# EVALUATION OF PBA-6GR BINDER FOR OPEN-GRADED ASPHALT CONCRETE 1993 AND 1994 PROJECTS

## Construction Report

**State Funded Project**

by


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**16. Abstract**

This report covers construction of open-graded asphalt concrete ("F" Mix) pavements with an asphalt-rubber binder, PBA-6GR. The PBA-6GR is manufactured at a refinery and delivered to the jobsite like conventional asphalt cement. Test sections and control sections were constructed in the fall of 1993, and summer and fall of 1994. One site is located in central Oregon on the Warm Springs Highway, US Route 26; the second site is located on Interstate 84 near Boardman; and the third site is located on Interstate 5, north of Grants Pass.

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

Conventional open-graded mix design procedures were used to determine the optimal asphalt binder content. Since the binder did not drain down like PBA-6, analysis of void content and voids filled with asphalt (VFA) were used for binder content determination.

Construction of the asphalt-rubber mix progressed smoothly and the mix appeared to be easier to handle than the asphalt concrete with PBA-6 binders. The binder was not sticky and stringy; it did not collect on the truck dump gates; it did not allow the paver to settle into the mat during delays; it did not shove laterally during compaction; and it did not separate at higher temperatures. The mix was also easier to handle than other types of asphalt-rubber mixes. The contractor needed no extra mixing and handling equipment.

The asphalt-rubber mix cost per ton was 16% more than the "F" mixes constructed with PBA-6. When compared to 1994 bid prices, for "F" mixes, however, the PBA - 6GR mix costs were 12% more. Advantages of the PBA-6GR mix, such as thick films, ease in construction, and ease in handling, may make the binder preferable to conventional PBA-6.

Additional testing is needed to evaluate a proper mix design. Also, the Brookfield viscometer should be evaluated as a means to determine the temperature viscosity properties of the binder. To determine the cold temperature properties of the binder, the SHRP Bending Beam Rheometer should be evaluated. This binder would be suitable for use to meet the ISTEA rubber content mandate.

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# SI* (MODERN METRIC) CONVERSION FACTORS

## APPROXIMATE CONVERSIONS TO SI UNITS

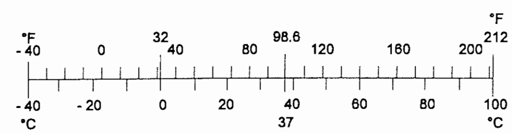
| Symbol | When You Know | Multiply By | To Find | Symbol |
|---|---|---|---|---|
| | | **LENGTH** | | |
| in | inches | 25.4 | millimeters | mm |
| ft | feet | 0.305 | meters | m |
| yd | yards | 0.914 | meters | m |
| mi | miles | 1.61 | kilometers | km |
| | | **AREA** | | |
| $in^2$ | square inches | 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 $m^3$.

| Symbol | When You Know | Multiply By | To Find | Symbol |
|---|---|---|---|---|
| | | **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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Your time and comments are greatly appreciated!

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## EVALUATION OF PBA-6GR BINDER FOR OPEN-GRADED ASPHALT CONCRETE CONSTRUCTION REPORT

# TABLE OF CONTENTS

## EVALUATION OF PBA-6GR BINDER FOR OPEN-GRADED ASPHALT CONCRETE

# LIST OF FIGURES



# LIST OF TABLES

# 1.0 INTRODUCTION

## 1.1 BACKGROUND

The Intermodal Surface Transportation Efficiency Act (ISTEA) enacted in 1991, requires the use of ground automobile and truck tires in federally funded hot mix asphalt concrete (HMAC) beginning in federal fiscal year 1994 (FFY- October 1 -- September 30). The Oregon Department of Transportation (ODOT) is interested in determining the most appropriate rubber modified HMAC to meet the intent of ISTEA. A two-year moratorium on the use of ground tires has been issued through FFY 1995, however, beginning in FFY 1996 the requirement will be enforced. In FFY 1996, ISTEA will require that 15 percent of all federally funded HMAC must include at least one percent of tire rubber. In FFY 1997, the requirement increases to 20 percent of all federally funded HMAC.

The three projects discussed in this report, used a "wet process" where the ground rubber is blended into the asphalt to make an asphalt-rubber binder (called PBA-6GR for performance based asphalt 6 with ground rubber), which is then mixed with the aggregate. HMAC construction using the "wet process" on this project will be compared to "dry process" projects where the ground rubber is blended into the aggregate, and other "wet process" projects constructed in Oregon.

## 1.2 PREVIOUS ODOT RESEARCH PROJECTS

Since 1985, the Research Unit has monitored twelve paving projects constructed in Oregon that have ground tire rubber incorporated in the HMAC. The dry processes used included Plus Ride 12 and Metro RUMAC (rubber modified asphalt concrete). Although the Plus Ride 12 was made by a dry process similar to the Metro RUMAC, the two systems are different. In the Plus Ride 12 system, granulated rubber is added to a gap-graded aggregate. In the non-patented Metro RUMAC system, crumb rubber is added to a conventional aggregate gradation (*1*).

The wet processes used were the International Surfacing Incorporated's asphalt-rubber concrete (ISI ARC), powdered rubber asphalt-rubber concrete (PRARC), and PBA-6GR. The ISI ARC and PRARC processes mix the asphalt and the rubber at the construction site (*2*). The difference between the two processes is that the ISI process is proprietary and the PRARC process is not. In addition, the gradation of the PRARC rubber is finer (powdered) than ISI's which is granulated. The PBA-6GR binder is prepared at the refinery where powdered rubber is blended with a base asphalt to meet modified PBA-6 specifications.

State Planning and Research (SP&R) Project #5255, entitled "Crumb Rubber Modifiers in Asphalt Concrete Pavements" will evaluate the projects as a whole. The intent of the SP&R project is to determine the most appropriate method of including rubber in HMAC to meet the ISTEA requirements.

## 1.3 OBJECTIVES

The objectives of this study include evaluating the use of PBA-6GR as a binder. Construction data will be discussed and performance will be monitored to determine the effect of the rubber modifier on pavement life and serviceability. Additional objectives include determining the appropriate revisions to the ODOT specifications and the ODOT mix design procedures for use of PBA-6GR.

Monitoring of the PBA-6GR projects will continue for five years. The initial findings are included in this construction report which gives details of the projects' location and design, materials, mix designs, construction, sampling and testing, in-place unit costs, and pavement condition just after construction. The longterm performance will be documented in the SP&R Project #5255 reports.

# 2.0 LOCATION AND DESIGN

This chapter covers project locations, cross sections, environment and traffic, and overlay designs. The Vicinity Map, Figure 2.1, shows the general locations of the projects. Both ends of the test and control pavement sections are marked in the field, on the shoulders, with paddles that display the mix type.

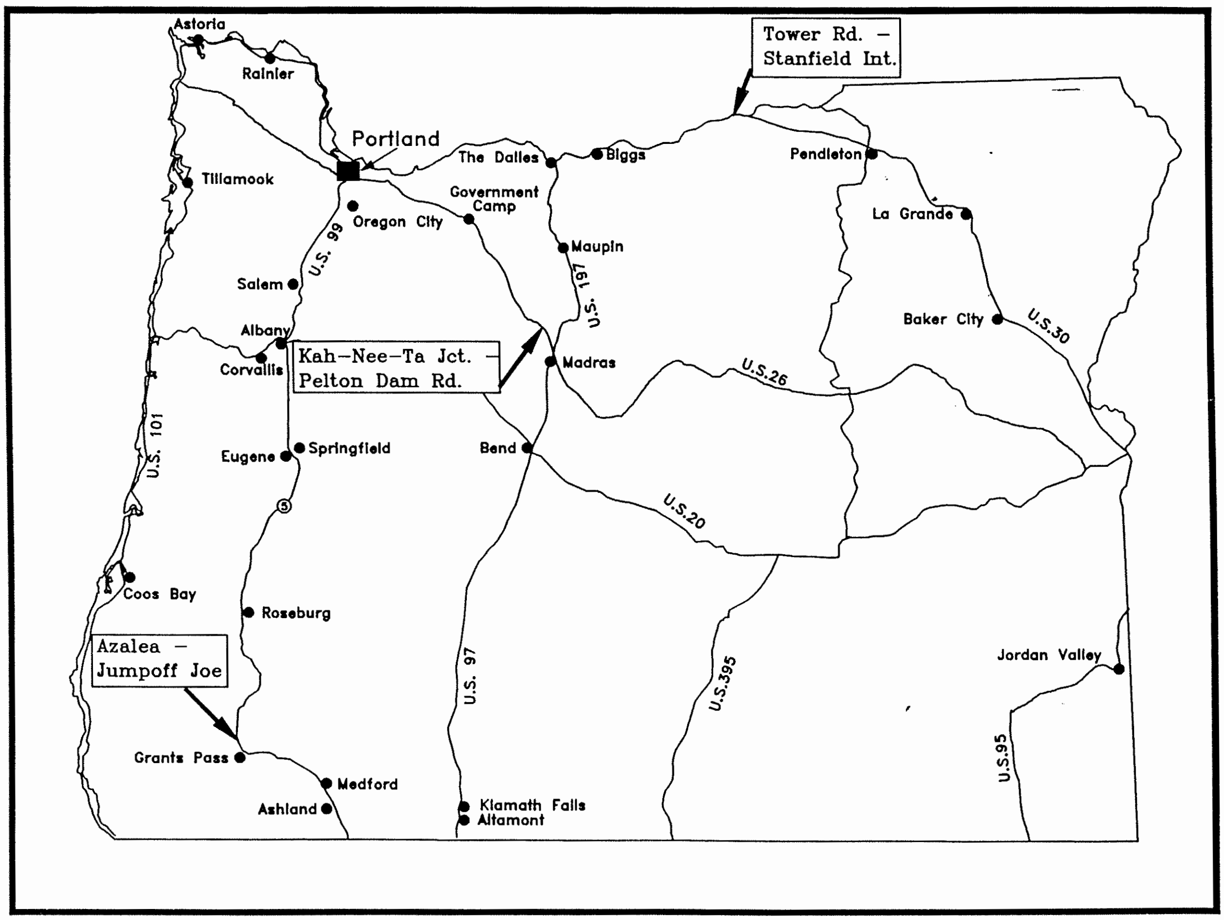



**Figure 2.1. Vicinity Map.**

## 2.1 LOCATION AND CROSS SECTION

### 2.1.1 Kah-Nee-Ta Junction -- Pelton Dam Road, West Unit

This project is located in north central Oregon approximately ten miles northwest of Madras. The test section is located between Sta. 1623 and 1635 (M.P. 104.98 and 105.20) in the eastbound travel lane on US Route 26. The control section is located between Sta. 1645 and 1660 (M.P. 105.37 and 105.62), in the eastbound travel lane of Unit I of the Kah-Nee-Ta Junction -- Pelton Dam Road section.

The typical cross sections are shown in Figure 2.2. The roadway cross section includes:

**Wearing Course -** The wearing course is a single lift of open-graded asphalt concrete with a 2-inch (50 mm) nominal thickness.

**Old Pavement and Base -** The old pavement is a 2- to 11-inch (50 to 280 mm) thick layer of asphalt concrete over 12 inches (300 mm) of aggregate base.

The control section for the project includes widening, as noted on the cross sections. For study purposes, the variable conditions will be taken into consideration when comparing the test and control sections.

### 2.1.2 Tower Road-Stanfield Junction

This project is located on I-84, between the town of Boardman to the west and Stanfield Interchange to the east. The western portion of the project is part of the Columbia River Highway and the eastern portion, part of the Old Oregon Trail Highway. The test section is located between Sta. 186 and 196 (M.P. 166.34 and 166.53). The control section is located between Sta. 230 and 240 (M.P. 167.17 and 167.36). Both sections are in the eastbound lane.

The typical cross sections are shown in Figure 2.3. The roadway cross section includes:

**Wearing Course -** The wearing course is a single lift of open-graded asphalt concrete with a 2-inch (50 mm) nominal thickness.

**Old Pavement and Base -** The old pavement depth ranges from 7.5 to 12.0 inches (190 to 300 mm).

### 2.1.3 Azalea-Jumpoff Joe Creek

This project is located on I-5, north of Grants Pass in Douglas and Josephine counties. The test section is located between Sta. 477 and 489 (M.P. 80.09 and 80.31). The control section is located between Sta. 300 and 310 (M.P. 83.50 and 83.69). Both sections are in the northbound lane.

The typical cross sections are shown in Figure 2.4. The roadway cross section includes:

**Wearing Course** - The wearing course is a single lift of open-graded asphalt concrete with a 2-inch (50 mm) nominal thickness.

