Rubber Modified Asphalt Concrete (METRO RUMAC) Evaluation

N. Marine Drive in Portland, Oregon
S.E. Stark Street in Gresham, Oregon

Construction Report

FHWA Experimental Project No. 3

by

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November 1992

Technical Report Documentation Page

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
FHWA-OR-RD-92-14		

4. Title and Subtitle	5. Report Date
Rubber Modified Asphalt Concrete (METRO RUMAC) Evaluation: N. Marine Drive in Portland, OR S.E. Stark Street in Gresham, OR	November 1992
	6. Performing Organization Code
7. Author(s) Bo Miller	8. Performing Organization Report No. FHWA-OR-RD-92-14
9. Performing Organization Name and Address Oregon Department of Transportation Engineering Services Section Research Unit 2950 State Street Salem, OR 97310	10. Work Unit No. (TRAIS)
	11. Contract or Grant No. DTFH71-91-TE03-OR-15
12. Sponsoring Agency Name and Address Federal Highway Administration 400 Seventh Street S.W. Washington, D.C. 20590	13. Type of Report and Period Covered Construction Report August 1991
	14. Sponsoring Agency Code HTA-21

15. Supplementary Notes

16. Abstract

This report covers the construction in 1991 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 use a dense-graded rubber modified asphalt concrete (METRO RUMAC) developed for the Metropolitan Services District (METRO) of the Portland metropolitan area. In this process, crumb rubber made from recycled tires is mixed with aggregate before the asphalt is blended into the mix. Adjacent to the test pavements, control pavements were paved with conventional asphalt concrete. The test pavements are compared to these control pavements.

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 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.

The METRO RUMAC mixes cost about 1½ times more than their conventional counterparts. Most of this increase was due to the cost of the rubber and the expense of adding the rubber. At this time, it is not certain that the greater initial cost of these rubberized mixes will be offset by a commensurate increase in the pavement's service life.

17. Key Words	18. Distribution Statement
PAVEMENTASPHALT, ADMIXTURES, RUBBER, GROUNDTIRES	Available through the National Technical Information Service (NTIS)

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price
Unclassified	Unclassified	105	

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

ACKNOWLEDGEMENTS

The author thanks Dick Godfrey and Steve Berg of the City of Portland and their crew for help with the N. Marine Drive test pavement; and Roy Morrison of Multnomah County, his crew, and Oregon Asphaltic Paving for their help with the S.E. Stark Street test pavement. In addition, the author thanks Jim Lundy and Todd Scholz of the Oregon State University (OSU), and Andy Sloop of the Metropolitan Services District for their help with the resilient modulus, fatigue, and rutting testing. Furthermore, the author is grateful to Scott Nodes, Tony George, Wes Heidenreich, Keith Martin, Jim Huddleston, Jeff Gower, and Lynn White of the Oregon Department of Transportation (ODOT); and Cal Frobig and Michael Heitzman of the Federal Highway Administration (FHWA) for their review of the report drafts. Also, the author thanks Jo Anne Robison, Lauri Kroeker and Lisa Kling for typing the report.

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1.0 INTRODUCTION

1.1 BACKGROUND

Local governments are burdened with the increasing costs of both roadway rehabilitation and solid waste disposal. Rubber modified asphalt concrete (RUMAC) may provide benefits in both of these areas. RUMAC may reduce road rehabilitation costs by producing crack resistant pavement overlays. For example, a Plus Ride® RUMAC overlay had less transverse cracking than a comparable surface of conventional hot mix in a current study by the Oregon Department of Transportation[1] (ODOT). RUMAC may reduce waste disposal costs by using portions of rubber tires that would normally be solid waste, as about 60% of the tire, by weight, is recycled into RUMAC rubber. As an example, the 1¾ inch deep by 24 foot wide by ½ mile long Plus Ride® RUMAC overlay in the ODOT study used rubber from about 3,000 tires.[1]

To explore alternative methods of waste tire disposal, the Oregon Department of Environmental Quality (DEQ) and the Metropolitan Services District (METRO) of the Portland metropolitan area contracted with CTAK Associates of Portland to develop a new non-proprietary RUMAC system. This is in contrast with most existing paving systems that use tire rubber, because they typically use patented products or processes. This new system, called METRO RUMAC, is the subject of this study.

The METRO RUMAC system has been developed for these dense-graded mix aggregate gradations used by the ODOT: Class "A" (1¼" to 0"), Class "B" (¾" to 0"), and Class "C" (½" to 0"). In all of these mixes, the crumb rubber is used as an aggregate substitute, the same gradation rubber is used (#8 to 0"), and rubber comprises the same percentage of the mix (2% of total mix weight).

This study is funded by several sources. The compiling of the design and construction data was paid for by the agencies responsible for the construction of the projects, the City of Portland (CoP) and Multnomah County (Mult. Co.); the pavement evaluations and part of the report writing costs were paid for by the FHWA as part of their Test and Evaluation Project No. 3, "Asphalt Additives;" the mix plant opacity tests were paid for by the DEQ; the rutting, resilient modulus and fatigue tests were paid for by METRO; and the remaining costs were funded by the ODOT.

1.2 OTHER METRO RUMAC RESEARCH

Besides the two METRO RUMAC pavements covered by this study, the ODOT is studying the construction and initial performance of other METRO RUMAC test sections, including: a test section placed in 1991 on Interstate Route #I-84 near Troutdale, Oregon;[2] a test section constructed near Klamath Falls, Oregon in May 1992; a test section placed in Springfield, Oregon in September 1992; and two other test sections scheduled for construction in 1993.

1.3 OBJECTIVES

The study goal is to describe and comment on the construction and initial performance of these rubberized pavements. The study results will be included in three reports: a Construction Report detailing the project's layout, environment, structural and mix designs, construction, sampling and testing, in-place unit costs, and the pavement's condition just after construction; an Interim Report telling about the performance of the test pavements during the first two years; and a Final Report summarizing the test pavement's performance throughout the five-year study.

2.0 LOCATION, DESIGN AND MATERIALS

This chapter covers the project's location, layout, cross-section, environment, structural design, materials, suppliers, and mix designs. The project's METRO RUMAC specifications are in Appendix A and the mix design guidelines are in Appendix B.

2.1 LOCATION

N. Marine Drive Project - This project is located on North Marine Drive in the northwest corner of the City of Portland between North Lombard Street and Interstate Route #5, as shown in Figure 2.1a. This street is the major arterial roadway in the Rivergate Industrial Park.

S.E. Stark Project - This project is located on Southeast Stark Street in the City of Gresham between Burnside Street and 202nd Avenue, as shown in Figure 2.1b. This street is a major east-west arterial.

2.2 LAYOUT

N. Marine Drive Project - This project is two miles long, and it extends eastward from the Terminal 6 Access Road, as shown in Figure 2.2. It contains three types of pavement. METRO RUMAC was used in almost all of the westbound lanes, westbound shoulder, and north half of the median lane. This mix was also used in most of the western two thirds of the eastbound lane, eastbound shoulder, and south half of the median. A 500-foot long segment of the METRO RUMAC was selected for intensive evaluation during this study. This "evaluation section" is located between Stations 66+00 and 71+00, and it includes the eastern intersection of North Bybee Lake Road and N. Marine Drive. The ends of the evaluation section are marked by stakes adjacent to the sidewalk and white striping tape on the pavement, as shown in Figure 2.3.

Class "C" mix without rubber nor recycled asphalt concrete pavement (RAP) comprises a short, 500-foot long, evaluation section within the METRO RUMAC section. This is the conventional mix to which the METRO RUMAC will be compared in detail to determine the effects of adding rubber to a paving mix. The ends of this evaluation section at Stations 41+00 and 46+00 are marked by stakes and tape.

Figure 2.3: Typical Marking of N. Marine Drive Evaluation Sections
(The stake adjacent to the sidewalk is in the center of the photo and the striping tape is in the far right of the photo.)

Within the Class "C" section, in the westbound lane, there is a short 150-foot long section of METRO RUMAC pavement. This rubberized mix was accidentally placed in the Class "C" evaluation section, and it is not part of the section. Class "C" mix with RAP is used in the eastern third of the eastbound lane, shoulder, and the south half of the median. This mix is normally used by the CoP for paving. There is no evaluation section on the Class "C" with RAP pavement.

S.E. Stark Street Project - This project is just over ½ mile long and it consists of three types of pavement, as shown in Figure 2.4. METRO RUMAC with a reduced rubber content is used in a 1,200-foot long section of the eastbound outer travel lane and shoulder extending from the west end of the project to approximately Station 272+50.

Class "B" mix is used in a 700-foot long section in the middle of the project between Stations 272+50 and 280+50, in the eastbound inner travel lane, outer travel lane, and shoulder. This is the conventional mix to which the METRO RUMAC will be compared. A 500-foot long segment of this section, between Stations 274+00 and 279+00, is an evaluation section, and it will undergo a detailed comparison with the METRO RUMAC evaluation section. The stationing in the evaluation section is marked by silver spray paint on the curb.

METRO RUMAC is used in the remainder of the project, which includes the eastern third of the eastbound travel lanes from Station 280+50 to the east end of the project, the median lane throughout the project, and all of the westbound travel lanes and shoulder. The METRO RUMAC evaluation section extends 500 feet east from the intersection of S.E. Stark Street and S.E. 199th Avenue between Stations 282+00 and 287+00. The stationing in this evaluation section is marked on the curb.

2.3 CROSS-SECTION

N. MARINE DRIVE PROJECT - -

Wearing Course - The wearing course is a single lift of dense-graded asphalt concrete with a 1¾ inch nominal thickness, except on the shoulder where the overlay was feathered to meet the gutterline, as shown in Figure 2.5. The experimental and control mixes are in this course.

Leveling Course - This course is a single lift of dense-graded asphalt concrete with a nominal thickness of 1½ inches. The actual thickness of the leveling course varies between 1 to 2 inches, as this course was used to relocate the crown of the road. The crown was located in the eastbound lane 8 feet from the curb on the old roadway, and it was moved 13 feet to the north to be at the center of the new surfacing. To maintain curb exposure near the gutterline, a strip of asphalt concrete several feet wide and an inch deep was milled out near the gutters prior to the overlay.

Old Roadway - The old road was a 2½ to 3 inch layer of asphalt concrete over an aggregate base. The subgrade supporting the base is well drained sandy alluvium or sandy dredge spoilage. The surface condition and realignment of the old roadway is discussed in Section 5.1 of this report.

S.E. STARK STREET PROJECT - -

Wearing Course - This wearing course is a single lift overlay of dense-graded asphalt concrete with a 1½ inch nominal thickness, as shown in Figure 2.6. The actual thickness varied from 2 inches in the median and inner lanes to 1 inch near the gutterlines.

Old Roadway - The old roadway was a 4¾ inch thick asphalt concrete pavement supported by a 17 to 19 inch thick layer of aggregate. The subgrade is well drained soil and gravel. The surface condition of the old roadway is discussed in Section 5.1 of this report.

2.4 ENVIRONMENT AND TRAFFIC

Both projects are in the Willamette Valley climatic region, and they experience mild wet winters and hot dry summers. Environmental data is shown in Table 2.1.[3]

Table 2.1: Environment and Traffic Data

BOTH PROJECT'S ENVIRONMENTAL DATA	
Elevation (feet)	50
Average Daily Temperature of Coldest Month (°F) (January)	37
Mean Daily Temperature Swing in January (°F)	9
Average Daily Temperature of Warmest Month (°F) (July)	66
Mean Daily Temperature Swing in July (°F)	27
Average Annual Precipitation (inches)	39
N. MARINE DRIVE PROJECT TRAFFIC DATA	
1985 Average Daily Traffic (Two-way)	4,000
Heavy Trucks (% of Average Daily Traffic)	28
S.E. STARK STREET PROJECT TRAFFIC DATA	
1988 Average Daily Traffic (vehicles/day)	9,000 Westbound 9,000 Eastbound
Heavy Trucks (% of Average Daily Traffic)	<10

Traffic characteristics differ between the two projects. Traffic on N. Marine Drive has a relatively low volume with many heavy trucks, as this is the major arterial road for the shipping terminals in the City of Portland's Rivergate Industrial Park. In contrast, traffic on

S.E. Stark has a much higher traffic volume and a lower percentage of trucks, as this is one of the major east-west arterials in Gresham. Traffic data is shown in Table 2.1. Current traffic volumes may be greater than those listed, as this information is several years old and the region's population is increasing.

2.5 OVERLAY DESIGN

N. Marine Drive Project - The main purpose of this overlay was to extend the pavement life until funds are available for a pavement reconstruction, and a surfacing design was not made. A 1¾ inch wearing course thickness was selected, as it is the maximum thickness that can be paved by CoP maintenance forces. The overlay is intended to last five years before it needs major repairs.

S.E. Stark Street Project - A structural design was performed for Multnomah County in 1989 based on AASHTO methods and the properties of conventional Class "B" asphalt concrete.[4, 5] One of the surfacing alternatives proposed in this design was a 3½ inch thick overlay of Class "B" mix. The county discussed this design alternative with a supplier of asphalt-rubber binder, and the supplier claimed that 1¾ inches of asphalt-rubber concrete would be equivalent to the 3½ inches of conventional mix. Subsequent negotiations between the county and the asphalt-rubber supplier failed, so the county decided to overlay the project with 1¾ inches of the rubberized METRO RUMAC, instead of 3½ inches of conventional mix.

2.6 MATERIALS AND SUPPLIERS

Paving material suppliers are listed in Table 2.2.

Table 2.2: Suppliers
June 1992

Asphalt Binder	**Chevron USA Inc.**, 5501 N. W. Front Avenue, Portland, Oregon, 97208. Contact: Carl Dunlap (503) 221-7818. **McCall Oil and Chemical Corporation**, 5724 N. W. Front Avenue, Portland, Oregon 97210. Contact: Jim Weir (503) 221-6400.
Asphalt Concrete	**Lakeside Industries**, 4850 N. W. Front Avenue, Portland, Oregon, 97210. Contact: Chuck Gaskill (503) 222-6421. **Oregon Asphaltic Paving**, P. O. Box 16537, Portland, Oregon 97216. Contact: Orin Adams (503) 252-1497.
Rubber	**Rubber Granulators Inc.**, P. O. Box 692, Snohomish, Washington, 98290. Contact: Milton Chryst (206) 353-8040.

N. Marine Drive Project - All mixes were made by the CoP's supplier for northwest Portland, Lakeside Industries. The asphalt in all mixes was McCall Oil's PBA-2 without an anti-stripping additive. The rubber in the METRO RUMAC was produced by Rubber Granulators from used light truck or car tires. As allowed in the METRO RUMAC specifications, the larger particles of rubber were made by granulation and the finer portions of the rubber were made by grinding. The aggregate in all mixes was crushed river cobbles and gravels from Lonestar Northwest's Santosh Pit, ODOT Source No. 5-4-1, located on the Columbia River northeast of Scappoose, Oregon. This rock was mainly basalt, with smaller amounts of other extrusive igneous rocks, and some quartzites.

S.E. Stark Street Project - All mixes were made by the contractor, Oregon Asphaltic Paving. The asphalt in all mixes was Chevron's PBA-2 without an anti-stripping additive, and the rubber was produced by Rubber Granulators. The aggregates in all mixes were from Oregon Asphaltic Paving's 190th Avenue pit in Gresham, ODOT Source No. 26-22-1. This aggregate was crushed from river cobbles and gravels composed of basalt, other extrusive igneous rocks, and quartzites.

2.7 BINDER, AGGREGATE, AND RUBBER TEST RESULTS

This section gives the results of tests on the wearing course's binder, aggregate, and rubber sampled prior to and during production. Most of the tests followed AASHTO and ODOT methods.[6, 7] The sources of the test data are in the table footnotes, and special sampling and test methods are discussed in Chapter 4.

Binders - Tests were done on binder samples taken during the production of each project's mix. Both samples passed ODOT's 1991 PBA-2 specifications. The test results and specification limits are shown in Table 2.3.

Aggregate - Samples of aggregate were taken from the stockpiles of each project and tested. The stockpile gradations and gradation specifications are not presented in this report. The results of other tests on the stockpiled material are in Table 2.4, and the gradations and gradation specifications of the mix are presented in Chapter 3.

