# Rubber Modified Asphalt Concrete (METRO RUMAC) Evaluation

**Lakeview Junction - Matney Road Section (OR #50)**
**Pacific Highway - 42nd Street Section (OR #227)**

**Construction Report**

State Funded Report

by

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Prepared for

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Salem, Oregon 97310

**September 1995**

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16. Abstract


This report covers the construction in 1992 of test sections on two projects using asphalt concrete modified with tire rubber. One project's test sections are part of a single lift overlay on a lightly travelled two-lane road south of Klamath Falls, Oregon. The other project's test sections are part of the base course of a three-lift overlay on a heavily travelled four-lane divided highway between Eugene and Springfield.

All test sections use a dense-graded rubber modified asphalt concrete developed for the METRO agency of the Portland, Oregon urban area (METRO RUMAC). Control sections were paved with conventional asphalt concrete adjacent to the test sections. The test sections are compared to these control sections.

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

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

Sampling and testing methods were developed to see if the crumb rubber added to these pavements met the METRO RUMAC specifications.

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

The METRO RUMAC mixes cost 1.3 to 2.0 times as much as their conventional counterparts. Much of this cost was due to the addition of the rubber, and the extra asphalt required by the rubberized mixes.


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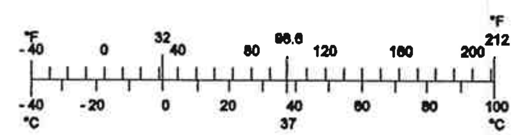
# SI* (MODERN METRIC) CONVERSION FACTORS

## APPROXIMATE CONVERSIONS TO SI UNITS

| Symbol | When You Know | Multiply By | To Find | Symbol |
|---|---|---|---|---|
| | | **LENGTH** | | |
| in | inches | 25.4 | millimeters | mm |
| ft | feet | 0.305 | meters | m |
| yd | yards | 0.914 | meters | m |
| mi | miles | 1.61 | kilometers | km |
| | | **AREA** | | |
| $in^2$ | square inches | 645.2 | millimeters squared | $mm^2$ |
| $ft^2$ | square feet | 0.093 | meters squared | $m^2$ |
| $yd^2$ | square yards | 0.836 | meters squared | $m^2$ |
| ac | acres | 0.405 | hectares | ha |
| $mi^2$ | square miles | 2.59 | kilometers squared | $km^2$ |
| | | **VOLUME** | | |
| fl oz | fluid ounces | 29.57 | milliliters | mL |
| gal | gallons | 3.785 | liters | L |
| $ft^3$ | cubic feet | 0.028 | meters cubed | $m^3$ |
| $yd^3$ | cubic yards | 0.765 | meters cubed | $m^3$ |
| NOTE: Volumes greater than 1000 L shall be shown in $m^3$. | | | | |
| | | **MASS** | | |
| oz | ounces | 28.35 | grams | g |
| lb | pounds | 0.454 | kilograms | kg |
| T | short tons (2000 lb) | 0.907 | megagrams | Mg |
| | | **TEMPERATURE (exact)** | | |
| °F | Fahrenheit temperature | 5(F-32)/9 | Celsius temperature | °C |

## APPROXIMATE CONVERSIONS FROM SI UNITS

| Symbol | When You Know | Multiply By | To Find | Symbol |
|---|---|---|---|---|
| | | **LENGTH** | | |
| mm | millimeters | 0.039 | inches | in |
| m | meters | 3.28 | feet | ft |
| m | meters | 1.09 | yards | yd |
| km | kilometers | 0.621 | miles | mi |
| | | **AREA** | | |
| $mm^2$ | millimeters squared | 0.0016 | square inches | $in^2$ |
| $m^2$ | meters squared | 10.764 | square feet | $ft^2$ |
| ha | hectares | 2.47 | acres | ac |
| $km^2$ | kilometers squared | 0.386 | square miles | $mi^2$ |
| | | **VOLUME** | | |
| mL | milliliters | 0.034 | fluid ounces | fl oz |
| L | liters | 0.264 | gallons | gal |
| $m^3$ | meters cubed | 35.315 | cubic feet | $ft^3$ |
| $m^3$ | meters cubed | 1.308 | cubic yards | $yd^3$ |
| | | **MASS** | | |
| g | grams | 0.035 | ounces | oz |
| kg | kilograms | 2.205 | pounds | lb |
| Mg | megagrams | 1.102 | short tons (2000 lb) | T |
| | | **TEMPERATURE (exact)** | | |
| °C | Celsius temperature | 1.8 + 32 | Fahrenheit | °F |




* SI is the symbol for the International System of Measurement

(4-7-94 jbp)

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# SUMMARY

## - Location, Design and Materials -

**Location** - The Lakeview Jct. - Matney Rd. sections are located on the Klamath Falls - Malin Highway (Oregon Highway #50 or Oregon Route #39) immediately south of Klamath Falls, Oregon. The Pacific Highway - 42nd Street sections are located on the Eugene - Springfield Highway (Oregon Highway #227 or Oregon Route #126) in Springfield, Oregon.

**Cross-Section** - The Lakeview Jct. - Matney Rd. test and control pavements are sections of a new 2" (51 mm) thick wearing course overlay paved directly over the old road. Both the METRO RUMAC and the conventional control pavements use an Oregon Department of Transportation (ODOT) Class "B" ¾" to 0" (19 mm to 0 mm) gradation and lime treated aggregate. The Pacific Highway - 42nd Street test and control pavements are part of a 2" (51 mm) thick upper lift in a 4" (102 mm) thick base course. A new 2" (51 mm) thick wearing course of open-graded conventional pavement will be paved over the METRO RUMAC in 1993. The METRO RUMAC and conventional pavements use a Class "B" mix.

**Climate** - The Lakeview Jct. - Matney Rd. project is in an area with hot summers, cold winters, low precipitation, and many freeze-thaw cycles. In contrast, the Pacific Highway - 42nd Street project is in a region with mild summers, cool winters, high precipitation, and few freeze-thaw cycles.

**Traffic** - Traffic loadings vary considerably between the two projects. The Lakeview Jct. - Matney Rd. sections are on a two lane road with low traffic volumes, and the Pacific Highway - 42nd Street sections are on a four lane divided highway with high traffic volumes.

**Design** - The Lakeview Jct. - Matney Rd. sections were part of a single lift surface preservation overlay with no surfacing design. In contrast, the Pacific Highway - 42nd Street sections were part of a surfacing rehabilitation project with a surfacing design.

**Materials** - The materials used in the pavements varied between the projects. The Lakeview Jct. - Matney Rd. sections used quarry aggregate and a PBA-3 asphalt binder with considerable polymer modification. The Pacific Highway - 42nd Street mixes used pit aggregate and a PBA-2 asphalt with little or no added polymers. Each METRO RUMAC mix used crumb tire rubber from a different source.

All materials except the rubber met specifications. The rubber from both sources consistently had moisture contents that were higher than the maximum in the specifications. One project's rubber had free metal in a sample which is prohibited by the specifications.

Both project's rubber were substantially within the gradation specifications, and both job's rubber passed all chemical composition tests.

**Mix Designs** - Both of the METRO RUMAC mixes used a modified Marshall mix design method, and both conventional control mixes used modified Hveem mix design procedures.

Both mixes had target values for some mix constituents which were close to the broadband limits. Consequently, the narrowband limits that govern mix production were constricted, as narrowband limits cannot be outside of the broadband limits, according to the specifications. Consequently, the constriction in narrowband limits increased the chance that the contractor would produce out-of-specification mix.

On the Lakeview Jct. - Matney Rd. METRO RUMAC design, a mix with the desired properties could not be obtained using the 2.0% rubber content required by the specifications. Consequently, the rubber content had to be lowered to 1.5% to get a mix with suitable properties.

The METRO RUMAC job mix formulae (JMF's) were similar to the ones used on previous projects, as they required more asphalt than their control section mixes.

## - Construction -

**Mixing** - Both METRO RUMAC mixes were made in batch plants, and the rubber was added to the mix by laborers who tossed unopened bags of rubber into the pugmill. Mix production was significantly slowed by the need to mix the rubber with the dry aggregate before the asphalt was added. This method of adding rubber was easy to monitor and the METRO RUMAC appeared to be thoroughly blended. However, this method was labor intensive, and the contractors may automate the rubber addition process if METRO RUMAC is used more frequently. These modifications could be costly, and in some cases, they could prevent the use of recycled asphalt concrete in the mix.

The workers adding the rubber to the mix used and needed protective clothing and safety equipment, as they labored in noisy and dusty conditions on a platform high above the ground.

**Compaction** - Roller patterns for the METRO RUMAC and conventional mixes were determined by control strips. On one project, neither of the two control strips could achieve the required density. This compaction difficulty may be due to the low percentage of aggregate fines in the mix. On the other project, both control strips and the rest of the pavement had the required density.

On the project where the required density was achieved, maximum compaction occurred during the finish rolling by a tandem steel wheel roller ballasted with water-filled drums. This was the first METRO RUMAC section that used a ballasted roller.

The conventional control mixes met the required density during compaction; and they required less rolling than their rubberized counterparts.

**Traffic on Hot Pavement** - The tires of the mix hauling trucks and trailers adhered to and damaged the METRO RUMAC on one project. This damage occurred when the vehicles stopped on pavement that was recently compacted and still hot. While this type of damage is occasionally seen on rubberized pavements made by other processes, this was the first time it occurred on METRO RUMAC. Typically, this damage is prevented by sprinkling sand on the hot pavement before traffic is allowed onto it.

## - Sampling and Testing -

**Rubber Specifications and Rubber Testing** - The METRO RUMAC specifications provided to the ODOT by METRO did not indicate specific test methods for determining if the crumb rubber met the specifications. Consequently, the ODOT developed draft sampling and testing methods for the rubber. These draft methods consisted of a sampling procedure, a method to determine the rubber's gradation, several tests to see if the rubber was contaminated, and a series of chemical composition tests to see if the rubber was made from tires.

The moisture content limit in the crumb rubber specifications may be too precise and too low. This low limit may reduce the number of manufacturers willing to supply rubber, and it may make the rubber needlessly expensive.

The requirement that no free metal is in the rubber may be too stringent, and it may make the rubber needlessly expensive.

It was difficult performing the mineral content test for the crumb rubber using distilled water to float the rubber off of the mineral matter. Use of a saline solution, in place of distilled water, may make this test easier.

Using chemical composition tests to differentiate between tire rubber and other types of rubber is an expensive procedure. The specification limits need to be periodically evaluated as the tests are costly.

**Use of Nuclear Asphalt Content Gauge** - Nuclear gauge readings were used on one project to determine the mix's asphalt content. This method worked on this particular project because the rubber content of the mix was controlled more precisely than the degree specified in the broadband limits. However, problems could occur if this method was used on projects where the rubber content of the mix was within the broadband limits.

**Use of Solvent Extractions** - Solvent extractions of the blended METRO RUMAC were used on one project to determine the overall gradation of the mix. These extractions were not difficult and they gave satisfactory results. Normally, the gradation of METRO RUMAC mixes is determined by testing aggregate that is sampled before the mix is blended.

**Sample Preparation for Index of Retained Strength (IRS) Testing** - Unlike samples of conventional asphalt concrete, uncontained METRO RUMAC samples often fall apart in the oven curing phase of the sample conditioning process. To prevent the METRO RUMAC samples from disintegrating, the ODOT uses a modified curing process in which the samples are contained in their molds during conditioning.

**Sample Preparation for Index of Retained Resilient Modulus ($IRM_R$) Testing** - Samples for this test are prepared by the California kneading compactor, according to the ODOT test method. The consultants who prepared the samples for this test, as part of their mix designs, used the Marshall method of fabricating samples. This method was convenient for them, as they used Marshall apparatus to prepare their mix design samples, and in both cases, they did not have California kneading compactors.

**Moisture Susceptibility Tests** - The specification limits for the IRS and $IRM_R$ tests are based on experience with conventional pavements and sample preparation methods. They may not be valid for METRO RUMAC.

## - Pre and Post-Construction Evaluation -

**Pre-Construction Condition** - The pavement under the Lakeview Jct. - Matney Rd. sections was visually inspected before construction. The pavement had numerous transverse thermal cracks, fatigue cracking in the wheeltracks, and extensive inlay patches that were in poor condition.

The pavement under the Pacific Highway - 42nd Street METRO RUMAC and Class "B" base course lift was a 2-inch thick inlay course placed a few weeks before the base course was paved. This inlay was in good condition.

**Post-Construction Condition** - On both projects, the METRO RUMAC and Class "B" sections had similar appearances, and all sections resembled typical ODOT Class "B" pavements. The only exceptions were scattered pockmarks on one project due to tires adhering to the hot METRO RUMAC, and a short section of METRO RUMAC on the other project which had sections with spots on the surface about one to 2 square inches (645 to 1,290 sq. mm) in an area composed of rubber mixed with asphalt.

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

The pavement roughness, or ride, of the Lakeview Jct. - Matney Rd. sections were measured just after construction, and all sections had ride values typical of a newly constructed thin overlay over a rough roadway.

The aggregate of all mixes was fully coated, based on visual inspection of cores. Consequently, if there is any future loss in aggregate coating, it is probably due to stripping.

Index of Retained Strength and Index of Retained Resilient Modulus tests on METRO RUMAC samples from the Lakeview Jct. - Matney Rd. and Pacific Highway - 42nd Street sections, respectively, had lower results than similar tests on their conventional counterparts.

The METRO RUMAC sections had low Hveem stability values, while the conventional control sections had the stabilities of typical new pavements.

## - Costs -

The METRO RUMAC mixes cost 1.26 to 2.02 times as much as their conventional counterparts. Most of this greater cost was due to the expense of adding the rubber to the mix and the cost of the additional asphalt required for the rubberized mixes.

The mix plants would need $4,000 to $20,000 of extra equipment to efficiently store and add the rubber to the METRO RUMAC if this type of pavement was used frequently.

## - Conclusions -

**Overall Conclusion** - METRO RUMAC pavements can be constructed without major problems. However, METRO RUMAC specifications and mix design guidelines need modification before they can be successfully used on future ODOT projects.

**Mix Designs** - To prevent the constriction in narrowband limits that often occurs when METRO RUMAC job mix formula target values are close to the broadband limits, the specifications can be revised to allow narrowband limits outside of the broadband limits.

In some cases, to obtain a mix with the desired properties, the rubber content of the METRO RUMAC has to be lowered from 2% of the mix weight to 1.5%. If this occurs while the current specifications are used, the ODOT may have to buy unused rubber. This problem may be prevented on future projects by lowering the rubber content in the METRO RUMAC specifications to 1.5%.

These two METRO RUMAC mixes required substantially more asphalt than their conventional counterparts. This high demand for asphalt offsets many of the environmental benefits of the system.

**Mixing** - Unopened bags of rubber can be added directly to the pugmill to produce a well blended mix.

The workers who add the rubber to the mix need protective clothing and equipment.

**Placing and Compacting** - METRO RUMAC can be compacted to the required density. Like conventional mixes, METRO RUMAC mixes which are closer to the job mix formula are easier to compact. Also, METRO RUMAC mixes require more compactive effort than conventional mixes, and compaction is often achieved late in the rolling process. In some cases, a ballasted finish roller may aid compaction.

**Tire Damage** - Tires can adhere to, and damage, METRO RUMAC that is cooling after compaction. This damage may be prevented by keeping traffic off of the pavement until it is cool, or by lightly sanding the surface if traffic must use the hot pavement.

**Rubber Moisture and Metal Contents** - To assure that rubber of adequate quality is available at a reasonable price, the moisture content limit in the specifications should be raised, and some free metal should be allowed in the rubber.

**Rubber Mineral Content Test** - Use of a saline solution to float the rubber off of the mineral contaminants may make this test easier.

**Rubber Chemical Composition Tests** - In place of the testing required to assure the rubber is made from tires, the rubber's origin can be verified by a manufacturer's certification it is made from tires.

**Asphalt Content by Nuclear Gauge** - The nuclear gauge can be used to measure asphalt content in situations where the rubber content of the mix is tightly controlled and monitored. Problems may occur if the gauge is used when the rubber addition is not tightly controlled.

**Solvent Extractions** - Solvent extractions can be used to determine the overall gradation of the mix for the contractor's process control testing.

**Sample Preparation for Index of Retained Strength (IRS) and Index of Retained Resilient Modulus ($IRM_R$) Testing** - Procedures that are not included in the ODOT test methods can be used to prepare samples for these tests. These modified procedures include retaining the samples in the mold during conditioning for the IRS test and using Marshall samples for the $IRM_R$ test.

**Moisture Susceptibility Tests** - The IRS and $IRM_R$ limits in the specifications are based on conventional pavements and samples tested and prepared by conventional methods. These specification limits may not be valid for METRO RUMAC.

**Post-Construction Evaluation** - The METRO RUMAC and control pavements were similar, based on appearances and friction, ride, and void content tests.

Both projects' METRO RUMAC had low Hveem stability values, and these low stabilities indicate that the pavements may prematurely rut and shove under traffic. In addition, one METRO RUMAC section had a low IRS, and this indicates that the pavement may have premature moisture damage. The other project's METRO RUMAC section had an adequate $IRM_R$ so it may resist moisture damage. These predictions, however, must be interpreted with caution - they are based on tests normally used on conventional pavements, and insufficient data is available to tell if they can predict METRO RUMAC performance.

**Costs** - The METRO RUMAC pavements cost substantially more than their conventional counterparts due to the costs of the rubber, adding the rubber, and the extra asphalt that METRO RUMAC typically requires.

## - Recommendations -

**General** - If METRO RUMAC is to be used, revise the METRO RUMAC specifications and mix design guidelines before they are used again. Use METRO RUMAC on small jobs until trouble free construction is routine and long-term performance data shows that the pavements are durable.

**Construction Practices** - Continue to add bags of rubber to the pugmill of batch plants, and assure that the workers adding the rubber are adequately protected. Try a ballasted finish roller if the METRO RUMAC is hard to compact and if the compaction is occurring late in the rolling process. If tires damage the hot and recently compacted pavement, allow the pavement to cool before traffic uses it, or lightly sand the surface before traffic is allowed onto the hot pavement.

**Mix Design Guidelines** - Delete rubber specifications and test methods in the mix design guidelines, and require that the rubber meet the requirements in the project's METRO RUMAC specifications.

**Specifications** - Require use of the draft test methods to determine rubber quality, raise the moisture content limit for rubber, and allow a limited amount of free metal in the rubber. Also, delete the tests for determining if rubber is from tires, and in place of the tests, require the rubber to be certified that it is from tires.

Lower the rubber content broadband limits from 2.0% $\pm$ .2% to 1.5% $\pm$ .2%. Allow narrowband limits to be outside the broadband limits, as long as JMF target values are within the broadband limits.

Continue to prohibit the use of the nuclear gauge to determine asphalt content, and allow exceptions only when the rubber addition is tightly controlled. Allow solvent extractions to determine the overall gradation of the mix for the contractor's process control testing.

Allow the samples to be conditioned in the mold for IRS testing, and allow Marshall specimens for $IRM_R$ testing.

**Other** - Prepare revised test methods for mineral content of crumb rubber, IRS, and $IRM_R$ testing.

# 1.0 INTRODUCTION

## 1.1 BACKGROUND

The storage and disposal of worn rubber tires has become a statewide and nationwide problem, as millions of tires have accumulated in dumps and storage areas. In response to this problem, the 66th Oregon Legislature required the Oregon Department of Transportation (ODOT) to conduct and study two paving projects using waste tire rubber. In addition, the Federal Highway Administration (FHWA) has required a portion of the asphalt concrete used on federally funded highway projects built in or after 1994 to contain rubber from recycled tires. The test sections discussed in this report were constructed for the Oregon Legislature. In addition, both test pavements are intended to give the ODOT information for the development of a rubber modified pavement program to satisfy future FHWA requirements.

The rubber modified asphalt concrete (RUMAC) on these projects used guidelines originally developed by CTAK Associates of Portland, Oregon for the METRO agency of the Portland, Oregon urban area and the Oregon Department of Environmental Quality (DEQ). This RUMAC system is public property, and it is often called "METRO RUMAC".

The METRO RUMAC is also commonly called a "dry" process, as the tire rubber is blended with the aggregate to the mix. This system has been developed for the dense-graded mixes commonly used by the ODOT, which include these aggregate gradations: Class "A" 1¼" to 0" (32mm to 0mm), Class "B" ¾" to 0" (19mm to 0mm), and Class "C" ½" to 0" (13mm to 0mm). In all of these mixes, the crumb rubber is used as an aggregate substitute, and the rubber comprises the same percentage of the mix (2% of total mix weight).

This is an ODOT funded study.

## 1.2 ODOT METRO RUMAC RESEARCH

In addition to this study, the ODOT is studying the construction and short-term performance of other METRO RUMAC pavements, including three test pavements placed in the Portland Metropolitan area in 1991[1,2] and two other test sections scheduled for construction in 1993.

The main difference between the Lakeview Jct. - Matney Rd. project's test pavements and the three pavements built in 1991 are:

2) This was the first test pavement built to METRO RUMAC specifications based on the ODOT's 1991 Standard Specifications[3] and experience obtained from the construction of the 1991 sections. The ODOT's 1991 METRO RUMAC project, the 181st Avenue - Troutdale test section, used an earlier version of the ODOT specifications.