**Old Pavement and Base** - The old pavement is a 9 to 11-inch (230 to 280 mm) thick layer of asphalt concrete over 6 inches (150 mm) of aggregate base.

## 2.2 ENVIRONMENT AND TRAFFIC

Table 2.1 presents the elevations and range of temperature conditions for the projects. The normal temperatures are based on monthly mean maximum and minimum temperatures collected from 1961-90. The monthly mean temperatures were calculated by taking the adjusted daily temperatures and averaging them for the month. Adjustments were made to account for missing data, time of observation, and exposure changes. The adjustment methodology is described in greater detail in Section II of the National Oceanic and Atmospheric Administration publication of Oregon climatography. Precipitation calculations are also based on the 30-year collection period. *(3)*

**Table 2.1 Elevation and Environmental Conditions.***(3)*

| **Project** | **Elevation** | **Normal Low Temperature** (Month) | **Normal High Temperature** (Month) | **Annual Precipitation** |
|---|---|---|---|---|
| Kah-Nee-Ta Jct.-Pelton Dam | 2,300 ft. (700 m) | 26 °F (-3 °C) (January) | 93 °F (34 °C) (July) | 10 in. (250 mm) |
| Tower Road-Stanfield Junction | 625 ft. (190 m) | 26 °F (-3 °C) (December) | 88 °F (31 °C) (August) | 9 in. (230 mm) |
| Azalea-Jumpoff Joe | 700 -1725 ft (210 - 525 m) | 31°F (-0.6 °C) (January) | 75 °F (24 °C) (August) | 35 in. (890 mm) |

The following table presents the 1993 recorded traffic conditions for each of the projects.

**Table 2.2 Traffic Conditions(*4*)**

| Project | Average Daily Traffic (ADT) | % Trucks |
|---|---|---|
| Kah-Nee-Ta Jct.-<br>Pelton Dam | 4,900 | 10 |
| Tower Road-<br>Stanfield Junction | 10,000 | 30 |
| Azalea-<br>Jumpoff Joe | 18,000 | 20 |

# 2.3 OVERLAY DESIGN

## 2.3.1 Kah-Nee-Ta Junction-Pelton Dam Road, West Unit

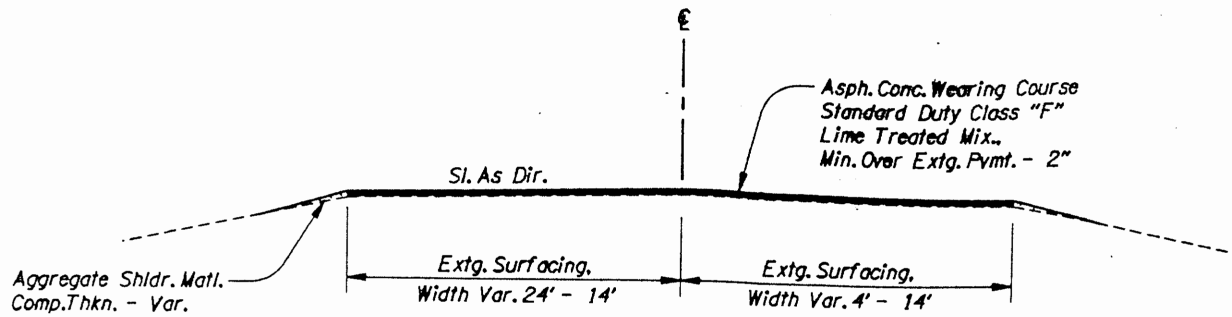
The original design recommended a structural overlay of 2.5 inches (64 mm) of Class "B" (maximum agggregate size 1" (25 mm), dense graded mix) base course overlaid with 2 inches (50 mm) of Class "F" (maximum agggregate size 1" (25 mm), open graded mix) wearing course (*5*). The design was later changed to "preservation" work and only 2 inches (50 mm) of Class "F" wearing course was specified.

## 2.3.2 Tower Road-Stanfield Junction

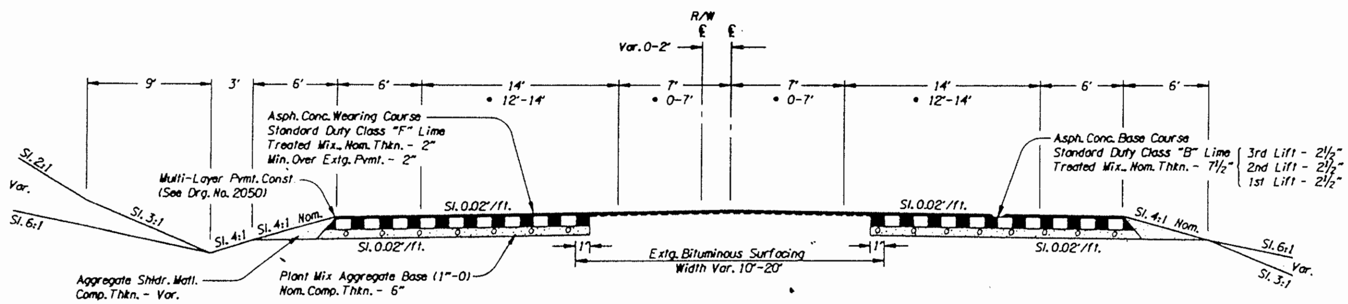
The truck lane on this project had been milled out and inlaid with "B" mix in the mid 1980's. The field investigation by the ODOT Pavement Design Unit indicated that a 2 inches (50 mm) "F" mix overlay would be satisfactory.

## 2.3.3 Azalea-Jumpoff Joe Creek

The pavement design for this project recommended that the distressed pavement areas be milled out approximately 2 inches (50 mm) deep and inlaid with standard duty Class "C" asphalt concrete (maximum aggregate size 3/4" (19 mm), dense graded mix) prior to being overlaid with Class "F" mix. A 2- inch (50 mm) overlay of "F" mix was also recommended for the pavement that was not distressed.




Test Section (PBA -6GR)
STA. 1623+00 TO STA. 1635+00




Control Section (PBA - 6)
STA. 1645+00 TO STA. 1649+40 (TAPER SECTION)
STA. 1649+40 TO STA. 1660+00

Kah-Nee-Ta Jct. - Pelton Dam Rd.
**Typical Cross Sections**

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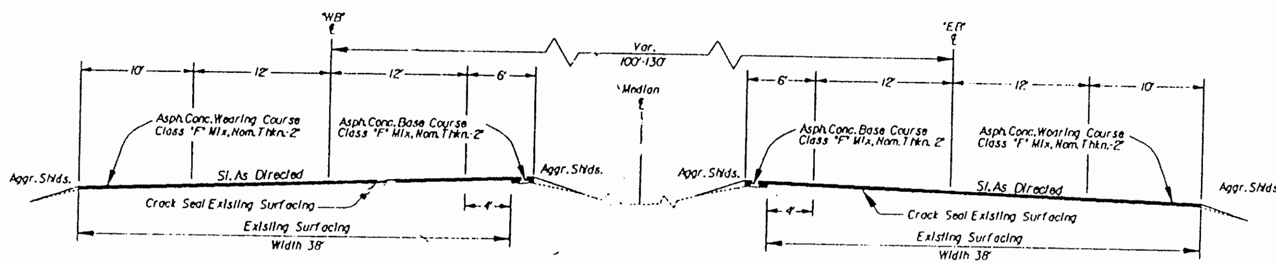
FIGURE 2.2




Test and Control Section

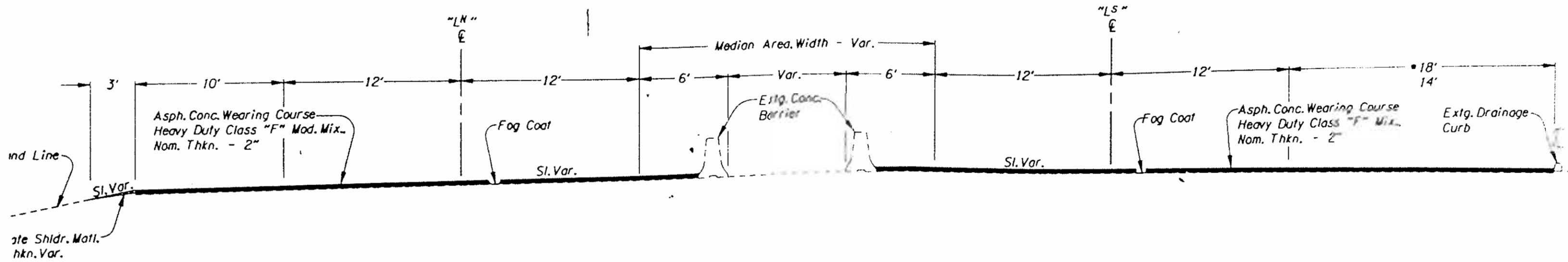
Test Section (PBA - 6GR): MP 166.34 - MP 166.53
STA. 186+00 TO STA. 196+00

Control Section (PBA - 6): MP 167.17 - MP 167.36
STA. 230+00 TO STA. 240+00

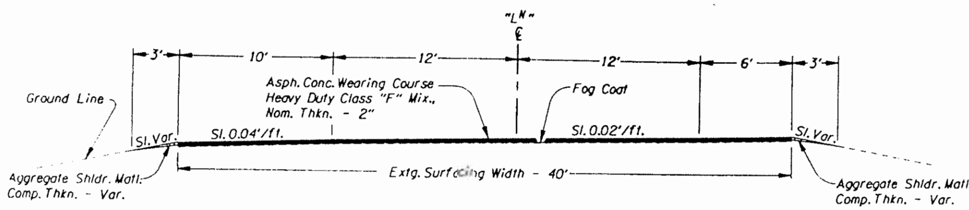
Tower Rd. - Stanfield Int.
**Typical Cross Sections**

RESEARCH UNIT
OREGON DEPARTMENT OF TRANSPORTATION

FIGURE 2.3




Test Section (PBA - 6GR)
MP 80.09 - MP 80.31
STA. 489+00 TO STA. 477+00




Control Section (PBA - 6)
MP 83.50 - MP 83.69
STA. 310+00 TO STA. 300+00

Azalea - Jumpoff Joe
**Typical Cross Sections**

RESEARCH UNIT
OREGON DEPARTMENT OF TRANSPORTATION

FIGURE 2.4

# 3.0 MATERIALS

The paving material suppliers for the PBA-6GR are listed in Table 3.1. The materials used are described following the table.

**Table 3.1 Material Suppliers**

| Materials | Suppliers |
|---|---|
| Asphalt-Rubber: PBA-6GR | U.S. Oil and Refining Co.<br>3001 Marshall Ave.<br>Tacoma, WA 98421<br>Sue McFarland (206) 383-1651 |
| Powdered Rubber: GR-80<br>(Used to produce the PBA-6GR) | Rouse Rubber Industries, Inc.<br>P.O. Box 820369, 1000 Rouse Way<br>Vicksburg, MS 39182-0369<br>Michael Rouse (601) 636-7141 |

## 3.2 MATERIAL DESCRIPTION

**Asphalt Concrete** -- The standard duty Class "F" asphalt-rubber concrete and the standard duty Class "F" mixture were supplied by the contractor.

**PBA-6GR (used in the Class "F" test mix)** -- PBA-6GR was a blend of base asphalt with 10.6, 11.5, or 11.6 percent by weight of powdered rubber. No other modifiers were used. These materials were blended at the U.S. Oil and Refining Company in Tacoma, Washington, pumped into a tanker truck, and transported to the job site. No other blending or special equipment was required.

**Powdered Rubber** -- The powdered, ground tire rubber was supplied to the refinery by Rouse Rubber, Inc. on pallets of bulk storage containers each weighing 3,000 pounds.

**PBA-6 (used in the Class "F" control mix)** -- The PBA-6 used for the three projects was polymer modified. The current ODOT specification for PBA-6 does not require the supplier to designate the polymer used. PBA-6 for the Kah-Nee-Ta Jct. - Pelton Dam project was supplied by Albina Fuel Company. Chevron supplied the PBA-6 material for the Tower Road - Stanfield Interchange and Azalea Jumpoff- Joe projects.

**Truckbed Release Agent** -- A fine mist of diesel was used in the bed of the belly-dump trucks without any observed damage to the mixture or pavement.

**Aggregate** -- Crushed rock from the quarry located near M.P. 110.7 on the Warm Springs Highway, source no. 16-017-04, was used for both the test and control sections on the Kah-Nee-Ta Jct. - Pelton Dam Road project. As a precaution against potential moisture damage, all aggregate was treated with 1.0% hydrated lime prior to entering the paving plant drum. The aggregates were produced in three separate sizes.