Rubber - Gradation tests were made on rubber sampled during the production of each projects METRO RUMAC. The rubber passed specifications. The test results and specifications are listed in Table 2.5. The rubber was not tested for properties other than gradation.

Table 2.3a: Binder Test Results - N. Marine Drive Project			
TEST	METHOD	TEST RESULTS[a]	SPECIFICATIONS[b]
Pen @ 39.2°F, 100g, 5s, on Residue (dmm)	AASHTO T49[c]	4	None
Pen @ 39.2°F, 200g, 60s, on Residue (dmm)	AASHTO T49[c]	16	15 (min)
Pen @ 77°F, 100g, 5s, on Residue (dmm)	AASHTO T49[c]	38	None
Abs Vis @ 140°F, on Original (P)	AASHTO T202	1,780	1,100 (min)
Abs Vis @ 140°F, 30cm Hg Vac, on Residue (P)	AASHTO T202[c]	3,580	2,500 (min) 6,000 (max)
Abs Vis Ratio (Residue/Original)	AASHTO T202	2.0	4.0 (max)
Kin Vis @ 275°F, on Original (cSt)	AASHTO T201	235	None
Kin Vis @ 275°F, on Residue (cSt)	AASHTO T201[c]	436	275 (min)
Duct @ 45°F, 1cm/min, on Residue (cm)	AASHTO T51[c, d]	25+	10 (min)
Duct @ 77°F, 5cm/min, on Residue (cm)	AASHTO T51[c, d]	100+	75 (min)
Flash Point, COC, Original (°F)	AASHTO T48	560	450 (min)
Solubility in Trichlorethylene, Original (%)	AASHTO T44	99.84	99.0 (min)
Loss on Heating, of Residue (%)	AASHTO T47[c]	.38	None

[a] Tests on binder sampled during mix production
[b] ODOT 1991 PBA-2 specification limits
[c] AASHTO T240 used to age asphalt
[d] AASHTO T51 as modified by the Washington DOT (using a special method of applying the release agent).

Table 2.3b: Binder Test Results - S.E. Stark Street Project			
TEST	METHOD	TEST RESULTS[a]	SPECIFICATIONS[b]
Pen @ 39.2°F, 100g, 5s, on Residue (dmm)	AASHTO T49[c]	6	None
Pen @ 39.2°F, 200g, 60s, on Residue (dmm)	AASHTO T49[c]	21	15 (min)
Pen @ 77°F, 100g, 5s, on Residue (dmm)	AASHTO T49[c]	47	None
Abs Vis @ 140°F, on Original (P)	AASHTO T202	1,540	1,100 (min)
Abs Vis @ 140°F, 30cm Hg Vac, on Residue (P)	AASHTO T202[c]	3,840	2,500 (min) 6,000 (max)
Abs Vis Ratio (Residue/Original)	AASHTO T202	2.5	4.0 (max)
Kin Vis @ 275°F, on Original (cSt)	AASHTO T201	333	None
Kin Vis @ 275°F, on Residue (cSt)	AASHTO T201[c]	484	275 (min)
Duct @ 45°F, 1cm/min, on Residue (cm)	AASHTO T51[c, d]	25+	10 (min)
Duct @ 77°F, 5cm/min, on Residue (cm)	AASHTO T51[c, d]	100+	75 (min)
Flash Point, COC, Original (°F)	AASHTO T48	510	450 (min)
Solubility in Trichlorethylene, Original (%)	AASHTO T44	99.89	99.0 (min)
Loss on Heating, of Residue (%)	AASHTO T47[c]	.71	None

[a] Tests on binder sampled during mix production
[b] ODOT 1991 PBA-2 specification limits
[c] AASHTO T240 used to age asphalt
[d] AASHTO T51 as modified by the Washington DOT (using a special method of applying the release agent).

Table 2.4: Aggregate Test Results (Except Gradations)

TEST AND STOCKPILE	METHOD	TEST RESULT
N. MARINE DRIVE PROJECT		
Bulk Specific Gravity		
½ - ¼	AASHTO T85	2.68
Coarse ¼ - 0	AASHTO T84	2.66
Fine ¼ - 0	AASHTO T84	2.63
Bulk Specific Gravity (Saturated Surface-Dry)		
½ - ¼	AASHTO T85	2.72
Coarse ¼ - 0	AASHTO T84	2.71
Fine ¼ - 0	AASHTO T84	2.69
Apparent Specific Gravity		
½ - ¼	AASHTO T85	2.79
Coarse ¼ - 0	AASHTO T84	2.79
Fine ¼ - 0	AASHTO T84	2.80
Absorption (%)		
½ - ¼	AASHTO T85	1.42
Coarse ¼ - 0	AASHTO T84	1.67
Fine ¼ - 0	AASHTO T84	2.31
S.E. STARK STREET PROJECT		
Bulk Specific Gravity		
¾ - ½	AASHTO T85	2.67
½ - ¼	AASHTO T84	2.68
¼ - 0	AASHTO T84	2.62
Bulk Specific Gravity (Saturated Surface-Dry)		
¾ - ½	AASHTO T85	2.72
½ - ¼	AASHTO T84	2.74
¼ - 0	AASHTO T84	2.69
Apparent Specific Gravity		
¾ - ½	AASHTO T85	2.81
½ - ¼	AASHTO T84	2.84
¼ - 0	AASHTO T84	2.83
Absorption (%)		
¾ - ½	AASHTO T85	1.81
½ - ¼	AASHTO T84	2.06
¼ - 0	AASHTO T84	2.86

Table 2.5: Rubber Test Results			
N. MARINE DRIVE PROJECT			
TEST	**METHOD**	**TEST RESULTS**	**SPECIFICATIONS**
Dry Gradation, % Passing	AASHTO T27		
Screen: # 4		100[a]	100
# 8		82[a]	70 - 100
# 16		55[a]	40 - 65
# 30		32[a]	20 - 35
# 50		11[a]	5 - 15
#100		3[b]	[c]
#200		.1[a]	[c]
S.E. STARK STREET PROJECT			
Dry Gradation, % Passing	AASHTO T27		
Screen: # 4		100[b]	100
# 8		88[b]	70 - 100
# 16		57[b]	40 - 65
# 30		34[b]	20 - 35
# 50		13[b]	5 - 15
#100		2[b]	[c]
#200		.4[b]	[c]

[a] Average of four tests.
[b] Average of one test.
[c] No tolerance given.

2.8 MIX DESIGN

This section presents the mix designs and job mix formulae for the test and control pavements. To make the discussion in this section clearer, a brief explanation of the ODOT's broadband limits, job mix formula (JMF) target values, tolerances and limits, and narrowband limits follow.

Broadband limits are the upper and lower percentage limits for the constituents of each class of mix, for all projects, statewide. As examples, asphalt concrete within Class "A" broadband limits would be coarse and dense-graded, and mix within Class "E" broadband limits would be fine and open-graded. METRO RUMAC mixes use broadband limits for aggregate gradation and asphalt content that are usually used for conventional dense-graded ODOT mixes.

JMF target values are determined during the mix design. These target values are the proportions of each ingredient of the mix, and they represent a mix that should give optimum performance. The JMF target values must be within the broadband limits for the specified class of mix.

Tolerances and limits are used to determine the allowable range of proportions for an ingredient of the produced mix. Using aggregate gradation as an example; the tolerances for aggregate passing the ½" or coarser screens are the broadband limits, and the tolerances for aggregate passing the ¼" or finer screens are the JMF target values plus or minus a tolerance. A typical tolerance value is the JMF target value plus or minus 4 to 6%.

According to ODOT specifications, the tolerances must be within the broadband limits, and if the JMF target value is close to the broadband limits, the tolerances may be affected. For example, a mix has an upper broadband limit for a constituent of 40%, the tolerances are plus or minus 5% of the JMF target value, and the target value is 39%. As the broadband limit is only 1% higher than the target value, the tolerances for this constituent are 39% plus only 1%, and minus 5%.

Narrowband limits are the upper and lower limits for the allowable proportions of a mix ingredient. They are established by broadband limits, or JMF target values and tolerances, as discussed in the previous paragraphs.

N. Marine Drive Project - The METRO RUMAC mix design was made by TAK Associates of Portland, Oregon using rock stockpiled for this project. It used aggregate and asphalt content broadband limits of an ODOT Class "C" (½ inch to 0 inch) dense-graded mix and a modified Marshall mix design based on void content, stability, and flow. The mix design method is included in Appendix B. Broadband limits, mix design criteria, and design mix properties for this METRO RUMAC mix are shown in Table 2.6a. The gradations of the JMF, produced mix, broadband limits, and narrowband limits are shown in Figure 2.7.

The control section's Class "C" mix design was provided by the mix supplier, Lakeside Industries. This design was made for another project which used materials from the same sources as this project. Like the METRO RUMAC mix, it used aggregate and asphalt content broadband limits for an ODOT Class "C" mix. The design used a 75-blow Marshall method based on Asphalt Institute procedures,[9] and the design mix properties are listed in Table 2.6b.

S.E. Stark Street Project - The METRO RUMAC mix design was done by TAK Associates with aggregate and asphalt content broadband limits of an ODOT Class "B" (¾ inch to 0 inch) dense-graded mix using a modified Marshall method (Appendix B). This design used rock stockpiled for this project. Data on the METRO RUMAC section's mix design is shown in Table 2.6c. The design used broadband limits for a 1984 ODOT Class "B" gradation. These limits are shown by the dashed double line in Figure 2.8. These 1984 limits allow a coarser mix than the 1990 Section 403 Class "B" broadband limits used on the ODOT's other 1991 METRO RUMAC project.[2] The gradations for the JMF, produced mix, broadband limits, and narrowband limits are shown in Figure 2.8.

The control section used a 1990 version of an ODOT Class "B" mix, and the design is shown in Table 2.6d. The design was made by the ODOT under contract to Multnomah County several months before the METRO RUMAC design, and it used materials from another project that used the same sources as this project. This design used a modified Hveem method based on void contents and stabilities.[10]

Experience with the two METRO RUMAC mix designs used on these projects show that further refinement is needed in the mix design process and in the presentation of the job mix formula. Areas that need refinement are:

1) The gradations in METRO RUMAC mix designs should be clearly labeled. On both METRO RUMAC mixes for these projects, the broadband limits listed with the JMF in the mix designs were not clearly labeled and they were accidently interpreted by the suppliers to be the narrowband limits governing mix production. The broadband limits that were accidentally used as narrowband limits are shown as thick solid lines in Figure 2.7 for the N. Marine Drive METRO RUMAC mix, and as thick dashed double lines in Figure 2.8 for the S.E. Stark Street mix. In both figures, the narrowband limits that should have been used are shown by dotted lines.

2) The gradations in METRO RUMAC mix designs should indicate whether or not they include rubber with the aggregate. The presence of rubber in the gradations were not noted in the JMF supplied with the mix designs. On the N. Marine Drive project, the mix design included rubber in the JMF gradations. The CoP did not know this, and they did not include rubber in their gradation test reports. On the S.E. Stark Street project, the mix design had no rubber in the JMF gradations. Multnomah County did not know this, and they included rubber in the results of their gradation tests.

Table 2.6a: Broadband Limits, Mix Design Criteria, and Design Mix Characteristics at Design Binder Content - METRO RUMAC on N. Marine Drive Project		
Characteristic	**METRO RUMAC Mix Design Criteria[a]**	**METRO RUMAC Design Mix[b]**
Gradation (% Passing Screen)		
¾ inch	99 - 100	100
½ inch	90 - 100	97
⅜ inch	-	
¼ inch	52 - 80	53
#10	21 - 46	28
#40	8 - 25	14
#200	3 - 8	5.4
Rubber Content (%)	2	2.0
Binder Content (%)	4 - 8	6.5
Absorption of Aggregate (%)	-	1.61
Voids in Mineral Aggregate (%)	≥ 17	19.2
Sp. Gr. of Aggregate	-	2.666
Voids (%)	3 - 5	4.0
Stab. (lbs)[c]	≥ 1800	2180
Flow (.01 inch)[c]	8 - 20	21.0
Rice Max. Sp. Gr.	-	2.398
Bulk Density (lbs/ft³)	-	143.7
Effective Asphalt Content (%)	6.0 - 7.0	-

[a] Broadband limits for gradation, rubber content, and binder content. Gradations are % of dry ingredient weight including rubber. Rubber and binder contents are % of total mix weight.
[b] Design mix values from briquet with 6.5% binder content. Gradations include rubber.
[c] Marshall stability and flow.

Table 2.6b: Broadband Limits, Mix Design Criteria, and Design Mix Characteristics at Design Binder Content - Class "C" on N. Marine Drive Project		
Characteristic	**Class "C" Mix Design Criteria[a]**	**Class "C" Design Mix[b]**
Gradation		
(% Passing Screen)		
¾ inch	-	100
½ inch	99 - 100	98
⅜ inch	-	89
¼ inch	60 - 80	71
#10	26 - 46	33
#40	9 - 25	14
#200	3 - 8	5.5
Binder Content (%)	4 - 8	5.3
Sp. Gr. of Aggregate	-	2.62
Voids (%)	2 - 5	4.9
Voids Filled (%)	-	67.6
Stab. (lbs)[c]	≥ 1800	2707
Flow (.01 inch)[c]	8 - 16	-
Rice Max. Sp. Gr.	-	2.460
Absorption of Aggregate (%)	-	2.09
Voids in Mineral Aggregate (%)	-	15.0
Bulk Density (lbs/ft^3)	Maximum	146.0

[a] Broadband limits for gradation, rubber content, and binder content. Gradations are % of dry ingredient weight. Binder content is % of total mix weight.
[b] Design mix values interpolated from briquets with 5.0% and 5.5% binder contents.
[c] Marshall stability and flow at 75 blows.

Table 2.6c: Broadband Limits, Mix Design Criteria, and Design Mix Characteristics at Design Binder Content - METRO RUMAC on S.E. Stark Street Project		
Characteristic	METRO RUMAC Mix Design Criteria[a]	METRO RUMAC Design Mix[b]
Gradation		
(% Passing Screen)		
1 inch	99 - 100	100
¾ inch	90 - 98	96
½ inch	75 - 91	88
¼ inch	50 - 70	53
#10	21 - 41	28
#40	8 - 24	12
#200	2 - 7	6.3
Rubber Content (%)	2	2.0
Binder Content (%)	4 - 8	6.4
Voids in Mineral Aggregate (%)	≥ 17	18.2
Absorption of Aggregate (%)	-	2.05
Sp. Gr. of Aggregate	-	2.644
Voids (%)	3 - 5	4.0
Stab. (lbs)[c]	≥ 1800	3400
Flow (.01 inch)[c]	8 - 20[c]	21.6
Rice Max. Sp. Gr.	-	2.408
Bulk Density (lbs/ft^3)	-	144.2
Effective Asphalt Content (%)	6.0 - 7.0	-

[a] Broadband limits for gradation, rubber content, and binder content. Gradations are % of dry ingredient weight without rubber. Rubber and binder contents are % of total mix weight.
[b] Design mix values interpolated from briquets with 6.0% and 6.5% binder contents. Gradations do not include rubber.
[c] Marshall stability and flow.

Table 2.6d: Broadband Limits, Mix Design Criteria, and Design Mix Characteristics at Design Binder Contents - Class "B" on S.E. Stark Street Project		
Characteristic	**Class "B" Mix Design Criteria[a]**	**Class "B" Design Mix[b]**
Gradation (% Passing Screen)		
1 inch	99 - 100[a]	100
¾ inch	90 - 98	95
½ inch	75 - 91	80
⅜ inch	-	67
¼ inch	50 - 70	57
#10	21 - 41	29
#40	8 - 24	11
#200	2 - 7	5.4
Binder Content (%)	4 - 8	5.3
Binder Film Thickness	Sufficient	Sufficient
Sp. Gr. @ 1st Comp.	-	2.36
Voids @ 1st Comp.	≥5	5.6
Stab. @ 1st Comp.[c]	≥35	37
Sp. Gr. @ 2nd Comp.	-	2.42
Voids @ 2nd Comp.	≥ 2.0	3.2
Stab. @ 2nd Comp.[c]	≥35	46
Rice Max. Sp. Gr.	-	2.499
Voids in Mineral Aggregate (%)	≥ 14	14.3
Index of Ret. Strength (%)	≥ 75	80
Index of Ret. Resilient Modulus (%)	≥ 70	121

[a] Broadband limits for gradation and binder content. Gradations are % of dry ingredient weight. Binder contents are % of total mix weight.
[b] Design mix values interpolated from briquets with 5.0% and 5.5% binder content.
[c] Hveem stability.