The major differences between the Pacific Highway - 42nd Street project's test pavements and the 1991 test pavements are:

1) The METRO RUMAC is used in a base course. The rubberized mix in the 1991 sections and the Lakeview Jct. - Matney Rd. section are in wearing courses.

2) The test pavement was built to METRO RUMAC specifications based on 1991 ODOT specifications, like the Lakeview Jct. - Matney Rd. test pavement.

## 1.3 OBJECTIVES

The study's goals are to describe and comment on the construction and short term performance of these rubberized pavements. This report includes the project's layout, environment, structural and mix designs, construction, sampling, testing in-place unit costs, and the pavement's condition just after construction. The future performance of the pavement will be monitored and documented under SPR project #5255, *Crumb Rubber Modified Asphalt Concrete in Oregon.*

# 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 Pacific Hwy. - 42nd St. project's METRO RUMAC specifications are in Appendix A. The specifications are similar to those used for the Lakeview Jct. - Matney Rd. project.

## 2.1 LOCATION, LAYOUT, AND CROSS-SECTION

**Lakeview Jct. - Matney Rd. Project** - This project is located on the Klamath Falls - Malin Highway (Oregon Highway #50 or Oregon Route #39) immediately south of Klamath Falls, Oregon.

The test pavements are part of a 1992 ODOT Surface Preservation Project overlay that extends from M.P. 0.22 (just south of the junction between Oregon Highway #50 and Oregon Highway #20) to M.P. 6.75 (just south of the intersection between Oregon Highway #50 and Matney Road). The METRO RUMAC pavements are in the northbound lane between M.P. 1.64 and M.P. 0.96, and in the southbound lane between M.P. 0.95 and M.P. 1.63. The ends of the METRO RUMAC pavements are marked by paddles alongside the road.

Within each of the METRO RUMAC pavements there is a 2,000' (610 m) long test section that will be monitored throughout the study. In the northbound lane, the test section is between M.P. 1.54 and M.P. 1.16; and in the southbound lane, the test section is between M.P. 1.16 and M.P. 1.54.

On the conventional Class "B" pavement which is used for the majority of the overlay, there are 1,900' (580 m) long control sections for METRO RUMAC test section comparison. In both lanes, the control sections are between M.P. 0.55 and 0.91. The Class "B" pavement is the surfacing that the ODOT normally uses for a dense-graded wearing course. The ends of the test and control sections are marked by paddles on the side of the road saying "Coring Site". Cores will be removed from these sites throughout the study for testing.

**The roadway cross-section is:**

**Wearing Course** - The wearing course is a single lift overlay of dense-graded asphalt concrete with a 2" (51 mm) nominal thickness. The experimental and control mixes are in this course. The overlay completely covered the old road, and it includes two 3' to 6' (.9 m to 1.8 m) wide shoulders, two 12' (3.7 m) wide travel lanes, and occasionally, a 14' (4.3 m) wide right or left turn lane.

**Old Pavement** - The old pavement before the overlay was 6½" to 8½" (165 mm to 216 mm) thick. It consisted of several asphalt concrete pavements and patches placed since the highway was first paved in 1949. The condition and deflections of the old pavement are described in Chapter 5 of this report.

**Pacific Hwy. - 42nd St. Project** - This project is located on the Eugene-Springfield Highway (Oregon Highway #227 or Oregon Route #126) in Springfield, Oregon. The test pavements are part of a 1992 ODOT reconstruction project that extends from M.P. 4.00 (just east of the intersection between Oregon Highway #227 and Interstate Route #5) and M.P. 7.50 (just west of the intersection between Oregon Highway #227 and 42nd Street in Springfield). Most of this reconstruction uses a base course of conventional ODOT Class "B" mix without lime. The METRO RUMAC pavements are in the base course of the westbound lanes between M.P. 5.97 and 5.42, and in the eastbound lanes between M.P. 4.73 and 5.39.

The METRO RUMAC pavements use lime treated aggregate, and control pavements with lime treated aggregate are used on sections of the base course of this project. These control pavements extend from M.P. 5.39 to 4.73 in the westbound lanes, and between M.P. 5.42 to 5.97 in the eastbound lanes. The ends of the test and control pavements are marked by paddles alongside the road.

Within the test and control pavements, there are 1,000' (305 m) long test and control sections that will be monitored throughout the study. In the westbound lanes, the METRO RUMAC test section is between M.P. 5.79 and 5.60, and the Class "B" control section is between M.P. 5.28 and 5.09. In the eastbound lanes the test section is between M.P. 5.09 and 5.28, and the control section is between M.P. 5.60 and 5.79. The ends of the sections are marked by "Coring Site" paddles, and cores are periodically removed from these locations for testing.

**The roadway cross-section is:**

**Wearing Course** - The wearing course is a single 2" (51 mm) thick lift of conventional ODOT Class "F" open-graded mix without lime-treated aggregate. In each direction, this course covers a 10' (3.0 m) wide shoulder, two 12' (3.7 m) wide travel lanes, and a median of varying width. This lift was paved in 1993.

**Base Course (Upper lift)** - The upper lift of the base course is a 2" (51 mm) thick layer of dense-graded mix. The METRO RUMAC and Class "B" with lime mixes are in this lift, and the remainder of the lift is Class "B" without lime. Like the wearing course, this lift covers the shoulders, travel lanes, and median. This lift was paved in 1992.

**Base Course (Lower lift)** - The lower lift of the base course is a 2" (51mm) thick layer of ODOT Class "B" mix without lime. This lift is an inlay in the travel lanes of the old roadway, and it was paved in 1992.

**Old Pavement** - Just before construction, the old pavement was 5¼" to 6" (133 mm to 152 mm) thick. It consisted of asphalt concrete pavements and patches[4] placed since the highway was first paved in 1964 and 1965. The condition and deflections of the old pavement are presented in Chapter 5.

## 2.2 ENVIRONMENT AND TRAFFIC

The traffic loadings and environments vary considerably between the two projects, as shown in Table 2.1.

**Lakeview Jct. - Matney Rd. Project** - This project is on a two lane secondary highway linking Klamath Falls with the agricultural valleys to the south of the city. This area is in the High Plateau climatic region of Oregon, and it has a continental climate characterized by low rainfall and extreme temperatures.[5]

**Pacific Hwy. - 42nd St. Project** - In contrast to the Lakeview Jct. - Matney Rd. project, this road is on a four lane divided highway with controlled access that links Springfield with neighboring Eugene and heavily travelled Interstate Route #5. This highway is in the Willamette Valley climatic region of Oregon which has mild, wet winters and moderate, dry summers.[5]

## 2.3 OVERLAY DESIGN

**Lakeview Jct. - Matney Rd. Project** - As this was an ODOT Surface Preservation Project, its main purpose was to provide a functional, rather than structural, improvement to the roadway. Therefore, a structural design was not performed. The 2" (51 mm) layer thickness that was used was the minimum required to provide the worn roadway with a smooth and durable wearing surface.

**Pacific Hwy. - 42nd St. Project** - A surfacing design was made for this project using ODOT and American Association of State Highway and Transportation Officials (AASHTO) procedures.[4] The layer thicknesses used on this project were based on a 20-year surfacing design life at a reliability of 90%. The design did not address the use of METRO RUMAC, as the design was completed before the decision was made to use the rubberized mix. When the decision was made to use METRO RUMAC, Class "B" METRO RUMAC was chosen, and it was used as a substitute for an equal thickness of conventional ODOT Class "B" mix in the base course. The METRO RUMAC could not be used as a substitute for the Class

"F" wearing course, as METRO RUMAC specifications and mix design methods are developed for dense-graded mixes, only.

**Table 2.1: Environment and Traffic Data**

| | Lakeview Jct. - Matney Rd. Project | Pacific Hwy. - 42nd St. Project |
|---|---|---|
| Elevation, ft. (m) | 4,100 (1,250) | 420 (130) |
| Average Daily Temperature of Coldest Month (January), °F (°C) | 31 (-2) | 39 (4) |
| Mean Daily Temperature Swing in January, °F (°C) | 19 (-11) | 13 (7) |
| Average Daily Temperature of Warmest Month (July), °F (°C) | 69 (21) | 67 (19) |
| Mean Daily Temperature Swing in July, °F (°C) | 40 (22) | 30 (17) |
| Average Annual Precipitation, inches (mm) | 18 (460) | 39 (990) |
| 1992 Average Daily Traffic, vehicles/day | 2,540 N.B.<br>2,850 S.B. | 21,700 W.B.<br>20,000 E.B. |
| Heavy Trucks, % of Average Daily Traffic* | 3.7 N.B.<br>3.5 S.B. | 4.3 W.B.<br>4.4 E.B. |
| 1992 Annual 18-Kip (80Kn) Equivalent Single Axle Loads ESALs | 37,500 N.B.<br>39,200 S.B. | 66,700 W.B. (Inside Lane)<br>267,000 W.B. (Outside Lane)<br>65,200 E.B. (Inside Lane)<br>261,000 E.B. (Outside Lane) |

*Single unit, 2 axle, 6 tire or larger vehicles are classified as "heavy trucks".

## 2.4 MATERIALS AND SUPPLIERS

The suppliers of the experimental paving materials are listed in Table 2.2, and the materials used in the pavements are described below.

**Lakeview Jct. - Matney Rd. Project -**

**Asphalt Concrete** - The METRO RUMAC and conventional asphalt concrete were supplied by the contractor, Klamath Pacific Corp.

**Binder** - Both mixes used PBA-3 asphalt from Albina Fuel of Portland, Oregon. PBA-3 grade asphalts are normally used for ODOT's dense-graded mixes in the Klamath Falls area, and they typically have a moderate to high degree of polymer modification. This binder was tested periodically throughout construction and it consistently met the PBA-3 specifications. No antistripping agent was used.

**Aggregate** - The aggregate for all mixes was crushed basalt from Klamath Pacific's quarry on Stukel Mountain near Klamath Falls, ODOT Source No. 18-36-4. This rock was very vesicular, which was unusual for a hot mix aggregate, however, it met specifications. In contrast, the majority of the basalt used on ODOT roads has a very low void content.

**Rubber** - The crumb rubber for the METRO RUMAC was made from tires by BAS Recycling, Inc. of Carlsbad, California. The rubber was delivered to the jobsite in 60-pound (27 kg) bags. This size of bag was specified when the rubber was ordered, as three 60-pound (27 kg) bags of rubber added to a 6-ton (4.5 Mg) batch of mix would give the 2% rubber content required in the METRO RUMAC specifications. It is common for plant operators to order rubber in a bag size that will allow whole bags to be added to the batch, as it is very inconvenient to add a fraction of a bag to a batch of mix.

The first load of rubber was tested for gradation and moisture content when it arrived at the mix plant. It was rejected by the ODOT, as it was out of specification. The gradation was too coarse and the moisture content was too high.

A second load of rubber was delivered by the supplier to correct the gradation problem. This load consisted of two sets of 30-pound (14 kg) bags. One set of 30-pound bags had rubber of a much finer gradation than the rubber in the 60-pound (28 kg) bags, and the other set of 30-pound bags had rubber with an intermediate gradation between the coarse gradation of the rubber in the 60-pound bags and the fine gradation of the rubber in the other set of 30-pound bags. To correct the gradation problem, the rubber supplier recommended that one 60-pound bag of the coarse rubber, one 30-pound bag of the rubber with the intermediate gradation, and one 30-pound bag of the finer rubber be added to each batch.

The ODOT tested this combination of blended rubber and it did not meet all of the specifications. It was consistently out of specification for moisture content. It failed all five tests, and its average moisture content was 1.10%, which was higher than the upper limit of .75%. The rubber was also out of specification for free metal content, as free metal was detected in a sample. It was substantially within the gradation limits. It failed only two of eight tests, and on the failing tests, the rubber was out of specification on only one or two screen sizes. The rubber met the specifications for all of the other tests. The test results are shown in Table 2.3a, and sampling, test methods, and specification limits are discussed in Chapter 4.

| Table 2.2: Suppliers for Experimental Materials<br>January 1993 | |
|---|---|
| **Material** | **Supplier** |
| **Lakeview Jct. - Matney Rd. Project** | |
| Asphalt Concrete | Klamath Pacific Corp.<br>2918 Edison Avenue<br>Klamath Falls, Oregon 97603<br>Contact: Jim McClung (503) 884-7017 |
| Mix Design for METRO RUMAC and Rubber | BAS Recycling Inc.<br>1921 Palomar Oak Way, Suite 201<br>Carlsbad, California 92008<br>Contact: Mike Harrington (619) 431-9314 |
| **Pacific Hwy. - 42nd St. Project** | |
| Asphalt Concrete | Wildish Paving Company<br>3600 County Farm Road, P.O. Box 7428<br>Eugene, Oregon 97401<br>Contact: Mike Wildish (503) 485-1700 |
| Mix Design for METRO RUMAC | Pavement Services, Inc.<br>2510 S.W. 1st Avenue<br>Portland, Oregon 97201<br>Contact: Bud Furber (503) 227-7630 |
| Rubber | Rubber Granulators, Inc.<br>P.O. Box 692<br>Snohomish, Washington 98290<br>Contact: Milton Chryst (206) 353-8040 |

### Pacific Hwy. - 42nd St. Project -

**Asphalt Concrete** - The METRO RUMAC and conventional asphalt concrete were supplied by Wildish Sand and Gravel Co. of Eugene, Oregon and paved by Wildish Paving Co. of Eugene.

**Binder** - PBA-5 asphalt with .5% (by weight of asphalt) Pave Bond Special® complex amine anti-stripping additive was used in the METRO RUMAC and the rest of the base course throughout the project. The Pave Bond was required for the Class "B" mix in the majority of the base course to prevent moisture damage, and it was not required in the Class "B" with lime mix in the control section or the METRO RUMAC. However, Pave Bond was included, as it was impractical to use asphalt without Pave Bond for the short test and control sections. PBA-5 asphalt is often used for both open and dense-graded

**Table 2.3a: Rubber Test Results**
**Lakeview Jct. - Matney Rd. Project**

| Column | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Test | Sample[1] A-26122 Tested in Central Laboratory (Lab) | Sample[1] A-26122 Tested in Field Laboratory (Field) | Sample from Sublot 1-1 Tested on 5-14 and 5-20 in Field | Sample from Sublot 1-1 Tested on 5-21 in Field | Sample from Sublot 1-2 Tested on 5-14 and 5-20 in Field | Sample from Sublot 1-2 Tested on 5-21 in Field | Sample from Sublot 1-3 Tested on 5-14 and 5-20 in Field | Sample from Sublot 1-3 Tested on 5-21 in Field | Sample A-67484 Tested in Lab | Sample A-67483 Tested in Lab | Average Test Results | Spec. Limits |
| Dry Gradation, % Passing Screen: | | | | | | | | | | | | |
| #4 (4.75mm) | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | | | 100 | 100 |
| #8 (2.36mm) | 79.5 | 80 | 80 | 80 | 83 | 91 | 96 | 76 | | | 83 | 70-100 |
| #16 (1.18mm) | 52.6 | 53 | 40 | 53 | 51 | 55 | 62 | **34** | | | 50 | 40-65 |
| #30 (600$\mu$m) | 20.7 | 22 | **16** | 22 | 30 | 28 | 31 | 21 | | | 24 | 20-35 |
| #50 (300$\mu$m) | 6.7 | 7.7 | **3.9** | 7.7 | 13 | 13 | 14 | 7.4 | | | 9 | 5-15 |
| Fiber Content (%) | .12 | | | | | | | | | | .12 | .2 (max) |
| Free Metal | **Present** | | | | | | | | | | **Present** | None Present |
| Mineral Content (%) | .10 | | | | | | | | | | .10 | .3 (max) |
| Moisture Content (%) | **1.08** | **1.15** | | **1.15** | **1.05** | | **1.06** | | | | 1.10 | .75 (max) |
| Specific Gravity | 1.17 | | | | | | | | | | 1.17 | 1.10-1.20 |
| Carbon Black Content (%) | 15.6 | | | | | | | | | | 15.6 | 35.0 (max) |
| Ash Content (%) | 6.81 | | | | | | | | 5.91 | 7.62 | 6.78 | 8.0 (max) |
| Acetone Extract (%) | 10.4 | | | | | | | | | | 10.4 | 23.0 (max) |

[1] These tests were made on two splits from Sample A-26122.
Results of failing tests in bold.

**Table 2.3b: Rubber Test Results**
**Pacific Hwy. - 42nd St. Project**

| Column | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Test | Sample A-26545 Tested in Central Laboratory (Lab) | Sample A-26546 Tested in Lab | Sample A-26544 Tested in Lab | Sample[1] from Sublot 4-1 Tested in Field Laboratory (Field) | Sample[1] from Sublot 4-1 Tested in Field | Sample[2] from Sublot 4-2 Tested in Field | Sample[2] from Sublot 4-2 Tested in Field | Sample[3] from Sublot 4-5 Tested in Field | Sample[3] from Sublot 4-5 Tested in Field | Sample[4] Used in Mix Design and Tested by Pavement Services | Average Test Results | Spec. Limits |
| Dry Gradation, % Passing Screen: | | | | | | | | | | | | |
| #4 (4.75mm) | 100 | | | 100 | 100 | | | 100 | 100 | 100 | 100 | 100 |
| #8 (2.36mm) | 85 | | | 85 | 84 | | | 81 | 83 | 83.8 | 84 | 70-100 |
| #16 (1.18mm) | 53 | | | 54 | 53 | | | 52 | 55 | 55.1 | 53 | 40-65 |
| #30 (600μm) | 33 | | | 35 | 35 | | | 35 | **37** | 33.6 | 35 | 20-35 |
| #50 (300μm) | 12 | | | 14.7 | 14.8 | | | 13.3 | 14.5 | 10.6 | 14 | 5-15 |
| Fiber Content (%) | .04 | | | | | | | | | | .04 | .2 (max) |
| Free Metal | | | None Present | | | | | | | | None Present | None Present |
| Mineral Content (%) | | | <.2 | | | | | | | | <.2 | .3 (max) |
| Moisture Content (%) | | **1.23** | | **1.27** | **1.12** | **1.70** | **1.40** | **1.00** | **1.04** | | 1.25 | .75 (max) |
| Specific Gravity | | | 1.17 | | | | | | | | 1.17 | 1.10-1.20 |
| Carbon Black Content (%) | | | 26.6 | | | | | | | | 26.6 | 35.0 (max) |
| Ash Content (%) | | | 6.20 | | | | | | | | 6.20 | 8.0 (max) |
| Acetone Extract (%) | | | 16.9 | | | | | | | | 16.9 | 23.0 (max) |

[1] These tests were made on two splits from Sample 4-1.
[2] These tests were made on two splits from Sample 4-2.
[3] These tests were made on two splits from Sample 4-5.
[4] Unlike the other tests, this dry sieve analysis did not use talc. This test's results are not included in the average test results.
Results of failing tests in bold.

pavements in this area of Oregon, and the asphalt typically has little to no polymer modification. This binder was tested periodically and it met specifications.

**Aggregate** - The aggregate for all mixes was crushed river cobbles from the pit at Wildish's Plant No. 2 near the Willamette River in Eugene, ODOT Source No. 20-48-3. The cobbles were mainly basalt, with smaller amounts of other extrusive igneous rocks, and some quartzites.

**Rubber** - The crumb rubber in the METRO RUMAC was made from tires by Rubber Granulators of Snohomish, Washington. This rubber was specially ordered for this project in 53.33-pound (24.0 kg) bags, as three bags added to a 4-ton (3.6 Mg) batch of mix would give the desired 2% rubber content. The ODOT tested this rubber, and the results are listed in Table 2.3b.

The rubber was not entirely within the specification limits. It was consistently out of specification for moisture content. It failed all seven tests, as its average moisture content was 1.25%, which was higher than the allowable maximum of .75%. The rubber was substantially within the gradation limits. It failed only one of five tests, and on the failing test, the rubber was slightly out of specification on only one of the five screen sizes. The rubber was within specifications for all other tests.

## 2.5 MIX DESIGNS

This section presents the mix designs and job mix formulae for the test and control pavements. The mixes broadband limits, design criteria, and properties at the design binder content are listed in Tables 2.4a through 2.4d. The gradations for the METRO RUMAC job mix formulae (JMF), produced mix, broadband limits, and narrowband limits are shown in Figures 2.1a and 2.1b.

**Lakeview Jct. - Matney Rd. Project** - The METRO RUMAC mix design was made by BAS Engineering of Irvine, California, using rock stockpiled for this project. The design used a modified Marshall method based on void content, stability, and flow[6]; and it used the aggregate and asphalt content broadband limits of a 1991 ODOT Class "B" [¾" to 0" (19mm to 0mm)] dense-graded mix[3]. The JMF target values and resulting narrowband limits from this mix design were on the coarse side of the broadband limits for the finer sizes of aggregate, as seen in Figure 2.1a. This is typical of METRO RUMAC mixes.