The aggregates used for the Tower Road Interchange - Stanfield Jct. project were crushed from a glacial type gravel deposit located at the Shockman Brothers Pit, source no. 25-033-5. The aggregates were produced in three sizes and were lime treated at the combined aggregate cold feed belt.

The Azalea - Jumpoff Joe Section aggregates were produced from recycled mining tailings from the Biencourt source no. 17-023-03. The aggregate was produced in four sizes and lime treated at the combined aggregate cold feed belt.

## 3.3 RESULTS OF TESTS ON BINDER, AGGREGATE, AND RUBBER

This section gives the results of tests on binder, aggregate, and rubber. The tests followed AASHTO, ASTM, or ODOT test methods (*6,7,8*).

### 3.3.1 Binders

Tests were conducted on the binders in three states. The "original" state was the binder as supplied by the manufacturer, the "residue" state was the binder after oven aging in the laboratory, and the "recovered" state was the binder after it was removed in the laboratory from the job asphalt concrete mix.

**Test Results and Specifications --** The test results and specifications for the PBA-6 and PBA-6GR are shown in Tables 3.1 and 3.2. PBA-6 was tested by standard laboratory procedures for that grade. The PBA-6GR was tested to meet the specifications for PBA-6GR, which is the same as PBA-6 with a few exceptions.

PBA-6GR asphalt-rubber specifications require that it meet PBA-6 requirements except:

1. The "Kinematic Viscosity on Original Binder" (AASHTO T-201) specification may be deleted if the contractor makes a written request accepting full responsibility for pumpability of the asphalt cement within the contractor's plant.

2. The ductility test on Rolling Thin Film Oven (RTFO) aged residue (AASHTO T-51) is deleted.

3. The Certification of Compliance accompanying the refinery test report shall certify that ground recycled tire rubber was used as the predominant modifier.

4. The refinery test report shall include the amount of ground recycled tire rubber and total amount of modifier(s) used in the asphalt, expressed as a percentage by weight of total PBA-6GR.

The kinematic viscosity specification was waived in the specification because of the potential for the rubber to plug the viscosity tubes. The ODOT Materials Laboratory was able to test the binder using 10 factor viscosity tubes without problems. If a coarser gradation of rubber would have been used, however, testing may not have been possible.

The current ODOT special provision allowing PBA-6GR does not specify a minimum rubber content for the binder. A rubber content will be specified if/when the ISTEA legislation on the use of tire rubber is reinstated.

**Results of Aging Tests** -- The blending and reaction of asphalt cement with rubber is reported to enhance the engineering properties of the binder (*11*). The reported improved characteristics include resistance to oxidation and aging due in part to the presence of carbon black in the rubber. To compare the aging properties of the binders used on the three jobs, the percent change from the original absolute and kinematic viscosities to the aged viscosities were calculated. The results of the analysis are shown in Figures 3.1a and 3.1b.

Based on the results shown in the Figures, the percent change from original to aged was less in the PBA-6GR than the PBA-6. For the kinematic viscosity, however, there is no well defined relationship. Based on these results, no conclusion on the ability of the PBA-6GR to resist aging can be drawn. Changes in the blending process for the PBA-6GR from 1993 to 1994 may have affected the test results. When the blending process is further refined the variability in the change in the kinematic viscosity should be reduced.

**Film Thickness** -- Film thicknesses were calculated for the three projects for both the PBA-6 and PBA-6GR samples. The film thickness was calculated to be slightly greater for the PBA-6GR versus PBA-6 samples for the Kah-Nee-Ta and Azalea projects. The PBA-6GR film thickness was less than the PBA-6 sample, however, for the Tower Road project. The variability may be due to the use of different polymers in the PBA-6 binders. That is some

PBA-6 binders may provide thicker films depending on the polymer modifier, which may be thicker than PBA-6GR.

**Testing Variability** -- Test results for the cold penetration test (done at 4 °C) done at ODOT were often 3-6 points lower than tests done at the U.S. Oil laboratory. Discussions with the Washington Department of Transportation (WsDOT) indicated that they had not had problems with the cold penetration test results. WsDOT had reported problems, however, in meeting the absolute viscosity specification.

To determine the nature of the variability, round robin testing was initiated between U.S. Oil, WsDOT, OSU, and ODOT labs. The intent of the testing was to determine if the variability in the material may be due to rubber segregation during transport since the WsDOT material was not transported a significant distance and the ODOT material was; or due to laboratory procedures; or ? The results of the testing are not yet available.

**Future Testing --** Because of the variability of results, and to compare the properties of the PBA-6GR binders, the Brookfield Viscometer and the Bending Beam Rheometer (BBR) should be used on future projects for comparison. The Brookfield Viscometer may be easier to use than the conventional capillary tube viscometer which may become clogged with rubber particles. If reliable results are obtained, specification limits should be established.

### 3.3.2 Aggregate

The gradations and gradation specifications of the combined aggregate are presented in Chapter 4. The aggregates passed all listed specifications.

### 3.3.3 Powdered Rubber

The Certificate of Compliance accompanying the Refinery Test Report certified ground recycled tire rubber was used as the modifier. The Refinery Test Reports stated that ground tire rubber in the amount of 10.6% by total weight of PBA-6GR was used in the asphalt for the Kah-Nee-Ta Junction - Pelton Dam project; 11.6% rubber was used for the Tower Road - Stanfield project; and 11.5% rubber was used for the Azalea- Jumpoff Joe project. No additional modifiers were used in the binder. No testing was done on the rubber.

## Table 3.1: Binder Test results - PBA-6

| Test | Method | Specifications | Results | | |
|---|---|---|---|---|---|
| | | | Kah-Nee-Ta Jct.-Pelton Dam Rd. | Tower Rd.-Stanfield Jct. | Azalea-Jumpoff Joe |
| Pen @ 39.2°F (4°C), 100g, 5s, on Residue (dmm) | AASHTO T49[b] | None | 13[a] | - | - |
| Pen @ 39.2°F (4°C), 200g, 60s, on Residue (dmm) | AASHTO T49[b] | 30 (min.) | 35[a], 30[c] | 36[a], 31[c] | 37[a], 33[c] |
| Pen @ 77°F (25°C), 100g, 5s, on Residue (dmm) | AASHTO T49[b] | None | 67[a], 65[c], 82[f] | 84[a], 78[c], 109[f] | 84[a], 78[c], 99[f] |
| Abs. Vis. @ 140°F (60°C), on Original (P) | AASHTO T202[d] | 2000 (min.) | 2210[a], 2967[c] | 5740[a], 3515[c] | 3980[a], 3213[c] |
| Abs. Vis. @ 140°F (60°C), 30 cm, Hg Vac, on Residue (P) | AASHTO T202[b,d] | 5,000 (min.) | 5020[a], 9997[c], 5340[f] | 12,700[a], 8466[c], 3560[f] | 8080[a], 7927[c], 2950[f] |
| Abs. Vis. Ratio (Residue/Original) | AASHTO T202 | 4.0 (max.) | 2.3[a], 3.4[c] | 2.2[a], 2.4[c] | 2.0[a], 2.5[c] |
| Kin. Vis. @ 275°F (135°C), on Original (cSt) | AASHTO T201 | 2,000 (max.) | 593[a], 680[c] | 363[a], 765[c] | 707[a], 830[c] |
| Kin. Vis. @ 275°F (135°C), on Residue (cSt) | AASHTO T201[b] | 275 (min.) | 783[a], 1049[c], 861[f] | 961[a], 986[c], 758[f] | 894[a], 1112[c], 815[f] |
| Duct. @ 77°F, 5 cm/min., on Residue (cm) | AASHTO T51[b,e] | 60 (min.) | 113[a], 60+[c] | 100+[a], 100+[c] | 100+[a], 98[c] |
| Flash Point, COC, Original, °F, (°C) | AASHTO T48 | 450 (min.) (230) | 590+ (310)[a,c] | 520(271)[a], 534(279)[c] | 505(263)[a], 525(274)[c] |

## Table 3.1: Binder Test Results - PBA-6 (continued)

| Test | Method | Specifications | Results | | |
|---|---|---|---|---|---|
| | | | Kah-Nee-Ta Jct.-Pelton Dam Rd. | Tower Rd.-Stanfield Jct. | Azalea-Jumpoff Joe |
| Loss on Heating, of Residue (%) | AASHTO T47[b] | None | 0.13[a,c] | 0.20[a], 0.56[c] | 0.22[a], 0.48[c] |
| Specific Gravity | | | | 1.011 | 1.036 |

[a]Acceptance tests on the binder used in the mix design for ODOT Class "F" mix.
[b]AASHTO T240 test used to age asphalt.
[c]Average of check/record test on the binder used in Class "F" mix.
[d]Viscosity determined at 1 $sec^{-1}$ using ASTM P-159 (Vol. 4.03, 1985) with Asphalt Institute Vacuum Capillary Viscometers.
[e]AASHTO T51 as modified by the Washington DOT (using a special method of applying the release agent).
[f]Test results from binder recovered from mix sampled at the job site.

## Table 3.2: Binder Test Results - PBA-6GR

| Test | Method | Specifications | Results | | |
|---|---|---|---|---|---|
| | | | Kah-Nee-Ta Jct.- Pelton Dam Rd | Tower Rd.- Stanfield Jct. | Azalea- Jumpoff Joe |
| Pen @ 39.2°F (4°C), 100g, 5s, on Residue (dmm) | AASHTO T49[b] | None | 10[a], 7[c] | - | - |
| Pen @ 39.2°F (4°C), 200g, 60s, on Residue (dmm) | AASHTO T49[b] | 30 (min.) | 36[a], 26[c] | 30[a], 32[c] | 31[a], 28[c] |
| Pen @ 77°F (25°C), 100g, 5s, on Residue (dmm) | AASHTO T49[b] | None | 74[a], 57[c], 88[f] | 70[a], 71[c], 104[f] | 67[a], 64[c], 93[f] |
| Abs. Vis. @ 140°F (60°C), on Original (P) | AASHTO T202[d] | 2,000 (min.) | 2060[a], 2400[c] | 2360[a], 2283[c] | 2240[a], 5123[c] |
| Abs. Vis. @ 140°F (60°C), 30 cm, Hg Vac, on Residue (P) | AASHTO T202[b,d] | 5,000 (min.) | 5010[a], 5230[c], 1270[f] | 5700[a], 4818[c], 1140[f] | 5650[a], 10931[c], 1290[f] |
| Abs. Vis. Ratio (Residue/Original) | AASHTO T202 | 4.0 (max.) | 2.4[a], 2.2[c] | 2.5[a] | 2.5[a], 3[c] |
| Kin. Vis. @ 275°F (135°C), on Original (cSt) | AASHTO T201 | 2,000 (min.) | 1540[a], 1240[c] | 1680[a], 1380[c] | 1490[a], 2430[c] |
| Kin. Vis. @ 275°F (135°C), on Residue (cSt) | AASHTO T201[b] | 275 (max.) | 3070[a], 1520[c] | 2910[a], 2150[c], 412[f] | 2460[a], 3190[c], 399[f] |
| Duct. @ 45°F (7°C), 1 cm/min., on Residue (cm) | AASHTO T51[b,e] | None | 32[a], 18+[c] | - | - |
| Duct. @ 77°F, (25°C), 5 cm/min., on Residue (cm) | AASHTO T51[b,e] | 60 (min.) | 48[a], 53[c] | 44[a], 49[c] | 48[a], 55[c] |

## Table 3.2: Binder Test Results - PBA-6GR (continued)

| Test | Method | Specifications | Results | | |
|---|---|---|---|---|---|
| | | | Kah-Nee-Ta Jct.-Pelton Dam Rd. | Tower Rd.-Stanfield Jct. | Azalea-Jumpoff Joe |
| Flash Point, COC, Original, °F, (°C) | AASHTO T48 | 450 (min) (230) | 590+ (310+)[a], 561 (294)[c] | 568 (298)[a], 586 (308)[c] | 522 (272)[a], 514 (268)[c] |
| Loss on Heating, of Residue (%) | AASHTO T47[b] | | 0.24[a], 0.35[c] | 0.23[a], 0.36[c] | 0.26[a], 0.33[c] |
| Specific Gravity | | | 1.0328[h] | 1.025[a] | 1.025[a] |

[a]Acceptance tests on the binder used in the mix design for ODOT Class "F" mix.
[b]AASHTO T240 test used to age asphalt.
[c]Check/record test on the binder used in Class "F" mix
[d]Viscosity determined at $sec^{-1}$ using ASTM P-159 (Vol. 4.03, 1985) with Asphalt Institute Vacuum Capillary Viscometers.
[e]AASHTO T51 as modified by the Washington DOT (using a special method of applying the release agent).
[f]Test results from binder recovered from mix sampled at the job site.
[g]The contractor made a written request to delete this test requirement. Subsequently, the requirement was deleted as allowed by special provisions.
[h]Reported on the Certificate of Compliance supplied by the manufacturer.