In addition, the METRO RUMAC specifications did not state whether or not rubber is included in the broadband limits listed in the 1990 revisions of the Section 403 specifications that they supplement.[8]

3) The METRO RUMAC specifications should be revised to allow narrowband limits outside of the broadband limits - as long as the JMF target values are within the broadband limits. The ODOT specifications that the METRO RUMAC specifications supplement do not allow the narrowband limits to be outside of the broadband limits, and there is nothing in the METRO RUMAC specifications to void that requirement. This requirement has not been a problem for conventional asphalt concrete, as it is unusual for a target value to be very close to a broadband limit. However, unlike conventional asphalt concrete JMFs, METRO RUMAC JMFs often have target values close to the broadband limits. This was observed on most of the 1991 and 1992 METRO RUMAC projects.

If the correct narrowband limits were used on either of these 1991 projects, a constriction would occur for the aggregate passing ¼ inch screen as shown in Figures 2.7 and 2.8. In these figures, the narrowband limits are shown as dotted lines. If the narrowband limit was not constricted by the broadband limit, the upper narrowband limit would always be 12% higher than the lower narrowband limit. For the N. Marine Drive METRO RUMAC mix, the upper narrowband limit would have been the target value of 53% plus the tolerance of 6% for a upper limit of 59%. The lower tolerance limit would have been the lower broadband limit of 52%. This results in narrowband limits that are only 7% apart. For the S.E. Stark Street METRO RUMAC, the upper narrowband limit would have been the target value of 53% plus the 6% tolerance for a upper limit of 59%. The lower narrowband limit would have been the lower broadband limit of 50%. This results in narrowband limits that are 9% apart.

The supplier risks a penalty for being out of the narrowband limit if they try to blend to the target value, as the gradation of the blended aggregate cannot be controlled exactly. Consequently, the supplier may try to blend to the center of the narrowband limits rather than the JMF target values. As a result, the mix that was produced would have a different gradation than the JMF mix, and this may result in a produced mix that does not behave like the JMF mix.

The reader may assume that the ODOT could widen the broadband limits for the Class "B" and Class "C" METRO RUMAC. This would allow the contractor to make mixes with reduced fractions of aggregate passing the finer screens, and these gradations are commonly called "gap-graded" aggregates. Unfortunately, the ODOT may not have this option, as at least one patented RUMAC process in the United States uses gap-graded aggregate. This creates the possibility that the ODOT could infringe on a patent.

4) If instability such as rutting or shoving occurs on these METRO RUMAC pavements, mix design guidelines using a 75-blow Marshall design method may be needed. The current METRO RUMAC mix design guidelines use a 50-blow Marshall method. For conventional pavements, the 50-blow method is usually used for streets and roads with relatively light traffic loadings. A 75-blow Marshall mix design was used by the CoP for the control section's Class "C" mix, and a 75-blow design is required by many agencies for heavily travelled roads. However, if a 75-blow Marshall design method is developed, it should be verified that the construction equipment normally used for paving can compact the METRO RUMAC to the job mix formula density.

5) Language in the mix design guidelines that allows or recommends that the mix designer change the rubber gradation or rubber content of the mix should be deleted. On Page 1 of the design guidelines it states: "... the mix design procedure develops the optimum asphalt cement content and crumb rubber content for the selected job mix formula aggregate gradation." Although the guidelines do not say how this optimum rubber content is to be determined, they do say that it is an alternative.

   Furthermore, the design guidelines state on Page 1:

   > "If there is insufficient void space in the mixture, this can be detected during the mix design procedures. High variation of air void content between specimens with the same asphalt content, constant specimen air void by increasing asphalt content, and increase in the height of specimen, due to expansion, after specimen extraction from mold and spongy characteristic are indications of a lack of sufficient space for crumb rubber. These effects can be reduced by reducing the size of crumb rubber and opening up, loosing up, the aggregate gradation."

   This guidance conflicts with the METRO RUMAC specifications, which require in Section 401.11 (e) that the crumb rubber be within specific gradation limits, and the requirements in Section 403.13 (b) that the crumb rubber content be within the tolerance range of 2% plus or minus .2% of the total mix weight. These gradation and rubber content limits are sufficiently wide to allow for normal variation in the production and addition of the rubber. However, they are much too narrow to allow for substantial changes to the rubber gradation and/or rubber content.

   If the rubber gradation or rubber content of the mix is changed during the mix design, these changes may cause delays in the contractor's paving process, the waste of rubber that was produced for the project, and costly litigation between the sponsoring agency and the contractor. To help illustrate the problems that might occur, the relationship between rubber production and the METRO RUMAC mix design follow. This sequence of events was typical of four of the five METRO RUMAC projects built in 1991 and 1992.

a) The contractor ordered the rubber well ahead of the paving date, as the rubber suppliers did not stockpile crumb rubber for METRO RUMAC and the rubber had to be made for each project. The gradation and quantity of the rubber that was ordered was based on the METRO RUMAC specifications. In addition, on the projects that used batch plants, the rubber was packaged in a bag size that allowed an even number of bags to be added to each batch of mix. This made adding the rubber to the pugmill and monitoring the rubber addition easier.

b) After the rubber was produced, representative samples were taken, and these rubber samples were sent with aggregate and asphalt samples to the consultants who did the mix designs.

c) Using these representative samples, the mix designs were made and sent to the contractor. Typically, the mix design process took several weeks.

A change in rubber gradation or an increase in the proportion of rubber in the mix could delay paving, as several weeks would be needed to make a new batch of rubber. In addition, if a batch plant is used, a change in the proportion of rubber in the mix may mean that an even number of bags of the rubber can no longer be added to each batch of mix, and the need to add partial bags of rubber to the pugmill may delay mix production.

In addition to delaying paving, a change in rubber gradation or proportioning may waste rubber, as the rubber produced prior to the mix design may not be useable, or only part of it could be used. The unused rubber may need to be discarded.

In some cases, the contractor could charge the sponsoring agency for the costs of the initial batch of unused rubber and the second batch of rubber that was actually used, as the sponsoring agency supplied the mix design. Also, the sponsoring agency could be liable for the costs incurred by the contractor due to delays in paving while new or additional rubber was being made.

6) Guidance is needed for the use of mineral filler. The METRO RUMAC mix design guidelines do not tell the designer when to use mineral filler or how much mineral filler to use, even though mineral filler is allowed in Section 403.11 of the METRO RUMAC specifications.

7) Revised guidelines are needed for the selection of compaction temperatures. The target compaction temperatures listed on Page 6 of the METRO RUMAC mix design guidelines are for AC or Penetration graded asphalts. These grades of asphalt are hard to find on many areas of the west coast, as the Performance Based Asphalt (PBA) grading system is often used.

The ODOT, and many other agencies, use guidelines for compaction temperatures that are not based on the grading system of the asphalt. Instead, these guidelines recommend compaction temperatures based on the results of viscosity tests on the asphalt used in the mix design.

Use of compaction temperatures based on the viscosity of the asphalt used in the mix design may improve the quality of METRO RUMAC mix designs. However, before test based compaction temperatures guidelines are adopted, the effects of the rubber on the viscosity of the asphalt at laydown should be investigated. If the rubber significantly alters the viscosity of the asphalt, these effects need to be considered when the compaction temperatures are selected.

2.9 SUMMARY

The overlay on the N. Marine Drive project in Portland, Oregon was a 1¾ inch wearing course over a 1½ inch leveling course. All mixes were dense-graded Class "C" asphalt concrete with a ½ inch to 0 inch gradation. The wearing course contained the experimental METRO RUMAC mix, the conventional Class "C" control mix, and Class "C" mix with RAP. The leveling course was also Class "C" mix with RAP.

The overlay on the S.E. Stark Street project in Gresham, Oregon was a 1½ inch wearing course of dense-graded Class "B" asphalt concrete with a ¾ inch to 0 inch gradation. Both the experimental METRO RUMAC and conventional Class "B" control mixes were in this wearing course.

Both projects are in an area with cool wet winters and mild dry summers. Of the two projects, the N. Marine Drive section has a relatively low traffic volume and the largest percentage of heavy truck traffic, while the S.E. Stark Street project has a very high traffic volume with a smaller percentage of trucks.

These mixes used aggregates made from crushed river gravels and cobbles and conventional asphalt. The materials passed specifications.

Both METRO RUMAC mixes and the Class "C" control mix used Marshall mix designs. The Marshall procedure used for the METRO RUMAC was modified to account for the rubber in the mix. The Class "B" control mix used an ODOT Hveem mix design.

The gradations in METRO RUMAC mix designs needs to be clearly labeled. The mix designs confused the mix suppliers, as some of the gradations presented with the job mix formulae were not clearly labeled as to whether or not they were broadband or narrowband limits, or as to whether or not they included rubber with the aggregate.

The METRO RUMAC specifications should allow narrowband limits to be outside of the broadband limits. The METRO RUMAC mix designs had job mix formula target values that were close to the broadband limits. Based on the current METRO RUMAC specifications, this causes a constriction in the narrowband limits and it increases the chances that the contractor will produce out-of-specification aggregate if they blend to the JMF.

If these METRO RUMAC pavements do not have adequate stability, mix design guidelines based on a 75-blow Marshall method may be needed. A 50-blow method is used in the current mix design guidelines. Based on experience with conventional asphalt concrete, the 50-blow method is usually suitable for roads with light to moderate traffic, and the 75-blow method is usually used on roads with moderate to heavy traffic. If 75-blow designs are made, it should be verified that these mixes can be compacted to the design densities during construction.

The METRO RUMAC mix design guidelines should not allow the rubber content of the mix or the rubber gradations to be changed from the values listed in the specifications. The current guidelines allow these changes, and they may cause problems, as the rubber is almost always ordered and produced before the mix design is made.

New compaction temperature guidelines are needed in the METRO RUMAC specifications. The compaction temperature guidance in the current specifications is based on AC or penetration graded asphalts, and this grading system is not in widespread use on the west coast. In addition, the current temperature selection guidelines do not account for the specific properties of the asphalt used in the mix or any effects that the rubber may have on asphalt viscosity during laydown.

3.0 CONSTRUCTION

This chapter describes the construction of the N. Marine Drive and S.E. Stark Street projects. The test results, test methods, air temperature, road surface temperature prior to paving, wind speed, and other data are listed in Table 3.1. AASHTO sampling and testing methods were used in most cases. The METRO RUMAC specifications are in Appendix A.

3.1 MIXING

N. Marine Drive Project - All mixes were made on August 17, 18, and 19, 1991 in a Gencor Bituma parallel flow drum mixer rated at 500 tons per hour. Aggregate was drawn from three stockpiles; a ½ inch to ¼ inch pile, a coarse ¼ inch to 0 inch pile, and a fine ¼ inch to 0 inch pile. Fine materials that blew through the drum were trapped in the baghouse and recirculated back into the mix. These fines substituted for some of the mineral filler required in the job mix formula.

The crumb rubber was fed into the mix by a system normally used for RAP, as shown in Figure 3.1. This system met the "Requirements for Drum Drier Mixing Plants" in Section 403.21 of the METRO RUMAC specifications. The rubber entered the drum through a center entry feed, as shown in the lower right corner of Figure 3.1. This entry point was well suited for crumb rubber, as the rubber was shielded from the burner flame by a veil of aggregate.

The rubber was conveyed to the drum by the long belt conveyor visible in the bottom of the Figure 3.1. If both rubber and RAP were to be used in the mix, both components would simultaneously share this long belt. The long belt was fed rubber by the shorter belt visible in the left half of the Figure. Rubber was metered onto the shorter belt from a hopper, as shown in Figure 3.2a. The hopper was filled by an end-loader which scooped rubber from the stockpile visible in the upper left corner of Figure 3.1 and in Figure 3.2b.

The amount of rubber added to the mix was controlled by the operation of the hopper and shorter belt. An electronic interlock between the rubber feed and the drum made the rubber feed rate dependent on the drum's mix production rate. To calibrate this equipment, a pre-weighed truckload of rubber was dumped into the hopper, metered through the hopper onto the lower end of the moving belt, and dropped from the upper end of the belt into the empty truck. The weight of the rubber based on the truck scale readings was compared to the weight of the rubber based on belt scale readings.

Table 3.1a: Job Mix Specifications and Properties - METRO RUMAC on N. Marine Drive Project

TEST	METHOD	PRODUCED MIX TEST RESULTS	JOB MIX SPECIFICATIONS
Gradation	AASHTO T164[c]		
(% Passing Screen)	AASHTO T30		
¾ inch		100[a,b]	99 - 100[d,h]
½ inch		98	90 - 100
¼ inch		61	48 - 58
#10		28	24 - 32
#40		12	10 - 18
#200		5.5	3.4 - 7.4
Binder Content (%)	c	6.9[a,e]	6.0 -7.0[d,f]
Rubber Content (%)		1.4[i]	1.8 - 2.2[f,g]
Moisture Content (%)	ODOT TM311[c]	.2[a]	≤ .6[f,h]
Compaction (% of Rice)	Nuclear	91.1	≥ 94.0[g]
Mix Temp. at Discharge (°F)		293 - 339[j]	≤ 350[g]
Mix Temp. at Delivery to Paver (°F)		270 - 327[j]	≥ 285[k]
Placement Air Temp. (°F)		59 - 97[j]	≥ 50[h]
Placement Surface Temp. (°F)		126 - 138[l]	None
Wind		Slight breeze	None
Weather		Overcast - Sunny	None

[a] Average from tests on six samples.
[b] Percentage of total aggregate weight, not including rubber.
[c] Extraction method modified to account for rubber.
[d] Narrowband limits.
[e] Value may not be correct due to problems with extraction method.
[f] Percentage of total mix weight.
[g] Limits in METRO RUMAC specifications.
[h] Limits in September 1989 ODOT asphalt concrete specifications for "C" mix.
[i] Value based on rubber feed meter.
[j] Range of test results.
[k] Mix temperature behind paver.
[l] Random measurements.

Table 3.1b: Job Mix Specifications and Properties - Class "C" on N. Marine Drive Project			
TEST	**METHOD**	**PRODUCED MIX TEST RESULTS**	**JOB MIX SPECIFICATIONS**
Gradation (% Passing Screen)	AASHTO T164 AASHTO T30		
¾ inch		100[a,b]	100[c]
½ inch		99	95 - 100
¼ inch		73	65 - 77
#10		32	29 - 37
#40		14	10 - 18
#200		6.6	3.5 - 7.5
Binder Content (%)	AASHTO T164	5.2[a]	4.8 - 5.8[c,d]
Moisture Content (%)	ODOT TM311	.22[a]	$\leq$ .70[e]
Compaction (% of Rice)	Nuclear	89.6	$\geq$ 92
Mix Temp. at Discharge (°F)		310 - 328[f]	None
Mix Temp. at Delivery to Paver (°F)		296 - 301[f]	240 - 325[e]
Placement Air Temp. (°F)		92[f]	$\geq$ 40
Placement Surface Temp. (°F)		133[g]	$\geq$ 45
Wind		Slight breeze	None
Weather		Sunny	None

[a] Test result for one sample.
[b] Percentage of total aggregate weight.
[c] Narrow band limits.
[d] Percentage of total mix weight.
[e] Limits in CoP asphalt concrete specifications.
[f] Range of test results.
[g] Random measurements.