This mix design had a target value for aggregate passing the ¼" (6mm) screen which was close enough to the lower broadband limit to cause a constriction in the narrowband limits. Normally the narrowband limits for passing ¼" (6mm) aggregate on a Class "B" mix are 10% apart, as the tolerances in the specifications allow the upper narrowband limits to be 5% above the JMF target value, and the lower narrowband limit to be 5% below the target value. However, on this mix the target value was 54%, which was only 4% higher then the lower broadband limit of 50%. As the narrowband limits cannot be outside of the broadband limits, the lower narrowband limit for this mix was set at 50%. This resulted in narrowband limits that were 9% apart. This constriction of the narrowband limits did not inconvenience the contractor on this project, as they had no problem producing aggregate within the narrowband limits. However, this constriction of narrowband limits for aggregate passing the ¼" (6mm) screen has been observed on three of the five METRO RUMAC projects constructed in Oregon,[1,2] and in some cases the constriction was much more severe.

The mix designer could not produce a design mix with desired characteristics such as the proper stability and flow using a rubber content of 2%. Consequently, the rubber content was lowered to 1.5% during the mix design, and the resulting design mix had the desired characteristics.

On this particular project the rubber manufacturer knew that the rubber content would be only 1.5%; consequently, excess rubber was not produced. However, this was an exceptional situation. In the typical case, a job mix formula requiring less than a 2% rubber content may create problems. Typically, the contractor orders the rubber well ahead of the paving date, as the rubber is often manufactured and packaged specifically for the particular project. In addition, a sample of the production rubber is needed for the mix design. Usually the contractor orders enough rubber needed to attain the 1.8 to 2.2% rubber content required in the METRO RUMAC specification's broadband limits. If the job mix formula from the mix design required a lower rubber content, there would be unused rubber remaining after paving.

This unused rubber would create two problems for the ODOT. First, the ODOT may be contractually obligated to purchase part of the unused rubber. This portion may be the unused rubber needed to make a mix with a 1.8% rubber content, as this is the lower broadband limit in the specifications, and the contractor is required to supply enough rubber to make a mix with at least this rubber content.

Second, the small lot of unused rubber left over after the job may not be suitable for other METRO RUMAC projects. This small lot of rubber may differ considerably in gradation from the rubber used for the majority of another project, and the rubber may not be compatible with the other project's mix design.

The control section's mix design was for a standard duty ODOT Class "B" [¾" to 0" (19mm to 0mm)] dense-graded wearing course, and the design was made by the ODOT using a modified Hveem method based on void contents and stabilities.[7]

**Pacific Hwy. - 42nd St. Project** — This project's METRO RUMAC mix design was made by Pavement Services, Inc. of Portland, Oregon. The mix design used a modified Marshall method[6] and materials stockpiled for the project. The aggregate and asphalt broadband limits were for an ODOT Class "B" mix. Like most METRO RUMAC mixes, this mix had JMF target values and narrowband limits that were on the coarse side of the broadband limits, as shown in Figure 2.1b.

**Table 2.4a: Broadband Limits, Mix Design Criteria, and Design Mix Characteristics at Design Binder Content - METRO RUMAC on Lakeview Jct. - Matney Rd. Project**

| Characteristic | METRO RUMAC Mix Design Criteria[a] | METRO RUMAC Design Mix[b] |
|---|---|---|
| Gradation, | | |
| % Passing Screen | | |
| 1 inch (25.4mm) | 99 - 100 | 100 |
| ¾ inch (19.1mm) | 92 - 100 | 96 |
| ½ inch (12.7mm) | 75 - 91 | 85 |
| ⅜ inch (9.5mm) | - | 73 |
| ¼ inch (6.3mm) | 50 - 70 | 54 |
| #10 (2.03mm) | 21 - 41 | 28 |
| #40 (425$\mu$m) | 6 - 24 | 12 |
| #200 (75$\mu$m) | 2 - 7 | 6.4 |
| Rubber Content, % | 1.8 - 2.2 | 1.5 |
| Binder Content, % | 4 - 8 | 7.4 |
| Absorption of Aggregate, % | - | 2.43 |
| Voids in Mineral Aggregate, % | ≥ 17 | 18.0 |
| Sp. Gr. of Aggregate | - | 2.566 |
| Voids, % | 3 - 5 | 3.0 |
| Stab., lbs.[c] (N) | ≥ 800 (≥ 3,560) | 2,698 (12,000) |
| Flow, .01 inch[c] (mm) | 8 - 20 (2.0 - 5.1) | 22.8 (5.8) |
| Rice Max. Sp. Gr. | - | 2.346 |
| Bulk Density, lbs./ft.$^3$ (kg/m$^3$) | - | 141.9 (2,273) |
| Effective Asphalt Content | 6.0 - 7.0 | - |
| P200/AC Ratio | - | .9 |
| Index of Retained Strength, % | ≥ 75 | 75[d] |
| Index of Retained Resilient Modulus, % | ≥ 70 | 99[d] |

[a] Broadband limits for gradation, rubber content, and binder content. Gradations are % of dry ingredient weight including rubber and lime. Rubber and binder contents are % of total mix weight.
[b] Design mix values are interpolated from briquettes at 7.0 and 7.5% binder content. Gradations include rubber and lime.
[c] Marshall stability and flow.
[d] Values are interpolated from briquets at 7.0 and 8.0% binder content.

**Table 2.4b: Broadband Limits, Mix Design Criteria, and Design Mix Characteristics at Design Binder Content - Class "B" on Lakeview Jct. - Matney Rd. Project**

| Characteristic | Class "B" Mix Design Criteria[a] for Standard Duty Wearing Course | Class "B" Design Mix[b] |
|---|---|---|
| Gradation, | | |
| % Passing Screen | | |
| 1 inch (25.4mm) | 99 - 100[a] | 100 |
| ¾ inch (19.1mm) | 92 - 100 | 95 |
| ½ inch (12.7mm) | 75 - 91 | 80 |
| ⅜ inch (9.5mm) | - | 72 |
| ¼ inch (6.3mm) | 50 - 70 | 56 |
| #10 (2.0mm) | 21 - 41 | 29 |
| #40 (425$\mu$m) | 6 - 24 | 13 |
| #200 (75$\mu$m) | 2 - 7 | 6.6 |
| Binder Content, % | 4 - 8 | 6.1 |
| Binder Film Thickness | Sufficient | Sufficient |
| Sp. Gr. @ 1st Comp. | - | 2.297 |
| Voids @ 1st Comp., % | ≥ 5 | 5.4 |
| Stab. @ 1st Comp.[c] | ≥ 35 | 38 |
| Sp. Gr. @ 2nd Comp. | - | 2.358 |
| Voids @ 2nd Comp., % | ≥ 2 | 2.9 |
| Stab. @ 2nd Comp.[c] | ≥ 35 | 46 |
| Rice Max. Sp. Gr. | - | 2.427 |
| P200/AC Ratio | .6 - 1.2 | 1.1 |
| Index of Retained Strength, % | ≥ 75 | 81[d] |
| Index of Retained Resilient Modulus, % | ≥ 70 | 119[d] |

[a] Broadband limits for gradation and binder content. Gradations are % of dry ingredient weight, including lime. Binder contents are % of total mix weight.
[b] Design mix values interpolated from briquets with 6.0 and 6.5% binder content.
[c] Hveem stability.
[d] Values are interpolated from briquets with 6.0 and 7.0% binder content.

**Table 2.4c: Broadband Limits, Mix Design Criteria, and Design Mix Characteristics at Design Binder Content - METRO RUMAC on Pacific Hwy. - 42nd St. Project**

| Characteristic | METRO RUMAC Mix Design Criteria[a] | METRO RUMAC Design Mix[b] |
|---|---|---|
| Gradation, | | |
| % Passing Screen | | |
| 1 inch (25.4mm) | 99 - 100 | 100 |
| ¾ inch (19.1mm) | 92 - 100 | 96 |
| ½ inch (12.7mm) | 75 - 91 | 80 |
| ¼ inch (6.3mm) | 50 - 70 | 56 |
| #10 (2.0mm) | 21 - 41 | 27 |
| #40 (425$\mu$m) | 6 - 24 | 12 |
| #200 (75$\mu$m) | 2 - 7 | 6.5 |
| Rubber Content, % | 1.8 - 2.2 | 2.0 |
| Binder Content, % | 4 - 8 | 7.8 |
| Voids in Mineral Aggregate, % | ≥ 17 | 19.9 |
| Absorption of Aggregate, % | - | .89 |
| Sp. Gr. of Aggregate | - | 2.639 |
| Voids, % | 3 - 5 | 4.8 |
| Stab., lbs.[c] | ≥ 800 (≥3,560) | 965 (4,290) |
| Flow, .01 inch[c] | 8 - 20[c] (2.0 - 5.1) | 18 (4.6) |
| Rice Max. Sp. Gr. | - | 2.343 |
| Bulk Density, lbs./ft.$^3$ | - | 139.1 (2,229) |
| Effective Asphalt Content, % | 6.0 - 7.0 | 7.0 |
| P200/AC Ratio | - | .8 |
| Index of Retained Strength, % | ≥ 75 | 78 |
| Index of Retained Resilient Modulus, % | ≥ 70 | 85 |

[a] Broadband limits for gradation, rubber content, and binder content. Gradations are % of dry ingredient weight, including rubber and lime. Rubber and binder contents are % of total mix weight.

[b] Design mix values interpolated from briquets at 7.5 and 8.0% binder content. Gradations include rubber.

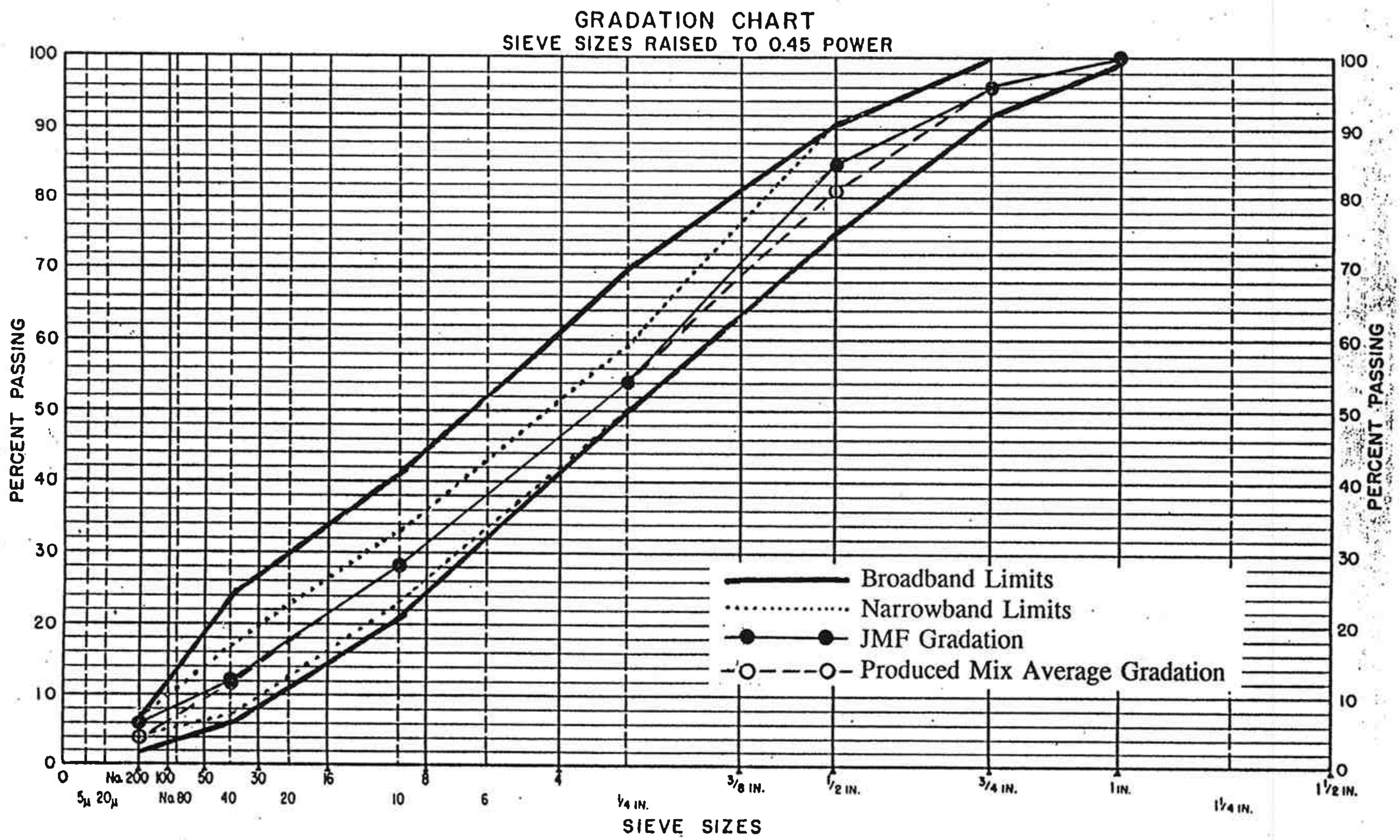
[c] Marshall stability and flow.

[d] Values are interpolated from briquets with 7.0 and 9.0% binder content.

**Table 2.4d: Broadband Limits, Mix Design Criteria, and Design Mix Characteristics at Design Binder Content - Class "B" on Pacific Hwy. - 42nd St. Project**

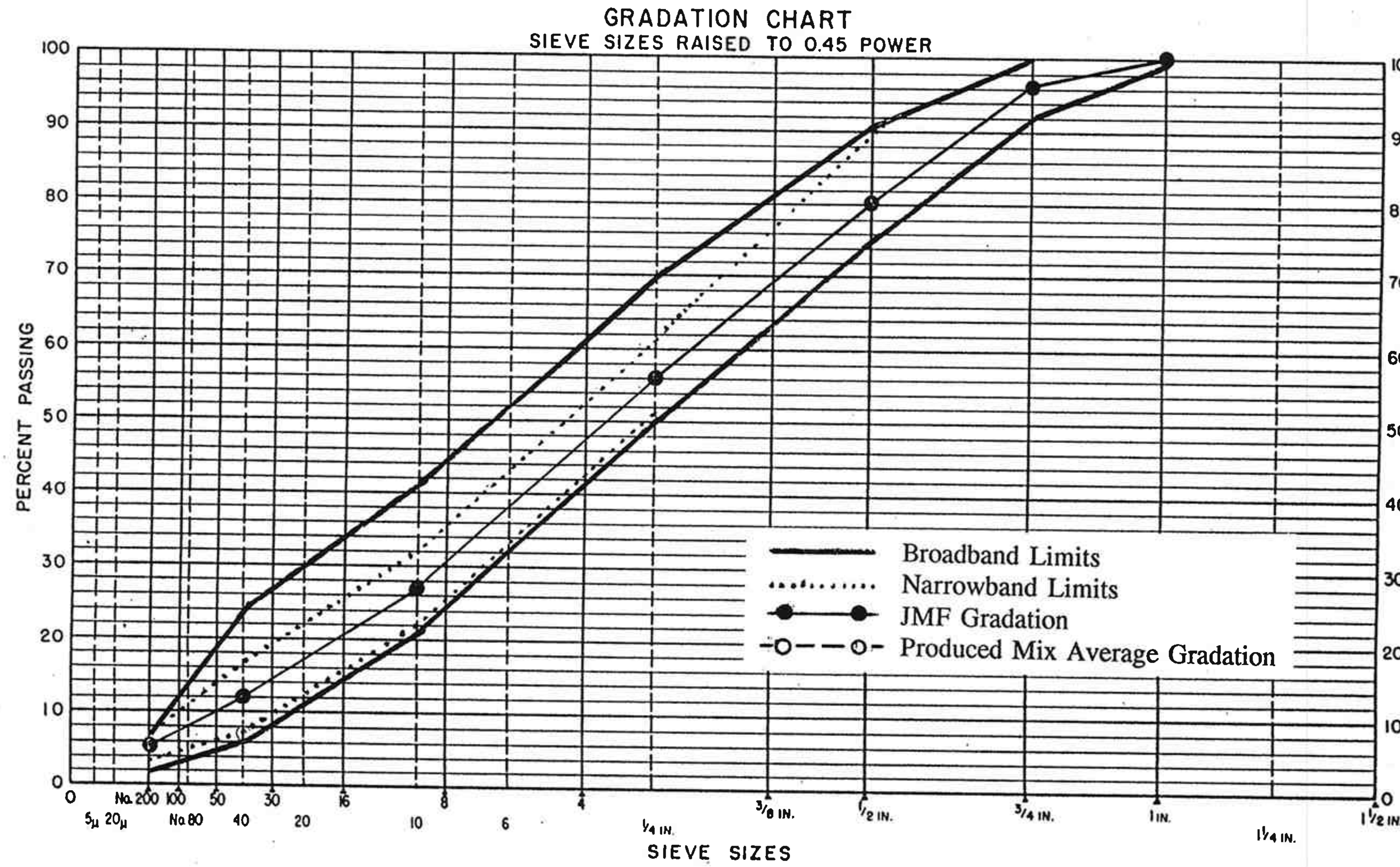
| Characteristic | Class "B" Mix Design Criteria[a] for Standard Duty Base Course | Class "B" Design Mix[b] |
|---|---|---|
| Gradation, | | |
| % Passing Screen | | |
| 1 inch (25.4mm) | 99 - 100[a] | 100 |
| ¾ inch (19.1mm) | 92 - 100 | 96 |
| ½ inch (12.7mm) | 75 - 91 | 82 |
| ⅜ inch (9.5mm) | - | 73 |
| ¼ inch (6.3mm) | 50 - 70 | 58 |
| #10 (2.0mm) | 21 - 41 | 28 |
| #40 (425$\mu$m) | 6 - 24 | 13 |
| #200 (75$\mu$m) | 2 - 7 | 5.8 |
| Binder Content, % | 4 - 8 | 5.2 |
| Binder Film Thickness | Sufficient | Sufficient |
| Sp. Gr. @ 1st Comp. | - | 2.376 |
| Voids @ 1st Comp., % | ≥ 4 | 4.3 |
| Stab. @ 1st Comp.[c] | ≥ 30 | 34 |
| Sp. Gr. @ 2nd Comp. | - | 2.432 |
| Voids @ 2nd Comp., % | ≥ 1.5 | 2.1 |
| Stab. @ 2nd Comp.[c] | ≥ 30 | 43 |
| Rice Max. Sp. Gr. | - | 2.491 |
| Voids in Mineral Aggregate, % | ≥ 14 | 14.0 |
| P200/AC Ratio | .6 - 1.2 | .96 |
| Index of Retained Strength, % | ≥ 75 | 82 |
| Index of Retained Resilient Modulus, % | ≥ 70 | 94 |

[a] Broadband limits for gradation and binder content. Gradations are % of dry ingredient weight, including lime. 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.




Gradations include aggregate, rubber, and lime.

Figure 2.1a: Gradation Curves -- Lakeview Jct. - Matney Rd. METRO RUMAC




Gradations include aggregate, rubber, and lime.

Figure 2.1b: Gradation Curves -- Pacific Hwy. - 42nd St. METRO RUMAC

This mix design had a JMF target value for binder content that was close enough to the upper broadband limit to cause a severe constriction in narrowband limits. Normally the narrowband limits for binder content are 1.0% apart, and these narrowband limits are within the broadband limits of 4.0 to 8.0%. However, on this mix design the JMF target value was 7.8%, which was only .2% lower than the upper broadband limit of 8.0%. As a consequence, the narrowband limits were only .7% apart. This constriction in the narrowband limits was not a problem for this contractor, as they had a good control of their asphalt addition. However, the constriction did increase the chances that they would produce mix that was outside of the narrowband limits.

The METRO RUMAC JMF had a 2.6% higher binder content than the control section's Class "B" JMF. This is an exceptionally large difference in binder contents, in comparison to other METRO RUMAC pavements and their corresponding control sections. It is typical for a METRO RUMAC mix to require more asphalt than a comparable conventional mix. The Lakeview Jct. - Matney Rd. METRO RUMAC JMF, for example, required 1.3% more binder then the control section mix, and the 1991 METRO RUMAC JMFs required 1.1 to 1.2% more binder then their control section JMFs.

The control section used an ODOT mix design for a standard duty Class "B" [¾" to 0" (19mm to 0mm)] dense-graded base course[7] using materials stockpiled for this project.

These changes are recommended to the METRO RUMAC specifications, based on experience with these two projects:

1) 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. Unlike the JMFs for conventional asphalt concrete, the JMFs for METRO RUMAC often have target values close to the broadband limits.

2) The rubber content allowed in the METRO RUMAC specification's broadband limits should be lowered from 2.0% plus or minus .2%, to 1.5% plus or minus .2%. It is likely that future METRO RUMAC mixes may require a rubber content of 1.5% to obtain satisfactory mix properties, as this lower rubber content was needed for a mix in this study. Consequently, to avoid the problems that could occur if the mix design required a lower rubber content than the specifications, the rubber content should be lowered in the specifications for all future mixes.

# 3.0 CONSTRUCTION

This chapter describes the construction of the sections and gives the results of the quality control tests on the mix and pavement. The test results, test methods, and temperature data are listed in Tables 3.1a through 3.1d. AASHTO and ODOT sampling and testing methods were used in most cases. The Pacific Hwy. - 42nd St. project's METRO RUMAC specifications are in Appendix A.