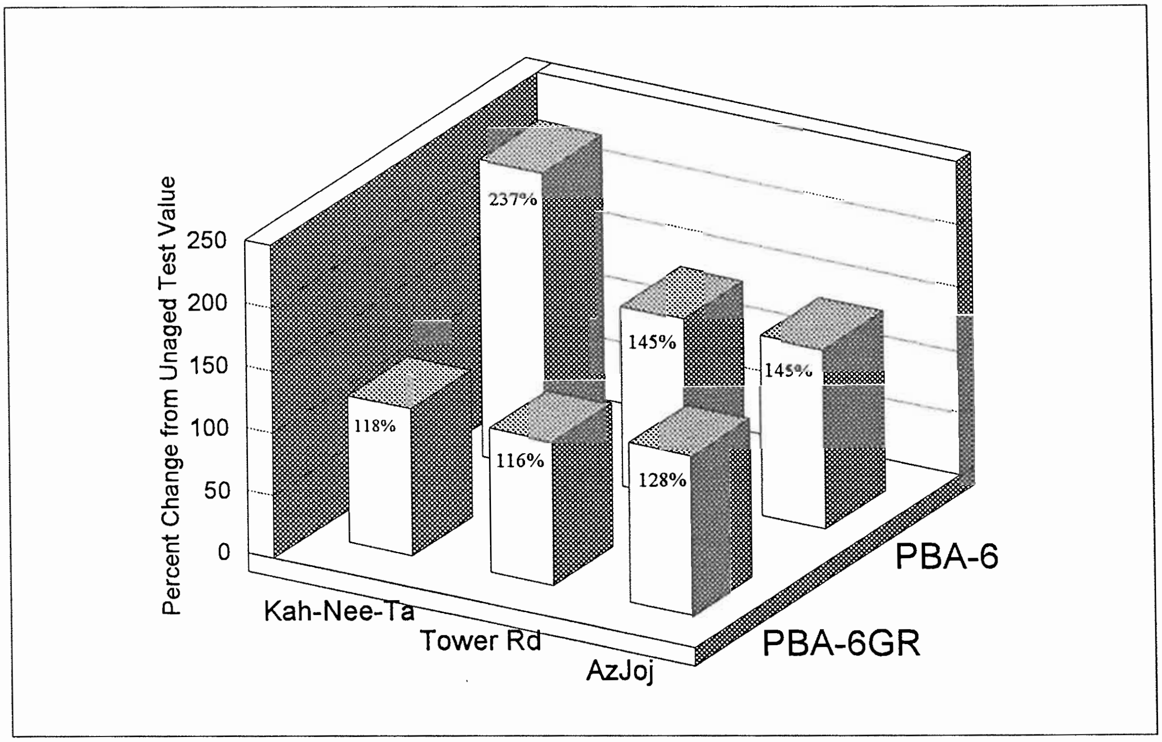



Figure 3.1a. Percent Change from Original to Aged Absolute Viscosity (60°C).

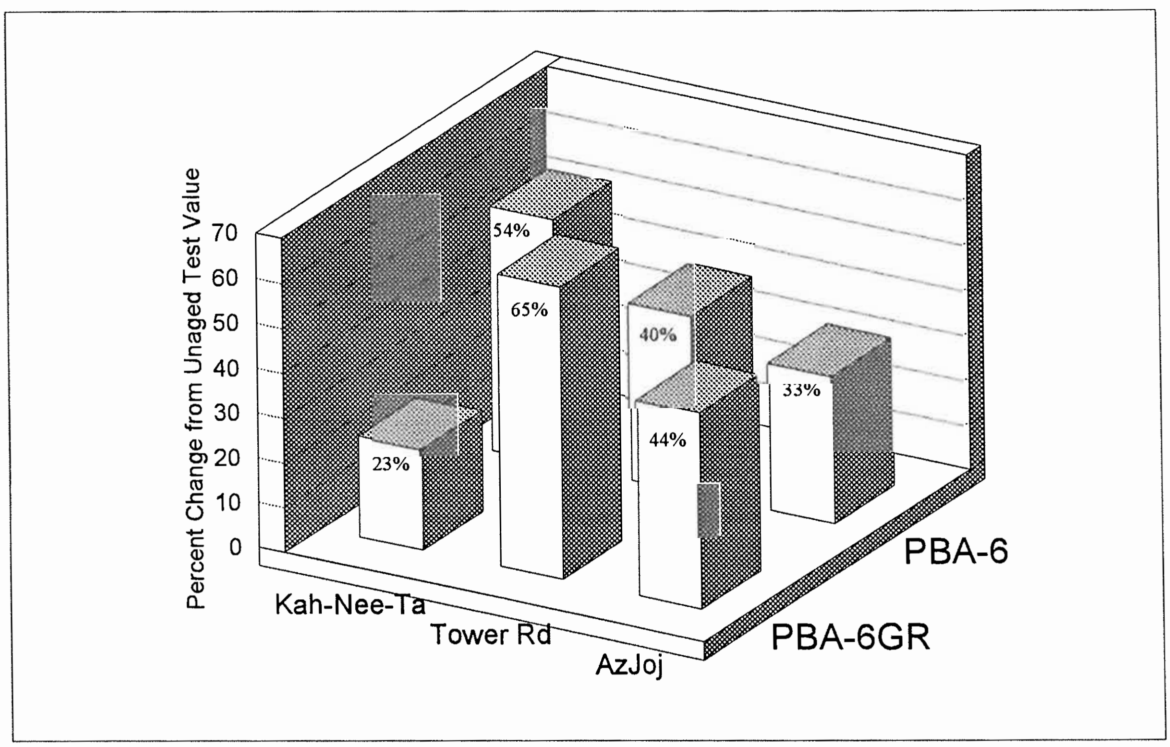



Figure 3.1b. Percent Change from Original to Aged Kinematic Viscosity (135°C).

# 4.0 MIX DESIGNS

This section presents the mix designs and job mix formulae for the test and control pavements. The mix design criteria and the mix design results are presented in Table 4.1.

## 4.1 ODOT's CLASS "F" MIX DESIGN

The Class "F" mix design is based on a modified FHWA procedure for open-graded mixes (*9*). The procedure is based on void content of compacted specimens and binder film thickness based on binder drain down. The binder drain down specified by ODOT is 75-90% (*9*). This relates to a binder drain down from the aggregate mixture while being heated in an oven at 325 °F (163 °C). The mixture is placed in a clear glass cake pan and the drain down percentage is gauged by the amount of binder collected on the bottom of the cake pan. Broadband limits, mix design criteria, and design mix properties are listed in Table 4.1.

The Index of Retained Strength (IRS) test or the environmental conditioning system (ECS) test was used to determine the need for an anti-stripping additive. Only lime treatment of the aggregate was indicated.

## 4.2 CLASS "F" MIX DESIGN USING PBA-6GR

The same design method used for the standard Class "F" mix was used for the Class "F" mix with PBA-6GR. The binder drain down method to determine optimum film thickness, however, was found to be ineffective since the PBA-6GR does not drain down like conventional asphalt. Reports published by the National Center for Asphalt Technology (NCAT) indicate that adding fine rubber to asphalt could significantly decrease the drain down of asphalt off the aggregate particles due to the increased viscosity of the binder. The modified binders would also produce thicker films on the aggregate, compared to unmodified asphalts at a given temperature (*10*). After the first PBA-6GR mix was designed, the optimum asphalt content was selected based on a target of 12-16% voids at first compaction (determined geometrically), while limiting the voids filled with asphalt (VFA) to less than 50%.

## Table 4.1: Mix Design Criteria and Design Mix Characteristics at Design Binder Contents
## Class "F", Open-Graded Mix

| **Characteristics** | **Class "F" Mix Design Criteria** | **Class "F" Design Mix** | | | | | |
|---|---|---|---|---|---|---|---|
| | | Kah-Nee-Ta Jct.-Pelton Dam Rd. | | Tower Rd.-Stanfield Interchange | | Azalea-Jumpoff Joe | |
| | | w/PBA-6[b] | w/PBA-6GR[b] | w/PBA-6 | w/PBA-6GR | w/PBA-6 | w/PBA-6GR |
| Gradation (% Passing Screen) | | | | | | | |
| 1-inch (25.4 mm) | 99 - 100[a] | 100 | 100 | 100 | 100 | 100 | 100 |
| 3/4-inch (19.1 mm) | 85 - 96 | 89 | 89 | 91 | 91 | 93 | 93 |
| 1/2-inch (12.7 mm) | 60 - 71 | 61 | 61 | 63 | 63 | 65 | 65 |
| 3/8-inch (9.5 mm) | - | 42 | 42 | 43 | 43 | 45 | 45 |
| 1/4-inch (6.3 mm) | 17 - 31 | 25 | 25 | 23 | 23 | 23 | 23 |
| #10 (2.03 mm) | 7 - 19 | 10 | 10 | 10 | 10 | 12 | 12 |
| #40 | - | 5 | 5 | 5 | 5 | 6 | 6 |
| #200 | 1 - 6 | 3.1 | 3.1 | 3.3 | 3.3 | 2.9 | 2.9 |
| Binder Content, % | 4 - 8[a] | 5.1 | 5.1 | 5.5 | 5.5-6.0 | 5.6 | 5.0 |
| Binder Film Thickness | Sufficient[c] | Sufficient | Dry | Suff.-Thick | -- | Thick | Dry-Suff. |
| Voids @ 1st Comp, % | 12 - 16[e] | 13.7[f] | 14.0[f] | 12.3 | 13.4 - 12.1 | 12.4 | 13.7 |
| Rice Max. Sp. Gr. | None | 2.664 | 2.647 | 2.522 | 2.545 - 2.523 | 2.670 | 2.683 |
| Voids in Mineral Aggregate, % (VMA) | None | 23.9 | 24.4 | 23.1 | 23.4 | 23.8 | 24.1 |
| Voids Filled with Asphalt, % (VFA) | None | 42.7 | 43.8 | 46.9 | 42.8 - 48.2 | 47.9 | 43.2 |
| Index of Retained Strength, % | 75 | 74 | 62; 78[d] | [g] | [g] | [g] | [g] |

**Table 4.1: Mix Criteria and Design Mix Characteristics at Design Binder Contents Class "F", Open-Graded Mix (continued)**

| Characteristics | Class "F" Mix Design Criteria | Class "F" Design Mix | | | | | |
|---|---|---|---|---|---|---|---|
| | | Kah-Nee-Ta Jct.-Pelton Dam Rd | | Tower Rd.-Stanfield Interchange | | Azalea-Jumpoff Joe | |
| | | w/PBA-6[b] | w/PBA-6GR[b] | w/PBA-6 | w/PBA-6GR | w/PBA-6 | w/PBA-6GR |
| Draindown, 0% | 75 | 85 | 45 | 65 | 20 - 30 | 80 | - |
| Environmental Conditioning System, % (ECS) | 80 | - | 90 | 79 | - | 80 | 82[h] |

[a]Broadband limits for gradation and binder content. Gradations are percentages of dry ingredient weight, including 1 % lime. Binder contents are percentage of total mix weight.
[b]Mix Design sample at design binder content results in this column.
[c]Visual examination based on ODOT mix design procedure and guidelines.
[d]With 0.5% Pave Bond special; additional "Environmental Conditioning System" testing done by OSU indicated adequate resistance to stripping without Pave Bond special.
[e]Based on geometrically measured core.
[f]Determined at a binder content of 5%.
[g]ECS test used to determine moisture susceptibility.
[h]Tested at a binder content of 5.6%.

### 4.2.1 Kah-Nee-Ta Junction-Pelton Dam Road

The mix design drain down data for the Kah-Nee-Ta Jct. - Pelton Dam Road ranged from 45% at 5.1% binder content to 60% at 7.0% binder. Since the drain down percentages were low at relatively high asphalt contents, the PBA-6GR asphalt content was based on the results of the PBA-6 mix design. Therefore, the same percent of asphalt, 5.1%, was selected for the test section as well as the control section. Figure 4.1 shows the variation in percent drain down to binder content for both the PBA-6 and PBA-6GR.