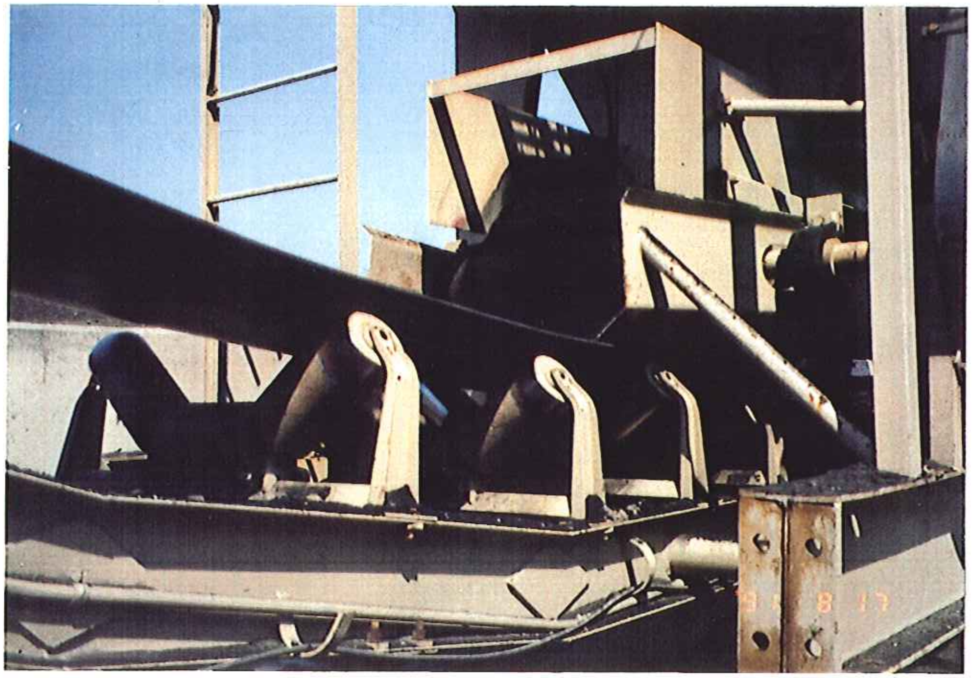
Table 3.1c: Job Mix Specifications and Properties - METRO RUMAC on S.E. Stark Street Project			
TEST	**METHOD**	**PRODUCED MIX TEST RESULTS**	**JOB MIX SPECIFICATIONS**
Gradation (% Passing Screen) 1 - inch ¾ inch ½ inch ¼ inch #10 #40 #200	AASHTO T164 AASHTO T30	 95.8[a,b] 95.7[c] 85.1 84.8 50.4 49.9 27.6 26.6 12.7 12.5 5.3 5.4	 100[c,d] 99-100[c,e] 95-100 90-98 81-100 52-91 52-72 47-59 21-41 23-33 8-24 7-17 2-7 4.3-8.3
Binder Content (%)		6.2 - 6.4[g]	5.9 - 6.9[e,f]
Rubber Content (%)		1.5 - 2.0[h]	1.8 - 2.2[f,g,l]
Moisture Content (%)	ODOT TM311	.069[a]	$\leq$ .6[m]
Compaction (% of Rice)	Nuclear	94.6[j] 94.7[k]	$\geq$ 94.0[l]
Mix Temp. at Discharge (°F)		300 - 325[i]	$\leq$ 350[l]
Mix Temp. behind Paver (°F)		250 - 270[i]	$\geq$ 285[l]
Placement Air Temp. (°F)		65 - 91[i]	$\geq$ 50[m]
Placement Surface Temp. (°F)		80 - 136[i]	None
Wind		Slight breeze	None
Weather		Sunny	None

[a] Result of test on one sample.
[b] Percentage of aggregate weight including rubber.
[c] Percentage of aggregate weight without rubber.
[d] Narrowband limits used during production.
[e] Narrowband limits based on JMF.
[f] Percentage of total mix weight.
[g] Values based on weight of binder added to mix.
[h] Rubber content based on number of bags added to mix.
[i] Range of test results.
[j] Average compaction at 1.5% rubber content.
[k] Average compaction at 2.0% rubber content.
[l] Limits in METRO RUMAC specifications.
[m] Limits in September 1989 ODOT asphalt concrete specifications.

Table 3.1d: Job Mix Specifications and Properties - Class "B" on S.E. Stark Street Project			
TEST	**METHOD**	**PRODUCED MIX TEST RESULTS**	**JOB MIX SPECIFICATIONS**
Gradation (% Passing Screen) 1 - inch ¾ inch ½ inch ¼ inch #10 #40 #200	AASHTO T164 AASHTO T30	a	99 - 100[b,c] 90 - 98 75 - 91 51 - 63 24 - 34 3.0 - 7.0
Binder Content (%)		a	4.8 - 5.8[b,d]
Moisture Content (%)	ODOT TM311	a	$\leq$ .6[d,e]
Compaction (% of Rice)	Nuclear	a	$\geq$ 89[e]
Mix Temp. at Discharge (°F)		a	301 - 310[f]
Mix Temp. behind Paver (°F)		a	283 - 291[f]
Placement Air Temp. (°F)		a	$\geq$ 50[e]

[a] No data collected.
[b] Percentage of total aggregate weight.
[c] Narrowband limits.
[d] Percentage of total mix weight.
[e] Limits in September 1989 ODOT asphalt concrete specifications.
[f] Requirements in mix design.

Figure 3.1: Mixing METRO RUMAC for N. Marine Drive Project



(a) Metering rubber from RAP hopper onto rubber belt conveyer

(b) Rubber in stockpile

Figure 3.2: Rubber Addition and Storage for N. Marine Drive Project

For the 5.36 tons of rubber in the truck, the truck scale readings and belt scale readings were 120 pounds apart. This discrepancy was 1.1% of the rubber weight, or .0002% of the total mix weight. This was an acceptable error, as the actual amount of rubber fed into the mix can vary within .2% of the desired 2.0% of the total mix weight and be within the METRO RUMAC specifications.

If RAP is to be added to METRO RUMAC mix, the supplier would add RAP using the hopper and shorter rubber belt conveyor that added rubber to this project's mix. To add the rubber, they would purchase a similar hopper and rubber belt conveyor. The rubber conveyor would have a more sensitive scale than the RAP feeder, and both shorter conveyors would simultaneously drop their contents onto the lower end of the longer conveyor that feeds the center entry port. The supplier estimated that the hopper and belt would cost $10,000; and that the electronics, scales, and miscellaneous items would add another $15,000 to $20,000; for a total added cost of $25,000 to $30,000. He also said they may need a covered storage shed for the rubber stockpile, and this would be an additional cost.

Prior to the METRO RUMAC paving, a short section of a nearby side street was overlaid to gain experience with the mix. The rubber feed was set at 2% of the total mix weight using scale readings. Samples of this mix were analyzed for the gradation, rubber content, and asphalt content. Solvent extractions were used to separate the rock, rubber, and asphalt; and the rubber content of the mix was indicated to be 2.6% to 2.7%. As the extractions showed that the rubber content was higher than the desired 2%, the rubber feed rate was reduced .6% for the production of the project's mix. After the rubber feed rate was adjusted the extractions indicated that the rubber content was 2%. However, the belt scale readings showed that the rubber content was reduced to 1.4%. The extraction results were assumed to be reliable, and no further adjustments were made to the rubber feed rate. Details of the extractions are discussed in Chapter 4.

Production of the METRO RUMAC mix went smoothly, with no significant problems. The gradation of the produced mix matched closely with the target values in the JMF with the exception that the percentage of aggregate passing the ¼ inch screen was 8% higher than the target value. All mix was discharged at temperatures below the maximum limit of 350°F, and most mix was produced at 300 to 330°F. With an average moisture content of .2%, this mix was well below the maximum allowable .6%. The mix's asphalt content is unknown due to problems with the extraction test. Although the average value was 6.9% by solvent extractions, this method is suspect, as discussed in Chapter 4.

Rubber was left over after production. A comparison between the amount of rubber used for the project and the total tonnage of mix produced indicated that this leftover rubber would have been used if the mix's rubber content was the desired 2.0% As a result, the belt scale readings were an accurate measure of the rubber content of the mix, and the extractions were in error.

The METRO RUMAC surface had scattered spots of rubber mixed with asphalt without aggregate as seen in Figure 5.2a. The reason for this spotting is not known, and further experience with blending METRO RUMAC in drum plants may be needed to determine the cause. Initially, it was thought that the drum plant could not thoroughly mix the rubber with the aggregate before the mix was discharged. However, the rubber was added at the center entry recycled feed near the middle of the drum, tumbled for several revolutions in the drum with the aggregate before the asphalt was added, and tumbled some more before the mix was discharged. On the 181st Avenue - Troutdale project's METRO RUMAC test section placed later in 1991, there was no spotting on the pavement.[2] On this later project, the rubber was added at the rear of the drum near the asphalt spray bar, and there were many fewer revolutions during which to disperse the rubber in the aggregate before the mix was discharged.

No problems occurred when the Class "C" control mix was produced. This mix used aggregate from the stockpiles for the METRO RUMAC, and the mix had a slightly finer overall gradation.

For both mixes, the baghouse exhaust gas opacities were similar and below the maximum of 20% allowed by the Oregon DEQ.[11]

S.E. Stark Street Project - Both mixes were made on August 19 and 20, 1991, in a 1972 Stansteel batch plant, as shown in Figure 3.3. The rated capacity was 350 tons/hour. The aggregate was drawn from stockpiles with three gradations: ¾ inch to ½ inch, ½ inch to ¼ inch, and ¼ inch to 0 inch. Portions of the baghouse fines were recirculated back into the mix to keep the passing #200 fraction within the narrowband limits.

The rubber was fed into the mix by dropping bags into the pugmill, as shown in Figure 3.4a. This method met the requirements for batch plants in Section 403.21 of the METRO RUMAC specifications. The bags were lifted to a platform near the pugmill by a forklift, as shown in the left side of Figure 3.3. Prior to being picked up by the forklift, the outer wrapping of each palletized unit was removed. A pallet of rubber, as received from the manufacturer, is shown in Figure 3.4b. The supplier used three laborers to add the rubber; two stood on the platform and added rubber to the mix, and the remaining laborer unwrapped the loaded pallets and brought them to the platform using the forklift.

To assure that the METRO RUMAC was thoroughly blended, the rubber and hot aggregate were mixed for 25 seconds in the pugmill before the asphalt was added, and for 35 seconds after the asphalt addition. This slowed the batching operation, as the 25-second dry batch time is not required for conventional mixes. Initially, unopened bags of rubber were tossed into the pugmill. This is allowed in the METRO RUMAC specifications, as the bags should be made of plastic with a low melting point, and they are supposed to disintegrate when they contact the hot aggregate and pugmill paddles. However, on this project, spots of a material that appeared to be made of either molten black plastic or rubber and asphalt were seen on the pavement made by the first few truckloads of mix. Like the spotting on the N. Marine

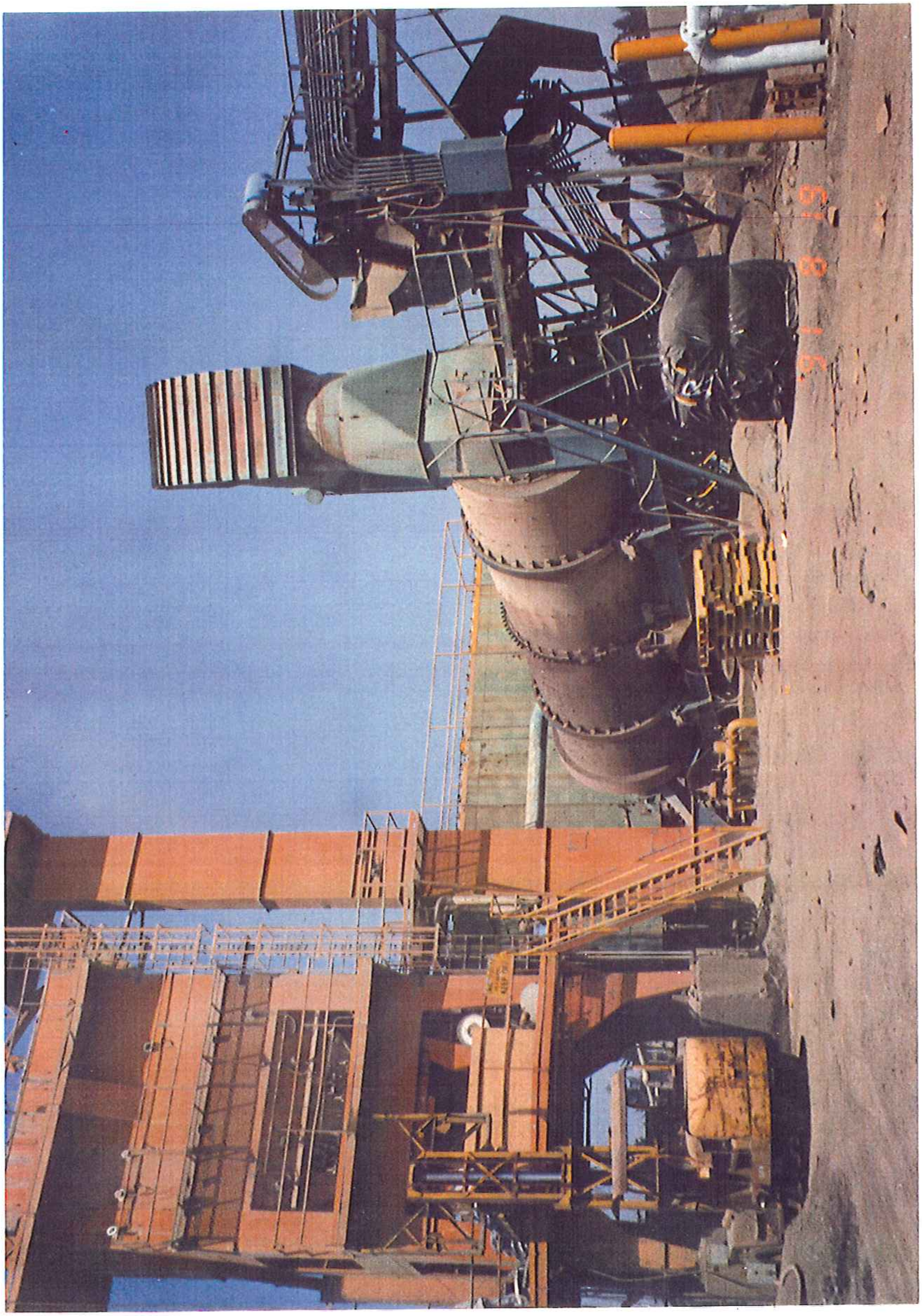
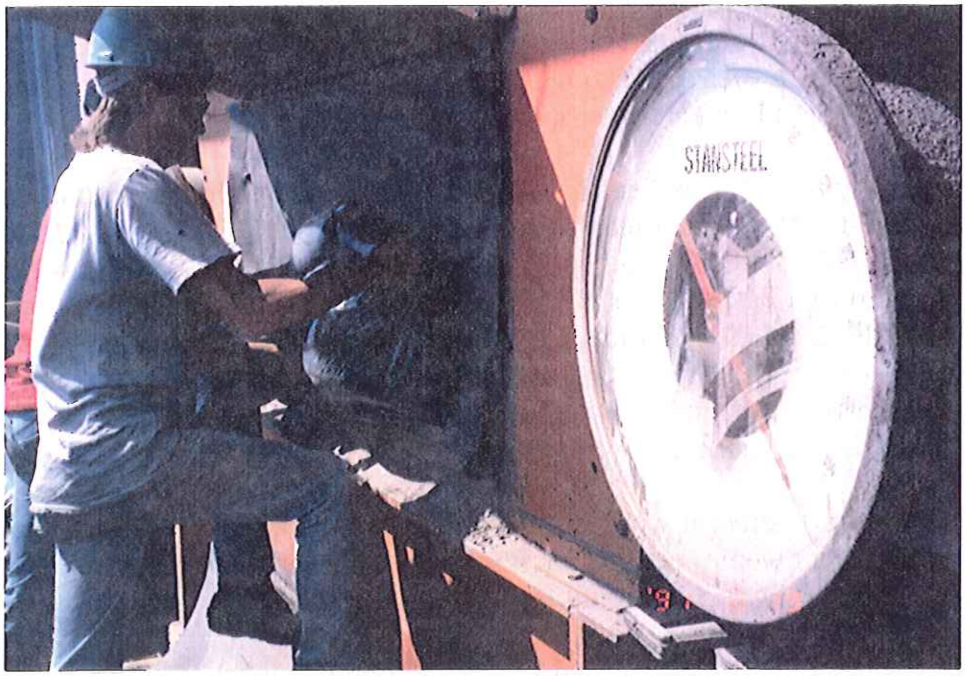


Figure 3.3: Mixing METRO RUMAC for S.E. Stark Street Project



(a) Adding bags of rubber to the pugmill

(b) Bags of rubber on pallets

Figure 3.4: Rubber Addition and Storage for S.E. Stark Street Project

Drive project, these spots contained no aggregate. After the spots were noted, the laborers emptied the rubber from each bag into the mix and put the bags in the trash. No molten spots were seen in the mix after this change.