## 3.1 MIXING

**Lakeview Jct. - Matney Rd. Project** — The METRO RUMAC was mixed and paved on May 21, 1992 and the Class "B" was mixed and paved from April 29 through May 13, 1992. Both mixes were made in Stansteel "Continue-Batch" batch plant. The aggregate was drawn from stockpiles with three gradations: ¾" to ½" (19mm to 13mm), ½" to ¼" (13mm to 6.3mm), and ¼" to 0" (6.3mm to 0mm). All aggregate was coated with a lime slurry immediately before it entered the mix plant at an addition rate of 1 to 1.5% dry lime as a percent of the dry ingredient weight. Portions of the baghouse fines were recirculated back into the mix to keep the passing #200 (75$\mu$m) fraction within the specification limits.

The rubber was fed into the mix by dropping unopened bags of rubber into the pugmill. This method met the requirements for batch plants in Section 00745.21-q-1 in the METRO RUMAC specifications. The bags were lifted up to the pugmill by a forklift. Six people were involved with adding the rubber: two laborers stood on a platform on the side of the pugmill, unloaded the forklift, and added the rubber; three laborers loaded the forklift and moved the rubber to the platform; one ODOT inspector watched the laborers throughout the METRO RUMAC production to verify that the rubber was added correctly; and one ODOT technician sampled and tested the rubber.

To assure that the METRO RUMAC was thoroughly blended, the rubber and dry hot aggregate were mixed for 25 seconds after the unopened bags were dropped into the pugmill, and for 35 seconds after the asphalt was added. The addition of unopened bags is allowed in the METRO RUMAC specifications, as the plastic in the bags should have a low melting point and is supposed to disintegrate when it contacts the hot aggregate and pugmill paddles. With the exception of the first truckload of mix, it seemed that the bags did not hinder mixing, as the METRO RUMAC appeared to be thoroughly blended. On the first truckload, shiny spots were seen on the surface of the pavement, and these spots indicated that the rubber and bags were not completely dispersed. These spots appeared to be asphalt mixed with rubber and/or plastic from the bags. The spots contained no aggregate, and they were 1 to 2 square inches (645 to 1,290 sq. mm) in area. On this load, the laborers added the rubber after, rather than before, the 25 second dry batch time.

Table 3.1a: Job Mix Specifications and Properties - METRO RUMAC on Lakeview Jct. - Matney Rd. Project

| Characteristic | Method | METRO RUMAC Produced Mix Test Results | METRO RUMAC Job Mix Specifications[a] |
|---|---|---|---|
| Gradation, | AASHTO T11 | | |
| % Passing Screen | AASHTO T27 | | |
| 1 inch (25.4mm) | AASHTO T2 | 100[b] | 99 - 100 |
| ¾ inch (19.1mm) | | 96 | 92 - 100 |
| ½ inch (12.7mm) | | 81 | 75 - 91 |
| ¼ inch (6.3mm) | | 53 | 50 - 59 |
| #10 (2.0mm) | | 27 | 23 - 33 |
| #40 (425μm) | | 9.7 | 7 - 17 |
| #200 (75μm) | | 4.0 | 4.0 - 7.0 |
| Binder Content, % | ODOT TM 321 (Cold Feed/Meter) | 7.5 | 6.9 - 7.9 |
| Rubber Content, % | [c] | 1.48 | 1.8 - 2.2[d] |
| Moisture Content, % | ODOT TM 311 M-91 | .26[b] | ≤ .80[e] |
| Compaction, % of Rice | ODOT TM 304 (Nuclear) | 92.7 | ≥ 92.1[d] |
| Mix Temp. at Discharge, °F (°C) | [h] | 313 - 340[f,g,h] (156 - 171) | 315 - 330[d] (157 - 166) |
| Mix Temp. Behind Paver, °F (°C) | [h] | 290 - 330[f,g,h] (143 - 166) | 290 - 300[d] (143 - 149) |
| Placement Air Temp., °F (°C) | | 82 - 86[f,g] (28 - 30) | ≥ 50[e] (≥ 10) |
| Placement Surface Temp., °F (°C) | | 100 - 126[f,g] (38 - 52) | - |
| Wind, mph (m/s) | | 0 - 4[g] (0 - 1.8) | - |
| Weather | | Sunny | - |

[a] Narrowband limits for gradation, rubber content, and binder content. Gradations are % of dry ingredient weight including rubber and lime. Rubber and binder contents are % of total mix weight.
[b] Average from tests on three samples.
[c] Based on inspector's observations of the addition of the rubber to the mix in the pugmill.
[d] Limits in METRO RUMAC specifications.
[e] Limits in 1991 ODOT asphalt concrete specifications for "B" mix.
[f] Range of test results.
[g] Random measurements.
[h] Thermometer inserted into mix.

**Table 3.1a: Job Mix Specifications and Properties - METRO RUMAC on Lakeview Jct. - Matney Rd. Project**

| Characteristic | Method | METRO RUMAC Produced Mix Test Results | METRO RUMAC Job Mix Specifications[a] |
|---|---|---|---|
| Gradation, | AASHTO T11 | | |
| % Passing Screen | AASHTO T27 | | |
| 1 inch (25.4mm) | AASHTO T2 | 100[b] | 99 - 100 |
| ¾ inch (19.1mm) | | 96 | 92 - 100 |
| ½ inch (12.7mm) | | 81 | 75 - 91 |
| ¼ inch (6.3mm) | | 53 | 50 - 59 |
| #10 (2.0mm) | | 27 | 23 - 33 |
| #40 (425$\mu$m) | | 9.7 | 7 - 17 |
| #200 (75$\mu$m) | | 4.0 | 4.0 - 7.0 |
| Binder Content, % | ODOT TM 321 (Cold Feed/Meter) | 7.5 | 6.9 - 7.9 |
| Rubber Content, % | [c] | 1.48 | 1.8 - 2.2[d] |
| Moisture Content, % | ODOT TM 311 M-91 | .26[b] | ≤ .80[e] |
| Compaction, % of Rice | ODOT TM 304 (Nuclear) | 92.7 | ≥ 92.1[d] |
| Mix Temp. at Discharge, °F (°C) | [h] | 313 - 340[f,g,h] (156 - 171) | 315 - 330[d] (157 - 166) |
| Mix Temp. Behind Paver, °F (°C) | [h] | 290 - 330[f,g,h] (143 - 166) | 290 - 300[d] (143 - 149) |
| Placement Air Temp., °F (°C) | | 82 - 86[f,g] (28 - 30) | ≥ 50[e] (≥ 10) |
| Placement Surface Temp., °F (°C) | | 100 - 126[f,g] (38 - 52) | - |
| Wind, mph (m/s) | | 0 - 4[g] (0 - 1.8) | - |
| Weather | | Sunny | - |

[a] Narrowband limits for gradation, rubber content, and binder content. Gradations are % of dry ingredient weight including rubber and lime. Rubber and binder contents are % of total mix weight.
[b] Average from tests on three samples.
[c] Based on inspector's observations of the addition of the rubber to the mix in the pugmill.
[d] Limits in METRO RUMAC specifications.
[e] Limits in 1991 ODOT asphalt concrete specifications for "B" mix.
[f] Range of test results.
[g] Random measurements.
[h] Thermometer inserted into mix.

**Table 3.1b: Job Mix Specifications and Properties - Class "B" on Lakeview Jct. - Matney Rd. Project**

| Characteristic | Method | Class "B" Produced Mix Test Results | Class "B" Job Mix Specifications[a] |
|---|---|---|---|
| Gradation,<br>% Passing Screen<br>1 inch (25.4mm)<br>¾ inch (19.1mm)<br>½ inch (12.7mm)<br>¼ inch (6.3mm)<br>#10 (2.0mm)<br>#40 (425μm)<br>#200 (75μm) | AASHTO T11<br>AASHTO T27<br>AASHTO T2 | <br><br>100[b]<br>95<br>81<br>57<br>28<br>12<br>5.9 | <br><br>99 - 100<br>92 - 100<br>75 - 91<br>50 - 62<br>24 - 34<br>8 - 18<br>3.6 - 7.0 |
| Binder Content, % | ODOT TM 319 (Nuclear) | 6.1 | 5.6 - 6.6 |
| Moisture Content, % | ODOT TM 311 M-91 | .34[b] | ≤ .80[c] |
| Compaction, % of Rice | ODOT TM 304 (Nuclear) | 90.8 | ≥ 89.2[c] |
| Mix Temp. at Discharge, °F (°C) | [f] | 299 - 315[d,e,f]<br>(148 - 157) | 318 - 328[c]<br>(159 - 164) |
| Mix Temp. Behind Paver, °F (°C) | [f] | 300 - 305[d,e,f]<br>(149 - 152) | 297 - 307[c]<br>(147 - 153) |
| Placement Air Temp., °F (°C) | | 80[e]<br>(27) | ≥ 50[c]<br>(≥ 10) |
| Placement Surface Temp., °F (°C) | | 138[e]<br>(59) | - |
| Wind, mph (m/s) | | 3 - 5[e]<br>(1.3 - 2.2) | - |
| Weather | | Slightly Cloudy | - |

[a] Narrowband limits for gradation and binder content. Gradations are % of dry ingredient weight, including lime. Binder contents are % of total mix weight.
[b] Average from tests on 23 samples.
[c] Limits in 1991 ODOT asphalt concrete specifications for "B" mix.
[d] Range of test results.
[e] Random measurements.
[f] Thermometer inserted into mix.

**Table 3.1c: Job Mix Specifications and Properties - METRO RUMAC on Pacific Hwy. - 42nd St. Project**

| Characteristic | Method | METRO RUMAC Produced Mix Test Results | METRO RUMAC Job Mix Specifications[a] |
|---|---|---|---|
| Gradation, | AASHTO T11 | | |
| % Passing Screen | AASHTO T27 | | |
| 1 inch (25.4mm) | AASHTO T2 | 100[b] | 99 - 100 |
| ¾ inch (19.1mm) | | 96 | 92 - 100 |
| ½ inch (12.7mm) | | 79 | 75 - 91 |
| ¼ inch (6.3mm) | | 58 | 51 - 61 |
| #10 (2.0mm) | | 27 | 22 - 32 |
| #40 (425$\mu$m) | | 12 | 7 - 17 |
| #200 (75$\mu$m) | | 4.9 | 3.5 - 7.5 |
| Binder Content, % | ODOT TM 321 (Cold Feed/Meter) | 7.7 | 7.6 - 8.0 |
| Rubber Content, % | [c] | 1.96 | 1.8 - 2.2[d] |
| Moisture Content, % | ODOT TM 311 M-91 | .26[b] | ≤ .80[e] |
| Compaction, % of Rice | ODOT TM 304 (Nuclear) | 93.4 | ≥ 92.1[d] |
| Mix Temp. at Discharge, °F (°C) | [h] | 290 - 305[f,g,h] (143 - 152) | 300 - 325[d] (149 - 163) |
| Mix Temp. Behind Paver, °F (°C) | [h] | 275 - 290[f,g,h] (135 - 143) | 280 - 300[d] (138 - 149) |
| Placement Air Temp., °F (°C) | | 50 - 65[f,g] (10 - 18) | ≥ 50[e] (≥ 10) |
| Placement Surface Temp., °F (°C) | | 60[g] (16) | - |
| Wind, mph (m/s) | | 2 - 5[g] (.4 - 2.2) | - |
| Weather | | Night, Clear to slightly cloudy | - |

[a] Narrowband limits for gradation, rubber content, and binder content. Gradations are % of dry ingredient weight including rubber and lime. Rubber and binder contents are % of total mix weight.
[b] Average from tests of seven samples.
[c] Based on inspector's observations of the addition of the rubber to the mix in the pugmill.
[d] Limits in METRO RUMAC specifications.
[e] Limits in 1991 ODOT asphalt concrete specifications for "B" mix.
[f] Range of test results.
[g] Random measurements.
[h] Thermometer inserted into mix.

**Table 3.1d: Job Mix Specifications and Properties - Class "B" on Pacific Hwy. - 42nd St. Project**

| Characteristic | Method | Class "B" Produced Mix Test Results | Class "B" Job Mix Specifications[a] |
|---|---|---|---|
| Gradation, | AASHTO T11 | | |
| % Passing Screen | AASHTO T27 | | |
| 1 inch (25.4mm) | AASHTO T2 | 100[b] | 99 - 100 |
| ¾ inch (19.1mm) | | 95 | 92 - 100 |
| ½ inch (12.7mm) | | 78 | 75 - 91 |
| ¼ inch (6.3mm) | | 61 | 52 - 64 |
| #10 (2.0mm) | | 32 | 23 - 33 |
| #40 (425μm) | | 14 | 8 - 18 |
| #200 (75μm) | | 6.1 | 3.0 - 7.0 |
| Binder Content, % | ODOT TM 319 (Nuclear) | 5.6 | 5.6 - 6.6 |
| Moisture Content, % | ODOT TM 311 M-91 | .31 | ≤ .80[c] |
| Compaction, % of Rice | ODOT TM 304 (Nuclear) | 90.0 | ≥ 89.2[c] |
| Mix Temp. at Discharge, °F | f | - | 306 - 315[c] (152 - 157) |
| Mix Temp. Behind Paver, °F | f | 295 - 305[d,e,f] (146 - 152) | 287 - 296[c] (142 - 147) |
| Placement Air Temp., °F (°C) | | 57 - 78[d,e,f] (14 - 25) | ≥ 50[c] (≥ 10) |
| Wind, mph (m/s) | | Slight Breeze | - |
| Weather | | Night - Clear | - |

[a] Narrowband limits for gradation and binder content. Gradations are % of dry ingredient weight, including lime. Binder contents are % of total mix weight.
[b] Average from tests of seven samples.
[c] Limits in 1991 ODOT asphalt concrete specifications for "B" mix.
[d] Range of test results.
[e] Random measurements.
[f] Thermometer inserted into mix.

Normally, this project's batch plant produces conventional mix at 260 to 270 tons (236 Mg to 245 Mg) per hour, and the addition of rubber to the mix cut that production rate to 150 tons (136 Mg) per hour. Part of this reduction was due to the 25 second dry mixing time, as dry mixing is not required with conventional asphalt concrete. The mix production was further slowed by the use of 4-ton (3.6 Mg) batches, as the contractor could not make the 6-ton (5.4 Mg) batches that they normally use. If a 4-ton (3.6 Mg) batch was used, one 60-pound (27 kg) bag of rubber and two 30-pound (14 kg) bags of rubber could be added to each batch. If a 6-ton (5.4 Mg) batch was used, one and one-half 60-pound (27 kg) and one and one-half of each of the 30-pound (14 kg) bags of rubber would have to be added to each batch. As dividing bags prior to the rubber addition would be inconvenient, the batch size was reduced. Other than the slowdown in production, the mixing of the METRO RUMAC went smoothly, and the produced mix was within specifications. The production of the Class "B" mix also went smoothly, and the produced mix was within specifications.

The manual addition of bags of rubber to the pugmill was labor-intensive, and this method would be inefficient for large or frequent METRO RUMAC projects. According to the contractor, to make the rubber addition more efficient, the bags of rubber would be lifted up to, and dumped in, the pugmill by a conveyor. This conveyor's estimated cost would be $4,000 to $10,000, depending on the sophistication of the system's automation.

**Pacific Hwy. - 42nd St. Project** — The METRO RUMAC was paved on September 22, 23, 25, and 26, 1992 and the Class "B" control mix was paved on September 20, 21, and 22, 1992. Both mixes were made in a Barber-Greene BE-82 batch plant using aggregate from three stockpiles with these gradations: ¾" to ½" (19mm to 13mm), ½" to ¼" (13mm to 0mm), and ¼" to 0" (6.3mm to 0mm). The aggregate was mixed with a lime slurry before it entered the mix plant at a ratio of 1 to 1.5% dry lime as a percent of aggregate weight. The baghouse fines were recirculated back into the mix, as needed, to keep the passing #200 ($75\mu$m) fraction within the specification limits.

Like the Lakeview Jct. - Matney Rd. METRO RUMAC, the rubber was added to the mix by dropping unopened bags into the pugmill, a 25-second dry batch time was used, and the bags were lifted to the pugmill by a forklift. The dry batch time slowed production, as the plant usually produced conventional mix at 275 to 280 tons (249 Mg to 254 Mg) per hour, and the dry batching reduced production to 180 tons (163 Mg) per hour.

Spots of asphalt mixed with rubber were visible after compaction on pavement from the first truckloads of mix. These spots were shiny, black, and they contained no aggregate. Usually they were one to two square inches (645 to 1,290 sq. mm) in area. When these spots were seen, the inspector requested that bagged rubber no longer be added to the mix. Instead, he recommended that the bags of rubber be emptied into the pugmill and the bags discarded into the trash. It was felt that the bags may have hindered mixing. This change was made, and the inspector was told that the first truck that would arrive with mix made with emptied bags would be truck #585.

Several trucks arrived before truck #585 which had mix made with unopened bags. Unexpectedly, there was no spotting on the pavement made from mix hauled by these trucks. Consequently, it was decided that the spots seen on pavement from the initial loads were caused by something besides adding the unopened bags. As a result, the contractor was given permission to add unopened bags to the mix, and the contractor resumed the addition of unopened bags.

As the METRO RUMAC was paved at night, the pavement was carefully inspected in the daylight soon after construction. The METRO RUMAC appeared to be thoroughly mixed immediately ahead of the section where the bags were opened and emptied into the mix, thoroughly mixed in the section where the bags were opened and emptied, and well mixed on all pavement made after the addition of unopened bags resumed. This inspection verified that the use of unopened bags did not hinder mixing. However, the cause of the spotting on pavement made from the first truckloads of mix is not known.

The addition of the rubber required several additional workers to drop the rubber into the pugmill and lift pallets of bagged rubber to the platform near the pugmill. In addition, an ODOT inspector watched the rubber addition to insure that the proper number of bags were added to each batch and the required batch time was used.

Workers added bags of rubber to a batch plant pugmill on three of the five METRO RUMAC sections paved in Oregon in 1991 and 1992. As these workers labored on a noisy and dusty platform, they used and needed protective equipment and clothing. The worker shown in Figure 3.1 is wearing protective gear consisting of a hardhat, goggles, earplugs, a mask, and a safety harness. The safety harness is attached to the side of the batch plant and it is especially important, as a section of the platform railing is usually removed to make it easier to move the bags from the forklift. If a worker was to fall off of the platform, the safety harness may save his life; the platform is usually 15 to 20 feet (4.6 to 6.1 m) above the ground and in many cases, there is a truck under the platform that is being loaded with hot mix.

If the use of METRO RUMAC was frequent or widespread, the contractor said that they may want to automate the rubber feed system. They estimated that the added equipment would cost $20,000. $10,000 of this cost would be an impact scale and any other instrumentation needed to weigh the rubber added to each batch and to feed the rubber into the mix using an existing recycled asphalt-concrete bin. The other $10,000 of the cost would be for bulk rubber storage facilities. The contractor said that this system would have a drawback, as it would prevent them from adding recycled asphalt concrete to the mix.

Aside from the previously described problems, the production of the METRO RUMAC and Class "B" control mixes went smoothly, and both mixes met the required specifications.

**Figure 3.1: Worker on Pugmill**

## 3.2 HAULING

**Lakeview Jct. - Matney Rd. Section** — The mix was hauled with end dumps and end dump trailers. Two non-petroleum based release agents were used, Slipeazee SB® made by Rochester Midland and Quik Slik® by Golden State. Many drivers said that both release agents were not always effective. They said that most loads would cleanly release and a few loads would leave mix on the dump beds or bed aprons.

The METRO RUMAC was very sticky when it was hot. Hauling trucks and trailers were the first traffic allowed on the pavement, and occasionally the trucks and trailers would stop or park on the newly paved northbound lane while the southbound lane was being paved. Even though the finish rolling was completed on the northbound lane, the pavement was still hot, and the vehicle's wheels would tear patches of the mix from the surface when they moved, as shown in Figure 3.2. This problem stopped when the mix cooled. The damage was limited and not a serious problem, as the hauling vehicles were few in number, as compared to the more numerous vehicles of the travelling public. If the public had been allowed to use the hot pavement, the damage may have been much worse, as many vehicles would have had to stop and start several times on the hot surface.

The problem of tires sticking to a hot, fully compacted pavement is uncommon for METRO RUMAC, as this has occurred on only one of the five METRO RUMAC pavements paved in 1991 and 1992. It does occur more often on rubberized pavements made by other processes, and it is usually seen on pavements that use asphalt-rubber. On asphalt-rubber pavements, the tire damage is often prevented by allowing the mat to cool before it is exposed to traffic; and if this is inconvenient, the pavement is lightly sanded before traffic is allowed on it. Typically, the sand is of No.4 to 0" (4.75mm to 0mm) gradation and it is applied by a sand spreader at an application rate of 1 to 2 pounds of sand per square yard (.54 to 1.1 kg/m$^2$) of pavement surface.

It is recommended that future METRO RUMAC projects be watched to see if tires damaging hot pavements are a consistent problem. If it is, a requirement should be included in the METRO RUMAC specifications to prohibit traffic from travelling on the pavement until it is cool, or if traffic must travel on the hot pavement, the surface must be sanded.

**Pacific Hwy. - 42nd St. Project** — This mix was hauled in belly dumps and Zep R-6690® was used as a release agent. This non-petroleum based agent worked well, and no sticking problems were noted.

Figure 3.2: Damage caused by tires sticking to hot METRO RUMAC pavement.