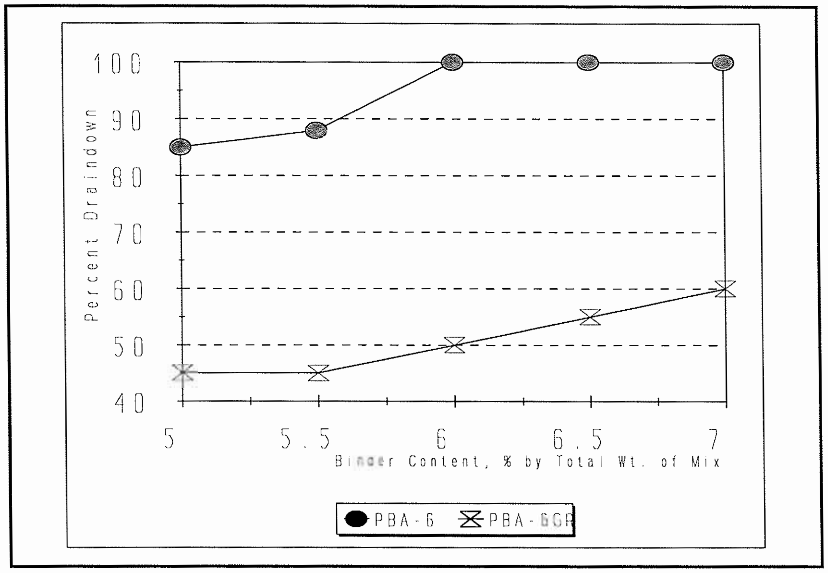



Figure 4.1. Draindown Comparison for Kah-Nee-Ta Project Mix Design.

By specifying the binder content for the test section based on the drain down results from the control section, the voids for both mixes were similar. If the PBA-6GR mix binder content had been increased to 6.0%, the void content would have dropped to about 11.4%, below the specified void content limit.

To further investigate the performance of the PBA-6GR, binder film thicknesses were calculated based on the effective volume of asphalt, surface area of the aggregate, and weight of aggregate for a given volume of mix. Based on results of the mix design samples, the "F" mix with PBA-6GR film thickness was estimated to be about 5.5% greater than the conventional "F" mix. Field sample test calculations (based on data from Table 6.1) confirmed the thicker film on the PBA-6GR mix.

### 4.2.2 Tower Road-Stanfield Interchange

Drain down for the PBA-6GR mixes was not considered in the design. The mix design for the Tower Road project included a calculation of the volume of voids and the VFA calculated at various asphalt contents. The void content determined after the first compaction was 13.4% and VFA calculated was 42.8% at the design binder content of 5.5%. Figures 4.2a and 4.2b, indicate the variation in volume of voids and VFA as a function of binder content.

### 4.2.3 Azalea-Jumpoff Joe Creek

The mix design for the Azalea project also included calculation of the volume of voids and the VFA at various asphalt contents. The void content determined after the first compaction was 13.7% and the VFA was 43.2% at the design binder content of 5.0%. Figures 4.3a and 4.3b, indicate the variation in volume of voids and VFA as a function of binder content.

## 4.3 SUMMARY

Several mix design methods were evaluated to determine the design binder content for the PBA-6GR mixes. The FHWA modified test based on drain down, was not effective in determining the design binder content for the PBA-6GR mixes as demonstrated in the Kah-Nee-Ta project. For that project, the PBA-6 drain down was 85% and the PBA-6GR drain down was 45% at the same binder content. Therefore, it may be appropriate to develop a mix design specific to asphalt-rubber binders. One approach would be to determine the asphalt content based on drain down results for a conventional open-graded mix and use that design for the asphalt-rubber mix (as was done for the Kah-Nee-Ta projects) or increase the binder content proportional to the rubber content of the modified binder (*11*).

The alternate mix design used included preparing a range of mix samples at varying asphalt contents, evaluating drain down, and calculating void contents. The design binder content was determined where the void content was at least 12% and the VFA did not exceed 50%. The greater film thickness gained by an increase in binder content may increase the life of the pavement by increasing the resistance to oxidation, water damage, and stud wear.