Although the spotting on this particular project was attributed to the addition of unopened bags to the pugmill, this problem may be unique to this project. Little or no spotting was noticed on two METRO RUMAC test pavements constructed in 1992 where whole bags of rubber were added to a batch plant's pugmill. On both later projects, the spotting occurred on the first truckloads of mix, and they were due to an operator adding rubber to the mix too late in the mixing process. No spotting was seen on any of the other loads. One of these later projects used rubber supplied by the same supplier in the same type of bags as the rubber used on the S.E. Stark Street project.

The contractor estimated that it would cost $75,000 to automate the rubber feed system. This automated system would feed rubber from a bin into the plant. The rubber in the bin would not be bagged; instead, it would be delivered to the job site in bulk.

The exhaust gas opacity was not affected by the addition of rubber, as this was a batch plant. In batch plants, the aggregates are dried and heated in a drum and the exhaust gases are produced by this drum. No rubber was in the drum, as this material was added later in the process to the hot rock in the pugmill.

3.2 HAULING

N. Marine Drive Project - The mix was hauled in end dumps, end dump trailers, and "Flow-Boy" trailers. Haul time was about 20 minutes. Zep R-6690® diluted with water was used as a release agent.

S.E. Stark Street Project - The mix was hauled in end dumps and end dump trailers. Haul time was 15 to 20 minutes. United 596 E-Z-GO® diluted with water was the release agent.

These release agents were satisfactory, although they did not work as well as diesel oil, according to the drivers. However, due to environmental considerations, diesel cannot be used as a release agent in the Portland metropolitan area for either rubberized or conventional mixes.

3.3 PLACING AND COMPACTION

N. Marine Drive Project - It took four days to overlay the project. The south half of the roadway was paved first and the north side was paved last. The paver did not stop when it passed through the control sections. To make the 500-foot long control section, trucks carrying conventional mix, rather than rubberized mix, dumped their contents into the paver.

This method did not work well, as small amounts of rubberized mix contaminated the conventional pavement throughout the control section. With one exception, this rubberized mix was residue left in the paver from the METRO RUMAC paving. The exception was a truckload of METRO RUMAC accidently dumped into the paver in the north half of the control section.

Two pavers were used, a Barber-Greene 260-B and a Barber-Greene SB131. Three rollers were used: an Ingersoll-Rand DD-90 10-ton static weight dual steel drum vibratory roller, a Sakai SW 100 12-ton static weight dual steel drum vibratory roller, and an Ingersoll-Rand DD-65 5-ton static weight dual steel drum vibratory roller. In accordance with the METRO RUMAC specifications, soapy water was used to wet the drums of all rollers.

Roller patterns for the METRO RUMAC were established using control strips. When describing these patterns, a single coverage includes as many passes as needed to cover the entire pavement one time, and a pass is one movement of the roller in either direction. The August 17 and 19 roller patterns used a breakdown pattern of five vibratory coverages by the DD-90, an intermediate pattern of four vibratory followed by two static coverages by the SW 100, and a finish pattern of as many static coverages as needed by the DD-65 to remove all roller marks. The August 18 roller pattern was the same, except that the intermediate roller pattern was three static coverages. The use of a pneumatic roller was prohibited on METRO RUMAC by the specifications, even though these rollers are often used to compact conventional mixes. Previous experience by other agencies indicates that this rubberized mix sticks to these roller's rubber tires.

With an average density of 91.1%, the 1¾ inch thick lift of METRO RUMAC could not be compacted to the required minimum of 94% of maximum theoretical density. In addition, the mix was hard to roll as it was tender and sticky. The tenderness made it very difficult to remove the roller marks, and the finish roller had to work several hours after the paving was completed. The stickiness made is difficult to keep the roller train near the paver, as the breakdown roller could not get closer than about 500 feet to the paver without the mix sticking to the drum. The operator estimated that the mat had to cool to 200 to 220°F before he could roll it without sticking.

The 1¾ inch thick lift of Class "C" mix used the same roller pattern as the METRO RUMAC. The conventional mix was not sticky, and the breakdown roller could compact immediately behind the paver. The Class "C" control section was compacted to 89.6% of maximum theoretical density. This is a low density for a conventional pavement, and it was lower than the 92% minimum required by the CoP. The Class "C" density may have been higher if a pneumatic roller was used. Pneumatic rolling was not done, as it was very inconvenient to furnish a rubber tired roller for the short control section.

As the placement temperatures and compactive effort seem to have been adequate, the problems with the compaction of the METRO RUMAC may have been due to differences between the design and job mixes. As shown in Figure 2.7, the average percentage of the produced mix passing the ¼ inch screen was 8% higher than the job mix formula. This excessive amount of fine aggregate could make the mix tender and difficult to compact by occupying space in the mix that was supposed to be filled by rubber.[12] The variation in rubber content between the design and job mixes may be less of a factor, as compaction could not be achieved on the practice section that had the desired 2.0% rubber content, or on the majority of the METRO RUMAC paving which had a 1.4% rubber content.

The cause of the stickiness of the N. Marine Drive METRO RUMAC has not been determined. As the conventional Class "C" mix was made with the same asphalt, produced at similar temperatures, and rolled by the same rollers using the same drum wetting agent, it seems that the presence of rubber may have caused the sticking. However, on the S.E. Stark Street project, there was no sticking with the rubberized mix and similar rollers and drum wetting agents were used.

S.E. Stark Street Project - The first panel of METRO RUMAC paved was the outer eastbound travel lane and shoulder between S.E. Burnside Street and the 700 foot long Class "B" control section, as shown in Figure 2.4. This 1,200 foot long first panel used a 1.5% rubber content and a 6.2% binder content. Although this mix handled and compacted well, it appeared to be coarse and dry.

The second panel of METRO RUMAC was paved in the outer eastbound travel lane between the Class "B" control section and 202nd Avenue. The rubber content on this 1,100 foot long panel was raised to 2%, and it compacted satisfactorily, as did the previous METRO RUMAC panel with a 1.5% rubber content. In addition, the binder content was raised to 6.4% to enrich the mix. This panel continued to compact well and no longer appeared dry. However, it still appeared to be coarse.

The third panel of METRO RUMAC was the outer westbound travel lane and shoulder starting at 202nd Avenue and ending at S.E. Burnside Street. The fraction of aggregate passing the ½ inch screen was increased 4% to make the mix finer. This change worked, as the mix compacted satisfactorily and it appeared to have the correct gradation and binder content. The gradation after these changes was used for the remainder of the panels, and it is listed in Table 3.1c and shown in Figure 2.8.

The mix was placed using a BG-245 Barber-Greene paver. Two rollers were used: a Caterpillar 10-ton static weight dual steel drum vibratory roller and a Dynapac CC21A 8-ton static weight dual steel drum vibratory roller. Soapy water was used to wet the roller drums. No sticking was noted, and the breakdown roller could compact right up to the rear of the paver.

The same roller pattern was used throughout the project. Breakdown rolling was done with two coverages by the Caterpillar. Breakdown passes were static and comeback passes were vibratory. Intermediate rolling was done with two additional vibratory coverages by the

Caterpillar. Finish rolling was done with the Dynapac using as many coverages as needed to remove roller marks and get compaction. Usually compaction was obtained at 150 to 160°F, and finish rolling continued to 140 to 150°F. It was noted that the mat would rebound after the roller passed if the mix was above the compaction temperature, and there was no rebounding if the mat was below the compaction temperature.

Unlike the N. Marine Drive METRO RUMAC, the 1½ inch thick lift of rubberized mix used on S.E. Stark Street could be compacted to the specified density, was not tender, and could be compacted quickly. Although there may be other causes for this easier compaction, it may be due to the S.E. Stark Street mix's aggregate gradation being closer to JMF target values than the N. Marine Drive mix.[12]

No problems were noted when the 1½ inch thick lift of Class "B" control mix was produced or paved. This mix used aggregate from the same stockpiles, and the same asphalt, as the METRO RUMAC.

3.4 SUMMARY

The N. Marine Drive mixes were made in a drum plant and the S.E. Stark Street mixes were made in a batch plant. In both cases, the suppliers were able to modify their processes and equipment to satisfactorily produce METRO RUMAC. No increases in stack opacity were seen at either plant.

The mix supplier using the drum plant added the rubber with equipment normally used to add recycled asphalt concrete to the drum. This method was precise, however, the amount of rubber that was added was too low. The supplier based the addition rate on the results of extraction tests, and these extractions gave incorrect results. The supplier with the batch plant added whole bags of the rubber to the mix in the pugmill. This method was both a precise and accurate way of achieving the correct rubber content.

On both projects, spots that appeared to be rubber mixed with asphalt without aggregate were seen on the fresh METRO RUMAC pavements. On the N. Marine Drive pavement, these spots were seen throughout the project and their cause is unknown. On the S.E. Stark Street project, spotting was seen on the pavement from the first truckloads of mix. As whole unopened bags of rubber were thrown into the pugmill to make the first loads, these bags may have hindered mixing. However, this problem may be unique to this project, as unopened bags of rubber have been added to batch plants on subsequent METRO RUMAC projects without any problems.

No significant differences were noted during the hauling and placement of the rubberized or conventional mixes. However, the mixes behaved differently during compaction. Unlike the other mixes, the N. Marine Drive METRO RUMAC was tender, sticky, and it could not be compacted to the required density. The problems with tenderness and achieving density may be due to differences in aggregate gradation between the produced mix and the job mix formula. Non-petroleum based release agents worked satisfactorily with both the rubberized and conventional mixes.

4.0 SAMPLING AND TESTING

Solvent extractions are permitted in the METRO RUMAC specifications. This chapter describes some of the CoP's and Mult. Co.'s experiences with solvent extractions as a means of determining the aggregate gradations, rubber gradations, rubber content, and asphalt content of their METRO RUMAC mixes. Also, it presents some of the CoP's experience with using a nuclear compaction gauge on METRO RUMAC.

4.1 DETERMINING RUBBER CONTENT OF SAMPLE

In order to determine the amount of rubber in the mix sample, the CoP removed the rubber from the sample prior to the extraction.[13] To do this, they placed mix samples in bowls of the solvents they normally use for extractions. The solvent was decanted from the bowl onto a tared #200 or #270 screen. It was hoped that the rubber particles would float in the solvent and become trapped on the screen as the solvent passed through the screen. Problems occurred with this method.

First, neither of the solvents used, 111 Trichloroethane (111 Tri) or Trichloroethylene (TCE), floated all of the rubber. Some of the rubber floated in the upper, middle, and lower layers of the solvent, and some rubber did not float at all. The rubber that did not float was very hard to remove from the sample by decanting, as it laid in the aggregate particles on the bottom of the pan. When the operator tried to decant the solvent containing this finer rubber, some of the finer aggregate particles were also removed. This decanting process added about one hour to the time needed for a normal extraction test, as the decanting was repeated approximately twenty times per test.

Multnomah County did not attempt to remove the rubber from the mix prior to the extraction.

4.2 EFFECTS OF RUBBER ON EXTRACTION TEST

The CoP used a vacuum extraction method (AASHTO T164 Method E) to determine the aggregate gradation and asphalt content of the METRO RUMAC mixes.[6, 13] When the N. Marine Drive METRO RUMAC was paved on August 17 through 18, five extractions were made, and the indicated rubber content varied from 2.0 to 2.6% of the mix weight, with an average of 2.3%. As noted in Chapter 3.0, production records indicate that about 1.4% of the mix weight was rubber. The extractions were in error, as they indicated that the rubber content was .9% higher than it actually was, on the average. Most, if not all of this error in rubber content may be due to the loss of fine aggregate that was washed out of the sample with the rubber during the decanting process.

In order to minimize the amount of fine aggregate trapped on the screen with the rubber, the CoP has considered using #50 or #100 screens to trap the rubber after the decanting. They feel that these screens would trap almost all of the rubber and allow the solvent and any very fine aggregate to pass through. CoP testing has shown that little rubber passing the #50 screen is in a sample that has been soaked in extraction solvents, as discussed in Section 4.3 of this chapter. This modified rubber removal method has not been tried.

As Multnomah County did not remove the rubber from their mixes prior to their extractions, they obtained the combined gradation of the aggregate and the rubber.

4.3 EFFECTS OF SOLVENT ON RUBBER GRADATION

The CoP was concerned that the chemicals they used for solvent extractions could dissolve or change the size of the rubber particles. To see if this would occur, two samples of rubber were weighed and tested for gradation, soaked in solvent for one hour, reweighed, and retested for gradation. In addition, two other samples were weighed, soaked in solvent for 2¾ hours, and reweighed.

The solvents, 111 Tri and TCE, significantly altered the gradations and reduced the weights of the rubber samples. As shown in Table 4.1, after soaking there were fewer particles passing the #10 and finer screen sizes and the samples lost 9.5 to 11.8% of their initial weight. Based on the results of these tests, the CoP assumed a 10% weight loss for the rubber during the decanting process when the rubber was removed from the aggregate before the extraction.

4.4 EFFECTS OF RUBBER ON TESTS FOR MAXIMUM SPECIFIC GRAVITY

Normally, the CoP uses the "Rice" method (AASHTO T209) to determine the maximum specific gravity of a paving mix.[6] One step in this test is to separate the mix sample into small pieces. This separation process usually takes fifteen to twenty minutes for conventional mixes. The separation of the METRO RUMAC mix took 1 to 1¼ hours, as this mix was very sticky.

Table 4.1: Changes in Gradation and Weight of Rubber Samples Soaked in Extraction Solvents						
Sample No.	1-437-A		1-437-B		1-440-B	1-441-B
Solvent	111 Trichloroethane		Trichloroethylene		Trichlorethylene	Trichloroethylene
Time Soaked	1 hour		1 hour		2-¾ hours	2-¾ hours
Sample Condition	**Before Soaking**	**After Soaking**	**Before Soaking**	**After Soaking**	**After Soaking**	**After Soaking**
% Passing Screen						
¼"	100	100				
# 4			100	100		
# 8			81	80		
# 10	72	73				
# 16			54	50		
# 30			32	17		
# 40	21	13				
# 50			10	2		
#100	3	1				
#200	.2	0	0	0		
% Rubber Loss by Weight		9.5		9.5	11.8	10.6

4.5 COMMENTS ON EXTRACTIONS FOR METRO RUMAC MIXES

During the 1992 construction season, the ODOT oversaw the construction of two METRO RUMAC test sections on State highways. Although the ODOT no longer uses extractions for acceptance testing of asphalt concrete mixes, the contractor is allowed to use extractions for the process control of their mix production, and contractors asked the ODOT if the extraction method could be satisfactorily used on METRO RUMAC. To answer this question, the extraction method was analyzed using the information provided by the CoP on rubber loss summarized in Table 4.1. A summary of this analysis follows. This analysis is based on the AASHTO T164 Method E procedure for vacuum extraction using 111 Tri or TCE as a solvent.

1. Can the extraction method be used to determine aggregate gradation?

Yes. The best way of determining aggregate gradation may be to extract the asphalt from the mix and to sieve the remaining aggregate and rubber mixture without removing the rubber. If the gradation limits are provided for aggregate without rubber, the gradation of the aggregate and the gradation of the rubber can be mathematically combined to get the gradation limits for the combined material.

