (S,I,O)	X15.42	X15.92	F	Control	0	0	0	0	150	31
9/92	Redmond - Bend (N.U.)	US97/S (I,M)	123.18	124.41	F	PBA-6GR	90	0	10%	—	500	46
9/92	Eastside Bypass	OR39/E (S,I,O,M)	X4.07	X4.42	F	PRARC	80	0	15%	—	440	63
9/92	Eastside Bypass	OR39/W (S,I,O,M)	3.97	4.42	F	ISI	97	0	17%	—	440	58
9/92	Eastside Bypass	OR39/E (S,I,O,M)	X3.82	X3.96	F	Control	0	0	0	0	197	35

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Table B.2. Detailed Project Information for Open-Graded Mixes

Date of Construction Mo/Yr	Project Identification				Mix Type (1)	Process	Quantity Containing CRM		Concentration of CRM in		Price	
	Project	Highway/ Direction (Lane)^2	MP	to MP			Binder, Tons	Hot Mix Asphalt, Ton	Binder, % by wt. of Asphalt Cement	Hot Mix Asphalt, % by total wt. of Mix	Binder, $Per Ton	Hot Mix Asphalt $Per Ton
10/93	Kah-Nee-Ta-Pelton Dam	US-26/E,W (S,EB,WB)	103.26	105.20	F	PBA-6GR	286	0	10.6%	—	310	33
10/93	Kah-Nee-Ta-Pelton Dam	US-26/E (S,EB,WB)	105.37	105.62	F	Control	0	0	0	0	245	26
9/94	Tower Rd. Stanfield	I-84/E (S,I,O,M)	163.50	167.08	F	PBA-6GR	600	0	11.6%	--	265	27
9/94	Tower Rd. Stanfield	I-84/E (S,I,O,M)	167.17	167.36	F	Control	0	0	0	0	23	24
9/94	Azalea - Jumpoff Joe	I-5/N (S,I,O,M)	X78.38	X80.75	F	PBA-6GR	600	0	11.5%	--	310	33
9/94	Azalea - Jumpoff Joe	I-5/N (S,I,O,M)	X83.50	X83.69	F	Control	0	0	0	0	240	31

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