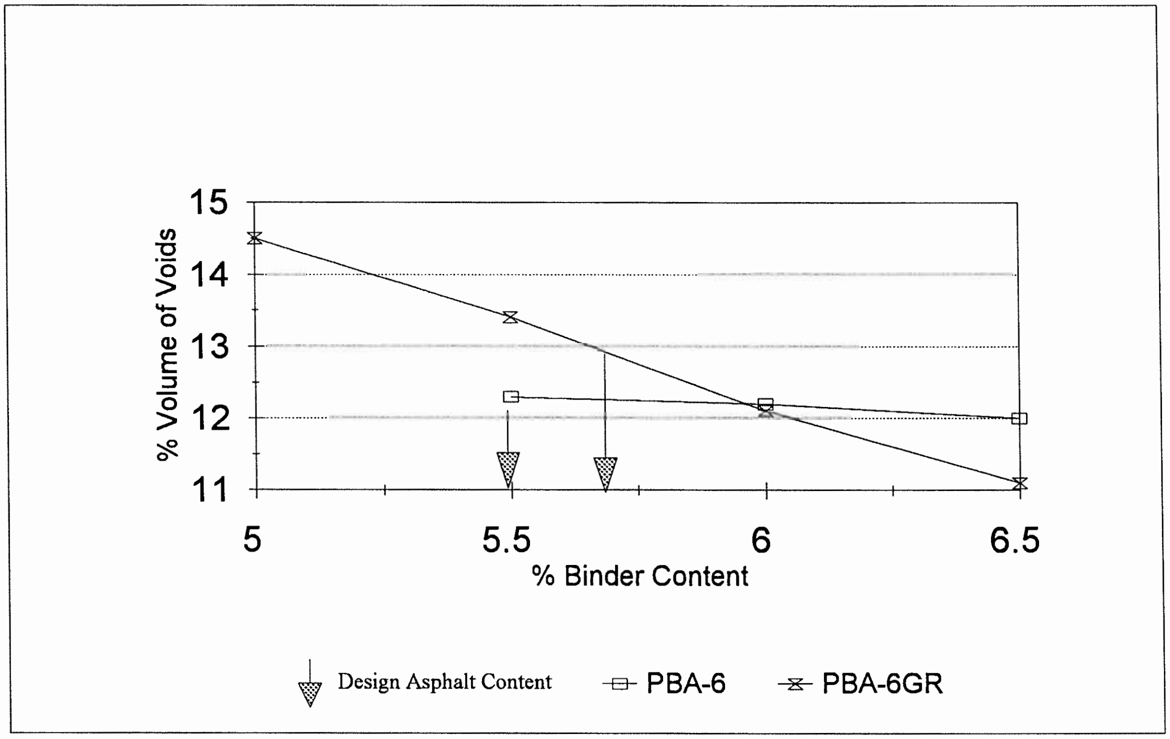



**Figure 4.2a. Tower Road - Stanfield Int.: Volume of Voids vs. Binder Content.**

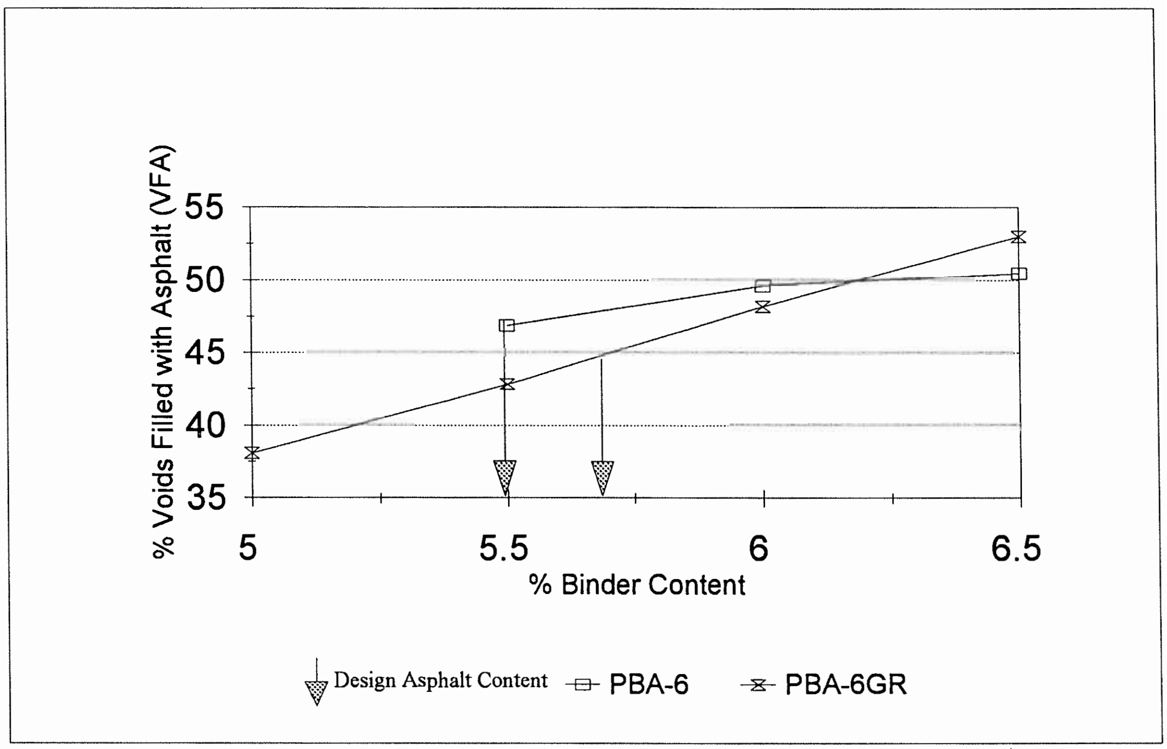



**Figure 4.2b. Tower Road - Stanfield Int.: Voids Filled with Asphalt vs. Binder Content.**

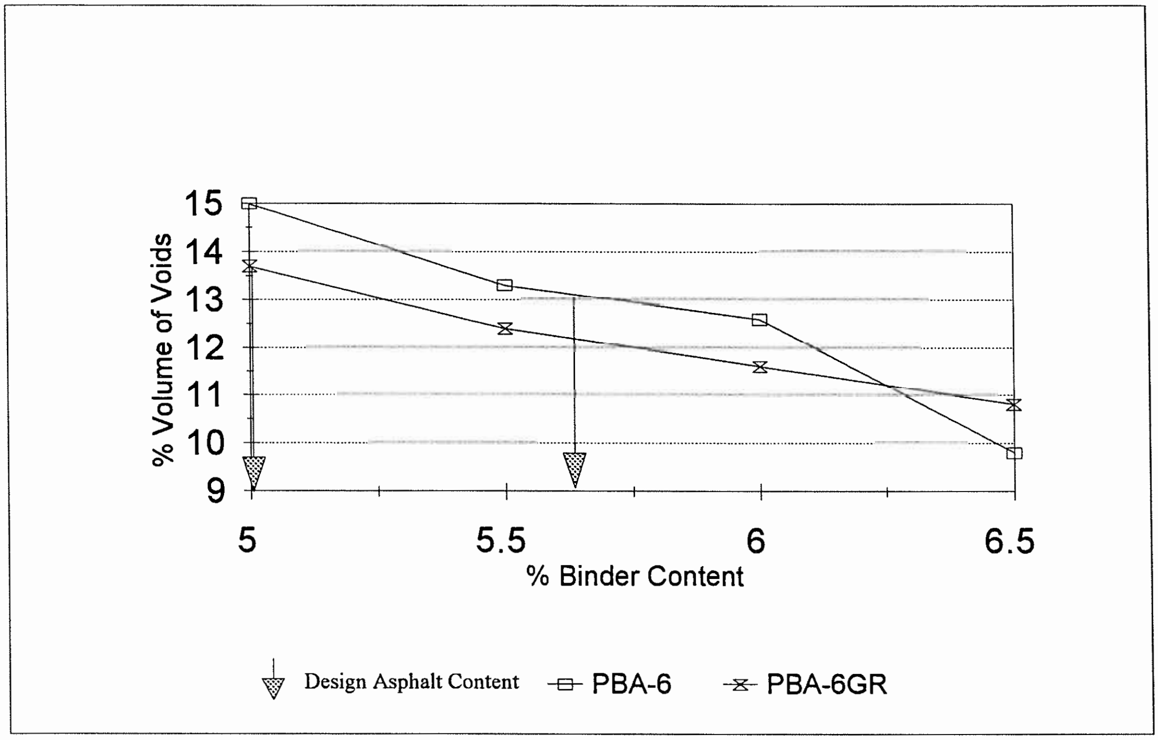



**Figure 4.3a. Azalea - Jumpoff Joe: Volume of Voids vs. Binder Content.**

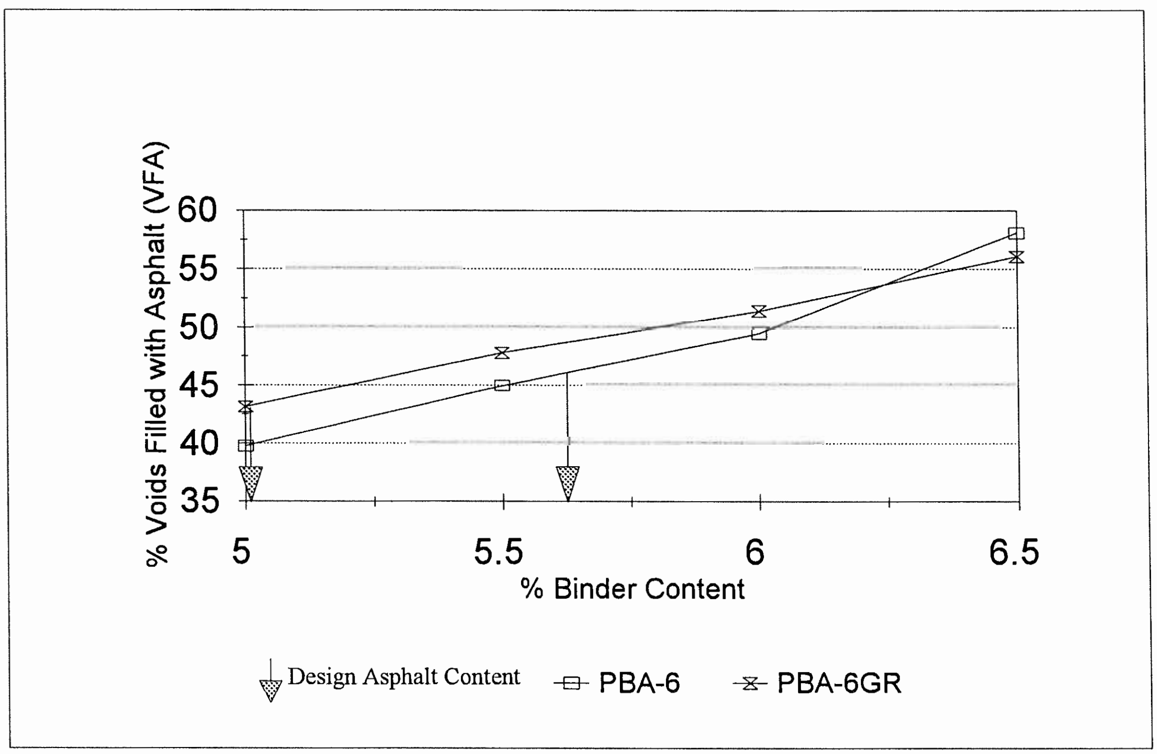



**Figure 4.3b. Azalea - Jumpoff Joe: Voids Filled with Asphalt vs. Binder Content.**

# 5.0 CONSTRUCTION

This chapter describes construction of the three subject projects. Data on weather conditions during construction, including random measurements of air temperature and road surface temperature prior to paving, are included. The test results from samples collected in the field during control and test section construction are also summarized. The sections of the project's Special Provisions that apply to the use of PBA-6GR are in the Appendix (*13*).

## 5.1 KAH-NEE-TA JCT-PELTON DAM SECTION

Construction of the test section occurred in September 1993. The following discussion includes direct observations of the Class "F" mix with PBA-6GR only. Construction of the "F" mix control section with PBA-6 was done six weeks earlier and was not monitored by Research. Class "F" mix construction with PBA-6 observations were obtained from the Project Manager and based on previous experience with similar mixes.

### 5.1.1 Mixing Plant

The mixes were produced in a Caterpillar brand drum dryer asphalt hot plant, Model 2000, rated at 360 tons (330 metric tons) per hour. The average production was about 240 tons per hour (220 metric tons per hour) for the control and test mixes. The plant was equipped with a 100-ton (90-metric ton) storage silo for the hot mix and a 50-ton (45-metric ton) storage silo for the hydrated lime.

The PBA-6GR was pumped directly from the tanker truck to the hot mix plant. No intermediate mixing of the binder was necessary. It was noted by the plant foreman that the PBA-6GR did not pump as easily as the PBA-6 even though the temperature was increased from the PBA-6 pump temperature of 315 °F (157 °C) to 340 °F (170 °C). The pump volume, however, was adequate for the aggregate quantity being fed into the plant.

The Class "F" mix with PBA-6GR discharge temperature from the plant ranged from 305 °F (152 °C) to 315 °F (157 °C). This was much higher than the normal temperature of 260± °F (127 °C) for the Class "F" mix with PBA-6. The estimated normal temperature is based on the mix design and typical Class "F" mixes with PBA-6.

### 5.1.2 Hauling

The mixture was hauled to the paving site in belly dump trucks. Haul times ranged from 30 to 45 minutes with pilot car traffic flow occasionally creating an additional 10 to 20 minute delays between trucks. To prevent the mix from sticking to the truck beds, a light mist of diesel was used as a truckbed release agent without any detrimental effect observed.

### 5.1.3 Placement and Compaction

The paving operation was not continuous due to traffic congestion caused by the piloting of traffic through the construction zone. The Class "F" mix with PBA-6GR, however, held the heat very well. In addition, because of the mix consistency, the paver did not settle into the mat during delays.

The PBA-6GR mixture was spread in a windrow at 275 °F (135 °C) to 285 °F (140 °C) in front of a CMI pickup machine attached to a Blaw Knox PF220 paver. The mixture flowed through the paver smoothly with little segregation.

The mat temperature immediately behind the paver ranged from 260 °F (127 °C) to 270 °F (132 °C). Breakdown was done with an Ingersol Rand DA50 double drum vibrating roller used only in static mode. The mat consolidated 3/8-inch (10 mm) to 1/2-inch (13 mm) leaving a final mat thickness of 2 inches (50 mm). The breakdown roller made four passes. The finish roller continued rolling until all roller marks were removed. The finish roller was the same brand and model as the breakdown roller and was also operated in the static mode. The mat temperature before finish rolling was about 235 °F (113 °C), and about 190 °F (88 °C) to 200 °F (93 °C) at completion.

The mix had a flat-black appearance compared to a conventional mix which appears shiny. Because of the appearance, adjustments to the binder content should not be based on visual observations.

Weather conditions were very good during construction as shown in Table 5.1.

Table 5.1 Construction Climatic Conditions (Kah-Nee-Ta Jct. - Pelton Dam Section)

| Date/Weather | Time of Day | Air Temperature, °F (°C) | Pavement Temperature, °F (°C) |
|---|---|---|---|
| 10/5/93 | | | |
| Clear | 11:00 a.m. | 73 (23) | 94 (34) |
| Clear/Humid | 3:00 p.m. | 85 (29) | 104 (40) |
| 10/6/93 | | | |
| Overcast | 9:00 a.m. | 58 (14) | 71 (22) |
| Overcast/ | 12:00 p.m. | 74 (23) | 91 (33) |
| Pleasant | 4:00 p.m. | 70 (21) | 83 (28) |

### 5.1.4 Control "F" and Test Section "F" Mix Comparison

The same equipment and personnel were used to mix and place the control and test sections. Based on observations made during construction it appeared that the mix produced with PBA-6GR binder was easier to handle.

According to the inspector, the PBA-6GR mixture was easier to work with than the PBA-6. The freestanding edge of the mat with the PBA-6GR did not round over as it cooled and kept a sharp edge until the next lane could be paved to support it. When raking a joint, the PBA-6GR mix would compact at the joint and nearly become invisible when compared to the control. With the PBA-6GR, a hot lap joint worked equally as well as the cold longitudinal and transverse joint match. The PBA-6GR mat did not shove or creep under the rollers or slough-off in areas of extra thickness, i.e., during construction of super elevated curves.

## 5.2 TOWER ROAD-STANFIELD JUNCTION

The discussion includes direct observation of the construction of the Class "F" mix with PBA-6GR test section and PBA-6 control section.

### 5.2.1 Mixing Plant

The plant was an AESCO DM 400 drum mix plant rated at 400 tons/hour (360 metric tons/hour). The normal rate of production for the "F" mixes is about 315 tons/hour (285 metric tons/hour). The recorded production rate for the PBA-6GR mix was 300 tons/hour (270 metric tons/hour). The plant was equipped with a 100-ton (90-metric ton) short term storage silo for the hot mix and a 50-ton (45-metric ton) storage silo for the hydrated lime.

The PBA-6GR was pumped directly from the tanker truck into a heated storage tank, held at 335 °F (168 °C), and then pumped to the paving plant. The PBA-6 was handled the same way.

The paving plant operator said the PBA-6 mix appeared to have a stiffer consistency. The electric motor that pulled the slat conveyer required more amperage to move the same amount of mix at a given temperature up into the storage silo. To adjust for the stiffer mix, the mix temperature was increased by 20 °F (11 °C) as measured at the drum discharge chute.

The mix temperatures at the discharge chute of the plant as measured with an infrared gun were 285 °F (141 °C) to 295 °F (146 °C) for the PBA-6GR, and 305 °F (152 °C) to 315 °F (157 °C) for PBA-6 mixture.

### 5.2.2 Hauling

The mixture was hauled in belly dump trucks with a turn around time from 45 to 75 minutes. To prevent the mix from sticking to the truck beds a light mist of diesel was used. However, the truck drivers said the PBA-6GR mix did not stick as much as the PBA-6.

### 5.2.3 Placement and Compaction

**PBA-6GR**

The mixture was spread in a windrow at 260 °F (127 °C) in front of a pickup machine attached to a Blaw Knox PF220 paver. Both the PBA-6 and PBA-6GR flowed through the paver smoothly. The PBA-6GR mixture held heat longer than the PBA-6 mix and was more manageable.

The mat temperature behind the paver ranged from 250 °F (121 °C) to 285 °F (141 °C). The hot lap joint constructed at the Boardman exit looked very good. The rakers had little trouble pushing the mix where they wanted it to go. The paving foreman said he would like to do all the job with this mix.

The roller operator on the DynaPac model CC50A 15.5-ton (14.0-metric ton) breakdown roller said the PBA-6GR mix was very forgiving and did not leave a bump when reversing direction. The finish roller, a Hyster model C766A 10-ton (9-metric ton), had difficulty rolling out the marks when the air temperature was near 100 °F (38°C) because the mix held the heat.

When the air temperature was near 100 °F (38 °C) the panel paved the previous day became very tacky. Where the binder appeared to be at a maximum film thickness, the traffic had a tendency to pull off some of the binder creating a glossy look instead of a dull flat black look.

A fat spot was noticed on the inside lane near the center of the panel around Station 1413. The area was about 4 feet (0.3 m) long and 5 - 6 inches (130 to 150 mm) wide, and angled across the panel, not parallel with the centerline. This area of the panel contained 6.0% binder and the surface was quite shiny compared to other areas with less PBA-6GR. The shiny area was the only one observed and could possibly be caused by the migration of the crack sealer used prior to the overlay.

On the second day of paving, the binder content was reduced from 6.0% to 5.7% and the mixture looked dull or flat black again.

The weather conditions were very good during construction as shown in Table 5.2.

**Table 5.2 Construction Climatic Conditions for Tower Road-Stanfield Interchange**

| DATE/WEATHER | TIME OF DAY | AIR TEMP °F (°C) | PAVEMENT TEMP °F (°C) |
|---|---|---|---|
| 7/11/94 | | | |
| Clear | 7:30 a.m. | 66° (19°) | 135° (57°) |
| Clear/Hot | 2:30 p.m. | 91° (33°) | 150° (66°) |
| 7/12/94 | | | |
| Clear | 10:00 a.m. | 80° (27°) | 142° (61°) |
| 7/13/94 | | | |
| Clear | 7:30 a.m. | 73° (23°) | 126° (52°) |
| Clear/Hot | 2:30 p.m. | 104° (40°) | 160° (71°) |
| 7/14/94 | | | |
| Clear | 9:30 a.m. | 87° (31°) | 146° (63°) |
| Clear/Hot | 11:00 a.m. | 96° (36°) | - |
| Clear/Hot | 3:00 p.m. | 103° (39°) | - |

**PBA-6**

This mix was very shiny and black. The sun sparkled on the surface like black water. As this mixture began to cool, a film of binder seemed to set-up on the surface and the mixture became nearly impossible to rake or shovel. The paver operator said the PBA-6 cooled more quickly in the windrow creating a stiff mix. The stiff mix would tear off the paddles of the pickup machine if it cooled too much.