The gradations obtained by the extraction process are not, however, an exact representation of the combined gradation of the rubber and aggregate added to the mix. As the CoP data in Table 4.1 shows, there can be a loss in rubber weight due to the rubber dissolving in certain solvents. In addition, some of the rubber may dissolve into the asphalt during the mixing process, and consequently, there may be a further reduction in the amount of particulate rubber recovered after the extraction.

The loss of rubber due to rubber dissolving in solvent during the extraction and rubber dissolving into the asphalt during mixing have negligible effects on the overall gradation of the mix. This can be shown by mathematical modeling using three theoretical samples. The gradations of these samples are shown in Table 4.2, and they are:

Table 4.2: Mathematical Modeling of Rubber Loss and Its Effect on Mix Gradation

Column No.	1	2	3	4	5
Sample No.	A	B	C	Difference in % Passing (A - B)	Difference in % Passing (A - C)
Description	No rubber loss	10% rubber loss	All rubber lost		
% Passing Screen					
1 inch	99.51	99.51	99.50	0.00	0.01
¾ inch	94.13	94.12	94.00	0.01	0.13
½ inch	83.37	83.33	83.00	0.04	0.37
¼ inch	61.35	61.27	60.50	0.08	0.85
# 10	31.95	31.82	31.00	0.13	0.95
# 40	16.05	16.04	16.00	0.01	0.05
#200	4.40	4.41	4.50	-0.01	-0.10

Sample A) This theoretical sample has a rubber content of 2.0% of mix weight, an aggregate gradation midway between the Class "C" aggregate broadband limits, and a rubber gradation between the rubber broadband limits. The percentages listed are for dry ingredient weight, which includes aggregate and rubber at a content of 2% of total mix weight. This sample corresponds to a mix with no loss of rubber during mixing or extraction.

Sample B) This theoretical sample has an aggregate gradation midway between the broadband limits for Class "C" aggregate, and a rubber gradation and rubber quantity loss that models the loss in the CoP's Sample 1-437-A in Figure 4.1. The percentages are for dry ingredient weight, which includes a 1.8% rubber content. The reduced rubber content includes an 11% loss of rubber retained on the #10 screen, a 71% loss of rubber retained on the #40 screen, and an 18% loss of rubber retained on the #200 screen. This sample represents a mix that had 10% of its rubber dissolved in the solvent during the extraction, and it is expected that this loss would occur if the rubber was removed from the rock by decanting or if the rubber remained with the aggregate during the extraction. This loss does not consider rubber dissolving in the asphalt during mixing. This is a theoretical extreme reflecting the lowest probable rubber loss, as some rubber dissolves in the asphalt as well as in the solvent.

Sample C) This theoretical sample has an aggregate gradation midway between the Class "C" aggregate broadband limits, and it contains no rubber. It represents the extreme case where all of the rubber either dissolved in the solvent during the extraction or in the asphalt during mixing. This does not occur in reality, but it is useful for mathematical modeling. Based on the ODOT's experience with numerous METRO RUMAC extractions, there was always some particulate rubber remaining with the aggregate after the extraction.

The difference in gradations between samples with no rubber loss and 10% rubber loss are listed in Column 4. This is the minimum probable difference. The difference in gradations between samples with no rubber loss and a 100% rubber loss are listed in Column 5. This represents the maximum possible difference.

The greatest theoretical losses occur on the fraction of dry ingredient weight passing the #10 screen, with a range of .13 to .95%. As actual rubber losses will probably be within this range, and they will not render the extraction test results useless for process control, as the mix plant operator typically can control the gradation of the mix to only 2 or 3% of a given value for any screen size.

2. Can the extraction method be used to determine asphalt content?

Possibly. If rubber dissolves in either the solvent during extraction or the asphalt during the plant mixing, the asphalt content indicated by the extraction will be significantly higher than the amount of asphalt actually added to the mix. This can be shown by mathematical modeling using three theoretical samples, as shown in Table 4.3.

The theoretical extremes of the effects of rubber loss on asphalt content are listed in the bottom row of Table 4.3. In Column 2 is the minimum extreme, which assumes that 10% of the rubber is dissolved in the solvent and no rubber dissolved in the asphalt, and Column 3 is the maximum extreme which assumes that all of the rubber dissolves in either the solvent or the asphalt.

Table 4.3: Mathematical Modeling of Rubber Loss and Its Effect on Asphalt Content			
Column No.	1	2	3
Sample No.	D	E	F
Description	**No Rubber Loss**	**10% Rubber Loss**	**All Rubber Lost**
Rubber Added as % of Mix	2.0	2.0	2.0
Asphalt Added as % of Mix	5.0	5.0	5.0
Rubber Loss as % of Mix	0.0	.2	2.0
Asphalt Content Indicated by Extraction	5.0	5.2	7.0
Difference in Asphalt Content Between % Added and % Indicated	0.0	0.2	2.0

Sample D) This theoretical sample has 2.0% rubber and 5.0% asphalt as percent of total mix weight, and no rubber dissolved in the solvent during extraction or in the asphalt during plant mixing.

Sample E) This theoretical sample has 2.0% rubber and 5.0% asphalt, and 10% of the rubber dissolves in the solvent during the extraction.

Sample F) This theoretical sample has 2.0% rubber and 5.0% asphalt, and all rubber is either dissolved in the solvent during the extraction or in the asphalt during plant mixing.

As the actual rubber loss will probably be between 10 and 100% of the rubber weight, the asphalt content indicated by the extraction may be .2 to 2.0% higher than the percentage of asphalt actually added. This error may cause problems for contractors relying on the extraction method to determine asphalt content, as they usually try to keep their asphalt content within plus or minus .5% of the desired percentage.

As the error in asphalt content reading due to rubber loss always increases the indicated percentage of asphalt in the mix, and the error should be consistent if mixing times and temperatures are not varied; a correction factor can be developed to adjust the indicated asphalt content to be closer to the actual asphalt content. To do this, asphalt content values may be determined by both extractions and tank stickings for the first day of mix production. The asphalt content indicated by extraction can be compared to the asphalt content by tank sticking, and a correction factor determined. This correction factor can be used on the extraction test results for the process control of subsequent day's mix production.

3) Can the extraction method be used to determine the gradation of the rubber added to the mix?

No. The effects of solvent on the rubber gradation are too severe, and they could easily make rubber that was within the gradation limits appear to be out-of-specification. In addition, the rubber may change gradation during the plant mixing process. These changes would be reflected in the gradation of the extracted rubber.

4) Can the extraction method be used to determine rubber content?

No. The decanting and extraction method used by the CoP did not reflect the actual rubber content of the mixture, as discussed in this chapter and Chapter 3 of this report. There is the possibility that an extraction method exists that accurately reflects the rubber content of a sample, as there are various extraction methods and solvents other than those used by the CoP. Unfortunately, even if an extraction method accurately determines the amount of particulate rubber in the mix, there is always the possibility that the indicated amount will be different than the actual amount added, as some rubber may dissolve in the asphalt.

4.6 DENSITY MEASUREMENT BY NUCLEAR GAUGE

The CoP used a Troxler Model 4640 thin layer density gauge to measure the in-place density of the METRO RUMAC.

To obtain density readings, a handful of sand was spread on the pavement surface. The gauge was set onto the sand pad and wiggled back and forth to smooth out the sand and assure that the gauge had a good seat prior to the density test. This procedure is used by the CoP on conventional pavements, as well as METRO RUMAC.

The METRO RUMAC, however, required an extra step. After the sand was flattened as described above, the gauge was removed. Any large chunks of rubber that protruded above the sand pad were pulled out by hand. The gauge was then reseated onto the sand pad and the density measured. Experience had shown that the protruding rubber particles would hold the gauge off of the surface and an artificially low density reading would result.

4.7 SUMMARY

The CoP used a modified vacuum extraction method to determine the rubber content, asphalt content, and gradation of the METRO RUMAC mix.

The CoP removed the rubber from the sample before the vacuum extraction by immersing the sample in a bowl of solvent and washing the rubber out of the sample with the solvent.

Unfortunately, some of the aggregate fines were washed out with the rubber, and these fines may have caused an error in the rubber content test results.

The CoP determined that the two chlorinated hydrocarbon solvents they normally use for extractions dissolve some of the rubber particles. They compensated for this loss in their calculations of rubber content by adding 10% to the weight of the rubber that they captured during the washing process.

The sticky nature of the rubber mix made the particles hard to separate for the "Rice" maximum specific gravity test. This difficulty added 40 to 60 minutes to the time it would take to do this test on a conventional mix.

In response to questions from contractors about the usefulness of the extraction method for the process control of METRO RUMAC mix production, the extraction process was analyzed using data on rubber loss in solvent provided by the CoP. Based on mathematical modeling, it was found the extractions are suitable to determine the overall gradation of the mix for process control, that extraction test results with a correction factor may be used for determining the asphalt content of METRO RUMAC, and that extractions are not suitable to determine the gradation and/or quantity of rubber added to the mix. These conclusions, however, are only valid for the one extraction method and two solvents analyzed. Other extraction methods and/or solvents may give different results.

The nuclear compaction gauge was successfully used by the CoP. However, rubber particles on the METRO RUMAC pavement could prevent the nuclear gauge from resting solidly on the surface, and artificially low density readings would result. To prevent this, protruding rubber particles were removed from the pavement surface where the density gauge rested.

5.0 PRE AND POST CONSTRUCTION EVALUATION

This chapter presents the results of roadway inspections before and after construction and the results of tests on materials removed from the newly constructed pavements.

5.1 VISUAL INSPECTION

N. Marine Drive Project - The roadway was visually inspected and rut depths were measured several weeks before the overlay.

The roadway had moderate fatigue and alligator cracking in all wheeltracks throughout the site of the proposed test and control sections. In addition to the cracking, there were several patches over severely distressed areas and utility trench excavations. The patches were in good condition. Ruts were 1/8 to 13/16 inches deep, with an average depth of 7/16 inches. Typical cracking and patches are shown in Figure 5.1a.

The cracked and rutted wheeltracks of the old roadway do not lie under the wheeltracks of the new pavement. As seen in Figure 5.1a, the old road had wide shoulders, two travel lanes, and no median. As shown in Figure 2.5, the new roadway has very narrow shoulders, two travel lanes, and a median lane. As a result, the outer wheeltracks of the old road are in the center of the travel lanes of the new roadway.

The fresh METRO RUMAC surfacing appeared to be in good condition, and it was similar to the conventional Class "C" mix, except that it was glossier and the surface had scattered spots. These spots are visible in Figure 5.2a, and they appeared to be rubber mixed with asphalt without aggregate. This spotting is discussed in Section 3.1 of this report.

S.E. Stark Street Project - This roadway was visually inspected and the ruts were measured four months prior to the overlay. Like N. Marine Drive, this roadway had experienced severe fatigue related distress in the wheeltracks. However, unlike N. Marine Drive, almost all of this distress was milled out and replaced by inlay patching a year or two prior to the overlay, as seen in Figure 5.1b. Also, unlike N. Marine Drive, the wheeltracks on the new overlay are directly over the wheeltracks of the old roadway. Rut depths were between 1/8 and 5/8 of an inch deep, with an average depth of 3/16 of an inch.

After construction, the fresh METRO RUMAC and control sections looked almost identical. The only difference was some spotting on the mix brought in the first truckloads. This spotting looked very similar to the spots on the N. Marine Drive METRO RUMAC shown in Figure 5.2a, and it is discussed in Section 3.1 of this report. There was tearing in the outer

(a) N. Marine Drive

(b) S.E. Stark Street

Figure 5.1: Typical Pavement Prior to Overlay

(a) N. Marine Drive

(b) S.E. Stark Street

Figure 5.2: METRO RUMAC surface immediately after construction

wheeltrack of the outer lane of the METRO RUMAC between the west end of the project and the control section. This section had a rubber and asphalt content that was lower than the rest of the METRO RUMAC, as discussed in Section 3.3 of this report. The remainder of the METRO RUMAC had much less tearing, and its typical surface is shown in Figure 5.2b.

5.2 FRICTION

The pavement friction was measured three months after construction. All testing was done at speeds near 40 mph in the left wheelpath of the outer lane. The test data was adjusted to standard 40 mph friction numbers (FN_{40}) using correlation equations. The test methods, calibration techniques, and equipment conformed to AASHTO T242-90.[6]

All sections had friction numbers typical of newly constructed asphalt concrete in Oregon. In addition, none of the experimental surfaces were significantly different than their conventional counterparts.

5.3 ROUGHNESS

The pavement roughness, or ride, was measured with a "South Dakota" type profilometer immediately after construction. The test results are shown in Table 5.1a.

The N. Marine Drive METRO RUMAC and Class "C" sections, with International Roughness Index (IRI) values of 117 and 123, respectively, had similar roughness; and the S.E. Stark Street METRO RUMAC and Class "B" sections, with values of 94 and 82, respectively, also had similar roughness. All values are within the roughness range expected for thin overlays of rough roadways.

5.4 DEFLECTIONS

Deflections were measured with a KUAB falling weight deflectometer several months before construction and a month after construction.

5.4.1 Reduction in Deflections

To see how much the METRO RUMAC would stiffen the roadway in comparison to an equal thickness of conventional mix, deflections were taken in the wheeltracks of the old roadway before the overlay and over the same locations after the overlay.

Table 5.1: Pavement Roughness and Deflections

a) Roughness

Project	Section	Average International Roughness Index (IRI) October 1991
N. Marine Drive	METRO RUMAC	117
N. Marine Drive	Class "C"	123
S.E. Stark Street	METRO RUMAC	94
S.E. Stark Street	Class "B"	82

b) Deflection Reductions

			Average Deflections in Thousandths of an Inch		Reduction in Average Deflections in Thousandths of an Inch
Project	Section	Lane	Pre-Construction June 1991	Post-Construction October 1991	
N. Marine Drive	METRO RUMAC	EB	30	17	13
N. Marine Drive	METRO RUMAC	WB	30	17	13
N. Marine Drive	Class "C"	EB	29	18	11
N. Marine Drive	Class "C"	WB	33	16	17
S.E. Stark Street	METRO RUMAC	EB	26	12	14
S.E. Stark Street	Class "B"	EB	27	12	15

c) Deflections of New Overlay

			Average Deflections in Thousandths of an Inch
Project	Section	Lane	Post-Construction October 1991
N. Marine Drive	METRO RUMAC	EB	8
N. Marine Drive	METRO RUMAC	WB	12
N. Marine Drive	Class "C"	EB	8
N. Marine Drive	Class "C"	WB	15
S.E. Stark Street	METRO RUMAC	EB	10
S.E. Stark Street	Class "B"	EB	12

N. Marine Drive Project - The METRO RUMAC and Class "C" overlays in conjunction with the Class "C" leveling course reduced the average pavement deflections a similar amount. As seen in Table 5.1b, the overlay in the METRO RUMAC section reduced the average deflection of 13 thousandths of an inch in both lanes. This is similar to the overlay in the Class "C" section, which reduced average deflections 11 thousandths in the eastbound lane and 17 thousandths in the westbound lane, for an average deflection reduction of 14 thousandths. For both sections, it is estimated that 1/3 to 1/2 of the deflection reductions are due to the Class "C" leveling course.

S.E. Stark Street Project - The METRO RUMAC and the Class "B" overlays reduced the average deflections a similar amount, as shown in Table 5.1b. The overlay in the METRO RUMAC section had a deflection reduction of 14 thousandths of an inch which was almost identical to the Class "B" overlay's reduction of 15 thousandths. All of this reduction was due to the METRO RUMAC and Class "B" wearing courses, as no leveling course was used.

5.4.2 Deflections of New Overlay

To determine the changes in deflection that occur as the pavement deteriorates, deflections were taken in the outer wheeltracks of the new overlay in the evaluation sections.

N. Marine Drive Project - The pavements in the METRO RUMAC and Class "C" evaluation sections had similar rigidity. The average deflections were 8 and 12 thousandths for the METRO RUMAC and 8 and 15 thousandths for the Class "C" pavements, as shown in Table 5.1c. The deflections in Table 5.1c are less than the deflections of the new pavement listed in Table 5.1b. The deflections in Table 5.1b are over the distressed wheeltracks of the old road and the deflections in Table 5.1c are over the relatively undistressed center of the old road's travel lanes.