## 3.3 PLACEMENT AND COMPACTION

**Lakeview Jct. - Matney Rd. Project** — Both mixes were placed by a Caterpillar AP-1050 paver. Roller patterns for both the test and control mixes 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 temperatures mentioned in this discussion are from the interior of the pavement lift, and they were measured by a digital or analog thermometer.

On the METRO RUMAC, three double-drum vibratory rollers were used. While breakdown or intermediate rolling of conventional mixes is often done by a pneumatic-tired roller, this type of machine is not allowed on METRO RUMAC. Experience has shown that the rubberized mix may stick to the roller's rubber tires. Instead of a pneumatic roller, breakdown was done by a Caterpillar CB514 12-ton (11 Mg) roller. Intermediate rolling was done by a Dynapac CC21A 8-ton (7.2 Mg) roller, and finish rolling was done by a Caterpillar CB414 8-ton (7.2 Mg) roller. All of the roller's drums were empty and water mixed with Calgon® water softener was used to keep the mix from sticking to the drums. The METRO RUMAC in the northbound lane was compacted by three coverages with the breakdown roller using vibratory breakdown and comeback passes, four coverages with the intermediate roller using static passes, and four coverages with the finish roller using static passes. On the control strip, the mat temperature was 250°F (121°C) at the start of rolling, 150°F (66°C) when the mix density stopped increasing, and 140°F (60°C) when finish rolling was completed.

The control strip in the northbound lane did not achieve the minimum allowable density. As a result, when the southbound lane was compacted, two vibratory coverages were added to the breakdown roller's pattern, and the intermediate and finish roller patterns were not changed. In addition to the additional coverages, the mat was hotter when it was rolled. On the southbound control strip, it was 270°F (132°C) at the start of rolling, 170°F (77°C) when mix density stopped increasing at the beginning of finish rolling, and 165°F (74°C) when the finish rolling was completed.

None of these changes worked, as the control strip in the southbound lane could not achieve the minimum required density. According to the contractor, this difficulty in compaction may have been due to a shortage of fines in the mix. When the produced mix's gradation test results were examined, it was discovered that the average percentage of aggregate passing the No.200 (75$\mu$m) screen was 4.0% for the job mix, and this average was 2.4% lower than the JMF target value of 6.4%. The contractor felt that an added 2.4% of fines would have filled some of the voids and brought the pavement density up to acceptable levels. These added fines could have been recirculated back into the mix from the baghouse. Other than the compaction difficulty, the mix handled well and it was not tender.

The Class "B" mix needed much less compaction equipment and effort than the METRO RUMAC. It was compacted by two of the double drum vibratory rollers. Breakdown rolling was done by the CB514, and finish rolling was done with the CB414. All of the roller drums were empty and water was used to keep the mix from sticking to the drums.

The Class "B" mix's roller pattern was three coverages by the breakdown roller with all passes vibratory, and four coverages by the finish roller with the first three passes vibratory and the last pass static. On the control strip, the mat was 190°F (88°C) at the start of rolling, 170°F (77°C) when the density stopped increasing midway through the finish rolling, and 160°F (71°C) when finish rolling stopped. The mix met density requirements. However, occasionally the mix was tender and it would tear under rolling. Initially the contractor tried to compact this conventional mix with a pneumatic roller. The roller was immediately taken off of the mat, as the Class "B" mix would stick to the machine's rubber tires.

**Pacific Hwy. - 42nd St. Project** — Most of the mix in these sections was paved by a Blaw-Knox PF220 paver, and occasionally a second paver was used. Roller patterns for both the test and control pavements were determined by control strips.

On the METRO RUMAC, breakdown was done by a Bomag BW202AD 11-ton (9.9 Mg) static weight dual drum vibratory roller. Intermediate rolling was done by two dual drum vibratory rollers, a Dynapac CC50A 12-ton (11 Mg) roller and a Dynapac CC42A 11-ton (9.9 Mg) roller. These two intermediate rollers often worked side-by-side. Finish rolling was done by a Hyster C350D 12-ton (11 Mg) tandem steel wheel static roller. All of the roller drums were empty except for the Hyster. Soapy water was used to wet the drums.

The roller pattern used to compact the METRO RUMAC consisted of four to five coverages by the breakdown roller with the breakdown passes vibratory and the comeback passes static, three coverages by one of the intermediate rollers with the initial pass vibratory and the two remaining passes static, and as many passes as needed by the finish roller to achieve compaction and remove the roller marks. On the control strip, the mat was at about 240°F (115°C) at the start of rolling, about 175°F (79°C) when it achieved maximum density after the next to last pass of the finish roller, and about 170°F (77°C) when rolling was finished. This roller pattern worked, as the mix met density requirements. In addition, the METRO RUMAC was easy to handle and it did not stick to the roller drums.

On two of the four earlier METRO RUMAC projects, maximum density was achieved during the finish rolling, and in some cases, prolonged finish rolling was needed to achieve the maximum density. In addition, the density requirements in the METRO RUMAC specifications were met on only one of the previous four projects. While many of these earlier compaction problems were due to the mix ingredients having less than optimum proportioning, the ODOT suspected that METRO RUMAC may need more or different compactive effort than conventional mixes. As a result, the ODOT suggested to the contractor that they ballast their roller drums by filling them with water. It was felt that the extra weight of the water would increase the compactive effort.

The only roller that the contractor could ballast with water was the finish roller, and on this project, maximum density was achieved during the finish rolling. Consequently, it is probable that the ballast may have helped the contractor achieve maximum density. However, it is not known if the ballast was critical in achieving density, as the METRO RUMAC was not compacted with an empty finish roller.

The Class "B" mix was compacted by four rollers, and it required less compactive effort. The BW202AD was used for breakdown, the CC-50A and CC42A was used for intermediate rolling, and the CC42-A was used for finish rolling. All drums were empty and soapy water was used to keep the mix from adhering to the drums.

The roller pattern was three breakdown passes, three intermediate passes, and one finish pass. On the control strip, the mat was about 280°F (138°C) at the start of rolling, about 210°F (99°C) when the density stopped increasing at the end of the intermediate rolling, and about 180°F (82°C) when the finish rolling was completed.

# 4.0 SAMPLING AND TESTING

This chapter discusses the ODOT's draft sampling and test methods for crumb rubber. In addition, it includes comments about the rubber specifications, asphalt content testing by the nuclear gauge, and sample preparation for moisture susceptibility tests. The METRO RUMAC specifications provided by METRO to the ODOT had specification limits and test methods for the crumb rubber. However, in many cases, established and published test methods were not specified, and when unfamiliar or unpublished test methods were mentioned, the test could not be done because insufficient information was given about the test procedure. Consequently, these draft methods were developed to see whether or not the rubber met the METRO RUMAC specifications. The latest draft sampling and test methods are included in Appendix B. These test methods have not been formally adopted by the ODOT and they may be revised if they are adopted.

It is recommended that these sampling and test methods be used on future METRO RUMAC projects. They should be replaced by suitable AASHTO or American Society for Testing and Materials (ASTM) procedures when these methods become available.

## 4.1 SAMPLING CRUMB RUBBER

This procedure was used to obtain the rubber for the tests. The gradation and fiber content tests can be performed simultaneously on the same sample. Consequently, if the results of both tests are needed, a separate fiber content test sample is not necessary.

## 4.2 SIEVE ANALYSIS OF CRUMB RUBBER

This test is used to see if the crumb rubber is within the specification limits for gradation. Rubber gradation is important, as it influences many of the properties of the pavement.

This procedure was based on the ODOT and the Arizona Department of Transportation[8] methods, and it was used to obtain the gradations listed in Table 2.3a, and Columns 1, 4, 5, 8, and 9 of Table 2.3b. Based on this limited data, it appears the test is consistent and repeatable, as shown by a split sample of rubber tested in the field and central laboratories by different operators using different equipment. The results were similar, as shown by the gradations in Columns 1 and 2 of Table 2.3a. In addition, tests by the field laboratory on both halves of samples split in the field had similar results, as shown by the gradations in Columns 4, 5, 8, and 9 of Table 2.3b.

## 4.3 RUBBER CONTAMINANT TESTS

These tests indicate if the rubber is excessively contaminated by moisture, fibers, mineral matter, or metal. The contaminate tests assure that the rubber will be in good enough condition to give adequate performance. In addition, these tests provide an incentive for cleanliness during the processing and protection of the rubber from the elements during transport and storage. These tests were used to provide the data in Table 2.3a and 2.3b.

**Moisture Content of Crumb Rubber** — This test is used to determine if the moisture content of the rubber is excessive. One of the effects of excess water would be to affect the proportioning of the mix, and the most probable effect would be to significantly lower the mix's actual rubber content. This lowered rubber content could cause problems, such as difficulty in compaction. A likely source of water could be rain on an unprotected rubber stockpile.

The moisture content limit in the METRO RUMAC specification limits needs to be evaluated, as it may be too precise and it may be too low. The specification limit may be too precise, as the METRO RUMAC rubber's maximum moisture content limit is .75%, and consequently it requires that the sample's moisture content be determined to the nearest .01%. This degree of precision cannot be obtained in the ODOT field laboratories where this test is usually done. The field laboratories can determine a sample's moisture content to only .1%, as their scales typically indicate weight in .2 gram increments and they typically use a ½ can (200 to 300 gram) sample. A solution to this problem may be to revise the METRO RUMAC moisture content limit to a value significant to the nearest .1%. This would decrease the precision requirements of the test.

The specification limit may be too low, and raising the allowable moisture content limit for the rubber may benefit the ODOT. A higher moisture content limit may not compromise the performance of the METRO RUMAC, and it may help to assure that crumb rubber will be readily available for future projects.

Performance may not be compromised, as the upper moisture content limit of .75% was exceeded by both supplier's rubber on these two projects, and no problems were noted during rubber addition or mixing. The rubber's average moisture content was between 1.00 and 1.70%, with an average of 1.19%. The rubber appeared to be free flowing when the bags disintegrated upon contacting the pugmill paddles, and excessive steam was not produced during mixing.

Both of the rubber suppliers were asked about the equipment and processes they would need to reduce their rubber's moisture content to .75% or lower. One manufacturer stated they process dry tires, using dry equipment, and they load and seal the rubber into dry watertight bags. Furthermore, they said their plant is in the desert, and processing occurs during hot weather with low humidity. They did not see a practical means of drying the tire rubber to a .75% moisture content.

The other manufacturer said they may be able to meet the moisture content limit if they processed whole tires from their storage yards. However, they said that this is not always practical, and they often use shredded tire stock supplied by other manufacturers. They said that this stock contains slightly more moisture than the whole tires, and it gives the processed rubber a moisture content over .75%. Furthermore, this manufacturer stated that drying the rubber to a moisture content below .75% would be expensive. In addition, they said that they will no longer supply METRO RUMAC rubber because they cannot economically meet the moisture content limit.

It is recommended that the moisture content limit for crumb rubber be raised to 2.0% of the dry rubber weight. Based on experience with these two projects, this higher moisture content may not cause construction problems, and it could increase the availability and lower the price of the crumb rubber. However, if moisture related problems are noted with rubber having a moisture content between .75 and 2.0%, the moisture content may need to be lowered.

This 2% moisture content limit is recommended for tests performed by the method in the Appendix to this report, which uses approximately 200g of rubber, a 215 to 233°F (102 to 113°C) drying temperature, and a one hour drying time. This moisture content limit is not recommended for different sample sizes of rubber dried at different temperatures, or rubber dried for different lengths of time. If a rubber test by a method other than the procedure in the Appendix is used, the moisture content limit should be re-evaluated.

**Fiber Content of Crumb Rubber** — This test determines the amount of loose fibers in the crumb rubber, where a lot of loose fibers may inhibit the mixing of the rubber with the aggregate. This test is often performed simultaneously with the gradation test.

**Mineral Content of Crumb Rubber** — This test determines the amount of loose mineral matter in the crumb rubber. It indicates whether the rubber has been contaminated by dirt or sand. A possible source of mineral matter could be the processing of dirty tires or the exposure of a rubber stockpile to dirty equipment or a dusty environment.

This test uses distilled water to decant the rubber off of the mineral particles. On tests for these two projects, this method did not work well because many of the rubber particles were too dense to be suspended in the distilled water.

A saline solution composed of one part table salt to three parts of water[8] would be denser than distilled water, and it may aid in the suspension of heavier rubber particles. It is recommended that this saline solution be tried on future mineral content tests to see if it is an improvement.

**Presence of Free Metal in Crumb Rubber** — This test determines if there are loose metal particles in the rubber sample that adhere to a magnet. Typically, these particles are steel or stainless steel wires from the beads or belts of the tire, or nails or other metal embedded in the tire tread. Free metal is usually prohibited in rubber which will be blended with asphalt to make asphalt-rubber binder because the metal will wear the rotors of the equipment that blends the binder and adds the binder to the mix plant.

The rubber in METRO RUMAC, however, typically contacts equipment which normally handles aggregate, such as recycle feeds or pugmills. As a result, pump wear due to free metal in the rubber is not a problem. Consequently, allowing some free metal in the rubber may not damage the METRO RUMAC processing equipment. In addition, a small amount of free metal may not hurt the performance of the METRO RUMAC. This is shown by the rubber for the Lakeview Jct. - Matney Rd. project. Although free metal was found in a sample, no problems due to free metal were observed during construction.

It is recommended that the requirement in the METRO RUMAC specifications, which allows no free metal in the rubber, be deleted. In its place, it is recommended that a limit on the amount of free metal in the rubber be included. An upper limit on free metal content of .3% of total rubber weight is recommended. However, this recommendation is based on the author's intuition, and it is not based on experience with using rubber with differing metal contents. Consequently, the metal content of rubber used on future projects should be recorded and any problems due to free metal noted. Based on this data, the limit on free metal should be adjusted to a value which will allow the maximum amount of metal in the rubber without compromising the METRO RUMAC's performance.

## 4.4 RUBBER CHEMICAL COMPOSITION TESTS

These tests indicate whether or not the crumb rubber is made from tires, and they measure properties that are not as critical to pavement performance as the gradation and contaminant tests. The results of tests using these methods are listed in Tables 2.3a and 2.3b. All test procedures incorporate ASTM methods.

The specification limits for these tests need to be evaluated periodically. The chemical composition of tires entering the waste stream has been changing over the years and may continue to change in the future, as tires are being developed that have different chemical compositions than their predecessors. As a result, these specification limits may be, or may become, obsolete as a means of assuring that the crumb rubber is from tires.

It is recommended that the rubber chemical composition tests be deleted from the METRO RUMAC specifications. Using chemical composition tests to determine if tire rubber is used in METRO RUMAC is expensive, as a full series of tests costs about $500 from the ODOT's central laboratory. In addition, the periodic evaluation of the specification limits may require the expertise of people in the rubber industry, and employing these consultants may be costly. As a less expensive alternative to these chemical composition tests, the ODOT could accept the rubber based on the manufacturer's certification that it was made from tires. A manufacturer's certification is already required in the METRO RUMAC specifications. This approach would avoid the cost of both these tests and the periodic evaluation of the specification limits.

**Specific Gravity of Crumb Rubber** — This test determines the specific gravity of the rubber.

**Carbon Black content of Crumb Rubber** — This test determines the amount of carbon black in the rubber. Although carbon black is a normal component of tire rubber, excessive amounts of this material can indicate that the rubber came from a different source.

**Acetone Extract of Crumb Rubber** — This test indicates the amount of the tire rubber that is soluble in acetone. While almost all tires contain oils and other components that are soluble in acetone, the presence of too much soluble material may indicate that the rubber is not made from tires.

**Ash Content of Crumb Rubber** — This test indicates the amount of ash that remains after a sample is incinerated. While tire rubber leaves some ash after incineration, other types of rubber leave larger amounts. As a result, this test may indicate if the rubber is from another source.

## 4.5 ASPHALT CONTENT TESTING BY NUCLEAR GAUGE

On the Lakeview Jct. - Matney Rd. project, the asphalt content was determined by a nuclear asphalt content gauge for the statistical quality control tests. This method was successful, as the contractor was adding pre-weighed bags of rubber to a batch plant. On this particular plant, using this rubber addition system, the contractor could maintain the rubber content to closer than $\pm$ 0.1% of the total mix weight. This accuracy of the rubber addition was greater than the $\pm$ 0.2% of the total mix weight allowed in the METRO RUMAC specifications, and this greater accuracy was essential if the nuclear asphalt content gauge was to be sufficiently accurate.

Tight control of the rubber content is important, as the asphalt content indicated by the nuclear gauge includes both the rubber and asphalt in the mix, and the gauge cannot differentiate between the two materials. Consequently, if the asphalt content readings are to be valid, rubber must be included in the gauge calibration samples in the correct proportion, and rubber must also be added to the production mix in the same proportion. Problems can occur when the nuclear gauge is used and the proportion of rubber in the mix is not tightly controlled and known. For example, the nuclear gauge indicates that the mix has a high asphalt content; and as a result, the contractor reduces the amount of asphalt added to the mix. The contractor's adjustment would not affect mix durability if the asphalt content was excessive. However, if the high asphalt content reading was caused by excess rubber in the mix, the contractor's reduction in the asphalt feed rate would result in a mix with a low asphalt content and a high rubber content. A mix with this proportioning may be difficult to compact, and it may disintegrate prematurely by ravelling.

It is recommended that the nuclear gauge be prohibited in the specifications as a means of determining METRO RUMAC asphalt content. Many methods of rubber addition will meet the tolerances in the METRO RUMAC specifications, yet they are not accurate enough to allow use of the nuclear asphalt content gauge. However, use of the gauge could be allowed in circumstances where the amount of rubber added to the mix is controlled and monitored to a sufficient degree of accuracy.

## 4.6 SOLVENT EXTRACTIONS TO DETERMINE MIX GRADATION

For the type of batch plant used on this project, the METRO RUMAC specifications require that acceptance tests for gradation be performed on aggregate sampled from the plant's hot bins. On this particular plant the hot bin samples were very difficult to take. Consequently, the contractor asked the ODOT if they could use solvent extractions of the produced mix to obtain a sample to determine the mix's overall gradation. Solvent extractions of a produced mix are a permitted alternative to hot bin samples in the ODOT specifications for conventional asphalt concrete. However, they are not allowed for METRO RUMAC because the extraction solvent can dissolve some of the mix's rubber, and this rubber loss may cause an error in the gradation test results[2]. As the potential error in gradation test results were not as significant as the problems that would occur if hot bin samples were taken from this plant, the ODOT allowed the contractor to use extractions for determining the overall gradation of the mix. The contractor said that the extractions were no more difficult than with a conventional mix.

While the contractor was allowed to use extractions to determine the overall gradation of the mix for process control testing, they continued to be prohibited from using extractions to determine asphalt content, rubber content, or rubber gradation. The decision to allow extractions for the overall mix gradations was based on an analysis of solvent extractions in an earlier study of METRO RUMAC. The analysis was based on vacuum extractions and chlorinated hydrocarbon solvents similar to those used by the contractor, and it concluded: "...vacuum extractions using these solvents may give adequate test results for the overall gradation of the METRO RUMAC mix; and be a poor indicator of asphalt content, rubber content, and rubber gradation."[2]

It is recommended that solvent extractions be allowed to determine the overall gradation of the mix (aggregate, rubber and lime combined) for the contractor's process control testing. The method was successfully used on the Pacific Hwy. - 42nd St. project in this study, and on the S.E. Stark Street METRO RUMAC section in 1991.

## 4.7 SAMPLE PREPARATION FOR INDEX OF RETAINED STRENGTH TESTING

The ODOT required samples from the mix made with the JMF to pass a moisture damage susceptibility test which determines the mix's Index of Retained Strength (IRS) using method OSHD TM308C.[3,10] This test is based on AASHTO T165, and it compares the compressive strength of an unconditioned briquet to a sample that has been conditioned in a water bath. The samples are prepared by OSHD TM307C, which is a method based on AASHTO T167.[11]

In the OSHD 307C procedure, two samples are made inside of cylindrical molds, ejected from the molds, and subjected to an initial cure period in an oven. After the initial curing, the samples undergo the final cure, where one sample is stored in a dry container, and the other sample is submerged in a water bath.

In the ODOT's experience, METRO RUMAC samples often disintegrate in the oven during the initial cure. Samples made from conventional dense-graded hot mix do not do this. This disintegration appears to be a loss of cohesion between the mix particles. Although the cause of this distress is not known, it is not caused by moisture damage because the samples have not been exposed to water at this stage of the test.

In order to keep the samples from disintegrating, the ODOT keeps the METRO RUMAC mix in the molds throughout the initial cure, and the samples are ejected from the molds immediately prior to the final cure. This modification to the test procedure has not been written into published versions of the OSHD TM315 method.

It is recommended that a modified version of OSHD TM315 be developed for METRO RUMAC samples using the modified method of curing. In addition, it is recommended that the METRO RUMAC specifications be revised so they refer to the modified test method.

## 4.8 SAMPLE PREPARATION OF INDEX OF RETAINED RESILIENCE MODULUS TESTING

For both project's mix designs, the ODOT required samples of the mix made with the JMF to pass a moisture damage susceptibility test which would determine the mix's Index of Retained Resilient Modulus ($IRM_R$). This test method is OSHD TM315.[3,9] The test is based on the diametral resilient modulus of a sample before and after one water-saturated freeze-thaw cycle. There is nothing in the METRO RUMAC specifications that waives this test requirement. Consequently, the consultants performed this resilient modulus testing.