Compaction of the PBA-6 mix was more difficult since the mix was stiffer than the PBA-6GR mix. The roller operator indicated that it was more difficult to remove the "bump" marks when a roller stopped to change direction of travel. The high gloss surface made it difficult for the roller operator to see where more rolling was required to remove roller marks.

## 5.3 AZALEA-JUMPOFF JOE CR.

The discussion includes observation of the construction of the Class "F" mix with PBA-6GR and information collected on the construction of the PBA-6 control section.

### 5.3.1 Mixing Plant

The mixing plant used on this project was an Astec PFM 368 with a rated capacity of 400 tons per hour (360 metric tons per hour). The typical production rate for the Class "F" with PBA-6 was about 360 tons per hour (330 metric tons per hour) and the production using PBA-6GR was between 280 and 320 tons per hour (250 and 290 metric tons per hour). The plant was equipped with a 65-ton (60-metric ton) short-term storage Silo for hot mix and a 50-ton (45-metric ton) capacity storage silo for the hydrated lime.

The contractor used an off loading pumping system with a 3-inch (80 mm) intake line and a 2-inch (50 mm) discharge line. The unloading time for the asphalt-rubber delivery tankers was increased by about 2 1/2 to 3 times compared to the PBA-6, due to the higher PBA-6GR viscosity. Because of the problems in pumping the PBA-6GR, the mix production was reduced by about 20 percent.

The mix temperatures at the discharge chute of the plant as measured with an infrared gun were 270 °F (132 °C) to 275 °F (135 °C) for the PBA-6 mixture and 293 °F (145 °C) to 320 °F (160 °C) for the PBA-6GR mixture. Both the PBA-6 and PBA-6GR mixtures produced a noticeable amount of blue smoke and steam when dumped into the trucks.

### 5.3.2 Hauling

The mixture was hauled in belly dump trucks with a turn around time of about 30 minutes. To prevent the mix from sticking to the truck beds a light mist of diesel was used and applied through a garden hose nozzle.

### 5.3.3 Placement and Compaction

PBA-6GR and PBA-6

The PBA-6GR mixture was spread in a windrow at 290 °F (143 °C) with one reading at 312 °F (156 °C) in front of a pickup machine attached to a Blaw Knox PF 220 paver. The mixture flowed through the paver smoothly and was easy to handle as far as raking and repairing minor imperfections in the panel. The binder content was deceiving because the mixture looked dull or flat black as compared to the shiny, glossy look of the PBA-6 mixture.

After working with the PBA-6GR mix for an hour or two, the paving foreman asked if this mixture could be substituted for the PBA-6 mix to be placed on the interchange ramps because of the workability. The paving crew all agreed that this mix was easier to work with and made a better looking panel than the PBA-6 mixture.

The roller operator on the breakdown DynaPac #CC501 12-ton (11-metric ton) roller said the PBA-6GR was easier to work with than the PBA-6 mix. The PBA-6GR mixture would support the roller better and would not leave a permanent bump when a reverse in direction was made. The finish roller, a cat #BC534 8-ton (7-metric ton) roller had no trouble removing the roller marks in the panel. When laying the PBA-6GR mixture on "supered" curves, the mixture did not push down to the low side when rolled.

The PBA-6GR mixture did not create "gobs" of fines and binder that collected on the discharge gate of the mix storage silo or on the gates of the belly dump trailers as did the PBA-6 mixture.

Project observed temperatures:

**Table 5.3 Construction Climatic Conditions for Azalea-Jumpoff Joe**

| | PBA-6 | PBA-6GR |
|---|---|---|
| Air Temperature | 95°F (35 °C) | 98°F (37 °C) |
| Pavement Temp. | 133°F (56 °C) | 126°F (52 °C) |

### 5.3.4 Observations and Comments

There were problems pumping the PBA-6GR binder from the transport truck into the asphalt storage tank with a Viking pump with a two-inch (50 mm) diameter discharge line. Apparently the flow was reduced because of the PBA-6GR viscosity. The reduced flow created an increased unloading time for the asphalt transport trucks and reduced the mixing plant production.

The PBA-6GR manufacturer had increased the viscosity of the asphalt-rubber binder to allow for testing variations between laboratories for the project. The increased binder viscosity should be manageable by contractors with well maintained heated circulating asphalt storage tanks that are equipped with transfer pumps with large enough flow lines to accommodate the higher viscosity materials.

## 5.4 SUMMARY

Based on the results of monitoring the PBA-6GR mix construction, the rubber modified binder may require hotter mixing temperatures. No problems or special needs associated with construction of the PBA-6GR mix were encountered. Substitution of the PBA-6GR for PBA-6 binder should not present any problems during construction.

A summary of the control and test mix characteristics are presented in Table 5.4. Table 5.5 presents a summary of binder mix temperatures at various stages of construction.

**Table 5.4 Control and Test Section Mixture Comparisons**

| | **Control "F" Mix (PBA-6)[1]** | **Test "F" Mix (PBA-6GR)[2]** |
|---|---|---|
| Binder Sticky and Stringy | Yes | No |
| Binder Collects on Truck Dump Gates | Yes | No |
| Paver Settles into the Mat During Delays | Yes | No |
| Mix Shoves Laterally During Compaction | Yes | No |
| Aggregate and Binder Separates at Elevated Temperatures | Yes (and puddles) | No |

[1]Conditions that generally occur with PBA-6 Class "F" Mix.
[2]Conditions measured in the field during construction.

**Table 5.5 Control and Test Section Mixture Comparisons**

| | **Kah-Nee-Ta Jct.- Pelton Dam Rd.** | | **Tower Rd.- Stanfield Interchange** | | **Azalea- Jumpoff Joe** | |
|---|---|---|---|---|---|---|
| | PBA - 6 | PBA - 6GR | PBA - 6 | PBA - 6GR | PBA - 6 | PBA - 6GR |
| Binder Temp. at Mixing °F (°C) | 315 (157) | 340 (171) | - | 335 (168) | - | 305 (152) |
| Plant Discharge Temp. °F (°C) | 260 (127) | 315 (157) | 310 (154) | 290 (143) | 300 (150) | 300 (150) |
| Windrow Temp. °F (°C) | 220 (104) | 280 (130) | 296 (147) | 260 (127) | - | 290 (143) |
| Temp. Behind Paver °F (°C) | - | - | 280 (138) | 265 (129) | - | 280 (138) |
| Finish Rolling Begins °F (°C) | 212 (100) | 235 (113) | - | - | - | - |

# 6.0 SAMPLING AND TESTING

This chapter describes the special sampling and testing methods needed for the evaluation of the PBA-6GR binder performance. The sections of the Special Provisions that applied to the PBA-6GR binder are in the Appendix (*13*).

## 6.1 BINDER TESTING

All tests normally performed on conventional asphalt were used for the PBA-6GR binder with the exception of the kinematic viscosity test on the original binder (AASHTO T-201) and the ductility on the aged residue (AASHTO T-51). The contractor made a written request to delete the kinematic viscosity test on the original binder, and by doing so, assumed full responsibility for the pumpability of the product. The results of the binder testing are included in Tables 3.2 and 3.3.

## 6.2 RUBBER CERTIFICATION

The amount of ground recycled tire rubber and the total amount of modifier(s) used was included with the Refinery Test Report. A Certificate of Compliance was also with the Refinery Test Report certifying that ground recycled tire rubber was used as the predominant modifier.

## 6.3 BINDER CONTENT DETERMINATION

A nuclear asphalt content gauge was used on the Kah-Nee-Ta Junction - Pelton Dam Road project to determine the binder content of both the control and test mixes. The ODOT central laboratory furnished the calibration transfer data (*14*). Comparisons made between daily asphalt cement reports, which include daily calculations of asphalt content, were within 0.1% of the nuclear asphalt content gauge readings. The close correlation supports the use of the nuclear asphalt content gauge in determining PBA-6GR binder content. The meter method was used to determine the asphalt content for the 1994 projects.

## 6.4 MIXTURE SAMPLING FOR RESEARCH

Several boxes of the mixes sampled at the jobsite were obtained for testing. The gradation and asphalt content test results are included in Table 6.1 Four core samples were also obtained in each test and control section after construction. The resulting average void contents and rice gravities are included in the table.

The volume of voids determined during mix design testing was compared to the volume of voids determined from cores taken from the constructed control and test sections. A graph of the relationship is shown in Figure 6.1. The in-place void contents from cores for two of the projects were 3 to 4% lower than the design void content. PBA-6 "F" mix projects that have been sampled as parts of other research projects, typically have higher in-place void contents than their design. The condition for the two projects noted here does not appear to be unique for the PBA-6GR mix since the PBA-6 mix also has lower in-place voids.

Possible causes of the differences in lab versus field voids could be variations in the gradations and asphalt content. Differences could also be attributable to compaction method.

Even though the field void contents have historically been higher than the design void contents, samples taken during this study indicate the opposite. To determine if this is a trend, the condition of lower field voids compared to design voids should be further investigated to insure adequate constructed void content to maintain splash and spray resistance after years of wear and build-up of fines.

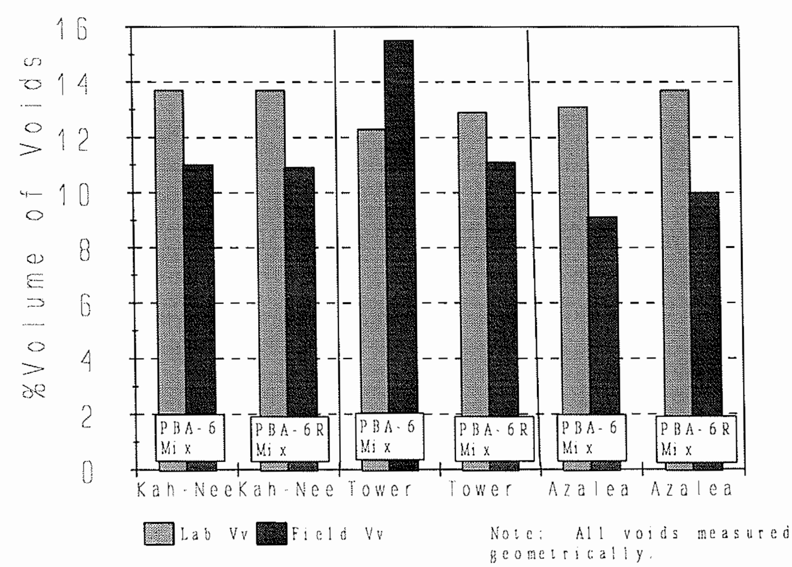



Figure 6.1 Volume of Voids Comparison: Lab to Field.

## Table 6.1: Field Samples Test Results

| Characteristics | Class "F" Mix Design Criteria[a] | Kah-Nee-Ta Jct.- Pelton Dam Rd. | | Tower Rd.- Stanfield Interchange | | Azalea- Jumpoff Joe | |
|---|---|---|---|---|---|---|---|
| | | Class "F" Field Mix Test Results[b] (w/PBA-6) | Class "F" Field Mix Test Results[b] (w/PBA-6GR) | Class "F" Field Mix Test Results[b] (w/PBA-6) | Class "F" Field Mix Test Results[b] (w/PBA-6GR) | Class "F" Field Mix Test Results[b] (w/PBA-6) | Class "F" Field Mix Test Results[b] (w/PBA-6GR) |
| 1 - inch | 99 - 100 | 100 | 100 | 100 | 100 | 100 | 100 |
| 3/4 - inch | 85 - 96 | 91.0 | 91.6 | 92 | 91 | 99 | 100 |
| 1/2 - inch | 60 - 71 | 63.6 | 64.7 | 63 | 65 | 81 | 84 |
| 1/4 - inch | 17 - 31 | 30.4 | 30.0 | 23 | 25 | 38 | 41 |
| #10 | 7 - 19 | 11.7 | 11.0 | 11 | 11 | 15 | 17 |
| #200 | 1 - 6 | 2.9 | 3.4 | 1.2 | 2.2 | 3.9 | 3.6 |
| Binder Content (%) | 4 - 8 | 5.1 | 5.1 | 4.7 | 4.9 | 5.0 | 5.2 |
| Field Void Content[c,d] | 12 - 16 | 11.0 | 10.9 | 15.5 | 11.1 | 9.1 | 10.0 |
| "Rice" Max. Sp. Gr[c,d] | None | 2.611 | 2.633 | 2.538 | 2.536 | 2.649 | 2.678 |

[a]Broadband limits for gradation and binder content. Gradations are percentages of dry ingredient weight, including 1% lime. Binder contents are percentage of total mix weight.
[b]Values determined from samples obtained during construction.
[c]Field Void Content determined from cores sampled in the evaluation sections, determined by geometric measurement.
[d]Kah-Nee-Ta Junction - Pelton Dam Road cores sampled one year after construction. 1994 projects sampled within three months of construction.