S.E. Stark Street Project - The new METRO RUMAC and Class "B" evaluation sections had similar rigidity, with average deflections of 10 and 12 thousandths of an inch, respectively.

5.5 RUTTING, FATIGUE, STRIPPING, AND VOID CONTENT TESTS

5.5.1 Rutting

The rutting potentials of the METRO RUMAC and conventional mixes were measured at Oregon State University (OSU) using a Laboratoire Central des Ponts et Chausses (LCPC) rutting tester and test method OSU-TM-91-2.[14, 15] Two slabs of the METRO RUMAC pavement and two slabs of conventional pavement from each project were tested. In each test, the rectangular slabs were placed in molds, heated to testing temperature, and subjected to repeated passes of a loaded pressurized tire. Rut depths were periodically measured by a depth gage. The test results are listed in Table 5.2a. Although this test is used extensively in France to predict the rutting susceptibility of AC mixes, at present, there is insufficient data to tell if this test accurately predicts rutting in ODOT mixes.

The METRO RUMAC and conventional mixtures had similar rutting resistance. After 20,000 wheel passes, the average rut depths on the N. Marine Drive project's METRO RUMAC and Class "C" samples were .44 and .30 inches respectively; and the S.E. Stark Street project's Class "B" samples were .29 and .25 inches, respectively. Although there was a slight difference between the averages, "... there is no statistical difference between the results at the 95% confidence level" according to Lundy and Scholz of OSU.[14]

5.5.2 Fatigue

Each core that was tested for resilient modulus was also tested at OSU for diametral fatigue.[14, 16] The test results are listed in Table 5.2b.

The results of these tests are mixed, and they do not indicate whether or not the rubberized mixes are better at resisting fatigue than the conventional mixes, or vice-versa. The N. Marine Drive METRO RUMAC samples with an average fatigue life of 952 repetitions, were less durable than the Class "C" samples which had an average fatigue life of 1,490 repetitions. The opposite occurred with the S.E. Stark Street samples, as the METRO RUMAC samples had an average fatigue life of 2,630 repetitions which was over twice as long as the Class "B" sample's average of 1,290 repetitions.

5.5.3 Stripping

Cores will be removed from the pavement throughout the study to see if the asphalt coating strips from the aggregate as the pavement ages. To determine if any aggregate is not fully coated due to incomplete mixing, cores from the newly constructed pavements were examined, and all core's aggregate was fully coated. Consequently, any future loss in aggregate coating is probably due to stripping.

5.5.4 Void Content

The average in-place void contents of the sections based on nuclear density tests are listed in Table 5.2c. These values are the most accurate representation of the void contents of the test sections, as they are an average of many tests at different locations.

Performance predictions based on the void contents of the METRO RUMAC sections are not possible, as there is no data linking METRO RUMAC void content to field performance. However, there is information linking void content to performance level of conventional ODOT mixes,[17] and based on this data: the void content of the

Table 5.2: Rutting, Fatigue, and Void Content Test Results

a) Rutting Test Results

No. of Wheel Passes	Average Rut Depth in Inches			
	N. Marine Drive		S.E. Stark Street	
	METRO RUMAC	Class "C"	METRO RUMAC	Class "B"
200	.03	.01	.01	.01
1,000	.07	.02	.04	.02
5,000	.20	.07	.09	.07
20,000	.44	.30	.29	.25

Note: Test conducted at 104°F, 100 psi contact pressure, and 1,550 to 1,650 lbs. wheel load.

b) Fatigue Test Results

Property	Pavement Type			
	N. Marine Drive		S.E. Stark Street	
	METRO RUMAC	Class "C"	METRO RUMAC	Class "B"
Average Fatigue Life (Repetitions)	952	1,490	2,630	1,290

Note: Fatigue tests were conducted at 73°F at an initial tensile strain of 200 microstrain.

c) Void Content Test Results

Project	Section	Average In-Place Void Content Post-Construction Tests	
		Nuclear Density Tests 8/91	Core Density Tests 10/91
N. Marine Drive	METRO RUMAC	8.9	8.5
N. Marine Drive	Class "C"	10.4	6.2
S.E. Stark Street	METRO RUMAC	5.3	11.3
S.E. Stark Street	Class "B"	-	9.2

conventional Class "C" pavement is higher than normal for an ODOT pavement, and this high void content indicates that this pavement has a greater than normal susceptibility to fatigue cracking in the wheel tracks.

Density measurements on cores are used to monitor changes in the void content of the pavement due to consolidation under traffic and other causes. The cores are tested according to AASHTO T166 and T209. The void content test results listed in Table 5.2c are intended to represent the new overlay before traffic was allowed on the pavement. As traffic was on the pavement several weeks before coring, these cores were taken from areas near, but not in, the wheeltracks. Subsequent cores will be removed from nearby wheeltracks.

The void contents listed in Table 5.2c are intended to be a baseline that subsequent void content measurements will be compared to. They are not a statistically valid indicator of the average void content of the overlay, as they are taken from only two locations on each section.

5.6 SUMMARY

Both sections were visually inspected before the overlay. The N. Marine Drive pavement had exposed alligator cracking in almost all of the wheeltracks, numerous patches, and moderate rutting. The S.E. Stark Street had extensive alligator cracking at one time. A year or two before the overlay, however, almost all of this alligator cracking was ground out and replaced by inlay patching. Most of these patches were in good condition and the road was lightly rutted.

After the overlay, both sections were visually inspected a second time. On N. Marine Drive, the METRO RUMAC appeared to be in good condition, and it was similar to the Class "C" mix with two exceptions. It was slightly glossier, and its surface had scattered spots composed of asphalt mixed with rubber. The S.E. Stark Street section appeared to be in good condition. It was similar to the Class"B" pavement, except that it had some spotting on the pavement made from the initial truckloads of mix, and some tearing on a section of the pavement made with a low rubber and asphalt content.

Pavement friction was measured on all sections just after construction. All sections had friction number typical of new ODOT asphalt concrete pavements, and both METRO RUMAC sections had friction numbers similar to their respective control sections.

Pavement roughness or ride, was measured just after construction. Both METRO RUMAC sections had ride values similar to their respective control sections, and all sections had ride values typical of newly constructed thin overlays over rough roadways.

Deflections were measured before and after the overlay at the same locations. Based on these tests, the overlay reductions from the METRO RUMAC and conventional pavements were similar. Additional deflections were measured in locations that will be tested later in the study to monitor changes in pavement rigidity.

The mix's potential for rutting was measured by laboratory tests, and the results indicate that the METRO RUMAC and conventional mixes have similar resistance to rutting. However, as this rutting test is performed experimentally in Oregon, its predictions should be interpreted with caution.

The aggregate from all mixes was fully coated, based on the examination of cores from the newly constructed pavements. Consequently, any future loss in aggregate coating may be due to stripping.

Void contents were measured by nuclear gauges during construction, and the high void content of one control section indicates that it is susceptible to premature fatigue related distress. In addition, void contents were measured on cores from each pavement, and these void measurements will be compared to measurements on cores removed from the wheeltracks later in the study to see if the mixes densify under traffic.

6.0 QUANTITIES AND COSTS

This chapter presents the quantities and costs for the rubberized and conventional mixes. The quantities and costs are summarized in Table 6.1.

6.1 MIX COSTS

To compare the costs of these mixes per square yard of coverage, costs were calculated for a 2-inch thick lift compacted to job mix formula density using the contractor's bid prices.

N. Marine Drive Project - The METRO RUMAC cost $40.29 a ton in-place. This includes the $31.75 a ton price the mix supplier charged the CoP to furnish the mix-including rubber, asphalt, aggregate and mixing; and the CoP's placement cost of $8.54 a ton.

The Class "C" cost $28.04 a ton in-place. This includes the $19.50 a ton price the supplier charged for the mix-including asphalt, aggregate and mixing; and the CoP's placement cost of $8.54 a ton.

The METRO RUMAC cost an $4.34 per square yard coverage; assuming a $40.29 a ton in-place mix price, a 2 inch lift thickness, and the mix compacted to its job mix formula density of 143.7 pounds per cubic foot.

The Class "C" mix cost $3.07 per square yard coverage; assuming a $28.04 per ton in-place mix price, a 2 inch lift thickness, and a job mix formula density of 146.0 pounds per cubic foot.

S.E. Stark Street Project - The METRO RUMAC cost $44.77 a ton in-place, including rubber, asphalt, aggregate, mixing, and placement.

The Class "B" cost $28.01 per ton in-place, including asphalt, aggregate, mixing, and placement.

The METRO RUMAC cost $4.84 per square yard coverage; assuming a $44.77 per ton in-place mix price, a 2 inch lift thickness, and the mix compacted to its job mix formula density of 144.2 pounds per cubic foot.

The Class "B" cost $3.09 per square yard coverage; assuming a $28.01 per ton in-place mix price, a 2 inch lift thickness, and a job mix formula density of 147.3 pounds per cubic foot.

Table 6.1: Quantities and Costs		
N. Marine Drive Project -		
Item	**Quantity**	**Price Per Unit**
Furnishing METRO RUMAC	3,859 tons[a]	$31.75 per ton[b]
Placing METRO RUMAC	3,859 tons	$8.54 per ton
Total Cost of METRO RUMAC In-Place	3,859 tons	$40.29 per ton $4.34 per square yd.[f]
Furnishing Class "C" Mix	262 tons[d]	$19.50 per ton[e]
Placing Class "C" Mix	262 tons	$8.54 per ton
Total Cost of Class "C" In-Place	262 tons	$28.04 per ton $3.07 per square yd.[f]
S.E. Stark Street Project -		
Rubber in METRO RUMAC	32 tons	$410.00 per ton
Asphalt in METRO RUMAC	113 tons[c]	$170.00 per ton
Furnishing and Placing METRO RUMAC	1,786 tons	$24.90 per ton
Total Cost of METRO RUMAC In-Place	1.786 tons	$44.77 per ton $4.84 per square yd.[f]
Asphalt in Class "B"	8 tons[c]	$170.00 per ton
Furnishing and Placing Class "B"	160 tons	$19.00 per ton
Total Cost of Class "B" In-Place	160 tons	$28.01 per ton $3.09 per square yd.[f]

[a] Includes practice section.
[b] Includes asphalt and rubber.
[c] Estimated.
[d] Includes mix in wearing course of control section, only.
[e] Includes asphalt.
[f] Coverages per square yard are for 2-inch thick lifts compacted to design density.

The N. Marine Drive METRO RUMAC cost 1.41 times as much as the Class "C" pavement, and the S.E. Stark Street METRO RUMAC cost 1.57 times as much as the standard "B" mix, per square yard of coverage. This greater cost is within the range expected for this type of rubberized pavement based on the ODOT's experience with five experimental METRO RUMAC test pavements paved in 1991 and 1992. On these five projects, the METRO RUMAC cost between 1.26 to 2.02 times as much as comparable conventional mixes, based on a 2 inch lift thickness and compaction to design density.

6.2 OTHER COSTS

To efficiently mix METRO RUMAC for more frequent or larger projects, the drum plant used for the N. Marine Drive project and the batch plant used for the S.E. Stark Street project would need specialized equipment to feed the rubber into the mix. This added equipment may cost over $30,000 and $75,000 for the drum and batch plant, respectively. Details of the equipment are given in Section 3.1 of this report.

The METRO RUMAC mix designs cost $2,000 each. For comparison, a conventional ODOT mix design prepared in the ODOT laboratory cost $1,300 in 1991.

6.3 SUMMARY

The METRO RUMAC mixes cost 1.4 to 1.6 times as much as their conventional counterparts. Most of this cost increase was due to the rubber and the cost of adding the rubber to the mix. This greater cost is typical of METRO RUMAC compared to conventional mix based on the ODOT's experience with five METRO RUMAC pavements constructed during 1991 and 1992.

The mix plants would require extra equipment to add rubber to METRO RUMAC mixes if this pavement was used frequently. This equipment may cost between $30,000 and $75,000, depending on the type of plant used.

7.0 CONCLUSIONS AND RECOMMENDATIONS

This chapter presents conclusions and recommendations about the METRO RUMAC system based on the construction of the test pavements.

7.1 CONCLUSIONS

Overall Conclusions - The METRO RUMAC system is a viable means of adding tire rubber to asphalt concrete. However, there are many problems with the system, and further development is needed before it can be routinely used by the ODOT. Although this additional development can solve many of the problems, there are inherent limitations to the METRO RUMAC system.

The major inherent limitation of METRO RUMAC is its higher cost than conventional asphalt concrete. This higher cost could be justified if the METRO RUMAC pavements performed better or lasted longer than conventional pavements. However, long-term performance data is needed to see if METRO RUMAC gives additional performance or life, and this information will not be available for many years.

Another inherent limitation of METRO RUMAC is its complexity. Compared to conventional asphalt concrete, the contractor has to order the rubber, store the rubber, and add the rubber to the mix. In addition to the contractor's tasks, the ODOT has to contract the mix designs to consultants, test the rubber for specification compliance, and monitor the rubber addition. Furthermore, use of METRO RUMAC complicates the contractor's process control testing and the ODOT's quality assurance testing, as many testing procedures normally used for asphalt concrete cannot be used for METRO RUMAC.

A further inherent limitation of METRO RUMAC mixes are their need for more asphalt cement than comparable conventional mixes. This demand offsets many of the environmental benefits of this system, as asphalt is a non-renewable resource.

Rubber for METRO RUMAC - Rubber can be manufactured for METRO RUMAC paving projects using conventional crumb rubber processing equipment and methods.

METRO RUMAC Mix Designs - Mix designs can be made using METRO RUMAC design guidelines. However, based on visual observation of the mix at the beginning of laydown, the job mix formula may need to be altered while paving is in progress. If the job mix formula requires alterations, it should only be done by a technical expert on METRO RUMAC.

These mix designs may be difficult to interpret unless the gradations and the constituents included in the gradations are clearly labeled.

The target values in METRO RUMAC job mix formulae are often near the broadband limits. This often results in a constriction of the mix's narrowband limits, as the METRO RUMAC specifications do not allow the narrowband limits to be outside of the broadband limits.

A 75-blow design method may be needed for METRO RUMAC if mixes designed by the current 50-blow method show rutting or other signs of instability under traffic. However, it should be verified that mixes designed by the 75-blow method can be compacted to the design density in the field.

Using the current mix design guidelines, the mix designer can recommend a rubber content and gradation in conflict with the rubber proportions and gradations in the METRO RUMAC specifications. As the rubber is almost always ordered and manufactured before the mix design is started, a change in the rubber gradation or proportion during the mix design may make the rubber that was already produced useless. If this happens, new rubber may be needed, and costly delays may occur.

Guidance for the use of mineral filler is missing from the mix design guidelines.

If asphalts selected by the Performance Based Asphalt grading system are to be used, the compaction temperature guidelines in the METRO RUMAC mix design procedure may not be adequate. Compaction temperature guidelines based on viscosity tests of the project's asphalt may be useful.

Mixing METRO RUMAC - Experience with the drum plant used on the N. Marine Drive project shows that it is possible to add rubber to the drum by a center entry recycle feed without slowing mix production or increasing the exhaust gas opacity above an objectionable level. In addition, the plant on this project demonstrated that a feed device normally used for RAP could successfully meter rubber to the center entry.

Spots of asphalt mixed with rubber without aggregate on the surface of the newly constructed pavement indicate that the drum mixing system did not completely mix the rubber into the METRO RUMAC. However, much more experience is needed with METRO RUMAC in drum plants to see if this problem was unique to this particular mix or drum plant, or if the problem occurs on all plants using similar rubber feed systems.

The batch plant mixing of the Stark Street METRO RUMAC shows that adding pre-weighed bags directly to the pugmill will work successfully. However, the additional dry mixing time needed to mix the rubber and aggregate slowed production considerably. Experience on subsequent METRO RUMAC projects indicates that this dry mixing time cannot be reduced without lowering the mix quality.

Spots of asphalt and rubber without aggregate on the pavement made from the initial truckloads of mix indicate that tossing unopened bags of rubber into the pugmill prevents the rubber from being thoroughly mixed with the aggregate. This problem may be unique to the rubber and/or equipment used on this project. Experience with batch plants on subsequent METRO RUMAC projects shows that adding unopened bags to the pugmill can produce a completely blended mixture.