The methods the consultants used to prepare the samples for their resilient modulus tests differed from the sample preparation method required in OSHD TM315. The OSHD method requires the use of a California kneading compactor to prepare the samples. This requirement is convenient for the ODOT, as they use a kneading compactor to prepare their mix design samples. The consultants, however, did not have kneading compactors. Consequently, they used the Marshall procedure to prepare their $IRM_R$ samples.

It is recommended that a modified version of OSHD TM315 be developed for determining the $IRM_R$ of METRO RUMAC from Marshall samples. Marshall samples should not cause problems with the $IRM_R$ testing, as Marshall samples are allowed in the ASTM D4123 procedure. This ASTM method is for a resilient modulus test which is similar to the method used by the ODOT. Furthermore, it is recommended that the METRO RUMAC specifications be revised so that they refer to the modified test method.

## 4.9 MOISTURE SUSCEPTIBILITY TESTS

Currently the ODOT is requiring METRO RUMAC mix design samples, at the job mix asphalt content, to have an IRS of at least 75%, and an $IRM_R$ of at least 70%. These limits are used for most of the ODOT's conventional mixes, and they are based on the moisture damage susceptibility of conventional pavements compared to mix design briquets compacted and conditioned by normal ODOT methods. As a result, these IRS and $IRM_R$ limits may not be applicable to METRO RUMAC, as it is not a conventional mix, and its samples are prepared by modified methods. Consequently, it is recommended that the results of IRS and $IRM_R$ tests be compared to the short and long term moisture susceptibility damage on METRO RUMAC pavements. Based on this comparison, the validity of the IRS and $IRM_R$ specification limits can be checked, and if necessary, new limits can be established.

# 5.0 PRE- AND POST-CONSTRUCTION EVALUATION

This chapter presents the results of roadway inspections before and after construction, and it gives the results of tests on the new pavement.

## 5.1 VISUAL INSPECTION

**Lakeview Jct. - Matney Rd. Project** - The roadway was inspected and cracks and patches were mapped several weeks before paving. In addition, the road was inspected immediately after the overlay.

Before the overlay, the roadway had fatigue and alligator cracking in the wheeltracks, and occasional transverse thermal cracks. Most of the wheeltracks were covered by old inlay patches that were in poor condition. Some isolated and severely alligatored sections of the wheeltrack were patched with asphalt concrete immediately before paving. Rutting was moderate, as rut depths varied from 1/8 to 13/16" (3 mm to 21 mm) deep, with an average depth of ½" (13 mm).

After the overlay, both the test and control pavements had similar appearances, and they resembled typical dense-graded ODOT pavements. The only distress was the isolated pockmarks on the METRO RUMAC due to the tire damage discussed in Section 3.2.

**Pacific Hwy. - 42nd St. Project** - Prior to the overlay, the surface of the travel lanes was milled off. The road's condition was described in the surfacing design report as having "moderate to high severity cracking, moderate rutting, moderate ravelling, and patching with moderate to high severity distress."[4]

After the overlay, both the METRO RUMAC and the Class "B" control pavement had identical appearances, and both resembled typical dense-graded ODOT pavements. The only exception was a short section of the METRO RUMAC which had spots of rubber mixed with asphalt on its surface, as discussed in Section 3.1.

## 5.2 FRICTION

The pavement friction of the Lakeview Jct. - Matney Rd. project was measured five months after paving, and the friction of the Pacific Hwy. - 42nd St. project was measured one month after paving. 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.

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

**Lakeview Jct. - Matney Rd. Project** — The pavement roughness, or ride, was measured five months after construction. All testing was done with a "South Dakota" type profilometer. The test results are shown in Table 5.1a.

The METRO RUMAC and Class "B" sections, with International Roughness Index (IRI) values at 75 and 88, respectively, had similar roughness; and both values were within the roughness range expected for new thin overlays of rough roadways.

**Pacific Hwy. - 42nd St. Project** — The roughness was not measured, as the test sections will be covered by a wearing course. Consequently, the METRO RUMAC and Class "B" mixes will not wear under traffic and a long-term comparison of changes in ride cannot be done.

## 5.4 MOISTURE DAMAGE SUSCEPTIBILITY

### Visual Examination of Cores

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 was not fully coated due to incomplete mixing, cores from the newly constructed pavements were examined and all the core's aggregate was fully coated. Consequently, any future loss in aggregate coating is probably due to stripping.

### Index of Retained Strength

Samples of the mix were taken at the mix plant, compacted into briquets in the central laboratory, and tested for their index of retained strength (IRS). The Class "B" samples were made and tested by the methods in OSHD TM307C and OSHD TM308C, which are based on AASHTO T167 and AASHTO T154, respectively.[10,11] The METRO RUMAC samples were also fabricated and tested by these OSHD methods, with one exception: the briquets were not removed from the molds when they were conditioned in the water bath, as discussed in Section 4.7 of this report. The IRS is an indicator of the mix's resistance to moisture damage, and the higher the IRS, the better the mix's resistance to damage. The test results are listed in Table 5.1b.

**Table 5.1: Pavement Roughness, Deflections, and Void Contents**

**a) Roughness**

| Project | Section | Average International Roughness Index (IRI) October 1992 |
|---|---|---|
| Lakeview Jct. - Matney Rd. | METRO RUMAC | 75 |
| " | Class "B" | 88 |

**b) Moisture Susceptibility Test Results**

| Project | Section | Index of Retained Strength (%) | Index of Retained Resilient Modulus (%) |
|---|---|---|---|
| Lakeview Jct. - Matney Rd. | METRO RUMAC | 61 | * |
| | Class "B" | 87 | 100 |
| Pacific Hwy. - 42nd St. | METRO RUMAC | ** | 87 |
| | Class "B" | 95 | 112 |

**c) Void Contents and Stabilities**

| Project | Section | Average Bulk Specific Gravity (In-Place) | Average In-Place Void Contents (%) | Average Recompacted | |
|---|---|---|---|---|---|
| | | | | Hveem Stabilities | Void Contents (%) |
| Lakeview Jct. - Matney Rd. | METRO RUMAC | 2.1 | 4.4 | 7 | 2.243 |
| " | Class "B" | 2.0 | 5.7 | 50 | 2.280 |

| Project | Section | Average Bulk Specific Gravity (In-Place) | Average In-Place Void Contents (%) | Average First Compaction | | Average Second Compaction | |
|---|---|---|---|---|---|---|---|
| | | | | Void Contents (%) | Hveem Stabilities | Void Contents (%) | Hveem Stabilities |
| Pacific Hwy. - 42nd St. | METRO RUMAC | 2.255 | 3.7 | 1.9 | 5 | .7 | 4 |
| " | Class "B" | 2.345 | 5.1 | 3.5 | 41 | 1.5 | 39 |

**Sample fell apart during conditioning and, as a result, test was not done.
* Test was not done.

**Lakeview Jct. - Matney Rd. Project** - The METRO RUMAC and Class "B" mixes had IRS values of 61% and 87%, respectively. The METRO RUMAC's test result of 61% was below the design criteria of 75%. These tests indicate that the METRO RUMAC may be more susceptible to moisture damage than the Class "B" mix. In addition, the low IRS of the METRO RUMAC indicates it may show premature distress due to moisture damage, while the high IRS of the control section indicates it may resist moisture damage.

**Pacific Highway 42nd Street Project** - The METRO RUMAC samples fell apart in the conditioning bath and they could not be tested. The Class "B" samples did not fall apart however, and their IRS value of 95% indicates this pavement may resist stripping damage.

**Index of Retained Resilient Modulus**

Samples of mix were taken at the plant, made into briquets in the laboratory, and tested for their index of retained resilient modulus ($IRM_R$). All samples were made and tested by the methods in OSHD TM302 and OSHD TM315, which are based on AASHTO T247 and ASTM D4123, respectively.[10,12] Like the IRS, the $IRM_R$ is an indicator of the mix's resistance to moisture damage, and the higher the $IRM_R$, the better the mix's resistance to damage.

**Lakeview Jct. - Matney Rd. Project** - A comparison of the two sections' $IRM_R$ cannot be made, as the METRO RUMAC was not tested. The Class "B" mix's $IRM_R$ was 100%, well above the design criteria of 70%. This high value indicates that this mix may resist moisture damage.

**Pacific Hwy. - 42nd St. Project** - Both mixes have sufficiently high $IRM_R$ to indicate that they will resist moisture damage. However, the Class "B" mix may have better resistance to moisture damage, as its $IRM_R$ of 112% was higher than the METRO RUMAC's 87%. This statement should be viewed cautiously, as there is insufficient data to know if the $IRM_R$ accurately predicts METRO RUMAC performance.

## 5.5 VOID CONTENTS AND STABILITIES

Cores will be periodically removed from the pavements, and in-place void content measurements determined by AASHTO T166 and T209 will be used to monitor changes in the pavement due to consolidation under traffic and other causes. The in-place void contents of the new overlays are listed in Table 5.1c.

The in-place void contents are intended to be a baseline to which subsequent void content measurements will be compared. They are not intended to represent the average void content of the overlay, as they are taken from only two locations on each section. The compaction data in Table 3.1 is a more accurate indicator of the average void content for each section, as this data is based on an average of many tests at many different locations.

For the Lakeview Jct. - Matney Rd. project, the recompacted Hveem stabilities are intended to predict the pavement's stability under traffic immediately after construction. The test results are listed in Table 5.1c. The Class "B" mix had an average recompacted Hveem stability of 50, and this high value predicts that the pavement will be stable under traffic.

The METRO RUMAC had an average stability of 7, and this low value predicts that the mix may not be stable enough to support traffic loadings, and it will rut and flush immediately after construction.

Briquets made out of mix from cores removed from the Pacific Hwy. - 42nd St. sections were measured for first compaction Hveem stabilities, and the test results are in Table 5.1c. The first compaction stability design criteria for a standard duty base course is 30 or greater. Based on these tests, the Class "B" mix is predicted to remain stable immediately after construction, as its first compaction was 41; and the METRO RUMAC mix is predicted to become unstable and rut or flush immediately after construction, as its first compaction was only 5.

The briquets from the Pacific Hwy. - 42nd St. project were tested for second compaction Hveem stabilities. The second compaction design criteria for a standard duty base course is 30 or higher. Based on predictions from these tests, the Class "B" pavement would resist rutting and flushing for many years, as its second compaction stability was 39; and the METRO RUMAC pavement would rut and flush, as its second compaction was a low 4.

As this report is written, both sets of test sections have been under traffic for one winter, and no signs of instability have been noted. Consequently, the results of theses stability tests should be interpreted with caution. Although these tests are used by the ODOT to predict the behavior of conventional mixes, they may not be a reliable predictor of METRO RUMAC performance.

# 6.0 QUANTITIES AND COSTS

This chapter presents the quantities and costs for the rubberized and conventional mixes. A summary is shown in Table 6.1.

## 6.1 MIX COSTS

The Lakeview Jct. - Matney Rd. METRO RUMAC and Class "B" mixes cost $3.77 and $2.99 per square yard coverage ($4.51 and $3.58 per square meter), respectively, and the Pacific Hwy. - 42nd St. METRO RUMAC and Class "B" mixes cost $4.39 and $2.25 per square yard ($5.25 and $2.68 per square meter), respectively. These coverages are based on the prices in Table 6.1, a 2-inch (51 mm) lift thickness, and compaction to the mix design's bulk specific gravity. When the coverage prices are compared, the Lakeview Jct. - Matney Rd. METRO RUMAC cost 1.26 times as much as the standard "B" mix, and the Pacific Hwy. - 42nd St. METRO RUMAC cost 2.02 times as much as the "B" mix.

## 6.2 OTHER COSTS

To efficiently mix the METRO RUMAC for more frequent or larger projects, the batch plants would need specialized equipment to automate the rubber storage and addition systems. This equipment may cost $4,000 to $20,000, and details on the equipment are given in section 3.1 of this report.

The mix designs cost $2,175 and $2,600 apiece, whereas a conventional ODOT mix design prepared in the ODOT laboratory cost $1,300 in 1991.

**Table 6.1: Quantities and Costs**

**Lakeview Jct. - Matney Rd. Project**

| Item | Quantity | Price Per Unit |
|---|---|---|
| Rubber in METRO RUMAC | 19 tons | \$365 per ton[1] |
| Asphalt in METRO RUMAC | 97 tons | \$175 per ton[1] |
| Furnishing METRO RUMAC | 1,329 tons | \$17 per ton |
| Total Cost of METRO RUMAC In-Place | | \$35.37 per ton (\$34.84 per Mg)<br>\$3.77 per sq. yd.[2] (\$4.51 per $m^2$) |
| Asphalt in Class "B" | 774 tons | \$175 per ton[1] |
| Furnishing Class "B" | 12,205 tons | \$16 per ton[1] |
| Total cost of Class "B" In-Place | | \$27.79 per ton (\$27.37 per Mg)<br>\$2.99 per sq. yd.[2] (\$3.58 per $m^2$) |

**Pacific Hwy. - 42nd St. Project**

| Item | Quantity | Price Per Unit |
|---|---|---|
| Rubber in METRO RUMAC | 64 tons | \$520 per ton[1] |
| Asphalt in METRO RUMAC | 260 tons | \$100 per ton[1] |
| Furnishing METRO RUMAC | 3,269 tons | \$24 per ton |
| Total Cost of METRO RUMAC In-Place | | \$42.00 per ton (\$41.37 per Mg)<br>\$4.39 per sq. yd.[2] (\$5.25 per $m^2$) |
| Asphalt in Class "B" | 188 tons[3] | \$100 per ton[1] |
| Furnishing Class "B" | 3,325 tons | \$14.50 per ton |
| Total Cost of Class "B" In-Place | | \$20.15 per ton (\$19.85 per Mg)<br>\$2.24 per sq. yd.[2] (\$2.68 per $m^2$) |

[1] Contractor's bid prices. Actual costs may vary.

[2] Coverages per square yard for 2-inch (51-mm) thick lifts compacted to the bulk specific gravity in the mix design.

[3] Estimated.

# 7.0 CONCLUSIONS AND RECOMMENDATIONS

This chapter presents conclusions and recommendations about METRO RUMAC based on experience with these two projects. These findings supplement the conclusions and recommendations from the construction reports on earlier projects.[1,2]

## 7.1 CONCLUSIONS

**Overall Conclusions** — These two projects show that METRO RUMAC pavements can be constructed without major difficulties. However, the METRO RUMAC specifications and mix design guidelines need further modifications before they can be successfully used on future ODOT projects.

**Mix Designs** — The ODOT specifications do not allow the mix's narrowband limits to be outside of the broadband limits. The METRO RUMAC specifications do not delete this requirement. This requirement is seldom a problem for conventional mixes, as the job mix formula target values and corresponding narrowband limits are usually well within the broadband limits. However, for typical METRO RUMAC mixes, some target values are close to the broadband limits. When this happens, the requirement that the narrowband limits are inside of the broadband limits causes a constriction in the narrowband limits. As a consequence, the constricted narrowband limits increase the chances that the contractor would produce a mix that is out of specification. The constriction in narrowband limits could be prevented by allowing narrowband limits to be outside of broadband limits.

On one of the two projects in this study, to make a METRO RUMAC mix with the desired properties, the rubber content had to be lowered to 1.5% of mix weight. This was lower than the 2% required in the specifications. If this happens on future projects, it could be costly for the ODOT, as the agency may have to pay the contractor for substantial quantities of unused rubber. To prevent this problem in the future, the broadband limits for rubber content could be lowered.

The JMFs for these two METRO RUMAC mixes required approximately 1.95% more asphalt than their conventional counterparts on the average. These high demands for asphalt offset many of the environmental benefits of this system, as asphalt is a non-renewable resource.

**Mixing** — Experience on these projects shows that unopened bags of rubber can be added to the pugmill without hindering the mixing of the rubber and aggregate. However, strict attention is needed to assure that the bags are added at the proper moment and the specified dry mixing time is used.

The workers who add the rubber to the mix on batch plants work in noisy, dusty, and dangerous conditions. Consequently, they need protective clothing and equipment.

**Placing and Compacting** — These projects show that METRO RUMAC can be compacted to the density required in the specifications, and like conventional pavements, mixes that conform to the job mix formula are easier to compact. However, METRO RUMAC mixes usually require more compactive effort than equivalent conventional mixes, and the compaction is often achieved later in the rolling process. A ballasted finish roller may aid compaction, as it adds compactive effort late in the rolling when the pavement starts to cool and solidify.

**Tire Damage** — When the tires of mix hauling vehicles adhered to, and damaged, the surface of one project's METRO RUMAC, it was not a serious problem, as the number of hauling vehicles was limited. If the public was allowed to travel on this hot pavement, however, the tire damage could be much worse, as a much larger number of vehicles would be on the surface. Consequently, if future METRO RUMAC projects show that tire damage is a recurring problem, a clause may be needed in the specifications that requires the pavement be allowed to be cool before traffic uses it.

**Rubber Moisture and Metal Content** — The requirements for rubber quality in the METRO RUMAC specifications may be too stringent, and they may make the cost of the rubber needlessly high. The moisture content limit is too precise to be measured by most ODOT laboratories, and the limit may be unrealistically low. The limit may be so low that it makes suppliers reluctant to produce rubber for future projects. Likewise, the specification's requirement that the rubber contain no free metal may be too stringent.

**Rubber Mineral Content Test** — It was difficult to perform the mineral content tests for the crumb rubber using distilled water because the heavier rubber particles would not float in the water. Use of a saline solution, which is denser, may make this test more effective, as it would float heavier particles.

**Rubber Chemical Content** - The METRO RUMAC specifications require a series of tests to determine if the rubber is made from tires. This testing may not be the most cost-effective way of determining the rubber's source and the tests are expensive. In addition, the specification limits need periodic evaluation because the chemical composition of tires entering the waste stream changes as new tires are continually being developed which have a different chemical composition than their predecessors. A cost effective alternative to these tests may be to accept the rubber based on a certification it is made from tires.

**Asphalt Content by Nuclear Gauge** — The nuclear asphalt content gauge can be used to measure asphalt content. However, if the gauge is to be used successfully, the percentage of rubber in the mix must be precisely controlled. Many systems of adding rubber may be sufficiently precise to meet the requirements in the broadband limits for rubber content, but these systems may not be precise enough to allow use of the nuclear gauge. Consequently, use of the gauge may not be suitable for all METRO RUMAC projects, and its use can continue to be prohibited in the specifications.

**Solvent Extractions** — Solvent extractions were used to determine the overall gradation of the mix on one project for the contractor's process control testing and this method worked satisfactorily. Currently, solvent extractions are not permitted in the METRO RUMAC specifications. However, they may be useful in cases where alternative means of determining the overall mix gradation are impractical.

**Sample Preparation for Index of Retained Strength (IRS) Testing** — Retaining METRO RUMAC samples in their molds during the oven conditioning phase of this test procedure helps to assure that the samples will be in suitable condition for testing. Developing written guidelines for this modified testing procedure will help the consultants and others who do IRS tests on these rubberized mixes.

**Sample Preparation for Index of Retained Resilient Modulus ($IRM_R$) Testing** — $IRM_R$ test results are required from the mix design. In the test method listed in the current specifications, the samples for this test must be made by a kneading compactor. While laboratories that routinely perform Hveem mix designs have these compactors, they are not always available to the people who do the METRO RUMAC mix designs, because these designs are based on the Marshall method. Due to the lack of equipment, the consultants who made the METRO RUMAC mix designs for the three ODOT projects in 1991 and 1992 used Marshall methods to prepare their samples, and those samples performed satisfactorily. Consequently, allowing the use of Marshall specimens for resilient modulus testing may aid mix designers on future METRO RUMAC projects.

**Moisture Susceptibility Tests** — The current specification limits for the IRS and $IRM_R$ tests are based on experience with conventional pavements, and mix samples compacted and conditioned by ODOT procedures. These specification limits may not be applicable to METRO RUMAC. Consequently, the specification limits need to be evaluated, and possibly revised for METRO RUMAC mixes.

**Post-Construction Evaluation** — These Class "B" METRO RUMAC pavements resemble conventional Class "B" pavements, based on the visual inspections after construction, surface friction testing, surface smoothness testing, and void content tests.

Both projects' METRO RUMAC pavements may be susceptible to rutting and shoving, as the mix samples had low Hveem stability values. In addition, one METRO RUMAC section may be more susceptible to moisture damage than its control section, and it may show moisture damage prematurely, as it had a low IRS. The other project's METRO RUMAC pavement may resist moisture damage, as it had an adequate $IRM_R$.

**Costs** — These METRO RUMAC pavements cost considerably more than their conventional counterparts. Most of this added cost was due to the rubber, the addition of the rubber, and the extra asphalt that METRO RUMAC typically requires.

## 7.2 RECOMMENDATIONS

### General Recommendations

If METRO RUMAC is to be used, mix design guidelines and specifications should be revised before this mix is specified on future projects. Furthermore, these revised guidelines and specifications should be used on small scale projects until trouble-free construction becomes routine and long term performance data shows the pavements are sufficiently durable.

### Construction Practices Recommendations

**Mixing** - Continue to allow the practice of adding unopened bags of rubber to the pugmill. If the mix does not appear to be completely blended, assure the bags are added at the correct moment and the specified dry batch time is used.