# 7.0 PRICES AND COSTS

This chapter presents the major differences in prices and costs between the rubberized and conventional mixes. The bid prices are summarized in Table 7.1

**Table 7.1 Bid Prices and Unit Costs**

| **Bid Item** | **Kah-Nee-Ta Jct.- Pelton Dam Rd.** | | **Tower Rd.- Stanfield Interchange** | | **Azalea- Jumpoff Joe** | |
|---|---|---|---|---|---|---|
| | Quantity | Price | Quantity | Price | Quantity | Price |
| PBA - 6 Asphalt | 820 tons | $245/ton | 6,430 tons | $22.75/ton[2] | 4,979 tons | $240/ton |
| Furnish PBA - 6 Class "F" Mix | 16,103 tons | $13/ton | 116,341 tons | $22.75/ton | 88,630 tons | $17/ton |
| Total Class "F" Mix in Place[1] | 16,183 tons | $25.42/ton | 116,341 tons | $24.01/ton | 88,630 tons | $30.48 |
| 2" Thick Pavement | - | $2.63/Yd.[2] | - | $2.49/Yd.[2] | - | $3.01/Yd.[2] |
| PBA - 6GR Asphalt | 286 tons | $310/ton | 578 tons | $265/ton | 343 tons | $310/ton |
| Furnish PBA - 6GR Asphalt Rubber | 5,989 tons | $18/ton | 10,221 tons | $12.50/ton[2] | 6,771 tons | $17/ton |
| Total PBA - 6GR Class "F" Mix in Place[1] | 5,998 tons | $32.78/ton | 10,221 tons | $27.49/ton | 6,771 tons | $32.70/ton |
| 2" Thick Pavement | - | $3.47/Yd.[2] | - | $3.15/Yd.[2] | - | $3.55/Yd.[2] |

[1]Total cost of mixture, per unit, calculated from bid price data.
[2]Unbalanced bid price.
Note: To convert from ton to metric ton multiply by 0.907.
To convert from $/ton to $/metric ton divide by 0.907.
To convert from $/yd$^2$ to $/m$^2$ divide by 0.836.

## 7.1 BID PRICES AND MIX COSTS

For the three projects, the PBA-6GR mix was more expensive than the polymer modified PBA-6 mix. Some of the additional cost may have been added by the contractor due to the unknowns associated with handling and processing mix with PBA-6GR binder.

Table 7.2 presents the average bid prices for the furnished mixes. The increased cost of the PBA-6GR binder and furnishing it resulted in the total cost of the PBA-6GR mix in place being 16% more than the PBA-6 mix. Figure 7.1 shows the relative bid prices for the total cost/ton of mix in place.

**Table 7.2 Average Bid Prices**

| Bid Item | PBA-6 | PBA-6GR | %Difference (PBA-6 to PBA-6GR) |
|---|---|---|---|
| Asphalt | $243/ton[1] | $295/ton | +21% |
| Furnish "F" Mix | $15/ton[1] | $15.80/ton | +5% |
| Total "F" Mix in Place | $26.63/ton | $30.99/ton | +16% |

[1]The unit bid price was not included from the Tower Road - Stanfield Interchange project because the bid was unbalanced.

Note: To convert from $/ton to $/metric ton divide by 0.907.

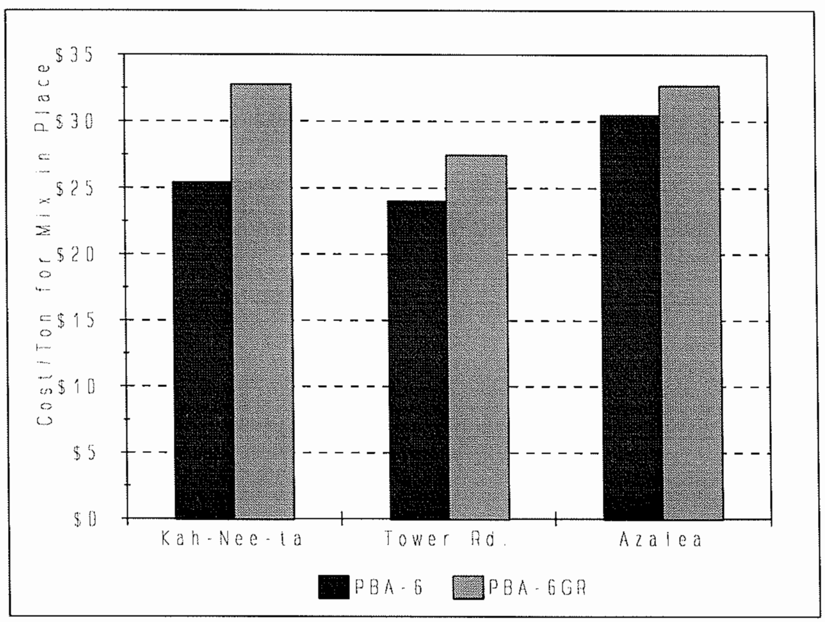



Figure 7.1. Comparison for Cost per Ton of Mix In-Place.

An additional comparison was made between the 1994 ODOT bid prices for PBA-6 and PBA-6GR mixes. The 1994 weighted average, including both the cost of the binder and the cost to furnish "F" mix, is $27.64/ton ($30.47/metric ton). Comparing this to the PBA-6GR mix average cost of $30.99/ton ($34.17/metric ton) indicates that the PBA-6GR mixes cost 12% more. The 12% difference would be significant considering the volume of "F" mix constructed each year.

Even though the cost for "F" mix with PBA-6GR is at least 12% more than "F" mix with PBA-6, the mix is considerably less than other asphalt-rubber and crumb rubber modified mixes being evaluated by the ODOT Research Unit. The costs of other rubber modified mixes have ranged from $58 to $63/ton ($64 to $69/metric ton).

If the ISTEA moratorium is not extended, PBA-6GR may be the most economical, advantageous alternative to meeting the crumb rubber requirement. The advantages include ease of construction (which should reflect in a lower cost) and increased film thickness leading to a potential increase in pavement life. These advantages should be considered when determining the appropriate binder for open-graded mixes.

# 8.0 POST-CONSTRUCTION INSPECTION

The control and test pavements were inspected after construction. No visual distresses were noted.

The Kah-Nee-Ta Jct. - Pelton Dam Road sections were evaluated after one winter. Slight rutting of 0.01' (3.0 mm) was noted. Ravelling and pit marks were noted in the control section. The test section, however, did not show any signs of wear, indicating a potentially more durable pavement. The shadow line caused by the Blaw Knox paver was noticeable in the control section and not in the test section.

## 8.1 FRICTION TESTING

The Kah-Nee-Ta project was friction tested one year after construction. The friction numbers for the control and test section were comparable, well above the acceptable minimum. The 1994 projects were tested in the fall within two months after construction. The friction numbers for the Tower Road - Stanfield Int. project were above the acceptable minimums and comparable for the PBA-6 and PBA-6GR sections. The friction numbers for the Azalea - Jumpoff Joe project were near the acceptable minimum for both the control and test sections. The average friction number for the Azalea PBA-6GR section was 12% higher than the control section.

The friction numbers will be monitored over time to determine if the PBA-6GR resists wear, providing better resistance than polymer modified asphalt.

# 9.0 SUMMARY AND CONCLUSIONS

Open-graded mixes constructed with a PBA-6GR, an asphalt-rubber binder, and a PBA-6, a polymer modified binder, were compared to determine relative mixing, construction, and performance properties.

The normal acceptance tests performed on conventional asphalts were done. The PBA-6GR binder met the specifications of PBA-6, however, the kinematic viscosity on the original binder and the ductility test on rolling thin film oven (RTFO) aged residue requirements were deleted, as allowed by the Special Provisions, at the contractor's written request. Since PBA-6GR is a modified binder, new test methods and criteria will need to be identified since current test procedures do not consider the addition of rubber to binders. Deleting portions of the ODOT specification to allow an evaluation of a new modified product is acceptable, however, other tests should be specified to determine the pumpability and handling characteristics, related to the kinematic viscosity, and the internal compatibility, related to the ductility.

The mix design for the first PBA-6GR mix evaluated was based on a modified FHWA procedure based on void content and binder film thickness estimated by binder drain down. The mix did not drain down. Consequently, the design was based on the PBA-6 control mix design. The 1994 PBA-6GR mix designs were based on volume of voids and voids filled with asphalt.

Construction and handling using the PBA-6GR mix went well. Construction was simplified in comparison to other rubber modified mixes since the contractor did not need to bring in extra mixing equipment. The powdered rubber had been blended with the asphalt at the refinery. After delivery, paving operations proceeded normally. Reports on handling collected on the projects indicated the PBA-6GR mixes were easier to place than PBA-6 mixes.

The average cost of the PBA-6GR mixes was 16% more than the "F" mix with PBA-6 controls, 12% more than all PBA-6 mixes constructed in 1994. Advantages of the PBA-6GR mix, such as ease in construction and handling, may make the rubber modified binder preferable over PBA-6 which may reduce the bid prices.

# 10.0 RECOMMENDATIONS

## 10.1 RECOMMENDATION FOR IMPLEMENTATION

1. The PBA-6GR binder should be considered for use to satisfy the federal requirements for the use of ground recycled tire rubber in hot mix asphalt concrete.

## 10.2 RECOMMENDATIONS FOR FURTHER RESEARCH

1. The Brookfield viscometer should be evaluated for determining the viscosity of the asphalt-rubber binder at mixing temperatures since the PBA-6GR binder could plug the kinematic tubes.

2. The SHRP Bending Beam Rheometer should be evaluated as a means of testing the cold temperature properties of PBA-6GR and PBA-6 binder.

3. The use of volume of voids and voids filled with asphalt to determine the appropriate design for the PBA-6GR mixes should be further evaluated. The testing should include a range of samples at varying asphalt contents and mix temperatures to evaluate drain down, calculate void contents, and determine moisture susceptibility.

4. Target laboratory void contents and voids filled with asphalt (VFA) should be validated by monitoring field performance. After construction of PBA-6GR projects, cores should be obtained to determine the relationship between laboratory determined void contents and field void contents. The evaluation will help in "fine-tuning" the mix design process.

# 11.0 REFERENCES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## Appendix

# SPECIAL PROVISIONS AND SUPPLEMENTAL STANDARD PROVISIONS FOR HIGHWAY CONSTRUCTION

(a) Light Duty AC:

(1) Asphalt Cement - Use PBA-2 or PBA-5 grade asphalt that meets the requirements of Section 02710.

(2) Asphalt Cement Additives - When specified, add antistripping additives for Light Duty AC meeting the requirements of Section 02710 to the asphalt.

Accompany each shipment of asphalt and additives with a quality compliance certificate, as required in 00165.60, and a copy of the weight of each delivery.

(b) Standard Duty and Heavy Duty AC:

(1) Asphalt Cement - New asphalt that meets the requirements of Section 02710.

Use PBA-2 or PBA-5 grade asphalt for dense graded AC.

Use PBA-6 grade asphalt for open graded AC and PBA-6GR grade asphalt for the open graded Class "F" modified AC.

PBA-6GR is asphalt cement which meets the PBA-6 asphalt specifications modified as follows:

1. The Kinematic Viscosity on Original Binder (AASHTO T-201) speciication may be deleted if the Contractor makes a written request accepting full responsibility for the pumpability of the asphalt cement within the Contractor's plant. Agreement to delete this specification will be documented by contract change order.

2. The ductility on the RTFO Aged Residue Specification (AASHTO T-51) is deleted.

3. The Certificate of Compliance accompanying the Refinery Test Report shall certify ground recycled tire rubber was used as the predominant modifier.

4. The Refinery Test Report shall include the amount of ground recycled tire rubber and the total amount of modifier(s) used in the asphalt, expressed as a percentage by weight of total PBA-6GR.

(2) Asphalt Cement Additives - Add antistripping additives meeting the requirements of Section 02710 to the asphalt to satisfy the Index of