Compacting METRO RUMAC - METRO RUMAC can be compacted to the specified density. In addition, it appears that a METRO RUMAC mix that follows the job mix formula is easier to compact to specified density than a mix that does not resemble the JMF. While this is true of almost all mixes, it may be especially critical for METRO RUMAC.

Solvent Extractions on METRO RUMAC Mixes - The crumb rubber used for METRO RUMAC will partially dissolve in two chlorinated hydrocarbon solvents often used for vacuum extractions. Consequently, vacuum extractions using these solvents may give adequate test results for the overall aggregate gradation of a METRO RUMAC mix; and be a poor indicator of asphalt content, rubber content, and rubber gradation. Consequently, the addition of asphalt and rubber need to be carefully monitored to determine their proportions in the produced mix.

Measuring Density of METRO RUMAC with a Nuclear Gauge - The density of METRO RUMAC can be measured by a nuclear gauge. However, care is needed to see that rubber particles do not prevent the gauge from seating directly on the surface of the pavement.

Properties of METRO RUMAC vs Conventional Pavement - Based on the results of tests made just after construction, the new METRO RUMAC and comparable conventional mixes had these similar properties: appearance, friction values, ride quality, and the ability to reduce surface deflections.

Cost of METRO RUMAC - The METRO RUMAC pavements cost about 1½ times as much as their conventional counterparts per square yard of coverage at an identical lift thickness. This greater cost was within the expected range, based on ODOT's experience with other METRO RUMAC test pavements. At this time, there are no METRO RUMAC pavements that are old enough to provide long-term performance data. Consequently, it is not known if the greater initial cost of these rubberized mixes will be offset by extended pavement life.

7.2 RECOMMENDATIONS

If METRO RUMAC is to be used, the following recommendations are applicable.

Use of METRO RUMAC - Use METRO RUMAC in limited quantities. This caution is not based on any performance shortcoming on these two test pavements. Instead, it reflects concern about the ability of designers to successfully and consistently design METRO RUMAC mixes with the rubber proportions, aggregate gradations, and rubber gradations consistent with the METRO RUMAC specifications. In addition, caution is advised because of the complete lack of long-term performance data on METRO RUMAC pavements. When METRO RUMAC is to be used, its best use may be as a substitute for an equally thick layer of conventional dense-graded mix, as METRO RUMAC and conventional dense mixes have similar properties.

METRO RUMAC Mix Designs - Include with the mix design request, a list of the data needed, or an example of a complete METRO RUMAC mix design in the desired format. This will help to assure that the mix designer submits a complete and easily interpreted mix design, the designer must know the information that is needed and the format by which the information is to be presented.

Include a clause in the METRO RUMAC specifications that allows the narrowband limits for mix constituents to be outside of the broadband limits if the JMF target value is within the broadband limits.

If pavements designed by the current 50-blow method consistently become unstable under heavy traffic, develop a 75-blow METRO RUMAC mix design method. However, it should be verified that the compaction level required by the 75-blow design can be obtained by the compaction equipment and methods allowed in the specifications.

Revise the mix design guidelines so they require the materials and proportions in the job mix formula to be consistent with the METRO RUMAC specifications and any deviations from the limits in the specifications must be approved by the sponsoring agency. A designer could take the current METRO RUMAC mix design guidelines literally and vary the job mix formula rubber gradation and mix rubber content from the requirements in the specifications.

Develop guidelines for the use of mineral filler in METRO RUMAC or delete all references to mineral filler in the METRO RUMAC mix design guidelines and specifications.

Conduct tests to see if the viscosity of the asphalt is altered by the addition of the METRO RUMAC rubber. If the viscosity of the asphalt is not affected by the rubber, incorporate the compaction and placement temperature guidelines currently used by the ODOT into the METRO RUMAC mix design guidelines. If the rubber does affect the asphalt's viscosity, other compaction and placement temperature guidelines may need to be developed.

Mixing METRO RUMAC - When using a batch plant and bagged rubber, if spots of rubber mixed with asphalt are seen on the surface of the freshly compacted road, the first corrective step should be to verify that the bags are added at the beginning of a dry mix time lasting at least 25 seconds. If the spotting continues, emptying the contents of the bags into the pugmill and discarding the bags may solve the problem.

Solvent Extractions of METRO RUMAC Mixes - If solvent extractions are to be used for METRO RUMAC, the duration that the rubber will be exposed to the solvent should be estimated. Then, a sample of rubber should be exposed to the solvent for the same length of time to see if it dissolves or the gradation changes. A significant change in the rubber properties may invalidate the extraction test results.

If an agency's solvent extraction method will not work with METRO RUMAC, use alternative methods to determine mix properties. The ODOT has alternative methods in their 1992 version of the METRO RUMAC specifications, and they include: aggregate gradation by sieve analysis of the aggregate before it is blended with the asphalt and rubber, asphalt content by meter readings and verified by tank stickings, rubber properties by tests on rubber sampled from bags or stockpiles, and rubber content by monitoring the addition of the rubber to the mix.

Use of Nuclear Density Gauge - Remove excessive rubber particles from the METRO RUMAC pavement surface prior to placing the nuclear density gauge on the pavement to insure that the gauge seats properly.

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APPENDIX A

METRO RUMAC Specifications

APPENDIX B

METRO RUMAC Mix Design Guidelines

MIX DESIGN GUIDELINES

FOR

RUBBER MODIFIED ASPHALT CONCRETE

by

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1.0 BACKGROUND

The Marshall Method is a mix design procedure used to establish proper proportions of aggregates, asphalt cement and crumb rubber to meet the mix properties criteria in specifications. Also, the mix design procedure develops the optimum asphalt cement content and crumb rubber content for the selected job mix formula aggregate gradation.

A complete Marshall mix design is required for each aggregate gradation, aggregate source, rubber gradation, and rubber source.

2.0 MARSHALL MIX DESIGN PROCEDURE

This section outlines specific procedures for preparing the mix design for rubber modified asphalt concrete mixtures (RUMAC). Also, this section describes the procedure for the testing and analysis to establish marshall mix properties for use of crumb rubber in the dense graded asphalt mixtures.

2.1 Analysis of Aggregate Gradation

The analysis of aggregate gradation and the combining of aggregates to obtain the desired gradation are important steps in the Marshall mix design for rubber modified asphalt concrete. Aggregate should meet the same quality requirements as conventional asphalt concrete, which would be used in similar applications. The aggregate gradation shall conform to the Oregon State Highway Division, Specified General Limits, listed in the Standard Specifications. Due to differences in the specific gravities of crumb rubber and aggregate, the aggregate gradation for dense-graded asphalt mixtures should be maintained on the coarse side of the gradation band. Special attention should be given "the aggregate gradation curve in the sieve size No. 4 to No. 10 mesh to provide sufficient void spaces in the aggregate for the rubber particles. If the rubber particle is too large, or the aggregate gradation is too fine, compaction problems resulting from rubber interference between aggregate particles can result. In this case early ravelling may result in the pavement particles.

If there is not sufficient void space in the mixture, this can be detected during the mix design procedures. High variation of air void content between specimens with the same asphalt content, constant specimen air void by increasing asphalt content, and increase in the height of specimen, due to expansion, after specimen extraction from mold and spongy characteristic are indications of a lack of sufficient space for crumb rubber. These effects can be reduced by reducing the size of crumb rubber and opening up, loosing up, the aggregate gradation.

2.2 Evaluation of Crumb Rubber Properties

The crumb rubber should be ambient granulated or ground from whole passenger and/or truck tires. It is required to use a granulation processing method for crumb rubber particle size between sieve size number 4 to number 16. Both granulation and grinding processing methods are acceptable for crumb rubber smaller than sieve size number 16. The crumb rubber shall be cubical in shape and individual particles shall not be greater than 3/16 inches in length.

The crumb rubber shall be free of contaminates, including: fiber, metal, and mineral matter, to the following tolerances. The fiber content shall be less than 0.2% by weight. Fiber content shall be determined by weighing fiber agglomerations formed during the gradation test procedure. Rubber particles shall be removed from the agglomerations and free fabric before weighing.

The crumb rubber shall contain no free metal particles. Metal embedded in rubber particles may be allowed. The amount of mineral contaminate allowed shall not exceed 0.30% by weight as determined after water separation of a 100 gram crumb rubber sample in a half gallon glass beaker filled with water.

The rubber shall be dry with a moisture content of less than 0.75%. Moisture content will be determined by weighing a 100 gram crumb rubber sample both before and after it is placed in an oven and subjected to a temperature of 225°F for one hour.

The crumb rubber, tested in accordance with ASTM C-136 using a 100 gram sample, should meet the following gradations:

Sieve Size	Percent Passing (by weight)
No. 4	100
No. 8	70-100
No. 16	40- 65
No. 30	20- 35
No. 50	5- 15

The following chemical analysis shall apply to the rubber granulate:

Specific Gravity	1.15 ± .05
Percent of Carbon Black	35.0 Max.
Percent of Ash	8.0 Max.
Percent of Acetone Extract	23.0 Max.

Asphalt Cement Content

Rubber modified asphalt concrete mixtures require higher binder contents than conventional asphalt concrete mixtures. At least two reasons for higher asphalt cement content:

(1) The asphalt-rubber is significantly more viscous than conventional binder providing thicker film coating on the aggregates, and,

(2) The unreacted rubber particles act as a solid filler, increasing the binder volume but not necessarily binder adhesive characteristics.

Conventional mix design procedures should be used to determine optimum binder content for asphalt rubber mixtures. However, criteria for establishing optimum binder content should be modified to account for the potentially elastomeric properties provided by the asphalt-rubber. The Marshall stability and flow could be expected to be lower and higher, respectively, due to the elastic nature and lower modulus of rubber modified asphalt concrete. These effects shall increase as the rubber content increases. The suggested marshall criteria for rubber modified asphalt concrete are as follows:

Marshall Stability (Min)	800 Lbs.
Flow (.01 in)	8 - 20
VMA (% Min)	17
Air Voids (%)	3 - 5
Effective Binder, %	6.0 - 7.0

Marshall Specimen Formulation

Obtain representative hot bin or composite aggregate samples in accordance with instructions as outlined in Oregon State Highway Division, Testing Procedures. A sufficient quantity of samples shall be obtained to prepare a minimum of 25 specimens. Since additional testing is often required, it is recommended that additional aggregate components be obtained when sampling.

Also, obtain at least two (2) gallons of asphalt cement from the plant in approximately 4 to 6 individual containers so that multiple reheating of the sample can be avoided.

1. Five Marshall specimens shall be prepared for each of the five different asphalt contents used in the mix design. Three Marshall specimens shall be compacted to test for the Marshall design criteria and two shall remain uncompacted (loose mix) for use in the Rice Test, ASTM

D041, "Theoretical Maximum Specific Gravity of Bituminous Paving Mixtures".

2. Design Specimen Formulation

   a. Set the total weight of each mix specimen equal to 1200.0 grams.

   b. The following formulas will apply for determination of individual ingredients.

   -- By weight $R = \dfrac{(\text{Percent of Rubber})}{(1 - \%\ \text{Rubber})} A$

   -- By volume $.917R + .373A = \text{weight of aggregate } (.373)$

Example:

Design Rubber Percentage:	3.0
Design Asphalt Cement Percentage:	6.0
Briquette Size:	4 inch X 2.5 inch height

By Weight:

1200 gram x 6%	=	72 grams asphalt cement
1200 - 72	=	1128.0 grams aggregate
1128.0 x 3%	=	33.8 grams rubber

Therefore aggregate content: 1128 - 33.8 = 1094.2 grams

$$R = \frac{\text{grams rubber}}{\text{grams aggregate}} = \frac{33.8}{1094.2} = 0.031\ A$$

By Volume:

$$0.917\ R + 0.373\ A = 1128\ (.373)$$
$$0.917\ (0.031A) + 0.373\ A = 420.7$$
$$0.028A + 0.373\ A = 420.7$$

Aggregate: $A = \dfrac{420.7}{0.401} = 1049.1$ grams aggregate

Rubber: $R = 0.031 \times 1049.1 = 32.5$ grams rubber

Asphalt: $AC = (1049.1 + 32.5) \times 6.0\%$ asphalt $= 64.8$ asphalt cement

3.0 Batching and Compacting Marshall Specimens

a. Heat all specimen aggregate samples to a temperature of 350F. Due to temperature variations that may occur within an oven, a thermometer should be placed in each of the aggregate samples while the material is heated to ensure that the aggregate temperature achieves 350F. Preheat the Marshall hammer on a hot plate, preheated to approximately 300F. Also, preheat implements used for mixing.

b. Bring the asphalt cement temperature to 300F by means of constant temperature heating mantle or oven. The temperature of the asphalt cement should be checked periodically. If the asphalt cement temperature exceeds 325F, the sample of asphalt cement should be discarded. Precaution should also be taken to prevent altering of the asphalt cement characteristics by prolonged heating and/or reheating. The asphalt cement should not be held at the mixing temperature for more than one hour before using. Open containers should not be used for heating asphalt cement. Containers with friction top lids with hole, punctured prior to heating, for pouring is recommended.

c. Using the flat - bottom scoop, weigh the required amount of rubber crumbs in a separate pan.

d. When the asphalt and aggregate have reached the desired temperature, remove the container of aggregate from the oven, and, quickly place it in the mixing bowl. Add the required amount of the rubber crumbs (previously weighed) to the mixing bowl and using the mixer, dry mix the aggregate and rubber crumbs for 15 seconds.

e. The scale should be set to the total specimen weight plus bowl tare weight. Next add sufficient asphalt cement to balance the scale. Care should be taken to weigh the exact quantity of asphalt cement, however, excess can be removed by absorbing asphalt in paper towels. Care should be taken not to remove fines.

f. Remove bowl from scale and commence mixing. Mix until all particles are coated or until two minutes have elapsed. If all particles are not coated after two minutes of mixing (proper coating is often difficult at the low asphalt cement percentages) the mixing bowl and its contents shall be placed in the oven and its temperature checked. If the temperature is below 285 F the mix shall remain in the oven until the mix becomes 285 F or above, and then the mixing may be resumed. Final mixing temperature in the bowl shall not exceed 325 F.

g. Using a steel compaction mold, preheated to approximately 235 F to 325F, insert a filter disc onto the base plate. Next, spoon the asphalt cement mix into the mold from the mixing bowl being careful not to lose material or cause segregation.

h. Spade the mold 25 times with a hot spatula, 15 times around the perimeter and 10 times over the interior. the material should be slightly crowned in the center of the mold.

i. Immediately insert two thermometers into the mold, one at the center of the molded material and the other one-quarter inch from one edge. Cover the top of the mold as well as possible with gloved hands to prevent non-uniform cooling.

j. Target temperature for compaction is as follows:

AC 15 or 85 - 100 PEN	285 F ±5 F
AC 20	295 F ±5 F

Compaction shall begin when the average of the two thermometer readings are within the temperature range prescribed above. Place paper disc on top of the spaded mix prior to compaction. If the mix temperature is below those limits listed above, the samples should not be compacted. These samples may be used for determining the Maximum Theoretical Specific Gravity - ASTM D2041 "Rice Test". This test is run on uncompacted (loose mix) specimens.

k. A mechanical hammer should be used for compaction. Hand hammers will generally result in a different compaction effort. Therefore, to avoid a lack of uniformity in design submissions a mechanical hammer should be used. The compaction apparatus shall meet the requirements of ASTM D1559 Section 2, Apparatus. The mechanical hammer shall be held rigidly, straight and stable on top of the mixture by means of appropriate supports and weights. The mechanical hammer must not "jump" or move about on the surface of the mixture. Its base plate may not rotate. The mechanical hammer must be as devoid as possible of any motion except the smooth rise and fall of the hammer. The chain drive shall be properly adjusted for tension. Similar model mechanical hammers achieve better lab to lab repeatability.

l. The compactive effort shall be 50 blows per side.

m. Maximum times for each phase of mold preparation:

Batching (asphalt, aggregate & crumb rubber combination):	1.5 min.
Mixing:	2.5 min.
Compaction:	3.5 min.