Assure that the workers adding the rubber to the mix are adequately protected.

**Compaction** - Try a ballasted finish roller if the METRO RUMAC is difficult to compact and compaction is still occurring during the finish rolling.

**Preventing Tire Damage** - If tires adhere to the hot pavement, keep traffic off the METRO RUMAC until it is cool. If this is not possible, lightly sand the surface before traffic is allowed onto the hot pavement. Monitor future projects to see if tire damage is a recurrent problem. If it is, include provisions in the specifications to assure that the fresh pavement is not damaged.

### Changes to Mix Design Guidelines

Delete all rubber specifications and test methods from the mix design guidelines. In their place, include a requirement that the rubber used in the mix design shall conform to the requirements in the project's METRO RUMAC specifications.

### Changes to Specifications

**Rubber** - Require use of the ODOT draft test methods for determining rubber properties, and delete references to other methods. These draft test methods should be used until suitable AASHTO or ASTM methods are available.

Increase the allowable moisture content of the crumb rubber from .75% to 2.0%, and monitor future projects to see if rubber with this higher moisture content performs satisfactorily.

Delete the requirement that the rubber be free of metal. Require the metal content of the rubber to be no higher than .3% of the total rubber weight. Monitor the metal content of the rubber used on future projects and whether or not the free metal causes any problems.

Revise the test method for determining the mineral content of the rubber. In the revised method, use a saline solution instead of distilled water.

Do not include any of the rubber chemical composition tests in the specifications. Instead, require that the manufacturer certify that the crumb rubber is made from tires.

**Rubber Content** - Lower the rubber content broadband limits from 2.0% ± 0.2% to 1.5% ± 0.2%.

**Broadband Limits** - Include a clause that requires JMF target values to be within the broadband limits and allows the narrowband limits to be outside of the broadband limits.

**Asphalt Content by Nuclear Gauge** - Continue to prohibit the use of the nuclear gauge to determine asphalt content. Allow its use only in cases where the rubber addition is tightly controlled, and variations in the mix's rubber content will not cause unacceptable variations in the gauges asphalt content readings.

**Solvent Extractions to Determine Mix Gradations** - Allow solvent extractions as an option for the contractor's process control testing. Allow the procedure for determining the overall gradation of the mix, only.

**Sample Preparation of Index of Retained Strength (IRS) Testing** - Require the use of the modified procedure to prepare test samples. Prepare a revised method of preparing test samples which allows the samples to be conditioned in the molds.

**Sample Preparation for Index of Retained Resilient Modulus ($IRM_R$) Testing** - Allow the use of either Marshall or California kneading compactors to prepare samples. Prepare a revised method for preparing test samples which allows both the Marshall method of preparation, as well as use of the procedure based on the California kneading compactor.

**Moisture Susceptibility Tests** - Record the IRS and $IMR_R$ test results and compare them to the METRO RUMAC pavement's susceptibility to moisture damage. Revise the IRS and $IMR_R$ specification limits, if necessary.

# 8.0 REFERENCES


1. Bo Miller and Haiping Zhou, Asphalt-Rubber Concrete (ARC) and Rubber Modified Asphalt Concrete (METRO RUMAC) Evaluation: N.E. 181st Avenue -Troutdale Section, Columbia River Highway (US I-84), Construction Report (Salem, Oregon: Oregon Department of Transportation, February 1992).

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

3. Oregon Department of Transportation, Standard Specifications for Highway Construction, (Salem, Oregon: Oregon Department of Transportation, 1991).

4. Haiping Zhou, Final Pavement Design Report: Pacific Highway - 42nd St. (Springfield), Eugene-Springfield Highway No. 227, M.P. 4.0 - M.P. 7.5, Lane County, C120-1486, (Salem, Oregon: Oregon Department of Transportation, April 1991).

5. William Loy et al, Atlas of Oregon, (Eugene, Oregon: University of Oregon Books, 1976).

6. H. Barry Takallou, Mix Design Guidelines for Rubber Modified Asphalt Concrete, (Portland, Oregon: TAK Associates, 1991).

7. Anthony J. George, Glenn Boyle, and Andy Blachly, Oregon State Highway Division Asphalt Concrete Mix Design Guidelines, (Salem, Oregon: Oregon Department of Transportation, September 1989).

8. Arizona Department of Transportation, Sieving of Granulated Rubber, July 9, 1991 Draft (Phoenix, Arizona: Arizona Department of Transportation, July 1991).

9. Heitzman, Michael, "Session 7.0: Specification Guidelines" in Workshop Notes: Design Procedures and Construction Practices prepared for the Crumb Rubber Modifier Workshop sponsored by the Northwest Technology Transfer Center and the Federal Highway Administration, Spokane, Washington, March 1993.

10. Oregon Department of Transportation, Materials Section, Laboratory Manual of Test Procedures, Manual No. 26, 1986 Edition with revisions through March 1993 (Salem, Oregon: Oregon Department of Transportation, 1986).

11. American Association of State Highway and Transportation Officials, Standard Specifications for Transportation Materials and Methods of Sampling and Testing, (Washington D.C.: American Association of State Highway and Transportation Officials, 1990).

12. American Society of Testing and Materials, 1991 Annual Book of ASTM Standards, (Philadelphia, Pennsylvania: American Society of Testing and Materials, 1991).

# APPENDIX A: METRO RUMAC Specifications

## METRO RUMAC MIXTURE

Asphalt concrete for the Class "B" METRO RUMAC Mixture shall be constructed in accordance with Section 00745 of the Standard Specifications supplemented and/or modified as follows:

00745.00 Scope - Delete this subsection and add the following:

Standard Duty METRO RUMAC Mixture used on test sections of this project, shall be placed in the second lift of the travel lanes and first lift of the median and shoulder areas, between Stations "LE" 193+21 to 228+84 and the Stations "LW" 228+84 to 260+40. The initial control strip testing to establish optimum rolling procedures, patterns, and target density shall be performed between Stations "LE" 193+21 to 209+04 and Stations "LW" 247+20 to 260+40.

00745.01 Abbreviations - Add the following:

AC - METRO RUMAC

00745.02 Definitions - Delete the fourth definition and substitute the following:

Mixture - METRO RUMAC hot mixture of asphalt cement, graded aggregate, mineral filler, crumb rubber, and additives as required.

00745.03 Reclaimed Asphalt Pavement (RAP) Material - In accordance with the provisions of this subsection no RAP will be permitted on this project.

### Materials

00745.09 Crumb Rubber - Add the following:

The crumb rubber shall be ambient ground from whole passenger and/or light truck tires. Heavy equipment tires shall not be used. The crumb rubber greater than 10 Mesh in size shall be produced by ambient granulation. The crumb rubber that passes the 10 Mesh size (minus 10), may be produced from either ambient granulation or ambient grinding. Rubber tire buffings from either recappers or tire manufacturers may not be used as supplement to the rubber mixtures. The rubber granulate shall be processed by ambient granulation to maintain the structural integrity and maximum solid (non-porous) surface area. In order to remove steel and fabric, the first stage of the whole tire processing can use other methods.

The granulated 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 contaminants, 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 contaminant allowed shall not exceed 0.3% 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%. The 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 following shall apply to the crumb rubber:

| Test | Method | Specification |
|---|---|---|
| Specific Gravity | ASTM D-1817 | 1.15±.05 |
| Percent of Carbon Black | ASTM D-297-37 | 35.0 MAX |
| Percent of Ash | ASTM D-297-36 | 8.0 MAX |
| Percent of Acetone Extract | ASTM D-297-19 | 23.0 MAX |

The crumb rubber, tested in accordance with AASHTO T27 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 |

If the rubber is delivered in bags, it shall be packaged in low density polyethylene sacks having a melting point less than 240°F and loaded to a maximum weight of 80 pounds per sack. For a drum plant, the rubber may be shipped and received in bulk, (i.e. tote containers) to a maximum weight per container of 1 ton.

The sacks or containers shall be marked by the processor with the processor's name and designation for the rubber, the specific type and grade, the nominal bag weight, and the manufacturer's lot number designation. Palletized units shall contain the above information plus the net pallet weight.

The rubber processor shall furnish a written certification of compliance with the foregoing specifications.

00745.11(b-1) Asphalt Cement - Delete the second paragraph and substitute the following:

Use PBA-2 or PBA-5 grade asphalt as the Contractor elects.

00745.11(b-3) Mineral Filler - Delete the first sentence and substitute the following:

When specified in the JMF, add one of the following mineral fillers:

00745.11(b-4) Aggregate Treatment - Delete the first sentence and substitute the following:

Treat crushed aggregates with dry hydrated lime meeting the requirements of 02090.20.

00745.11(b-4-c) Treatment During AC Mixture Production - Revise the minimum moisture content of aggregate to:

4.00% for Class A,B, and C Mixes
3.50% for Class E Mix
3.00% for Class F Mix

00745.12(b) Broadband Limits - Delete the table and substitute the following:

| Sieve Size Passing | Broadband Limits Dense Graded Class "B" |
|---|---|
| 1-½" | - |
| 1-¼" | - |
| 1" | 99-100 |
| ¾" | 92-100 |
| ½" | 75-91 |
| ¼" | 50-70 |
| No. 10 | 21-41 |
| No. 40 | 6-24 |
| No. 200 | 2-7 |
| Crumb Rubber* | 1.8-2.2 |
| Asphalt Cement* | 4-8 |
| Mineral Filler | (As required by JMF) |

* Percent of total mix (by weight)

00745.13(b-1) JMF for Permanent Courses - Add this sentence to the first paragraph:

After all crumb rubber has been delivered to the job site, take a representative sample.

Delete the second and third paragraphs and substitute the following:

For each JMF requested, furnish two sets of representative samples of materials to be used in the mixture on the project. Both sets shall be sampled at the same time, and each set shall contain:

| Material | Amount |
|---|---|
| New Aggregate | 200 pounds of each separated size (4 bags) |
| Crumb Rubber | 20 pounds |
| Hydrated Lime | 20 pounds |
| Mineral Filler | 20 pounds |
| Asphalt Cement (without antistrip) | 2 gallons in 1 quart metal containers |
| Antistripping Additive | 2 pints in 1 pint metal containers |

Ship one set of these representative samples to the laboratory designated by the Engineer. Provide the other sample so that it can be shipped and received at the Division's Materials Laboratory in Salem. Both samples shall be provided at least 45 calendar days before anticipated use in the AC pavement. This 45-day period begins when **both** sets of materials complying with specifications have been received at the laboratories.

00745.13(b-1-a) JMF Materials Testing - In the third paragraph, change the quantity to the first 500 tons of AC mixture produced.

The Division will provide one JMF for each class of mix specified at no cost to the Contractor.

00745.14 Tolerances and Limits - Delete the table and substitute the following:

| Constituent of Mixture | Light Duty AC and Temporary Surfacing* Leveling Course All Courses | *Standard Duty AC All Courses | Heavy Duty AC All Courses |
|---|---|---|---|
| Aggregate (Sieve Size Passing): | | | |
| 1-½", 1-¼", 1", ¾" and ½" | Within the broadband limits of 00745.12(b) | Within the broadband limits of 00745.12 (b) | Within the broadband limits of 00745.12(b) |
| ¼" | ±6% | ±5% | ±5% |
| No. 40 and No. 10 | ±5% | ±5% | ±4% |
| No. 200 | ±2.0% | ±2.0% | ±2.0% |
| Crumb Rubber | Within the broadband limits of 00745.12(b) | Within the broadband limits of 00745.12(b) | Within the broadband limits of 00745.12(b) |
| Asphalt Cement (Cold Feed-Meter) OSHD TM 321 | ±0.2% | ±0.2% | ±0.2% |
| Temperature of mixture after adjustment for 00745.43(d) at time placed in final position | ±25°F | ±25°F | ±25°F |
| Moisture content at time of discharge from the mixing plant OSHD TM 311M-91 | 0.80% Max. | 0.80% Max. | 0.70% Max. |
| Compaction Density | See 00745.49 (b,c,e) | See 00745.49 | See 00745.49 |

* Includes Temporary surfacing and leveling courses constructed using Standard Duty and Heavy Duty AC mixture.

00745.15(c-2-a) Asphalt Content - Delete this subsection.

00745.15(c-2-b) Aggregate Gradation - Delete this subsection.

00745.16(b-2) AC Mixture - Delete this subsection and substitute the following:

(2) AC Mixture - Take samples when directed by the Engineer as follows:

a. Random Sampling - The Engineer will determine when and where to sample on a random basis. A sample will not be required from the first 25 tons of mixture each day.

b. Aggregate Gradation - Take one sample from each sublot using an approved mechanical sampling device as required by 00745.21(o) when directed as follows:

- Drum Plants - After lime treatment from the cold feed prior to entering the dryer.

- Batch Plants - If no aggregate is rejected from the storage bins, cold feed, or hot feed prior to screening. Otherwise sample from the hot bins.

c. Crumb Rubber Gradation, Moisture Content, and Other Properties - Take one can of rubber to be used in each sublot, when directed, for acceptance testing. Take three cans of rubber to be used in the first, twentieth, and every twentieth sublot thereafter, when directed, for complete rubber tests. Provide the samples to the Project Manager.

d. Mix Moisture Content - Take one sample from each sublot, when directed, from the discharge of the paving plant mixer prior to incorporation into the storage hopper or silo. Use an approved mechanical sampling devices as required by 00745.21(o). For batch plants that discharge directly into trucks, the sample may be taken directly from the truck.

e. Compaction - Sample for compaction according to 00745.49.

f. Lot Size - A lot is the total quantity of material or work produced per JMF with the same specification limits of all constituents. Increase sampling frequency of lots with two or less sublots according to 00165.30.

g. Sublot Size - A sublot is 500 tons of AC, except when sampled at an increased frequency according to 00745.16(b-2-g) of these special provisions or when a terminated sublot.

h. Acceptance Testing:

**Pacific Hwy. - 42nd St. (Springfield) Section**
**Grading, Paving, Structures, Signing, and Signals**

1. General - The Engineer will furnish copies of test results on the morning of the next workday after sampling, except for where differences in process control testing and Division testing required acceptance tests to be performed by the Materials Laboratory. Division test results include the following:

    - Acceptance testing performed in the field.
    - Acceptance testing performed in the Materials Laboratory.
    - The CPF of the completed sublots after three sublots have been produced.

2. Aggregate Gradation - Except as noted below, aggregate samples will be sampled and tested using AASHTO T 2, AASHTO T 27 and T 11.

    - For batch plants, if hot bins samples are used, separated size test result will be mathematically combined in the same proportions as batched.
    - Cold feed by sieve analysis.

3. Crumb Rubber Gradation, Moisture Content, and Other Properties - Gradation and moisture content acceptance testing will be done on samples form the first, fifth, and every fifth sublot thereafter. A complete rubber test in accordance with 00745.09 will be done on samples from the first, twentieth, and every twentieth sublot thereafter. Samples from intervening sublots may be tested if rubber from a sublot does not pass specifications.

4. Asphalt and Rubber Content - Asphalt content will be determined using OSHD TM 321 (Asphalt Content by Cold Feed/Meter Procedure) from the plant's asphalt metering/ weighing system and confirmed by invoices and tank stickings.

    For drum/continuous dryer plants, the rubber content shall be calculated from belt scale readings. The plant shall be calibrated according to OSHD TM 322 (Asphalt Concrete Plant

Calibration - Drum Dryers) before the start of paving and then once a week thereafter, or anytime there is a breakdown or change in plant equipment. The rubber feed shall be calibrated by the method described in TM 322 for mineral filler or hydrated lime additive.

For batch plants, the rubber content shall be calculated by belt scale readings if a continuous feed is used, or by recording the number of preweighed bags of rubber added to each batch of mix if the rubber is added directly to the weigh hopper or pugmill.

5. Moisture - Samples will be tested using OSHD TM 311M-91.

6. Asphalt Aging - METRO RUMAC shall be excluded from asphalt aging testing.

7. Backup Testing - If the test result of any AC constituent except rubber varies from the JMF by 1-½ times or more the tolerance limits specified in 00745.14, a backup sample from the random samples will be tested. The test result which yields the highest CPF through that sublot will be used. If the original and backup test results yield the same CPF, the original test results will be used.

8. Compaction - Acceptance testing for compaction will be according to 00745.49. New nuclear gauge tests will be obtained for any failing sublot of pavement at the same randomly selected sites used for the original nuclear gauge tests, if a new test is requested in writing on the same day nuclear gauge tests are provided. The average of these five new density tests will constitute the "in place" density of the sublot of pavement and will prevail over the original nuclear results.

   The Engineer may test any area that appears defective in compaction and require further compaction of any area that does not meet specifications.

## Equipment

00745.21(o) Sampling Devices - Add the following:

Provide a mechanical sampling device for each hot bin used in batch plants.

00745.21 Asphalt Concrete Mixing Plant - Add the following subsection:

(q) METRO RUMAC - A batch or a drum mix plant may be used to make METRO RUMAC. Mixing plants shall conform to the requirement of 00745.21, except the following shall be added:

1. Requirement for Batch Plant - The amount of crumb rubber shall be determined by weighting on springless dial scales, or by a method which uniformly feeds the mixer within the broadband limits indicated in 00745.12(b) herein. To obtain maximum accuracy, the addition of preweighted bags directly to the pugmill is recommended.

2. Requirements for Drum Mixing Plants - Crumb rubber introduced into the mixer shall be drawn from storage bins by a continuous mechanical feeder which will uniformly feed the mixer within the broadband limits indicated in 00745.12(b) herein.

   The continuous feed system shall be calibrated according to OSHD TM 322 or approved alternate method.

   There shall be a positive interlocking control between the flow of the crumb rubber and aggregates.

   The crumb rubber shall not enter the drum with the cold aggregates. The crumb rubber must be introduced beyond the flame.

   Do not convey the METRO RUMAC on rubber belts.

00745.24 Compactors - Delete this subsection and substitute the following:

00745.24 Compactors - Provide specified self-propelled rollers capable of reversing without backlash, as follows:

(a) Steel-Wheeled Rollers - Steel-wheeled rollers shall have:

- A gross static weight of at least 8 tons.
- A static weight on the drive wheel of at least 250 pounds per inch of width.

- Fully operational water spray bars to coat the roller drum with water mixed with a wetting agent.
- Use of a wetting agent such as tri-sodium phosphate is recommended. No petroleum-based wetting agents may be used.

If used for finish rolling:

- A gross static weight of at least 6 tons.
- No drivewheel static weight requirement.

(b) Vibratory Rollers - Vibratory rollers shall be:

- Equipped with amplitude and frequency controls.
- Specifically designed to compact AC.
- Capable of at least 2000 vibrations per minute.
- Be equipped with fully operational water spray bars to coat the roller drum with water mixed with a wetting agent.
- Use of a wetting agent such as tri-sodium phosphate is recommended. No petroleum based wetting agents may be used.

If used for finish rolling:

- Have a gross static weight of at least 6 tons.
- Not be operated in the vibratory mode.

(c) Pneumatic-Tired Rollers - Pneumatic tired rollers shall not be used.

00745.43(d) Heating Temperatures - Delete the table and substitute the following:

| AC Temperature (°F) | |
|---|---|
| Maximum at Paver | Minimum Behind Paver |
| 350 | 285 |

00745.44 Mixing - Delete this subsection and substitute the following:

The Contractor shall submit to the Project Manager, 30 days before production of METRO RUMAC, a work plan describing:

- The method and equipment used to add the crumb rubber to the mixture.
- The metering device or scale used to measure the inflow of rubber into the mix.
- The method of calibration for the metering device or scale.
- The mixing times to be used.

No mixing of the material will be allowed until the Project Manger has approved the work plan in writing. Approval of the work plan shall not relieve the Contractor of any responsibilities under the terms of the contract.

For batch plants, the aggregates and crumb rubber shall be combined and mixed thoroughly for a minimum of 25 seconds prior to introducing the bituminous materials.

00745.48(c) Placing - Delete the last two sentences of the last paragraph at this subsection.

00745.49(b-2-c-1) Construction of Control Strip - Delete the third paragraph and the table of this subsection and substitute the following:

The minimum target density shall be 94% of the MAMD (OSHD TM 306B).

00745.80 General - Delete the first sentence of this subsection and substitute the following:

The quantities of METRO RUMAC mixture shown in the bid schedule were computed on the basis of aggregates having a specific gravity of 2.75.

00745.81(b) Asphalt - Delete the second sentence of the second paragraph and substitute the following:

Measurement will be based on OSHD TM 321 and the "Asphalt in Mixture" shall be calculated to the nearest 0.01 tons.

00745.90 General - Delete the second paragraph and substitute the following:

Payment for all acceptable METRO RUMAC incorporated into the project will be made under applicable pay units, as follows:

| Pay Item | Unit of Measurement |
|---|---|
| (a) ___ Class ___ ___ METRO RUMAC Mixture | Ton |
| (b) ___ Asphalt in METRO RUMAC Mixture | Ton |
| (c) Crumb Rubber in METRO RUMAC Mixture | Ton |

In item (a) the type of AC, (Light Duty, Standard Duty, or Heavy Duty), will be inserted in the first blank. The respective class of AC will be inserted in the second blank. The words "Lime Treated" will be inserted in the third blank when applicable. Also, item (a) includes the cost of furnishing all materials except crumb rubber and asphalt in mixture and all equipment and labor necessary to complete the work.

In item (b), the types of asphalt will be inserted in the first blank.

00745.95 AC Price Adjustments - In both price adjustment formulas, after "JMF %", substitute "÷" for "-".

# APPENDIX B: Draft Sampling and Testing Methods for Rubber

**OSHD TM ____**

**Draft Method of Test for**

**SAMPLING CRUMB RUBBER**
(June 9, 1992 Version)

## 1. SCOPE

This procedure is to be used when obtaining crumb rubber samples in the field.

## 2. APPLICABLE DOCUMENTS

ODOT Manual of Field Test Procedures:

FOP for AASHTO T2: Method of Test for Sampling Aggregates and Aggregate Mixtures

FOP for AASHTO T248: Standard Methods for Reducing Field Samples of Aggregate to Testing Size

## 3. EQUIPMENT NEEDED

A. One-quart friction top cans with lids.
B. Masking tape (optional).
C. Equipment required for sampling as described in the FOP for AASHTO T2.
D. Equipment required for sample quartering and splitting as described in the FOP for AASHTO T248.

## 4. PROCEDURE

A. Sample Sizes

1. 100 ± 10 grams of rubber (approximately 1/4 can) for sieve analysis or fiber content test.

2. 1/2 can of rubber for a moisture content test.

3. One full can of rubber for the series of chemical tests. These tests are listed in the specifications for the rubber. Typically, they include: specific gravity, metal content, mineral content, percentage of carbon black, percent of ash, and percentage of acetone extract.

Use a separate can of rubber for the samples for each test. For example, if gradation, fiber content, moisture content, and a series of chemical tests are needed, submit four cans.

B. Sampling Crumb Rubber in Bags

Select a bag of rubber that represents the material used, or to be used, in the mix. The bag should be sealed and have no holes or tears.

If a moisture content test sample is needed, open the bag and take this sample immediately. Seal the can right after it is filled. If chemical tests are needed, take this sample after the moisture sample. Do not sample rubber from sections of the bag that have segregation among particles of different sizes.

Note: When a can is scooped into the rubber, the rubber often fills the groove in the top of the can where the lid fits, and it is very hard to put the lid on and get a proper seal. To avoid this problem, cover the groove with masking tape before the can is scooped into the rubber. Remove the tape before putting the lid on the can.

If a sieve analysis and/or fiber content test sample is needed, take the sample from the rubber remaining in the bag. To do this:

1. Quarter the contents of the bag according to 3. and 4. of the FOP for AASHTO T248.

2. Split one of the quarters with the mechanical splitter as many times as needed to get a 100 ± 10 gram sample for each test, according to 1. and 2. of the FOP for AASHTO T248. If the sample is to be stored or shipped, seal it in a can.

C. Sampling Crumb Rubber in Bulk Containers or Stockpiles

Sample rubber that represents the rubber used, or to be used, in the mix.

If a moisture content test sample is needed, sample material approximately a foot deeper than the surface of the rubber in the container or the working face of the stockpile. Seal the can immediately after it is filled. If chemical tests are needed, scoop this material from the same location that the moisture sample was taken. Do not sample rubber from sections of the container or stockpile that have segregation among particles of different sizes. To make sealing the cans easier, see the note in Section 3.B. of this Test Method. If a sieve analysis and/or fiber content test sample is needed:

1. Sample the container or stockpile according to 2.B. or 2.D., respectively, of the FOP for AASHTO T2. Sample as needed to get a combined field sample weighing at least 25 pounds.

2. Quarter the combined field sample according to 3. or 4. of the FOP for AASHTO T248.

3. Split one of the quarters with the mechanical splitter as many times as needed to get a 100 ± 10 gram sample. If the sample is to be stored or shipped, seal it in a can.

D. Write the type of test desired on the cans.

**OSHD TM ____**

**Draft Method of Test for**

**SIEVE ANALYSIS OF CRUMB RUBBER**
(February 17, 1993 Version)

## 1. SCOPE

A. This procedure is used to determine the gradation of crumb rubber.

## 2. EQUIPMENT NEEDED

A. Scale sensitive to .2 grams.
B. Flat-bottomed pan.
C. Sample splitter with 1/2-inch or smaller openings.
D. A one-quart glass jar with a large opening and a lid.
E. Talcum powder.
F. Sieves, including the sizes listed in the specifications for the rubber gradation and a #200 screen.
G. A mechanical sieve shaker that imparts a vertical, or lateral and vertical, motion to the sieves, causing the particles thereon to bounce and turn so as to present different orientations to the sieving surface.
H. A soft bristle brush.

## 3. SAMPLE PREPARATION

If the sample is received in a can, typically it will contain approximately 100 grams of rubber and be labeled as a gradation test sample.

A. Place the sample in a tared flat-bottomed pan. If the sample is received in a can, open the can and pour the <u>entire</u> contents into the pan. Spread the sample into an even layer on the bottom of the pan. Break up any clumps of rubber with the fingers.

B. Let the rubber dry until there is no visible moisture in the sample or in the pan, and when the rubber does not adhere to itself, metal surfaces, or glass surfaces; such as the bottom of the pan, spoons, or stirring rods.

C. Weigh the sample. If necessary, split the sample in the splitter to get a 100 ± 10 gram test sample.

Note: Do not use the weight of the rubber determined in this step, or the weight of the combined rubber and talc, as the "Initial Dry Weight" in the sieve analysis calculations.

D. Place the test sample in the jar and add 5 ± .2 grams of talcum powder (talc). Record the weight of this added talc. Mix thoroughly by shaking until the rubber and talc are uniformly mixed (a minimum of one minute).

## 4. PROCEDURE

A. Mechanically sieve the test sample for 10 ± 1 minutes. In no case shall fragments be turned or manipulated through the sieves by hand. If there are agglomerates of material retained on any of the screens, break these apart, recombine the material (including talc), place in the jar, reshake, and resieve.

Note: To check the adequacy of the mechanical shaker, continue shaking for a sufficient period and in such manner that, after completion, not more than 0.5 percent by weight of the total sample passes any sieve during 1 minute of continuous hand salvo. During hand salvo, the sieve shall have a snug fitting pan and cover and be held in a slightly inclined position in one hand. Strike the side of the sieve sharply and with an upward motion against the heel of the other hand at the rate of about 150 times per minute, and turn the sieve about one sixth of a revolution at intervals of about 25 strokes.

B. Determine the weight retained on each sieve and record to the nearest .2 gram. Any material adhering to the bottom of a screen shall be brushed onto the next finer screen.

## 5. CALCULATIONS

A. (a) If the weight of the material retained in the pan is less than or equal to the weight of the added talc, cross out the weight of the material in the pan and replace it with a zero.

(b) If the weight of the material retained in the pan is greater than the weight of the added talc, subtract the weight of the added talc from it, to get the difference. Cross out the weight of the material retained in the pan and replace it with the difference.

Note: The adjustments made in paragraphs (a) and (b) above are made to account for the weight of the talc added to the sample.

(c) Add the retained weights for all sieves together and record as the total sample weight.

## 6. REPORT AND EXAMPLES

A. Use Form #734-2277: "Asphalt Concrete Plant Report". Report rubber passing to the nearest percent.

B. An example of the calculation when the weight of the material retained on the pan is less than, or equal to, the weight of the added talc is shown in Figure 1. An example of the calculation when the weight of material in the pan is more than the weight of the added talc is shown in Figure 2.

**OSHD TM ____**

**Draft Method of Test for**

**MOISTURE CONTENT OF CRUMB RUBBER**
(February 10, 1993 Version)

## 1. SCOPE

This procedure is used to determine the moisture content of crumb rubber.

## 2. EQUIPMENT NEEDED

A. Conventional oven.
B. Scale sensitive to .2 grams.
C. Flat-bottomed pan.

## 3. PROCEDURE

If the sample is received in a can, typically it will contain approximately 1/2 can of rubber and be labeled as a moisture content test sample.

A. Preheat the oven to 225 $\pm$ 10$^{\circ}$F.

B. Tare pan.

C. Weigh the pan with the unopened can in the pan.

D. Open the can and pour the <u>entire</u> contents in the pan. Place the can and lid in the pan.

E. Place the pan and its contents in the oven and dry the sample at 225$^{\circ}$F for one hour.

**Note:** If smoke is seen during the drying process, the rubber is being overheated. Discard the sample if this occurs. Perform the moisture test on another sample at 10$^{\circ}$F lower oven temperature. If the smoking problem continues, check for localized hot spots in the oven or a faulty oven temperature regulator.

F. Weigh the pan with the dried rubber, can, and lid in the pan. Dump the rubber out of the pan and clean any rubber residue off of the pan, can, and lid.

G. Weigh the pan with the can and lid in the pan.

**4. CALCULATIONS**

Calculate the percent moisture based on the dry weight of the sample.

A = Weight of pan and unopened can. (From Step 3C.)

B = Weight of dried rubber, pan, can, and lid. (From Step 3F.)

C = Weight of pan, can, and lid. (From Step 3G.)

$$\text{Percent Moisture} = \frac{[A - B] \times 100}{[B - C]}$$

**4. REPORT**

A. Use Form #734-2277: "Asphalt Concrete Plant Report."

B. Report moisture content to the nearest .1 percent.

**OSHD TM ____**

**Draft Method of Test for**

# FIBER CONTENT OF CRUMB RUBBER
(February 17, 1993 Version)

## 1. SCOPE

This procedure is used to determine the fiber content of crumb rubber.

## 2. EQUIPMENT NEEDED

A. Scale sensitive to .2 grams.
B. Flat-bottomed pan.
C. Sample splitter with 1/2-inch or smaller openings.
D. Sieves in the sizes listed in the specifications for the rubber gradation.
E. A mechanical sieve shaker that imparts a vertical, or lateral and vertical, motion to the sieves, causing the particles thereon to bounce and turn so as to present different orientations to the sieving surface.

## 3. SAMPLE PREPARATION

If the sample is received in a can, typically it will contain approximately 100 grams of rubber and be labeled as a fiber content test sample.

A. Place the sample in a tared flat-bottomed pan. If the sample is received in a can, open the can and pour the entire contents into the pan. Spread the sample into an even layer on the bottom of the pan. Break up any clumps of rubber with the fingers.

B. Let the rubber dry until there is no visible moisture in the sample or in the pan, and when the rubber does not adhere to itself, metal surfaces, or glass surfaces; such as the bottom of the pan, spoons, or stirring rods.

C. Weigh the sample. If necessary, split the sample to get a 100 $\pm$ 10 gram test sample.

Note: Record the dry weight of the rubber as the "Initial Dry Weight" in the fiber content analysis calculations.

**4. PROCEDURE**

A. Mechanically sieve the test sample for 10 ± 1 minutes. In no case shall fragments be turned or manipulated through the sieves by hand.
apart, recombine the material in the pan and resieve.

B. Pick the fibers from the rubber retained on each screen and the pan with tweezers.

C. Determine the total the weight of the fibers to the nearest .2 grams.

**5. CALCULATIONS**

Calculate the fiber content based on the initial dry weight of the sample.

A = Total weight of fibers. (From Step 4C.)

B = Initial dry weight of the rubber. (From Step 3C.)

$$\text{Fiber Content} = \frac{A \times 100}{B}.$$

**6. REPORT**

A. Use Form #734-3069: "Laboratory Report Record."

B. Report fiber content to the nearest .2 percent.

OSHD TM ____

**Draft Method of Test for**

**MINERAL CONTENT OF CRUMB RUBBER**
(February 17, 1993 Version)

## 1. SCOPE

This procedure is to be used to determine the mineral content of crumb rubber.

## 2. EQUIPMENT NEEDED

A. A one liter glass beaker.
B. Stirring rod.
C. Scale sensitive to .05 grams.
D. Flat bottomed pan.
E. Distilled water.

## 3. SAMPLE PREPARATION

If the rubber is received in a can, typically it will be part of the rubber in the can labeled as a chemical test sample.

A. Place the sample in a tared flat-bottomed pan. If the sample is received in a can, open the can and pour the <u>entire</u> contents into the pan. Spread the sample into an even layer on the bottom of the pan. Break up any clumps of rubber with the fingers.

B. Let the rubber dry until there is no visible moisture in the sample or in the pan, and when the rubber does not adhere to itself or to metal surfaces or glass surfaces; such as the bottom of the pan, spoons, or stirring rods.

C. Split the sample to get a 50 $\pm$ 5 gram test sample.

## 4. PROCEDURE

A. Weigh the beaker.

B. Place the test sample the beaker. Weigh the beaker and the rubber.

C. Fill the beaker containing the rubber with one liter of distilled water. Stir the rubber and water to dislodge mineral particles from the rubber.

D. Let the beaker stand undisturbed for one hour.

E. Slowly decant the rubber and water from the beaker. Take care to remove all rubber from the beaker and leave all mineral particles in the beaker.

F. Allow the beaker and mineral particles to dry to a constant weight. These items can be dried in the ambient air or in a laboratory oven at a temperature at or below 250°F.

G. Weigh the beaker containing the mineral particles.

## 5. CALCULATIONS

Calculate the mineral content based on the dry weight of the sample.

A = Weight of beaker and mineral particles. (From Step 4G.)

B = Weight of beaker. (From Step 4A.)

C = Weight of beaker and rubber. (From Step 4B.)

$$\text{Mineral Content} = \frac{[A - B] \times 100}{[C - B]}$$

## 6. REPORT

A. Use Form #734-3069: "Laboratory Report Record."

B. Report mineral content to the nearest .1 percent.

**OSHD TM ____**

**Draft Method of Test for**

**PRESENCE OF FREE METAL IN CRUMB RUBBER**
(June 17, 1992 Version)

## 1. SCOPE

This procedure is to be used to detect free metal particles in crumb rubber. It is applicable to ferrous particles, only.

## 2. EQUIPMENT NEEDED

A. A one liter glass beaker.
B. Magnet.
C. Scale sensitive to 1 gram.
D. Flat bottomed pan.

## 3. SAMPLE PREPARATION

If the rubber is received in a can, typically it will be part of the rubber in the can labeled as a chemical test sample.

A. Place the sample in a tared flat-bottomed pan. If the sample is received in a can, open the can and pour the <u>entire</u> contents into the pan. Spread the sample into an even layer on the bottom of the pan. Break up any clumps of rubber with the fingers.

B. Let the rubber dry until there is no visible moisture in the sample or in the pan, and when the rubber does not adhere to itself or to metal surfaces or glass surfaces; such as the bottom of the pan, spoons, or stirring rods.

C. Split the sample to get a 50 $\pm$ 5 gram test sample.

## 4. PROCEDURE

A. Place the test sample the beaker.

B. Stir the rubber with the magnet.

C. Examine the particles that adhere to the magnet. Note if free metal is present. Free metal is metal that is not attached to a particle of rubber.

**5. REPORT**

A. Use Form #734-3069: "Laboratory Report Record."

B. If free metal is present, write "Free metal in sample." on the laboratory report.

C. If free metal is not present, write "No free metal in sample." on the laboratory report.

**OSHD TM ____**

**Draft Method of Test for**

**SPECIFIC GRAVITY OF CRUMB RUBBER**
(June 9, 1992 Version)

## 1. SCOPE

This procedure is to be used to determine the specific gravity of crumb rubber.

## 2. APPLICABLE DOCUMENTS

ASTM Standards: D 297-90 Standard Test Methods for Rubber Products - Chemical Analysis
Section 16: Density

## 3. EQUIPMENT NEEDED

Use the equipment required to determine the density of the rubber based on ASTM D 297-90 Section 16.

## 4. SAMPLE PREPARATION

If the rubber is received in a can, typically it will be part of the rubber in a can labeled as a chemical test sample.

A. Place the sample in a tared flat-bottomed pan. If the sample is received in a can, open the can and pour the <u>entire</u> contents into the pan. Spread the sample into an even layer on the bottom of the pan. Break up any clumps of rubber with the fingers.

B. Let the rubber dry until there is no visible moisture in the sample or in the pan, and when the rubber does not adhere to itself or to metal surfaces or glass surfaces; such as the bottom of the pan, spoons, or stirring rods.

C. Split the contents of the can to get a test sample of the needed size.

## 5. PROCEDURE

Use the procedure required to determine the density of the rubber at 25°C in $Mg/m^3$ based on ASTM D 297-90 Section 16.

**6. CALCULATION**

Divide the density of the rubber by .9971 $Mg/m^3$. This gives the specific gravity of the rubber.

**7. REPORT**

A. Use Form #734-3069: "Laboratory Report Record."

B. Report the specific gravity of the rubber to the third decimal place.

OSHD TM ____

**Draft Method of Test for**

**CARBON BLACK CONTENT OF CRUMB RUBBER**
(February 10, 1993 Version)

## 1. SCOPE

This procedure is to be used to determine the carbon black content of crumb rubber.

## 2. APPLICABLE DOCUMENTS

ASTM Standards: D 297-90 Standard Test Methods for Rubber Products - Chemical Analysis Section 38: Carbon Black, Method A, Nitric Acid Digestion Test Method

## 3. EQUIPMENT NEEDED

Use the equipment required to determine the carbon black content of the rubber based on ASTM D 297-90 Section 38.

## 4. SAMPLE PREPARATION

If the rubber is received in a can, typically it will be part of the rubber in a can labeled as a chemical test sample.

A. Place the sample in a tared flat-bottomed pan. If the sample is received in a can, open the can and pour the <u>entire</u> contents into the pan. Spread the sample into an even layer on the bottom of the pan. Break up any clumps of rubber with the fingers.

B. Let the rubber dry until there is no visible moisture in the sample or in the pan, and when the rubber does not adhere to itself or to metal surfaces or glass surfaces; such as the bottom of the pan, spoons, or stirring rods.

C. Split the contents of the can to get a test sample of the needed size.

## 5. PROCEDURE AND CALCULATION

Use the procedure and calculation methods required to determine the carbon black content of the rubber based on

ASTM D 297-90 Section 38. Use a 16 hour acetone extraction. Do not use a chloroform extraction.

Note: This test requires an acetone extraction. The "Acetone Extract, %" value obtained from this extraction can be used as a test result for "OSHD TM ____ Draft Method of Test for Acetone Extract of Crumb Rubber".

**6. REPORT**

A. Use Form #734-3069: "Laboratory Report Record."

B. Report the carbon black content of the rubber to the nearest .1 percent.

**OSHD TM ____**

**Draft Method of Test for**

**ACETONE EXTRACT OF CRUMB RUBBER**
(June 9, 1992 Version)

## 1. SCOPE

This procedure is to be used to determine the percentage of a crumb rubber sample that is soluble in acetone.

## 2. APPLICABLE DOCUMENTS

ASTM Standards: D 297-90 Standard Test Methods for Rubber Products - Chemical Analysis
Section 19: Acetone Extract

## 3. EQUIPMENT NEEDED

Use the equipment required to determine the acetone extract of the rubber based on ASTM D 297-90 Section 19.

## 4. SAMPLE PREPARATION

If the rubber is received in a can, typically it will be part of the rubber in a can labeled as a chemical test sample.

A. Place the sample in a tared flat-bottomed pan. If the sample is received in a can, open the can and pour the <u>entire</u> contents into the pan. Spread the sample into an even layer on the bottom of the pan. Break up any clumps of rubber with the fingers.

B. Let the rubber dry until there is no visible moisture in the sample or in the pan, and when the rubber does not adhere to itself or to metal surfaces or glass surfaces; such as the bottom of the pan, spoons, or stirring rods.

C. Split the contents of the can to get a test sample of the needed size.

## 5. PROCEDURE AND CALCULATION

Use the procedure and calculation methods required to determine the acetone extract of the rubber based on ASTM D 297-90 Section 19. Use a 16 hour acetone extraction.

**6. REPORT**

A. Use Form #734-3069: "Laboratory Report Record."

B. Report the acetone extract of the rubber to the nearest .1 percent.

**OSHD TM ____**

**Draft Method of Test for**

**ASH CONTENT OF CRUMB RUBBER**
(June 9, 1992 Version)

## 1. SCOPE

This procedure is to be used to determine the percentage of ash in a crumb rubber sample.

## 2. APPLICABLE DOCUMENTS

ASTM Standards: D 297-90 Standard Test Methods for Rubber Products - Chemical Analysis Section 35: Fillers, Referee Ash Test Method

## 3. EQUIPMENT NEEDED

Use the equipment required to determine the ash content of the rubber based on ASTM D 297-90 Section 35.

## 4. SAMPLE PREPARATION

If the rubber is received in a can, typically it will be part of the rubber in a can labeled as a chemical test sample.

A. Place the sample in a tared flat-bottomed pan. If the sample is received in a can, open the can and pour the <u>entire</u> contents into the pan. Spread the sample into an even layer on the bottom of the pan. Break up any clumps of rubber with the fingers.

B. Let the rubber dry until there is no visible moisture in the sample or in the pan, and when the rubber does not adhere to itself or to metal surfaces or glass surfaces; such as the bottom of the pan, spoons, or stirring rods.

C. Split the contents of the can to get a test sample of the needed size.

## 5. PROCEDURE AND CALCULATION

Use the procedure and calculation methods required to determine the ash content of the rubber based on ASTM D 297-90 Section 35.

6. **REPORT**

   A. Use Form #734-3069: "Laboratory Report Record."

   B. Report the ash content of the rubber to the nearest .1 percent.